Final Report for the Habitat Strategic Initiative

Puget Sound-wide Zooplankton Monitoring Program

Long Live the Kings

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Summary:

In its pilot phase, the Puget Sound-wide Zooplankton Monitoring Program produced data of regional importance and demonstrated the critical need for continued, long-term zooplankton monitoring in Puget Sound sub-basins. Long Live the Kings successfully transitioned the pilot program to a long-term home at the Washington Department of Fish and Wildlife. Program priorities and alignment with regional needs were identified and documented, and development of a program Steering Committee will ensure that the program continues to meet the needs of the Puget Sound recovery community to the extent practicable. This report was updated December 2019 to include zooplankton program data 2014-2018.

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Project goals and objectives

**ENSURE ZOOPLANKTON MONITORING CONTINUES UNINTERRUPTED IN PUGET SOUND**
The Puget Sound-wide Zooplankton Monitoring Program was initiated as a pilot program in 2014 via the Salish Sea Marine Survival Project. Zooplankton are a key link between phytoplankton and upper trophic level species like salmon and forage fish and they are responsive to environmental and anthropogenic forcing. Because of these characteristics, zooplankton community patterns can serve as an informative indicator of ecosystem health and can improve management and forecasting for commercially important species like salmon. Understanding the relationships between zooplankton patterns, environmental change, and resultant impacts up the food web requires long-term data series of consistently-sampled sites throughout multiple Puget Sound basins. Therefore, uninterrupted continuation of zooplankton monitoring is of critical importance to both Puget Sound salmon recovery and ecosystem recovery. This report was updated December 2019 to include zooplankton program data 2014-2018.

**TRANSFER COORDINATION ROLE AND TRANSITION THE PILOT ZOOPLANKTON MONITORING PROGRAM TO A LONG-TERM, ONGOING PROGRAM**
The success of the initial pilot zooplankton sampling program and the utility of the early data emerging from that program demonstrates the necessity to transition the pilot program to a long-term, ongoing monitoring program for the region. This long-term program should maintain the existing collaborative structure among regional partners.

**ENHANCE SAMPLING, ANALYSES, AND DATA DISTRIBUTION TO MORE EFFECTIVELY MEET THE NEEDS OF THE PUGET SOUND RECOVERY COMMUNITY TO THE BEST EXTENT PRACTICABLE**
Without compromising the initial intent and overall objectives of the Puget Sound-wide Zooplankton Monitoring Program, project coordinators should facilitate regional discussion around sampling and data needs to ensure that the benefits of the existing sampling platform and monitoring program are maximized.
Coordinate with Department of Ecology and partners to align physical or chemical water property data with zooplankton sampling locations/timing if practicable

Pairing physical and/or chemical water property data collection with zooplankton sampling locations allows for concurrently-collected data series and may produce better understanding of relationships among small-scale physical environments and their local biota.

Test relationships among physical and biological variables in Puget Sound

Analyzing relationships among environmental variables and zooplankton community composition enables researchers to understand how changes in the local versus oceanic physical environment translate up the food web, measure how the prey field of salmon and other fish varies spatio-temporally and correlates with fish survival, and provide improved forecasting tools and guidance towards ecosystem-based management decisions.

Make data publicly available to be used in regional analyses such as food web/end-to-end ecosystem models

Zooplankton play a critical role in the Puget Sound food web; reflecting zooplankton dynamics in food web and end-to-end ecosystem models is essential to accurately modeling the system. The Puget Sound-wide Zooplankton Monitoring Program is currently the only source of long-term, spatially-comprehensive zooplankton data for Puget Sound.

Methods

Transition to a long-term, ongoing program and ensure zooplankton monitoring continues uninterrupted in Puget Sound

Long Live the Kings worked with sampling partners and Salish Sea Marine Survival Project Coordinating Committee members to identify the optimal home for a long-term, ongoing zooplankton monitoring program. Long Live the Kings then worked with the Washington Department of Fish and Wildlife over the course of 2018 to transition all program coordination responsibilities from LLTK to WDFW. This included documenting program coordination activities, facilitating discussion among analysis and sampling partners to determine ways to streamline and improve the program, developing Memoranda of Understanding with each sampling partner that preserve the collaborative structure of the program, and providing assistance and guidance to WDFW staff throughout the transition period. Long Live the Kings worked with WDFW and the Washington Department of Natural Resources to secure the necessary funding to support uninterrupted continuation of the Puget Sound-wide
Zooplankton Monitoring Program. The program received $500k from Washington State to continue sampling over the 2019-2021 biennium.

**Enhance sampling, analyses, and data distribution; Align physical/chemical sampling with zooplankton sampling**

On August 1, 2017, Long Live the Kings hosted a meeting of sampling collaborators and interested members of the broader Puget Sound recovery community to ensure that the collaborative sampling platform and program’s data products were utilized to the best extent practicable for overall Puget Sound recovery. Meeting participants addressed these questions:

- How can the current zooplankton program contribute more broadly to Puget Sound recovery?
- How could the program be enhanced?
- How can we better align the current program with other efforts?

The following question was added based on advisory comments from the Salish Sea Marine Survival Project Coordinating Committee to reflect the initial intent of the program:

- How can the program be improved to meet the needs of salmon forecasting?

This meeting also included discussion on sampling alignment between the zooplankton sampling program and other regional sampling programs conducted by the Department of Ecology.

As part of the transition to a long-term zooplankton monitoring program, LLTK guided WDFW in development of a Steering Committee to provide advisory oversight to the Puget Sound-wide Zooplankton Monitoring Program. This Steering Committee will guide the program forward in accordance with the identified priorities and objects and will re-evaluate as needed to ensure that the program continues to satisfy regional needs for both salmon recovery and overall Puget Sound ecosystem recovery. The Steering Committee held its inaugural meeting in August 2019, reviewed the program structure and data/analyses produced to date, and committed to demonstrating the ongoing value and need for this program by continuing to analyze and develop relationships among zooplankton, climate impacts, and salmon growth and survival, by encouraging broad use of the open-access dataset produced via this sampling program, and by improving program communications.
TEST RELATIONSHIPS AMONG VARIABLES AND MAKE DATA PUBLICLY AVAILABLE
Full methods for data collection, processing, and statistical analyses are attached in the Puget Sound Zooplankton Monitoring Report developed by University of Washington (Attachment A).

Data are being served publicly by King County and linked through the Northwest Association of Networked Ocean Observing Systems (NANOOS). The direct data link is: http://green2.kingcounty.gov/ScienceLibrary/Document.aspx?ArticleID=556. Full datasets have also been provided to researchers currently working on Puget Sound food web models and end-to-end ecosystem models associated with the Salish Sea Marine Survival Project.

Results

PROJECT OUTCOMES
- The pilot zooplankton sampling program initiated by Long Live the Kings and the Salish Sea Marine Survival Project has successfully been transitioned to a long-term Puget Sound-wide Zooplankton Monitoring Program housed at Washington Department of Fish and Wildlife. Attachment B provides official confirmation of program transition.
- WDFW has developed Memoranda of Understanding to preserve the existing collaborative nature of the program and ensure sampling partner commitment to long-term sampling. WDFW is currently working with samplers to enact the MOUs; several have been finalized already. An example MOU is included as Attachment C.
- Funding to support the Puget Sound-wide Zooplankton Monitoring Program was included in the proposed 2019-21 biennial budget and ultimately approved at $500k as a result of Washington Department of Natural Resources working with LLTK and WDFW to add it to their requests. There is region-wide recognition of the need for continued zooplankton monitoring, and it was identified as a priority in the Governor’s Orca Task Force recommendations.
- Regional agreement on program priorities and recommended program enhancements to ensure that the long-term collaborative sampling platform is fully utilized and aligned with other relevant regional data collection efforts to the best extent practicable has been documented (Attachment D) and will continue to guide the future of the program. A Steering Committee for the program is being formed to ensure continued focus and discussion on program priorities and regional needs.
- Full results of relationships among physical and biological variables are described in Attachment A. In summary:
  - Data produced through this program show distinct sub-basin dynamics in Puget Sound zooplankton composition and indicate that the relative strength of environmental drivers is sub-basin specific.
Zooplankton response to dramatic environmental change (“the Blob”) was captured in the years this program has been sampling. Puget Sound’s response to this environmental change was very different from coastal responses: coastal data did not reflect Puget Sound processes. This result highlights the importance of continued zooplankton sampling in Puget Sound, and strengthens our understanding of the unique dynamics of the Puget Sound ecosystem.

Initial evidence from the first five years of the sampling program support the hypothesis that higher temperatures over those years were linked to higher zooplankton abundance and biomass, which in turn was linked to higher juvenile salmon growth and marine survival.

The existing sampling program is capable of identifying interannual, seasonal, and spatial signals in zooplankton community composition and zooplankton abundance/biomass, and these patterns can be linked to physical (temperature, salinity, etc.) and biological (chlorophyll, salmon) factors. The samples collected by this program document the Puget Sound zooplankton community’s rapid response to a large-scale climate event (the warm “Blob” ocean anomaly) and demonstrate the utility of zooplankton sampling as a measure of ecosystem response to change and its potential to improve salmon forecasting and management.

SUCCESS OF ACHIEVING PERFORMANCE MEASURES
This project has successfully achieved all performance measures and produced all agreed-upon contract deliverables.

Conclusions
LESSONS LEARNED
In its pilot phase, the Puget Sound-wide Zooplankton Monitoring Program produced data of regional importance and demonstrated the critical need for continued, long-term zooplankton monitoring in Puget Sound sub-basins. The pilot program sampled through an intense period of environmental change (the warm “Blob” ocean anomaly), successfully captured the response of the Puget Sound zooplankton community to that change, and showed a linkage between the impact of the warm “Blob” on zooplankton and on salmon. These results strongly support the need for long-term continuation of this monitoring program.
RECOMMENDATIONS FOR FUTURE WORK
The Puget Sound-wide Zooplankton Monitoring Program provides regional value to salmon recovery and ecosystem recovery and should be continued on a long-term basis. Ongoing regional reflection and discussion to ensure that the Puget Sound-wide Zooplankton Monitoring Program continues to achieve its primary objectives and remains aligned with regional needs is necessary. The development and finalization of a Steering Committee for the program will help achieve this outcome.
ATTACHMENT A:
PUGET SOUND ZOOPLANKTON MONITORING REPORT
Puget Sound
2014-2018 Zooplankton Monitoring Report

Prepared by Dr. Julie E. Keister, BethElLee Herrmann, and Amanda Winans in the University of Washington School of Oceanography, with environmental data contribution from Julia Bos with the Marine Monitoring Program at the Washington Department of Ecology, and sample and data contributions from numerous collaborators.

Abstract
We used zooplankton data from the Salish Sea Marine Survival Project (SSMSP) with hydrographic and chlorophyll data from several monitoring programs in U.S. regions of the Salish Sea (the San Juan Islands, Bellingham Bay, and Puget Sound) to explore zooplankton community response to environmental change in 2014-2018, a period of unusually large climate anomalies for the region. A marine heatwave affected the region beginning in late 2014, with high temperature anomalies throughout the region and record high temperatures recorded in 2015 in several regions of Puget Sound. In 2016 temperatures were slightly cooler but still very warm, followed by a very cold winter and a return toward near-normal temperatures in some regions in 2017, then similar or slightly warmer in most regions in 2018. These large interannual shifts in the physical environment had strong bottom-up effects on the zooplankton with responses differing among sub-regions. All regions had higher zooplankton biomass in 2015 compared to 2014, followed by regional differences in response in 2016-2018, likely due to differences in local mixing, stratification, and degree of ocean influence. Chinook salmon growth and coho salmon survival were also higher in 2015 than 2014, indicating that the elevated temperature and prey availability provided better rearing conditions and growth potential through bottom-up processes. General spatial patterns in zooplankton biomass are also emerging: biomass is typically lowest in N. Washington (San Juan Islands and Bellingham Bay); highest in central regions including Admiralty Inlet, N. Hood Canal, N. Central Basin and S. Whidbey Basin; and lower in S. Central Basin and South Sound. Hot spots of crab larvae, an important juvenile salmon prey, occur in Admiralty Inlet and north Central Basin. The similarities and differences in response among years and regions improve our understanding of the underpinnings of observed changes and their implications for future fisheries.

Introduction
Zooplankton occupy a key role in marine ecosystems as the link between phytoplankton and upper trophic level taxa. Their species composition and abundances are affected by environmental and anthropogenic influences, which in turn can impact the entire food web. To
accurately diagnose the causes of changes in zooplankton communities and resultant impacts on upper trophic level organisms, multi-year time series that sample across a range of conditions are needed. But little historical data on zooplankton in Puget Sound exist to help understand changes that have been observed in fisheries and ecosystems over the past several decades.

In 2014, zooplankton monitoring throughout Puget Sound and Northern Washington began as part of the Salish Sea Marine Survival Project (SSMSP) to understand how changes in the local versus oceanic physical environment translate up the food web, measure how the prey field of salmon and other fish varies spatio-temporally and correlates with fish survival, and provide improved forecasting tools and guidance towards ecosystem-based management decisions. The baseline data tracks shifts in the zooplankton and the effects their changes have on local ecosystems. A better understanding of the mechanisms that control ecosystem dynamics will help position the region to mitigate or adapt to future changes.

Since the monitoring program began in 2014, the Pacific Northwest has experienced a broad range of environmental conditions including a large marine heatwave that resulted in unprecedented temperature anomalies that persisted for several years. The extreme climate variability had clear impacts on the biology throughout the Northeast Pacific and Salish Sea, providing the opportunity to explore mechanisms through which large-scale climate change influences local systems.

Methods

Field collections

The zooplankton data reported herein were collected as part of the Salish Sea Marine Survival Project (SSMSP) by scientists from federal, state, and county agencies, tribes, and nonprofit organizations (Table 1). Sampling was conducted approximately bi-weekly in spring through fall 2014-2018 at sites throughout Northern Washington and Puget Sound, and monthly through winter at some locations (Figure 1, Table 2). Two types of net tows were conducted: at all locations, a 60-cm diameter, 200-µm mesh single ring net was towed vertically to sample zooplankton throughout the full water column; at most locations, 60-cm diameter, 335-µm mesh double-ring (bongo) nets were also towed obliquely through the upper 30 m of the water column at 1.5-2 kts to sample the larger, more motile zooplankton. All samples were preserved in a 5% buffered formalin/seawater and stored until processed in the laboratory.

Laboratory processing

Taxonomy of all samples was conducted in Dr. Julie Keister’s laboratory at the University of Washington. In the laboratory, samples were microscopically examined for taxonomic composition and abundance. First, rare larger (>1 cm) organisms were removed from the entire sample for identification and measurement. When abundances were very high, samples were
first split with a Folsom splitter and large taxa were analyzed from the split. Then two small (1 ml) aliquots were then taken using a Stempel pipette from a quantitatively diluted whole sample (or split) for analysis. Finally, a larger aliquot (5-10 ml) was taken to quantify mid-size taxa not adequately subsampled by smaller aliquots. All heterotrophic organisms in subsamples were enumerated, identified, differentiated by life history stage (for most taxa), and measurements were taken for organisms which vary greatly in size within a life stage. For taxa that were measured, up to 30 individuals were measured per sample.

Full laboratory processing protocols can be found in the annual King County Zooplankton Monitoring reports (available from King County or J. Keister on request).

**Data synthesis and analysis**

**Zooplankton data analyses**

The density of organisms (# of individuals m⁻³) was calculated from sample counts using the volume of water each net filtered. Eggs and copepod nauplii were recorded but not included in analyses unless otherwise noted because they are temporally and spatially patchy and can be present in very high abundances. The dinoflagellate *Noctiluca* were only enumerated in vertical tows and were not included in all analyses for this reason. Siphonophore gonophores, a reproductive component of the colonial calycophoran *Muggiaea atlantica*, were also removed before calculating densities. While they are included in biomass calculations, siphonophore gonophores are not considered individuals and have no perceived predatory/prey interactions (Purcell 1982). Krill (Euphausiidae) were separated based on life stages of marked developmental differences: “Krill Nauplii” (includes nauplii & metanauplii) “Krill Calyptopes” (includes calyptopis stages I-III) “Krill Furcilia” (includes all furcilia stages) and “Krill Adults & Juveniles.” Krill nauplii and metanauplii were not included in oblique net tows because the larger mesh size of those tows is believed to allow extrusion of those life stages.

Biomass (in carbon) of large taxa was calculated from densities either using length:dry weight or length:carbon relationships reported in the literature (e.g. Lavaniegos and Ohman, 2007; Webber and Roff, 1995; Williams and Robins, 1979), and, for small organisms, from carbon conversions by species and life stage taken from the literature. Where literature conversions were reported in dry weight (DW) rather than carbon values, C:DW relationships were used to convert to carbon weight.

To create time-series plots, the semi-monthly sampling dates were categorized as falling on either the 1st or the 15th of the month, regardless of actual date sampled (dates typically deviated a few days from the 1st or 15th). Density for a taxon was recorded as zero if that taxon was not found in a sample that was collected and processed; if a sample was not collected and processed for a particular date, those data points were left blank. Microsoft Excel and Tableau® 2019.3 were used to plot time series.
Nonmetric Multidimensional Scaling (NMS) ordinations were run using PC-ORD™ 7.06. Species biomass X Station matrices were created from monthly averages of biomass (C m$^{-3}$) at each station. Due to the rarity of some taxa and high abundance of others, data were normalized using a logarithmic transformation [$\log_{10}(Y + 0.001) + 3$]. No rare taxa were removed from the vertical sample ordinations to identify environmental shifts relating to oceanic or estuarine species. Ordinations were run using the Sørensen (Bray-Curtis) distance measure. Distances between points in the ordination indicate the level of dissimilarity between zooplankton communities, where closer points are less dissimilar than points that are farther apart. Ordinations were run on vertical net tow data from all stations combined, and separately for six regions: Northern Washington, Admiralty Inlet, Hood Canal, Whidbey Basin, Central Basin, and South Sound.

Environmental matrices were created using long-term monitoring data from the Washington Department of Ecology’s core monthly stations which had the closest proximity to the SSMSP zooplankton stations (Figure 1, Table 2, Table A3). Missing environmental data were filled with values from the closest depth where data were otherwise available in the water column (e.g., data from 4 or 5 m depth was used to fill missing 3-m data). If data from within ±5 m depth were not available, linear interpolation within sites and months along the same depth was used to fill missing values. Correlations between environmental metrics and zooplankton ordination axes were calculated in PC-ORD.

Overall, >200 zooplankton taxa were identified in samples. Detailed abundance and biomass data by species and life stage are publicly available as a download from King County’s website: https://green2.kingcounty.gov/ScienceLibrary/Document.aspx?ArticleID=556.

**Salmon growth and survival**

Chinook salmon growth data shown in this document were calculated by Iris Kemp (Long Live the Kings) from individual measurements of fish captured during mid-water trawls conducted in Puget Sound by the Fisheries and Oceans Canada during annual juvenile salmon surveys. Depth-stratified trawls were conducted during daylight hours in offshore waters (> 30 m bottom depth), with about 85% of tows conducted in the upper 30 m of the water column where juvenile salmon primarily reside. All juvenile Chinook and coho salmon were scanned for coded-wire-tags (CWTs). Individual fork lengths were measured onboard for all CWT salmon, and snouts containing CWTs were preserved for later dissection and decoding by Washington Department of Fish and Wildlife (WDFW) personnel (primary contact: Lynn Anderson, WDFW, Olympia, WA). Catch locations were coded to align with WDFW recreational fishing areas. Release date and average weight of fish released from each hatchery were retrieved from the Regional Mark Processing Center Regional Mark Information System (RMIS) databases (www.rmpc.org) on 2 October 2018. Where length but not weight of a fish was recorded on recapture, weight was calculated from a length:weight regression ($R^2=0.98$). Data were carefully QC’d and discarded where questionable; fish from regions in which <10 fish were captured in
any particular year were discarded, resulting in a total of 3730 individual fish in the dataset released in 1999-2017 from North Puget Sound, Central Sound, and South Sound hatchery release regions. Average annual growth $d^{-1}$ was calculated as the change in weight over the number of days since hatchery release.

At the time of this report, Chinook smolt-to-adult survival data were not yet available for out-migration years in which we have zooplankton data. Coho survival data were available for from several Puget Sound and Northern Washington stocks (several hatchery and two wild stocks) for brood years 2013 and 2014 which equate to out-migration years 2014 and 2015 and adult return years of 2015 and 2016. Coho survival data shown in this report were calculated by Marianna Alexandersdottir under a contract from the Tulalip Tribes.

### Results

**Environmental conditions**

The five years of sampling covered in this report (2014-2018) encompass a time period of the largest marine heatwave on record in the North Pacific (Bond et al. 2015; Di Lorenzo and Mantua 2016) and its partial recovery. The warm anomalies first developed in the Subarctic Pacific in Winter 2013-14 but did not greatly affect temperatures in coastal Washington and Puget Sound until late summer and fall 2014. This extreme warm event, termed “The Blob” (Bond et al. 2015), was followed by a substantial El Niño that persisted until the spring of 2016. Water temperatures throughout Northern Washington and Puget Sound were anomalously warm from fall 2014 through fall 2016, with some regions experiencing record high temperatures in 2015 (PSEMP 2016). Summer temperatures remained very high in 2016, although not as high as 2015 (PSEMP 2017). Very cold 2016-2017 and 2017-2018 winters helped return the system near normal in some regions of Puget Sound, particularly nearer the ocean, while more southern regions were warm in 2017; 2018 was slightly warmer or similar to 2017 across most regions (Figure 2).

In regions where zooplankton was sampled, there was a clear spatial pattern of warmer temperatures in the more southern latitudes, moving from the coldest Strait of Juan de Fuca, through Admiralty Inlet, into the warm South Sound, and a greater persistence of the anomalous warmth in Central and South Sound compared to Northern Washington and Admiralty Inlet (Figure 2).

Regional differences were more apparent in chlorophyll biomass (Figure 3). Chlorophyll biomass was much lower in all years in the Strait of Juan de Fuca and South Sound, moderately high in Central Basin and Admiralty Inlet. Intense blooms occurred every year in N. Hood Canal and Whidbey Basin. In most regions, there was evidence of spring and fall blooms. In Central Basin, chlorophyll biomass seemed higher overall during bloom periods in the cooler years of 2014 and 2017 than in 2015 and 2016 (data are missing during that period in 2018) In Whidbey
Basin, the pattern was opposite. Patterns in other regions did not as clearly relate to temperature, and because monthly chlorophyll profiles can miss much of the temporal variability, it is difficult to draw conclusions from relatively minor differences.

For more detailed description of environmental changes in Washington State waters during these study years, see the annual reports of the Puget Sound Marine Waters working group: http://www.psp.wa.gov/PSmarinewatersoverview.php.

**Zooplankton abundance and biomass**

Total zooplankton abundance and biomass from vertical and oblique net tow samples varied spatially and temporally (Figures 4, 5, and 6). The strongest patterns were the seasonal cycles from low abundances and biomass in winter to high abundances and biomass in (typically) late spring through summer; at all locations, there was high variability within the productive seasons. Overall, sites in S. Whidbey Basin and Central Sound supported the highest biomass, but sites in Admiralty Inlet and N. Hood Canal also had very high abundances periodically, particularly in comparison to the San Juan Islands which had the lowest zooplankton abundances and biomass. N. Whidbey Basin had occasional high abundances, but of many small taxa which didn’t translate into particularly high biomass.

In most regions, abundances and biomass increased from 2014 to 2015, and remained high in 2016. This was most apparent in vertical net tows which sample the entire water column and have a smaller mesh size than oblique bongo net tows. In some regions, e.g., Admiralty Inlet, peak biomass remained very high in 2017; in other areas, biomass was lower than in 2015 and 2016. Most sites decreased in biomass in 2018, with many resembling 2014 levels. At Admiralty Inlet and Pt. Jefferson (Central Basin) stations, unusually high biomass was seen in fall and early winter 2018 relative to previous years. (Note most regions do not sample through winter.)

Cumulative biomass plots for each station (Figure 7) show differences among years and sites more clearly than the time series plots. Most notably, at every station where 2014 samples were collected, biomass was lower in 2014 than in the warmer years of 2015 and 2016. Biomass in some regions reached 2-4X higher in 2015 than similar time periods in 2014, with biggest differences occurring in May and June when juvenile salmon are beginning their early marine phase and are primarily zooplanktivorous. Differences in biomass in 2015-2018 were more variable among sites. At some sites, notably several to the north (Watmough, Eliza, and Thorndyke), highest biomass occurred in the warmest year, 2015. Biomass at Watmough and Eliza then decreased slightly each year through 2017, with a small increase in 2018. In Admiralty Inlet and at KSBP in Central Basin, biomass peaked in 2016 then dropped to intermediate levels in 2017, where they remained in 2018. In S. Whidbey Basin (Camano, Mukilteo), the more southern stations of Central Basin (LSNT and NSEX), and in South Sound (S. Ketron), biomass in 2017 was even higher than in 2015 and 2016: the biggest differences did not occur until July and August at most of those stations, indicating a shift in the timing in 2017, perhaps related to the colder winter and later warming. In 2018, those biomass levels dramatically dropped, close
to those of the lowest year. Thorndyke Bay and Cowlitz also showed a decrease in 2018 from 2017 to levels close to those of 2014.

Cancridae crab larvae, important prey of juvenile salmon, were not uniformly available through the region (Figures 8 and 9). Admiralty Inlet often had the highest biomass, reaching 47 mg C m$^{-3}$ in vertical net tows in May 2015. S. Whidbey Basin, Central Basin and occasionally Bellingham Bay also supported high crab larvae biomass. Biomass was very low in Fall through Winter, and highest in April through June each year. Biomass was notably higher in 2015-2017, and there appeared to be a shift in phenology to earlier occurrence of high biomass in the warmer years, particularly 2015.

**Zooplankton community structure**

Ordination of the vertical net tow zooplankton biomass data matrix showed clear regional and seasonal structure in the zooplankton community and, to a lesser extent, separation among years (Figure 10). The strongest clustering of communities showed regional differences. Many samples from Northern Washington and Admiralty Inlet separated from other regions. From bottom to top along Axis 2, samples from Northern Washington and Admiralty Inlet separated from those collected in Central and Whidbey Basin. Samples from N. Whidbey Basin lay mostly to the left, while S. Whidbey lay to the right on Axis 1. Samples from N. Hood Canal and South Sound showed the largest variance and nearly overlapped in the ordination space, whereas S. Hood Canal shifted to the left on Axis 1 and to the top of Axis 2.

The seasonal cycle of communities moved roughly clockwise around Axis 1 and 2: January, February, and most March communities fell at the bottom right of the ordination space (almost all of which were sampled from S. Whidbey and Central Basin); April and May were more spread, primarily falling towards the lower left of the ordination; late spring though late summer communities (a period when all sampling groups collected), were much more varied, occupying more than half of the full ordination space, but still showed some clockwise structuring; October and November communities occupied the upper half of Axis 2, moving toward the right on Axis 1, while most of December occupied the bottom of Axis 2.

Differences in community structure among years was less well defined than regional and seasonal patterns. Many samples collected in 2014 fell to the left on Axis 1 compared to the other years. Differences among 2015, 2016, 2017, and 2018 were not discernable in this analysis. However, 2015 and 2016 were less variable than 2014, 2017, and 2018.

Taxa most strongly correlated with Axis 1 were barnacle larvae (nauplii + cyprids) and polychaetes. Both were negatively correlated ($r = -0.83$ and $r = -0.62$, respectively) indicating that they were in highest biomass in samples to the left on Axis 1 in samples which were primarily collected in late summer and early fall, from N. Whidbey Basin and South Sound (Table 3). The siphonophore *Muggiaea atlantica*, the copepods *Pseudocalanus spp.* and *Paracalanus spp.* correlated with Axis 2 ($r = 0.76$, -0.68, and 0.66, respectively), while the large-bodied copepod *Metridia pacifica* ($r=0.6$) correlated positively with Axis 3 (Table 4). Chlorophyll
at 20 m and 30 m weakly correlated with Axis 1 ($r \sim -0.40$). The strongest environmental correlates with Axis 2 were 10-m and 20-m temperature ($r = 0.63$); i.e., warmer temperatures to the top of the axis.

Because of the strong regional differences in communities, we also explored zooplankton community structure within each region to more closely examine taxonomic and environmental correlations with regional community structure. Those results are given in Appendix A. In most regions, seasonal cycles strongly structured communities. In several regions, communities in 2014 separated from other years, however, taxonomic identifications, particularly of Cancridae (crab) larvae, improved after 2014, which may explain the separation of 2014 from other years. Several environmental factors strongly correlated with community structure in Admiralty Inlet, Central Basin and South Sound; less environmental influence was detected in Northern WA, Whidbey Basin (except salinity), and Hood Canal (except dissolved oxygen).

**Salmon growth and survival**

The time series of juvenile Chinook salmon growth calculated from re-capture of hatchery released coded-wire tagged individuals shows strong relationships with regional temperature anomalies (Figure 11). High growth of individuals from in regions occurred during warmer years. Particularly high growth occurred in 2015 and 2016 coincident with the marine heatwave. Growth of fish released from rivers that enter into Central Sound declined slightly from 2016 to 2017; growth of fish from South Sound declined somewhat less, but was slightly lower than in 2016.

Coho salmon survival data from 2014 and 2015 outmigration years showed dramatically increased survival of populations from almost every region available (Figure 12). In some cases, survival more than tripled in 2015 compared to 2014.

**Acknowledgments**

Numerous people contributed to the conception and development of the program, to sampling, and data collections that contributed to this report. We thank them all, and particularly would like to acknowledge the following individuals and organizations for their contributions to the successful development of the program and on-going sample collections.

For program development and management: Michael Schmidt and Iris Kemp from Long Live the Kings; Michael Crewson from the Tulalip Tribe.

For program funding: The Salish Sea Marine Survival Project (Long Live the Kings and the Pacific Salmon Foundation for program development and 2014 and 2015 sampling and analysis); King County (for Central Basin sampling and taxonomy); the NOAA Saltonstall-Kennedy Program and
Tulalip Tribes (for 2016 sampling and analysis); WA Dept. of Natural Resources; and the Environmental Protection Agency (for 2017 and 2018 sampling and analysis).

For sample collection: from King County: Lyndsey Swanson, Christopher Barnes, and Bob Kruger; from Kwiáht: Russel Barsh, Madrona Murphy, and Ed Fisher; from Lummi Nation: Evelyn Brown and Nicholas Jefferson; from the Nisqually Indian Tribe: Jed Moore, Emiliano Perez, and Walker Duval; from NOAA: Correigh Greene and Kathryn Sobocinski; from the Port Gamble S’Klallam Tribe: Hans Daubenberg, Emily Bishop, Nikki Venneman, and Julianna Sullivan; from WDFW: Korie Griffith and Mark Millard; from the Tulalip Tribe: Max Lundquist and Todd Zackey; from the Hood Canal Salmon Enhancement Group: Clayton David and Sarah Heerhartz; from the Washington Department of Ecology: Mya Keyzers and Allison Brownlee. We would also like to thank the numerous crew members who assisted in sample collection over the years.

David Mackas, Cheryl Morgan, Marc Trudel, and William Peterson for assistance developing protocols; Parker MacCready, David Beauchamp and all of our sampling partners for assistance selecting sampling locations.

We thank our collaborators Moira Galbraith and Kelly Young from Fisheries and Oceans Canada Institute of Ocean Sciences for their expert guidance in species identification.

We thank Julia Bos at the Washington Department of Ecology for providing CTD data from their monthly monitoring program.

References


Table 1. Station name and sampling frequency at each site. Only stations sampled in 2018 are listed.

<table>
<thead>
<tr>
<th>Station name</th>
<th>Station code</th>
<th>Sampling group</th>
<th>Sampling frequency and months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cowlitz</td>
<td>COW</td>
<td>Kwiáht (KWT)</td>
<td>April-October since 2014: bi-weekly</td>
</tr>
<tr>
<td>Watmough Bay</td>
<td>WAT</td>
<td>Kwiáht (KWT)</td>
<td></td>
</tr>
<tr>
<td>Eliza Island</td>
<td>ELI</td>
<td>Lummi Nation (LUM)</td>
<td>March-October since 2014: bi-weekly</td>
</tr>
<tr>
<td>JEMS</td>
<td>JEMS</td>
<td>WA Department of Ecology (DOE)</td>
<td>January-November since 2003, monthly</td>
</tr>
<tr>
<td>Hope</td>
<td>HOPE</td>
<td>NOAA</td>
<td>April-October since 2014; monthly</td>
</tr>
<tr>
<td>Saratoga Passage</td>
<td>SARA</td>
<td>NOAA</td>
<td></td>
</tr>
<tr>
<td>Admiralty Inlet</td>
<td>ADI</td>
<td>Port Gamble S’Klallam Tribe (PGST)/WDFW</td>
<td>March-October since 2014: bi-weekly</td>
</tr>
<tr>
<td>Thorndyke Bay</td>
<td>TDB</td>
<td>PGST/WDFW</td>
<td>March-October since 2014: bi-weekly</td>
</tr>
<tr>
<td>Eldon</td>
<td>HCB003</td>
<td>Hood Canal Salmon Enhancement Group (HCSEG)/DOE</td>
<td>March-October since mid 2016: monthly</td>
</tr>
<tr>
<td>Sisters Point</td>
<td>HCB004</td>
<td>HCSEG/DOE</td>
<td></td>
</tr>
<tr>
<td>Camano Island</td>
<td>CAM</td>
<td>Tulalip Tribes (TUL)</td>
<td>March-October since 2015: bi-weekly, occasional winter</td>
</tr>
<tr>
<td>Mukilteo</td>
<td>MUK</td>
<td>Tulalip Tribes (TUL)</td>
<td></td>
</tr>
<tr>
<td>Pt. Jefferson</td>
<td>KSBP01</td>
<td>King County (KC)</td>
<td>March-October since 2014: bi-weekly</td>
</tr>
<tr>
<td>Pt. Williams</td>
<td>LSNT01</td>
<td>King County (KC)</td>
<td>November-February since 2014; monthly</td>
</tr>
<tr>
<td>East Passage</td>
<td>NSEX01</td>
<td>King County (KC)</td>
<td></td>
</tr>
<tr>
<td>S. Ketron Island</td>
<td>SKET</td>
<td>Nisqually Indian Tribe (NIT)</td>
<td>March-October since 2014: bi-weekly</td>
</tr>
</tbody>
</table>
Table 2. Salish Sea Marine Survival Project (SSMSP) zooplankton stations where vertical net samples are collected and paired Washington Department of Ecology (DOE) hydrographic stations. HGSEG collaborates with DOE to sample; PGST collaborates with WDFW to sample. Except for stations marked with *, all stations have 0-30 m oblique net tow samples collected nearby.

<table>
<thead>
<tr>
<th>SSMSP Group</th>
<th>SSMSP Station</th>
<th>SSMSP Lat.</th>
<th>SSMSP Long.</th>
<th>DOE Station</th>
<th>DOE Lat.</th>
<th>DOE Long.</th>
<th>SSMSP/DOE Depth (m)</th>
<th>Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>KWT</td>
<td>COW¹</td>
<td>48.6808</td>
<td>123.044</td>
<td>GRG002</td>
<td>48.808</td>
<td>122.953</td>
<td>70/205</td>
<td>San Juan</td>
</tr>
<tr>
<td>KWT</td>
<td>COW²</td>
<td>48.6744</td>
<td>123.048</td>
<td>GRG002</td>
<td>48.808</td>
<td>122.953</td>
<td>70/205</td>
<td>San Juan</td>
</tr>
<tr>
<td>KWT</td>
<td>WAT³</td>
<td>48.4355</td>
<td>122.793</td>
<td>SJF000</td>
<td>48.417</td>
<td>123.025</td>
<td>113/31</td>
<td>San Juan</td>
</tr>
<tr>
<td>KWT</td>
<td>WAT⁴</td>
<td>48.4346</td>
<td>122.804</td>
<td>SJF000</td>
<td>48.417</td>
<td>123.025</td>
<td>40/172</td>
<td>San Juan</td>
</tr>
<tr>
<td>LUM</td>
<td>ELI</td>
<td>48.6380</td>
<td>122.569</td>
<td>BLL009</td>
<td>48.687</td>
<td>122.598</td>
<td>40/172</td>
<td>San Juan</td>
</tr>
<tr>
<td>NOAA</td>
<td>HOPE</td>
<td>48.4062</td>
<td>122.578</td>
<td>SKG003</td>
<td>48.297</td>
<td>122.488</td>
<td>37/25</td>
<td>Whidbey</td>
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<tr>
<td>NOAA</td>
<td>SARA</td>
<td>48.2567</td>
<td>122.544</td>
<td>SKG003</td>
<td>48.297</td>
<td>122.488</td>
<td>73/25</td>
<td>Whidbey</td>
</tr>
<tr>
<td>TUL</td>
<td>CAM</td>
<td>48.0590</td>
<td>122.387</td>
<td>PSS019</td>
<td>48.011</td>
<td>122.3</td>
<td>188/107</td>
<td>Whidbey</td>
</tr>
<tr>
<td>TUL</td>
<td>MUK</td>
<td>47.9717</td>
<td>122.322</td>
<td>PSS019</td>
<td>48.011</td>
<td>122.3</td>
<td>201/107</td>
<td>Whidbey</td>
</tr>
<tr>
<td>PGST</td>
<td>ADI</td>
<td>48.0027</td>
<td>122.636</td>
<td>ADM001</td>
<td>48.03</td>
<td>122.617</td>
<td>121/153</td>
<td>Admiralty</td>
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<tr>
<td>PGST</td>
<td>TDB</td>
<td>47.7830</td>
<td>122.733</td>
<td>HCB010</td>
<td>47.667</td>
<td>122.82</td>
<td>115/103</td>
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<tr>
<td>HCSEG</td>
<td>HCB003*</td>
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<td>123.01</td>
<td>HCB003</td>
<td>47.538</td>
<td>123.008</td>
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<tr>
<td>HCSEG</td>
<td>HCB004*</td>
<td>47.3562</td>
<td>123.025</td>
<td>HCB004</td>
<td>47.357</td>
<td>123.023</td>
<td>51/55</td>
<td>Hood Canal</td>
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<tr>
<td>KC</td>
<td>KSBP01*</td>
<td>47.7437</td>
<td>122.428</td>
<td>PSB003</td>
<td>47.66</td>
<td>122.442</td>
<td>276/110</td>
<td>Central</td>
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<tr>
<td>KC</td>
<td>LSNT01</td>
<td>47.5333</td>
<td>122.433</td>
<td>ELB015</td>
<td>47.597</td>
<td>122.368</td>
<td>211/131</td>
<td>Central</td>
</tr>
<tr>
<td>KC</td>
<td>NSEX01*</td>
<td>47.3586</td>
<td>122.387</td>
<td>EAP001</td>
<td>47.417</td>
<td>122.38</td>
<td>180/212</td>
<td>Central</td>
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<tr>
<td>NIT</td>
<td>SKET</td>
<td>47.1524</td>
<td>122.659</td>
<td>NSQ002</td>
<td>47.1683</td>
<td>122.787</td>
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<td>S. Sound</td>
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<tr>
<td>NIT</td>
<td>DANA⁵</td>
<td>47.1833</td>
<td>122.831</td>
<td>DNA001</td>
<td>47.161</td>
<td>122.87</td>
<td>52/51</td>
<td>S. Sound</td>
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</tbody>
</table>

Table 3. Pearson correlations (r and R²) between taxa and axes from NMS ordination of vertical net tow data from all stations combined. Only taxa which correlated abs(r) ≥ 0.6 with one or more axes are shown; taxa most strongly correlated with each axis (R² > 0.5) are in bold.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Axis 1</th>
<th></th>
<th>Axis 2</th>
<th></th>
<th>Axis 3</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>R²</td>
<td>r</td>
<td>R²</td>
<td>r</td>
<td>R²</td>
</tr>
<tr>
<td>Barnacles</td>
<td>-0.834</td>
<td>0.696</td>
<td>-0.003</td>
<td>0</td>
<td>0.05</td>
<td>0.003</td>
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<tr>
<td><em>Metridia pacifica</em></td>
<td>0.052</td>
<td>0.003</td>
<td>-0.173</td>
<td>0.03</td>
<td>0.6</td>
<td>0.36</td>
</tr>
<tr>
<td><em>Muggiaea atlantica</em></td>
<td>-0.062</td>
<td>0.004</td>
<td>0.761</td>
<td>0.58</td>
<td>0.192</td>
<td>0.037</td>
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<tr>
<td><em>Paracalanus spp.</em></td>
<td>-0.275</td>
<td>0.075</td>
<td>0.655</td>
<td>0.429</td>
<td>0.044</td>
<td>0.002</td>
</tr>
<tr>
<td>Polychaetes</td>
<td>-0.618</td>
<td>0.381</td>
<td>0.384</td>
<td>0.147</td>
<td>0.136</td>
<td>0.018</td>
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<tr>
<td><em>Pseudocalanus copepodites</em></td>
<td>-0.244</td>
<td>0.059</td>
<td>-0.677</td>
<td>0.459</td>
<td>-0.054</td>
<td>0.003</td>
</tr>
<tr>
<td><em>Pseudocalanus large males</em></td>
<td>-0.276</td>
<td>0.076</td>
<td>-0.634</td>
<td>0.401</td>
<td>-0.067</td>
<td>0.004</td>
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<tr>
<td><em>Pseudocalanus moultoni</em></td>
<td>-0.377</td>
<td>0.142</td>
<td>-0.659</td>
<td>0.435</td>
<td>-0.025</td>
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<tr>
<td><em>Pseudocalanus newmani</em></td>
<td>-0.217</td>
<td>0.047</td>
<td>-0.642</td>
<td>0.412</td>
<td>-0.104</td>
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<tr>
<td><em>Pseudocalanus small males</em></td>
<td>-0.263</td>
<td>0.069</td>
<td>-0.666</td>
<td>0.444</td>
<td>-0.126</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Table 4. Pearson correlations (r and R²) between environmental factors and axes from NMS ordination of vertical net tow data from all stations combined. Only factors which correlated abs(r) ≥ 0.6 with one or more axes are shown. See Table A3 for list of abbreviations.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Axis 1</th>
<th></th>
<th>Axis 2</th>
<th></th>
<th>Axis 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>R²</td>
<td>r</td>
<td>R²</td>
<td>r</td>
<td>R²</td>
</tr>
<tr>
<td>T10</td>
<td>-0.053</td>
<td>0.003</td>
<td>0.632</td>
<td>0.4</td>
<td>0.044</td>
<td>0.002</td>
</tr>
<tr>
<td>T20</td>
<td>0.033</td>
<td>0.001</td>
<td>0.628</td>
<td>0.394</td>
<td>-0.01</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 1. Maps of A) the SSMSP zooplankton stations coded by basin and sampling group and B) the Washington Department of Ecology’s Long-Term Marine Water Monitoring Program CTD stations; stations used in these analyses are circled in red.
Figure 2. Temperature profiles over the upper 100 m from monthly Department of Ecology CTD casts at stations in closest proximity to Watmough Bay (S. San Juan Islands), Admiralty Inlet, NSEX01 in Central Basin, S. Ketron Island (South Sound), Thorndyke Bay (N. Hood Canal), and Camano (S. Whidbey Basin) zooplankton stations.
Figure 3. Upper 50-m chlorophyll biomass profiles from monthly Washington Department of Ecology CTD casts from stations closest to Watmough Bay (San Juan Islands), Admiralty Inlet, NSEX01 in Central Basin, and S. Ketron (South Sound) zooplankton stations.
Figure 4. Total zooplankton abundances from vertical net tows, coded by sampling group and station. See Table 1 and Figure 1 for locations. Note that Dana Pass was not sampled in 2016-2018. Eliza Cove was not sampled in 2014.
Figure 5. Total zooplankton biomass from vertical net tows, coded by sampling group and station, separated into two panels for clarity. See Table 1 and Figure 1 for locations. Eliza Cove was not sampled in 2014.
Figure 6. Total zooplankton biomass from oblique bongo net tows, coded by sampling group and station, separated into two panels for clarity. See Table 1 and Figure 1 for locations. The Lummi, Tulalip, and PGST/WDFW sites were partially or not sampled in 2014.
Figure 7. Total zooplankton biomass from vertical net tows at each station for which there were sufficient data in at least four years. Biomass was cumulated across bi-weekly collections in each year, starting from the earliest date sampled in all years, which varied among stations. Missing data points were linearly interpolated from the nearest dates. Note that the East Passage station NSEX01 was very similar to LSNT so is not shown here.
Figure 8. Biomass (mg C m$^{-3}$) of Cancridae crab larvae collected in full water column vertical net tows in March through July, 2014-2018. Note the different scales between this and Figure 9.
Figure 9. Biomass (mg C m$^{-3}$) of Cancridae crab larvae collected in upper 30-m oblique net tows in March through July, 2014-2018. Note the different scales between this and Figure 9.
Figure 10. Nonmetric Multidimensional Scaling ordination of zooplankton species biomass from vertical net tows collected at all stations sampled in 2014-2018. A 3-dimensional ordination explained 84% of the variance in zooplankton community structure: position along Axes 1, 2, and 3 explained 30.6%, 35.2%, and 18.1% of the variance, respectively; only the two dominant axes are shown. Top left panel: samples are colored by month of collection to show seasonality in community structure. Top right panel: samples are colored by year. Bottom panel: samples are symbol and color coded to show differences among stations and regions; similar colors fall within a geographic region. Circles approximately outline samples from each region. See Figure 1 and Table 1 for station locations.
Figure 11. Top panel: Annual average juvenile Chinook salmon growth calculated from weight change of hatchery released and re-captured coded wire tagged juvenile salmon, averaged in each year by hatchery release area (Northern Puget Sound, Central Puget Sound, and South Sound). Data provided by I. Kemp of Long Live the Kings. Years with <10 fish in any region are not shown. Bottom panel: Monthly seasonal anomaly of sea surface temperature from the Race Rock Lighthouse long-term record; for visual comparison with salmon growth, 2003 and 2010 were removed.
Figure 12. Smolt-to-adult survival of coho salmon: 2014 and 2015 out-migration years from eight rivers in Puget Sound. All stocks were hatchery-raised except the two wild stocks marked as (W). Data provided by Marianna Alexandersdottir via the Tulalip Tribes.
ATTACHMENT B:
VERIFICATION OF PROGRAM TRANSITION TO WDFW
STATE OF WASHINGTON
Department of Fish and Wildlife

December 11, 2018

To: Michael Schmidt, Long Live the Kings
From: Phillip Dionne, Washington Department of Fish and Wildlife

Confirmation of transition of coordinator duties of Puget Sound-wide Zooplankton Monitoring Program to WDFW

Dear Sir,

The purpose of this letter is to verify that, as described in Agreement # LLTK-SSMSP-59, the coordination responsibilities for the Puget Sound-wide Zooplankton Monitoring Program have transitioned from Long Live the Kings to the Washington Department of Fish and Wildlife (WDFW). As of January 1, 2019, contingent upon continued funding, WDFW will assume all the coordinator responsibilities of the Puget Sound-wide Zooplankton Monitoring Program.

Thank you for your time and effort to initiate this important program, and thank you for your support and patience during this transition period. We look forward to working with you again.

Regards,

Phillip Dionne, Forage Fish Scientist
Washington Department of Fish & Wildlife
360-902-2641
Phillip.Dionne@dfw.wa.gov
ATTACHMENT C:
EXAMPLE SAMPLER MOU
MEMORANDUM OF UNDERSTANDING
BETWEEN
THE STATE OF WASHINGTON
DEPARTMENT OF FISH AND WILDLIFE
(P.O. BOX 43150, OLYMPIA WA, 98504-3150)

AND
TULALIP TRIBES
NATURAL RESOURCES DEPT. ATTN: MIKE CREWSON
6406 MARINE DRIVE
TULALIP, WA. 98271

THIS MEMORANDUM OF UNDERSTANDING (MOU) is made and entered into by and
between the DEPARTMENT OF FISH AND WILDLIFE, hereinafter referred to as “WDFW” or
“Coordinator” and the TULALIP TRIBES, hereinafter referred to as the “Monitoring Partner.”
Implementation of the activities outlined in this MOU is contingent upon the zooplankton
monitoring program being funded. Any fiscal relationship between the Washington
Department of Fish and Wildlife and monitoring partners will be dealt with separately, on a
contract basis.

THE PURPOSE OF THIS MOU is:

The purpose of this memorandum of understanding is to document the roles and responsibilities of
WDFW and the Monitoring Partner during the transition period of coordination activities from Long
Live the Kings (LLTK) to WDFW and through the next 5 years of the Puget Sound-wide
Zooplankton Monitoring Program (January 1, 2019 through December 31, 2023), but may be
extended if agreed to by both parties.

LLTK is transitioning the coordination role of the collaborative Puget Sound-wide Zooplankton
Monitoring Program (Program) to WDFW. WDFW will assume sole responsibility for coordinating
the Program beginning January 1, 2019. Though the organization responsible for the Program
coordination is changing, the Principle Investigator (University of Washington Zooplankton Lab) will
maintain and continue their current role and responsibilities for sample processing and analysis,
taxonomy, data analysis, QA/QC, data interpretation and reporting.

THEREFORE, IT IS MUTUALLY AGREED THAT:

RESPONSIBILITIES OF WDFW

As Coordinator of the Program WDFW shall perform activities with guidance from the Steering
Committee and in support of overall Program goals. WDFW will work to maintain the quality of
information the Program provides by working with the monitoring partners and the Principal
Investigator to preserve the collaborative sampling design of the Program, monitor Program
performance, and advocate for resources to facilitate long-term monitoring of zooplankton in
Puget Sound.
Task 1: Program Tracking and Maintenance

-Maintain digital sample tracking sheet to document dates samples are collected, the number of samples collected, and the status of samples, and develop improvements to this system on an ongoing basis.

-Provide reminders to the Monitoring Partner to encourage prompt submission of samples and data to the Principal Investigator.

-Receive, QC, and organize CTD data, and provide this data to the Principal Investigator.

-Track age and condition of equipment and monitor inventory of supplies.

-Arrange for regular equipment maintenance/replacement and replenish supplies as needed.

-Provide regular updates and communication via group message board regarding Program activities, information, opportunities, areas for improvement, etc.

-Coordinate Program meetings, phone conferences, and workshops.

Task 2: Program Administration

-Establish a Program Steering Committee consisting of a representative from each monitoring partners' organization, the Coordinator, the Primary Investigator, and the primary funding organization.

-Solicit and implement guidance from the Steering Committee regarding changes to the Program, the Program budget and operations, and data and information requests and dissemination.

-Support communication and collaboration with other monitoring groups such as PSEMP workgroups and management entities that will utilize information generated by the Program.

-Provide Program updates to the Steering Committee, management committees, politicians, the public, etc. where applicable.

-Work with the Principal Investigator and the Steering Committee to identify opportunities to increase utilization of the Program sampling platform without impinging on primary Program goals.

-Coordinate with monitoring partners, and support the Steering Committee to identify and engage in opportunities to advocate for and seek long-term support for the program.
RESPONSIBILITIES OF THE MONITORING PARTNER

The Monitoring Partner shall perform such activities and accomplish such tasks, specified as Monitoring Partner responsibilities throughout this Agreement unless specifically changed through modification in writing. The Monitoring Partner shall perform the activities within compliance of all acts, regulations, guidelines and best management practices that pertain to the described activities.

- Collect and preserve zooplankton samples at designated sample areas using sampling protocols provided by the Principal Investigator.
- Record sampling data.
- Maintain sampling equipment.

Task 2: Administration
- Schedule sample dates and coordinate staff and vessel time as needed to collect samples.
- Provide samples and data to the Principal Investigator and WDFW in a timely manner.
- Notify Coordinator if circumstances arise that may prevent you from collecting samples, and inform Coordinator of impending equipment repair or replacement needs.
- Participate in Program phone calls, meetings, message board, and Steering Committee.

ROLE OF THE STEERING COMMITTEE

The Steering Committee will be comprised of a single representative from each of the monitoring partners, the Coordinator, the Primary Investigator, and the primary funding organization. The Steering Committee will be consulted and relied on to make decisions on behalf of the Program regarding changes to the Program, the Program budget and operations, and data and information requests. The Steering Committee may choose to select an Executive Committee comprised of the Primary Investigator and two to three additional Steering Committee members. The role of the Executive Committee will be to provide guidance on routine business matters, time sensitive matters, and determine when the whole Steering Committee should be consulted.

MOU CHANGES, MODIFICATIONS AND AMENDMENTS

This MOU may be changed, modified or amended by written agreement executed by both parties.

Records and other documents, in any medium, furnished by one party to this MOU to the other party, will remain the property of the furnishing party, unless otherwise agreed. The receiving party will not disclose or make available this material to any third parties without first giving notice to the furnishing party and giving it a reasonable opportunity to respond. Each party will utilize reasonable security procedures and protections to assure that records and documents provided by the other party are not erroneously disclosed to third parties.
IN WITNESS WHEREOF, the parties have executed this MOU.

STATE OF WASHINGTON  
DEPARTMENT OF FISH AND WILDLIFE

Signature

Title  Date

MONITORING PARTNER:  
TULALIP TRIBES

Signature

Salmonid Enhancement Scientist

Title  Date
ATTACHMENT D:
ZOOPLANKTON MONITORING PROGRAM PRIORITIES
Considerations of priorities and alignment and enhancement of the Puget Sound zooplankton sampling program to meet its objectives and broader needs of the Puget Sound recovery community

Long Live the Kings  |  October 11, 2017 (Draft)

The Puget Sound-wide zooplankton sampling program, initiated via the Salish Sea Marine Survival Project in 2014, was designed to gain a better understanding of the relationship between the pelagic zooplankton community and salmon survival, as well as provide a solid understanding of how the pelagic zooplankton community is responding to its environment over the time salmon are outmigrating. One of the primary management outputs associated with this program are indices that can be used to help predict how well salmon will survive during their stint in the marine environment. These indices are used for adult return forecasting, to improve harvest management and salmon recovery overall.

However, as we transition the program from a pilot into a long-term effort, there was interest in ensuring that the program is utilized to the best extent practicable for overall Puget Sound recovery. On August 1st, Long Live the Kings hosted a meeting with the collaborators of the zooplankton sampling program and interested members from the broader Puget Sound recovery community to have this discussion. Three questions were asked during that meeting:

1. How can the current zooplankton program contribute more broadly to Puget Sound recovery?
2. How could the program be enhanced?
3. How can we better align the current program with other efforts?

After reviewing the results of this meeting, the Salish Sea Marine Survival Project Coordinating Committee added the caveat that none of the proposed improvements to the program should compromise the initial intent of the program. In fact, the highest priority should remain refining the program so that it achieves the goal of being a broadly used indicator for salmon management. Therefore, the following has been added:

4. How can the program be improved to meet the needs of salmon forecasting?

Below are the responses to those questions, followed by a brief summary prioritizing next steps. The notes from the meeting are attached.

How can the current zooplankton program contribute more broadly to Puget Sound recovery?

The group identified the following ways the current program could be used:

The quantity and type of toxics in zooplankton could be compared among various basins. This follows some recent thinking that much of the contaminants entering the Puget Sound food web are coming via

1 Shellfish aquaculture was not represented at the meeting; however, the group thought there may be interest given they are increasingly turning to wild spat fall for propagation.
the water column and not the benthos (pers. comm. Sandie O’Neil). Samples from second net of bongo could be used.

Crab larval recruitment could be informed by this program. We currently don’t know whether recruitment is basin specific or dispersed. Nor do we know whether there are associations between larval and adult trends. This is particularly important given they are experience a dramatic decline in age 1-4 Dungeness crab in South Puget Sound. These data could contribute to crab forecasting for harvest and help identify and address particular limitations to crab productivity. No major changes are needed to the program to lend to this effort. Additional speciation among crab larvae may be required.

There are concerns about whether jellyfish are affecting herring larvae survival and reducing the productivity of the Puget Sound food web. Jellyfish consume plankton that could otherwise be contributing to the productivity of fish. Jellyfish may also be a direct predator of herring larvae. Analyses of jellyfish trends as well as diets could occur to some extent through this program. However, larval herring consumption may only be achievable with nearshore sampling, but something to consider given jellyfish are captured well in current effort.

There are known relationships between benthic invertebrate and zooplankton communities. Given that there have been substantial declines in benthic invertebrate communities, Washington Department of Ecology staff are wondering how that translates to food web. Ecology is initiating additional zooplankton sampling at some of their water quality sampling sites in South Puget Sound this fall and they will begin to investigate this. Ecology’s efforts will be aligned with the Puget Sound zooplankton monitoring program so that data can be compared.

Finally, invasive species could be identified in these efforts, contributing to invasive species monitoring Puget Sound wide. However, this program would not be a replacement for targeted work, such as Jeff Cordell’s efforts more nearshore in Bellingham Bay.

**How could the program be enhanced?**

The group concluded that sampling year-round was the highest priority program enhancement. Bi-weekly sampling should be extended from February-October; monthly sampling may be sufficient through November-January. Sampling year-round will allow for a better understanding of Puget Sound dynamics and improve larval forage fish collections.

A temporary (1-2 years), species-level analysis of ichthyoplankton may provide us a better understanding of herring metapopulation dynamics. For example: where are the larvae distributed relative to spawning beaches? Are they advected immediately after spawning to central locations by the currents, or do they remain in discrete aggregations associated with their spawning beaches? This is a major unknown that would help link early life stages to population dynamics. There is some concern the current program may not capture ichthyoplankton well enough; however, it may be that the timing of sampling is too late in the year (starting in March) to capture most larval dispersal. Samples were collected in December 2016 and February 2016/2017. Where tows aligned with collaborative zooplankton sampling sites, processing these samples, including assessing the ichthyoplankton to the species level, may begin to fill winter data gap.

The group concluded that day vs. night sampling, at least for a period of time, could be performed to understand differences due to diel migration of some plankton species. Neuston sampling at the current sites could also improve capture of crab megalope, fish larvae and terrestrial insects, the primary prey for salmon. The group suggested performing a paired neuston/current tow approach for a period of
time to assess to what degree critters are/are not being missed with the current approach. This may help gauge how well the oblique, prey-field tows are capturing the salmon prey field dynamics. Other recommendations including adding CTD casts to the zooplankton monitoring stations where possible. However, some of this could be addressed through improved alignment with Ecology’s water quality monitoring (see next section). Further, micro-zooplankton collection and analysis was a previously recommended addition via the Puget Sound Marine Water Quality Workgroup. Nearshore sampling could be added to improve capture of forage fish larvae dispersion and support invasive species analyses. However, the group concluded that nearshore environments are localized, dynamic, and would require extensive sampling with different gear and protocols from the current program. Opportunities may exist to compare nearshore to offshore sampling over a short period, especially if neuston sampling were added, to determine whether there are any similarities in plankton composition.

**How can we better align the current program with other efforts?**

The group concluded that coordinating locations and timing of physical through zooplankton sampling efforts and maximizing efficiency, to the best extent practicable, is important. Recommended approaches include:

- Initiating a shared calendar and group messaging to share sampling schedules, discuss coordination, and share what they are seeing in the field on the fly.
- Pair sampling sites where possible.
- Improve data coordination. King County has agreed to host the zooplankton dataset for Puget Sound for now. On a longer-term scale, consider best ways to coordinate data hosting and distribution. NANOOS is a good option for aggregating links to relevant datasets (e.g., King County’s data portal, DOE’s EIM). Ecology’s EIM system is where current physical and benthic data are stored.
- Host a taxonomic workshop to identify to broad taxa (functional groups) is of regional interest, specifically for folks with DOE’s benthic invertebrate group, Nicole Burnett (Padilla Bay), and Lyndsey Swanson (KC). A subgroup should have additional conversations on speciation needs and long-term storage plans. However, the zooplankton monitoring program Principal Investigator, Julie Keister, emphasized the importance of maintaining fine-scale speciation work (i.e. processing vertical tows) in one lab given the expertise and consistency required.

There is also some interest in figuring out a way to communicate about what folks are seeing, qualitatively, throughout the year, to a broader audience. Real-time information could help inform the public about ongoing changes and, farmers of salmon and shellfish, about things to consider during their seasonal activities.

**How can the program be improved to meet the needs of salmon forecasting?**

The Salish Sea Marine Survival Coordinating Committee noted the zooplankton post-sampling processing and analysis time must be reduced in order for the data to effectively contribute to salmon adult return forecasting. The strongest relationship we currently have is between zooplankton community composition and overall marine survival of coho. Forecasting for coho must begin the January following the previous year’s zooplankton sampling efforts, that end in October. The Coordinating Committee strongly recommended that results continue to be analyzed from the
perspective of how at least a portion of the samples can be prioritized and processed more quickly (or even differently) so that they provide the requested indices by January. Further, the Coordinating Committee emphasized the need to continue to assess the program from the perspective of intent, such as forecasting and other priorities that may be applied, to ensure its being done as efficiently and cost effectively as possible. They acknowledge it may be several years before this type of analysis can be performed.

**Summary of priorities**

Based upon the results of these discussions, Long Live the Kings determined the highest near-term priorities for the Puget Sound zooplankton monitoring program are, in order:

1. Ensure indices are providing for salmon adult return forecasting by the January following the previous year’s March-October zooplankton sampling.

2. Lengthen sampling so that it occurs year round. Extend bi-weekly sampling from February-October and have monthly sampling November-January. Further, where tows aligned with collaborative zooplankton sampling site, process the zooplankton samples collected in December 2016 and February 2016/2017 by Dayv Lowry et al at Washington Department of Fish and Wildlife.

3. Initiating a shared calendar and group messaging to improve coordination among physical through zooplankton sampling activities. Further consider opportunities to pair sampling efforts.

4. Further explore the approaches to improving utility for crab, forage fish and contaminants work in particular without compromising the current program.

5. Plan a taxonomic workshop to help the region identify to broad zooplankton taxa.

These priorities will be addressed within next year. The other proposed actions identified in this document will continue to be pursued as well. Further, this report will be transferred to the next coordinators of the Puget Sound zooplankton collaborative effort, to be determined within the next three months.
Attendees:
Allison Brownlee (DOE), Carol Maloy (DOE), Christopher Krembs (DOE), Maggie Dutch (DOE), Mya Keyzers (DOE), Sandra Weakland (DOE), Valerie Partridge (DOE), Kirsten Feifel (DNR), Sarah Heerhartz (HCSEG), Iris Kemp (LLTK), Michael Schmidt (LLTK), Jed Moore (Nisqually Tribe), Lucas Hart (NW Straits Commission), Mike Crewson (Tulalip Tribes), Mike McHugh (Tulalip Tribes), Jan Newton (UW), Jeff Cordell (UW), Julie Keister (UW), Alan Wald (WDFW), Andrea Carey (WDFW), Dayv Lowry (WDFW), Don Rothaus (WDFW), Jim West (WDFW), Sandie O’Neill (WDFW) [via WebEx] Dany Burgess (DOE), Kim Stark (KC), Lyndsey Swanson (KC), Russel Barsh (Kwiaht), Nicole Burnett (Padilla Bay), Nikki Aikman (PGST), Evelyn Lessard (UW), Fritz Stahr (UW), Jen Blaine (WDFW), Todd Sandell (WDFW)

Priority Information

- How can current program contribute more broadly:
  - Sandie O’Neill and Jim West (WDFW) are interested in working with the group to compare toxics in zooplankton from various basins. Samples from second net of bongo could be used.
  - Don Rothaus (WDFW) is interested in understanding whether crab larval recruitment is basin specific or dispersed. They are also interested in understanding whether there are associations between larval and adult trends. This is particularly important given they experience a dramatic decline in age 1-4 Dungeness crab in South Puget Sound.
  - Christopher Krembs mentioned the need for lipid analyses of zooplankton. This is already being done as part of the marine survival project for plankton from April through September.
  - Dayv Lowry asked whether there are larval herring in South Puget Sound. 5 of 6 herring populations “did not” spawn in South Puget Sound in 2016 and 2017, however, there have been lots of adult herring milling in South Puget Sound over those 2 years. (current program may not adequately capture. See suggested enhancements for reasons why).
  - Dayv Lowry mentioned he had vertical tow samples from bi-monthly Feb 2016 through Feb 2017 mid water trawl surveys and May 2014-105 bottom trawl surveys. The spatial extent of these surveys are greater, but data only capture snapshots in time. The group concluded that the December 2016 and February 2016/2017 samples, where tows aligned with collaborative zooplankton sampling sites, may be most compelling to process as priority given it could begin to fill winter data gap.
  - Tessa Francis previously asked whether we can assess whether jellyfish are depleting zooplankton and whether they are a major predator of herring larvae? This may only be achievable with nearshore sampling, but something to consider given jellyfish are captured well in current effort.
  - Maggie Dutch is interested in relationships between benthic invertebrate and zooplankton communities. There have been substantial declines in benthic invertebrate communities and
wondering how that translates to food web. Ecology is initiating additional zooplankton sampling at some of their water quality sampling sites in South Puget Sound this fall.

- The group discussed that this program could also contribute to invasive species monitoring in the offshore, but not as a replacement for targeted work.

**Suggested program enhancements:**

- Sampling year-round is the highest priority. Bi-weekly sampling should be extended from February-October; monthly sampling may be sufficient through November-January. Sampling year-round will allow for better understanding of Puget Sound dynamics and improve larval forage fish collections.
- Increased focus on ichthyoplankton analysis is important (especially forage fish).
- Day vs. night sampling at least for a period of time to understand differences due to diel migration of some plankton species.
- Neuston sampling to improve capture of crab megalope, fish larvae and terrestrial insects. Or, paired neuston for a period of time to assess to what degree critters are/are not being missed with the other nets.
- Consider adding CTD casts to Zooplankton Monitoring Program where possible.
- Consider micro-zooplankton collection and analysis (provided previously from Marine Water Quality Workgroup)
- Nearshore sampling to improve capture of forage fish larvae dispersion and support invasive species analyses. However, the group concluded that nearshore environments are localized, dynamic, and would require extensive sampling with different gear and protocols from the current program. Opportunities may exist to compare nearshore to offshore sampling over a short period, especially if neuston sampling were added, to determine whether there are any similarities in plankton composition.

**Improving coordination/communication between sampling efforts, physical through zooplankton.** The group concluded that coordinating locations and timing of sampling and maximizing efficiency, to the best extent practicable, is important. Recommended approaches include:

- Initiate a shared calendar and group messaging to share sampling schedules, discuss coordination, and share what they are seeing in the field on the fly. LLTK staff will work on this over the next 4 months.
- Pair sampling sites where possible.
- Improve data coordination. King County has agreed to host the zooplankton dataset for Puget Sound for now. On a longer-term scale, consider best ways to coordinate data hosting and distribution. NANOOS is a good option for aggregating links to relevant datasets (e.g., King County’s data portal, DOE’s EIM). Ecology’s EIM system is where current physical and benthic data are stored.
- Host a taxonomic workshop to identify to broad taxa (functional groups) is of regional interest, specifically for folks with DOE’s benthic invertebrate group, Nicole Burnett (Padilla Bay), and Lyndsey Swanson (KC). A subgroup should have additional conversations on speciation needs and long-term storage plans. However, Julie
emphasized the importance of maintaining fine-scale speciation work (i.e. processing vertical tows) in one lab given the expertise and consistency required.

- Christopher K. suggested that there be a way to communicate about what folks are seeing, qualitatively, throughout the year, to a broader audience. Real time information could help inform the public about ongoing changes and, farmers of salmon and shellfish, about things to consider during their seasonal activities.

- Shellfish aquaculture folks were not represented at the meeting; however, the group thought there may be interest given they are increasingly turning to wild spat fall for propagation.

- LLTK will be speaking with various entities regarding taking over coordination of the zooplankton sampling program. The current plan is to transfer coordination responsibilities by spring 2018.

Notes

Overview of Puget Sound Zooplankton Monitoring Program: program design, strengths and weaknesses, and examples of data utility

Zooplankton link the physical and biological environment and can serve as indicators of ecosystem function. A knowledge gap existed around zooplankton in Puget Sound: very little data was available on seasonal cycles, spatial patterns, and interannual variability. In 2014, the Puget Sound Zooplankton Monitoring Program was launched. Developed as part of the Salish Sea Marine Survival Project, the Program’s 10 collaborating groups collect zooplankton from 15 sites throughout Puget Sound every two weeks from March-October. At each site, sampling groups collect vertical tows over the full water column and oblique tows over the upper 30 m of the water column. Vertical tow data are used to develop ecosystem indicators and oblique tow data provide a metric of prey availability for juvenile salmon, forage fish, and other epipelagic fish. All sampling is performed during daylight hours. Sampling protocols were developed with input from regional zooplankton experts and salmon biologists, and mimic other successful zooplankton programs. Results from the first three years of sampling (2014-2016) are improving our understanding of seasonal cycles and phenology, as well as identifying interannual variation in abundance of taxa and basin-scale variation in community composition and dynamics. Data are currently hosted by King County, one of the Program’s collaborators, on their online data portal and available by public request.

- Christopher Krembs – are Canadian protocols comparable? Can data be shared across the border?
  
  - Julie Keister and Ian Perry are working together to compare Puget Sound and Strait of Georgia data. Protocols are mostly comparable.

- Data from the Program’s sites suggest variation in abundance such that Noctiluca was present at fewer sites and overall abundances declined from 2014-2016.
  
  - Christopher Krembs – we saw Noctiluca in South Puget Sound in 2016 that we did not see in 2014; could be site-specific.
  - Carol Maloy – vertical tows may not represent surface Noctiluca well.
  - Evelyn Lessard and Jan Newton – we quantitatively sample surface Noctiluca at WOAC stations and our data show the same relationship: highest abundances in 2014, declining through 2016. The South Puget Sound site is in Carr Inlet.
Christopher Krembs – can you statistically explore whether these stations are enough to characterize Puget Sound? Some method where sites are added/removed and information gain/loss is quantified?

Christopher Krembs – do we have any information on zooplankton site fidelity?
  - Jim West and Sandie O’Neill – our replication of Cooney 1969 survey only found krill in exactly the same spots he found them and contaminant fingerprints differed by location, so we think krill exist only in certain places in Puget Sound.
  - Jeff Cordell – site fidelity likely depends on the taxa. Krill need deep spots and would be likely to concentrate there. Crab megalopae, for example, might be much more dispersed.

Don Rothaus – how well are you able to speciate crab?
  - Julie Keister & Amanda Winans – it depends on lifestage. All megalopae can be speciated. Early zoea can be speciated, but late zoea can be virtually impossible. For red rock and Dungeness crabs specifically, zoea stages 3-5 are difficult to speciate because they look similar and their size ranges overlap.

Maggie Dutch and Carol Maloy – we will begin conducting vertical tows for zooplankton at five DOE long-term monitoring stations in South Puget Sound August 2017. We would like to add sites north of the Narrows later.

What regional needs can the current program and/or sampling platform fulfill?

Sandie O’Neill and Jim West – we want to explore spatial distribution and potentially seasonality of contaminants in salmon prey taxa. Crab megalopae and euphausiids are main taxa of interest. For contaminants analysis, we need two grams of tissue. Samples could potentially be pooled over time, but keep locations separate.
  - Jed Moore – from the sampler end, it is fairly easy for us to provide samples. It requires additional sampler time to add an extra tow per site.
  - Julie Keister – from the analyst end, any samples that must be processed fresh require a lot of additional time.
    - Sandie O’Neill – we can work from frozen samples, as long as they have not been fixed in preservative.

Christopher Krembs – coordinating sampling efforts in space and time to connect datasets is an important goal. How can we move towards that without compromising past data collection? We need a framework, infrastructure to create communication on the logistical level among sampling programs. Also, a platform where folks in the field could report observational data and create a shareable product could be powerful for communication across groups. There is a large constituency that wants information in close-to-real-time. Even observational data are compelling for non-scientists and managers. For example, these data could be useful for aquaculture: timing salmon releases or shellfish harvesting.
  - DOE water quality sampling sites and zooplankton sampling sites are not co-located in the San Juans. In other areas, water quality sites (DOE and KC) and zooplankton sites are located fairly close together.
    - Jan Newton – a single map overlaying all data sources would be useful. WOAC stations, PRISM, ORCA buoys, DOE water quality and sediment team sites, zooplankton sampling sites, etc.
  - Russel Barsh – our zooplankton sites are paired with fish sampling. We could add CTD casts. The Cowlitz site experiences large Fraser River influence.
    - Julie Keister – please add CTDs – for all zooplankton sampling groups if possible.
Jan Newton – the Friday Harbor Lab Observatory is getting started; it will have consistent CTD sampling between the harbor and channel. Emily Carrington’s surface sampling off Cantilever Pt shows Fraser influence over 5 years.

Julie Keister – I want a map of Puget Sound where anyone can add observational data by pinpointing a location and submitting a comment (e.g., “we saw lots of jellies here”).

Kirsten Feifei – this idea is very relevant. Our advisory team is keen on scientific monitoring and social outreach. Consider submitting this as a near-term action (NTA); it may be eligible for EPA funding.

Michael Schmidt – we will submit the Zooplankton Monitoring Program as an NTA to keep it continuing, and will include whoever takes over the coordination position.

Coordinating collection timing is challenging: weather, crew needs, technical failures, etc.

Jan Newton – continuous data (e.g., from ORCA buoys) can be used to place discrete sample collections in context.

Mike Crewson – collections also depend on the capacity of field crews.

Julie Keister – a calendar that sampling groups populate with their sampling dates would be helpful.

Carol Maloy – the Marine Waters Workgroup meetings every other month can provide a forum for communication.

Michael Schmidt – the long-term vision for the Zooplankton Monitoring Program includes a staff coordinator. This coordinator position could include managing a regional communication platform.

Mike Crewson – real-time coordination of basin-scale observations could lead to better coordination and partnerships among sampling groups.

Don Rothaus & Mike Crewson – consider bringing folks from aquaculture, shellfish biologists, etc. into this conversation.

Dayv Lowry – there is also a need to contextualize collections in space. We have conducted vertical zooplankton tows following Zooplankton Monitoring Program protocols during our bottom trawl survey every May since 2014. We also did vertical tows during our 2016-2017 midwater trawl surveys: every other month year-round at sites throughout Puget Sound.

Don Rothaus – we advocate for the current program to continue. The WDFW crustacean group has seen a dramatic decline in South Puget Sound landings over the past 4-5 years. We began sampling more intensively pre-harvest and juvenile (1-2 year) crab and are not seeing any recruit-sized crabs. The crabs caught in test fisheries are getting larger. The evidence suggests South Puget Sound recruitment failure or juvenile mortality event. We don’t know whether South Puget Sound produces its own larvae or if they recruit from elsewhere. Basin-specific zooplankton monitoring and analysis over the long-term is crucial for us to evaluate our crab harvest management strategies.

Julie Keister – when was the last good year for landings?

Don Rothaus – 2013-2014 were good seasons; we landed 200k lbs of Dungeness. Nowadays we are lucky to land 25k lbs. Crabs recruit to fishery at age 4. Old-timers in South Sound say that it has never been a consistently good source of Dungeness, and that there is a 7-10 year oscillation between really good years – a pattern that might indicate larval recruitment from outside of South Sound.
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- Jan Newton – 2010-2011 were La Niña years and we were in a cool PDO phase. In our San Juans time series during that time period, we saw peaks in seabirds, cetaceans, and pinnipeds.
- Mike Crewson – aggregation and analysis across datasets – physical to biological – is crucial to reveal data gaps and improve our ability to generate and understand ecosystem indicators that can improve management. Integration, collaboration across disciplines is needed.
- Maggie Dutch – the DOE Sediment Team is interested in the connection between benthic invertebrates and plankton. We have begun sampling contaminants in the benthos and we would like to pair those data with plankton data. We are interested in what percentage of plankton is coming from the benthos because over the past years we have seen declines. Based on some data from the current Zooplankton Monitoring Program, we estimated 20% plankton come from benthos (meroplankton).
- Christopher Krembs – the biogeochemistry of Puget Sound is not well-understood. Long-term data suggest that high chlorophyll impacts our nitrogen measurements, suggesting that we missed a nitrogen pool in previous sampling. We hypothesize that the biogeochemistry of the marine food web is changing (increases in Noctiluca, jellies, macroalgae; diatom decline). We are going to sample particulates to address this knowledge gap.
  - Jan Newton – at the WOAC sites, we measure inorganic carbon in April, July, and September. Organic carbon and nitrogen sampling could be easily added if someone else can analyze.
    - Evelyn Lessard – we could come up with estimates of living carbon; we could estimate ratios if we had total POC.
- Don Rothaus – does the current sampling program do a good job covering sills?
  - Jan Newton – the current locations in Admiralty Inlet and Hood Canal are sufficient. There may be a need to add another site near the Narrows. Commencement Bay is very spatially unique.

What needs cannot be fulfilled with the current program?

- Jim West – the current program misses the really small (e.g., microbes and phytoplankton) and the really large (e.g., adult krill).
- Michael Schmidt – the current program does not include nearshore sampling. Can offshore data be a proxy for nearshore?
  - Julie Keister – nearshore communities are very different from offshore communities, and they are difficult to sample because environments are localized on small scales. You would need an incredible amount of sampling effort to characterize the nearshore. Development of the Zooplankton Monitoring Program was focused around offshore sampling in part because Dave Beauchamp et al. argued that primary controls on variability in juvenile salmon growth occur in the offshore environment.
  - Jeff Cordell – plankton nearshore can be very different on local scales. The current Zooplankton Monitoring Program does not reflect nearshore prey availability in the earliest couple weeks after marine entry of salmonids (especially pink and chum). Bays and embayments can have localized prey communities and fish diets reflect that. Meroplankton and polychaetes recruit into shallow water, so may not be expected in offshore samples.
    - Sandie O’Neill – May-June nearshore sampling would be target to supplement from a salmon perspective.
Mike McHugh – nearshore epibenthic sampling would have completely different protocols from the current sampling.

Jeff Cordell – the most abundant non-indigenous copepods from ship discharges are embayment-dwelling species. The open-water species don’t seem to be invasive in Puget Sound. For example, nearshore areas in Samish Bay are dominated by *Oithona davisii* which was likely brought here from San Francisco Bay via tankers. Their dominance has driven down the size of zooplankton in that localized area. Do fish in that bay feed on *Oithona* now? Does that impact their growth?

- Don Rothaus – there is a well-established invasive green crab population on Dungeness Spit. We would be interested to see whether those larvae are in Puget Sound.
  - Amanda Winans – green crab larvae would be obvious; we have not seen any in our samples.

- Michael Schmidt – are jellies captured in the current program?
  - Julie Keister – the current sampling catches lots of jellies; no concerns there.

- Jeff Cordell – nighttime sampling would improve capture of diel vertical migrators.
  - The current program does not include night sampling, but Cheryl Morgan has found a strong relationship between daytime oblique tows in the upper water column off the coast of Oregon and returns of adult salmon to the Columbia River.
  - It’s challenging for sampling groups to consistently sample enough for a day/night comparison.
  - Adult krill are not well-captured with the current program’s daytime tows; it is possible but unknown whether juvenile krill catches index adult abundance.

What are priorities to improve sampling, analyses, and data distribution?

- Sampling year-round is the highest priority. Bi-weekly sampling should be extended from February-October; monthly sampling may be sufficient through November-January.
  - Christopher Krembs – without year-round data, we cannot fully understand Puget Sound dynamics or investigate impacts of climate change, river flow changes, etc.
  - Jeff Cordell – winter sampling (November-January) could be done on a monthly basis because zooplankton are less dynamic then.
    - Julie Keister – bi-monthly sampling should start with phytoplankton blooms (mid-February) if not earlier and must continue through productive season. We don’t want to miss the onset of primary productivity.
    - Dayv Lowry – we have February samples from 2016 and 2017 midwater trawls.
      - Julie Keister – let’s match up trawl locations; it would be useful to analyze samples from locations near the Program sites.

- Maggie Dutch – our lab wants to do some in-house taxonomy. We want to coordinate a training workshop with Julie’s lab and other taxonomists working on Puget Sound zooplankton.
  - Nicole Burnett does taxonomic analysis for Padilla Bay, but only identifies to broad categories (functional groups like copepods, amphipods, krill, crab).
  - Lyndsey Swanson is also interested in a training workshop.
  - Carol Maloy – our in-house taxonomists are experts on the benthos but are also interested in learning zooplankton.
  - Julie Keister – we can provide training to broad taxonomic groups, but it may not be a good approach to have distributed groups doing a speciose analysis. Even within our lab,
taxonomists are constantly checking in with each other: need very high levels of communication.

- Sandra Weakland – if we process to broad groups and preserve, can species be processed later?
  - Julie Keister – yes, if they are preserved in formalin.
- Dayv Lowry – our group would advocate for continuation of the program, adding more focus on ichthyoplankton, nearshore sampling, and year-round sample collections. In 5 of 6 South Puget Sound herring populations, we have failed to document spawning over the past two years. The remaining population spawned one day in one location. Our midwater trawl caught adults in South Puget Sound; if they’re there, why aren’t they spawning? We also suspect a decline in surf smelt populations and are very interested in anchovy in Puget Sound. We want to use data from the Zooplankton Monitoring Program to understand larval forage fish presence and dynamics.
  - Julie Keister – our intern analyzed several samples for forage fish eggs and larvae. We catch tons of fish larvae, but not many forage fish. However, we begin sampling in mid-March which is likely later than when many of eggs and larvae are present. They may also be able to avoid the net. Paired neuston tows and oblique tows would determine whether the oblique tows can capture ichthyoplankton well enough to address your questions. The current program may be catching enough to develop an index.
  - Dayv Lowry – the lag between herring egg deposition and fish recruiting to plankton is very short (30-60 days).
  - Dayv Lowry – nearshore sampling is critical from the forage fish perspective. Some species like surf smelt likely stay nearshore. We are trying to take nekton samples during herring surveys this year.
- Maggie Dutch – any data DOE generates goes into EIM. Zooplankton Monitoring Program data is at King County. Need to coordinate data hosting and distribution.
  - Julie Keister – NANOOS offered to host links to datasets; good place to aggregate.
  - Jan Newton – IOOS is moving towards hosting biological databases so there is opportunity beyond link aggregation also.