FY2015 Saltonstall-Kennedy Final Report

Project/Report Title: Improving Salmon Survival Forecasts through Prey Field Monitoring and Indicator Development

Name of Grantee and Sub Awardee: The Tulalip Tribes of Washington (Applicant Organization), University of Washington

Principal Investigator and Project Administrator (Authors): Dr. Julie Keister, Associate Professor, School of Oceanography, University of Washington; Michael Crewson, Tulalip Tribes, Natural Resources Dept.

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Executive Summary:

The Project Applicant (Tulalip Tribes), sub awardee (University of Washington), and Collaborating Partners successfully accomplished all of the goals and objectives for this Project. We conducted bi-weekly zooplankton sampling in spring through fall 2016 at 16 sites in Northern Washington and Puget Sound with support from this grant and collaborations with 10 federal, state, and county agencies, tribes, universities, and non-profit groups. These data constituted the third full year of zooplankton monitoring in the region which initially funded in 2014 and 2015 with Pacific Salmon Commission funding through the Salish Sea Marine Survival Project (SSMSP[1]). In this report, data from these 2016 zooplankton collections are combined with 2014, 2015, and 2017 zooplankton data collected under the newly-formed Puget Sound Zooplankton Monitoring Project and data collected as part of other projects to form three datasets: 1) data from the SSMSP throughout the region in 2014-2017, 2) a 2003-2017 monthly time series at a single station in the Strait of Juan de Fuca; and 3) a spatially-extensive dataset collected monthly in conjunction with juvenile salmon growth data in 2011. These zooplankton data were compared with survival hydrographic, chlorophyll, and salmon growth data provided from several other regional monitoring programs to explore zooplankton community response to environmental change and its implications to salmon.

2014-2017 was a period of unusually large climate variance for the region. A strong marine heatwave affected coastal and inland regions of the Northeast Pacific beginning in late 2014, with high temperature anomalies throughout the region and record high temperatures recorded in 2015 in several regions of Puget Sound. Warm, though slightly cooler, temperatures continued in 2016, followed by a very cold winter and a return toward near-normal temperatures in some regions in 2017, with continued warm anomalies in others. 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 and 2016 compared to 2014, followed

[1] See https://marinesurvivalproject.com/

by regional differences in response in 2017, likely due to differences in the return toward 'normal' conditions among regions. Chinook salmon growth and coho salmon survival were also higher in 2015 than 2014, indicating that the elevated temperature and prey availability provided better conditions and growth-potential through bottom-up processes.

Ordination of the 2003-2018 zooplankton time series revealed a clear relationship between the dominant axis of zooplankton community variance and the Pacific Decadal Oscillation and relationships between the second axis of community variance with marine survival time series estimates for some Puget Sound coho and Chinook salmon stocks. However, in 2011, preliminary examination of in situ measures of salmon growth (IGF-1) and zooplankton prey biomass showed no relationships.

The similarities and differences in response among years and regions improve our understanding of the underpinnings of observed changes and their implications for integrated fishery, hatchery, and habitat management integral to salmon recovery. Zooplankton abundance, biomass, and metrics of their composition have been provided to NOAA and local tribes for annual coho salmon return forecasting; zooplankton data are now publicly available for download for use in ecosystem modeling and other research activities. On-going research stemming from this project includes further investigation of environmental controls on zooplankton, relationships to salmon growth, and bottom-up processes that correlate with juvenile growth and survival of ESA-listed Chinook salmon.

Purpose: Detailed description of problem or impediment of fishing industry that was addressed by the project and objectives of the project.

Through implementation of annual zooplankton monitoring and comparisons to other biotic and abiotic factors that may influence salmon growth and survival, this project addresses impediments to the fishing industry by providing annual monitoring data that benefits local salmon and ecosystem management communities. This monitoring is needed to develop the important associations between zooplankton and other ecosystem indicators that affect salmon growth and marine survival. Understanding how those associations vary among regions of the Salish Sea as they may differ in physical conditions is integral to our understanding of how they respond in tandem to climate change. Since its inception and continuing, this project addresses impediments to the fishing community through direct participation among the fishing community, which benefitted all fishing communities with four of seven zooplankton collection partners being tribes currently exercising fishing rights. It refined and standardized, systematic, comprehensive sample collection and analysis methods and protocols for a sustainable Puget Sound Zooplankton Monitoring Program. Other fishery management agencies' regional involvement complimented the tribes' regional sampling to enable representative sampling in all Puget Sound subregions, including Hood Canal; which was complimented by ongoing zooplankton sampling in the Strait of Juan de Fuca Success in employing the methodology of this distributed approach benefits knowledge of marine factors affecting salmon survival that remains sorely lacking for geographic regions that support economically and culturally important salmon fisheries. Programmatic successes in sample collection and analysis methods benefit other similar zooplankton and ecosystem monitoring efforts, while the development and comprehensive update of marine survival rate time series datasets afforded by this study for all available Chinook and coho stocks across Puget Sound and the Strait of Georgia, are powerful tools needed to address impediments to the fishing industry.

In western Washington, resource managers continue to grapple with the overall need to sustainably integrate harvest, hatchery, and habitat actions (so called "All H" management), particularly in the face of climate variation and its cascading influences on the Puget Sound food web, with unpredictable effects on salmon marine survival. The inability to accurately assess the efficacy of All H management actions has impeded the fishing industry, salmon recovery actions, and nearly all aspects of fisheries management. Both domestic harvest management and international commitments with Canada under Pacific Salmon Treaty Annex amendments have been severely hampered without the tools needed to more accurately predict marine survival and forecast salmon returns. The inability to recover salmon has increasingly put Treaty Rights at risk and diminishes the Treaty Trust responsibilities held by the US government to the tribes.

All of these efforts have been complicated by lack of systematic comparable data leading to uncertainties surrounding factors that affect the relationship between prey availability, early marine growth of juvenile salmon, and the interannually and regionally, highly-variable marine survival rates that have been observed in Puget Sound, the Strait of Georgia and among different subregions. Ecological indicators affecting marine survival in key regions of the Salish Sea environment are unavailable for forecasting, clouding ability to understand how they may help predict survival or idenitfy limiting factors for recovery. These indicators are vital for lowering estimation error in forecasts of adult salmon returns, increasingly influenced by environmental variability. This causes increasing impediments to the fishing industry or in the ability to accurately assess the efficacy of fisheries management and recovery efforts.

Prey availability is one of the primary factors that control fish growth and hence size-at-age (LaPape and Bonhommeau 2013), and is known to be very important to juvenile salmon survival. Several studies have linked zooplankton prey availability to juvenile salmon growth and smolt-to-adult survival (e.g., Cross et al. 2009; Beamish et al. 2004), including a study of the relationships between feeding, growth, and survival of juvenile salmon in Puget Sound that found strong evidence of food-limited growth during the critical early ocean entry period of rapid growth for juvenile salmonids in epipelagic habitats, with differences in feeding and survival observed among regions (Duffy 2009, Duffy et al. 2010, Beauchamp and Duffy 2011; Figure 1). Under the "critical size/critical period" hypothesis, juvenile salmon that do not achieve a minimum size by the end of their first summer at sea will not survive through winter (Beamish and Mahnken 2001). Therefore, sufficient prey to support high growth rates during the first summer after river emigration is important to recruitment of a year-class (Beamish and Mahnken 2001; Beamish et al. 2004; Moss et al. 2005).

This study addresses impediments to the fishing community by improving fisheries management through the development and refinement of a standardized, systematic zooplankton collection and analysis program. Associations with biotic and abiotic factors afforded by the zooplankton collections under this study further our understanding of mechanistic relationships between prey availability, salmon feeding, growth, and survival; integral components of a Puget Sound Ecosystem Indictor Program. Understanding how growth limitation varies among life stages or regions is constrained by a paucity of data on the dynamics of food supply in Puget Sound. Little is known about the temporal and spatial availability of key zooplankton and other prey, or how they change with climate and environmental variability. This has been recognized as a significant information gap by many agencies around the region who seek to understand changes in fish production. This project directly helped to fill that data gap by accomplishing the three primary objectives of this project and their associated activities and tasks by providing spatially-resolved zooplankton data throughout Puget Sound and Northern Washington to improve our understanding of spatial and temporal patterns of zooplankton in the region (Objective 1), quantifying relationships between zooplankton, salmon growth, survival, and the environment (Objective 2), and providing biologically-based Ecosystem Indicators to aid adult salmon return forecasts (Objective 3).

Annually, this project provides stability in fisheries management planning and impediments to fishing community (fishers and industry) planning that can lead to fishing opportunities when harvestable abundances are available while enabling fishery managers to better control fisheries when fewer harvestable salmon are expected to return, preventing overfishing and future fisheries restrictions. Over the long-term, it will continue to address future impediments to the fishing community through furthering our understanding of how critical relationships between environmental variability and ecosystem predictors affect salmon prey availability, growth, and natural patterns of marine mortality in the face of increasing environmental variability due to climate change affecting ecosystem processes as they relate to the management and recovery of a sustainable Puget Sound ecosystem, from physical habitat to the top end of the food web: Orca whales and people. This directly benefits all fishers, fishing communities, tribal Treaty Rights, and has a broad economic benefit and quality-of-life impact to the northwest as many of the general public move here and live here because of our natural surroundings.

Approach - Detailed description of the work that was performed.

Field Collections

In 2016, a total of 391 new samples were collected by 10 participating groups from 15 monitoring stations in the San Juan Islands, Bellingham Bay, Strait of Juan de Fuca, and Puget Sound (Figure 1, Table 1, Table 2). At each location, one full water column vertical tow was conducted at the deepest local water depth using a 60-cm diameter, 200-µm mesh ring net with flow meter. Also at each location, an oblique bongo net tow was conducted using 60-cm, 335-µm mesh bongo nets equipped with a flow meter and towed over the upper 30 m of the water column (the depth over which juvenile salmon feed during daytime). Of the collected samples, 210 were bongo net tow samples and 181 were vertical net tow samples. Of all the samples collected, 95% of the bongo tows (n=200) and 100% of vertical net tows passed QC for high quality collections; the few that did not had collection issues such as missed target tow depths and erroneous flow meter readings so were not taxonomically analyzed. In addition, 22 new samples were collected from the JEMS[2] time series station in 2016 using a 75-cm diameter, 150-µm mesh net towed vertically over 0-40 m and 80-120 m depth strata (only 0-40 m data are reported on herein). All samples are archived at the University of Washington.

[2] Zooplankton samples have been collected monthly from the Strait of Juan de Fuca since 2003 at this station during research cruises conducted by the Washington Department of Ecology and the University of Washington Puget Sound Regional Synthesis Model (PRISM) program (http://www.prism.washington.edu/home).

Table 1. Station name and sampling frequency by site. Only stations sampled from 2016 on listed.

Station name	Station code	Sampling group	Sampling frequency and months
Cowlitz	COW	Kwiáht (KWT)	April-October since 2014: bi-weekly
Watmough Bay	WAT	Kwiáht (KWT)	
Eliza Island	ELI	Lummi Nation (LUM)	March-October since 2014: bi-weekly
JEMS	JEMS	Shannon Point Marine Center / WA Department of Ecology (DOE)	January-November since 2003, monthly
Hope	HOPE	NOAA	April-October since 2014; monthly
Saratoga Passage	SARA	NOAA	
Admiralty Inlet	ADI	Port Gamble Sklallum Tribe (PGST)/WDFW	March-October since 2014: bi-weekly
Thorndike Bay	TDB	PGST/WDFW	March-October since 2014: bi-weekly
Eldon	HCB003	Hood Canal Salmon Enhancement Group (HCSEG)/DOE	March-October since mid 2016: monthly
Sisters Point	HCB004	HCSEG/DOE	
Camano Island	CAM	Tulalip Tribes (TUL)	March-October since 2015: bi-weekly, occasional winter
Mukilteo	MUK	Tulalip Tribes (TUL)	
Pt. Jefferson	KSBP01	King County (KC)	March-October since 2014; bi-weekly November-February since 2014; monthly
Pt. Williams	LSNT01	King County (KC)	
East Passage	NSEX01	King County (KC)	
S. Ketron Island	SKET	Nisqually Indian Tribe (NIT)	March-October since 2014: bi-weekly

Table 2. Zooplankton stations where vertical net samples were collected and paired Washington Department of Ecology (DOE) hydrographic stations. HGSEG collaborated with DOE to sample; PGST collaborated with Washington Department of Fish and Wildlife (WDFW) to sample. Except for stations marked with *, all stations had 0-30 m oblique net tow samples collected nearby.

SSMSP Group	SSMSP Station	SSMSP Lat.	SSMSP Long.	DOE Station	DOE Lat.	DOE Long.	SSMSP/ DOE Depth (m)	Basin
KWT	COW[1]	48.6808	123.044	GRG002	48.808	122.953	70/205	San Juan
KWT	COW[2]	48.6744	123.048	GRG002	48.808	122.953	70/205	San Juan
KWT	WAT[3]	48.4355	122.793	SJF000	48.417	123.025	113/31	San Juan
KWT	WAT[4]	48.4346	122.804	SJF000	48.417	123.025	40/172	San Juan
LUM	ELI	48.6380	122.569	BLL009	48.687	122.598	40/172	San Juan
JEMS	--	--	--	SJF002	48.250	123.025	147	--
NOAA	HOPE	48.4062	122.578	SKG003	48.297	122.488	37/25	Whidbey
NOAA	SARA	48.2567	122.544	SKG003	48.297	122.488	73/25	Whidbey
TUL	CAM	48.0590	122.387	PSS019	48.011	122.3	188/107	Whidbey
TUL	MUK	47.9717	122.322	PSS019	48.011	122.3	201/107	Whidbey
PGST	ADI	48.0027	122.636	ADM001	48.03	122.617	121/153	Admiralty
PGST	TDB	47.7830	122.733	HCB010	47.667	122.82	115/103	Hood Canal
HCSEG	HCB003*	47.5379	123.01	HCB003	47.538	123.008	143/162	Hood Canal
HCSEG	HCB004*	47.3562	123.025	HCB004	47.357	123.023	51/55	Hood Canal
KC	KSBP01*	47.7437	122.428	PSB003	47.66	122.442	276/110	Central
KC	LSNT01	47.5333	122.433	ELB015	47.597	122.368	211/131	Central
KC	NSEX01*	47.3586	122.387	EAP001	47.417	122.38	180/212	Central
NIT	SKET	47.1524	122.659	NSQ002	47.1683	122.787	130/111	S. Sound
NIT	DANA[5]	47.1833	122.831	DNA001	47.161	122.87	52/51	S. Sound

[1]Sampled only in 2014; [2]Sampled in 2015-2017; [3]Sampled in 2014-2015; [4]Sampled in 2016-2017; [5]Sampled only in 2014-2015. *Does not have a companion oblique tow.

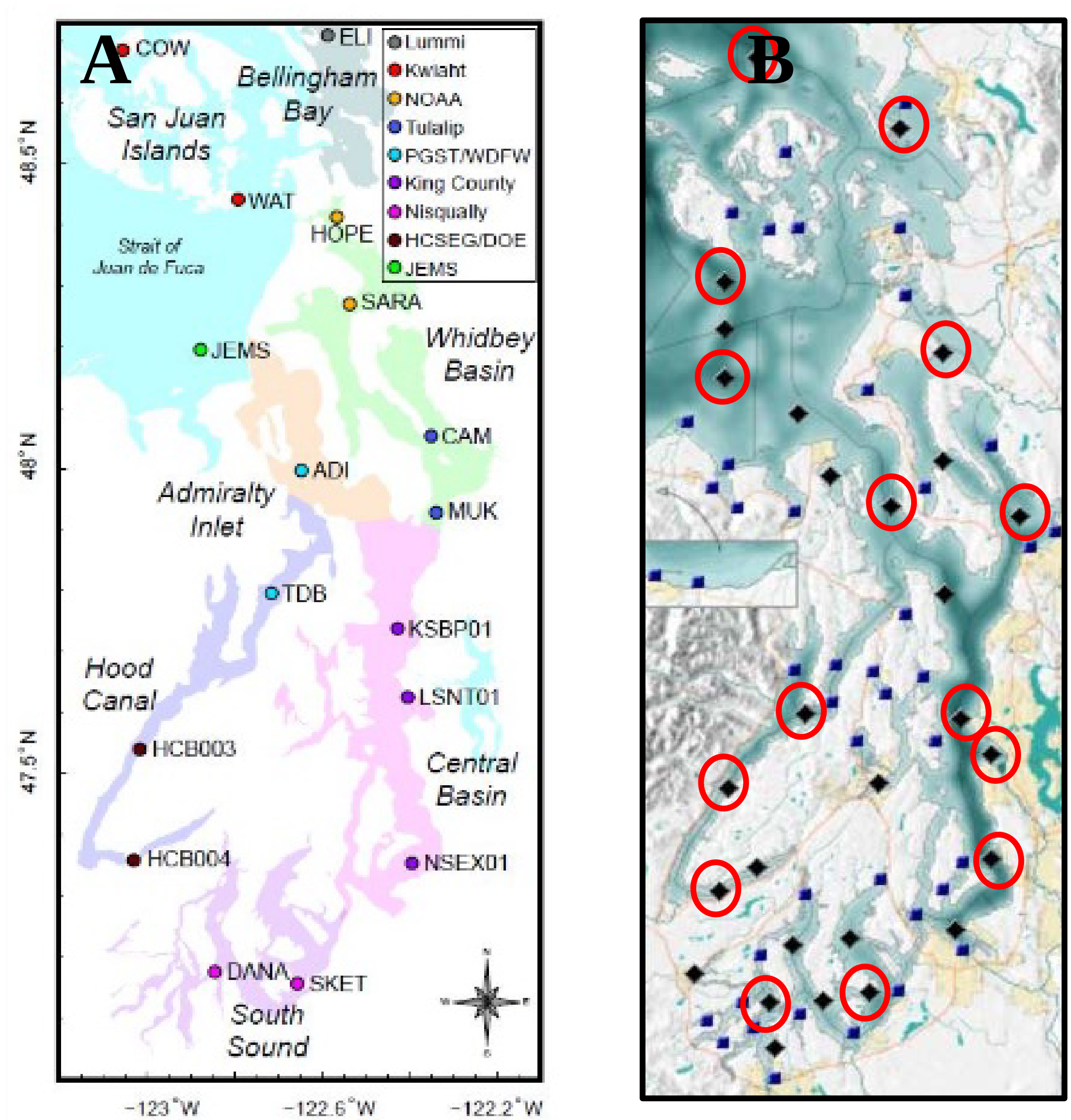

Figure 1. Maps of A) the SSMSP and JEMS zooplankton stations coded by basin and sampling group and B) the Washington Department of Ecology's Long-Term Marine Water Monitoring Program CTD stations; stations used in these analyses are circled in red.

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. 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.

In addition to the new field collections described above, an additional 180 sample jars equating to 125 dates/sites from collections in 2011 conducted through separate funding by C. Greene (NOAA Fisheries), were taxonomically analyzed using similar protocols. Full sampling protocols are available on request from C. Greene; sites are as in Chamberlain et al. (2017).

All taxonomic data were digitally entered, QC'd, and calculated for abundances and biomass by taxon and life history stage at the University of Washington. Full laboratory processing protocols can be found in the annual King County Zooplankton Monitoring reports (available from King County or J. Keister upon request).

Data Synthesis and Analysis:
Zooplankton data analyses

The density of organisms (number of 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, 0.45 x DW was used to convert to carbon weight.

To create time-series plots, semi-monthly sampling dates were categorized as falling on either the 1st or the 15th of the month, regardless of actual date, which typically deviated only 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. Tableau® 10.5 was used to plot time series.

Nonmetric Multidimensional Scaling (NMS) ordinations were run using PC-ORD™ 7.06. For 2014-2016 data, all taxa were used; for the JEMS time series station, only copepod species were used. For ordination of SSMSP data, Species Biomass X Station matrices were created from monthly averages of biomass (C m^{-3}) at each station. For ordination of the JEMS time series data, a Species Proportional Representation X Date matrix was created because quantitative abundance was missing for many samples due to the lack of flow meter information (whereas proportions of species within each sample were quantifiable). Due to the rarity of some taxa and high abundance of others, biomass data were normalized using a logarithmic transformation [$\text{Log}_{10}(Y + 0.001) + 3$], proportions data were arcsine-square root-transformed, and taxa that occurred in <5% of the samples were removed from each matrix. Ordinations were run on the remaining taxa 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 of the 2014-2017 SSMPS data 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 to compare to the ordinations 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 from surrounding months 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.

Juvenile salmon growth

Juvenile Chinook salmon growth data shown in this document came from two sources. A time series of growth in 1999-2017 came from data calculated by Iris Kemp (Long Live the Kings) from individual length and weight measurements of fish captured during mid-water trawls conducted in Puget Sound by the Fisheries and Oceans Canada during annual juvenile salmon surveys in Septembers of each year. 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 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 Information System (RMIS) database (www.rmpc.org) on 2 October 2018. Where length but not weight of a fish was recorded on re-capture, 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 3,730 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.

In 2011, broad spatial and temporal data on individual growth rates of juvenile Chinook salmon came from an EPA-funded project led by C. Greene. The concentration of insulin-like growth factor-1 (IGF-1) was measured in individual fish captured throughout Puget Sound. See Chamberlain et al. (2017) for full methods and a description of patterns in growth among months and regions. We add to that study here by comparing zooplankton biomass patterns to the measured growth rates.

Updating Coho and Chinook Salmon Population Data Resource Tables (PDRTs)
Salmon smolt-to-adult survival (SAR)

Salmon marine survival smolt-to-adult (SAR) time series data were updated for all Puget Sound and Strait of Georgia hatchery- and natural-origin Chinook and coho salmon stocks that had adult return data available during under this project (years) by Marianna Alexandersdottir, Alexanders Consulting, Olympia, WA., through a subcontract with the Tulalip Tribes under this project. For Salish Sea coho salmon stocks, this update was done as a continuation of work initiated by Kit Rawson[3] for brood years 1970 through 2007; also done through a contract with the Tulalip Tribes under this project, with participation under the Salish Sea Marine Survival Project by a team of US and Canadian biometricians and fishery scientists from WDFW, Department of Fisheries and Oceans Canada (DFO), NOAA Fisheries, University of Victoria, Victoria, BC, and private consultants, which was published in Zimmerman et.al (2015). The dataset of estimates of survival for coho salmon for outmigration years (OEY) 1972 to 2010 used by Zimmerman et.al. (2015) was updated for outmigration years 2011 to 2015 by Rawson and Alexandersdottir (for brood years 2008-2013), although the entire time series was not available for all stocks through return year 2016 at the time of this report.

Chinook survival data through outmigration year (OMY) 2008 were published in Ruff et al. (2017) also as part of the Salish Sea Marine Survival Project; Chinook salmon marine survival rates through OMY 2011 were also updated by Kit Rawson and Marianna Alexandersdottir as part of this project through contracts with the Tulalip Tribes in coordination with the same team of biometricians and fishery scientists that produced the coho marine survival retrospective analysis. Screening of data and computation of SARs from these data followed the same procedures as in the initial coho retrospective analysis project (Zimmerman et al. 2015), adding three additional broodyears for each of these retrospective marine survival analyses through return year 2017 for CWT recovery data available in the Pacific States Marine Fisheries Commission's Regional Mark Information System (RMIS) database for coho and Chinook salmon Salish Sea-wide. These databases are known as Population Data Resource Tables (PDRT) and can be accessed at: https://nwsalmonprojects.basecamphq.com, an internal project management website used by all collaborators under the Salish Sea Marine Survival Project. See Appendix B for a comprehensive report of methods used for estimation of tag recoveries and results of the survival rate estimates.

Project Management - List individuals and/or organizations actually performing the work and how it was done

- Tulalip Tribes: Mike Crewson (Project Administrator): overall project oversight and management.
- Subcontractors for salmon marine survival time series updates: Kit Rawson, Swan Ridge Consulting, Mount Vernon, WA; Marianna Alexandersdottir, Alexanders Consulting, Olympia, WA.
- Collaborating agencies and entities for zooplankton collections: The Tulalip Tribes, Kwiaht, the Lummi Tribal Nation, NOAA, the Port Gamble S'Klallam, WDFW, the Nisqually Indian Tribe, King County, the WA Department of Ecology, and the Hood Canal Salmon Enhancement Group.

[3] Swan Ridge Consulting, Mount Vernon, WA.

- University of Washington: Dr. Julie Keister (Principal Investigator): oversight of 2016 zooplankton sample collections, taxonomic analyses, zooplankton data analyses, public presentations, and data dissemination; BethElLee Herrmann for zooplankton taxonomy and QC, assistance with data analyses and report preparation; and Amanda Winans for oversight of field collections, sample collection QC, zooplankton taxonomy, and assistance with data analyses and report preparation.
- NOAA: Correigh Greene, Joshua Chamberlain, and Brian Beckman provided IGF-1 salmon growth data from 2011 surveys.

Findings: Actual accomplishments and findings:
2014-2017 Environmental Conditions

The four years of zooplankton sampling covered in this report (2014-2017) 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). A very cold 2016-2017 winter helped return the system near normal in some regions of Puget Sound, particularly nearer the ocean, while more southern regions stayed warm through 2017 (Figure 2).

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

Chlorophyll biomass patterns in 2014-2017 did not differ among years as strikingly as temperature patterns, but some pronounced differences among regions and years were apparent (Figure 3). Chlorophyll biomass was much lower in all years in the Strait of Juan de Fuca and South Sound compared to Central Basin and Admiralty Inlet. In most regions, there was evidence of large spring and fall blooms. In Central Basin, chlorophyll biomass appeared higher overall during bloom periods in the cooler years of 2014 and 2017 than in the warmer years of 2015 and 2016. That pattern was not as clear in other regions, 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.

2014-2017 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.

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, 2016, and 2017 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. In Admiralty Inlet and at KSBP in Central Basin, biomass peaked in 2016 then dropped to intermediate levels in 2017. 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.

Cumulative biomass plots of zooplankton taxa that are important prey items (decapod larvae, amphipods, euphausiids, pteropods, and ichthyoplankton) did not show coherent patterns among years and stations (Figure 8). Unfortunately, only a few stations were consistently sampled with oblique tows in 2014 to make a direct comparison to warmer years. Of those that were, 2014 prey biomass was relatively low compared to other years, but not generally the lowest year. Several stations in north central Puget Sound (Admiralty Inlet, Thorndyke Bay, Camano, and Mukilteo) all showed declining prey biomass from 2015 through 2017.

2014-2017 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 9). 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 on Axis 1. Samples from Hood Canal and South Sound showed the largest variance and nearly overlapped in the ordination space.

The seasonal cycle of communities moved roughly counter-clockwise around Axis 1 and 2: January, February, and most March communities fell at the top 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 right 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 counter-clockwise structuring; October, November, and December communities occupied the upper half of Axis 2, moving toward the left on Axis 1.

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, and 2017 were not discernable in this analysis.

Taxa most strongly correlated with Axis 1 were the siphonophore *Muggiaea atlantica* and the copepod *Paracalanus spp.* Both were negatively correlated (r = -0.77 and r = -0.73, 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). Barnacle larvae (nauplii + cyprids) and the amphipod *Cyphocaris challengeri* correlated with Axis 2 in opposite directions (r = -0.79 and 0.65, respectively). No taxa correlated strongly with Axis 3 (Table 4). No environmental factor strongly correlated with any axis: the strongest correlates with Axis 1 were 10-m temperature (r = -0.63) and minimum temperature in the water column (r = -0.60); i.e., warmer temperatures to the left 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. 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).

2014-2017 Salmon growth and survival

The time series of juvenile Chinook salmon growth calculated from re-capture of CWT hatchery releases showed strong relationships with regional temperature anomalies (Figure 10). High growth of individuals from all 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 11). In some cases, survival more than tripled in 2015 outmigrants compared to 2014.

It is likely that the elevated temperatures in 2015 and 2016 broadly increased metabolic rates of many taxa in Puget Sound, which if not outside their thermal performance optima and supported by sufficient food resources, enabled higher growth and survival. For zooplankton, the result was large population sizes and high total biomass; for juvenile salmon, higher individual growth was measured. Higher growth during the early marine period when juvenile salmon are zooplanktivorous is correlated with higher smolt-to adult survival (Beamish et al. 2004, Duffy and Beauchamp 2008, Beauchamp and Duffy 2011). The improved metabolic and feeding conditions in 2015 seem to have led to substantially higher coho salmon adult returns in 2016 through bottom-up processes. It is not yet known whether high growth and survival continued for outmigrating salmon in 2016 and 2017. Early reports of adult returns in 2017 and forecasts for 2018 indicate that they may not have fared as well, necessitating continued investigation of the factors that influence survival, including predation and winter growth and survival.

2003-2017 JEMS time series analysis

Ordination of the 2003-2017 copepod time series from the JEMS station in the Strait of Juan de Fuca resulted in a 3-dimensional ordination that explained 85.6% of the variance in copepod community structure. Axis 1 explained the most variance (38.9%); Axis 2 explained 21.4%; Axis 3 explained 25.2%. Axis 1 was strongly correlated with 3-m temperature (R^2=0.59) and progressively more weakly correlated with deeper water column temperatures. Anomalies in the Axis 1 time series (with the seasonal cycle removed) showed similarities to the Pacific Decadal Oscillation, indicating large-scale climate influence on the copepod composition (Figure 12). Copepods that drove variability along Axis 1 (Table 5) were *Pseudocalanus mimus* (r=0.64), *Triconia* (r=0.47), *Calanus marshallae* (r=0.40) and *Acartia longiremis* (r=0.45), all of which were positively correlated, indicating they were more important in the community when the Axis anomalies were positive. Negatively correlated were *Ditrichocorycaeus anglicus* (r=-0.92), *Paracalanus* spp. (r=-0.53), and *Tortanus discaudatus* (r=-0.51). These ensemblages of taxa represent end-members between the coastal ocean where the positively correlated taxa dominate, particularly during summer upwelling, and Puget Sound where the negatively correlated taxa dominate. Climate-related changes in their importance in the Strait likely indicate changes in estuary-ocean exchange on multi-month time scales. Neither Axes 2 or 3 showed strong relationships to environmental factors. Taxa that drove them were also not as clearly associated with different regions. Correlated with Axis 2 were *Calaocalanus*, *Paracalanus*, *Pseudocalanus* copepodites (unspeciatable), and *Pseudocalanus moultoni* (Table 5). Axis 3 was driven primarily by *Pseudocalanus mimus*, *Pseudocalanus moultoni,* and the small cyclopoid copepod *Oithona similis*.

Salmon survival - correlations with JEMS time series:
Correlations with coho survival:

Of the ordination axes, Axis 2 showed the strongest correlations with salmon smolt-to-adult survival. Several coho salmon stocks correlated strongly with Axis 2, although several others showed little to no correlation (Figure 13). Of twelve stocks that outmigrate from rivers that enter into Puget Sound or Northern Washington for which we had at least ten years of survival data available during 2003-2015, the strongest correlates are shown in Figure 13. Another four stocks which correlated very weakly ($R^2<0.1$) are not shown. These were Skagit W, Skagit H, Quilcene H, Kalama Crk H; where W indicates wild stocks and H hatchery stocks. All stocks correlated with Axis 2 in the same direction (negative correlations) except the Nooksack Hatchery stock which was weakly positively correlated. That stock is also the only one that is from outside of Puget Sound, which may indicate the zooplankton community at JEMS indexes some different environmental factors in the north than in Puget Sound. In general, stocks from Southern Whidbey Basin, Central Basin, and some from Hood Canal were better correlated with Axis 2 than those from South Sound and Northern Whidbey Basin. Proximity of the rivers to the JEMS station in the Strait of Juan de Fuca did not solely influence the strength of the correlations–in Hood Canal, a wild stock from Big Beef Creek and a Skokomish hatchery stock both had much stronger correlations with Axis 2 scores than a stock from Quilcene hatchery farther north. Further exploration of stock-specific factors that may influence the relationship to the copepod time series is warranted.

Correlations with Chinook survival

Of the JEMS copepod time series ordination axes, Axis 2 also showed the strongest correlations to Chinook survival time series, although few were strongly correlated (Table 6). As with coho survival, the correlations of Chinook survival from Puget Sound stocks with Axis 2 scores were all in the same direction (negative). Of 16 stocks for which at least eight years of survival data were available during 2003-2014 out-migration years at the time of this report, the strongest correlations were found for some stocks that enter into Whidbey and Central basins (Figure 14).

Zooplankton patterns and Chinook salmon growth in 2011

The high spatial resolution of zooplankton sampling in 2011 revealed high variability in total zooplankton biomass and biomass of prey field taxa (Figure 15 and 16). Biomass peaked in May, with very high biomass at some sites. Biomass was consistently higher in Admiralty Inlet, Central Basin, and South Sound compared to low biomass in Hood Canal and Whidbey Basin, particularly in May through August. Rosario Basin (Bellingham Bay) had intermediate levels with periodic high biomass. The spatial pattern in total biomass and biomass of prey field taxa were unrelated to IGF-1 concentrations in juvenile Chinook salmon (Figure 17), which are an indicator of *in situ* growth on several-day to week time scales. Growth in Hood Canal and Whidbey Basin were among the lowest measured, but not consistently so. Preliminary mixed-effects modeling also did not find zooplankton biomass as a significant predictor of IGF-1 in these samples. These comparisons are very preliminary and more thorough exploration of the growth to zooplankton relationships are underway.

Table 3. Pearson correlations (r and R^2) between taxa and axes from NMS ordination of 2014-2017 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 (R^2 > 0.5) are in bold.

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Muggiaea atlantica	**-0.771**	**0.595**	0.241	0.058	-0.132	0.017
Paracalanus spp.	**-0.731**	**0.535**	0.048	0.002	0.006	0
Pseudocalanus copepodites	0.658	0.433	-0.341	0.116	0.049	0.002
Barnacles	-0.251	0.063	**-0.793**	**0.629**	-0.082	0.007
Cyphocaris challengeri	0.345	0.119	**0.651**	**0.423**	-0.277	0.077
Metridia pacifica	0.266	0.071	0.092	0.009	-0.672	0.452

Table 4. Pearson correlations (r and R^2) between environmental factors and axes from NMS ordination 2014-2017 SSMSP 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.

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
T10	-0.627	0.393	0.155	0.024	-0.025	0.001
Tmin	-0.599	0.359	0.157	0.025	-0.010	0
StDepth	0.327	0.107	0.583	0.340	-0.127	0.016

Table 5. Pearson correlations (r and R^2) between taxa and axes from NMS ordination of JEMS time series data. All copepod taxa used in the ordination are shown; taxa most strongly correlated with each axis (r > 0.4) are in bold.

	Axis 1		Axis 2		Axis 3	
Taxon	**r**	**R^2**	**r**	**R^2**	**r**	**R^2**
Acartia imm.	0.02	0.00	0.13	0.02	-0.16	0.03
Acartia hudsonica	0.06	0.00	0.02	0.00	0.18	0.03
Acartia longiremis	**0.45**	**0.20**	0.17	0.03	0.36	0.13
Acartia tonsa	0.08	0.01	0.38	0.14	-0.23	0.05
Aetideidae	-0.05	0.00	-0.08	0.01	-0.05	0.00
Calanus marshallae	**0.40**	**0.16**	0.21	0.04	0.35	0.13
Calanus pacificus	-0.29	0.08	0.23	0.05	0.07	0.01
Calocalanus spp.	0.10	0.01	**0.43**	**0.18**	-0.10	0.01
Centropagidae	0.30	0.09	0.15	0.02	0.14	0.02
Clausocalanus	0.07	0.01	0.26	0.07	-0.24	0.06
Clausidiiidae	-0.11	0.01	0.02	0.00	-0.02	0.00
Ctenocalanus vanus	0.10	0.01	0.31	0.10	-0.17	0.03
Ditrichocorycaeus anglicus	**-0.92**	**0.84**	0.02	0.00	-0.15	0.02
Epilabidocera longipedata	-0.33	0.11	-0.05	0.00	0.07	0.01
Eucalanidae	0.28	0.08	-0.17	0.03	0.13	0.02
Euchaetidae	0.09	0.01	-0.10	0.01	0.04	0.00
Heterorhabdus spp.	0.03	0.00	-0.04	0.00	-0.11	0.01
Longipedia spp.	-0.18	0.03	0.05	0.00	-0.07	0.01
Mesocalanus tenuicornis	0.18	0.03	0.32	0.10	-0.17	0.03
Metridia	0.23	0.05	-0.22	0.05	-0.07	0.01
Microcalanus	0.18	0.03	-0.15	0.02	-0.09	0.01
Microcalanus pusillus	0.31	0.10	-0.23	0.05	0.02	0.00
Microcalanus pygmaeus	0.25	0.06	0.00	0.00	-0.18	0.03
Microsetella sp.	0.25	0.06	-0.31	0.10	-0.38	0.15
Neocalanus spp.	0.32	0.10	-0.08	0.01	0.16	0.03
Oithona atlantica	0.07	0.01	-0.17	0.03	-0.17	0.03
Oithona similis	0.18	0.03	0.26	0.07	**-0.50**	**0.25**
Paracalanus spp.	**-0.53**	**0.28**	**0.62**	**0.38**	-0.38	0.14
Paroithona sp.	0.11	0.01	-0.19	0.04	-0.35	0.13
Pseudocalanus (imm.)	0.28	0.08	**-0.71**	**0.51**	-0.35	0.12
Pseudocalanus mimus	**0.64**	**0.41**	0.18	0.03	**0.61**	**0.37**
Pseudocalanus minor	0.20	0.04	-0.28	0.08	0.26	0.07
Pseudocalanus moultoni	0.08	0.01	**-0.41**	**0.16**	**0.69**	**0.47**
Pseudocalanus newmani	-0.32	0.11	-0.12	0.01	0.10	0.01
Racovitzanus	0.27	0.07	-0.14	0.02	-0.20	0.04
Scolecithricella	0.23	0.05	-0.21	0.04	-0.05	0.00
Tisbe	0.09	0.01	-0.01	0.00	0.13	0.02
Tortanus discaudatus	**-0.51**	**0.27**	-0.12	0.01	-0.04	0.00
Triconia spp.	**0.47**	**0.22**	-0.18	0.03	-0.11	0.01
Triconia borealis	0.16	0.03	-0.09	0.01	-0.02	0.00
Triconia (tiny)	0.22	0.05	-0.14	0.02	-0.33	0.11
Triconia subtilis	0.17	0.03	-0.17	0.03	-0.30	0.09

Table 6. Chinook salmon survival correlations with JEMS NMS ordination axes. Stock names and abbreviations were provided by C. Ruff, Skagit River System Cooperative. Only stocks for which at least eight years of smolt-to-adult survival data were available for 2003-2014 outmigration years are shown. Correlations R^2<0.01 are shown as 0. Significance of the correlations was not tested.

Release Strategy	Basin	River - Stock	Correlation with JEMS Axes (R^2)		
			Axis 1	**Axis 2**	**Axis 3**
Sub-yearling					
	Central Basin	Garrison Springs H - GAR	0.02	0.10	0.08
		Grovers Creek H - GRO	0.01	0.18	0
		Soos Creek H - GRN	0	0.55	0.17
		Voights Creek H - PUY	0.02	0.03	0
	Hood Canal	George Adams H - GAD	0.02	0	0.07
	South Sound	Clear Creek H - NIS	0.03	0.39	0.27
		South Puget Sound F - SPS	0	0.37	0.05
	Whidbey Basin	Bernie Kai Kai Gobin H - TUL	0.04	0.67	0
		Marblemount H - SKF	0.10	0.18	0
		Marblemount H - SSF	0.07	0.65	0.08
		Stillaguamish H - STL	0.12	0.09	0
		Wallace River H - SKY	0.39	0.02	0.13
Yearling					
	Central Basin	White River H - WRY	0.03	0.30	0.35
	South Sound	Tumwater Falls H - SPY	0.06	0.02	0.56
	Whidbey Basin	Marblemount H - SKS	0.15	0.16	0.41
		Wallace River H - SNY	0	0.26	0.20

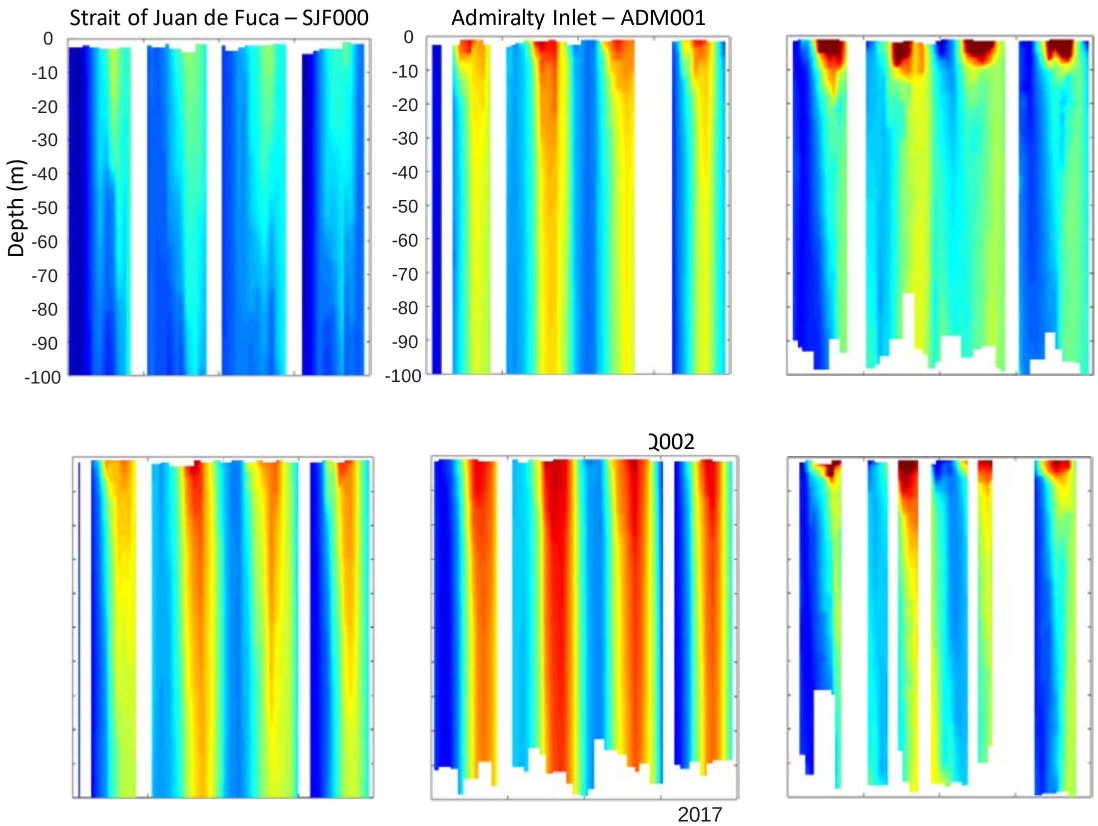

Figure 2. Temperature profiles over the upper 100-m from 2014-2017 monthly Department of Ecology CTD casts at stations in closest proximity to Watmough Bay (S. San Juan Islands), Admiralty Inlet, NSEX01 in Central Basin, S. Ketron Island (South Sound), Thorndyke Bay (N. Hood Canal), and Camano (S. Whidbey Basin) zooplankton monitoring stations.

Central Basin – PSB003

South Sound – NSQ002

Depth (m)

Figure 3. Upper 50-m chlorophyll biomass profiles from 2014-2017 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. Note that missing dates in these plots were interpolated – see Figure 2 for missing profiles.

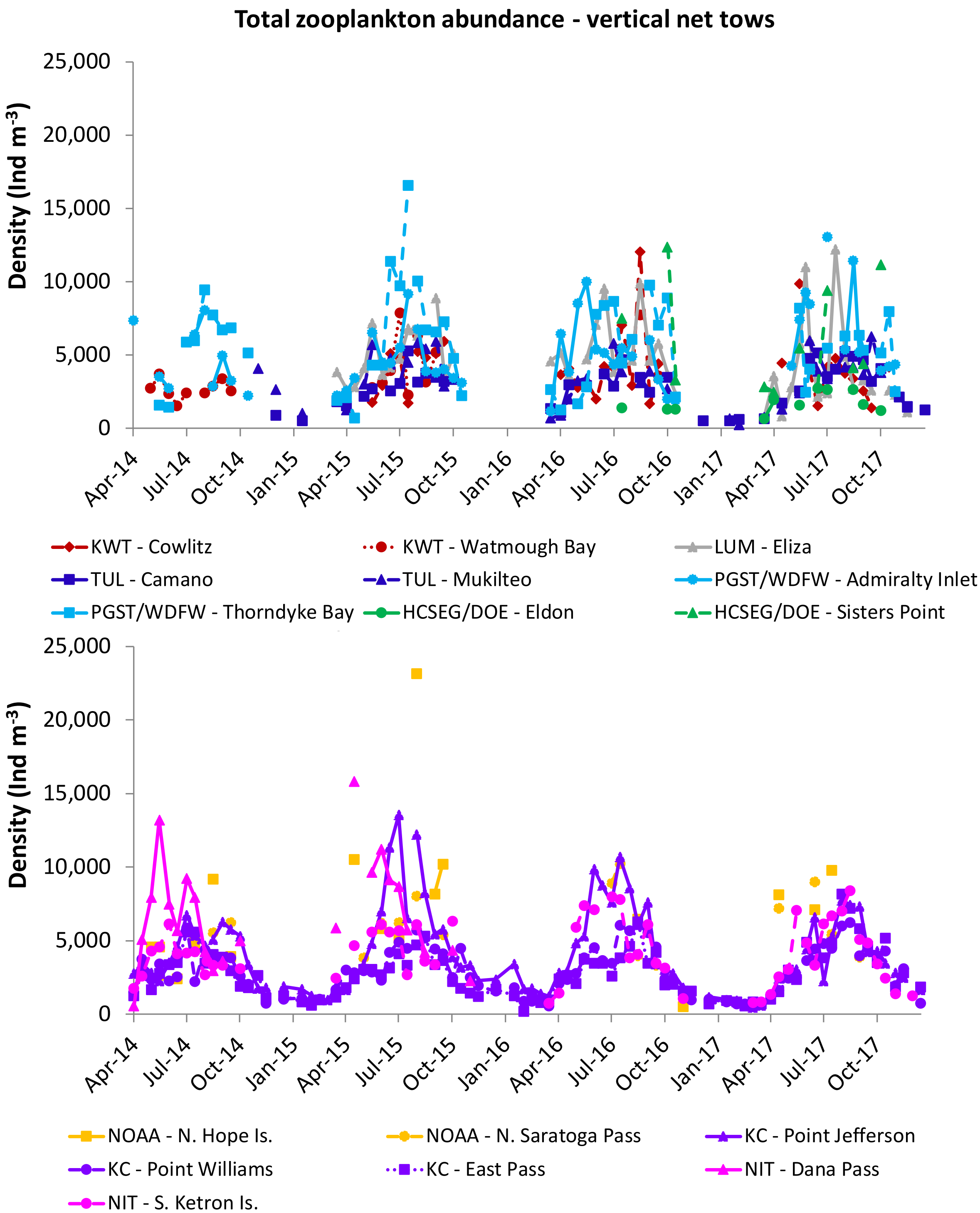

Figure 4. Total 2014-2017 zooplankton vertical net tows abundances, coded by sampling group and station. See Table 1 and Figure 1 for locations. Note Dana Pass not sampled in 2016 or 2017.

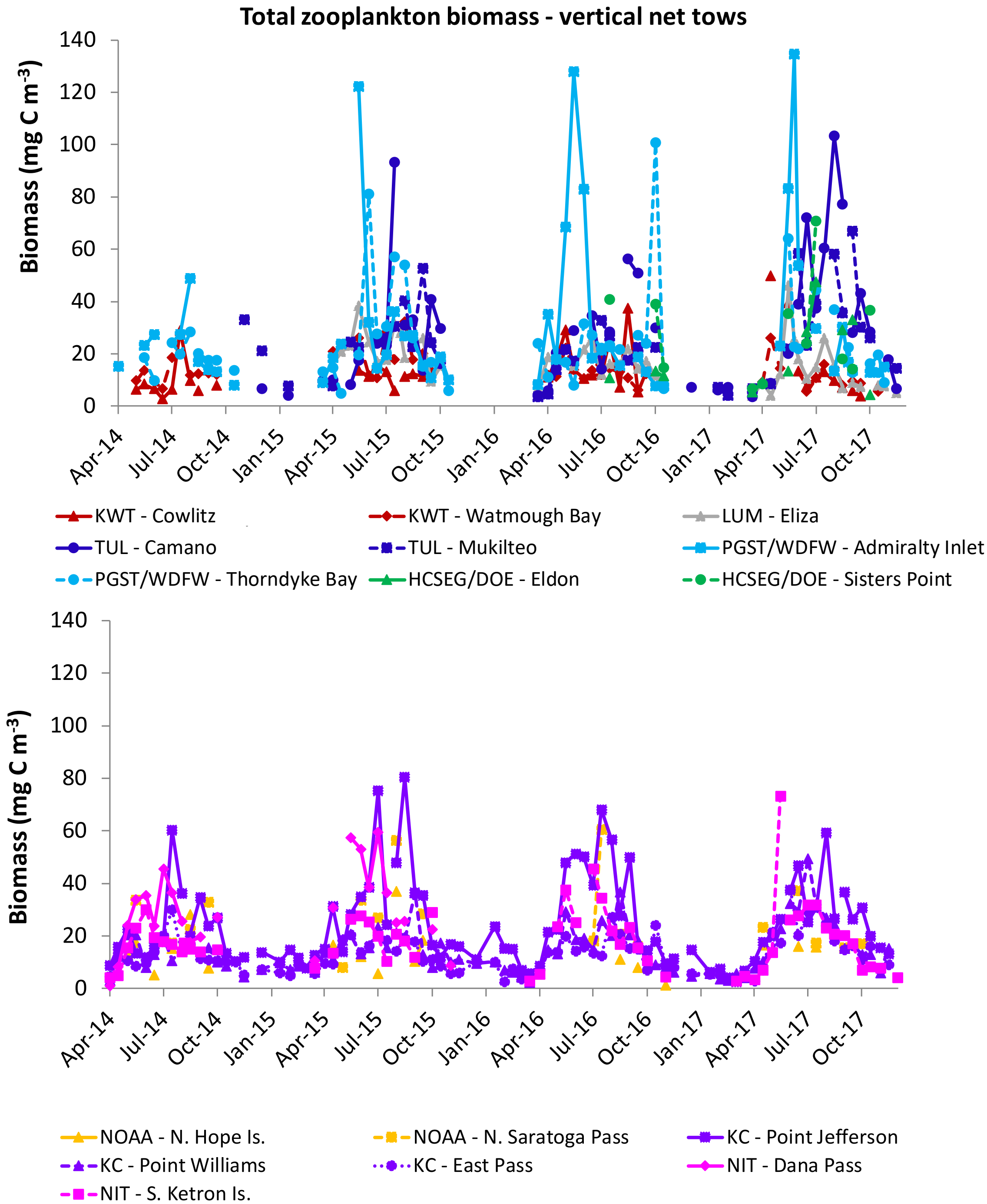

Figure 5. Total zooplankton biomass from 2014-2017 vertical net tows, coded by sampling group and station, separated into two panels for clarity. See Table 1 and Figure 1 for locations.

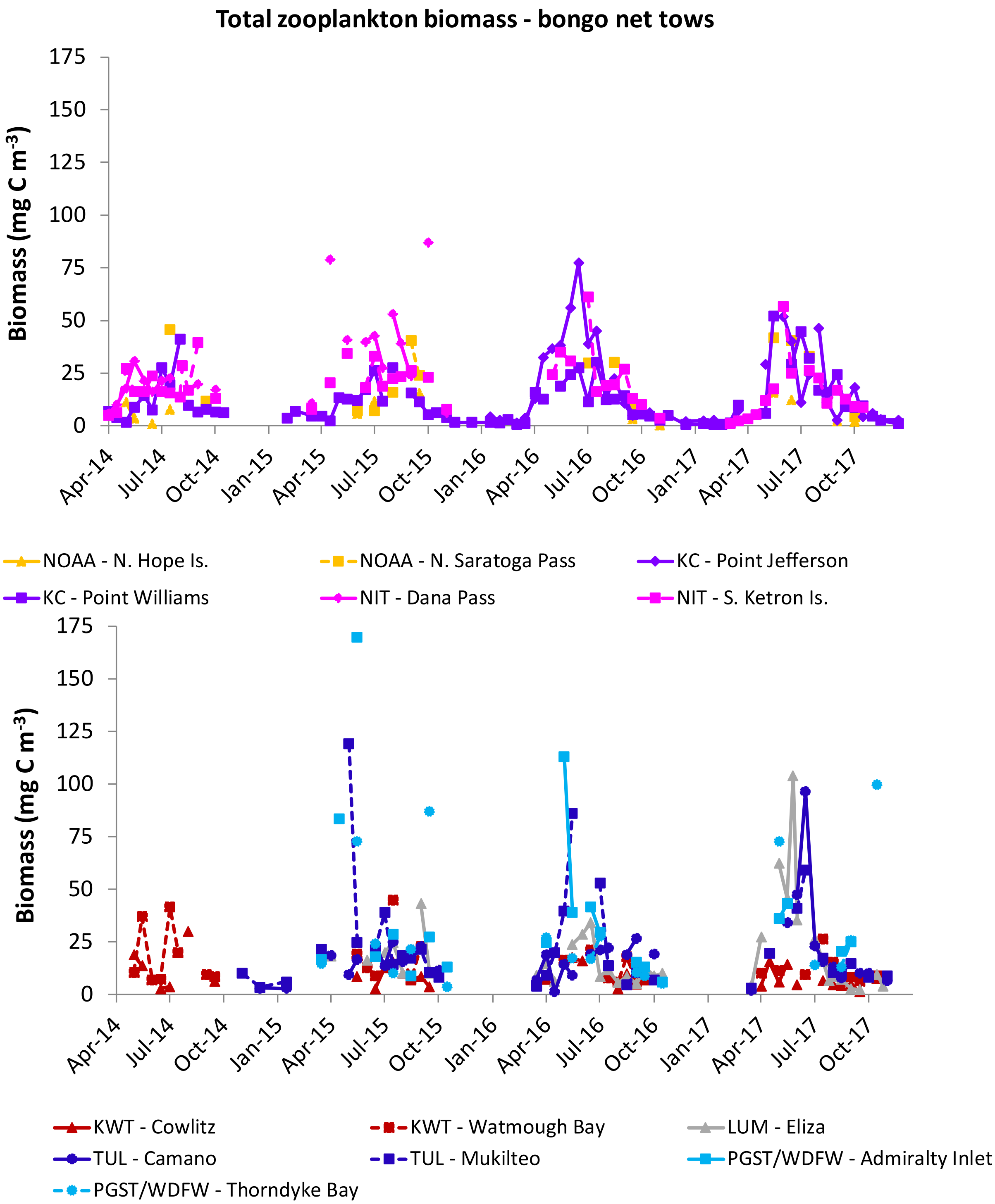

Figure 6. Total zooplankton biomass from 2014-2017 oblique bongo net tows, coded by sampling group and station, separated into two panels for clarity. See Table 1 and Figure 1 for locations.

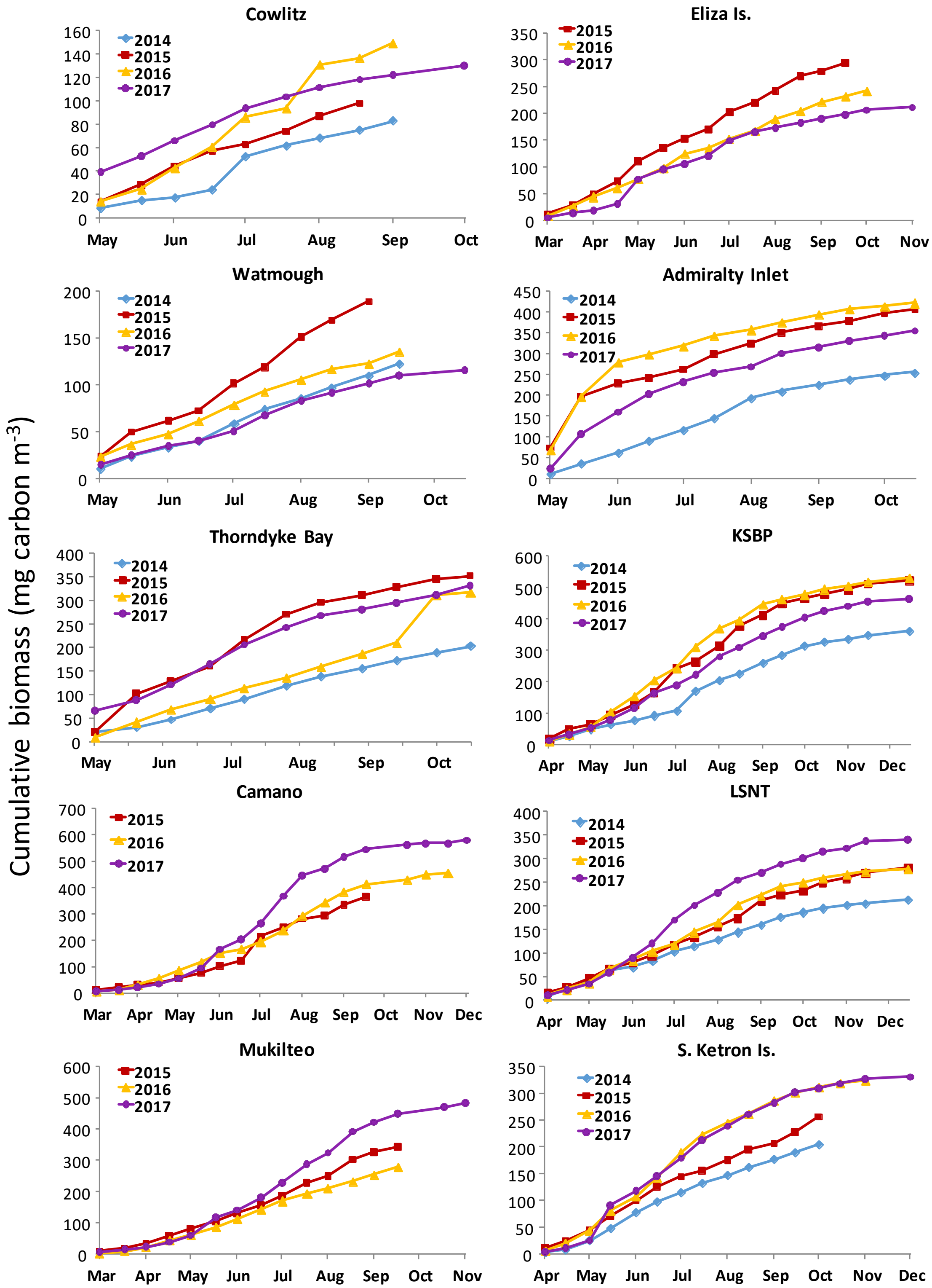

Figure 7. Total zooplankton biomass from 2014-2017 vertical net tows at each station for which there were sufficient data in at least three years. Biomass was cumulated across bi-weekly collections in each year, starting from the earliest date sampled in all years which varied among stations. Note that the East Passage station NSEX01 was very similar to LSNT so is not shown here.

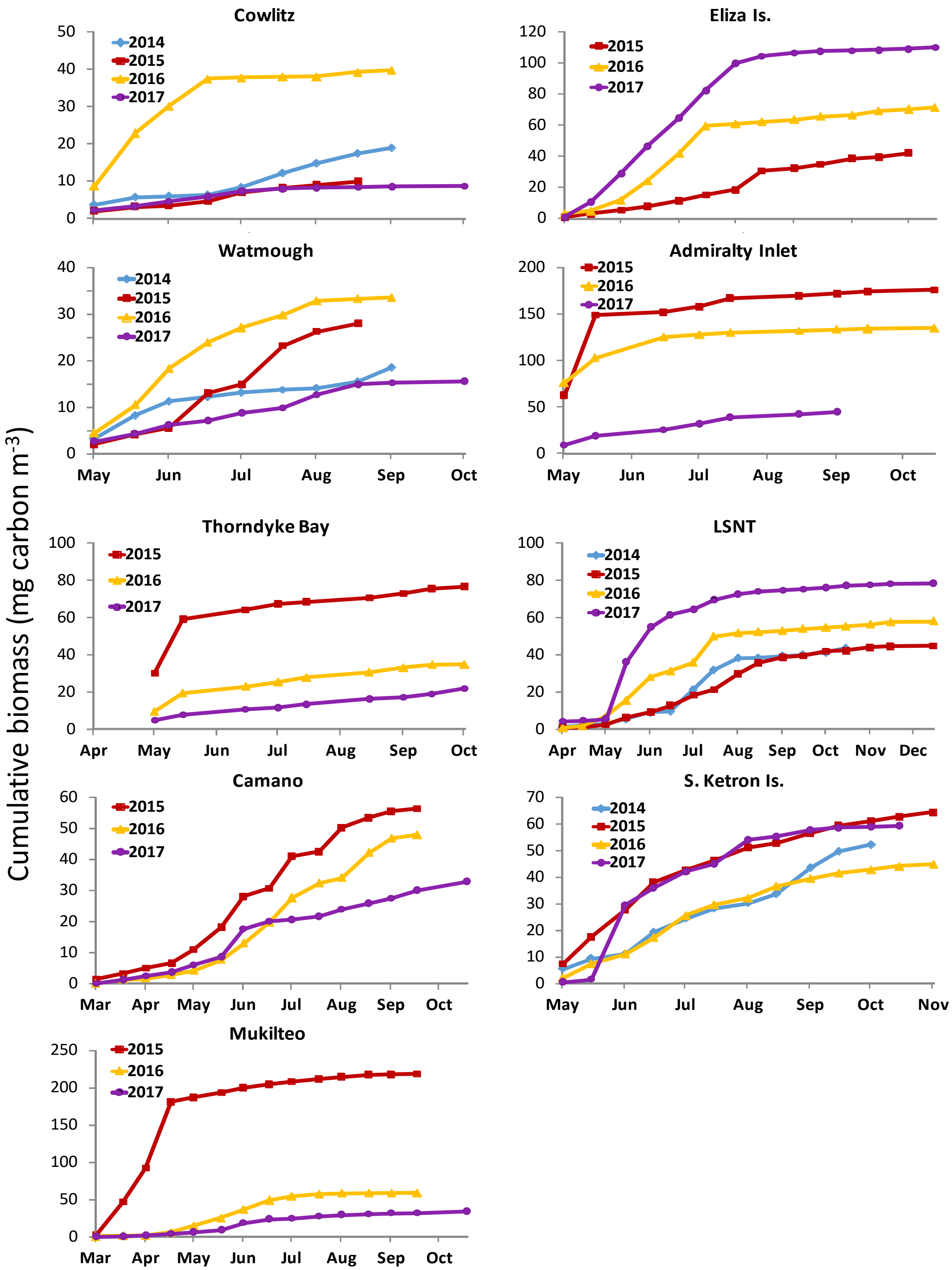

Figure 8. Biomass of zooplankton that are important juvenile salmon prey from 2014-2017 oblique bongo net tows at each station for which there were sufficient data in at least three years. Biomass was cumulated across bi-weekly collections in each year, starting from the earliest date sampled in all years, which varied among stations.

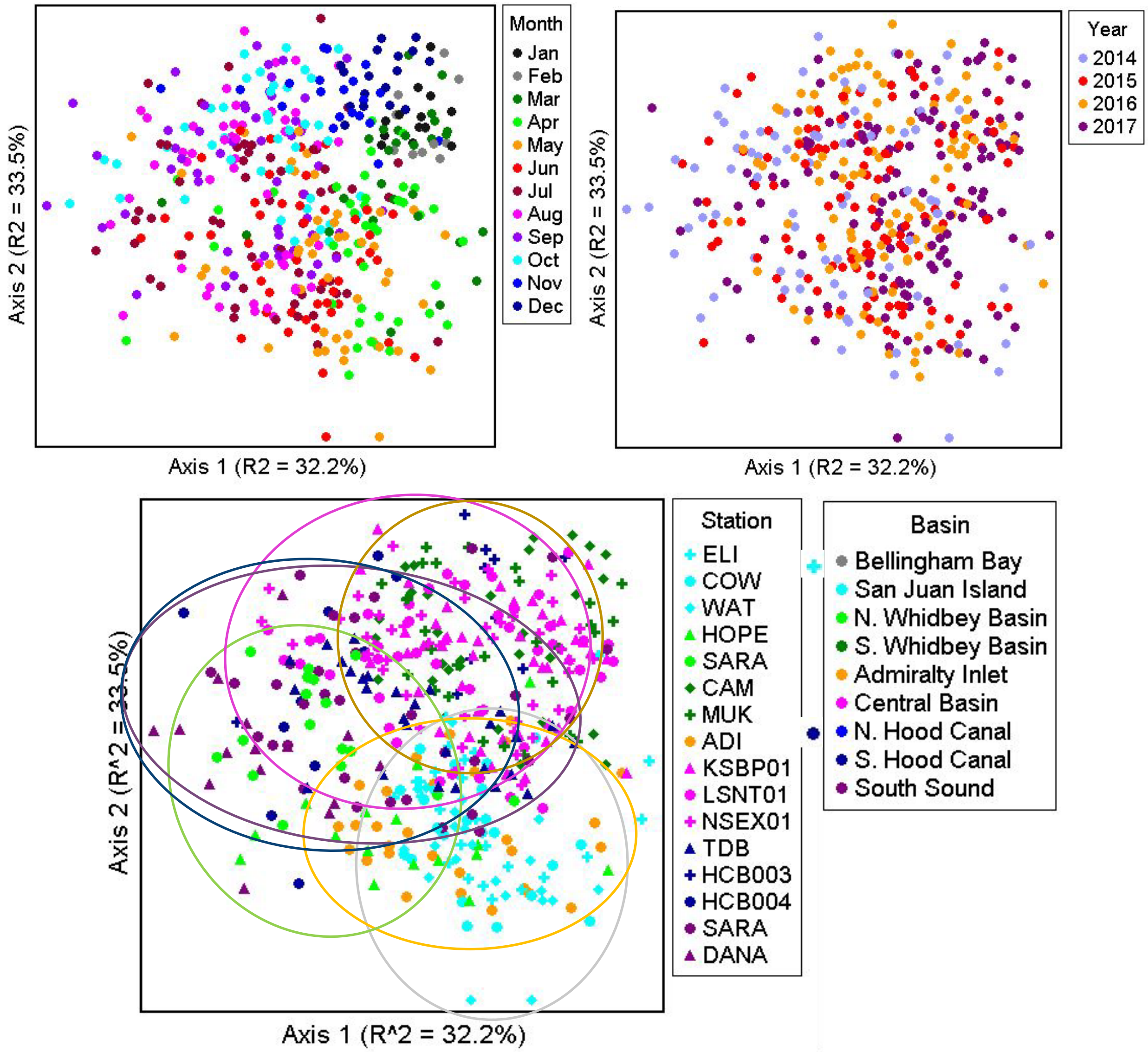

Figure 9. Nonmetric Multidimensional Scaling ordination of zooplankton species biomass from vertical net tows collected at all stations sampled in 2014-2017. 3-dimensional ordination explained 82.6% of the variance in zooplankton community structure: position along Axes 1, 2, and 3 explained 32.2%, 33.5%, and 16.9% of the variance, respectively; only two dominant axes are shown. Top left panel: samples colored by month of collection to show seasonality in community structure. Top right panel: samples colored by year. Bottom panel: samples are symbol- and color-coded showing differences among stations and regions; similar colors fall within a geographic region, circles generally outline regional communities. See Figure 1, Table 1 for station locations.

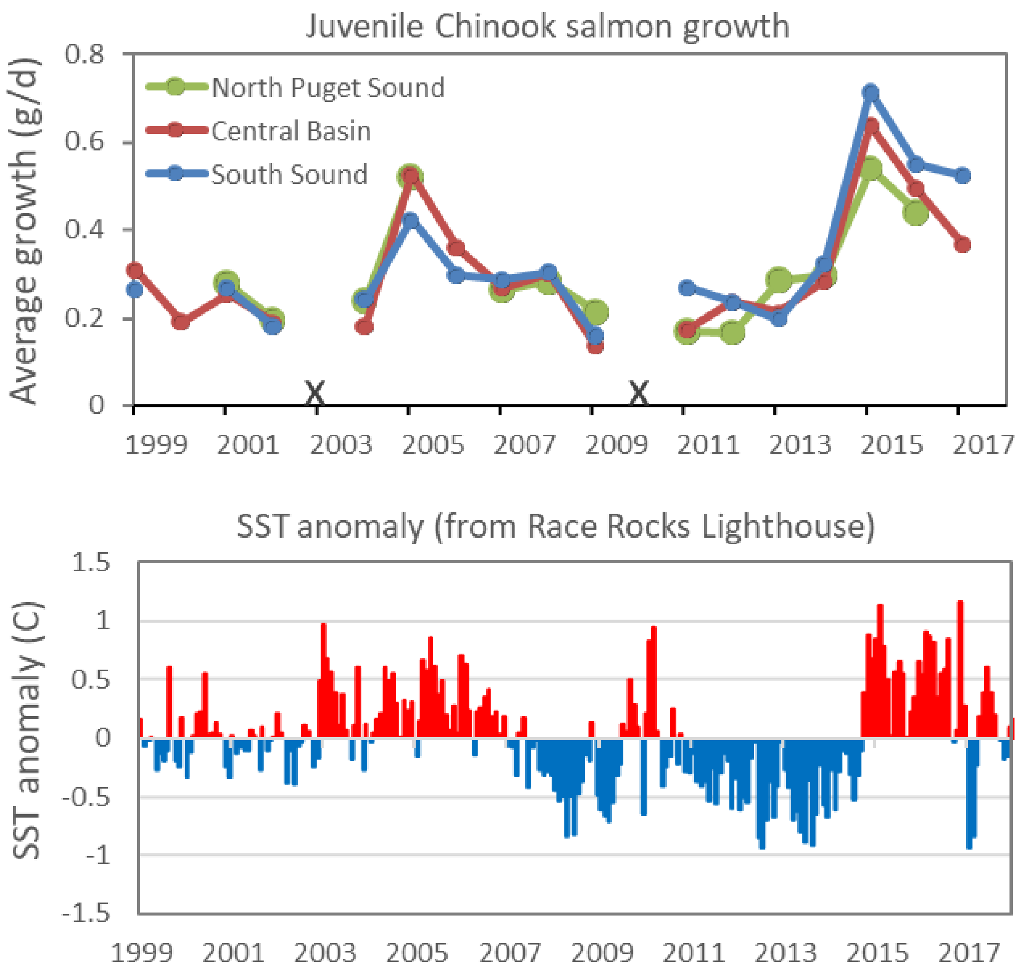

Figure 10. Top panel: Annual average juvenile Chinook salmon growth calculated from weight change of hatchery released and re-captured coded wire tagged juvenile salmon, averaged in each year by hatchery release area (Northern Puget Sound, Central Puget Sound, and South Sound). Data provided by I. Kemp of Long Live the Kings. Years with <10 fish in any region not shown. Bottom panel: Monthly seasonal anomaly of sea surface temperature from the Race Rock Lighthouse (Strait of Juan de Fuca) long-term record.

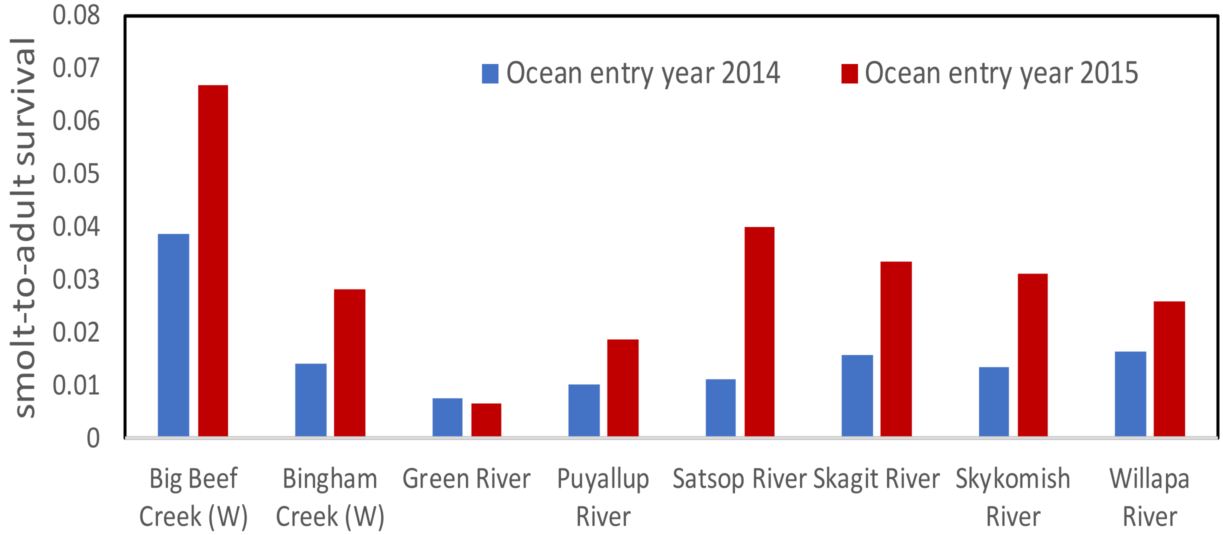

Figure 11. Smolt-to-adult survival of coho salmon: 2014 and 2015 out-migration years from eight rivers in Puget Sound. All stocks were hatchery-origin except the two wild stocks marked as (W). Data provided by Marianna Alexandersdottir, Alexanders Consulting, via the Tulalip Tribes.

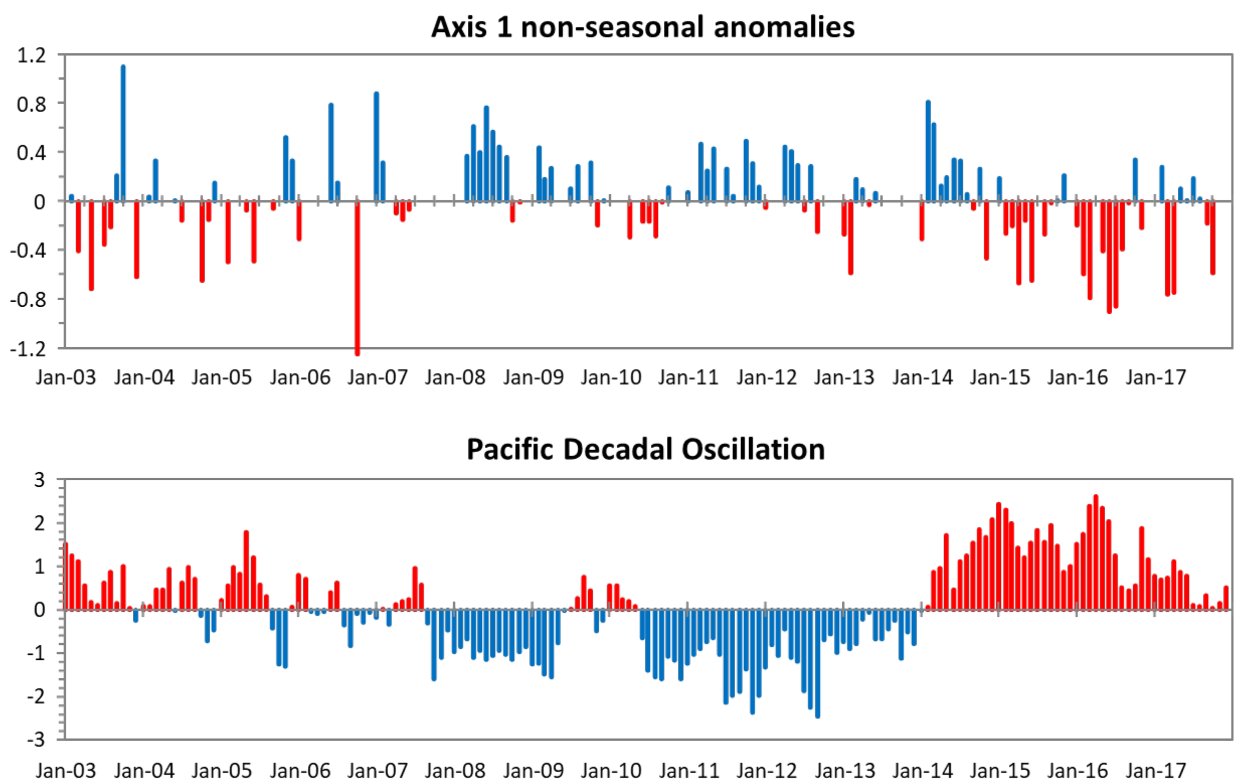

Figure 12. Top panel: Monthly JEMS copepod time series Axis 1 scores with the average seasonal cycle removed. Note that there are no zero values – all gaps were missed sample collections. Bottom panel: The Pacific Decadal Oscillation index data come from http://research.jisao.washington.edu/pdo/PDO.latest.txt.

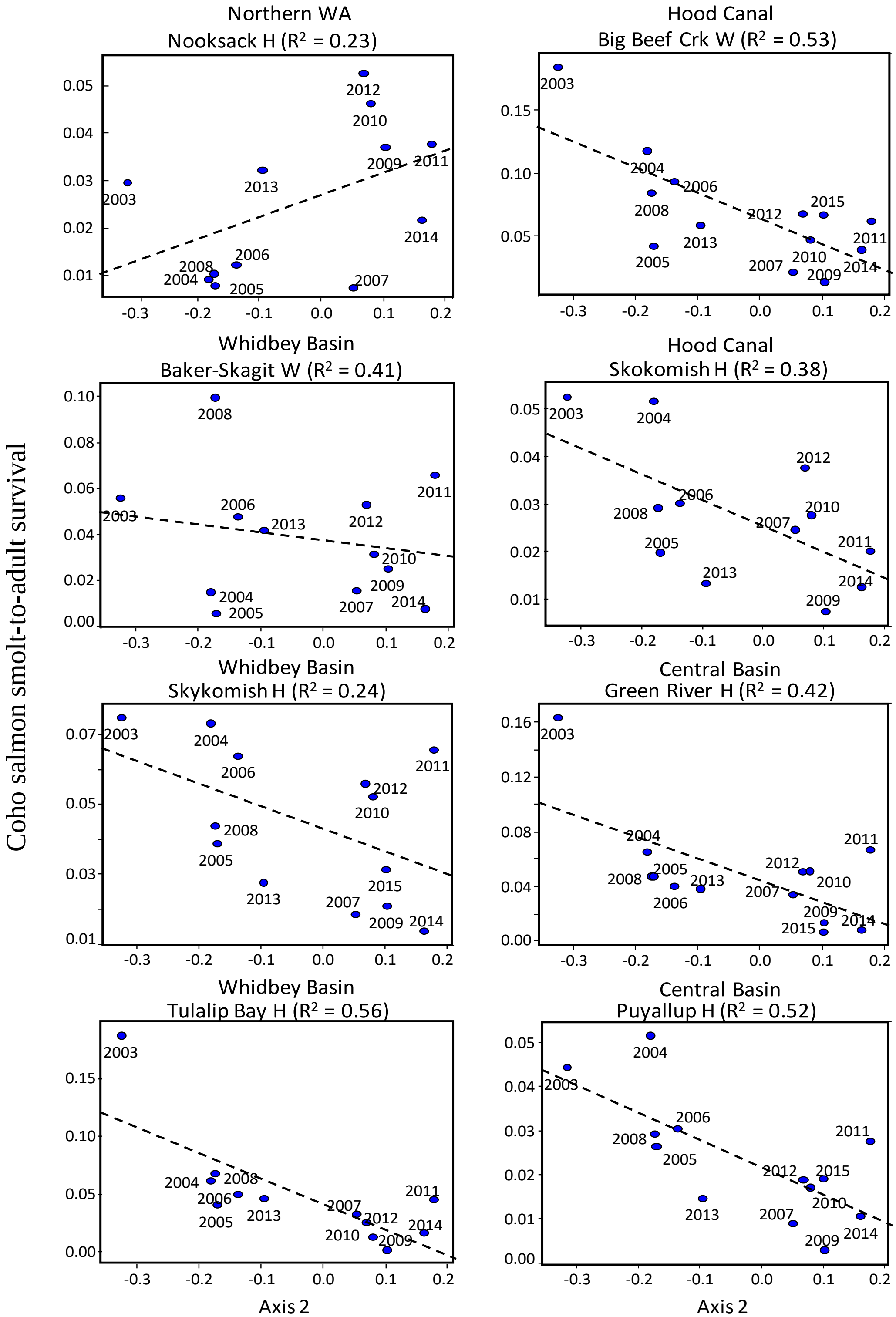

Figure 13. Correlation plots of coho salmon smolt-to-adult survival rates against Axis 2 scores from NMS ordination of the 2003-2017 JEMS time series data. Axis 2 scores were averaged over May to September in each year to correlate with annual survival values. Only stocks with at least seven years of survival data available since 2003, and that correlated with the axis scores with R^2>0.2, are shown. Significance of the correlations was not tested. H indicates hatchery-origin fish; W indicates wild stocks.

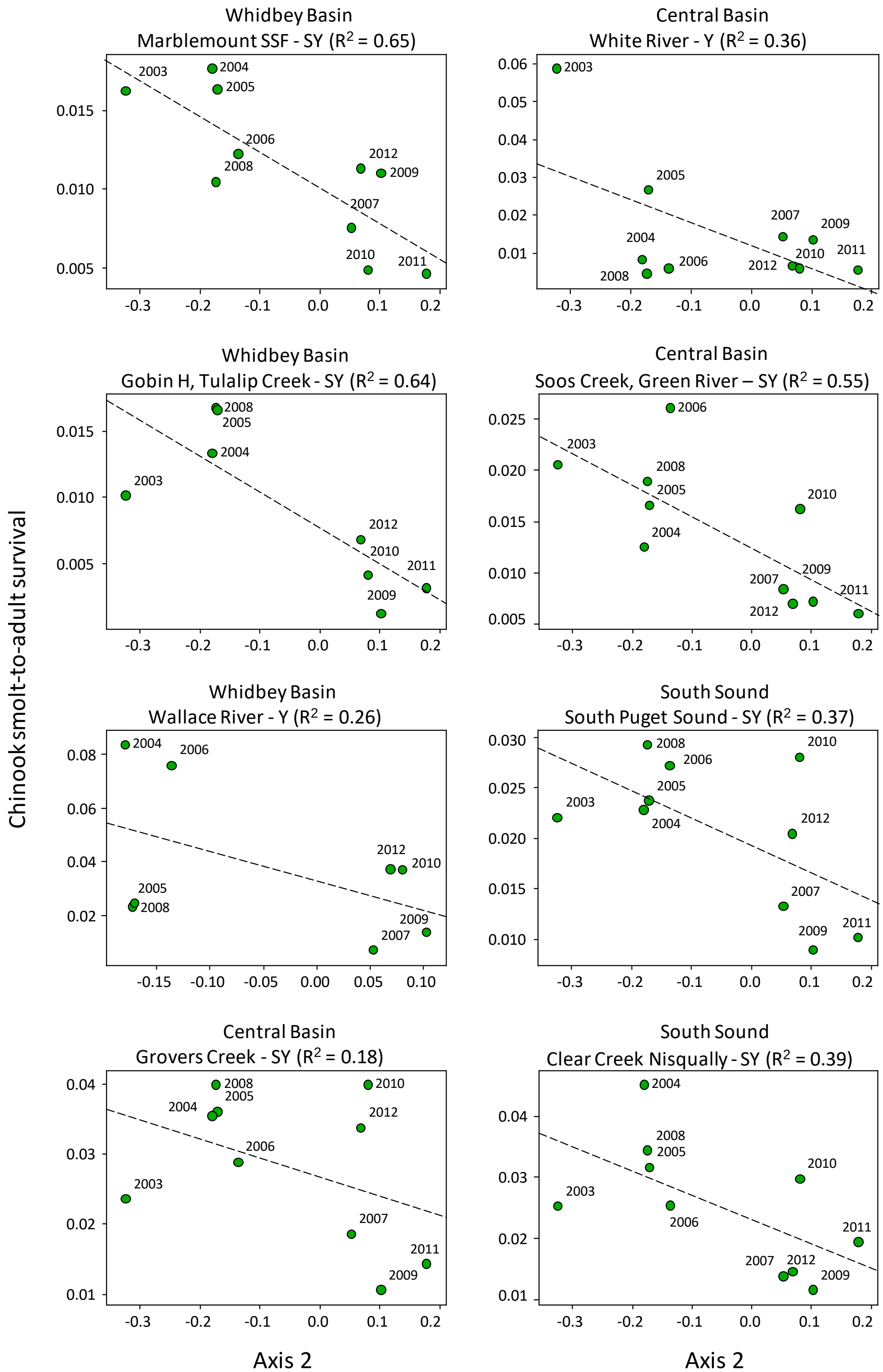

Figure 14. Correlation plots of hatchery-origin Chinook salmon smolt-to-adult survival rates against Axis 2 scores from NMS ordination of the 2003-2017 JEMS time series data. Axis 2 scores were averaged over May to September each year to correlate with annual survival values. Note: some regressions include <10 years of data. Y indicates yearling releases, SY subyearling releases.

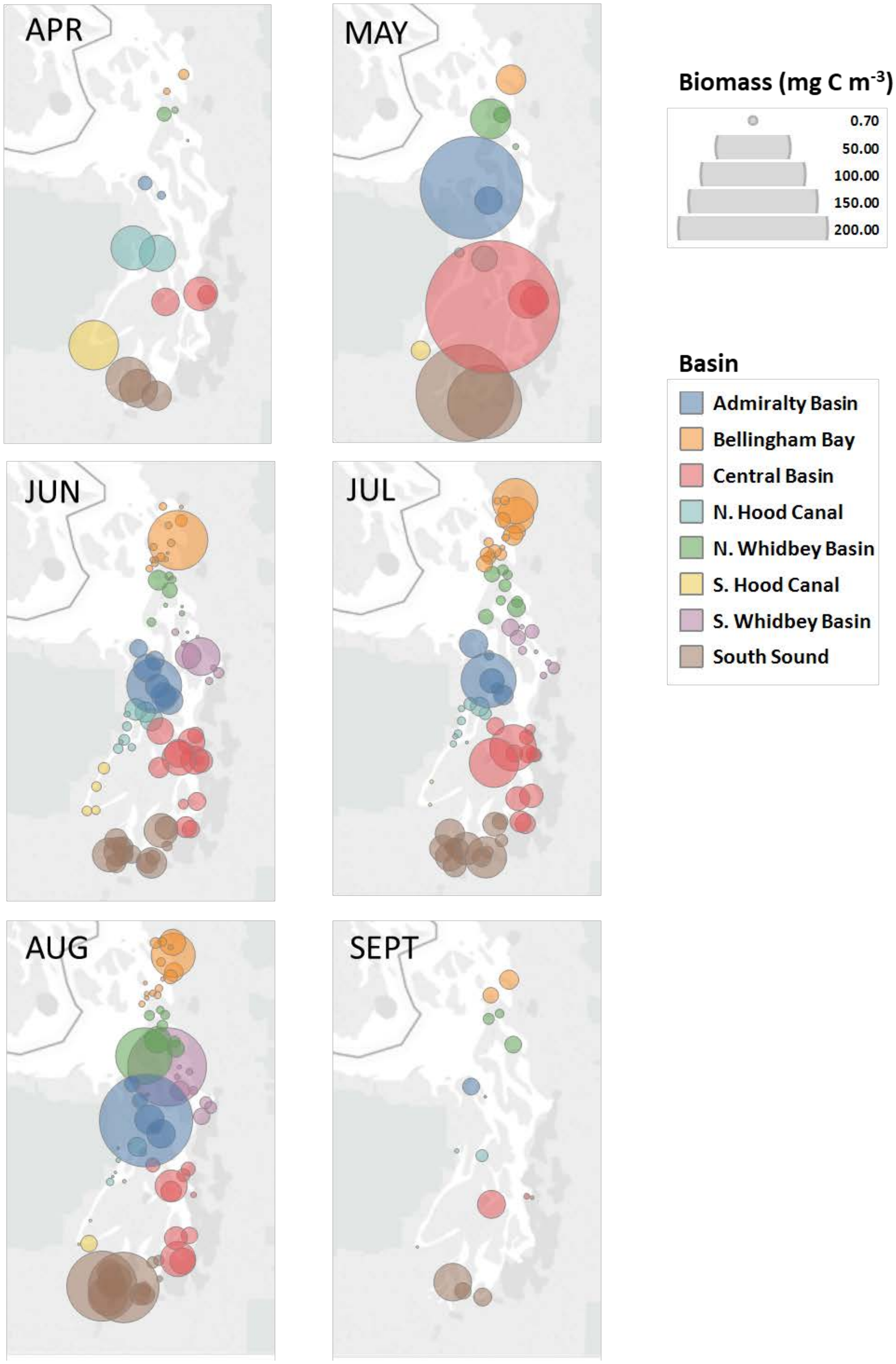

Figure 15. Total zooplankton biomass in 2011 from surface tows of a 1-m diameter, 500-µm mesh plankton net. Sites were mostly in <30 m water depth and are colored by basin. Note that not all sites were analyzed in all months.

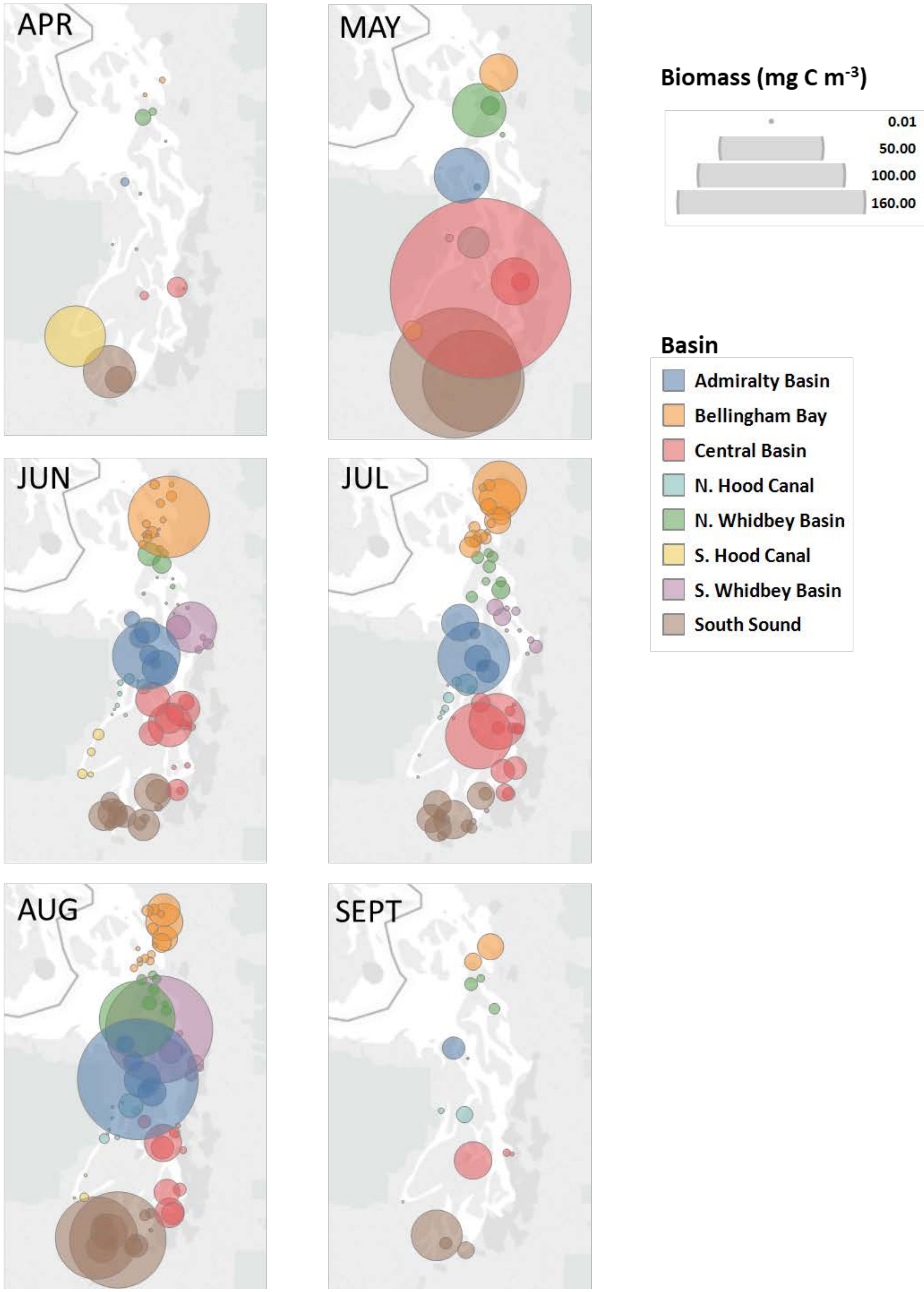

Figure 16. Biomass of juvenile salmon prey taxa in 2011 from surface tows of a 1-m diameter, 500-µm mesh plankton net. Sites were mostly in <30 m water depth and are colored by basin. Note that not all sites were analyzed in all months.

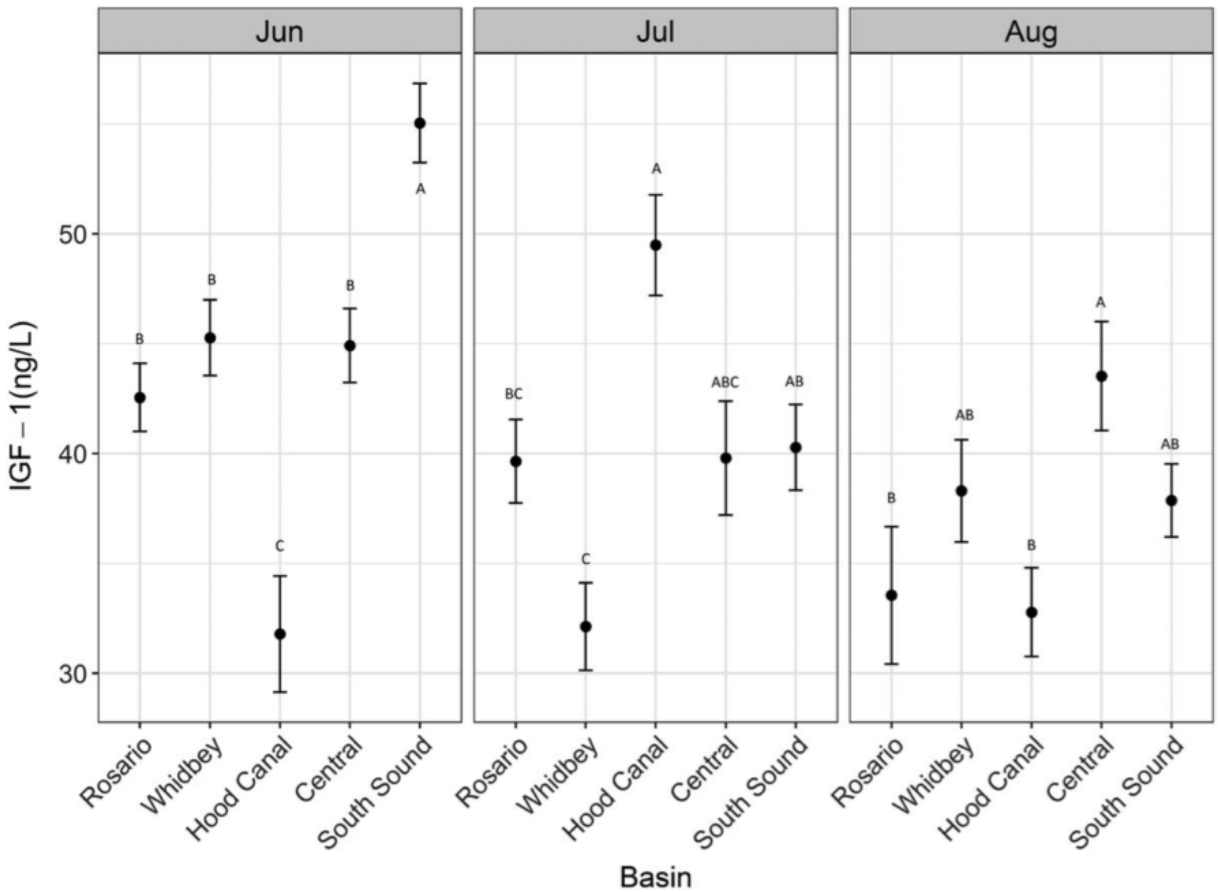

Figure 17. Mean IGF- 1 concentration (± SEM) for Chinook salmon by basin and month. Note that Rosario Basin here is the same as Belllingham Bay in Figures 15 and 16. Letters denote sub- basins within a month with significantly different means (Tukey HSD post hoc test).
From: Figure 5 in Chamberlain et al. (2017).

Description of need for additional work

There is ongoing work needed to refine salmon-zooplankton correlations and indices development. Ongoing “Bottom-Up” studies are needed to continue to explore relationships arising from the physics to zooplankton and juvenile fish. Ongoing zooplankton metrics and other ecosystem indicators of salmon survival are under investigation that need sustained time series data collection in order to be useful for forecasting salmon survival. In this study, zooplankton biomass showed clear regional and seasonal structure in the zooplankton community, which strongly correlated with several environmental factors that should be further investigated. Correlations with copepod community structure and temperature showed the strongest correlations with salmon smolt-to-adult survival. Further exploration of stock-specific factors that may influence the relationships with the copepod time series is warranted. Since regional variance in seasonal cycles strongly structured communities, additional taxonomic and environmental correlations with regional zooplankton community structure and biomass are needed perhaps with focus on the relatively strong correlations observed in community structure between some of the basins of Puget Sound. Since higher juvenile salmon growth is correlated with higher smolt-to adult survival, annual juvenile fish sampling is needed, e.g. annual mark-recapture fish sampling is needed to develop regional juvenile Chinook salmon growth time series to more closely examine factors that influence survival, including relationships with temperature and other regional environmental conditions, zooplankton community structures, biomasses, predation, seasonal growth and survival.

Further exploration of climate interactions with anthropogenic changes on ecosystem effects is definitely warranted. Data from DOE included in this report showed more intense diatom blooms in colder years, particularly in Central Basin in spring and fall. Previously, from 1999-2012, DOE documented increasing nitrate concentrations in many regions of Puget Sound, a trend which cannot be explained by oceanic influences or natural river inputs alone, suggesting Puget Sound water quality is changing due to excessive levels of nutrients, primarily nitrogen from human-derived sources. Decline in the diatom component of the phytoplankton community during summer months has been documented over the same period by DOE (as inferred by declining chlorophyll concentrations over the same period, which recently changed in some regions of the Sound). This in turn has coincided with visible and intense blooms of Noctiluca scintillans, a harmful dinoflagellate associated with eutrophication and coincident with the increasing nitrate concentrations and a decreasing silica to nitrogen ratio (Si:N), which is approaching a 1:1 ratio, whereas diatoms require a Si:N ratio of 1:1 or greater.

If the Si:N continues to decrease, the diatom portion of the phytoplankton community will continue to decrease in Puget Sound; increasingly displaced by excessive accumulations of dinoflagellates, which, in combination with climate change, could be having a major influence on the food web and biogeochemical cycling. Large blooms of Noctiluca and other dinoflagellates further excrete toxic ammonia, deplete oxygen, and are considered a dead end in the food chain. This amplifies the above-mentioned effects in a negative feedback loop where Noctiluca creates ever increasingly suitable conditions for themselves and decreasingly for diatoms. Furthermore, these efficient grazers can consume the standing stock of diatoms on a daily basis and have been associated with large diatom clearing events, with additional negative implications for nutrient cycling. They are also thought to be responsible for significant reductions in the amounts and types of benthic animals. There has been a 45% decrease in the abundance of the benthos in Puget Sound in the last 10-15 years. Benthos tolerant to pollution and low DO conditions are increasing, while species sensitive to pollution are declining.

Ongoing and future climate change conditions are projected to further reduce marine upwelling, snowpack, and river flows that affect Puget Sound water residence time and dilute human pollutants in the nation's second largest marine estuary. These changes are exacerbating buildup of local nitrogen sources. Signs of increasing eutrophication have been observed, e.g. decreasing dissolved oxygen and increasing blooms of harmful toxic algae, macro-algae mats, Noctiluca and other dinoflagellates, and jellyfish documented in large quantities near the surface of Puget Sound in recent years. More work is needed to investigate the degree to which this apparent shift in primary production may be materially affecting the Puget Sound food web and subsequent declines in zooplankton, ichthyoplankton, forage fish, planktivorous juvenile salmon, and marine mammals, especially when considered in combination with the large-scale effects of climate change.

Evaluation: Describe the extent to which the project goals and objectives were attained This description should address the following: Were the goals and objectives attained? How? If not, why? Were modifications made to the goals and objectives? If so, explain.

This project successfully accomplished all of the goals, all three primary objectives, and their associated Project Activities and Tasks, many of which were exceeded. The project provided spatially-resolved zooplankton data throughout Puget Sound and Northern Washington to improve our understanding of spatial and temporal patterns of zooplankton in the region (Objective 1). Relationships were quantified between zooplankton, salmon growth, survival, and the environment (Objective 2), and all of this work is contributing toward ongoing work to derive biologically-based Ecosystem Indicators that aid adult salmon return forecasts (Objective 3). It directly addressed Saltonstall-Kennedy Program Priority 1C under which the project proposal was centered:

> *"Maximize Fishing Opportunities and Jobs" by aiding in assessing the impacts that climate change and other environmental stressors including ocean acidification have on fisheries resources and affected communities, with specific emphasis on acquiring a direct understanding of interactions that protected salmonid species and salmonid species of concern have with their prey*."

Saltonstall-Kennedy funding under this project was critical for maintaining and refining standardized zooplankton collection and analysis methods and protocols that were successfully employed systematically across all of the key basins of Puget Sound. By accomplishing *Objective 1*, the resultant Puget Sound Zooplankton Monitoring Program therefore successfully addressed S-K FY2015 main Priority 1C*: "Improve our understanding of spatial and temporal patterns of zooplankton in Puget Sound."*- The comprehensive sampling program currently in operation across all of the main basins of the Sound is helping us to gain a better understanding of the spatial and temporal patterns of zooplankton to gain a more mechanistic understanding of interactions between juvenile salmon and their prey that affect salmon marine survival. It also addressed the fundamental goals of the Saltonstall-Kennedy program and Magnuson-Stevens Act by providing results that will help to rebuild and maintain sustainable fisheries and practices, which also benefits Treaty Rights and addresses the objective of NOAA's Next Generation Strategic Plan to improve our understanding of ecosystems to inform resource management decisions for species recovery and sustainable fisheries (NOAA 2010).

All three key Project Activities (1A-1C) under Objective 1 were accomplished:
"Activity 1A Collaborate with regional tribes, governments, nonprofits, and other entities to conduct Puget Sound-wide zooplankton sampling in spring through summer 2016" was accomplished and exceeded. We successfully collaborated with 10 participating groups from 15 monitoring stations in the San Juan Islands, Bellingham Bay, Strait of Juan de Fuca, and throughout Puget Sound that directly involved collections by four regional Tribes, Federal, State, and County governmental agencies, several nonprofits, the University of Washington, and numerous other fishery management agencies and entities. We successfully conducted consistent, bi-weekly zooplankton sampling across the Sound throughout the spring and summer of 2016. In addition, we were able to extend sampling in some select areas during the winter months as well.

We accomplished and exceeded Activity 1B by not only successfully conducting taxonomic analysis of archived zooplankton samples collected by NOAA during Puget Sound-wide sampling in 2011 (180 samples), we also successfully collected and analyzed 391 new zooplankton net tow samples in 2016 across all of the basins of the Sound under this project (see *Field Collections* under *Approach:*

Detailed description of the work performed above; Tables 1 and 2; and Figure 1). Of 210 bongo net and 181 vertical net tow samples, 95% of the bongo tows (n=200) and 100% of vertical net tows passed QC for high quality collections. In addition, 22 new samples were collected from the JEMS time series station in 2016 and additional samples collected there were also analyzed at no cost to this study but were used in the data correlations.
See *"2003-2017 JEMS time series analysis"* under *"Detailed description of the work performed"* above. We also accomplished the third (last) project activity (*"Activity 1C")* under Objective 1, which was to, "*Explore spatial and temporal relationships between environmental conditions, climate variability, zooplankton biomass, and species composition"* - these analyses are described in detail above and covered extensive comparisons of zooplankton biomass and species composition relative to environmental conditions and climate variability among three years (2014-2017) of zooplankton collections, well beyond just the 2016 collections (see *"2014-2017 Environmental Conditions", "2014-2017 Zooplankton abundance and biomass", and "2014-2017 Zooplankton community structure"* under "*Actual accomplishments and findings"*).

We successfully accomplished Objective 2, *"Quantify relationships between zooplankton, salmon growth and survival metrics, and the environment (including climate and ocean acidification)"*and its 3 Project Activities, which included, Activity 2A, "*Update coho and Chinook salmon survival time series from multiple regions across Puget Sound; assemble growth metrics (from scales, otoliths, and size measures)"* – For the first part of this Activity, see *"Updating Coho and Chinook Salmon Population Data Resource Tables (PDRTs)"* for the most comprehensive, updated retrospective analysis of marine survival rates that has been done to date for basically all of the natural- and hatchery-origin Chinook and coho salmon stocks in US and Canadian databases that were available. For the latter part of this activity, see the *"Juvenile salmon growth"* and "*Zooplankton patterns and Chinook salmon growth in 2011"* sections above (both under "*Actual accomplishments and findings"*). Extensive comparisons of juvenile salmon growth data were analyzed from two sources that included individual fish length and weight data from mid-water trawls conducted in Puget Sound by Department of Fisheries and Oceans Canada and broad spatial and temporal data on individual growth rates of juvenile Chinook salmon captured throughout Puget Sound using concentrations of insulin-like growth factor-1 (IGF-1).

Activity 2B: *"Quantify abundance and produce metrics of primary juvenile salmon prey items in each region of Puget* Sound"- was accomplished. For a comprehensive analysis of abundance and metrics of primary juvenile salmon zooplankton prey items, see, "*2014-2017 Zooplankton abundance and biomass, "2014-2017 Zooplankton community structure"*, and *"2003-2017 JEMS time series analysis"* sections above. We also accomplished and exceeded Activity 2C: *"Compare zooplankton data to juvenile salmon growth and marine survival across regions and years"* – See the extensive analyses under "*2003-2017 JEMS time series analysis", "Salmon survival: correlations with JEMS time series","Correlations with coho survival"*, and *"Correlations with Chinook survival"* sections above.

Wrapping everything together, we made important progress toward accomplishing Objective 3, *"Establish biologically-based Ecosystem Indicators to improve adult return forecasts, similar to NOAA NWFSC's Ocean Ecosystem Indicators of salmon marine survival."*- While the development of a complete Ecosystem Indicators Program for Puget Sound resembling NOAA's pacific coastal Ecosystem Indicators Program for the California Current[4] is a major endeavor that exceeds the scope of this study (e.g. it includes annual systematic juvenile fish sampling that has not yet been funded),

[4] See: http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm.

the annual, comprehensive zooplankton sampling program developed and refined here, along with the assemblages of the other physical, biological, and ecosystem indicators described above, are integral missing components needed to successfully build such a program specific to the fisheries management needs of Puget Sound. We conducted representative zooplankton collections across all of the different sub-regions of Puget Sound and conducted numerous single species and multivariate analyses across all years where data were available to identify candidate zooplankton indices that best correlate with salmon growth and marine survival time series. We assembled numerous comprehensive datasets of environmental indicators, zooplankton community diversity, structure, and biomass, and juvenile salmon growth indicators, and extensively updated marine survival time series for available Chinook and coho salmon stocks of the Salish Sea that we have made available to salmon managers.

Dissemination of project results:
Explain, in detail, how the project's results have been and will be disseminated

Data generated from 2014-2017 zooplankton sampling are all publicly available for download at: https://green2.kingcounty.gov/ScienceLibrary/Document.aspx?ArticleID=556. Linking to the dataset through NANOOS has been requested and establishing the link is underway by NANOOS personnel. Data generated from 2011 samples as part of this project are publicly available on request from J. Keister (jkeister@uw.edu) or C. Greene (correigh.greene@noaa.gov). Comprehensive databases updated for Salish Sea Chinook and coho salmon marine survival estimates, known as Population Data Resource Tables (PDRT) can be accessed at: https://nwsalmonprojects.basecamphq.com.

Results of this research have been disseminated to NOAA and WDFW scientists and fishery managers through multiple meetings (approximately quarterly project meetings that included several NOAA, WDFW personnel, and representatives from the four participating tribes) and conference presentations. Talks presented by PI Keister included:

- 2018 PICES Annual Meeting: "Diagnosing the impacts of large-scale climate variability on local ecosystems in the Salish Sea, USA", Yokohama, Japan
- 2018 ICES/PICES International Climate Change Symposium: "Inland sea and coastal ocean zooplankton communities show contrasting responses to recent Northeast Pacific climate variability", Washington, D.C.
- 2018 Puget Sound Marine Waters Working Group Annual Review: "Puget Sound Zooplankton," Seattle, WA.
- 2018 U. Strathclyde: "Climate controls on zooplankton community structure." Glasgow, Scotland
- 2017 Salish Sea Marine Survival Workshop, Richmond, B.C.
- 2017 Ocean Carbon and Biogeochemistry Summer Workshop: "North Pacific climate and zooplankton variability", Woods Hole, MA.
- 2017 Puget Sound Marine Waters Working Group Annual Review: "Puget Sound zooplankton," Seattle, WA.
- 2016 Salish Sea Marine Survival Workshop, "Zooplankton of the Southern Salish Sea," Bellingham, WA.
- 2016 Zooplankton Indicators workshop, "Qualities of a good indicator," Bergen, Norway.
- 2016 NOAA Eco-FOCI seminar series, "Zooplankton response to environmental change," Seattle, WA.

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We would like acknowledge the great work and dedicate this report to our late dear friend, Christopher “Kit” Rawson for overseeing the initial assemblage and derivation of comprehensive Salmon marine survival smolt-to-adult (SAR) time series data tables called Population Data Resource Tables (PDRT), for the available Puget Sound and Strait of Georgia hatchery- and natural-origin Chinook and coho salmon stocks under this project. We would like to thank Marianna Alexandersdottir, Alexanders Consulting, Olympia, WA., for continuing to thoroughly assemble, update, and complete these survival estimates for all of the available Salish Sea Chinook and coho salmon stocks for which there were reliable, uniform data available.

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Appendix A. NMS ordinations of vertical net zooplankton biomass by region.

Northern Washington (San Juan Islands and Bellingham Bay)

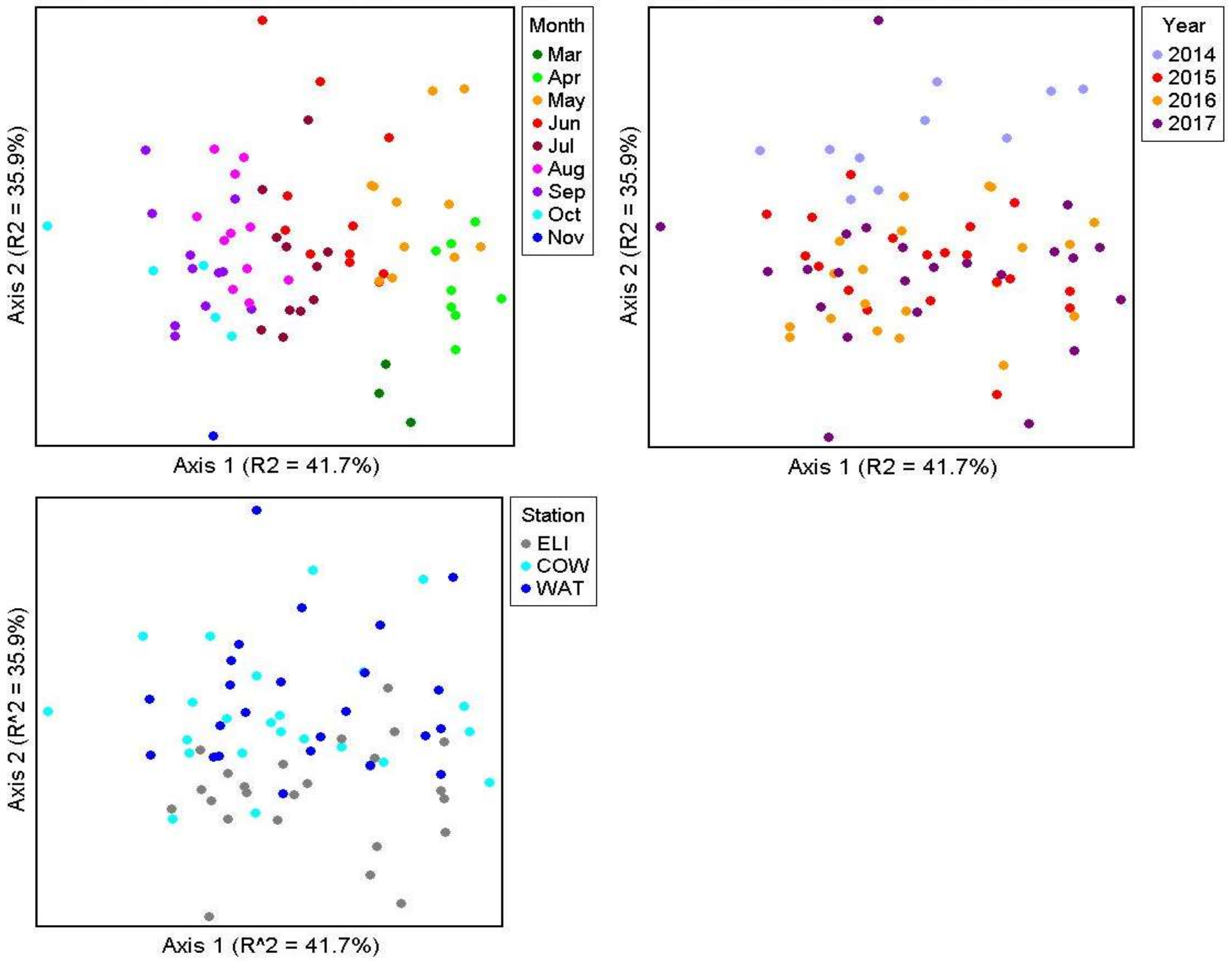

Figure A1. Nonmetric Multidimensional Scaling ordinations of 2014-2017 SSMSP vertical net zooplankton tows collected in Northern Washington, with panels color coded by month, year, or station. Stations include Cowlitz, Eliza Is., and Watmough Bay. Total variance in community structure explained by the 3-D ordination was 89.0%.

A strong seasonal cycle in zooplankton community structure was apparent along Axis 1, as well as some separation along Axis 2 between the Bellingham Bay (ELI) station from those in the San Juan Islands (COW and WAT). Among years, 2014 clustered apart from 2015-2017 along Axis 2; the other years were mixed. No hydrographic variables strongly correlated with the axes.

The oceanic copepods *Centrapages abdominalis*, *Pseudocalanus mimus*, and *Triconia borealis* were strongly positively correlated with Axis 1 while the Puget Sound taxa *Paracalanus spp.* (r = -0.72) and *Ditrichocoryceaus anglicus* (r = -0.72), were strongly negatively correlated with Axis 1. The dinoflagellate *Noctiluca* was the only taxon strongly correlated with Axis 2 (r = 0.77) which is also the axis the regions separated along.

Admiralty Inlet

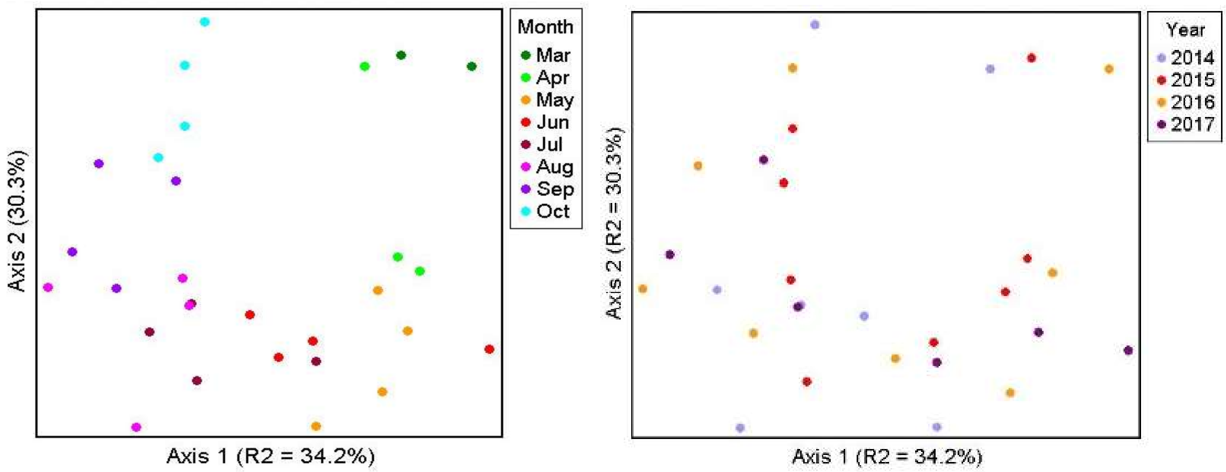

Figure A2. Nonmetric Multidimensional Scaling ordinations of 2014-2017 SSMSP vertical net zooplankton tows collected in Admiralty Inlet, color coded by month and by year. Stations include only Admiralty Inlet. Total variance in community structure explained by the 3-D ordination was 86.0%.

A strong seasonal cycle in community structure was apparent, cycling around Axes 1 and 2. There was no apparent separation among years on the two dominant axes. Most of the hydrographic variables tested correlated strongly with Axis 1 of the Admiralty Inlet ordination, the highest being salinity which was negatively correlated. No hydrographic variables strongly correlated with Axis 2 or Axis 3.

Highest species correlations with the axes were the copepods *Acartia hudsonica* (r = 0.80) and *Paracalanus spp.* (r = -0.79) on Axis 1, while the medusa *Clytia gregaria* was highest on Axis 2 (r = -0.79).

Whidbey Basin

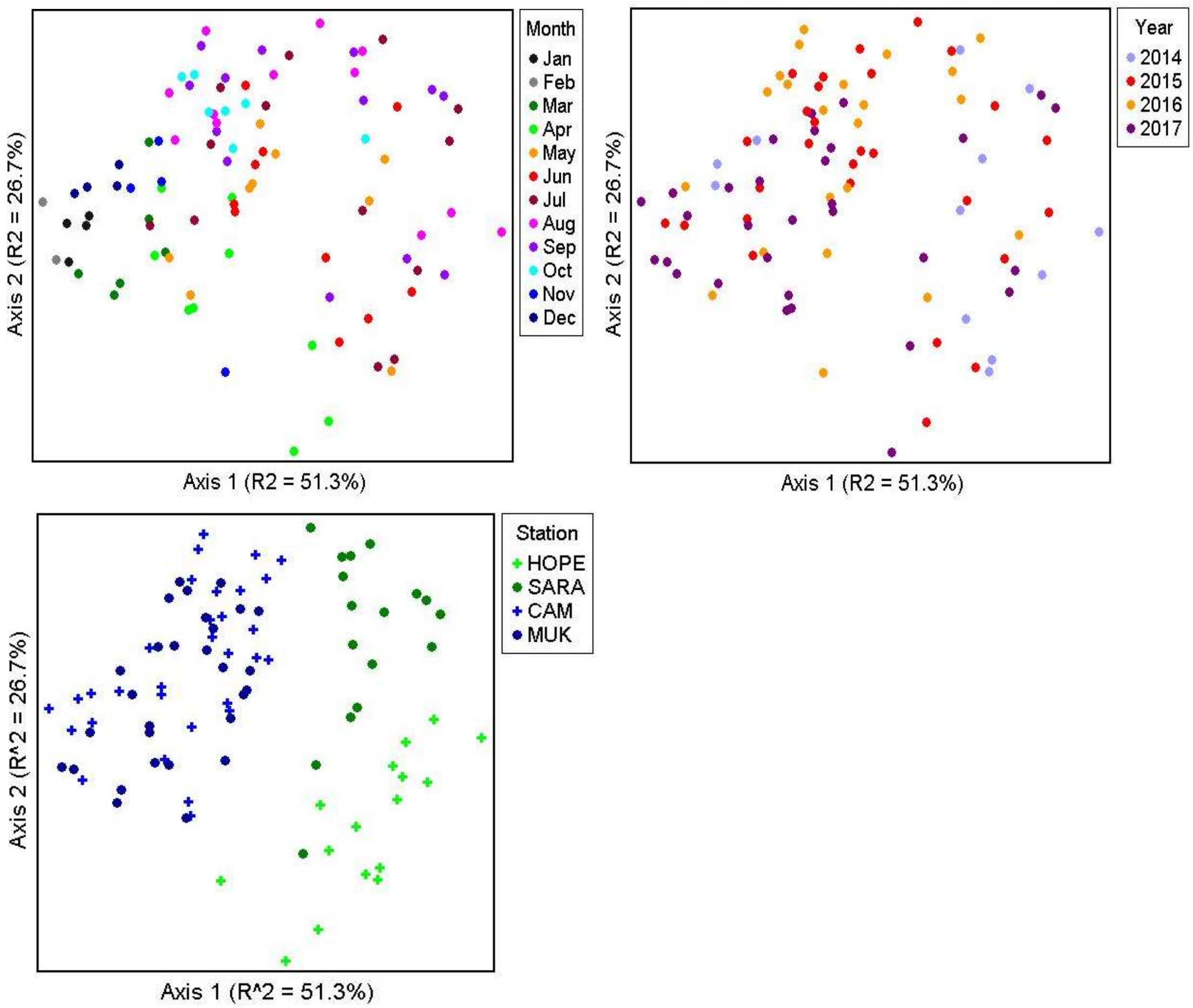

Figure A3. Nonmetric Multidimensional Scaling ordinations of 2014-2017 SSMSP vertical net zooplankton tows collected in Whidbey Basin, with panels color coded by month, year, or station. Stations include Hope Island, Saratoga Passage, Camano Head, and Mukilteo. Total variance in community structure explained by the 3-D ordination was 90.7%.

The clearest clustering in the Whidbey Basin samples was the strong separation between communities at the northern (HOPE and SARA) from southern (CAM and MUK) stations. There was a somewhat weak seasonal cycle within each region, and little apparent difference among years. There were also only weak correlations with hydrographic variables; maximum water column density was the highest correlate, correlating with Axis 1 r = -0.66.

Taxa that drove the strong pattern along Axis 1 were barnacles and polychaetes–both positively correlated with Axis 1 indicating more of them at the northern sites–and the shrimp *Pasiphaea pacifica* which was negatively correlated. The large-bodied copepod *Calanus pacificus* was the primary driver of Axis 2 (r = 0.71).

Hood Canal

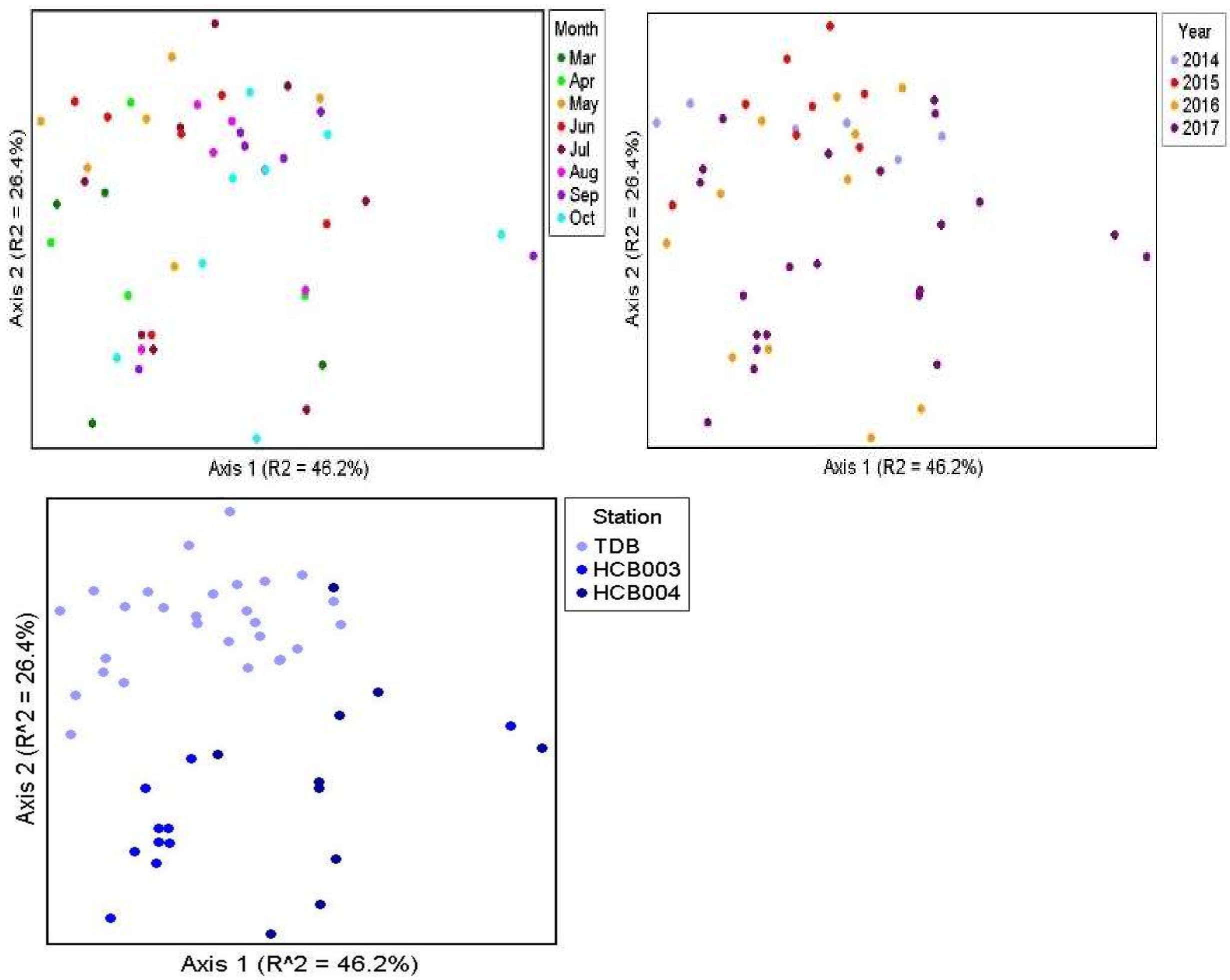

Figure A4. Nonmetric Multidimensional Scaling ordinations of 2014-2017 SSMSP vertical zooplankton tows collected in Hood Canal, with panels color coded by month, year, or station. Stations include Thorndyke Bay, Eldon, and Sister Point. Total variance in community structure explained by the 3-D ordination was 87.7%.

Compared to other regions, the seasonal cycle in community structure was weak in Hood Canal, particularly among samples at the HCB stations, and differences among years were subtle. Along Axes 1 and 2, samples primarily separated by station with the southernmost station HCB004 clustering to the right on Axis 1; TDB and HCB003 fell to the left on Axis 1 and separated along Axis 2. Axis 1 had only weak correlations with hydrographic variables, the highest being Dissolved Oxygen at 30 m (r = -0.68). In addition to Latitude and Longitude, Axis 2 correlated most strongly with minimum water column oxygen (r = 0.66).

The highest species correlation was the gammarid amphipod *Cyphocaris challengeri* (r = -0.82 with Axis 1). There were no other strong species correlations.

Central Basin

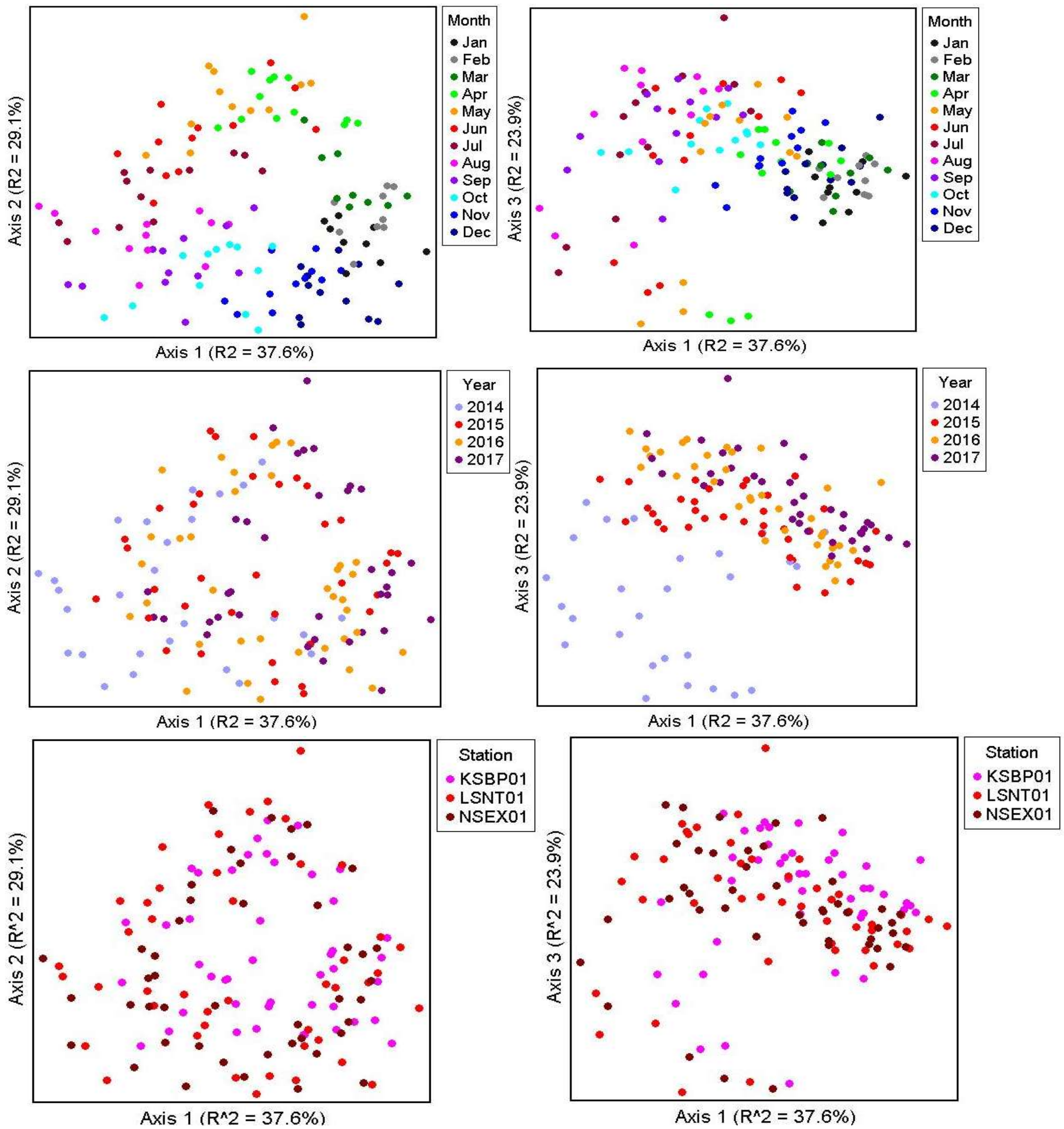

Figure A5. Nonmetric Multidimensional Scaling ordinations of 2014-2017 SSMSP vertical zooplankton tows collected in Central Basin, with panels color coded by month, year, or station. Stations include Point Williams, Point Jefferson, and East Passage. Total variance in community structure explained by the 3-D ordination was 90.6%.

The Central Basin zooplankton community showed a clear seasonal cycle on Axes 1 and 2, clear separation of 2014 from 2015-2017 on Axis 3, but little separation among stations overall on any axis. Consistent with the clear seasonal cycle, temperature was strongly, negatively correlated with Axis 1 (cooler temperatures on the right end of the axis); dissolved oxygen and salinity were strongly negatively correlated with the separation in communities along Axis 2.

Taxa which were important drivers of community structure were bivalves, the siphonphore *Muggiaea atlantica*, and the copepod *Paracalanus spp*., which all negatively correlated with Axis 1; several species of crab larvae positively correlated with Axis 2; and larvaceans were the strongest drivers of separation along Axis 3.

South Sound

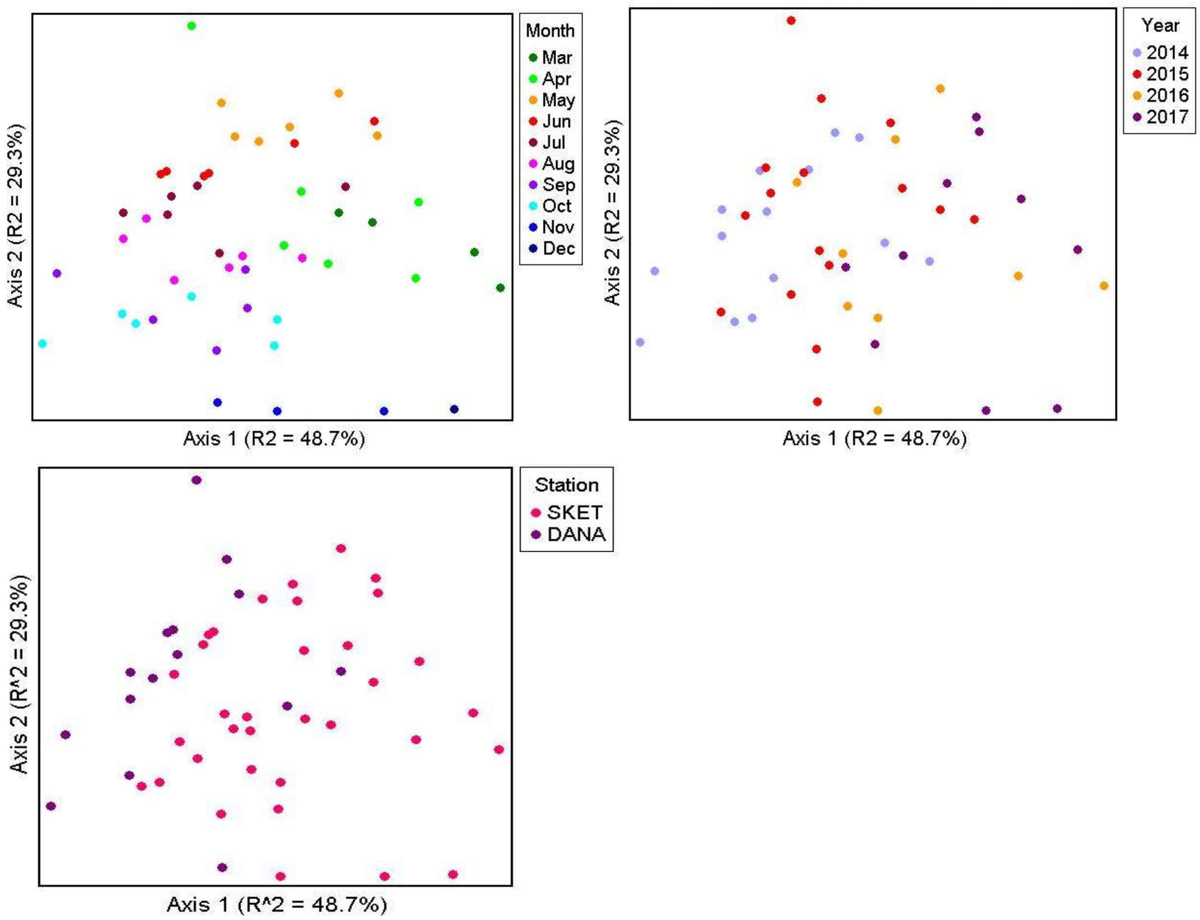

Figure A6. Nonmetric Multidimensional Scaling ordinations of 2014-2017 SSMSP vertical zooplankton tows collected in South Sound, with panels color coded by month, year, or station. Stations include South Ketron and Dana Passage. Total variance in community structure explained by the 3-D ordination was 90.5%.

The strongest separation of samples among months, years and station was station. Some seasonal and interannual separation in communities fell along Axis 1 and 2, with 2014 samples clustering closest to the fall samples (to the left on Axis 1). Near-surface salinity and temperature correlated strongly and negatively with community structure on Axis 1. Density, dissolved oxygen, and deep-water salinity all positively correlated with Axis 2.

As in Central Basin, the siphonophore *Muggiaea atlantica* were important in driving community structure along Axis 1, while the cladocera *Evadne,* barnacles, and larvae of the crab *Fabia subquadrata* were all positively correlated with differences in communities along Axis 2.

Table A1. Pearson correlations (r and R^2) between taxa and axes from NMS ordination of vertical net tow data indicating taxa which were important drivers of differences in community structure. Only taxa which correlated abs(r)≥0.6 with one or more axes are shown; taxa most strongly correlated with each axis ($R^2 > 0.5$) are in bold.

All locations combined:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Muggiaea atlantica	**-0.771**	**0.595**	0.241	0.058	-0.132	0.017
Paracalanus spp.	**-0.731**	**0.535**	0.048	0.002	0.006	0
Pseudocalanus copepodites	0.658	0.433	-0.341	0.116	0.049	0.002
Barnacles	-0.251	0.063	**-0.793**	**0.629**	-0.082	0.007
Cyphocaris challengeri	0.345	0.119	0.651	0.423	-0.277	0.077
Metridia pacifica	0.266	0.071	0.092	0.009	-0.672	0.452

Northern WA:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Metacarcinus magister	0.642	0.412	-0.223	0.050	-0.003	0
Centrapages abdominalis	**0.790**	**0.624**	0.212	0.045	0.091	0.008
Dirtichocoryceaus anglicus	**-0.721**	**0.520**	-0.086	0.007	0.470	0.221
Neocalauns plumchrus	0.655	0.429	0.021	0	-0.029	0.001
Paracalanus spp.	**-0.722**	**0.522**	-0.166	0.028	0.262	0.069
Pseudocalanus large males	0.676	0.457	-0.081	0.007	-0.297	0.088
Pseudocalanus mimus	**0.735**	**0.540**	-0.147	0.022	-0.004	0
Triconia borealis	**0.744**	**0.553**	0.050	0.002	-0.043	0.002
Acartia spp.	0.211	0.044	0.641	0.411	-0.253	0.064
Noctiluca sp.	0.066	0.004	**0.771**	**0.595**	-0.115	0.013

Whidbey Basin:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Barnacles	**0.823**	**0.677**	-0.232	0.054	0.120	0.014
Polychaetes	**0.801**	**0.641**	0.096	0.009	0.047	0.002
Pasiphaea pacifica	**-0.775**	**0.601**	0.153	0.024	0.151	0.023
Cyphocaris challengeri	-0.668	0.446	0.568	0.323	0.122	0.015
Noctiluca	0.665	0.442	0.184	0.034	0.180	0.032
Podon sp.	0.661	0.437	-0.320	0.102	0.210	0.044
Neocalanus christatus	0.660	0.436	0.355	0.126	0.181	0.033
Crangonidae	0.656	0.430	0.092	0.008	0.209	0.044
Oikopleura sp.	0.633	0.401	0.180	0.032	0.204	0.042
Muggiaea atlantica	0.568	0.322	0.661	0.436	-0.033	0.001
Calanus pacificus	-0.376	0.141	**0.708**	**0.501**	0.233	0.054
Limacina helicina	-0.054	0.003	0.654	0.428	0.017	0
Fish larvae	-0.054	0.003	-0.062	0.004	0.640	0.409

Admiralty Inlet:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Acartia hudsonica	**0.802**	**0.642**	-0.276	0.076	-0.202	0.041
Bivalves	**-0.755**	**0.570**	-0.199	0.040	0.193	0.037
Bryozoa	**-0.758**	**0.574**	0.110	0.012	0.233	0.055
Centropages abdominalis	0.678	0.459	-0.513	0.263	0.030	0.001
Ditirchocoryceaus anglicus	-0.652	0.425	-0.499	0.249	0.115	0.013
Oithona similis	-0.638	0.408	-0.229	0.053	0.220	0.049
Paracalanis spp.	**-0.788**	**0.620**	-0.390	0.152	-0.025	0.001
Pseudocalanus large males	0.649	0.421	0.171	0.029	0.447	0.200
Pseudocalanus moultoni	**0.708**	**0.502**	-0.186	0.035	-0.202	0.041
Clytia gregaria	0.189	0.036	**-0.793**	**0.629**	-0.078	0.006
Cyphocaris challengeri	0.249	0.062	**0.735**	**0.540**	-0.176	0.031
Fabia subquadrata	0.529	0.279	-0.677	0.458	-0.179	0.032
Cancridae large megalopa	-0.025	0.001	-0.157	0.025	**-0.813**	**0.661**
Fritillaria spp.	-0.078	0.006	-0.405	0.164	0.633	0.401

Hood Canal:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Chaetognaths	-0.697	0.486	0.285	0.081	-0.041	0.002
Cyphocaris challengeri	**-0.816**	**0.666**	-0.127	0.016	0.107	0.012
Muggiaea atlantica	0.658	0.433	0.079	0.006	-0.249	0.062
Barnacles	0.054	0.003	0.701	0.492	-0.287	0.083
Dirtichocoryceaus anglicus	-0.187	0.035	0.658	0.433	0.486	0.237
Acartia hudsonica	-0.090	0.008	-0.071	0.005	-0.682	0.465
Centrapages abdominalis	-0.258	0.066	0.101	0.010	-0.663	0.439

Central Basin:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Bivalve	**-0.829**	**0.687**	-0.043	0.002	0.292	0.085
Muggiaea atlantica	**-0.785**	**0.616**	-0.197	0.039	-0.258	0.066
Paracalanis spp.	**-0.778**	**0.606**	-0.090	0.008	0.381	0.145
Pseudocalanus newmani	**0.739**	**0.546**	0.226	0.051	0.242	0.059
Acartia hudsonica	0.144	0.021	**0.717**	**0.513**	0.042	0.002
Barnacles	-0.433	0.188	**0.764**	**0.583**	0.071	0.005
Glebocarcinus oregonensis	-0.032	0.001	**0.734**	**0.539**	0.380	0.144
Fabia subquadrata	0.129	0.017	**0.731**	**0.535**	0.093	0.009
Triconia borealis	-0.242	0.059	**0.759**	**0.577**	-0.072	0.005
Calanoids	-0.302	0.091	0.243	0.059	-0.658	0.433
Metacarcinus gracilis	-0.206	0.042	0.378	0.143	0.661	0.436
Larvacea	-0.469	0.220	0.104	0.011	**-0.722**	**0.521**
Oikopleura sp.	0.126	0.016	0.085	0.007	**0.807**	**0.651**
Themisto pacifica	0.062	0.004	-0.256	0.065	0.661	0.437

South Sound:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Gastropods	-0.760	**0.578**	0.293	0.086	-0.280	0.078
Muggiaea atlantica	-0.889	**0.791**	-0.002	0	0.052	0.003
Paracalanus spp.	-0.741	**0.549**	0.305	0.093	-0.389	0.151
Polychaete	-0.650	0.423	0.493	0.243	0.207	0.043
Pseudocalanus copepodites	0.715	**0.511**	0.123	0.015	-0.255	0.065
Pseudocalanus newmani	0.750	**0.562**	0.300	0.090	0.062	0.004
*Pseudocalanus s*mall males	0.709	**0.503**	0.252	0.064	-0.197	0.039
Acartia hudsonica	0.127	0.016	0.644	0.415	0.374	0.140
Barnacles	-0.217	0.047	0.777	**0.604**	0.364	0.133
Bryozoa	-0.163	0.027	-0.696	0.484	-0.389	0.151
Centrapages abdominalis	0.428	0.183	0.689	0.474	0.084	0.007
Evadne spp.	-0.082	0.007	0.779	**0.606**	0.140	0.020
Fabia subquadrata	0.189	0.036	0.740	**0.548**	0.287	0.083
Pinnixa spp.	0.017	0	0.637	0.405	0.064	0.004
Metacarcinus gracilis	-0.343	0.118	0.067	0.004	0.690	0.475
Dirtichocoryceaus anglicus	-0.279	0.078	0.236	0.056	-0.637	0.406

Table A2. Pearson correlations (r and R^2) between environmental factors and axes from NMS ordination of vertical net tow data. Only factors which correlated abs(r) ≥ 0.6 with one or more axes are shown; factors most strongly correlated with each axis ($R^2 \geq 0.5$) are in bold. See Table A3 for list of abbreviations.

All Vertical nets combined:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
T10	-0.627	0.393	0.155	0.024	-0.025	0.001
Tmin	-0.599	0.359	0.157	0.025	-0.010	0
StDepth	0.327	0.107	0.583	0.340	-0.127	0.016

Northern WA:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Month	**-0.903**	**0.815**	-0.030	0.001	0.011	0
Carbon	0.392	0.154	-0.025	0.001	0.438	0.192

Whidbey Basin:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
StDepth	**-0.818**	**0.670**	0.344	0.119	0.168	0.028
Lon	**-0.817**	**0.668**	0.272	0.074	0.117	0.014
Lat	**0.795**	**0.633**	-0.374	0.140	-0.157	0.025
Abund	**0.744**	**0.554**	0.042	0.002	0.040	0.002
Dmax	-0.663	0.439	0.278	0.077	-0.312	0.097
T20	0.145	0.021	0.636	0.404	-0.312	0.098
D20	-0.301	0.091	0.210	0.044	-0.658	0.433

Admiralty Inlet:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
D20	**-0.728**	**0.531**	0.361	0.131	-0.040	0.002
D30	**-0.731**	**0.535**	0.387	0.150	-0.162	0.026
DO10	**0.649**	**0.421**	-0.288	0.083	-0.189	0.036
DO20	**0.718**	**0.516**	-0.207	0.043	-0.190	0.036
DO30	**0.740**	**0.548**	-0.208	0.043	-0.146	0.021
DOmin	**0.789**	**0.622**	-0.029	0.001	-0.099	0.010
Month	**-0.830**	**0.689**	0.143	0.020	-0.034	0.001
S10	**-0.782**	**0.611**	0.253	0.064	0.078	0.006
S20	**-0.853**	**0.727**	0.186	0.035	0.067	0.005
S3	**-0.714**	**0.510**	0.360	0.129	0.197	0.039
S30	**-0.870**	**0.758**	0.197	0.039	-0.004	0
SMax	**-0.771**	**0.594**	0.116	0.014	-0.086	0.007
T10	**-0.777**	**0.604**	-0.268	0.072	0.269	0.072
T20	**-0.800**	**0.640**	-0.217	0.047	0.249	0.062
T3	**-0.719**	**0.517**	-0.365	0.133	0.235	0.055
T30	**-0.798**	**0.636**	-0.196	0.039	0.258	0.067
Tmax	-0.674	0.454	-0.428	0.183	0.197	0.039
Tmin	**-0.753**	**0.566**	-0.139	0.019	0.234	0.055

Hood Canal:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
DO30	**-0.683**	**0.466**	0.339	0.115	-0.377	0.142
Lon	-0.307	0.094	**0.803**	**0.645**	0.172	0.030
Lat	-0.427	0.182	**0.714**	**0.510**	0.222	0.049
DOmin	-0.445	0.198	**0.664**	**0.441**	-0.107	0.011

Central Basin:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
Tmax	**-0.758**	**0.574**	-0.201	0.040	0.390	0.152
T3	**-0.751**	**0.564**	-0.186	0.035	0.409	0.168
T10	**-0.692**	**0.479**	-0.301	0.090	0.441	0.195
T20	**-0.653**	**0.427**	-0.369	0.136	0.458	0.210
Abund	**-0.647**	**0.419**	0.184	0.034	0.301	0.091
S10	-0.387	0.150	**-0.659**	**0.435**	0.201	0.040
SMax	-0.380	0.144	**-0.688**	**0.474**	0.130	0.017
S20	-0.376	0.141	**-0.693**	**0.480**	0.185	0.034
S30	-0.339	0.115	**-0.714**	**0.510**	0.169	0.028
DO3	-0.207	0.043	**0.682**	**0.465**	-0.206	0.043
DO10	-0.121	0.015	**0.709**	**0.502**	-0.254	0.065
D10	-0.065	0.004	**-0.670**	**0.449**	-0.018	0
DO30	0.041	0.002	**0.762**	**0.581**	-0.301	0.091
D20	-0.044	0.002	**-0.714**	**0.509**	-0.081	0.007
DO20	-0.008	0	**0.760**	**0.578**	-0.285	0.081
D30	-0.008	0	**-0.696**	**0.484**	-0.137	0.019

South Sound:

	Axis 1		Axis 2		Axis 3	
	r	R^2	r	R^2	r	R^2
S3	**-0.633**	**0.401**	-0.598	0.358	-0.352	0.124
Smin	**-0.698**	**0.487**	-0.473	0.224	-0.265	0.070
T10	**-0.707**	**0.500**	-0.27	0.073	-0.491	0.241
T20	**-0.71**	**0.504**	-0.294	0.086	-0.477	0.228
T3	**-0.701**	**0.492**	-0.239	0.057	-0.496	0.246
T30	**-0.712**	**0.507**	-0.311	0.097	-0.474	0.225
Tmax	**-0.690**	**0.476**	-0.239	0.057	-0.513	0.263
Tmin	**-0.736**	**0.542**	-0.312	0.098	-0.439	0.193
Year	**0.685**	**0.469**	-0.113	0.013	-0.550	0.302
D10	-0.285	0.081	**-0.727**	**0.528**	-0.073	0.005
D20	-0.155	0.024	**-0.745**	**0.555**	-0.082	0.007
D3	-0.360	0.130	**-0.713**	**0.508**	-0.107	0.011
D30	-0.116	0.014	**-0.746**	**0.556**	-0.080	0.006
Abund	-0.419	0.175	**0.691**	**0.478**	-0.183	0.034
Dmax	-0.019	0	**-0.744**	**0.554**	-0.156	0.024
DO10	0.003	0	**0.799**	**0.639**	0.297	0.088
DO20	-0.001	0	**0.824**	**0.679**	0.324	0.105
DO3	0.058	0.003	**0.773**	**0.598**	0.236	0.056

DO30	-0.012	0	**0.815**	**0.664**	0.327	0.107
DOMax	0.051	0.003	**0.758**	**0.574**	0.212	0.045
DOmin	-0.106	0.011	**0.762**	**0.580**	0.388	0.151
Month	-0.410	0.168	**-0.716**	**0.513**	-0.313	0.098
S20	-0.545	0.297	**-0.675**	**0.455**	-0.345	0.119
S30	-0.517	0.267	**-0.693**	**0.480**	-0.338	0.115
SMax	-0.456	0.208	**-0.715**	**0.511**	-0.367	0.134

Table A3. Metrics of environmental variables used in NMS ordinations and their abbreviations.

Parameter	Unit	Abbr.	Depth (m)	Description
Month	-	Month	-	Numerical value of month
Year	-	Year	-	Numerical value of year
Latitude		Lat	-	
Longitude		Lon	-	
Depth	m	StDepth	-	Station Depth
Abundance	Ind m^{-3}	Abund	-	Total zooplankton abundance
Biomass	mg C m^{-3}	Carbon	-	Total zooplankton biomass
Salinity	PSU	S3	3	Salinity at 3 m depth
		S10	10	Salinity at 10 m depth
		S20	20	Salinity at 20 m depth
		S30	30	Salinity at 30 m depth
		SMax		Max. water column salinity
		Smin		Min. water column salinity
Temperature	^oC	T3	3	Temperature at 3 m depth
		T10	10	Temperature at 10 m depth
		T20	20	Temperature at 20 m depth
		T30	30	Temperature at 30 m depth
		Tmax		Max. water column temperature
		Tmin		Min. water column temperature
		T30-T3	30 minus 3	Temp. at 3 m – Temp. at 30 m
Density	sigma-t	D3	3	Density at 3 m depth
		D10	10	Density at 10 m depth
		D20	20	Density at 20 m depth
		D30	30	Density at 30 m depth
		Dmax		Max. water column density
		Dmin		Min. water column density
		D30-D3	30 minus 3	Dens. at 3 m – Dens. at 30 m
Chlorophyll a	µg L^{-1}	Chla3	3	Chla at 3 m depth
		Chla10	10	Chla at 10 m depth
		Chla20	20	Chla at 20 m depth
		Chla30	30	Chla at 30 m depth
		ChlaMax		Max. water column Chla
		Chlamin		Min. water column Chla
		TotChl	All	Integrated upper 30 m Chla
		Up30Chl	0 to 30	Chla at 3 m – Chla at 30 m
Dissolved Oxygen	mg L^{-1}	DO3	3	Oxygen at 3 m depth
		DO10	10	Oxygen at 10 m depth
		DO20	20	Oxygen at 20 m depth
		DO30	30	Oxygen at 30 m depth
		DOMax		Max. water column oxygen
		DOmin		Min. water column oxygen

Appendix B

UPDATE COHO AND CHINOOK SALMON SURVIVAL TIME SERIES FROM MULTIPLE REGIONS ACROSS PUGET SOUND AND BRITISH COLUMBIA

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1 Introduction

Estimates of survival for Chinook and coho salmon are documented in this report. The estimates for Chinook salmon stocks are made using coded wire tag (CWT) releases for brood years 2008-2012 from release to age 2. Estimates for coho salmon were made using two methods, the first using CWT releases for brood years 2008 to 2013 and the second using estimates of wild smolt outmigration, adult immigration and of exploitation rates.

1.1 Estimation of recoveries of tagged salmon

CWT releases and recoveries were downloaded from the Pacific States Marine Fisheries Commission's (PSMFC) Regional Mark Information System (RMIS). Recoveries in fisheries and escapement are estimated as the observed tagged fish in a sample over the sample rate in the fishery or escapement. The assumptions necessary for an unbiased estimate of fishery recoveries and of survival are:

1. All fisheries and escapement are sampled.
2. All tagged fish in a sample are detected and processed.
3. The estimate of total catch or escapement that is sampled is unbiased.

There are two sample methods for tagged fish in fisheries and escapement, visual and electronic. Where there is electronic sampling all tagged fish, clipped or unclipped, in the sample can be detected and counted as recoveries for each tag code. If sampling is visual (i.e., the adipose fin clip is an external indicator of a tagged fish) only clipped and tagged fish would be detected in a sample. For unclipped tag groups, there would be no recoveries in fisheries with visual sampling. In addition, if a stock is subject to mark selective fisheries, unclipped tagged fish would be released, and any release mortalities would not be included in the total mortalities for the tag group.

2 Chinook

Estimates of survival for Chinook salmon were made for tagged releases from ten Washington Coastal and Puget Sound hatcheries (Table 1). These include estimates for Dungeness and White River spring fingerlings which were unclipped releases as there were no clipped releases from these hatcheries. Otherwise estimates were made for clipped and tagged releases from hatcheries with only clipped releases or double index tag releases (i.e., there were clipped and unclipped releases).

2.1 Estimation of survival

CWT releases and recoveries were loaded into the Pacific Salmon Commissions (PSC) Chinook Technical Committee (CTC) Chinook salmon database (CAS) for use in the CTC exploitation rate analysis (ERA). The release table in RMIS records the mark and tag status and the number released in each tag release record (Appendix B Table 1). For each clipped tag code, there may be releases reported without the clip, due to bad clips for instance. In this analysis, all releases for a tag code (clipped and unclipped) are used in estimating the survival.

The CTC ERA estimates total cohort size at age including estimates of incidental mortalities (TCCHINOOK 2015)[5]. These are mortalities due to releases of sublegal size Chinook and of Chinook due to catch and release, e.g., Chinook release in coho salmon targeted fishery. The assumptions of the CTC ERA analysis and methods for estimating the incidental mortalities are described in TCCHINOOK (2015) section 2.1.1.

For the purposes of estimating the survival, the cohort at age 2 or 3 is the abundance prior to natural mortality occurring at the beginning of the age. The cohort includes all landed and incidental mortalities, escapement and natural mortality occurring between ages.

As described in TCCHINOOK (2015) section 2.1.3:

> For CWT data, the BY survival rate ($CohSurv_{BY,a}$) for a fingerling stock is the estimated age-2 cohort ($Cohort_{BY,a}$, from the cohort analysis) divided by the number of CWT fish released, whereas for yearling stocks, the survival rate is calculated for the estimated age-3 cohort.
>
> $$CohSurv_{BY,a=2or3} = \frac{Cohort_{BY,a=2or3}}{TotCWTRelease_{BY}} \qquad \text{Equation 2.3}$$
>
> where *CohortBY,a* is calculated recursively from the oldest age down to the youngest age using
>
> $$Cohort_{BY,a} = \frac{(\sum_{f=1}^{Numfisheries} TotMorts_{BY,a,f}) + Esc_{BY,a} + Cohort_{BY,a+1}}{1 - NM_a}. \qquad \text{Equation 2.4}$$
>
> and
>
> $TotCWTRelease_{BY}$ = Total mortalities for brood year BY
> $TotMorts_{BY,a,f}$ = Total mortalities for brood year BY, age a and fishery f
> $Esc_{BY,a,}$ = Total mortalities for brood year BY and age a .
> NM_a = Natural mortality rate from age a-1 to a.

The natural mortality rates used by the CTC are:

Age 1-2	Age 2-3	Age 3-4	Age 4-5
0.4	0.3	0.2	0.1

An unbiased estimate of cohort size, and of survival, can only be made for the stocks represented by tagged and clipped groups. As described above an unclipped and tagged group will not be recovered where there is visual sampling (e.g., in Canadian sport fisheries), and release mortalities in mark-selective fisheries cannot be estimated. Therefore, for the two tagged and unclipped releases (Dungeness and White River spring releases), estimates of survival are minimum estimates, i.e. are potentially underestimated.

[5] TCCHINOOK. 2015 a. 2014 Exploitation Rate Analysis and Model Calibration. Vols 1 and 2. PSC TCCHINOOK (15) -1 V.1 and V.2.

2.2 Results- Chinook salmon

The tag codes used for each stock group are shown in Appendix B Table 1. Appendix B Table 2 shows the estimates of survival for the Chinook salmon stocks.

Estimates of survival for clipped stocks are unbiased when the assumptions listed above are valid. For the two unclipped stocks, Dungeness and White River fingerlings, the estimates are underestimates. The bias depends on the number of mortalities for these stocks in fisheries where tag detection was visual or release mortalities in mark-selective fisheries. Table 3 shows recoveries by region of recovery location and source for clipped tagged groups for these two stocks. Dungeness spring salmon releases were tagged and clipped for 1971-1973 broods and for 1989-1996 White River spring salmon broods. For these releases on average, 75 and 96% of recoveries were in Puget Sound fisheries, while an average of 5 and 3% of recoveries were in BC sport fisheries. The BC sport fisheries are not sampled electronically and so any estimate of total return will be biased.

Table 1. Releases of stocks for broods 2008-2012 for Chinook salmon. Clipped releases include tagged fish with no clip having the clipped tag code (see Appendix B Table 1).

Stock Name	Mark	CTC Stock	Hatchery	Age at Release	Brood Year				
					2008	2009	2010	2011	2012
Dungeness/Gray Wolf Spring Fingerl	Noclip	DUN	Dungeness H.	1	-	49,694	27,387	54,104	51,340
				2	48,444	-	-	-	-
Garrison Fall Fingerl	Clip	GAR	Garrison H.	1	190,490	188,913	-	90,714	91,000
Green River Fall Fingerl	Clip	GRN	Soos Creek H.	1	192,495	200,073	202,102	200,460	203,086
Grovers Creek Fall Fingerl	Clip	GRO	Grovers Cr H.	1	195,227	200,431	198,276	205,050	173,916
Puyallup Fall Fingerl	Clip	PUY	Voights Cr H.	1	-	188,496	-	92,000	-
Skagit Fall Fingerl	Clip	SFF	Marblemount H.	1	157,232	-	-	-	-
Snohomish Summer Yearl	Clip	SNY	Wallace R H.	2	78,704	-	73,393	-	80,849
Tulalip Summer Fingerl	Clip	TUL	Bernie Gobin Hatch	1	110,506	104,705	111,509	105,486	101,995
White River Spring Fingerl	Noclip	WRF	White River H.	1	349,518	347,239	353,644	336,665	348,625
Willapa Bay Fall	Clip	WPA	Forks Creek H.	1	200,344	201,320	194,364	201,823	200,642

Table 2. Number released, estimated age 2 cohort size for Chinook salmon before and after natural mortality and estimated survival by stock and brood year for broods 2008-2011.

Hatchery	Stock		Brood	Release	Age 2 COH	Adjusted for NM	Survival
Clipped Stocks							
SOOS CREEK	**GRN**	**Green River Fall Fingerling**	**2008**	192,495	818.9	1,364.8	0.00709
			2009	200,073	1,942.7	3,237.8	0.01618
			2010	202,102	723.6	1,206.1	0.00597
			2011	200,460	833.1	1,388.5	0.00693
GARRISON HATCHERY	**GAR**	**Garrison Fall Fingerling**	**2008**	190,490	338.0	563.4	0.00296
			2009	188,913	1,271.4	2,119.1	0.01122
			2011	90,714	34.8	58.0	0.00064
GROVERS CR HATCHERY	**GRO**	**Grovers Creek Fall Fingerling**	**2008**	195,227	1,243.1	2,071.9	0.01061
			2009	200,431	4,796.5	7,994.1	0.03988
			2010	198,276	1,701.9	2,836.6	0.01431
			2011	205,050	4,155.3	6,925.5	0.03377
VOIGHTS CR HATCHERY	**PUY**	**Puyallup Fall Fingerling**	**2009**	188,496	1,867.7	3,112.9	0.01651
			2011	92,000	647.2	1,078.6	0.01172
WALLACE R HATCHERY	**SNY**	**Snohomish Summer Yearling**	**2008**	78,704	1,738.2	2,897.1	0.03681
			2010	73,393	1,635.6	2,725.9	0.03714
BERNIE GOBIN HATCH	**TUL**	**Tulalip Summer fingerling**	**2008**	110,506	77.7	129.6	0.00117
			2009	104,705	259.2	432.0	0.00413
			2010	111,509	207.7	346.1	0.00310
			2011	105,486	430.9	718.1	0.00681
FORKS CREEK HATCHERY	**WPA**	**Willapa Bay Fall Fingerling**	**2008**	200,344	660.5	1,100.9	0.00549
			2009	201,320	1,025.7	1,709.5	0.00849
			2010	194,364	1,286.9	2,144.8	0.01103
			2011	201,823	2,302.8	3,838.0	0.01902
MARBLEMOUNT	**SFF**	**Skagit Fall Fingerling**	**2008**	157,232	805.7	1,342.8	0.00854
Unclipped Stocks							
DUNGENESS HATCHERY	**DUN**	**Dungeness/Gray Wolf Spring Fingerling**	**2008**	48,444	128.7	214.6	0.00443
			2009	49,694	197.1	328.4	0.00661
			2010	27,387	49.2	82.1	0.00300
			2011	54,104	172.3	287.2	0.00531
WHITE RIVER HATCHERY	**WRF**	**White River Spring Fingerling**	**2008**	349,518	1,194.4	1,990.7	0.00570
			2009	347,239	3,737.7	6,229.5	0.01794
			2010	353,644	1,325.0	2,208.3	0.00624
			2011	336,665	1,364.0	2,273.3	0.00675

Table 3. Number and average percent of Chinook salmon tag recoveries for clipped tag groups by region and source over 1971-73 for Dungeness Spring and over 1989-1996 for White River Spring Fingerling

Recovery Location	Source	DUNGENESS HATCHERY		WHITE RIVER HATCHERY	
		Number of recoveries	%	Number of recoveries	%
AK	Troll	33	0.8%	3	0.1%
BC	Net	222	5.7%	41	0.7%
	Sport	179	4.6%	149	2.6%
	Troll	512	13.2%	18	0.3%
BC Total		913	23.5%	207	3.6%
PS	Net	96	2.5%	129	2.3%
	Sport	2656	68.2%	1312	23.0%
	Troll	65	1.7%	62	1.1%
	Spn grnd	0	0.0%	88	1.5%
	Hatch	126	3.2%	3899	68.4%
PS Total		2942	75.6%	5490	96.3%
WC	Sport	4	0.1%		0.0%
Grand Total		3892	100.0%	5700	100.0%

3 Coho Salmon

Estimates of survival were made for coho salmon releases in Washington and British Columbia for brood years 2008-2013. This is in continuation to work done by Kit Rawson for brood years 1970 through 2007 with participation under the Salish Sea Marine Survival Project by a team of US and Canadian biometricians and fishery scientists from WDFW, Department of Fisheries and Oceans Canada (DFO), NOAA Fisheries, University of Victoria, Victoria, BC, and private consultants, which was published in Zimmerman et.al (2015).

3.1 Estimation of survival

Two methods were used for estimation of survival for coho salmon, depending on the data available for the stocks. The first or method one was used when tagged releases were available for a stock, generally of hatchery releases. Then survival (SS) was estimated as:

$$Survival(SS1) = \frac{Age\ 3\ Fishery\ and\ Escapement\ Recoveries}{Release}$$

The second method was used for stocks for independent estimates of smolt outmigration (SMOLT), age 3 adult return (ADULTAGE3) and exploitation rates (ERAGE3), where

$$Exploitation\ Rate\ (ERAGE3)\ = \frac{Age\ 3\ Fishery\ Recoveries}{Age\ 3\ Fishery\ and\ Escapement\ Recoveries}$$

Given these three estimates then, the survival is estimated as:

$$Survival(SS2) = \frac{SMOLT}{\left[{}^{ADULTAGE3}/_{ERAGE3}\right]}$$

3.2 Data

3.2.1 Method one

Release and recovery data were downloaded from RMIS coho salmon tagcodes for brood years 2008-2013 for stocks included in the dataset (Table 4). The data were error-checked and records removed as follows:

1. RMIS releases that were not of age 2 fish
2. RMIS releases that did not include tagged coho salmon.
3. RMIS recovery fishery codes fall within the range defining fisheries or escapement types (10-99). Records not included in analysis are those with codes for juvenile and high seas recoveries and those falling outside the range, i.e. higher than 99.
4. Recoveries for coho not in the age range 2-4.

The release and recovery records were merged these two files to create the dataset to be used for survival estimation (***Coho Survival Database Oct 2018 MA.xls,*** *sheet= coho survival db oct 14 2018*). Definition of fields in this dataset are found in the sheet DICTIONARY and in Appendix B Table 2.

Records in the dataset used for the analysis (db Field=Use.Record), were:

1. Age 2 release
2. No escapement recoveries
3. Only age 2 escapement recoveries, or age 3 escapement recoveries very low
4. Age 3 recoveries were found but there were no estimates, specifically for spawning ground recoveries

Region and watershed codes were added to the dataset following the codes used in the previous dataset. In addition, codes were included indicating whether a release should be used for the survival estimate for the cluster analysis (Field=Use.for.Cluster), again using the previous dataset as a guide. There were two reasons data were not used for the survival estimate:

1. The tag releases were from net pens
2. The releases were from a location not used in previous analysis.

3.2.2 Method two

This method requires that independent estimates be available for stocks of smolt outmigration, and adult return and exploitation rates for age 3 coho salmon. As described in Zimmerman et.al. (2015): "A second estimation method relied on estimates of smolts leaving a system during spring and adults returning during fall/winter 18 months later……For this second method, returning adults were expanded by exploitation rate, either modeled or calculated using tag recoveries of a nearby population, to estimate numbers of fish retained in fisheries. Modeled exploitation rates were estimated using either a mixed stock model based on annual CWT recoveries or using backwards runs of the Fishery Regulation Assessment Model (FRAM)."

Table 5 shows the stocks included in the dataset showing source of estimates of smolt and adults and exploitation rates. Data for smolt and adult estimates for brood years 2008-2013 were provided by Cheryl Lynch of CDFO and for exploitation rates by Joel Sawada of CDFO.

3.3 Results

Table 6 shows the estimates of survival for the coho salmon stocks added to the dataset by region, method of estimation, and outmigration year.

Table 4. Coho salmon stocks included in the survival dataset showing first and last year of outmigration included.

Region	Watershed	Year of Outmigration First	Year of Outmigration Last
Puget Sound / Strait of Juan de Fuca (PS)	Baker	1983	2015
	Big Beef Crk	1975	2015
	Deschutes	1977	2015
	Dungeness	1972	2010
	Elwha	1979	2015
	Goldstream	1978	2013
	Green	1973	2015
	Kalama Crk	1979	2015
	Lake Washington	2009	2015
	Minter Crk	1972	2014
	Nooksack	1976	2015
	Puyallup	1973	2015
	Puyallup ponds	2011	2015
	Quilcene	1979	2015
	Skagit	1991	2015
	Skokomish	1973	2015
	Skykomish	1978	2015
	Stillaguamish	2011	2013
	Tulalip Bay	1974	2015
Strait of Georgia (SoG)	Big Qualicum	1971	2016
	Black	1978	2015
	Chilliwack	1976	2004
	Inch	1981	2017
	Lang	1989	2011
	Lemieux	1984	2011
	Louis	1983	2009
	Myrtle	2001	2011
	Puntledge	1978	2015
	Quinsam	1974	2017
	Salmon	1978	2009
Pacific Coast (PC)	Bingham Crk	1982	2015
	Carnation	1989	2011
	Chehalis	2010	2014
	Cowlitz	1982	2013
	Elochoman	1974	2009
	Grays	1977	2013
	Hoh	2010	2013
	Keogh	2010	2016
	Lewis	1978	2011
	Naselle	2010	2012
	Queets	2010	2015
	Quinault	1975	2015
	Robertson	1974	2016
	Satsop	1973	2015
	SolDuc	1973	2015
	Sooes	1982	2015
	Washougal	1976	2013
	Willapa	1973	2015

Table 5. Stocks where survival is estimated using method 2 showing method of estimating or source of smolt outmigration and age 3 exploitation rate and first and last year of outmigration in the Coho salmon survival dataset.

Region	Watershed	Smolt.Method	ER.Method	FIRST	LAST
Strait of Georgia (SoG)	**Black**	full spanning fence counts	updated from PSC Report TCCOHO (13)–1[6]	1997	2007
		full spanning fence counts	sBC indicator data master	2013	2016
			updated from PSC Report TCCOHO (13)–1	2008	2012
	Englishman	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	1998	2010
		(blank)	updated from PSC Report TCCOHO (13)–1	2000	2008
	Little	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	2000	2012
	Millard	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	1999	2012
		(blank)	updated from PSC Report TCCOHO (13)–1	2011	2011
	Morrison	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	2001	2009
	Myrtle	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	2000	2011
	Salmon	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	1997	2009
		(blank)	updated from PSC Report TCCOHO (13)–1	2006	2008
	Simms	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	1998	2008
	Tsolum	rotating screw trap	updated from PSC Report TCCOHO (13)–1	2004	2012
	Waterloo	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	2002	2010
Pacific Coast (PC)	**Carnation**	full spanning fence counts	Robertson H Ad/CWTs. See comments.	1974	2010
		full spanning fence counts	Robertson H Ad/CWTs. See comments.	2011	2012
			sBC indicator data master	2013	2016
	Keogh	full spanning fence counts	updated from PSC Report TCCOHO (13)–1	1997	2012
	Upper Cowlitz	Counted	MSM[7]	2001	2011

[6] TCCOHO 2013. 1986-2009 Periodic Report. PSC Joint Coho Tech. Comm. Report TCCOHO (13)-1.
[7] MIXED STOCK MODEL Fisheries management model used to estimate exploitation rates in mixed stock fisheries for Pacific Northwest Coho salmon fiseries.

Table 6. Estimates of Coho salmon survival for outmigration years 2010 to 2015 added to the dataset by region, watershed and method of estimation

			OEY					
Region	**Watershed**	**Method**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Puget Sound / Strait of Juan de Fuca (PS)	**Baker**	1	3.31%	6.57%	5.28%	4.19%	0.73%	
	Big Beef Crk	1	4.66%	6.15%	6.78%	5.79%	3.86%	6.68%
	Deschutes	1		1.82%			0.19%	
	Dungeness	1	1.86%					
	Elwha	1	0.19%	0.09%	0.19%	0.10%	0.03%	
	Goldstream	1	0.79%	0.36%	2.10%	1.17%		
	Green	1	5.35%	6.68%	5.04%	3.81%	0.75%	0.66%
	Kalama Crk	1	0.82%	2.17%	1.25%	1.57%	0.29%	
	Lake Washington	1			3.41%	3.95%	0.77%	
	Minter Crk	1		3.09%	1.86%	1.06%	0.74%	
	Nooksack	1	4.62%	3.76%	5.26%	3.21%	2.17%	
	Puyallup	1	1.68%	2.74%	1.88%	1.45%	1.03%	1.88%
	Puyallup ponds	1		0.36%	0.72%	0.58%	0.35%	0.06%
	Quilcene	1	5.76%	5.94%	3.53%	1.21%	1.98%	
	Skagit	1	5.82%	5.58%	7.46%	4.35%	1.59%	3.35%
	Skokomish	1	2.76%	2.01%	3.75%	1.31%	1.24%	
	Skykomish	1	5.37%	6.56%	5.57%	2.75%	1.35%	3.12%
	Snow Creek	2.1	5.73%					
	Stillaguamish	1		0.47%	0.83%	0.59%		
	Tulalip Bay	1	1.15%	4.51%	2.52%	4.62%	1.63%	
Strait of Georgia (SoG)	**Big Qualicum**	1	1.22%	1.44%	0.94%	0.30%	0.20%	0.58%
	Black	1.5	1.37%					
		2	7.52%	19.90%	33.51%	22.61%	4.79%	7.38%
	Englishman	2.1	7.52%					
	Inch	1	0.87%	2.62%	1.68%	1.09%	0.76%	0.76%
	Lemieux	1	0.10%	0.21%				
	Myrtle	1.5	2.08%	2.82%				
		2	1.99%	1.92%				
	Quinsam	1	0.92%	0.67%	1.04%	0.79%	0.19%	0.08%
Pacific Coast (PC)	**Bingham Crk**	1	5.04%	4.10%	1.93%	6.08%	1.41%	2.84%
	Carnation	1.5	1.28%	1.69%				
		2				25.90%	5.08%	18.21%
		2.2	8.71%	3.51%	9.44%			
	Chehalis	1	2.64%	2.49%		0.77%	0.49%	

Cowlitz	1	0.54%					
Grays	1	1.67%					
Keogh	2.1	3.08%					
Naselle	1	3.78%	2.22%	1.41%			
Queets	1	2.35%			2.99%	0.84%	
Quinault	1	6.73%	2.29%	4.50%	8.58%	3.80%	
Robertson	1	8.38%	1.85%	8.87%	3.66%	3.27%	1.98%
Satsop	1	3.19%	1.75%	2.83%	4.69%	1.11%	4.02%
SolDuc	1	3.61%	0.36%	2.54%	7.03%	1.59%	
Upper Cowlitz	2.1	8.85%					
Washougal	1	0.73%	0.47%	0.00%	0.00%		
Willapa	1	1.92%	1.09%	0.94%	10.00%	1.63%	2.60%

Appendix B Table 1. Chinook salmon tag codes used for analysis by stock, hatchery code, brood year, run type (1=spring, 2=summer, 3=fall), age at release and clip code (cwt_1st_mark=0000 for unclipped, 5000 for adipose fin clipped, 5500 for adipose fin clip and otolith mark) from RMIS showing total release for each tag code.

Spring stocks - Unclipped

STOCK	hatchery_location_code	brood_year	run	Age at rel	cwt_1st_ mark	tag_code_ or_release_id	Total release
DUN	**3F10806 180018 H**	2008	**1**	2	**0000**	210849	48,444
DUN	**3F10806 180018 H**	2009	**1**	1	**0000**	210773	49,694
DUN	**3F10806 180018 H**	2010	**1**	1	**0000**	210986	27,387
DUN	**3F10806 180018 H**	2011	**1**	1	**0000**	210969	54,104
DUN	**3F10806 180018 H**	2012	**1**	1	**0000**	210489	51,340
WRF	**3F10511 100031 H01**	2008	**1**	1	**0000**	210850	349,518
WRF	**3F10511 100031 H01**	2009	**1**	1	**0000**	210913	347,239
WRF	**3F10511 100031 H01**	2010	**1**	1	**0000**	210976	353,644
WRF	**3F10511 100031 H01**	2011	**1**	1	**0000**	211013	336,665
WRF	**3F10511 100031 H01**	2012	**1**	1	**0000**	211055	348,625

Summer stocks - Clipped

STOCK	hatchery_location_code	brood_year	run	Age at release	cwt_1st_ mark	tag_code_ or_release_id	No. Tagged	Tagged, no clip	Total release
SNY	**3F10308 070943 H**	2008	**2**	2	**5000**	634782	77,925	779	78,704
SNY	**3F10308 070943 H**	2010	**2**	2	**5000**	635590	73,115	278	73,393
SNY	**3F10308 070943 H**	2012	**2**	2	**5000**	635672	79,798	1,051	80,849
TUL	**3F10308 070001 H**	2008	**2**	1	**5000**	210861	110,285	221	110,506
TUL	**3F10308 070001 H**	2009	**2**	1	**5000**	210923	104,705		104,705
TUL	**3F10308 070001 H**	2010	**2**	1	**5500**	210950	111,509		111,509
TUL	**3F10308 070001 H**	2011	**2**	1	**5500**	211015	105,486		105,486
TUL	**3F10308 070001 H**	2012	**2**	1	**5500**	211061	101,995	-	101,995

Appendix B Table 1. Continued.

Fall stocks - Clipped

STOCK	Hatchery_ location_code	Brood year	run	Age at rel	Cwt_ 1st_mark	Tag_code/ release_id	Tagged	Tagged, no clip	Total release
GAR	3F10513 120007 H01	2008	3	1	5000	634278	190,490		190,490
GAR	3F10513 120007 H01	2009	3	1	5000	635086	185,030	3,883	188,913
GAR	3F10513 120007 H01	2011	3	1	5000	636196	90,106	608	90,714
GAR	3F10513 120007 H01	2012	3	1	5000	636470	90,745	255	91,000
GRN	3F10510 090072 H	2008	3	1	5000	634864	191,808	687	192,495
GRN	3F10510 090072 H	2009	3	1	5000	635297	195,175	4,898	200,073
GRN	3F10510 090072 H	2010	3	1	5000	635693	200,204	1,898	202,102
GRN	3F10510 090072 H	2011	3	1	5000	636164	200,460		200,460
GRN	3F10510 090072 H	2012	3	1	5000	636298	195,745	7,341	203,086
GRO	3F10510 150299 H	2008	3	1	5000	210822	186,978	8,249	195,227
GRO	3F10510 150299 H	2009	3	1	5000	210912	200,431		200,431
GRO	3F10510 150299 H	2010	3	1	5000	210963	198,276		198,276
GRO	3F10510 150299 H	2011	3	1	5000	211011	205,050	-	205,050
GRO	3F10510 150299 H	2012	3	1	5000	211051	173,916	-	173,916
PUY	3F10511 100414 H	2009	3	1	5000	635288	185,475	3,021	188,496
PUY	3F10511 100414 H	2011	3	1	5000	636197	92,000		92,000
SFF	3F10208 031421 H	2008	3	1	5000	210831	156,592	640	157,232
WPA	3F21902 240356 H	2008	3	1	5000	634870	197,835	2,509	200,344
WPA	3F21902 240356 H	2009	3	1	5000	635295	198,941	2,379	201,320
WPA	3F21902 240356 H	2010	3	1	5000	635976	194,364		194,364
WPA	3F21902 240356 H	2011	3	1	5000	636172	201,823		201,823
WPA	3F21902 240356 H	2012	3	1	5000	636487	199,030	1,612	200,642

Appendix B Table 2. Definitions of fields in coho salmon survival database (*sheet=coho survival db oct 14 2018* in worksheet *Coho Survival Database Oct 2018 MA.xls*). Taken from sheet DICTIONARY.

DATA FIELD	DEFINITION	REQUIRED	QUAL.CHECK
CAN.US	Canadian or American (US) data		Y
Use.Record	A flag (N) filled out if tag code record is unsuitable for use in analyses and should be filtered out		Y
Use.Record.Comment	A comment about why a tag code should be excluded from analysis		Y
Species	Coho for this project	Y	
Run.Type	Spring, summer, fall (includes Type S coho), winter, late fall (includes Type N coho)		Y
Rearing.Type	H (hatchery), W (wild), M (mixed hatchery & wild - downstream migrant or marine tagging), U (unknown)	Y	
OEY	Ocean entry year	Y	
Data.Source	Agency or group that provided data (indicate Regional Mark Information System [RMIS] or Mark Recovery Program (MRP) if data were retrieved from these databases).		Y
CU.ESU	Conservation Unit for wild Canadian coho; ESU for wild US coho	Y	
Region	Biogeographic region used for smolt survival analysis (PC – Pacific Coast, SoG – Strait of Georgia, PS – Puget Sound/Strait of Juan de Fuca)		Y
Watershed	Name of watershed for which estimate is made	Y	
Hatchery.Location.Code	Hierarchical location code to geographically identify actual site of hatchery (ch 13 PSC data specification document)		Y
Hatchery.Location.Name	Name of hatchery location	Y	
Stock.Location.Code	Hierarchical coding scheme to identify the stock's location or stream of origin		Y
Stock.Location.Name	Name of stock stream of origin	Y	
Release.Location.Code	Hierarchical coding scheme to identify the release location		Y
Release.Location.Name	Name of stream/river/estuary where fish are released		Y
Use.For.Cluster	A flag (Y or N) to indicate which of multiple versions to use for the cluster analysis		Y
Method	Data collection method (1 - individual CWTs, 1.5 - grouped CWTs due to wand detector use in escapement surveys, 2.1 - smolt and spawner counts expanded by modeled exploitation rate, 2.2 - smolt and spawner counts expanded by an exploitation rate based on cwt recoveries of a neighboring population)		Y
METHOD #1: Smolt (Marine) Survival = (CWT Harvest + CWT Escapement)/CWT Smolts			
Tag.Code	Coded-wire tag code	Y	
Release.Stage	See Chapter 2 in 2013 PSC Data Standard Work Group Report		Y
Mark.Code	See Chapter 11 in 2013 PSC Data Standard Work Group Report (allows us to identfy DIT groups and exclude cwt release groups with unusual fin clips)	Y	
Release.No	Number of fish with specific coded-wire tag code released	Y	

Adjusted.Rel.No	Number of coded-wire tags released corrected for tag loss and mortality	Y	
Fishery.n	Total number of CWT tagged jacks and adults observed in the catch (all fisheries combined)		
Fishery.No	Estimated total number of CWT tagged jacks and adults in the catch (all fisheries combined)		
Fishery.Age.2.n	Number of CWT tagged jacks observed in the catch (all fisheries combined)		
Fishery.Age.2.No	Estimated number of CWT tagged jacks in the catch (all fisheries combined)		Y
Fishery.Age.3.n	Number of CWT tagged adults age-3 observed in the catch (all fisheries combined)		
Fishery.Age.3.No	Estimated number of CWT tagged adults age-3 in the catch (all fisheries combined)	Y	
Fishery.Age.4.n	Number of CWT tagged adults age-4 observed in the catch (all fisheries combined)		
Fishery.Age.4.No	Estimated number of CWT tagged adults age-4 in the catch (all fisheries combined)		Y
Escapement.n	Total number of CWT tagged jacks and adults observed in the escapement		
Escapement.No	Estimated total number of CWT tagged jacks and adults in the escapement		
Escapement.Age.2.n	Number of CWT tagged adults age-2 observed in the escapement		
Escapement.Age.2.No	Estimated number of CWT tagged adults age-2 in the escapement		Y
Escapement.Age.3.n	Number of CWT tagged adults age-3 observed in the escapement		
Escapement.Age.3.No	Estimated number of CWT tagged adults age-3 in the escapement	Y	
Escapement.Age.4.n	Number of CWT tagged adults age-4 observed in the escapement		
Escapement.Age.4.No	Estimated number of CWT tagged adults age-4 in the escapement		Y
Comments	Qualifications or comments on data issues associated with CWT data, smolt release, fishery data, escapement data		Y
METHOD #2: Smolt (Marine) Survival = (Adult Escapement/(1-Exploitation Rate))/Smolts			
Smolt.No	Total number of smolts	Y	
Smolt.Method	Method for deriving smolt numbers (e.g., counted at weirs, estimated from smolt traps, trap & haul release around dams)		Y
Adult.No	Total number of adults (non-jacks) in escapement	Y	
Adult.Age.2.No	Total number of jacks in escapement		Y
Adult.Age.3.No	Total number of adults age-3 in escapement		Y
Adult.Age.4.No	Total number of adults age-4 in escapement		Y
Escape.Method	Escapement codes in Chapter 12 of 2013 PSC Data Standards Manual		Y
Exploitation.Rate	Fishing mortalities/(Fishing mortalities + escapement)	Y	
ER.Method	Backwards FRAM, Mixed Stock Model, Combination, Other		Y
Comments	Qualifications or comments on data issues associated with smolt estimates, adult estimate, exploitation rates		Y