SALISH SEA
MARINE SURVIVAL PROJECT

Puget Sound Research Plan Version 1

2014-2015 Research Details

Working Document – December 27, 2014

Prepared by the US Salish Sea Technical Team and contributing authors (see reverse)

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EXECUTIVE SUMMARY

The Salish Sea Marine Survival Project is a $20 million dollar, multi-disciplinary, ecosystem-based research effort to determine the most significant factors affecting juvenile salmon and steelhead survival in the Salish Sea. It is the largest and most important research of its kind in the shared waters of British Columbia and Washington State, addressing a key uncertainty impeding salmon recovery and sustainable fisheries. The project is coordinated by nonprofits, Seattle-based Long Live the Kings (LLTK) and Vancouver-based Pacific Salmon Foundation (PSF), and involves over 150 scientists and technical staff from over 40 Federal and State agencies, Tribes, academia, and nonprofit organizations. It was initiated in response to significant declines in Chinook, coho and steelhead marine survival relative to other regions in the pacific northwest; apparent changes in the Salish Sea marine ecosystem over the same time period; and increasing evidence that overall marine survival is largely dependent upon the growth and mortality rates of juvenile salmon after they first enter the marine environment.

We appreciate the complexity of ecosystems: how multiple factors may be interacting and contributing to the fate of juvenile salmon and steelhead in the Salish Sea. To address this, beginning in 2012, scientists from the U.S. and Canada were convened to develop a comprehensive, multi-disciplinary, and highly coordinated research program at an ecologically relevant scale – the entire Salish Sea.

The result is a five-year (2014-2018), intense research phase where scientists are:

- Tracking salmon and steelhead and examining their condition as they swim through the Salish Sea to the Pacific Ocean.
- Simultaneously analyzing the physical (weather and water conditions) and biological (plankton) characteristics of the Salish Sea, the cornerstone of the marine ecosystem, driving what is available for juvenile salmon to eat.
- Honing in on critical growth periods for salmon to develop a precise understanding of the factors affecting growth.
- Performing targeted studies of contributing factors such as: predation by marine mammals and other fish; competition between hatchery, wild, and other fish; and diseases and toxic chemicals.
- Using existing and new data to analyze and model relationships between salmon and their ecosystem, to evaluate the interaction over time.of multiple factors and build back to the mechanisms ultimately driving survival

Outcomes from this extensive international effort will be instrumental in informing and prioritizing hatchery, harvest, habitat and ecosystem management decisions to increase sustainable fishing opportunities and advance the recovery of ESA-listed salmon, steelhead and southern resident killer whales. Ultimately, we will determine whether the causes of weak Chinook, coho and steelhead survival are local (runoff, marine mammal management, habitat availability, hatchery production, etc.) or global (climate change, ocean acidification, ocean cycles). Local impacts will result in recommendations to improve the Salish Sea ecosystem, whereas global impacts will result in recommendations to adapt to our changing environment.

<u>This report</u> describes the Salish Sea Marine Survival Project and details the Puget Sound research activities. Activities relevant to Chinook and coho are described in greatest detail. Activities specific to

Puget Sound steelhead are summarized in this report and described in detail in the partnering report, Puget Sound Steelhead Marine Survival Research Work Plan (2014)[1].

The report primarily focuses on the Puget Sound research activities occurring during first two years of the proposed five-year research phase. To date, 35 activities (nearly all are individual studies) across 15 categories have been proposed. Of these, 19 have been implemented. The thought structure and evidence supporting the research proposed in this report is described in as sister document, the Hypotheses and Preliminary Research Recommendations for Puget Sound (2012) [2]

This is a working document. Revisions to and prioritization of the U.S. research activities described in this report is ongoing and dependent upon funding, alignment with Canadian activities and priorities, proper sequencing, etc. The focus has been on implementing the research activities that address priorities identified by the Advisory Panel of the 2012 U.S.-Canada Salish Sea Research Planning workshop[3], establish the backbone of the research project (e.g., bottom-up sampling program and marine survival trends analyses), and/or are cost effective NOW due to significant existing match: in partnering funds, and in in-kind effort primarily from tribal and state participants contributing to fish and zooplankton sample collection. Research planning will continue over the five-year research phase, with the results of this initial work informing next steps.

$4.8 million of the $10 million dollars required for Puget Sound research has been pledged or raised to date. $2.65 million of the U.S. funding is from the Pacific Salmon Commission's Southern Endowment Fund, $800,000 from Washington State, and $300,000 from NOAA, directed internally to pay for some of their staff contribution to this effort. An additional $800,000 in competitive grants was raised in 2013; however, another $450,000 requested was declined. This has resulted in delays to the completion and implementation of some aspects of this plan. As reflected in the budget, significant cost sharing ($8.1 million) is also occurring from the agencies, tribes and other organizations involved.

Fundraising continues. The plan for the remaining funds needed ($5.2 million) includes a combination of competitive grants (another $550,000), federal agency budget line items ($2.2 million NOAA and USGS), Washington State appropriations (another $1.2 million) and private money ($1.5 million) from foundations, corporations and individuals. Some of the proposed research activities serve Puget Sound ecosystem recovery research needs beyond the scope of this project. And, other research activities are expected to become long-term monitoring programs for ecosystem recovery and salmon adult return forecasting. For these activities with broad utility and/or long-term value, we will look beyond the funding resources identified to support them.

The table on the following 2 pages summarizes the Puget Sound research activities, timeline, and budget. The last three years are roughly planned, based on discussions to date, and will be dependent upon information gained as the project progresses. Next steps category funding is applicable to studies in concept phase. **Legend:** Active, Pending, Concept

*Color shade reflects the level of intensity for each activity: light = less, dark = more.
**Funded = Does not include additional ~1.4 million Pacific Salmon Commission Southern Endowment funds pledged in future years and not yet allocated.

[1] Available at: www.marinsurvivalproject.com.

[2] Available at: www.marinsurvivalproject.com.

[3] The Advisory Panel prioritized sampling the fish themselves to determine what story they tell us about limitations to their survival. From there, they recommended building out to a better understanding of the ecosystem around them. For the report and additional information, goto: www.lltk.org/SSMSPworkshop.

Salish Sea Marine Survival Project **Puget Sound Research Activities - continued** w/ focus on 2014-2015	Status (color coded)* & Timeline, 201-					Funded**	Remaining Cost	In Kind
Bottom-Up Sampling Program - *Evaluate critical growth periods for juvenile Chinook and coho, and relevant Puget Sound physical & biological characteristics during those growth periods. - Integrated U.S. - Canada*	*4*	*5*	*6*	*7*	*8*	**$1,430,000**	**$1,040,000**	**$7,160,000**
1. Juvenile Chinook & coho salmon - Determine where critical growth periods are & factors affecting growth & survival (prey, water quality, competition, predation by other fish)						$1,075,000	$725,000	$5,550,000
2. Zooplankton - Establish a Puget Sound-wide zooplankton sampling program to assess the salmon prey field & establish ecosystem indicators to evaluate change over time.						$295,000	$240,000	$410,000
3. Physical characteristics & phytoplankton production - Upgrade the three ORCA buoys in Puget Sound so they can collect surface wind & solar information. Provide support to NANOOS for data provision and management.						$60,000	$75,000	$1,200,000
Bottom-Up: Individual Studies- *Hone understanding of growth and build out to funamental drivers of growth.*						**$90,000**	**$575,000**	
4. Investigate life history, age, and growth of adult puget sound salmon using otolith microchemistry and scale morphometrics						$90,000	-	-
5. Calibrate techniques for estimating growth - Calibrate multiple growth analyses techniques (otolith, scale, IGF) used for evaluating growth						part of 1 &4	-	-
Next Steps (2016 & Beyond)							$575,000	-
Top-Down Studies - *Targeted studies of potential contributing factors (disease, predation, toxics, aquaculture impacts , etc). Process studies to compliment sampling program & build out to fundamental drivers of survival.*						**$990,000**	**$2,495,000**	**$825,000**
6. Puget Sound steelhead early marine survival research - Includes 11 studies, described in affiliated "Puget Sound Steelhead Marine Survival Research Work Plan" (2014) @ www.marinesurvivalproject.com						$790,000	$1,080,000	$800,000
7.Pathogens, in particular Nanopheytus, as contributing factors - Evaluate nanopheytus in steelhead, and build out to broader disease profiling once new techniques are fully developed by K. Miller-Saunders in Canada						in steelhead	$275,000	-
8. Contaminants as contributing factors - Complete the contaminants profile of outmigrating juvenile Chinook. Samples collected during mid-water trawls will be processed & added to lower river & estuary samples. Profile outmigrating juvenile steelhead. Perform any followup necessary.						$170,000	$150,000	$25,000
9. Effect of Salish Sea residency on the marine survival of Puget Sound Chinook & coho - Use toxics signatures & otolith microchemistry or carbon isotopes to discriminate between resident & migratory life						$30,000	$190,000	-
10. Hydroacoustic-midwater trawl survey - Night surveys to assess competition between salmon & forage fish, & the buffer effects of forage fish on predation						-	-	-
11. Harmful algae impacts - Improve sampling effort & perform a direct evaluation of impacts to juvenile						-	-	-
Next Steps (2016 & Beyond)							$800,000	-

Salish Sea Marine Survival Project **Puget Sound Research Activities - continued** w/ focus on 2014-2015	**Status (color coded)* & Timeline, 201-**	**Funded****	**Remaining Cost**	**In Kind**
Trend Analyses & Modeling *- Platform for comprehensive data analyses for the entire project. Combine factors & build out to fundamental survival drivers. Integrated U.S. - Canada*		**$480,000**	**$1,390,000**	**$150,000**
12. Salmon and steelhead survival trends - Evaluate long-term survival trends for Chinook, coho and steelhead. Formalize for use in correlative analyses.		$100,000	$30,000	$45,000
13. Life-history characteristics relative to survival				
13.1 Life-history characteristics & outmigrant abundance - Evaluate long-term data sets of life-history characteristics & correlations w/ survival. .		-	$60,000	$20,000
13.2 Life-cycle modeling & freshwater capacity effects - Model outmigrant life-history & evaluate potential freshwater density dependent effects		$125,000	-	$15,000
14. Ecosystem indicators relative to salmon survival		-	-	-
14.1. Developing ecosystem indicators to inform geographic variation in marine survival rates - Establish & manage data, evaluate/model metrics for correlations w/ survival, individually & combined. Inc. past data from activities 14.2-5 & new from 1-11.		$55,000	$435,000	-
14.2. Zooplantkon time series - Process/analyze Puget Sound's only long-term (2003-14) quantiative dataset (JEMS).		$30,000	-	-
14.3 Retrospective zooplankton sample analysis - Process & evaluate additional samples from 2011, compare to 2014+ and correlate with salmon survival.		-	$35,000	-
14.4. WDFW zooplankton dataset - Compile & assess 30 year, qualitative, presence/absence data set.		$15,000	-	-
14.5. Analyze long-term stratification datasets as a proxy for primary production - Correlative analyses & ecosystem modeling improvements.		-	$45,000	-
14.6. - 14.7 Analyze phytoplankton production rates, timing, & variability to assess inter-annual & inter-basin variation - Correlative analyses & ecosystem modeling improvements.		$95,000	$105,000	-
15.1- 15.2 End-to-end, spatiotemporal ecosystem model for Puget Sound & potentially the greater Salish Sea - Current proposal to establish an Atlantis model for Puget Sound; however, working w/ the Canadians to formalize best approach Salish Sea wide. Early focus is on manipulating existing EwE (1.51) & NPZ component (see 14.7).		$60,000	$340,000	$70,000
Next Steps (2016 & Beyond)		-	$340,000	-
Contingency		**$5,000**	**$35,000**	
Data Management			**$165,000**	
Project Coordination, Communications, Fundraising		**$480,000**	**$920,000**	
		$3,475,000	**$6,620,000**	**$8,135,000**

BACKGROUND AND OVERVIEW

Changes in the Salish Sea are thought to be significantly affecting the abundance of our region's salmon and steelhead.

1. Chinook, coho and steelhead survival in the marine environment—from juvenile smolts to returning adults--has declined up to tenfold since the 1980s. The survival of coastal and Columbia River populations has varied since the 1980's but does not follow the same overall declining trend.[4]
2. 80% of juvenile steelhead die in Puget Sound on their way to the Pacific Ocean.[5]
3. The early marine phase, as juveniles in the Salish Sea, is generally considered one of the most critical periods for salmon and steelhead, where they are known to experience some of their most rapid growth and highest mortality rates.
4. Data suggest the Salish Sea ecosystem has changed dramatically over the past 30 years, including increased water temperatures, increased acidity, the demise of the Fraser River eulachon and cherry point herring populations, less kelp and eel grass, more pink salmon, more harmful algae, more jellyfish and *noctiluca* (food web junk food), more harbor seals and porpoises… the list goes on.

The interaction between salmon and the Salish Sea is complex; while there exists a solid understanding of the factors affecting salmon survival in freshwater, our collective intelligence about salmon in the marine environment is limited. Addressing factors that affect survival and driving real, lasting recovery of the species will require a much more detailed and complete understanding of how salmon and steelhead interact with the physical, chemical and biological characteristics of the Salish Sea.

The Salish Sea Marine Survival Project is a five-year (2014-2018) international research effort that leverages human and financial resources from the United States and Canada to determine the most significant factors affecting the survival of juvenile salmon and steelhead in the Salish Sea marine environment. It is the largest and most important research of its kind in the shared waters of British Columbia and Washington State, addressing a key uncertainty impeding salmon recovery and sustainable fisheries.

Seattle-based Long Live the Kings (LLTK) and Vancouver-based Pacific Salmon Foundation (PSF) are managing this significant international research effort: developing the project as a whole, coordinating research activities and managing funding[6], ensuring appropriate alignment throughout the Salish Sea, establishing and maintaining project outreach and communications, and working to create the necessary funding mechanisms for the length of the research effort.

Beginning in 2012, LLTK and PSF convened federal, state, tribal and academic scientists from multiple disciplines to develop a comprehensive and highly coordinated ecosystem-based research program.

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[4] Decline of Salmon and Steelhead Marine Survival in the Salish Sea, www.marinsurvivalproject.com.

[5] Figure 11. Puget Sound Steelhead Marine Survival Workgroup. 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA.

[6] Portions of some of the research activities are funded directly via other sources (will be described in December 2014 reporting)

Preliminary recommendations were established for Puget Sound by the U.S. Salish Sea Technical Team (scientists listed at end of document) and for the Strait of Georgia by a PSF science team. Then, in November 2012, a workshop with 90 participants and a 15 member advisory panel (including experts in the field working in the Gulf of Alaska and Columbia River Plume/California Current) was held to review the recommendations and receive feedback from the broader scientific community regarding the critical elements of a US-Canada research program.

This report describes the Salish Sea Marine Survival Project and details the Puget Sound research activities. The report primarily focuses on the first two years of the proposed five-year (2014-2018) research phase: concentrating on developing the backbone of the research project, including the data analysis framework and core, bottom-up sampling program that focuses on understanding juvenile salmon growth and their association with the physical and biological (plankton) characteristics that are the cornerstone of the Salish Sea ecosystem. These are also the research areas that require the greatest functional alignment between U.S. and Canada. The initial focal areas are based upon recommendations from the 2012 U.S.-Canada Salish Sea Research Planning workshop[7]. Other research activities under consideration are also discussed; however, the details of those activities are not as complete.

Please note: this document can be read as a stand-alone report. However, the basis for these research recommendations are embedded in affiliated documents for the Salish Sea Marine Survival Project, primarily The Hypotheses and Preliminary Research Recommendations for Puget Sound.

All affiliated reports are available on the resources page of www.marinesurvivalproject.org. They include:

1. Salish Sea Marine Survival Project: US-Canada Alignment Plan (forthcoming)
2. Next Steps for US-Canada Alignment: 2013 Salish Sea Research Planning Retreat Report (2014)
3. Puget Sound Steelhead Marine Survival Research Work Plan (2014)
4. The Results and Recommendations of the Salish Sea Marine Survival Research Planning and Ecosystem Indicators Development Workshops (2013)
5. The Hypotheses and Preliminary Research Recommendations for Puget Sound (2012)
6. Strait of Georgia Chinook and Coho Research Plan (2009)

[7] www.lltk.org/SSMSPworkshop

STUDY DESIGN

Project Objective

The main objective of the Salish Sea Marine Survival Project is to determine the primary factors affecting juvenile salmon and steelhead survival in the Salish Sea marine environment. The proposed work is solutions oriented, intended to systematically:

- identify or help **prioritize hatchery, harvest, habitat and ecosystem management actions to increase the survival** of Salish Sea wild and hatchery salmon and steelhead (including Endangered Species Act (ESA) listed Puget Sound Chinook and steelhead)
- **improve adult salmon and steelhead return forecasting** and, thusly, natural spawning, harvest, and hatchery management; and
- help us **more accurately evaluate the success of freshwater habitat restoration and hatchery activities** by reducing uncertainty around the role of the marine environment in overall productivity.

Ultimately, the research results and subsequent management actions may also benefit other marine life in the Salish Sea food web, such as ESA-listed southern resident killer whales.

From a research perspective, this collaborative, multidisciplinary, ecosystem-based effort will improve information sharing, promote data standardization, and implement simultaneous data collection by integrating existing and proposed research and monitoring efforts into a comprehensive and hypothesis driven framework at an ecologically relevant scale – the entire Salish Sea.

Scope

Because the interaction between salmonids and the Salish Sea is complex, this issue will be approached from an ecosystem context, utilizing experts from multiple disciplines. Chinook, coho and steelhead[8] are the species of greatest concern given their significant declines in smolt (outmigrant)-to-adult survival (the primary indicator of marine survival) since the 1970s. However, chum, pink and sockeye will be included to the extent practicable in the research plan given potentially shared survival drivers; interspecies interactions; that future research methods can evaluate multiple species; and the recent, extraordinary variation in survival of these salmon species and its effects on fisheries management. The focus is principally on issues affecting juvenile salmon and steelhead survival while they are in the Salish Sea, from the river deltas to the open ocean: spatially and temporally ranging downriver of traditional freshwater monitoring locations (e.g., smolt traps, hatcheries) to the point where and time when salmon and steelhead leave the Salish Sea. The resident life-history component of specific salmon species may also be investigated as these fish stay within the Salish Sea through adulthood. Understanding the condition of fish entering the Salish Sea marine environment will be included to determine whether impacts occurring prior to their marine residence are reducing survival in the Salish Sea. However, it will

[8] Steelhead are addressed in the report titled "Puget Sound Steelhead Marine Survival Research Work Plan". Chinook and coho are the primary focus of this document, although overlap with the steelhead work is indicate where it exists.

more difficult to determine whether impacts occurring in the Salish Sea are reducing survival in the Pacific Ocean. Factors that don't appear to be driving survival will also be documented as both pieces of information will help inform management decisions.

Geographic Range

The geographic range of this project includes the entire Salish Sea, the body of water that extends from the north end of the Strait of Georgia and Desolation Sound to the south end of the Puget Sound and west to the mouth of the Strait of Juan de Fuca, including the inland marine waters of southern British Columbia, Canada and northern Washington, United States[9] (Figure 1)[10].

Figure 1. Topographic map of the Salish Sea

This research proposal reflects the work of the US Salish Sea Technical Team (herein referred to as the Technical Team) and focuses on the U.S. waters of the Salish Sea. This includes the entirety of Puget Sound and the portions of the Strait of Juan de Fuca and the Southern Strait of Georgia within the borders of the U.S.[11] For the purposes of this report, we will refer to this entire area as Puget Sound since contemporary resource management efforts also reference the entire area as such[12].

Sub-basins of Puget Sound

The Puget Sound study area encompasses up to seven sub-basins that reflect somewhat distinct domains of varying geology, tidal hydrology, physiography, and oceanography settings in Puget Sound (Simenstad 2011) (See figure 2, below). The basin designations are based upon the work of the Puget Sound Nearshore Ecosystem Restoration Partnership (PSRNERP). They were used because each basin encapsulates distinct physical processes in the nearshore and offshore, and because the basin designation correlates well with the geographic regions of diversity established for ESA-listed Puget Sound Chinook (Ruckelshaus et. al. 2002) and the major population groups established for ESA-listed

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[9] http://staff.wwu.edu/stefan/SalishSea.htm

[10] Figure from, http://www.newrelationship.gov.bc.ca/success_stories/aboriginal_gov_relations.html

[11] It should be noted that some of the research recommendations, such as those for Harmful Algae (hypothesis 9) extend beyond the US waters of the Salish Sea, and most all of the research recommendations could be considered in a broader geographic context.

[12] See the Puget Sound Partnership maps at http://www.psparchives.com/resources/maps.htm, and the ESA-listed Puget Sound Chinook salmon, summer chum, & steelhead ESU maps at http://www.nwfsc.noaa.gov/trt/puget.cfm.

Puget Sound steelhead (Hard et. al. 2012). And, this aligns with Puget Sound Partnership Action Areas http://www.psp.wa.gov/aa_action_areas.php.

While all sub-basins are included to some extent, a majority of the work will occur in South Puget Sound, South Central Puget Sound, Whidbey Basin, North Central Puget Sound and the San Juan Islands and Georgia Strait.

Puget Sound Sub-basin Map - courtesy of PSNERP 2012

Timescale and General Study Approach

The primary impetus for this research is the unique, long-term downward marine survival and abundance trends of Chinook, coho, and steelhead that have occurred between the 1970s and the present. This trend differs from the more frequent variability in marine survival and abundance of Chinook, coho and steelhead populations from the outer coast and the Columbia River basin (see the 2012 hypotheses and preliminary recommendations report). Therefore, a retrospective element will be present in this effort. The Technical Team is also concerned about future impacts in response to looming issues such as climate change and ocean acidification. However, the Technical Team proposes to largely implement a mechanistic approach to evaluating the factors that may be affecting salmon and steelhead survival in the present, with the assumption that the information gained from this approach can both explain current situation but also be attributed to past and future situations via modeling, process studies and retrospective analyses.

General research framework

Three research categories have been established for the entire Salish Sea Marine Survival Project to organize the U.S. & Canadian research that will occur over a 5-year (2014-2018), intensive study period:

1. Bottom-up Sampling Program and Individual Studies
2. Top-down Studies
3. Trend Analyses and Modeling

Retrospective studies, modeling, process studies, and experiments are imbedded in this research structure, founded on other large-scale, ecosystem-based, interdisciplinary research programs such as the Global Ocean Ecosystem Dynamics (GLOBEC) initiative, the estuarine and ocean salmon research program design proposed by Brodeur et al. (2000), and the subsequent Columbia River basin juvenile salmon marine ecology program (Jacobsen et. al. 2012). This research structure was also appropriately influenced by PSF's 2009 Strait of Georgia Chinook and Coho Proposal.

This report covers the first two to three years of the proposed five-year (2014-2018) research phase: concentrating on developing the backbone of the research project, including the data analysis framework and core, bottom-up sampling program that focuses on understanding juvenile salmon growth and their association with the physical and biological (plankton) characteristics that are the cornerstone of the Salish Sea ecosystem. These are also the research areas that require the greatest functional alignment between U.S. and Canada. The initial focal areas are based upon recommendations from the 2012 U.S.-Canada Salish Sea Research Planning workshop. Other process studies and experiments under consideration are also discussed; however, the details of those activities are not as complete.

Research planning will continue over the five-year research phase, with the results of this initial work informing next steps. Revisions to and prioritization of the U.S. research activities described in this report is ongoing and dependent upon funding, alignment with Canadian activities and priorities, proper sequencing, etc. Some of the research described in this report will begin in 2014, while other work will occur in later years.

As research is completed over the course of the 5-year intensive research effort, the research results will be disseminated and communicated to managers. And, the final year of the project will be used to convert the research results into general conclusions and management actions. The Technical Team envisions the results of this intensive research approach will provide the mechanistic framework for what factors should be monitored over the long-term to help achieve wild fish recovery and maintain sustainable fisheries in addition to helping identify specific management actions to improve marine survival. The research structure and its results will also feed into monitoring and adaptive management planning proposed for ESA-listed Chinook (and, likely steelhead and summer chum in the future)[13]. In this manner, the research effort helps fulfill the needs of ecosystem-based management and recovery efforts being developed and implemented for Puget Sound and the Strait of Georgia[14].

All efforts are highly collaborative—involving federal, state, tribal, academic and nonprofit staff—and will be coordinated intensively at the U.S. – Puget Sound level and broadly with the Canadian efforts, guided by the November 2012 workshop summary report that identifies the critical elements of the U.S. – Canada, Salish Sea research program. One important relationship is with the Puget Sound Ecosystem Monitoring Program (PSEMP), a coordinated monitoring program designed to evaluate progress towards ecosystem recovery and to serve as a foundation to continually improve the scientific basis for

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[13] As described in the draft April 2012 NOAA Technical Memorandum, "A Common Framework for Monitoring the Recovery of Puget Sound Chinook Salmon and Adapting Salmon Recovery Plans" produced by the Puget Sound Recovery Implementation Technical Team and their support staff (Puget Sound Recovery Implementation Technical Team 2012).

[14] Sustainable recreational and commercial fishing and the recovery of wild Chinook and southern resident killer whales have been identified as 4 of the 21 indicators of Puget Sound ecosystem recovery by the Puget Sound Partnership (http://www.psp.wa.gov/vitalsigns/index.php).

management actions in Puget Sound[15]. For a complete description of the U.S. – Canada collaborative aspects of this project, please refer to the report titled, "Overview of Proposed U.S. and Canadian Activities".

Conceptual Framework and Hypotheses

Conceptual Framework

The U.S. Technical Team established a conceptual framework and assumptions as part of a hierarchical process to lay the foundation for the research plan. The framework identifies, organizes by level, and describes general associations among the factors that could be affecting salmon and steelhead survival. The U.S. Technical Team used an organizational schema that illustrates different categories/levels of biological reference: Ecosystem, Community, Population, and Individual. These differ from the top-down and bottom-up categories used to generally describe ecosystem interactions (and used by the Canadians in their original 2009 Strait of Georgia Chinook and Coho Proposal); therefore, the U.S. Technical Team has incorporated the top-down, bottom-up nomenclature in their research descriptions to ensure synchronicity between U.S. and Canada. For more information about the original U.S. conceptual framework and assumptions, please see, the Hypotheses and Preliminary Research Recommendations for Puget Sound (2012).

Primary Hypotheses

At a high level, the hypotheses driving the Salish Sea research effort are, in order of significance:

A. Bottom-up processes —including weather, water, and plankton—that drive Chinook, coho and forage fish prey availability have changed, and salmon aren't able to compensate.

B. Top-down processes have changed, predominantly affecting steelhead, resident Chinook and coho , and larger forage fish. Predation is the direct cause of mortality, but fish condition (or the condition of their surrounding environment) may be compromised, increasing their susceptibility to predation.

C. Additional factors are exacerbating these ecological shifts, including toxics, disease, and the compounding effect of significant top-down and bottom-up shifts occurring simultaneously.

Could the causes of mortality be shared among species in the Salish Sea?

Yes, the shared patterns of declining marine survival rates for Chinook, coho and steelhead suggest that their survival could fundamentally be dictated by similar factors. However, the pathways to affecting the survival of each species could be different. For example, changes to the timing and abundance of zooplankton (prey) may be negatively affecting Chinook salmon and steelhead in different ways. Chinook salmon may be directly responding to a change in zooplankton availability by starving, increasing their susceptibility to disease, toxics substances and/or predation. Alternatively, steelhead may be indirectly responding to changes in zooplankton production. If herring, which prey on zooplankton, also decline and subsequently aren't available for predators to eat, those predators could target steelhead more. This logic could be extended to explain similar declines in other fish species in the Salish Sea, including herring, eulachon, pacific hake, pacific cod and rockfish.

[15] http://www.psp.wa.gov/MP_monitoring_program.php

The research will result in action-oriented management recommendations. We will build out from these hypotheses to determine whether the causes of weak Chinook, coho and steelhead survival are locally (e.g., runoff, wastewater, marine mammal management, habitat availability, hatchery production) or globally driven (climate change, ocean acidification, ocean cycles). Local impacts will result in recommendations to improve the Salish Sea ecosystem, whereas globally driven impacts will result in recommendations to adapt to our changing environment.

Puget Sound Operational Hypotheses

The 14 hypotheses the U.S. Technical Team developed to determine the most significant factors affecting the survival of salmon and steelhead in Puget Sound are described below and organized by research function and levels of the original Puget Sound conceptual framework. **These remain an operational framework for Puget Sound research and are referenced in the research activities descriptions following this section.**

Where and when is survival most affected?

1. Marine survival does a better job than freshwater survival in explaining productivity trends of salmon and steelhead in the Salish Sea
2. Ecosystem and community factors affecting salmon and steelhead survival are operating at different levels by area encountered, species, hatchery v. wild, and within species, by life history
3. Size-selective mortality is an important process regulating survival at one or more life stages of salmon and steelhead: Larger body size at certain life stages confers higher survival to adulthood (includes smolt size/condition at marine entry).

Individual and Population Factors

4. Outmigration timing influences the magnitude effect of competition, predation, and environmental variation on survival in the Salish Sea (match-mismatch).
5. Resident-type behavior and the duration of residence influences survival in the Salish Sea.
6. Through a process known as the portfolio effect, diversity among salmonid populations confers temporal stability and long-term persistence of the species within the Salish Sea.

Ecosystem Factors

7. Circulation and bottom-up processes hypothesis: Changes in circulation and water properties have altered phytoplankton and zooplankton production in ways that degraded salmon food-webs in the Salish Sea from the 1970s to 2000s (bottom-up effect).
8. Increased $C0_2$ concentrations indirectly affect salmon survival or increase their susceptibility to other sources of mortality (bottom-up or top-down effect).
9. Harmful algae directly affect salmon survival through acute or chronic mortality and may adversely affect prey availability by food web impoverishment (bottom-up or top-down effect).

10. Reduced habitat availability and/or diversity have affected the behavior (and reduced the diversity) of salmon while in the Salish Sea (top-down effect).
11. Toxic contaminant inputs have increased, affecting marine survival of salmon through reductions in growth and resistance to disease (top-down effect).

Community Factors[16]

12. Food supply limits growth, and thus survival, during critical periods of early marine rearing (Insufficient supply, mismatch, competition) (bottom-up effect).
13. Predation by larger fish and marine mammals has increased on salmon and steelhead, respectively. And, the potential effect of bird predation represents a significant knowledge gap (top-down effect).
14. Infectious and parasitic diseases are causing direct and indirect mortality (top-down effect).

Note that determining the impact of multiple factors influencing survival simultaneously[17] and determining the role of local human-induced pressures vs. larger ecological shifts is embedded in these hypotheses and the research activities used to address them. For a detailed description of the evidence supporting each of these hypotheses, see the Hypotheses and Preliminary Research Recommendations for Puget Sound (2012).

Guide to the Following Research Activities Descriptions

The research activities are described in the following sections. They are categorized based upon the general research framework described in the blue box of the "Timescale and General Study Approach" section, above. The activities also include dialog boxes illustrating which salmon species they focus on, and which of the Puget Sound operational hypotheses (describe above) they address. The cost and status of each activity is described in the "**Project Timeline, Budget, & Activity Status**" section near the end of this report. Additional detail about several of the research activities is provided in "**Appendix 1: Complete descriptions of research activities**". Also, all references are fully cited in each research activity section of Appendix 1.

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[16] Another hypothesis, reduced forage fish abundance may have increased the potential for predation of juvenile salmon and steelhead (aka. reduced buffer effect of forage fish), was discussed after the list was complete.

[17] As interactions between salmon and the Salish Sea are complex, part of the research process will be understanding which factors are more significant, whether they have synergistic or compounding effects, how factors interrelate and which factors are proximate/direct vs. root/fundamental causes of mortality. For example, limited food supply may be fundamentally driven by eutrophication.

Bottom-Up Sampling Program

Bottom-up processes—including weather, water, and plankton—drive what is available for juvenile salmon and steelhead to eat. A sampling program will be implemented in an integrated fashion in Puget Sound and the Strait of Georgia. This Salish Sea-wide sampling program will examine the condition of salmon and steelhead as they outmigrate while simultaneously evaluating the physical and biological (plankton) characteristics of the Salish Sea: the cornerstone of the marine ecosystem. This includes identifying critical growth periods for salmon and understanding the primary factors affecting growth during those periods.

The sampling program builds out from specific watersheds within Puget Sound and the Strait of Georgia. In Puget Sound, it is the Nisqually, Snohomish, Skagit and Nooksack watersheds. The U.S. is also utilizing the capacity of their large co-management structure combined with academic and federal Principal Investigators to man the salmon and zooplankton sampling activities, and the existing buoy and water quality sampling network managed by the University of Washington and Department of Ecology to capture the physical properties of Puget Sound.

1. Juvenile salmon: Diagnosing critical growth periods

Principal Investigators: Dave Beauchamp (U. of Washington), Josh Chamberlin (NOAA), Julie Keister (U. of Washington). Collaborators for sample collection: Nisqually Indian Tribe, Tulalip Tribes, Skagit River System Cooperative, Lummi Nation, Kwiaht, LLTK, City of Bellingham

This study will evaluate the role and drivers of juvenile, size-selective mortality as it relates to the overall marine survival of ESA-listed Puget Sound Chinook and Puget Sound coho salmon. This will be done by: a) identifying the critical periods of growth and associated habitats; and b) determining whether temperature, food supply, energetic quality of food, or competition are the primary factors limiting growth. The work will be performed over the course of the juvenile Chinook and coho outmigration period (March through October). Fish will be collected from four watersheds (Nisqually, Snohomish, Skagit, Nooksack) in the lower river, estuary, nearshore and offshore via a massive collaborative effort. Scale analyses and bio-energetics models will be used to evaluate growth and factors limiting growth.

Species: Chinook and coho

Operational Hypotheses:

(2) Factors operate at diff. levels by region, life-history, etc.
(3) Size-selective mortality
(4) Outmigrant timing (match-mismatch)
(7) Circulation patterns affect bottom-up processes / fish behavior
(12) Prey availability (Insufficient supply, mismatch, competition)
(13) Predation by fish (to some extent)

2. Zooplankton: Establishing a Puget Sound-wide zooplankton sampling program

Principal Investigator: Julie Keister (U. of Washington), with substantial coordination from multiple parties in Puget Sound, including: Tulalip Tribes, Nisqually Indian Tribe, King County, Port Gamble

S'Klallam Tribe, Lummi Nation, Squaxin Tribe, KWIÁHT, NOAA Fisheries, and other U. of Washington affiliates

This research activity will establish a zooplankton sampling program to:

1) Estimate the temporal-spatial availability of key zooplankton prey for juvenile Chinook and coho by depth strata in offshore regions of Puget Sound through the spring-summer growth period.
2) Contribute to the development of Ecological Indicators of salmon survival in Puget Sound. Data generated by sampling throughout Puget Sound will be compared to salmon growth and growth-survival time series to explore spatial and seasonal relationships between prey availability and survival. Samples collected by NOAA in 2011, in the 1970s by Bruce Frost (UW), and diet data conducted by D. Beauchamp (USGS) in 2001-2002 and in 2001-2013 in some Puget Sound sub-basins, will be compared to salmon SARs as a baseline.

Species: Chinook and coho, potentially other species

Operational Hypotheses:

(2) Factors operate at diff. levels by region, life-history, etc.
(3) Size-selective mortality
(4) Outmigrant timing (match-mismatch)
(7) Circulation patterns affect bottom-up processes / fish behavior
(12) Prey availability (Insufficient supply, mismatch, competition)

Sampling will occur bi-weekly from March through October, over the juvenile salmon outmigration period. This is another massive collaborative effort, involving eight different entities collecting zooplankton samples throughout Puget Sound.

3. Physical characteristics and primary production: Upgrading and utilizing the ORCAS buoy network and NANOOS

Principal Investigator: Jan Newton (U. of Washington), John Mickett (U. of Washington)

Species: Chinook, coho, potentially other species

Operational Hypotheses:

(2) Factors operate at diff. levels by region, life-history, etc.
(7) Circulation patterns affect bottom-up processes / fish behavior

The ORCA buoy network (along with the Washington Department of Ecology, King County and other party's buoy data and existing water quality cruises, where appropriate) will be updated and used to document spatial and temporal variability in weather (sunlight, air temperature, and wind), phytoplankton biomass (chlorophyll) and hydrographic features (water column temperature, salinity, density structure, including the mixed layer depths and degree of stratification). These data will contribute to the sampling program in order to evaluate bottom-up control of salmon productivity. The data are also critical for constraining the numerical model that will test the bottom up hypotheses stratification.

Photosynthetically active radiation (PAR) sensors and full weather stations (with surface wind sensors) will be updated on the three ORCAS buoys in Puget Sound proper (near in Central and South Puget Sound). This effort will also work directly with efforts focused on ocean acidification (e.g., new UW ocean acidification program) to ensure that marine carbon chemistry and pH are included in the suite of baseline physical attributes monitored in strategic locations within the Salish Sea. The physical data will be aggregated and managed via the online NANOOS platform. If funding becomes available, one additional ORCA buoy will considered for the network in Puget Sound proper. The locations for new buoys under consideration include Saratoga Passage in Whidbey Basin, Totten Inlet in South Puget Sound Basin, and Bellingham Bay in the Georgia Strait Basin.

Next Steps (2016 & Beyond)

The sampling program will operate for 2 to 4 years, depending upon available funding. If the program runs for more than 2 years, results of the first 2 years of operation will be used to streamline the program. Ultimately, a streamlined version of this type of program, including real-time scale (and otolith) analyses may be deemed critical for stock forecasting and ecosystem evaluation over the long-term. One concept for funding is a cooperative federal, state and tribal pool.

INDIVIDUAL BOTTOM-UP STUDIES

Individual bottom-up studies will be implemented that build off of the sampling program described above. These studies will hone our understanding of salmon growth, the relationship between salmon and their prey, and ultimately build out from the fish and their prey to the factors driving prey availability.

4. Investigating life history, age, and growth of adult Puget Sound salmon using otolith microchemistry and scale morphometrics

Principal Investigator: Lance Campbell (WDFW)

Species: Chinook. Some coho, chum

Operational Hypotheses:

(2) Survival, Marine v Fresh
(3) Factors operate at diff. levels by region, life-history, etc.
(4) Size-selective mortality
(5) Outmigrant timing (match - mismatch)
(6) Genetic & life-history diversity (portfolio effect)

The survival of hatchery Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) within Puget Sound have been linked to geographic location (Hobday and Boehlert 2001, Beetz 2009, Zimmerman et al 2013), ocean conditions and interspecific interactions therein (Ruggerone and Goetz 2004), and early marine growth and release size (Beamish et al. 2004, Duffy and Beauchamp 2011). However, relatively little is known about the early marine growth and survival of wild salmon stocks within Puget Sound. In this study, we will measure juvenile life history parameters (such as size and time of estuary/ocean entry) using otolith chemistry of adult Chinook salmon returning to three geographic regions within Puget Sound (southern, middle, and northern). We will evaluate the hypothesis that diversity of juvenile salmon life histories within Puget Sound differs among regions as a consequence of early ocean survival (task 4.1). Additionally, we will examine the age and marine growth (scale analysis) of selected returning adult Chinook, coho and chum salmon populations in the Salish Sea and Coastal Washington (task 4.2). We will test the hypothesis that interannual variation in early marine growth, and variation in growth among populations effects adult survival. The goal of this research is to: 1) enumerate any differences in age and marine growth among populations and geographic regions and 2) make marine growth data available for survival and forecasting models.

5. Calibrating techniques for estimating growth

Principal Investigators: Dave Beauchamp (UW), Lance Campbell (WDFW), Josh Chamberlin (NOAA), Brian Beckman (NOAA)

This activity is still conceptual and not fleshed out. The intent of this proposal is combine and simultaneously evaluate the variety of approaches currently used for growth analyses to:

- Determine how the results of each approach can be readily compared.

- Determine the most effective approach (or combination of approaches) for performing long-term growth sampling Salish Sea wide, if warranted.

This research activity will likely not involve independent funding. Instead, this will be done as part of the work proposed in research activities 1 and 4. This work will also be done in coordination with Canadian scientists.

Species: Chinook and coho

Operational Hypotheses:

(1) Survival, Marine v Fresh
(2) Factors operate at diff. levels by region, life-history, etc.
(3) Size-selective mortality
(4) Outmigrant timing match - mismatch)
(6) Genetic & life-history diversity (portfolio effect)

A mix of scale, otolith, and Insulin-like growth factor-I (IGF) analyses are used to analyze juvenile salmon growth in research activities throughout Puget Sound and the Strait of Georgia. Each has its strengths and weaknesses. IGF determines growth rates and sampling and analysis is cheaper than otolith analyses. However, IGF only captures a snapshot of growth at the time the sample is collected, sampling is difficult to do in some field situations, and there are little retrospective IGF data available. While otolith analyses don't currently describe growth rates, they do describe stage-specific growth throughout the life of the specimen. Otolith sample sets are more readily available, the samples are more commonly taken in present activities, and, while more expensive than IGF to analyze, there are several labs that can process the samples which may mitigate the cost. Scale sets don't provide as much stage-specific growth resolution as otoliths, but are readily available and likely have the longest historic catalogs. Scale samples also don't result in mortality of the specimens, critical when evaluating ESA listed salmon populations that have severe take/mortality limitations. Scales also cost less to evaluate.

The study approach has not been fleshed out. However, an example approach is determining whether IGF data can be used to develop a method for interpreting growth rates from otolith samples. IGF data could be superimposed on simultaneously collected otolith data to see if patterns emerge.

Next Steps (2016 & Beyond)

Next steps will build upon the activities proposed above. Ultimately, the work will build out from the fish and their prey to the factors driving salmon growth and prey availability, with the focus on determining whether the primary contributing factors are local or global. Examples include state shifts in the microbial food web, increases in temperature, reduced habitat availability, ocean acidification, and runoff and wastewater impacts. Examples of research activities include:

- Better determine the dietary value (energy content and fatty acid composition) for key prey in Puget Sound: zooplankton, ichthyoplankton, and insects. This would be an in-depth evaluation once key prey and nearshore or offshore habitats identified as critical to growth are established. Currently, data from other regions is used to establish the relative dietary value of the prey.
- Studies to determine whether there is a relationship between the availability of primary prey and/or prey selection and growth during critical growth periods for Chinook and coho and observed changes in water quality (increased nitrates, reduced chlorophyll, reduced turbidity)

and in the microbial food web (as indicated by potential increases in *nuctiluca sp.* and harmful algae such as *heterosigma a.*).[18]

- Experiments to determine whether Chinook and coho size and outmigration timing can be better aligned with prey availability.
- Partnership with University of Washington's Washington Ocean Acidification Center to evaluate the impact of acidification to prey in specific areas of Puget Sound identified as critical for growth and survival.

[18] Trends Analyses and Modeling activities will likely be used to isolate the role of large-scale influences (wind, NPGO, PDO, temperature, OA) vs local influences (runoff, waste water, carbon input from rivers) on prey and changes to the microbial food web, as also reflected in the that section's Next Steps.

TOP-DOWN STUDIES

Top-down effects are those limits to salmon survival imposed by what eats, competes with, weakens or otherwise kills juvenile salmon and steelhead. Targeted studies will evaluate predation (what eats salmon and steelhead) and other factors that may be contributing to mortality, including: disease and toxic chemicals. Competition between hatchery and wild fish is being evaluated at some level through the critical growth period study of the salmon sampling program (study 1). Studies of the effects of harmful algae are being considered; however, they are only in the conceptual stage. There remains debate about whether harmful algae (heterosigma in particular), like noctiluca, are having a greater impact by depleting food available for salmon versus directly injuring or killing them. Resolving which perspective is more important to investigate will inform priorities.

A study of the effect of salmon residency in the Salish Sea is included also in this section. Specific studies of the role of salmon individual and population characteristics in their marine survival do not have an obvious home in the bottom-up/top-down research framework. However, the current assumptions for fundamental drivers of potential changes in the proportion of fish that remain resident are more top-down than bottom-up oriented. Therefore, the study is housed here.

6. Puget Sound steelhead early marine survival research

Principal Investigators: See "Research Work Plan: Marine survival of Puget Sound Steelhead"[19]

A distinct research work plan was developed for Puget Sound steelhead. Hypotheses for low steelhead early marine survival predominantly focus on top-down effects. Data suggest juvenile steelhead experience rapid and high mortality in Puget Sound. Juvenile steelhead migrate through Puget Sound, from river mouths to the open ocean quickly, often in less than two weeks. Within this period approximately 80% die. Several factors may be at play. The primary hypotheses are: compromised fish health/condition and subsequent inability to avoid predators, changes in water quality that increase predation, and/or increases in predation rates by growing predator populations.

The Puget Sound steelhead research work plan consists of eleven studies.

Species: Steelhead

Operational Hypotheses:

(1) Survival, Marine v Fresh
(2) Factors operate at diff. levels by region, life-history, etc.
(4) Outmigrant timing match - mismatch)
(11) Toxic contaminants
(13) Predation by marine mammals

- Five studies use existing data to evaluate patterns and trends in steelhead marine survival and behavior compared to a range of factors that may be contributing to their mortality.
- Four field studies will be conducted to identify the locations, rate and timing of mortality and evaluate disease, toxic contaminants, genetics, and predator-prey interactions to reveal the direct and underlying causes of steelhead mortality in Puget Sound. Upgrading the Puget Sound acoustic receiver network is an essential component of this work.

[19]. Steelhead Marine Survival Workgroup. February 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA. Can be found at www.marinesurvivalproject.com

- A genetics study will be performed to determine whether there are inherent differences between steelhead that die or survive in Puget Sound, and ecosystem modeling will be used to look at the combined effects of the multiple factors that may be contributing to mortality.

These studies are aligned where appropriate with studies proposed in this document for other salmon species so that comparative analyses can be performed. These studies are described in detail in an affiliated document titled "**Research Work Plan: Marine Survival of Puget Sound Steelhead**".[20] Supporting references for the information in this section can also be found in the steelhead research work plan.

7. Analyzing pathogens, in particular *Nanopheytus,* as contributing factors

Principal Investigator: Paul Hershberger (US Geological Survey)

Species: Steelhead, coho and potentially Chinook

Operational Hypotheses:

(14) Disease
(2) Factors operate at diff. levels by region, life-history, etc.

Several pathogens are known to be present in Puget Sound. Many infections from these pathogens result in marine mortality, and we currently do not know broadly what infection rates are for specific salmon and steelhead species throughout Puget Sound. Doing blind surveillance, broad spectrum pathogen studies is currently very expensive. New technologies are being developed in Canada, supported in part by the Salish Sea Marine Survival Project. Once these technologies evolve, the U.S. scientists will reconsider the value of broad spectrum analyses. In the interim, U.S. disease experts have correlated what we know about Puget Sound salmon and steelhead marine survival patterns with the suite of potential pathogens. Through this process, they have determined that *Nanopheytus* is the primary disease candidate given the apparent alignment between its high prevalence and low marine survival rates for specific salmon and steelhead populations, especially in south Puget Sound.

Field work will be performed to determine the prevalence and intensity of *Nanopheytus* throughout Puget Sound and to determine if/when juvenile steelhead, coho and potentially Chinook acquire the trematode infection. A Puget Sound-wide *Nanopheytus* assessment will be carried out for juvenile steelhead; however, this work may be expanded to target coho and potentially Chinook if initial findings warrant this. Disease challenges will be performed to determine whether and to what extent *Nanopheytus* may be contributing to mortality. The results will be incorporated into the ecosystem modeling and indicators analyses. Potential treatments will also be evaluated. The activity will be performed in conjunction with other fish sampling efforts. See the "**Research Work Plan: Marine survival of Puget Sound steelhead**"[21] for a complete description of the research approach.

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[20]. Steelhead Marine Survival Workgroup. February 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA. Can be found at www.marinesurvivalproject.com

[21]. Steelhead Marine Survival Workgroup. February 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA. Can be found at www.marinesurvivalproject.com

8. Analyzing contaminants as contributing factors

Principal Investigator: Sandie O'Neill (Washington Department of Fish and Wildlife)

Species: Chinook and steelhead

Operational Hypotheses:

(11) Toxic contaminants

(2) Factors operate at diff. levels by region, life-history, etc.

Toxic contaminants in outmigrating juvenile Chinook Salmon *(Oncorhynchus tshawytscha)* from rivers, estuaries and offshore saltwater habitats of Puget Sound

Contaminants from multiple sources, including known chemicals of concern, enter Puget Sound via stormwater, wastewater treatment facilities, industrial discharges, and atmospheric deposition. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) migrating from freshwater to saltwater in Puget Sound enroute to the Pacific Ocean can encounter a wide range of water quality conditions, from relatively clean to highly contaminated, depending on their migration route. Impairment of water quality in freshwater, estuarine and nearshore habitats represents a significant threat to juvenile Chinook salmon populations, especially as they transition from fresh to saltwater, and may reduce their early marine survival. In this study, we are measuring juvenile Chinook salmon exposure to known chemicals of concern at four major Puget Sound river/nearshore marine systems (Skagit, Snohomish, Green, Nisqually), an additional marine industrial embayment, and four offshore marine basins. The objectives are to (1) measure the magnitude of exposure in outmigrants across four major rivers, five major embayments and four offshore basins, (2) evaluate potential effects on marine survival and (3) identify "sources" of contaminants inputs along the outmigrant pathway (i.e., river, estuarine or offshore locations). Results from this work will be used to provide a measure of the effectiveness of current toxic reduction strategies and actions, inform future pollution reduction efforts, and enhance recovery of Chinook salmon. This work began in 2013, supported by direct funding to WDFW via a National Estuary grant from the Washington Department of Ecology, for the in-river and estuary work. Through 2014 funding for the Salish Sea Marine Survival Project, the chemical analyses of the offshore samples will be completed. A similar analysis of contaminants is being done for steelhead, described in detail in an affiliated document titled "**Research Work Plan: Marine Survival of Puget Sound Steelhead**".[22]

Additional, targeted research will be considered, and there is strong support via Salish Sea Marine Survival Project for the proposed expansion of WDFW's Toxics in Fish program (see the "Affiliated Activities We Support" section, below).

[22]. Steelhead Marine Survival Workgroup. February 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA. Can be found at www.marinesurvivalproject.com

9. Evaluating the effect of Salish Sea residency on marine survival

Principal Investigators: Lance Campbell and Sandie O'Neill (Washington Department of Fish and Wildlife), Josh Chamberlin (NOAA)

> **Species:** Chinook (possibly coho)
>
> **Operational Hypotheses:**
>
> (5) Residency
>
> (2) Factors operate at diff. levels by region, life-history, etc.

Extended residence in the Salish Sea may negatively impact overall marine survival of salmon in the region, especially for Chinook and coho. Increased contaminant load, delayed competition for limited and seasonal prey, and increased predation by local marine mammal populations may all contribute to reduced survival and warrant further research. The proportions of Chinook and coho populations that display residency will be determined, whether the proportion has changed over time, and whether there is a correlation between the proportion of residents and marine survival.

Various analyses (otolith microchemistry, carbon isotopes) will be evaluated to determine which approach best identifies resident fish. Residents will be determined by capture location & month and by using the contaminant evaluation, described below, as an independent verification. Once a resident identification approach is established, existing otolith or scale sample sets from adult spawners will be analyzed to evaluate the proportion of residents that contributed to the spawning population in low vs. high years of marine survival.

PBT contaminant concentrations of Chinook and populations assumed to be resident and nonresident (based on capture location and timing) will used to determine if a distinct chemical signal indicative of residency can be developed for otoliths or via carbon isotopes. Recent results indicate that these resident Chinook and coho salmon have elevated levels of PBTs and distinct chemical fingerprints as a consequence of their feeding within the Puget Sound food web. However, PBT chemical fingerprint are expensive and less feasible to apply to long-term sample sets such as otoliths and scales.

10. Hydroacoustic-midwater trawl survey to evaluate competition and buffering

Principal Investigator: Dave Beauchamp (U. of Washington)

> **Species:** Chinook. Some coho, chum
>
> **Operational Hypotheses:**
>
> (6) Prey availability (Insufficient supply, mismatch, competition)

This activity is still conceptual and not fleshed out. A quantitative hydroacoustic-midwater trawl survey of the epi-pelagic fish community will be considered for July of 2015 to determine the species composition, abundance, distribution, biomass, and trophic interactions of juvenile salmon and forage fishes in epipelagic habitats. However, the cost vs. benefits must be further analyzed.

Objective: Assess the abundance and distribution of pelagic forage fish and juvenile salmon in Puget Sound to support evaluation of:

- Interspecific competition effects on juvenile salmon growth which links directly size-selective mortality
- Role of forage fishes in buffering predation impacts on juvenile salmon

Daylight hydroacoustic & midwater trawl surveys have been useful for determining monthly nearshore-offshore and regional shifts in relative abundance of salmon and other epi-pelagic fish. However, daylight surveys cannot adequately assess herring. Schooling during daylight leads to highly volatile estimates of their abundance and distribution. At night, schools disperse enabling good quantitative assessments of abundance, biomass and distribution of all pelagic fishes in the epi-pelagic zone (e.g., 0-60 m depths). Midwater trawling would be required to provide species identification of acoustic targets and an ancillary opportunity to collect biological samples.

11. Harmful Algae Impacts

Principal Investigators: Undetermined

Species: Chinook and coho

Operational Hypotheses:

(9) Harmful algae

(2) Factors operate at diff. levels by region, life-history, etc.

This activity is still conceptual and not fleshed out. The Technical Team will continue to consider sampling for harmful algae in conjunction with the zooplankton sampling program. There remains debate about whether harmful algae (heterosigma in particular), like noctiluca, are having a greater impact by depleting food available for salmon versus directly injuring or killing them. Resolving which perspective is more important to investigate will inform priorities and potentially lead to a different study altogether (of potential changes to the microbial food web and its effects on salmon).

For now, the Team will consider collecting gill and organ samples from salmon and herring during bloom periods, as part of the core fish sampling effort. Also, consider expanding harmful algae monitoring in southern Strait of George and North Puget Sound in and around the Fraser River plume during spring and late summer/early fall in all years but with special efforts in high risk years easily identified by weather and river discharge pattern. Communicate and build upon existing efforts such as monitoring at fish and shellfish farms; the HAMP program in Nanaimo; the Puget Sound, SoundHab and SoundToxin networks; Puget Sound tribal resources. Most of this work is voluntary and, therefore, cost effective but presently not extensive enough to be useful to examine many of the unknowns. Also, consider conducting portable bioassay assessments using live cages deployed at differing depths during known harmful algae major blooms for hypothesis validation or modification in the Southern Strait of Georgia and North Puget Sound. Monitor survival in exposure and reference areas and collect gill and organ tissues for histological and toxicological analyses together with cell counts and basic hydrographic profiles.

Next Steps (2016 & Beyond)

More work must be done to develop studies of top-down effects. Several study concepts were proposed by the Technical Team in the 2012 report, "The Hypotheses and Preliminary Research Recommendations for Puget Sound"[23]. However, many of these did not evolve into specific research activities. High costs of several of the research recommendations and the decision to prioritize implementing the bottom-up sampling program have delayed development and/or led the Technical Team to conclude that the work is beyond the scope of the current 2014-2015 phase of the research plan (see "Affiliated Activities We Support" section later in this document). Below are examples of activities proposed in the 2012 report and elsewhere by the Team since.

- Bio-energetic analysis of marine mammal, avian, and piscine predation (affiliated with food web modeling, research activity 15.)
- Retrospective analysis of existing acoustic telemetry data on seasonal and diel horizontal and, especially vertical movement and distribution of resident coho and Chinook salmon to determine regions, depths, periods, and potential hotspots of overlap with juvenile salmon and forage fishes. These data would provide insight into physical and biotic factors that influence the magnitude and dynamics of predation on juvenile Chinook salmon versus other salmon and forage fishes
- Identify and quantify the temporal-spatial patterns in predation as functions of predator species, predator size, prey size, the role of alternative prey, and environmental mediators (temperature, salinity, turbidity, light, DO). Highest priority would be purse seine sampling among regions in epi-pelagic waters of Puget Sound monthly in April and May, twice monthly June-September, and monthly in October.

[23] Ibid.

TREND ANALYSES AND MODELING

Trend analyses and modeling provides the primary, integrated data evaluation framework for the entire project. Existing and new data are brought together to analyze and model relationships between salmon and their ecosystem, to evaluate the cumulative effects of multiple factors, discriminate between factors that are proximate vs. ultimate causes of mortality, help narrow the field of likely survival drivers, and build back to factors ultimately driving survival over time. Historical data and modeling will be used to comprehensively evaluate survival and survival relative to life-history variation and ecosystem factors, comparing those that are natural to those that are human influenced and assessing variation within the sub-basins of Puget Sound and more broadly throughout the Salish Sea. Historical data will also be used to look for general ecosystem regime shifts that may correlate with changes in salmon and steelhead survival. To ensure lasting value and the ability to evaluate new information as we learn, these activities will be aligned with the proposed suite of research activities involving the collection of new data.

Each research activity in this section is being developed and implemented with significant collaboration between U.S. and Canadian scientists. There is currently, significant agreement between U.S. and Canadian scientists on the value of comprehensively evaluating salmon survival trends (1) and establishing a comprehensive suite of ecosystem indicators that identify and provide a mechanism for simultaneously evaluating multiple metrics (3). There is also significant agreement that advancing ecosystem modeling is imperative to our understanding of cumulative effects (4); however, the scientists concluded that initial efforts should focus on improving the modeled relationship between physical parameters through secondary production (zooplankton). There is less agreement on the value of evaluating the effects of outmigration timing and size relative to survival (associated with the hypothesis that changes to life-history variation (2) is related to the decline in marine survival of Chinook and coho). Currently, the U.S. intends to invest more in evaluating this, while the Canadians largely reference a recent publication by Dr. James Irvine indicating no apparent difference in survival of hatchery coho with various release and outmigration times (2013)[24].

12. Salish Sea salmon and steelhead survival trends

U.S. Principal Investigators: Mara Zimmerman (WDFW), Kit Rawson (contractor), Joe Anderson (WDFW), Correigh Greene (NOAA) [Neala Kendall (WDFW) for steelhead[25]]

Species: Chinook, coho, steelhead.

Operational Hypotheses:

(1) Survival, Marine v Fresh
(2) Factors operate at different levels by basin

Chinook, coho, steelhead (and potentially sockeye) will be analyzed to address:

1. What are the marine survival trends[26] for Salish Sea salmon and steelhead populations? How do these trends compare to nearby populations outside of the Salish Sea (i. e., control group)?

[24] Irvine, J.R., M.O'Neill, L. Godbout, and J. Schnute. 2013. Effects of varying smolt release timing and size on the survival of hatchery- origin coho salmon in the Strait of Georgia. Progress in Oceanography (In Press), doi: http://dx.doi.org/10.1016/j.pocean.2013.05.014

[25] See the draft Puget Sound Steelhead Marine Survival Research Work Plan (2014).

[26] Marine survival = smolt-to-adult survival, which is primarily a reflection of survival in the marine environment.

2. Does survival differ for stocks entering the Salish Sea within different sub-basins (in particular, comparing oceanographic basins of Puget Sound to the Strait of Georgia)? If so, where, when, and to what degree has it varied?
3. Does marine survival more strongly predict adult returns than freshwater survival?
4. How much does marine survival differ between hatchery stocks and naturally spawning populations?

This work will first be performed retrospectively, but the datasets will be updated as seen fit over the course of the project. Outmigration and adult return estimates for most Salish Sea and some coastal stocks will be included, providing a comprehensive picture of marine survival in this region. Early marine abundance/CPUE data from the Ricker marine trawl surveys and from future marine trawl or seine surveys will also be included where available, and freshwater survival will be analyzed for wild stocks to express the degree to which freshwater vs. marine mortality affects salmon returns. This effort provides the framework and foundation for future survival and correlative analyses and will contribute significantly to the baseline data required for ongoing[27] and proposed analysis and modeling activities, listed below. Participants are also interested in using the outcome of this work as a template for long-term monitoring.

13. Life-history characteristics and outmigrant abundance relative to survival

13.1. LIFE-HISTORY CHARACTERISTICS AND OUTMIGRANT ABUNDANCE RELATIVE TO SURVIVAL

Principal Investigators: Joe Anderson (WDFW), Correigh Greene (NOAA), Josh Chamberlain (NOAA), Mara Zimmerman (WDFW) [Neala Kendall (WDFW) for steelhead[28]]

Species: Chinook, coho, steelhead

Operational hypotheses:

(1) Survival, Marine v Fresh
(2) Factors operate at diff. levels by region, life-history, etc.
(3) Size-selective mortality
(4) Outmigrant timing
(6) Genetic & life-history diversity (portfolio effect)

Chinook, coho, and steelhead will be analyzed to address:

- Does variation in body size, smolt migration timing, or other life-history characteristics associated with freshwater rearing affect marine survival?
- Does outmigrant abundance affect marine survival?

This work will first be performed retrospectively, but the datasets will be updated over the course of the project where it is considered appropriate. Data on wild and hatchery life-history characteristics of stocks throughout the Salish Sea will be analyzed with reference to marine survival trends over time. This work will be performed to determine whether certain characteristics account for variability in the marine survival estimates and or are contributing uniquely to mortality (or are uniquely affected by the environment) in the Salish Sea. Characteristics within and among species will be compared. Hypotheses

[27] For example, FRAM (Pacific Fisheries Management Council, Fisheries Regulation Assessment Model).
[28] See the Puget Sound Steelhead Marine Survival Research Work Plan at www.marinesurvivalproject.com..

concerning spatial variation in mortality, size-selective mortality, match-mismatch, and life-history variation will be examined. This analysis will also compare changes in hatchery and wild smolt outmigrant abundance and marine survival rates to examine the marine carrying capacity hypothesis. This analysis may include developing enhanced life-cycle models that capture life-history variation better than current approaches.

13.2. LIFE CYCLE MODELING, AND FRESHWATER HABITAT CAPACITY FOR AFFILIATED STUDY

Principal Investigator: Correigh Greene (NOAA)

Species: Chinook, coho, steelhead

Operational hypotheses:

(5) Survival, Marine v Fresh
(6) Factors operate at diff. levels by region, life-history, etc.
(7) Size-selective mortality
(8) Outmigrant timing
(7) Genetic & life-history diversity (portfolio effect)

Several studies across the Pacific Northwest point to the importance of life history variation (e.g., variation in size, outmigration timing, and age structure) in influencing the productivity and resilience of salmon populations in response to environmental variation (Moore et al. 2009, Greene et al. 2010, Schindler et al. 2011, Thorson et al. 2013). Much of this variation is produced in freshwater before salmon enter marine waters, but the consequences of this variation in marine waters (and Puget Sound in particular) is not known. Understanding the extent to which variation in growth, migration, and survival of different life history types in freshwater and marine habitats is important to determine the extent to which changes in survival within Puget Sound affect adult returns. We propose a rigorous analysis of different life history components for two intensively monitored fish populations within Puget Sound: Chinook and coho salmon in the Skagit River data into life cycle models that can be used to test for the relative importance of various life history variables (e.g., age-specific or size-specific marine survival rate, frequency of yearling outmigrants)

14. Ecosystem indicators: stoplight modeling, single & multi-variant analyses, & other approaches

Species: Chinook, coho, steelhead

Operational Hypotheses:

(1) Survival, Marine v Fresh
(2) Factors operate at diff. levels by region, life-history, etc.
(3) Size-selective mortality
(4) Outmigrant timing (match-mismatch, etc)
(6) Genetic & life-history diversity (portfolio effect)
(7) Circulation patterns affect bottom-up processes / fish behavior
(12) Prey availability (Insufficient supply, mismatch, competition)

Ecosystem indicators will be developed and analyzed for their ability to predict the marine survival of salmon and steelhead. The objectives of the indicators work are to provide a central location for organizing and compiling metrics for the project, to determine whether the indicators can be used to improve forecasts of adult returns, and to look back through time to evaluate indicators that may have correlated with the decline in survival of Chinook, coho and steelhead.

Similar to the survival datasets, this work will initially be performed retrospectively but the datasets will be updated over the course of the project where appropriate and expanded to include new data collected via the proposed sampling program. A common suite of indicators will be established for the entire Salish Sea. This indicators list will function as the tool for compiling most of the metrics that will be utilized throughout the project: for indicators/correlative analyses, ecosystem modeling, and bottom-up data collection.

A stoplight modeling approach will be used to coarsely evaluate indicators across the Salish Sea basin and to ensure cross-talk between U.S. and Canada. However, finer-scale analyses will also be applied within this framework, to ensure the factors affecting in-basin variation are properly captured, and to provide scientists the capacity to apply their individual expertise to analyses. Furthermore, several individual studies will occur within the ecosystem indicators category, to analyze specific datasets for correlations with salmon survival.

14.1. DEVELOPING ECOSYSTEM INDICATORS TO INFORM GEOGRAPHIC VARIATION IN MARINE SURVIVAL RATES

Principal Investigators: Correigh Greene, Peter Lawson, and Jason Hall (NOAA)

Fisheries stocks are known for their high recruitment variability (Rothschild 2000) and the resultant difficulty in forecasting stock size to support sustainable harvest management. In light of variation in marine survival, much interest has developed across the Pacific Coast in using ecosystem indicators to improve predictions of productivity and adult abundance. In Puget Sound, anadromous salmon stocks spawn in six sub-basins, each with its distinct geomorphology and oceanography (Strickland 1983, Moore et al. 2008), creating the potential for strong spatial structuring of productivity patterns. Coastal ecosystem indicators do not readily predict marine survival and productivity of stocks spawning within Puget Sound. Likewise, marine survival of stocks entering different basins of Puget Sound does not necessarily track survival rates from other basins. Therefore, the ability of ecosystem indicators to reduce uncertainty in forecasts of adult returns across Puget Sound appears to require local spatial variation.

This research activity will produce and test a spatially variable framework of ecosystem indicators that can be used by harvest managers to forecast adult salmon returns. Specifically, we will:

- Develop a suite of indicators describing conditions within Puget Sound's sub-basins as smolts enter seawater. Do this in conjunction with Canadian indicators development for the Strait of Georgia.
- Combine sub-basin indicators with ecosystem indicators of the Northwest region.
- With Strait of Georgia data, establish the indicators dataset as the primary data catalog for the Salish Sea Marine Survival Project.
- Test these indicators for their ability to reduce uncertainty in predictions of marine survival.
- Examine the potential for improved forecasts to reduce management constraints.

- Develop tools that harvest managers in Puget Sound can use to forecast marine survival and adult returns.
- Convene a workshop to show managers how these tools can be used.

14.2. ANALYZING PUGET SOUND JEMS ZOOPLANKTON TIME SERIES AND OTHER ZOOPLANKTON DATA RELATIVE TO PHYSICAL CONTROLS AND SALMON SURVIVAL

Principal Investigator: Julie Keister (U. Washington)

This study will utilize a time series of zooplankton data collected in the Strait of Juan de Fuca to identify the primary environmental variability that correlates with changes in zooplankton communities and subsequent salmon returns. Zooplankton samples have been collected monthly since 2003 (75-cm diameter, 150-µm mesh vertical nets) during research cruises conducted by the University of Washington (UW) Puget Sound Regional Synthesis Model (PRISM) program, (http://www.prism.washington.edu/home), and the Washington Department of Ecology as part of the Joint Effort to Monitor the Strait of Juan de Fuca (JEMS). Additionally, a single year, region-to-region comparison between zooplankton data and salmon SARs/survival trends using data collected by NOAA in 2011 throughout Puget Sound may also be analyzed.

14.3. RETROSPECTIVE ANALYSIS OF PUGET SOUND ZOOPLANKTON DATASETS

Investigators: Correigh Greene (NOAA), Jeff Cordell (U. Washington), Casey Rice (NOAA), Julie Keister (U. Washington)

While Puget Sound's pelagic zone is critical to many fish and wildlife species including salmon, it is one of the least understood components of the Puget Sound's ecosystem. Zooplankton are a dominant feature of the pelagic system and their ecology has likely been significantly affected by many natural and anthropogenic influences including climate and water quality changes, fisheries, and introduced exotic species that have greatly altered other west coast waters. Given the evidence for strong bottom-up ecosystem dynamics in Puget Sound and the important roles zooplankton play in food webs, understanding the stability of zooplankton communities should provide insight into the stability of higher trophic levels, including whether regime changes in food web structure have or are likely to occur.

This research activity will complete the analysis of Sound-wide zooplankton samples collected in 2011. Comparisons of 2011 sites with spatially concordant samples collected in 2014 and 2015 will help characterize the nature of zooplankton communities in space and time. This work will continue to advance our understanding of pelagic ecology in Puget Sound, and provide invaluable information for improved assessment and monitoring of the Puget Sound ecosystem.

14.4. ANALYZING QUALITATIVE HISTORIC ZOOPLANKTON DATASET FROM WDFW HERRING SPAWNING SURVEYS

Principal Investigators: Iris Kemp (LLTK), Julie Keister (U. Washington)

Data from plankton tows that occurred coincident with WDFW herring spawning surveys are being evaluated. The presence/absence and relative dominance of zooplankton, by taxonomic category, and some phytoplankton and fish larvae data were collected over a 20-year period (1975-1994 and a few samples from 1997 and 1999). Surveys typically spanned the January-May period each year. Samples from June-December also exist but are less consistent. None of these data have been analyzed or published prior to this effort. Dan Penttila (retired, WDFW) and WDFW are credited for establishing this dataset.

While this is largely a qualitative dataset, the data could provide a description of plankton presence/absence trends over time (seasonally, interannually) and space (regionally). There is also potential to measure larval forage fish length distributions over time and space. These data may give insight to plankton response to large-scale ecosystem shifts (e.g., PDO regime shift) within Puget Sound. Additionally, trends found in these data will be analyzed with respect to trends in Puget Sound salmon marine survival. If bottom-up factors drive salmon marine survival, we might expect trends in certain plankton taxa (e.g., crab larvae) to correlate with trends in salmon growth and survival.

14.5. ANALYZING LONG-TERM PUGET SOUND STRATIFICATION DATASETS AS A PROXY FOR PRIMARY PRODUCTION

Investigators: Neil Banas, Parker MacCready, and Ryan McCabe (U. Washington)

Stratification will be analyzed for its utility as a proxy for primary production. It also has more historical data than chlorophyll, and its modeling in future scenarios is more robust. A retrospective analyses of density stratification documented in the Collias reports from 1952-1966 Puget Sound surveys will be conducted; those observations from 1952-1966 period will be compared with those from ORCA buoys from 2005-present; and this information will be compared with Department of Ecology monthly survey data to determine if monthly sampling is adequate for documenting seasonal, inter-annual and longer timescale trends and variations in Puget Sound properties. Seasonal and inter-annual variation and long-term stratification trends will be compared to salmon marine survival trends and to climate indices such as the PDO. A template for the analysis is the wonderful papers by Stephanie Moore, while she was working with Nate Mantua.

14.6. ANALYZING PUGET SOUND PRIMARY PRODUCTION VARIABILITY IN RELATION TO STRATIFICATION, PART ONE — OBSERVATIONAL VIEW

Principal Investigators: Neil Banas, Parker MacCready, and Ryan McCabe (U. Washington)

Existing ORCA records will be used to conduct analyses of phytoplankton production rates, timing, and variability to assess interannual and inter-basin variation. In addition, spatial and temporal variations in the relationship between bloom timing and stratification timing will be assessed, building on the stratification activity. Results will be compared to salmon marine survival time series.

14.7. ANALYZING PUGET SOUND PRIMARY PRODUCTION VARIABILITY IN RELATION TO STRATIFICATION, PART TWO — MODEL VIEW

Principal Investigators: Neil Banas, Parker MacCready, and Ryan McCabe (U. Washington)

A biophysical model will give a much more comprehensive view of primary production variation in space and time than can be inferred from existing ORCA data, although the ORCA data is absolutely essential for validation. This validation needs to be focused on the processes of particular concern to this project, rather than simply a skill assessment of model salinity or phytoplankton in general, because the processes of concern here—spring bloom timing, primary production dynamics at marginal light levels—are known weak spots of contemporary NPZ (nutrient-phytoplankton-zooplankton) models. Once we identify a model formulation that correctly reproduces early spring phytoplankton dynamics in one model system, that process understanding and mathematical formulation can be directly ported to another model system, such as Atlantis.

15. End-to-end, spatiotemporal ecosystem modeling for Puget Sound and potentially the greater Salish Sea (under development)

Principle Investigators: Chris Harvey (NOAA), Brandon Sackmann (contractor), Tarang Khangaonkar (PNNL), Isaac Kaplan (NOAA), and Neil Banas (U. Washington)

Species: Chinook, coho, steelhead with some information on pink, chum, sockeye

Operational Hypotheses:

(2) Factors operate at diff. levels by region, life-history, etc.
(4) Outmigrant timing (match-mismatch, etc)
(7) Circulation patterns affect bottom-up processes / fish behavior
(12) Prey availability (Insufficient supply, mismatch, competition)

Other hypotheses, such as those evaluating the effects of predation (13), disease (14), toxics (11), ocean acidification (8), and harmful algae (9) will be informed as modeling becomes more comprehensive.

Ecosystem modeling will used to examine how bottom-up processes, driven largely by circulation patterns, relate to spatiotemporal differences in the abundance of lower and middle trophic level species. Ecosystem modeling will also provide the framework for examining top-down processes and for examining the effects of various factors simultaneously influencing juvenile (and resident) salmon survival: understanding which factors are more significant, whether they have synergistic or compounding effects, how factors interrelate and which factors are proximate/direct vs. root/fundamental causes of mortality. Given the diversity and complexity of bottom-up and top-down forces that interactively influence the Salish Sea, a spatiotemporal ecosystem model is of great potential value, particularly an "end-to-end" ecosystem model that can integrate a broad range of oceanographic, biological, and social drivers, currencies, and scales. Contemporary models also help us develop ecosystem monitoring programs and test various management strategies. The specific questions examined will include:

- How do short- and long-term changes in circulation and water chemistry affect the salmon, steelhead (and, other relevant species) in the Salish Sea?

- How sensitive are bottom-up processes to the effects of human activities in the Salish Sea, relative to natural variability?

For Puget Sound, two research activities have been proposed:

15.1 Refine the Existing Puget Sound EcoSim with EcoPath Ecosystem Model and Run Scenarios for Coarse Analyses of Salmon Survival Drivers.

15.2 Develop a Puget Sound End-To-End, Spatiotemporal Model with Atlantis Software

This section is under development. U.S. and Canadian project scientists concluded that ecosystem modeling should be developed in an integrated fashion. However, there is general agreement that the initial focus should be on building a better association between physical and biological characteristics (a.k.a. Nutrient-Phytoplankton-Zooplankton or NPZ modeling). U.S. and Canadian scientists will continue to flesh out plans for addressing NPZ needs, as well as establishing the ecosystem modeling framework for more comprehensive, end-to-end, multi-factor analyses. Below are initial proposals drafted for Puget Sound. Please note that research activity, "**14.7. Analyzing puget sound primary production variability in relation to stratification, part two — model view**" could also categorically be associated with this section but was left in the previous section because it is part of a stepwise proposal that includes empirical data evaluations and modeling.

Note: In the U.S., physical process models are being updated via other funding sources and will soon be able to provide real-time forecasts, a major benefit toward completing this work.

Next Steps (2016 & Beyond)

The Technical Team will continue to build upon the foundation established by the trends analyses and modeling activities proposed above. Data sets will be added for modeling and correlative analyses (with salmon survival) from field work, lab work, and further retrospective investigations. For example, one recommendation described in the next steps of the Top-Down section is to perform a bio-energetic analysis of marine mammal, avian, and piscine predation. Furthermore, the questions asked of the data will continue to be refined as the system matures. For example, if results of initial activities support additional focus on factors affecting prey availability, modeling activities could be used to isolate the role of large-scale influences (wind, NPGO, PDO, temperature, OA) vs local influences (runoff, waste water, carbon input from rivers) on prey and changes to the microbial food web.

AFFILIATED ACTIVITIES WE SUPPORT

The following is a list of research and monitoring activities that this effort believes are important but are outside the scope of the current 2014-2015 Puget Sound research plan for the Salish Sea Marine Survival Project. Many of these projects are priorities through other ongoing efforts and could be funded via other mechanisms.

Ocean Acidification

We will advocate to ensure marine carbon chemistry and pH are included in the suite of baseline physical attributes monitored throughout the Salish Sea. Carbon monitoring should be coupled with biological monitoring of species potentially vulnerable to ocean acidification that affect salmon growth and survival (e.g. krill and copepods). These data are needed to establish any causative link between acidification and salmon performance.

The effects of pH/pCO2 variability on invertebrate prey of greatest importance locally to salmon and forage fish should also be studied in an experimental setting. A study of copepods and euphausiids by Dr.'s Julie Keister (University of Washington), Paul McElhany (NOAA), and Shallin Busch (NOAA) directly addresses this need but could be expanded upon to include other species of concern such as gammarid amphipods and decapod larvae and potential synergistic variables such as temperature and oxygen. Although lower priority, a study of the direct impacts of CO_2 on all species of salmon and steelhead (and forage fish) should be performed in a laboratory setting. The study should include early marine life stages. Focus on behavioral and sensory impacts.

Toxics in Fish

WDFW is pursuing expanding their toxics in fish program. Through this program, additional critical research for determining the role of contaminants as a limiting factor to juvenile salmon and steelhead growth and survival can be performed. As part of the Toxics in Fish program, juvenile salmon contaminant monitoring will be conducted to assess field exposure and effects from rivers to offshore in Puget Sound. In particular, measures of juvenile salmon exposure to xenoestrogen, pharmaceutical and personal care products, and pyrethroids are needed. Where possible, field assessments (and affiliated diagnostic studies) should assess potential effects of contaminants on salmon health in addition to exposure. Field assessments may include alterations in genes, proteins, and hormones that control growth, immuno-competence and reproductive development, as well as measures of growth and condition, such as lipid content. Such monitoring will further characterize the threat that contaminants pose to juvenile salmon and will provide a measure of the effectiveness of current strategies and near term actions to reduce toxics threats to Puget Sound. Existing contaminant data and the results of this work will be evaluated for population and ecosystem effects with ecosystem modeling, and will be used in indicators analyses. Diagnostic laboratory studies will also be considered. See the Technical Team's Report, "The Hypotheses and Preliminary Research Recommendations for Puget Sound (2012)[29]" for a complete list of relevant research areas.

[29] U.S. Salish Sea Technical Team. 2012. The Hypotheses and Preliminary Research Recommendations for Puget Sound. Long Live the Kings, Seattle, WA. Can be found at www.marinesurvivalproject.com

Chinook and coho acoustic telemetry data analyses

NOAA and UW graduate students are completing a review of existing acoustic telemetry data for Chinook and coho. While the resident life-history component of Puget Sound Chinook and coho movement and distribution of these species. Project scientists will also encourage affiliates to review the telemetry data to gain a better understanding of the seasonal, diel horizontal, and vertical movement and distribution of resident coho and Chinook (as predators) to determine regions, depths, periods, and potential hotspots of overlap with juvenile salmon and forage fishes.

Harbor seal and harbor porpoise censuses

Harbor seal and harbor porpoise censuses have not been performed throughout the Salish Sea for over a decade, and the focus generally hasn't been during the juvenile salmon outmigration period. Censuses should be performed to evaluate abundance, distribution and density. Marine birds that are predators of concern should be included if possible. This data should be used in conjunction with diet information in the ecosystem models established for the Salish Sea. A harbor seal census is proposed as part of the assessment of the impact of harbor seals in the Strait of Georgia, above.

Harmful Algae

We support the following: A) The use of remote sensing technologies such as satellite chlorophyll imagery with improved algorithms to deal with river water interference to expedite near real time identification of *Heterosigma* blooms. B) The testing and adaptation of remote sensing molecular sampling equipment such as the Environmental Sample Processor (ESP) and other advanced technologies for use in Salish Sea waters. C) Standardizing harmful algae monitoring protocol and consolidate/quality assess the data. Consider using existing HAMP data for additional analysis as a springboard to determine priorities for other algal species besides *Heterosigma*.

Monitoring spatial diversity and improving genetic identification

We support ongoing efforts to establishing diversity baselines and monitor diversity among salmon populations. We also support efforts to improve the use of genetics for stock identification.

PROJECT MANAGEMENT AND COORDINATION[30]

Seattle-based LLTK (for Puget Sound) and Vancouver-based PSF (for the Strait of Georgia) are co-managing this effort. Both LLTK and PSF have an excellent track record working with multiple parties on objective, science-based initiatives to solve problems in salmon and steelhead management. As independent nonprofit organizations, LLTK and PSF have demonstrated the ability to work quickly and seamlessly across the entities and authorities that must be engaged to make this work successful.

The PSF/LLTK management team will be responsible for administration, coordination, accounting, fundraising and communications. They will facilitate the coordinating and technical committees that will guide and implement the research, administer a portion of the total funding, monitor progress, and produce status reports for the committees, funders and participating parties. PSF and LLTK will each have a full-time project coordinator devoted to the project, and organization presidents/directors', Brian Riddell and Jacques White, will serve as project directors. Associate, communications and financial staff support will also be provided. Fundraising and communications strategies are described in the following sections.

U.S. and Canadian coordinating committees will convene quarterly, with two of the four meetings being U.S.-Canada together. The coordinating committees oversee the project and its funding, maintain the project as a priority for the agencies involved, help coordinate the effort with other initiatives, and ties the research to management. Coordinating committee members include chief scientists, high-level resource managers, and funding representatives. One or two technical committee members will participate in each coordinating committee meeting.

U.S. and Canadian, multi-disciplinary technical teams have already been established and this structure will be maintained to ensure within-nation collaboration across disciplines and responsible parties. Relevant technical team members and supporting scientists from both U.S. and Canada will convene as workgroups to refine[31] and implement the activities identified in the project areas that require significant transboundary collaboration. Other science task teams will be established as needed for various research activities. These task teams will have U.S., Canadian, or U.S.-Canadian representation, dictated by the task at hand. Having a multitude of workgroups or teams working on a variety of tasks is not unusual in private industry. Web-based project management utilities tailored for team management scenarios will be implemented to maintain communications and support data sharing of working datasets (sampling, initial analyses, etc). A more comprehensive data management approach is described in the next section. This will be implemented for maintaining the substantial datasets that will be part of this effort.

All participating scientists and managers will convene at a minimum of three workshops over the course of the project. The first workshop will occur in 2014 during the project ramp up period to jointly address any project hurdles and ensure the research, especially the core sampling program, will be fully

[30] This section is duplicated from the forthcoming Salish Sea Marine Survival Project summary report, which will be available at www.marinesurvivalproject.org

[31] The workgroups are currently being established to refine the Project activities that require significant US Canada collaboration. This work is funded via the Pacific Salmon Commission's Southern Endowment Fund (Grant #SF-2013-I-16A)

operational in 2015. The second workshop will occur mid-way through the project, in 2016, to discuss progress, findings and determine whether any strategic shifts should be made in research implementation. The final workshop will occur the last year of the project, in 2019, after the five-year research phase is complete (2014-2018).

LLTK and PSF will ensure proper coordination is occurring with other relevant initiatives, and will ensure the results of the workgroups are integrated into research and monitoring processes that are part of or relevant to the Salish Sea Marine Survival Project. In the US, for example, there will be significant alignment needed with the Puget Sound Partnership's, Puget Sound Ecosystem Monitoring Program (PSEMP). This involves attending PSEMP workgroup meetings, describing how the proposed work addresses needs identified by these workgroups, getting feedback from the workgroups, and integrated the project activities and results into their efforts.

As has been done for our standing committees and past activities (e.g., 2012 Research Planning Workshop), we will ensure that there is adequate representation of the federal, state, provincial, tribal, First Nation, and academic entities that are currently involved in relevant salmon and ecosystem research and management activities.

COMMUNICATIONS[32]

The PSF/LLTK management team will also oversee the communications and outreach effort. The communications strategy includes the following components:

- An independent project website will be created and regularly updated to describe the project as a whole, progress, ongoing activities and research findings.
- A press strategy will be implemented, including partnering with reporters to do stories on ongoing research activities, findings, and project progress.
- PSF and LLTK will work with the coordinating committees and the communications staff of the participating parties to utilize their media outlets when releasing public information about the project.
- PSF and LLTK will use their in-house publications and media outlets (annual reports, newsletters, facebook, twitter) to report on project progress. They will also work within their community networks to present on project progress and receive feedback.
- Participating scientists will disseminate their results at workshops and via peer-reviewed publications.
- An outreach and education strategy will be formalized with project partners' Seattle Aquarium, Vancouver Aquarium, and Washington Sea Grant. This may include establishing small exhibits at the aquariums describing the project and over time, project findings and outcomes.

PSF and LLTK staff will also work closely with scientists focused on utilizing newer analytical and visualization tools to help communicate the research activities and findings in an effective manner.

[32] This section is duplicated from the forthcoming Salish Sea Marine Survival Project summary report, which will be available at www.marinesurvivalproject.org

DATA MANAGEMENT[33]

The complete data management strategy is under development; however, it will likely include the following components:

- A password-protected, web-based project management utility will be used to support the sharing of working datasets for each of the research activities (sampling, initial analyses, etc). This will allow open access to participating scientists, but data protection from the greater community.
- Data collection protocols will be established for the various research activities that require significant collaboration. These protocols will managed and distributed via the project management utility.
- Existing data-sharing platforms, including the Strait of Georgia Data Centre, the Regional Mark Processing Center, NANOOS, SalmonScape, the Juvenile Migrant Data Exchange, and Nearshore Data Exchange will be utilized, referenced, and built upon where appropriate.
- Aggregated, comprehensive datasets and the associated analyses and modeling results will be shared. We envision a suite of management tools describing and evaluating ecosystem associations and indicators will be established that aide harvest (e.g., improved adult return forecasting), hatchery, and habitat decision making for wild fish recovery and sustainable fisheries. These will ultimately be managed by relevant parties participating in this effort, but may first be created independently and accessed via the project's public web site. See the Trends Analyses and Modeling section for relevant activities.
- Data collection, management, and sharing protocols will be integrated into the salmon and ecosystem management framework for any new activities considered necessary for long-term monitoring beyond the period of this project. Existing activities and their protocol and sharing processes will also be adapted by the project partners where appropriate.
- A comprehensive list of relevant references will be managed on the public web site. This list will extend beyond the research directly associated with this effort.

[33] This section is duplicated from the forthcoming Salish Sea Marine Survival Project summary report, which will be available at www.marinesurvivalproject.org

PROJECT TIMELINE, BUDGET, & ACTIVITY STATUS

The following table describes the timeline, budget and research activity status for the proposed Puget Sound research. The research activities occurring in 2014 -2015 are largely fleshed out as described in this report, and many are confirmed and underway. The last three years are roughly planned, based on discussions to date, and will be dependent upon information gained as the project progresses. Next steps category funding is applicable to studies in concept phase.

Legend: Active, Pending, Concept - Not Fleshed Out

*Color shade reflects the level of intensity for each activity: light = less, dark = more.
**Funded = Does not include additional ~1.4 million Pacific Salmon Commission Southern Endowment funds pledged in future years and not yet allocated.

Salish Sea Marine Survival Project: Puget Sound Research Activities w/ focus on 2014-2015	**Status (color coded)* & Timeline, 201-**					**Funded****	**Remaining Cost**	**In Kind**
Bottom-Up Sampling Program	*4*	*5*	*6*	*7*	*8*	**$1,430,000**	**$1,040,000**	**$7,160,000**
1. Juvenile Chinook & coho salmon: Critical growth periods						$1,075,000	$725,000	$5,550,000
2. Zooplankton: Puget Sound-wide monitoring program						$295,000	$240,000	$410,000
3. Physical characteristics & phytoplankton production						$60,000	$75,000	$1,200,000
Bottom-Up: Individual Studies						**$90,000**	**$575,000**	
4. life history, age, and growth (otolith & scale)						$90,000	-	-
5. Calibrating techniques for estimating growth						in 1 &4	-	-
Next Steps (2016 & Beyond)							$575,000	-
Top-Down Studies						**$990,000**	**$2,495,000**	**$825,000**
6. Puget Sound steelhead early marine survival						$790,000	$1,080,000	$800,000
7. Pathogens as contributing factors						in steelhead	$275,000	-
8. Contaminants as contributing factors						$170,000	$150,000	$25,000
9. Effect of Salish Sea residency						$30,000	$190,000	-
10. Hydroacoustic-midwater trawl survey						-	-	-
11. Harmful Algae Impacts						-	-	-
Next Steps (2016 & Beyond)							$800,000	-
Trend Analyses & Modeling						**$480,000**	**$1,390,000**	**$150,000**
12. Salmon and steelhead survival trends						$100,000	$30,000	$45,000
13. Life-history characteristics relative to survival								
13.1 Life-history characteristics & outmigrant abundance						-	$60,000	$20,000
13.2 Life-cycle modeling & freshwater capacity effects						$125,000	-	$15,000
14. Ecosystem indicators relative to salmon survival								
14.1 Ecosystem indicators analyses						$55,000	$435,000	-
14.2 Zooplantkon time series						$30,000	-	-
14.3 Retrospective zooplankton sample analysis						-	$35,000	-
14.4 WDFW historic zooplankton dataset						$15,000	-	-
14.5 Long-term stratification datasets						-	$45,000	-
14.6-7 Phytoplankton production rates, timing, variability						$95,000	$105,000	-
15.1-2 End-to-end, spatiotemporal ecosystem model						$60,000	$340,000	$70,000
Next Steps (2016 & Beyond)						-	$340,000	-
Contingency						**$5,000**	**$35,000**	
Data Management							**$165,000**	
Project Coordination, Communications,						**$480,000**	**$920,000**	
Totals						**$3,475,000**	**$6,620,000**	**$8,135,000**

FUNDRAISING STRATEGY

The total budget for the five-year Salish Sea Marine Survival Project is $20 million – estimated, as reflected above, at ~$10 million for the U.S./Puget Sound work (and $10 million for the Canadian/Strait of Georgia work).

In the U.S., $4.8 million has been raised to date. The plan for the balance of funds is described below:

- $2.65 million from the Pacific Salmon Commission (PSC), Southern Endowment Fund (raised)
- $2 million from the State of Washington ($800k raised)
- $2.5 million in direct allocations to the federal agencies involved, and/or the Pacific Coast Salmon Recovery Fund or EPA's Puget Sound program ($300k raised)
- $1.35 million from grants targeted at specific research activities ($800k million raised)
- $1.5 million from individuals, corporations and/or private foundations

As reflected in the budget, significant cost sharing ($8.1 million) is also occurring from the agencies, tribes and other organizations involved.

Some of the proposed research activities serve Puget Sound ecosystem recovery research needs beyond the scope of this project. And, other research activities are expected to become long-term monitoring programs for ecosystem recovery and salmon adult return forecasting. For these activities with broad utility and/or long-term value, we will look beyond the funding resources identified to support them.

APPENDIX 1: COMPLETE DESCRIPTIONS OF RESEARCH ACTIVITIES

The following are more complete descriptions of research activities, where they were provided. The activities are numbered consistent with the body of the report. A section table of contents is provided below for ease of navigation.

1. Juvenile salmon: Diagnosing critical growth periods

Principal Investigators: Dave Beauchamp (University of Washington), Josh Chamberlain (NOAA), Julie Keister (University of Washington), Ken Warheit (WDFW). Collaborators for sample collection: Nisqually Indian Tribe, Tulalip Tribes, Skagit River System Cooperative, Lummi Nation, Kwiaht, LLTK, City of Bellingham.

Recent evidence was presented that growth limitations in hatchery stocks of Chinook salmon influenced size-selective mortality during critical periods of early marine growth in Puget Sound (Beauchamp and Duffy 2011; Duffy and Beauchamp 2011). Size-selective mortality provides a promising framework for identifying critical growth periods and habitats for specific stocks of Chinook, as well as a method for diagnosing the factors that limit their growth and survival.

Size-selective mortality has been widely reported during the juvenile stages of many fish species in marine environments (Sogard 1997), and can be a predominant force affecting marine survival and adult abundance. For anadromous salmonids, size-selective mortality can operate at different life stages and habitats for different species and stocks (Beamish et al. 2004, Moss et al. 2005, Cross et al. 2009, Duffy and Beauchamp 2011, Tomaro et al. 2012, Miller et al. 2013, Woodson et al. in press). Reports of strong size-selective mortality for hatchery Chinook salmon in Puget Sound (Duffy and Beauchamp 2011) and coho salmon in the Strait of Georgia (Beamish et al. 2004) linked higher adult returns to larger sizes achieved during early months of marine life. For known coded-wire tag (CWT) groups of hatchery Chinook in Puget Sound, marine survival routinely varies 5-fold among years and stocks. Survival was strongly correlated with mean body mass of juveniles in July, after a month of offshore feeding; however, size at hatchery release was uncorrelated, and size in September showed a lower effect on survival and a weaker correlation than in July (**Figure 1**; Duffy and Beauchamp 2011). In addition, significant size-selective predation by larger salmonids on juveniles was reported during May-September (Duffy and Beauchamp 2008; Beauchamp and Duffy 2011).

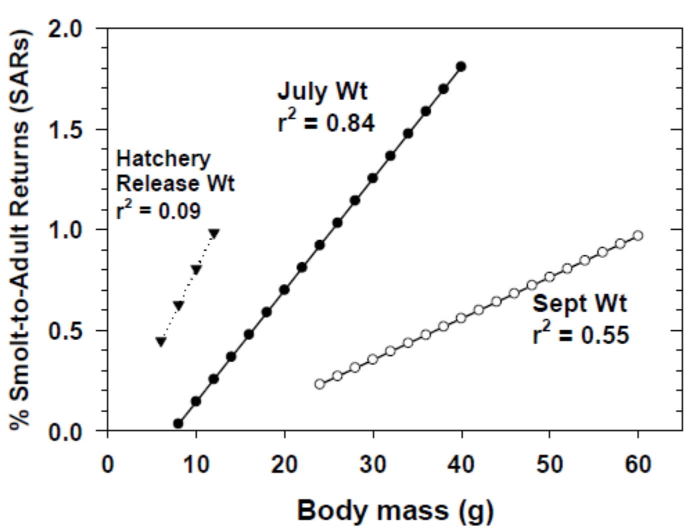

Figure 1. Relationships of SARs to mean body mass of CWT groups of hatchery Chinook salmon at release and when captured during marine offshore life stages in midwater trawls during July and September . Juvenile Chinook increased body mass by 2-4 times after moving offshore to feed for a month after peak nearshore presence in early June (modified from Duffy and Beauchamp 2011).

Given the current evidence for strong size-selective mortality during early marine growth, the next step toward understanding controls on survival is to determine the factors which limit growth during critical growth periods for hatchery and wild stocks of Chinook and coho salmon, and how those factors operate on different stocks, life stages, among habitats. For hatchery stocks, high variability in size, feeding and growth among years and regions support the hypothesis that food is limiting during a critical June-July period of rapid growth and feeding in epi-pelagic habitats of Puget Sound (Duffy 2009, Duffy et al. 2010, Beauchamp and Duffy 2011; **Figure 2**). Much of the variability in feeding and growth can be accounted for by the contribution of crab larvae, and secondarily by neustonic insects, to the energy budget of juvenile Chinook salmon.

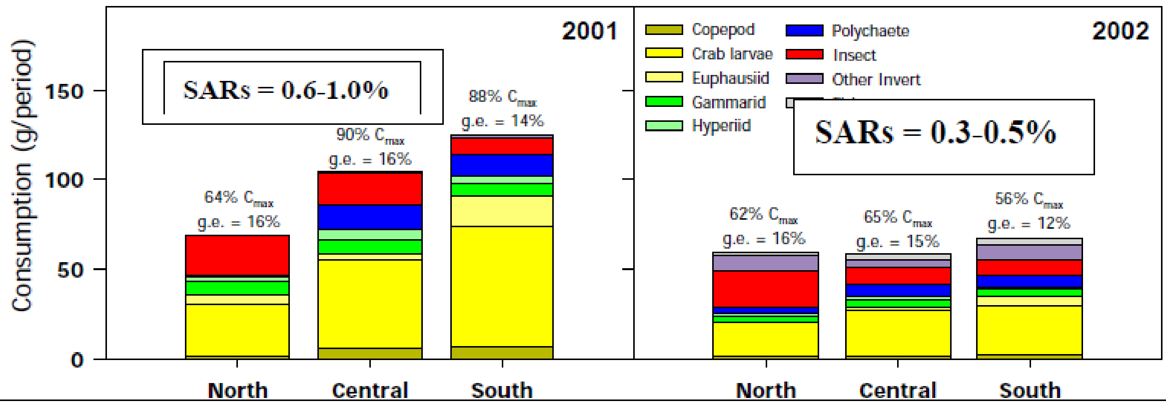

Figure 2. Estimated feeding rates (% Cmax) and mass of major prey consumed by juvenile Chinook salmon in different regions of Puget Sound during critical growth periods in years of high (2001) and low (2002) growth & survival (SARs). The contribution of crab larvae accounted for most of the variability in feeding rates among regions and years (Duffy 2009).

Factors limiting growth can vary considerably among life stages, and across time and space. Based on the range of epi-pelagic temperatures observed in Puget Sound during spring and summer, salmon growth is relatively insensitive to the prevailing thermal regime, but very sensitive to feeding rate, a surrogate measure of food supply (Beauchamp and Duffy 2011). In contrast, temperatures in the Strait of Georgia average 2$_{o}$C warmer during the summer, pushing salmon closer to their thermal tolerance limits and could significantly affect salmon growth in this region. Competition could influence size-selective mortality in certain periods and regions, as suggested by the lower and variable feeding rates associated with reduced marine survival of salmon, in combination with comparisons of prey demand among juvenile salmon and herring (Beauchamp and Duffy 2011). When pooled across all basins of Puget Sound (excluding Skagit Bay) bioenergetic simulations of population-level consumption demand indicate that Pacific herring can consume 10-40 times more biomass of the key prey species than juvenile Chinook during the critical growth period . Because herring are the most abundant consumer, competition for food in offshore regions is more likely driven by their dynamics than by competition between hatchery and wild conspecifics or among salmon species within Puget Sound. Density-dependent growth or hatchery-wild competition within or among salmon species could still occur in localized estuarine or nearshore marine habitats (Greene and Beechie 2004), but detecting localized bottlenecks in food supply and demand would require higher spatial-temporal resolution sampling of fish and zooplankton than has occurred to date.

How these size-selective relationships apply to wild Chinook (or coho) or among populations from different watersheds at similar life stages is uncertain, but preliminary data suggest that wild subyearling Chinook stocks from the northern watersheds like the Snohomish and Skagit remain in nearshore marine habitats for up to a month longer than the hatchery and south-central basin stocks described above. Therefore these northern wild stocks miss some of the rapid offshore June-July growth that benefit hatchery stocks from southern and central basins. We need an integrated examination of growth and survival for known stocks, from marine entry through the first summer of growth in Puget Sound, to identify the critical sizes, periods, and associated habitats that influence marine survival, and recognize how these can vary among stocks and between hatchery and wild Chinook and coho.

Understanding how growth limitation varies among life stages or regions is constrained by a paucity of data on the dynamics of food supply. Little is known about the temporal-spatial availability of key zooplankton and other prey or the factors that influence their production cycles in Puget Sound. Over the past two years as part of the Salish Sea Marine Survival Project (http://www.lltk.org/rebuilding-populations/salish-sea-marine-survival/overview), our group has been collecting the extant data on zooplankton studies that have been conducted by various agencies around Puget Sound. A few 1-2 year studies have been conducted at specific locations throughout region that provide general seasonal cycles and an indication that there can be large inter-annual variability. Spatially, the best data are from a 2011 NOAA survey of relatively shallow nearshore Puget Sound habitats. Those data show large differences in total zooplankton abundances among basins; it is not known whether the relative abundance among basins are consistent among years.

Objectives

This proposal addresses two of the primary hypotheses of the Salish Sea Marine Survival Project: 1) Size-selective mortality significantly regulates recruitment of salmon at one or more critical life stages; and 2) Growth limitation during critical early marine life stages influences the magnitude of size-selective marine mortality.

This proposal represents the first ever effort to methodically measure patterns in size-selective mortality for subyearling Chinook salmon from hatchery release or wild marine entry, through life stages utilizing river-mouth, nearshore marine, and offshore marine habitats within Puget Sound. From the growth, temperature, and diet data collected at each life stage, including concurrent offshore fish and zooplankton sampling, we will use bioenergetics model simulations to diagnose which factor(s) are primarily responsible for limiting growth during the identified critical growth periods.

1. Record smolt abundance and measure size distribution sequentially at hatchery release and downstream outmigrant traps in freshwater, in estuarine-nearshore marine samples, and in epi-pelagic habitats with midwater trawling and purse seining to track the timing, duration, and change in life stage-specific size distribution associated with different habitats and life stages for marked and unmarked groups of Chinook and coho salmon associated with key watersheds of Puget Sound.
2. From the stage- and habitat-specific sampling above, identify the critical periods of strong size-selective mortality, based on disproportionate reductions in the smaller members of a population between subsequent life stages, using scale- or otolith-based back-calculated size at life stage analysis. Critical periods will be related to size and growth of salmon at specific life stages and associated habitats for each watershed.
3. Conduct similar back-calculated size-at-life stage analysis for selected frozen archival samples of juvenile Chinook sampled from 2001-2012 and compare to scale patterns on returning adults from the same cohorts to determine critical sizes and growth periods that ultimately influence

survival to adulthood. This work will be coordinated with the research outlined in research activity 4.

4. Quantitatively determine the relative importance of feeding rate (a surrogate measure of food availability), composition and energetic quality of the diet, thermal conditions, and body size on growth of juvenile Chinook and coho during the critical life stages and adjacent marine periods and habitats.
5. Evaluate the temporal-spatial availability of key zooplankton prey for juvenile Chinook by depth strata in offshore regions of Puget Sound through the spring-summer growth period.
6. Estimate relative consumption demand of key prey by Chinook and coho and the potential primary competitors (i.e., other salmon spp., herring or other forage fishes) during critical growth periods for Chinook and coho in the associated habitats.
7. In conjunction with research activity 2. Zooplankton: Establishing a Puget Sound-wide zooplankton, calculate temporal patterns in prey supply versus consumption demand for key prey by juvenile Chinook and coho and potential competitors in reference offshore regions of Puget Sound.
8. Archive methodically-collected biological samples for representative subsets of all juvenile salmon, forage fishes, and predators for future analysis (genetic stock ID, scaleotolith growth back-calculations & microchemistry, IGF-1, body condition metrics, diet, etc.).

Collaboration and a Modular Approach

Considerable collaboration is needed to complete this study. Several entities currently operate sampling programs that can contribute to this study; therefore, we will predominantly focus on coordinating efforts, standardizing sampling approaches, and adding sampling to fill in key gaps. Additionally, this study has been drafted in a modular fashion so that it can capture the different activities that will be performed by the various collaborators, and so that others who are operating in other watersheds and are interested can apply the same study approach and expand the extent of this effort.

Representative Watersheds

Because critical growth and survival periods likely vary among life stages and habitats for different species, stocks, and life history groups, sampling and analyses should explicitly account for the stock of origin (via CWT, adipose clips, genetics) as much as possible, and focus, at least initially on representative watersheds, building from the freshwater and into the marine environment. The initial candidate watersheds were Nisqually, Green/Duwamish, Snohomish, Skagit, with the potential addition of Nooksack and Puyallup. These candidate watersheds represent the southern to northern geographic range of key salmon and steelhead-producing systems within Puget Sound and southern Strait of Georgia, a large component of the U.S. territory in the Salish Sea. The Nisqually, Snohomish and Skagit watersheds feature more extensive intact or restoring estuarine rearing habitat than the Green/Duwamish watershed, and thus provide a gradient of contrasting quality in estuarine and adjacent nearshore marine habitat available to juvenile salmonids. These watersheds all produce significant hatchery and wild components of Chinook, coho, or steelhead populations. In addition, the Nisqually River enters Puget Sound south of the Tacoma Narrows in a region both dominated by hatchery production overall and where the oceanographic conditions differ markedly in terms of lower temperature and higher salinity (Duffy et al. 2005) which is also reflected in marine dietary differences by salmon compared to central and northern basins of Puget Sound (Duffy 2003; Duffy et al. 2010). The freshwater influence of the larger northern rivers entering Puget Sound progressively increases from the Tacoma Narrows north through the Central and Whidbey Basins.

However, ultimately, the funding available and cost sharing activities required to complete the work narrowed the focus of this work to the Nisqually, Snohomish, Skagit and Nooksack systems, with opportunistic sampling in Central Puget Sound and from the Green River smolt trap. See Figure 3 for a rough illustration of the purse seine sites.

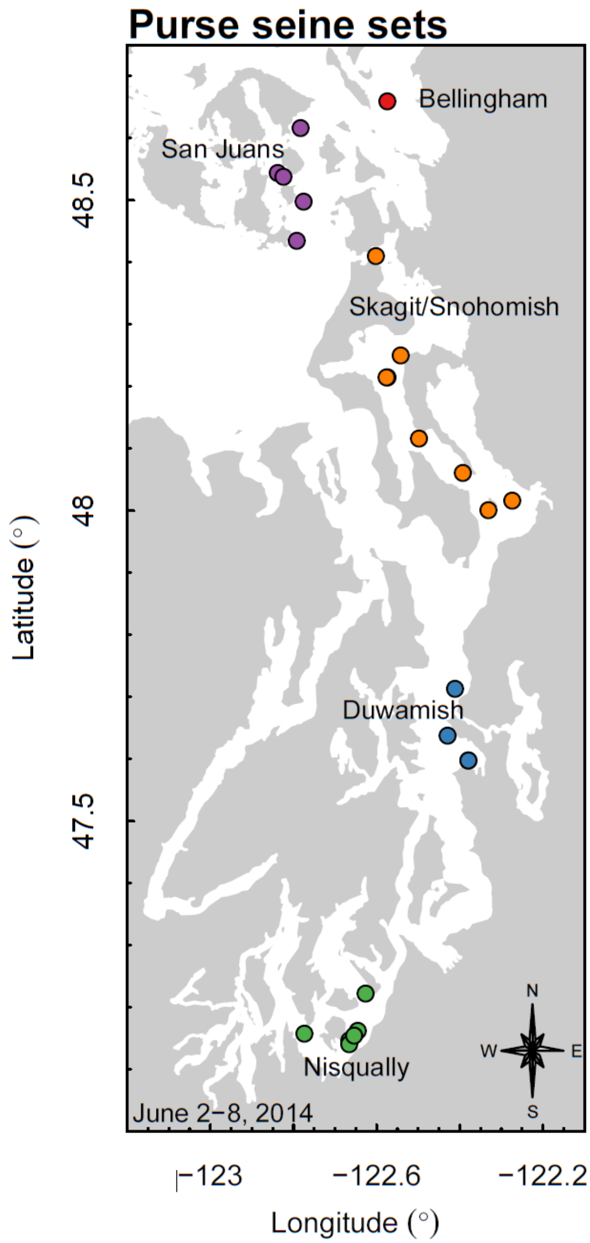

Figure 3. Purse seine sites for Puget Sound populations (Nooksack, Skagit, Snohomish, Nisqually). Green River population sampling occurred opportunistically, a result of seining for steelhead in that area[1].

Approach

Size-selective mortality has been widely reported during the juvenile stages of anadromous salmonids and is a predominant force affecting marine survival and adult run size, but can operate at different life stages for different species and stocks of anadromous salmonids. Consequently, size-selective mortality provides a conceptual framework for examining and linking processes that affect growth and survival at different life stages of anadromous salmonids, and for identifying and quantifying when and where critical periods of growth and survival occur. By relating size (weight, fork length, condition) of juveniles to adult returns or smolt-to-adult survival (SARs) at regular intervals during sequential life stages (i.e., at smolt trap and/or hatchery, estuarine, nearshore marine, and offshore marine), we can identify life stages that are most influenced by size-selective marine survival (critical sizes and critical periods) for fish originating from different regions of Puget Sound. By collecting length, weight, and scale (or otolith) samples at each juvenile life stage and for returning adults, shifts in back-calculated size at specific life stages will be used to: determine the magnitude of size-selective mortality during or following a specific life stage; identify the periods of critical growth or mortality; and quantify stage-specific relationships between size and survival. Furthermore, by collecting concurrent data on diet, size, scales, blood samples (for archival IGF-1 growth analysis), fin clips (for archival genetic & stable isotopes) for both marked and unmarked juvenile salmon and their potential competitors, biomass and numerical density of key zooplankton prey, and temperaturesalinity during each of these life stages, we can use bioenergetics model simulations to diagnose which factors most affect growth for specific periods, regions and stocks or species. ***While samples and data will be collected and archived methodically for all salmon and forage fish species encountered, sample processing and analysis for this project will focus primarily on Chinook and coho salmon..***

This work will focus on early marine life stages of Chinook salmon from marine entry past smolt traps, through the estuarine and nearshore-offshore marine regions of selected watershed. The primary watersheds identified (except for the Green/Duwamish) offer valuable collaborations with extensive sampling in freshwater, estuarine, and nearshore marine habitats by tribal, NOAA, WDFW, and others that allow us to link timing and growth performance and size-selective mortality of these earlier life stages to that of the critical offshore rearing stages of Chinook reported by Duffy and Beauchamp (2011) for hatchery Chinook.

Sampling activities will be conducted over the peak migration and residence timing of juvenile salmon through the lower river, estuary, nearshore and offshore. The collection activities, by location are described, below. Offshore sampling site selection will be influenced both by known migration routes for the targeted populations and physical oceanographic data and associated circulation models that provide insight into where prey productivity may be greatest.

Fish Collection Activities

Hatchery Release (state/tribal comanagers) – Representative size distribution (individual fork length & weight), scale & otolith samples, and freeze voucher specimens will be collected for subsequent analyses (baseline stable isotopes, genetics, energy density, condition) just prior to release. Also scales, archival fin tissue, and blood (IGF-1 analysis) samples will be taken prior to release. Abundance and dates of release and marking by release group will be recorded with ability to refer back to size distributions, etc. of specific release groups.

Smolt Trap (state/tribal comanagers and other operators)– Abundance and size structure will be recorded by trapping date for each species and marked group with ability to refer back to size distributions, etc. of specific marked-unmarked groups. Representative size distribution (individual fork length & weight), scale [& otolith if allowable] samples, and freeze voucher specimens will be collected for subsequent analyses (baseline stable isotopes, genetics, energy density, condition). Also, fin tissue for genetic stock ID and blood samples for future IGF growth analysis of wild and hatchery (all externally marked) salmon and a general sample of unknown-origin salmon will be collected.

Estuarine Sampling (NOAA, state/tribal comanagers, UW, and others)– Tide channel traps (fyke nets) or beach seines will be used. Timing, duration, and peak usage, size distribution will be recorded by stock & mark group, sample scales subsample for diet composition, otoliths, genetics, etc.

Nearshore Marine Sampling (NOAA, state/tribal comanagers, UW, and others) - At <u>4-6 nearshore sites</u> (2 delta sites and 2-4 nearshore marine sites) for each representative watershed, <u>beach seining</u> would be conducted at least biweekly from March-through August and monthly August-September, using a floating beach seine (37.0 m length x 2.0 m height, with mesh grading from 3 cm in the wings to 6 mm at the cod end) according to standard estuarine fish sampling protocol (Simenstad et al. 1991). The beach seine would be deployed from a small boat parallel to and 33 m from shore and 37 m tow lines on each end would be hauled into shore by hand.

Offshore sampling (UW, NOAA) for juvenile Chinook and coho, their primary zooplankton prey, and potential competitors and predators will be conducted in epi-pelagic habitats. We will record vertical profiles for environmental conditions (salinity, temperature, oxygen, light, turbidity, fluorescence) with CTD casts at all of the zooplankton and a subset of offshore fish sampling deployments. We will also combine our periodic oceanographic profile data with publicly available data including Wa Dept Ecology's long-term Water Quality Monitoring Program, King Co Marine Monitoring Program, UW PRISM. Bi-monthly or monthly purse seining (8-10 sets/basin, max April - October) will bracket the nearshore-offshore transition and primary offshore rearing period of Chinook and coho and provide samples for fish size and growth, scales, otoliths, diet, and relative abundance for juvenile salmon and forage fishes by region. Purse seining maximizes the number of useable scale samples, minimizes handling mortality of ESA-listed species, and provides representative samples of juvenile salmon, potentially competing forage fishes, and predators (i.e., resident forms of subadult Chinook and coho). Purse seining would sample epi-pelagic salmon once in April, twice monthly during May-September, and once in October in each marine basin. Purse seining would occur predominantly during daylight hours (approximately 1 set/hr) on a fixed transect or grid pattern. Within each basin and month, additional sets would sample through dusk and initial hours of the night to capture the presumed peak predation period by larger resident salmon on juveniles and to sample the other nocturnal fishes that represent potential competitors or species that might buffer predation impacts. Midwater trawling by Canada DFO (R/V Ricker) will be conducted in Admiralty Inlet, Central and Whidbey Basins for 3 days in July and September each year to provide depth-stratified (0-15m, 15-30m, 30-45m, & fewer 45-60m; Duffy et al. 2010) samples of salmon and forage fishes to maintain an essential time series (1997- present).

Note that representative samples of forage fishes and other species will be recorded and frozen onsite at all marine sites to provide a methodically-collected frozen archive available for processing and analysis in support of this or other programs.

Sample Processing- . All collected fishes will be identified and counted with a subsample retained for measuring fork length & weight, and for collecting diet, scale, and tissue samples. Each species of fish would be counted by marked (adipose clip, CWT) and unmarked groups, and all or a representative subsample of each species or mark/unmarked group would be measured for fork length (N = 30-50 if available), scale samples taken from the preferred location just below and posterior to the dorsal fin and affixed to pre-numbered gummed scale cards. For juvenile and resident Chinook and coho, up to 20 individuals from each 100-mm size class will be anesthetized to collect stomach contents via gastric lavage, scales for stage-specific growth, and archival blood and fin tissue samples for IGF-1 and genetic analysis. After recovery, they will be released near the capture site; any Chinook mortalities will be immediately frozen whole to provide archival samples for diet, fatty acid (FA) analysis, stable isotopes, genetic stock identification, calorimetry, and other potential analyses for this and future projects. A subsample 10-15 of non-ESA listed salmon, forage fishes, and other predatory fishes will be euthanized in an overdose of buffered MS-222 and frozen immediately for diet, fatty acid analysis, stable isotopes, and calorimetry. Coded Wire Tags (CWT) will be processed by WDFW and data will be obtained from the online database (http://www.rmpc.org/). Monthly diets of Chinook, herring, and all species of potential salmon predators will be determined as wet weight proportions of key prey taxa by size, month, and region (Beauchamp et al. 2007a, Duffy et al. 2010). Growth inputs for bioenergetics modeling of other fish will be taken from scales, modal size-at-age, or literature.

Analysis of Size-selective mortality and Critical Growth Periods- We will identify critical periods of size-selective mortality, based on disproportionate reductions in the smaller members of a population between earlier and subsequent life stages, using scale-based back calculated size at life stage analysis (e.g., Beauchamp and Duffy 2011; Figure 3).

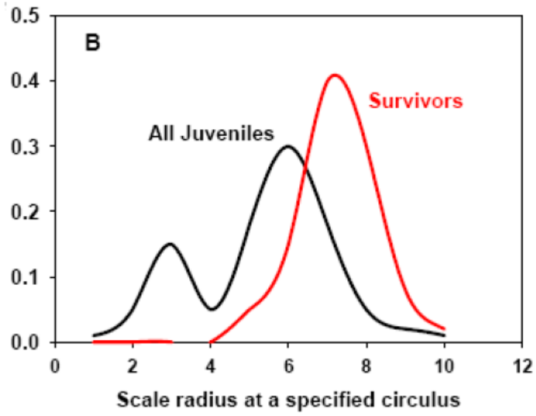

Figure 3. Hypothetical comparison of size-at-circuli frequency distributions for juveniles sampled at an earlier life stage (Black curve) and survivors (Red) at some later life stage. After accounting for emigration effects between sample periods, the right-ward shift indicates that size-selective mortality removed the smaller fish sometime between the initial and final sampling events.

Critical periods will be related to size and growth of salmon at specific life stages and associated habitats for each watershed. Scales will be mounted on gummed cards, pressed into acetate impressions and digital images captured through a video microscope (Leica MZ6 with attached RS Photometrics camera) at 16X magnification by Image-Pro Plus software. For each sample, the total circuli counts will be recorded and radius from the middle of the focus to each circulus measured. A regression of fork length (FL) to total scale radius will be developed and used to back-calculate body size-at-circulus. When sufficient sample size is available, the back-calculation regression will be generated for individual stocks and year classes; otherwise, a generalized regression will be developed for subyearling Chinook within the sample year. Individual growth histories for juvenile Chinook salmon of known origin (CWT and thermal otoliths) will be back-calculated using scale circuli measurements from scale samples associated with each life stage x sampling period x habitat combination. Modal circuli counts will be identified for each life-stage x habitat x time combination to determine benchmark circuli associated with these life stages. Frequency distributions of size-at-circuli for benchmark circuli will be compared at sequential life stages of known-origin Chinook to identify the timing, magnitude and life stage associated with size-selective mortality (Moss et al. 2005, Cross et al. 2009, Beauchamp and Duffy 2011).

Archival (2001-2009) early marine growth trajectories will also be compared between scales sampled from juvenile life stages & samples from returning adult Chinook from the same brood year to determine the magnitude of size-selective marine mortality, & identify successful growth strategies (Moss et al. 2005; Cross et al. 2009; Beauchamp and Duffy 2011; **Figure 4**).

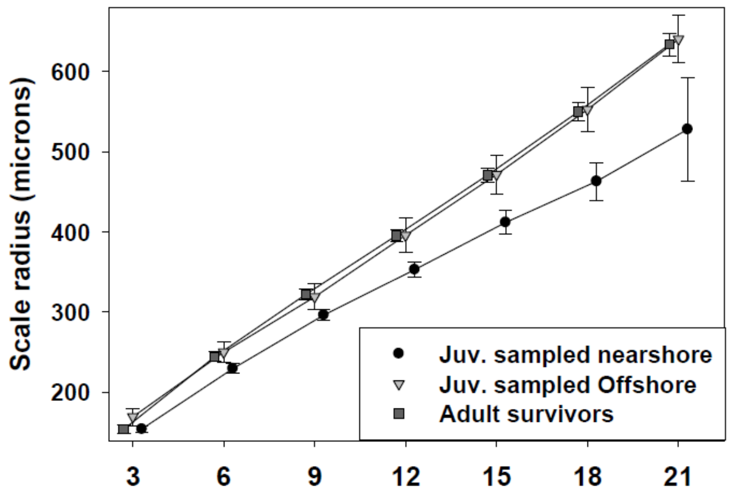

Figure 4. Early marine growth trajectories for Puget Sound Chinook captured as juveniles in nearshore vs offshore zones in Puget Sound during July, and from returning adults. Note that nearshore growth was lower, whereas offshore growth was similar to that of the surviving adults (from Beauchamp & Duffy 2011).

The adult growth trajectories also represent a statistical sampling of inter-annual growth patterns that resulted in survival to adulthood; the life-stage specific growth trajectories from each watershed and habitat/life stage will be compared to this generalized pattern for surviving adults. Similar growth back-calculations will be performed on unmarked (presumed wild) Chinook and will be analyzed separately and also as a pooled population of "generalized" juvenile Chinook. We expect that wild Chinook and coho will become genetically identifiable within the next few years. At that time we can revisit the stage-specific habitat use and growth performance of these identifiable wild stocks, by population, in comparison to the known hatchery stocks and general juvenile population.

Diagnostic Bioenergetics Modeling- We will estimate individual feeding rates and population-level consumption demand for zooplankton and other prey by juvenile Chinook, coho, and herring on a monthly and regional basis (Beauchamp et al. 2007a) using the Wisconsin bioenergetics model (Hanson et al. 1997) with the new and archival data for monthly habitatspecific diet, growth, and temperature. The models will fit consumption estimates to observed growth rates for juvenile salmon, herring, and predatory resident salmonids (older Chinook and coho salmon), given the thermal regime and temporal diet variation experienced by the consumers (Hanson et al. 1997; Beauchamp et al. 2007a). Corroborations of these models for salmonids have shown that model predictions of consumption fall within ±10% of independentlyderived estimates (Beauchamp et al. 1989; Brodeur et al. 1992; Madenjian et al. 2004). Feeding rates (%Cmax) will be estimated and compared among life stages and habitats and to previous years (Beauchamp and Duffy 2011; Kemp in prep.) to determine whether growth during critical periods is limited by feeding rate, prey quality or temperature regime. Population-level consumption rates (either based on absolute consumer abundance or based on a size-structured population of 1,000 for each species of consumer) will be compared to monthly and regional biomass and production estimates for key zooplankton prey to determine whether planktivorous fish deplete zooplankton supply, and thus evaluate whether inter- or intra-specific competition among planktivores affects growth (e.g., Beauchamp and Duffy 2011). The concurrent samples and data for the other major planktivorous fishes will also be analyzed as funding permits; otherwise, they will be frozen and data archived to maintain the capability to expand bioenergetics analysis to the greater pelagic planktivore community.

Sub-adult resident coho and Chinook salmon are highly piscivorous, and their per capita monthly and annual predation rates on all major prey species will be estimated in terms of a sizestructured unit population of 1,000 predators, based on their observed size structure, monthly diet, growth, and thermal experience in Puget Sound (Beauchamp and Duffy 2011). These predation estimates will then be scaled up to approximate the predation impact by the total resident population of each species using population reconstruction scenarios and residence periods developed from the CWT and telemetry data. Predation rates by salmon predators will be compared to the abundance or biomass of juvenile Chinook and other fishes to estimate mortality imposed by larger salmonids, and other predatory fishes.

Zooplankton Collection (UW, NOAA, and tribes) – See section 2. Zooplankton: Establishing a Puget Sound-wide zooplankton, above for methods. We will sample juvenile salmon prey fields (primarily zooplankton, but also ichthyoplankton) using identical protocols to those that scientists at NOAA and Oregon State University have used for years in their OR and WA coast assessments of juvenile Chinook & coho salmon growth and survival. Using these methods, zooplankton availability in June was highly correlated with adult returns of fall Chinook 2 years later (C. Morgan, OSU; Figure 5), as was juvenile growth (not shown), indicating that early summer prey fields are an excellent index of growth over the time scales that correlate with survival. In the laboratory, samples will be counted, measured for biomass, and organisms will be identified with a focus on taxa which are key prey items for juvenile salmon and forage fishes (i.e., crab larvae, amphipods, large copepods, euphausiids, polychaetes, other decapods, chaetognaths, pteropods).

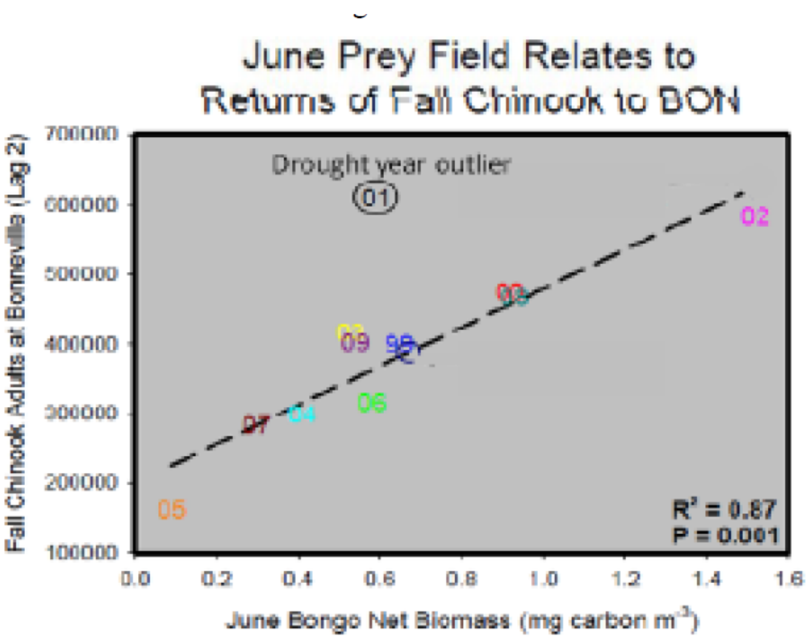

Figure 5. Relationships between an index of June food supply (C. Morgan, OSU) and adult Chinook returns 2 years later. Food supply was measured by the same methods we propose to use here: a set of 60-cm diameter, 335-µm mesh bongo nets towed over the upper 20-m of the water column.

Genetic Analysis (WDFW, NOAA) **[North Puget Sound Only] -**A primary piece of the proposed work will be to assign individual fish to specific populations. The Washington Department of Fish and Wildlife (WDFW) will conduct genetic stock identification (GSI) of all samples returned to the laboratory using the new Chinook Technical Committee's standard 192 SNP (single nucleotide polymorphism) panel. This PANEL promises improved resolution for specific stock identification. Prior to the GSI work, WDFW will genotype and analyze a new baseline of Chinook stocks to determine our ability to identify individuals stocks from within the Whidbey Basin and Nooksack watershed. This information will be used to identify juvenile outmigrants as well as sub-adults that potentially represent a resident life history type. Genetic stock identification of individuals of wild origin that represent this life history type has never been reported and would provide a critical piece to understanding a relatively unknown and, potentially very important, migratory strategy for Chinook salmon unique to the Salish Sea. For more information about this analysis question 3 of the Response to Early Review Comments uploaded in PRISM. Lead personnel: Ken Warheit, WDFW.

Recent growth history and habitat specific performance (NOAA) **[North Puget Sound Only]** - Recent growth history and individual performance among specific life stages/habitat types will be assessed by comparing insulin-like growth factor-I (IGF-1) values of sub-sampled individuals. IGF-1 is a plasma hormone directly related to skeletal growth in vertebrates (Lupu et al. 2001). IGF-1 is regulated internally by the hypothalamus and the pituitary gland via the release of growth hormones that stimulate IGF-1 production in the liver and other organs. However, external factors such as photoperiod, consumption, diet, and temperature also contribute to the production of IGF-1 and influence growth rates via food quality and metabolism allowing for a more holistic conceptual approach to habitat specific preformance. A number of studies have shown strong correlations between IGF-1 and instantaneous growth rates (e.g. % body/day) in Pacific salmonids and have corroborated its usefulness as a growth index representative of specific growth rates over the previous 1-2 weeks (Beckman et al. 1998; Beckman et al. 2004). IGF-1 differs from metrics such as condition factor when measuring recent growth history in that it directly stimulates cellular growth whereas condition factor simply reflects growth over a given period of time. In addition, sample processing costs are far lower than those associated with scale and/or otoliths and sample processing times are significantly faster. We propose to compare IGF-1 values among habitats/life stages to assess habitat quality and relative fitness and performance of individuals within and among populations and geographic areas. Such analysis, when paired with a bioenergetics approach as proposed, will provide critical information regarding individual performance in specific habitats. Lead Personnel: Brian Beckman, NOAA Fisheries; Josh Chamberlin, NOAA Fisheries.

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2. Zooplankton: Establishing a Puget Sound-wide zooplankton sampling program

Principal Investigator: Julie Keister (U. of Washington), with substantial coordination from multiple parties in Puget Sound, including: Tulalip Tribes, Nisqually Indian Tribe, King County, Port Gamble S'Klallam Tribe, Lummi Nation, Squaxin Tribe, KWIÁHT, NOAA Fisheries, and U. of Washington affiliates.

This research activity will establish a zooplankton sampling program to:

1) Estimate the temporal-spatial availability of key zooplankton prey for juvenile Chinook and coho by depth strata in offshore regions of Puget Sound through the spring-summer growth period.
2) Contribute to the development of Ecological Indicators of salmon survival in Puget Sound. Data generated by sampling throughout Puget Sound will be compared to salmon growth and growth-survival time series to explore spatial and seasonal relationships between prey availability and survival. Samples collected by NOAA in 2011, and diet data conducted by D. Beauchamp (USGS) in 2001-2002 and in 2001-2013 in some Puget Sound sub-basins, will be compared to salmon SARs as a baseline.

Project Design

The field program is designed to quantify zooplankton in Puget Sound to: 1) To measure how the prey field of salmon and other fish varies spatio-temporally and correlates with survival; 2) To address how environmental variability affects the Puget Sound ecosystem through (or reflected by) changes in zooplankton. Two types of sampling will be conducted. The first (obliquely-towed bongo nets) is designed to sample the dominant juvenile salmon prey and provides "Prey Field Indicators." The second (vertically lifted ring nets) can be used to develop what is referred to herein as "Ecosystem Indicators." Both (described in more detail below) have been used in other systems to understand how climate variability affects ecosystems and fish survival; indicators developed from both types of sampling have shown strong correlations to fish survival, have helped elucidate the mechanisms by which climate variability affects fish populations, and have been used as indicators of salmon returns.

The collections will span the out-migration period of juvenile salmon with bi-weekly sampling from mid-March through the end of September, 2014, to capture the dominant temporal and spatial patterns of prey availability to salmon. Up to twelve locations selected to represent the PSNERP geographical basins of Puget Sound will be sampled (Figure 3). Locations were carefully selected through consultation with oceanographers and fishery biologists. See "Representative Basins" below. Note: the final suite of locations may ultimately depend upon the extent of juvenile salmon sampling (see research activity 1).

At each location, onshore-to-offshore transects will be occupied consisting of three bongo net tows conducted for *Prey Field Indicators* at 25, 50, and 75 m water depth strata using 60-cm, 335-µm mesh bongo nets equipped with a flow meter and towed obliquely over the upper 20 m of the water column. At each location, one vertical water column tow, sampled at a water depth of ~100 m, will be conducted for *Ecosystem Indicators* using a 60-cm diameter, 200-µm mesh ring net with flow meter. Up to 720 zooplankton samples will be collected and analyzed during this sampling program (540 *Prey Field Indicator* and 180 *Ecosystem Indicator* samples). Specific protocols have been created and are available upon request.

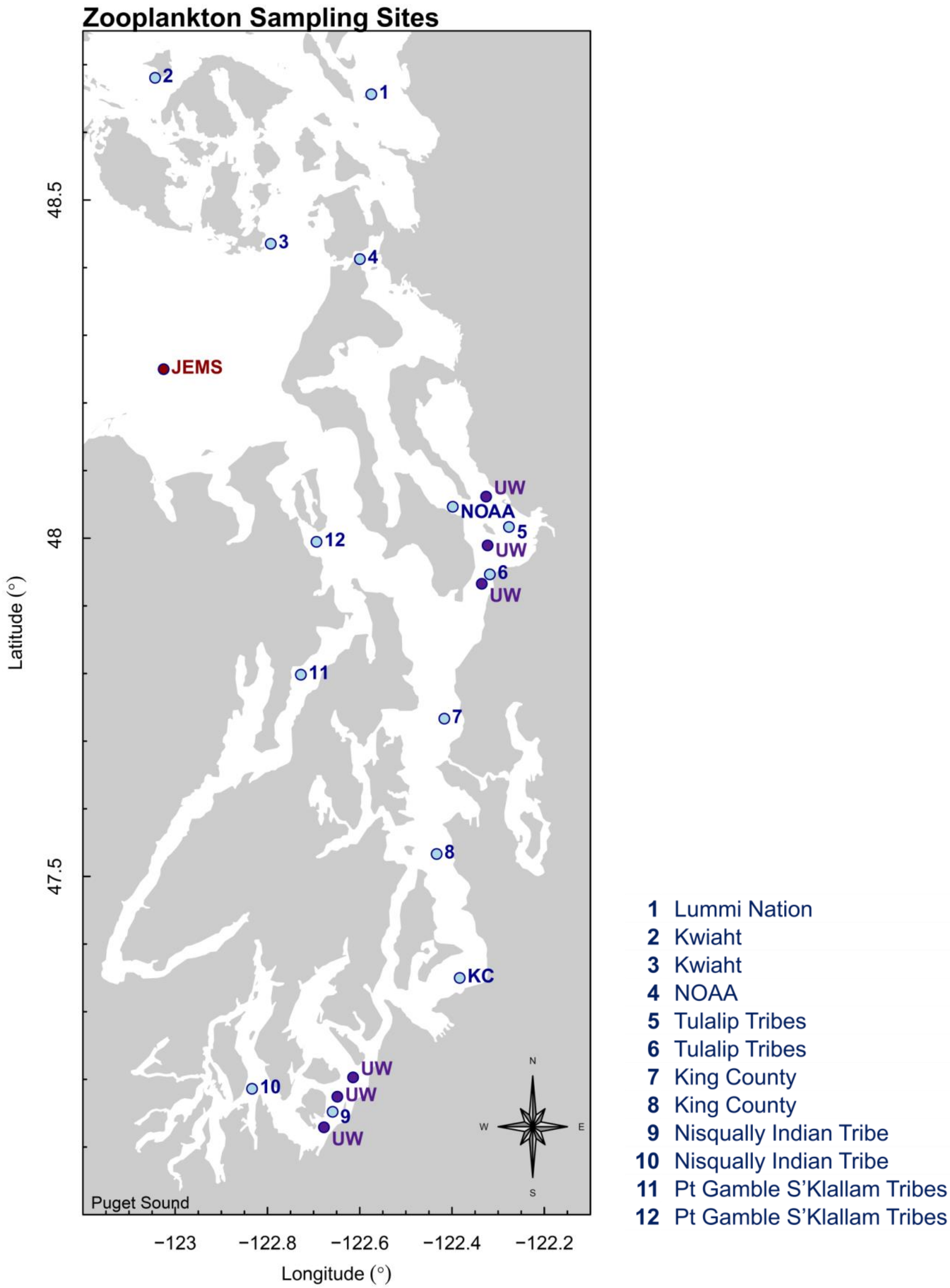

Figure 1. The twelve zooplankton monitoring locations representative of the PSNERP geographical basins and geographic range of key salmon and steelhead-producing systems within Puget Sound, Washington. Blue dots = monitoring sampling sites. Purple dots = supplementary sties for critical growth study. Red dot = JEMS site.

Prey Field samples will be analyzed in the laboratory with a focus on the taxa which are key prey items for juvenile salmon and forage fishes (i.e., crab larvae, amphipods, large copepods, euphausiids, polychaetes, other decapods, chaetognaths, pteropods). Organisms will be measured for conversion from abundances to biomass. For practical reasons, all sample collections will occur during daylight, so these methods will not capture organisms such as adult krill which perform large diel vertical migrations. However, identical protocols used in the California Current by NOAA NWFSC show strong correlations with juvenile salmon growth and survival, indicating that the collections index the available prey field.

Ecosystem Indicator samples will be analyzed at a higher taxonomic level to capture the relatively subtle shifts in species dominance that occurs in response to environmental variations. Those samples will be analyzed by a highly-trained taxonomist.

Representative Basins

Puget Sound sub-basin spatial representation (Simenstad et al. 2011) was considered when choosing sampling transect locations. The PSNERP basins represent oceanographically distinct regions of Puget Sound. Transects were selected from locations within 5 sub-basins:

- San Juan Islands and Georgia Strait Basin
- Whidbey Basin
- South Central Puget Sound Basin
- South Puget Sound Basin
- Hood Canal

In addition, the JEMS station in the Strait of Juan de Fuca will continue to be sampled by WDOE and Western Washington University. Proposed sampling sites (and those performing the sampling) within the representative basins include:

San Juan Islands/Georgia Strait Basin: (1) Bellingham Bay (Lummi Tribe collection), (2) N. and (3) S. San Juan Islands (KWIAHT Center collections), Whidbey Basin: (4) Skagit Bay (Skagit River System Cooperative and NOAA Fisheries collection), (5) N. Saratoga Passage and (6) Port Susan (Tulalip Tribes collections), South Central Puget Sound Basin: (7) Point Wells and (8) Alki Point (King County collections), South Puget Sound Basin: (9) S. Tacoma Narrows and (10) Budd Inlet (Nisqually Tribe collections), and Hood Canal/N. Central Puget Sound Basins: (11) Hoodsport and (12) N. Hood Canal (Port Gamble S'Klallam Tribe collections).

The regions shown in Figure 3 all produce significant numbers of hatchery- and natural-origin stocks of Chinook, coho, steelhead and other species and represent the geographic range of key salmon-producing systems within Puget Sound. There is a range of habitat quality, oceanographic conditions, and growth and survival of salmon (Duffy et al. 2005). The watersheds of the South and Whidbey Basins feature extensive high-quality estuarine-rearing habitat compared to the Central Puget Sound watershed. This is reflected in differences in juvenile salmon diets (Duffy et al. 2010). Temperatures, salinities, and the seasonal cycle of primary production also differ among regions; differences which will likely be reflected in the zooplankton assemblages present there.

Data analysis- Ecosystem Indicators and Relationships with Growth and Survival

The proposed sampling protocols replicate those currently used in NOAA NWFSC's "Red-Light, Green-Light" forecasts of California Current salmon returns[34]. The indicators developed from NOAA's sampling have been used to link climate variability to salmon survival (e.g., Keister et al. 2011; Peterson 2009; Peterson and Schwing 2003). Similar zooplankton indices have been used in the North Sea to understand changes in cod recruitment (Beaugrand and Reid 2003; Beaugrand et al. 2003)—larger copepod species dominate during cold climate regimes, which translates to higher growth (and thus survival and recruitment) of cod. These types of indices are important components of fish population forecasts, so developing these types of indices in Puget Sound is a high priority and is a major goal of this project.

Ecosystem Indicators analyses will be performed according to the methods described in section, "**Ecosystem indicators: stoplight modeling, single & multi-variant analyses, & other approaches**", below. Analyses of relationships of the temporal-spatial availability of key zooplankton prey with size and growth for juvenile Chinook and coho will be performed according to the methods described in research activity 1, above.

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[34] *See*: http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ea-copepod-biodiversity.cfm)

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3. Physical characteristics and primary production: Upgrading and utilizing the ORCAS buoy network and NANOOS

Principal Investigator: Jan Newton (U. of Washington), John Mickett (U. of Washington)

The ORCA buoy network (along with the Washington Department of Ecology, King County and other party's buoy data and existing water quality cruises, where appropriate) will be used to document spatial and temporal variability in weather (sunlight, air temperature, and wind), phytoplankton biomass (chlorophyll) and hydrographic features (water column temperature, salinity, density structure, including the mixed layer depths and degree of stratification). These data will contribute to the sampling program in order to evaluate bottom-up control of salmon productivity. The data are also critical for constraining the numerical model that will test the bottom up hypotheses stratification.

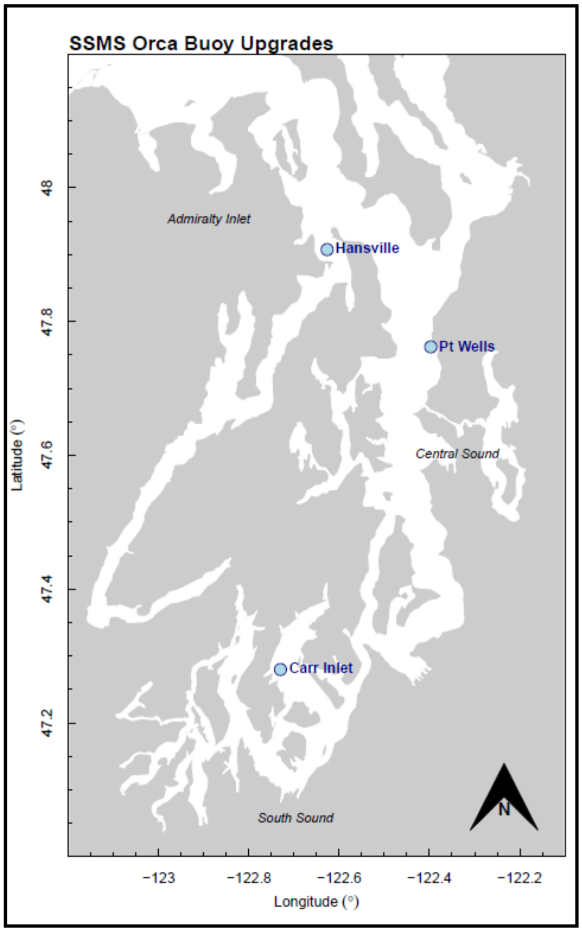

Figure 3. Current locations of ORCA buoys in Puget Sound network[1]

Photosynthetically active radiation (PAR) sensors and full weather stations (with surface wind sensors) will be updated on the three ORCAS buoys in Puget Sound proper (near in Central and South Puget Sound). This effort will also work directly with efforts focused on ocean acidification (e.g., new UW ocean acidification program) to ensure that marine carbon chemistry and pH are included in the suite of baseline physical attributes monitored in strategic locations within the Salish Sea.

The physical data will be aggregated and managed via the online NANOOS platform.

If funding becomes available, one additional ORCA buoy will considered for the network in Puget Sound proper. The locations for new buoys under consideration include Saratoga Passage in Whidbey Basin, Totten Inlet in South Puget Sound Basin, and Bellingham Bay in the Georgia Strait Basin.

Methods: Met Pak Pro Weather Stations (Model 100 1723-2A-4-111). The weather stations include sensors for temperature, relative humidity and dew point, and barometric pressure. The unit is supplied with 10 M Cable to work with remote wind sensor Model 200-7000-2 WindSonic Wind Speed & Direction Sensor. We will integrate a LiCOR LI190 PAR sensor to the buoys as well. These data streams will feed into existing data transmission routings we have established for near-real time data transmission. The data feeds are viewable and downloadable (up to 60 days) on the NANOOS Visualization System (NVS) portal (www.nvs.nanoos.org) and viewable on the ORCA buoy website (http://orca.ocean.washington.edu/) and the full QC'ed data sets will be made available to the project team by the UW principal investigators. The ORCA buoys are maintained and quality assured as described in the QAPP we established with the Washington State Department of Ecology (http://orca.ocean.washington.edu/QAPP.html).

4. Investigating life history, age, and growth of adult Puget Sound salmon using otolith microchemistry and scale morphometrics

Principal Investigator: Lance Campbell (WDFW)

Background

The survival of hatchery Chinook (Oncorhynchus tshawytscha) and coho salmon (O. kisutch) within Puget Sound have been linked to geographic location (Hobday and Boehlert 2001, Beetz 2009, Zimmerman et al 2013), ocean conditions and interspecific interactions therein (Ruggerone and Goetz 2004), and early marine growth and release size (Beamish et al. 2004, Duffy and Beauchamp 2011). However, relatively little is known about the early marine growth and survival of wild salmon stocks within Puget Sound. In this study, we will measure juvenile life history parameters (such as size and time of estuary/ocean entry) using otolith chemistry of adult Chinook salmon returning to three geographic regions within Puget Sound (southern, middle, and northern). We will evaluate the hypothesis that diversity of juvenile salmon life histories within Puget Sound differs among regions as a consequence of early ocean survival (task 1.1). Additionally, we will examine the age and marine growth (scale analysis) of selected returning adult Chinook, coho and chum salmon populations in the Salish Sea and Coastal Washington (task 1.2). We will test the hypothesis that interannual variation in early marine growth, and variation in growth among populations effects adult survival. The goal of this research is to: 1) enumerate any differences in age and marine growth among populations and geographic regions and 2) make marine growth data available for survival and forecasting models.

Approach

Calcified fish tissue and bones are well suited for studies of age, life history, residency, and growth due to three factors: 1) periodicity of newly deposited calcified tissue—days to weeks (Panella 1971, Boyce 1985); 2) relationship between fish size and structure size (scales, otoliths, bone) (Bilton 1975, Campana and Neilson 1985, Volk et al. 2010); 3) correspondence between water chemistry and the microchemistry of certain calcified structures (Kalish 1990, Fowler et al. 1995, Zimmerman 2005). Moreover, the formation of daily growth increments (otoliths), circuli (scales) and annuli (otoliths, scales, and bone) and to some degree the chemical signal in these structures are not subject to change once deposited (with some exceptions). Therefore these structures can potentially provide an archival record of size, growth, and the environmental chemistry an individual fish encounters during its life cycle (Campana and Neilson 1985). A critically-important transition made by juvenile anadromous salmonids occurs when they move from freshwater rearing areas into brackish or marine waters. Fortuitously, the concentration of strontium (Sr), a close chemical analog of calcium (Ca), increases dramatically from freshwater to seawater. As such, several researchers have used the difference in abundance of Sr to delineate when salmonids enter and start to rear in marine waters (Kennedy et al. 2002, Volk et al. 2010, Miller et al 2010, Campbell 2010). Transects of anadromous salmonid otoliths, for instance, are characterized by low Sr:Ca ratios for periods of freshwater rearing and increased Sr:Ca during periods of brackish and marine-water residency (Kalish 1990, Friedland et al. 1998, Zimmerman 2003).

4.1 Life history analysis of adult Chinook salmon otoliths (selected Puget Sound watersheds)

The objective of this study is to determine the contribution of juvenile fresh water life histories among returning adult Chinook to the selected Puget Sound watersheds. Adult otoliths will be selected based on availability and geographic region, with emphasis placed on samples from southern, middle, and northern Puget Sound. These locations could include the Nooksack, Skagit, Snohomish, Cedar, Green, and Nisqually Rivers or equivalent systems. Adult otolith samples (n~50-100 per year/ river) will be prepared for micro-chemical analyses to determine size at estuary/ocean entry by back calculation and Sr/Ca inflection point (fig 1). For the entire set of samples, we will calculate the proportion of various size classes (<45 mm, 45-60, 61-90, 91-120, >121) and times (emergent fry, summer parr, and fall parr) of brackish/marine entry (fig 2). The juvenile life history strategy of surviving adults will be compared to the life history strategies observed at smolt traps to determine if certain life history pathways survive better than others (table 1). For example, Chinook salmon in major Puget Sound rivers such as the Skagit, Cedar, Green, and Nisqually typically have two distinct migrations: an early (February – May) movement of fry caught shortly after emergence from spawning gravels (< 45 mm) and a later (July - August) migration of larger parr (> 60 mm) that have spent some time rearing in freshwater (Kinsel et al. 2008, Topping and Zimmerman 2013, Kiyohara 2013). Our otolith results, in conjunction with juvenile outmigration data, will allow us to examine the presence and magnitude of size selective mortality occurring at different juvenile life histories (fry, parr fingerling). This data is essential for understand the effects of size selective mortality on future runs (forecasting) as well as the critical information gaps needed to guide habitat restoration.

Furthermore, any differential survival of life histories among geographic regions would provide suggestive evidence for differential early marine survival within Puget Sound. Specifically, populations in southern Puget Sound have declined more than those in the middle and northern basins, and variation in size and growth of fish from different basins may shed light on factors associated with the population abundance differences.

4.2 Age and growth of Chinook, coho, and chum salmon in selected Puget Sound and coastal Washington watersheds

The objective of this portion of the study is to estimate the age and marine growth of selected Puget Sound and Coastal Washington Chinook, coho, and chum salmon populations. Specifically, does age and marine growth differ among large geographic regions: Puget Sound (southern, middle, northern), Hood Canal, Strait of Juan de Fuca, North Coast (small estuaries), and South Coast (large estuaries). For every species and population, approximately 30 scale samples per age group (primarily 2-5 years) will be examined in order to enumerate annuli and measure radial distances from the scale focus to points of interest (POI), such as freshwater annuli (FWA), primary and secondary marine checks, ocean annuli (OA) age 1-5, and total scale radius (fig 3). Back calculation at POI will then be conducted in order to estimate marine growth and size of fish at these stages (depending on species). We will also look for a correspondence between marine growth (as measured by; scale radius at ocean entrance, and 1^{st} and 2^{nd} ocean annuli) and published measures of ocean condition and survival. We will test the hypothesis that an increase in early marine growth effects overall survival. Differential marine growth for fish in Puget Sound vs. other regions will be viewed as a factor potentially limiting the recovery of endangered Puget Sound salmonids. Growth data will also be provided to researchers attempting to improve existing forecasting models; such data are an important component of these models as increased growth has been linked to higher survival rates.

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Appendix

Table 1. Location where smolt trap (juvenile data) and adult otolith collections currently exist.

location	Smolt Trap data	Adult Otolith Collection
Nooksack	Yes (LNR)	Yes (LNR/NoNR/WDFW)
Skagit	Yes (WDFW)	?
Snohomish	Yes (TNR)	Yes (TNR/WDFW)
Cedar	Yes (WDFW)	Yes (WDFW)
Green	Yes (WDFW)	no
Nisqually	Yes (WDFW)	Yes* (NiNR/USGS/WDFW)

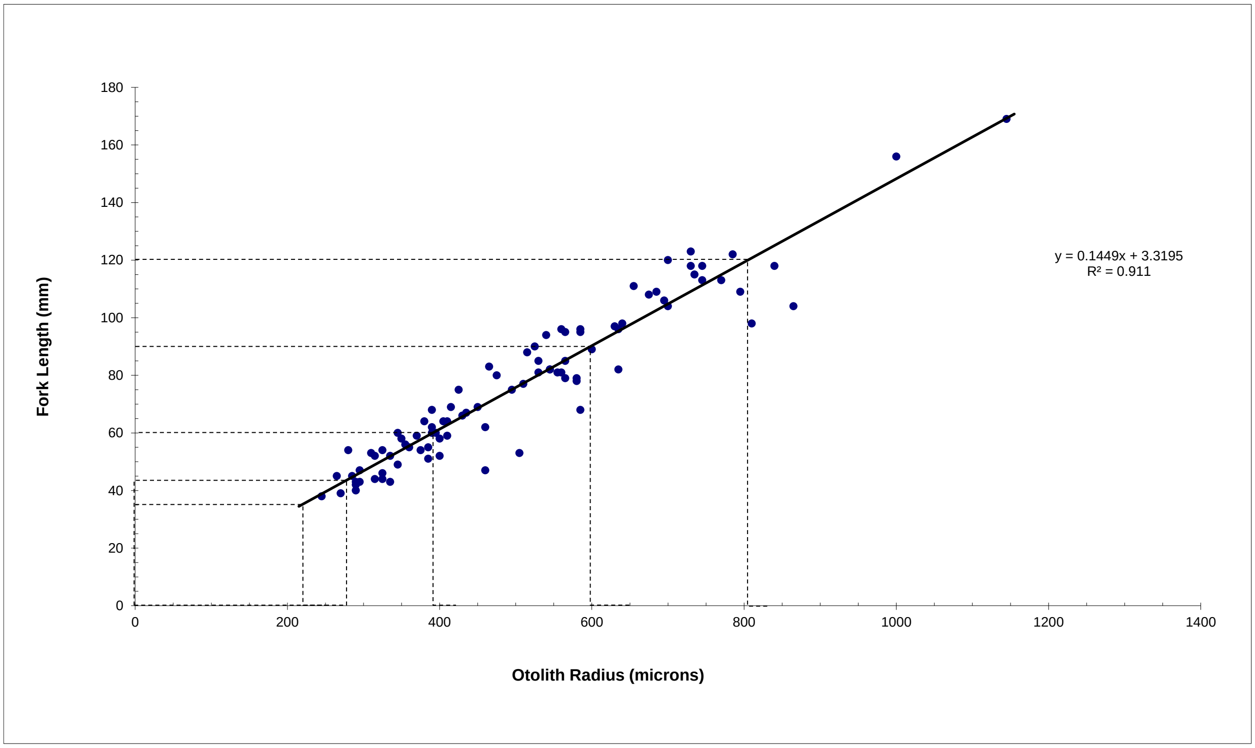

Figure 1. Fish size-otolith size relationship for juvenile Chinook salmon within the Columbia River estuary.

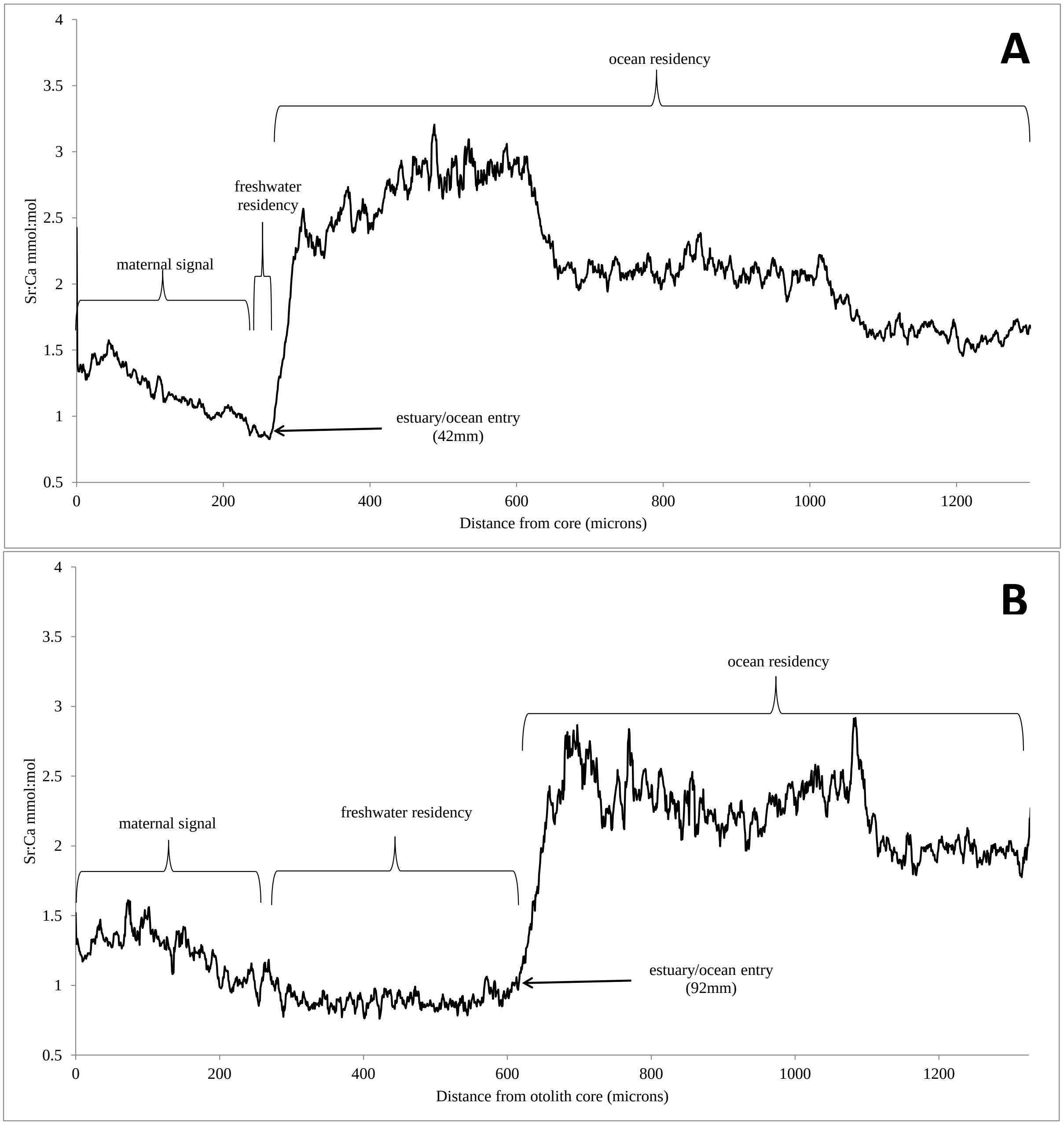

Figure 2. Sr:Ca profile (LA-ICPMS) of a life history transect from two adult Chinook salmon otoliths. A fry migrant (Panel A) and a later fingerling sized migrant (Panel B).

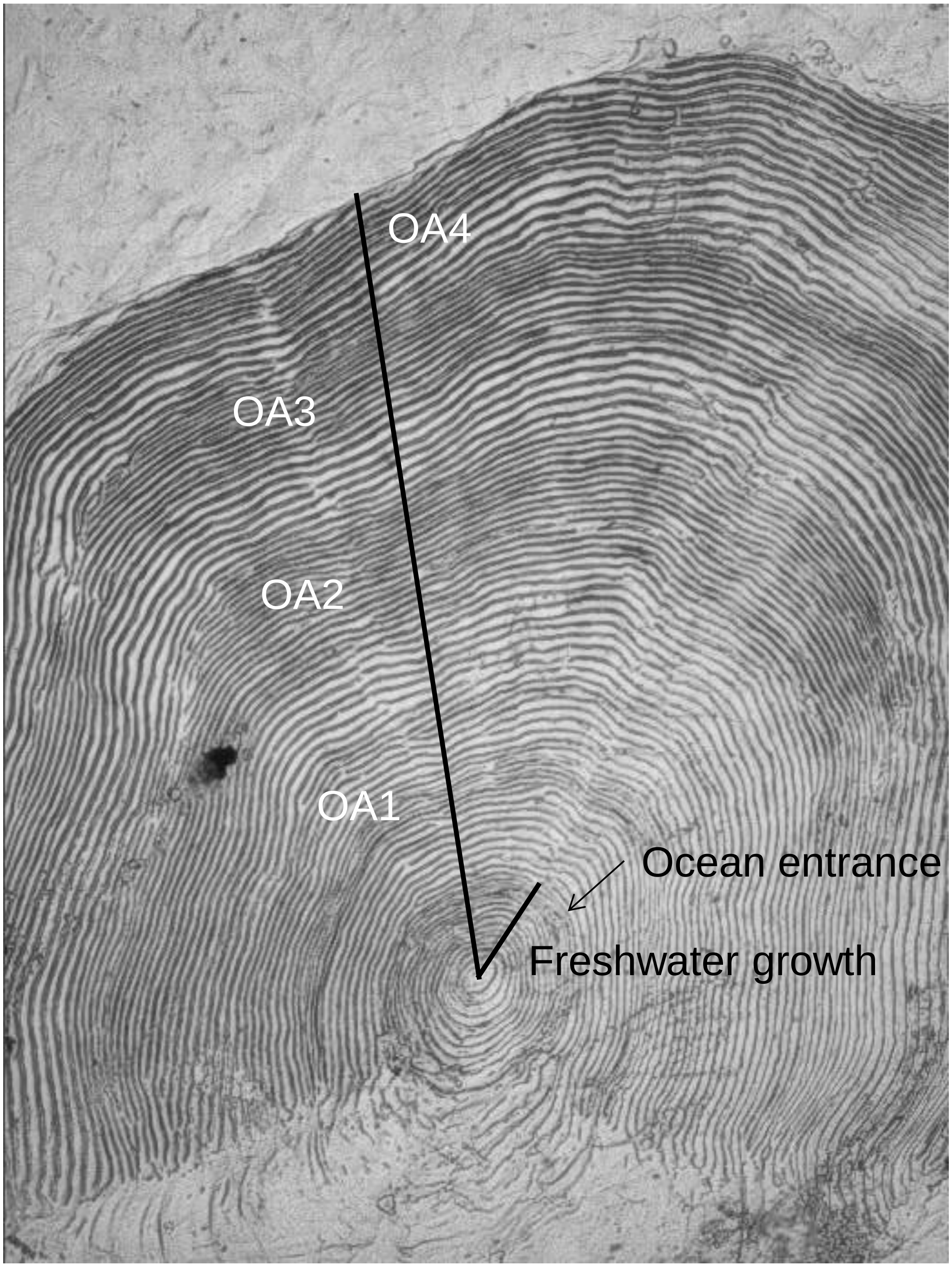

Figure 4. Adult Chinook salmon scale (age 5_1) noting ocean annuli (1-4), ocean entrance (OE) and freshwater growth.

7. Analyzing pathogens, in particular *Nanopheytus,* as contributing factors

Principal Investigator: Paul Hershberger (US Geological Survey)

Several pathogens are known to be present in Puget Sound. Many infections from these pathogens result in marine mortality, and we currently do not know broadly what infection rates are for specific salmon and steelhead species throughout Puget Sound. Doing blind surveillance, broad spectrum pathogen studies is currently very expensive. New technologies are being developed in Canada, supported in part by the Salish Sea Marine Survival Project. Once these technologies evolve, the U.S. scientists will reconsider the value of broad spectrum analyses. In the interim, U.S. disease experts have correlated what we know about Puget Sound salmon and steelhead marine survival patterns with the suite of potential pathogens. Through this process, they have determined that *Nanopheytus* is the primary disease candidate given the apparent alignment between its high prevalence and low marine survival rates for specific salmon and steelhead populations, especially in south Puget Sound.

The prevalence and intensity of *Nanopheytus* is extremely high for adult coho salmon from south Puget Sound. Juvenile coho likely become infected by *Nanopheytus* in the lower river or estuary as they outmigrate to the marine environment. It is currently unknown whether this disease leads to mortality in infected outmigrants, and its sheer prevalence warrants a better understanding of the impacts the disease may be having on Puget Sound coho populations. Similarly, *Nanopheytus* is known to affect steelhead, and steelhead from South Puget Sound and Hood Canal appear to be suffering higher early marine mortality (based upon acoustic telemetry data), known *Nanopheytus* hotspots.

Nanophyetus salmoincola, hereafter referred to generically, is a digenean trematode with a complex life cycle involving freshwater / estuarine snails, intermediate fish hosts, and definitive bird / mammalian hosts. The trematode life cycle begins when eggs are expelled into the intestine of fish-eating animals, including raccoons, otters, skunks, coyotes, foxes, herons, merganzers, etc. From the intestines, the eggs pass into the water, where a free-living life stage (miracidium) hatches and penetrates a freshwater or estuarine snail (*Oxytrema silicula* or *Juga silicula*). The parasite further develops and multiplies in the snail. Susceptible fish then consume the infected snails; afterwhich a xiphidiocercaria stage penetrates and encysts in the tissues of the fish host. Certain salmonids, including coho salmon, are particularly susceptible to infection. Once in the fish tissues, the xiphidiocercaria transition to a resting stage (metacercaria), the stage most commonly observed in infected fish, especially in the kidney. The trematode becomes sexually mature after infected fish are consumed by a definitive mammalian or avian host, thereby continuing the parasite life cycle.

Several unique characteristics of this parasite are relevant to the Puget Sound region:

- The trematode (*Nanophyetis*) is a vector for a rickettsial pathogen (*Neorickettsia helmintheca*) that causes severe disease (commonly referred to as 'salmon poisioning') in dogs throughout the Pacific Northwest. Canine exposure to the rickettsia most commonly occurs when *Neorickettsia*-associated *Nanophyetus* is consumed in raw salmon tissues. The resulting rickettsial disease causes fever, anorexia, vomiting, diarrhea, enlarged lymph nodes, and dehydration, and death if untreated. The disease often responds to treatment with antibiotics.

- *Nanophyetus* can be a zoonotic agent, infecting humans which can then serve as the definitive host. Route of human exposure is typically through consumption of raw or undercooked fish; however, transmission has also been reported in a *Nanophyetus* researcher who was handling many infected fish without using protective gloves. The trematode infection in humans responds quickly to treatment with praziquantel.
- The geographic range of *Nanophyetus* is limited by the range of the snail, the first intermediate host. The snail occurs in streams, rivers, and estuaries on the west slopes of the Sierra and Cascade Mountains, ranging from mid-California to southern Vancouver Island.

Recent surveillances of returning adult coho salmon indicate that the prevalence and intensity of *Nanophyetus* infections is currently extremely high in adult coho salmon from south Puget Sound. In recent years, *Nanophyetus* metacercaria have been detected in nearly 100% of the adult coho salmon returning to some south Puget Sound watersheds; further, kidney impressions indicate that the intensity of infection (indicated by parasite load) is often extremely high. In the south Puget Sound, infections are common to both hatchery and wild coho salmon. It is likely that both wild and hatchery coho become exposed to trematode and acquire the infection in the watershed, with hatchery coho being exposed sometime after release in the lower river or estuary. It is currently unknown whether this disease leads to mortality in infected outmigrants, and its sheer prevalence warrants a better understanding of the impacts the disease may be having on Puget Sound coho populations.

Field work will be performed to determine the prevalence and intensity of *Nanopheytus* throughout Puget Sound and to determine if/when juvenile steelhead, coho and potentially Chinook acquire the trematode infection. A Puget Sound-wide *Nanopheytus* assessment will be carried out for juvenile steelhead; however, this work may be expanded to target coho and potentially Chinook if initial findings warrant this. Disease challenges will be performed to determine whether and to what extent *Nanopheytus* may be contributing to mortality. The results will be incorporated into the ecosystem modeling and indicators analyses. The activity will be performed in conjunction with other fish sampling efforts. See the "**Research Work Plan: Marine survival of Puget Sound steelhead**"[35] for a complete description of the research approach.

[35]. Steelhead Marine Survival Workgroup. February 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA. Can be found at www.marinesurvivalproject.com

8. Analyzing Contaminants as Contributing Factors: Toxic contaminants in outmigrating juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) from rivers, estuaries and offshore saltwater habitats of Puget Sound

Overview

Contaminants from multiple sources, including known chemicals of concern, enter Puget Sound via stormwater, wastewater treatment facilities, industrial discharges and atmospheric deposition. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) migrating from freshwater to saltwater in Puget Sound enroute to the Pacific Ocean can encounter a wide range of water quality conditions, from relatively clean to highly contaminated, depending on their migration route. Impairment of water quality in freshwater, estuarine and nearshore habitats represents a significant threat to juvenile Chinook salmon populations, especially as they transition from fresh to saltwater, and may reduce their early marine survival. In this study we will measure juvenile Chinook salmon exposure to known chemicals of concern at four major Puget Sound river/nearshore marine systems, an additional marine industrial embayment, and four offshore marine basins. The objectives are to: (1) measure the magnitude of exposure in outmigrants across four major rivers, five major embayments and four offshore basins, (2) evaluate potential effects on marine survival and (3) identify "sources" of contaminant inputs along the outmigrant pathway (i.e., river, estuarine or offshore locations). Results from this work will be used to provide a measure of the effectiveness of current toxic reduction strategies and actions, inform future pollution reduction efforts, and enhance recovery of Chinook salmon.

Justification

Much attention has been paid to the physical habitat alterations and climate-driven processes that may be responsible for the recent declines in marine survival of salmon (Myers et al. 1998); Roni et al. 2002; Magnusson and Hilborn 2003) but toxic chemical contaminants also reduce habitat quality and can affect salmon survival (Meador 2014). Because of, their anadromous life-history, salmon and steelhead (henceforth, for simplicity, "salmon") may be exposed to contaminants in freshwater, estuarine and marine waters (Cullon et al. 2009, O'Neill and West 2009). While transitioning from freshwater to saltwater, juvenile salmon integrate contaminant conditions from across the freshwater/saltwater interface, the primary receiving waters for stormwater, industrial discharges and wastewater treatment plants. Impairment of water quality in freshwater, estuarine and nearshore habitats represents a significant threat to salmon populations and may reduce their early marine survival.

Sub-lethal contaminant exposures in freshwater may reduce growth of juvenile salmonids and subsequent size-dependent survival when they migrate to the ocean (Mebane and Arthaud 2010, Spromberg and Meador 2005, Baldwin et al. 2009). Likewise, sub-lethal contaminant exposure in freshwater that impairs immuno-competence may subsequently reduce marine survival, particularly as they make the parr-smolt transformation and enter marine waters (Bravo 2005, Bravo et al. 2011). Contaminant exposures that disrupt the smoltification process may alter time at entry into saltwater as well subsequent growth and immuno-competence. Once in estuaries and nearshore waters, salmon may continue to be exposed to contaminants that affect their behavior, growth, immuno-competence and disease susceptibility and ultimately, their survival (Varanasi et al. 1993; Arkoosh et al. 1994, 1998, 2001, 2010; Arkoosh and Collier, 2002; Meador et al. 2006; Meador 2014). Additionally, throughout freshwater, estuarine and nearshore saltwater habitats of Puget Sound, salmon eggs, alevins, fry, smolt and juveniles may be exposed to endocrine disrupting compounds that alter their reproductive health.

Chinook salmon are valued for their importance in commercial, recreational, and aboriginal fisheries, cultural importance to First Nations, and key role in marine and freshwater food webs (Quinn 2005). Since 1999, Puget Sound Chinook salmon have been listed as "threatened" under the U.S. Endangered Species Act. Many factors have contributed to the decline of Chinook salmon including urbanization that has resulted in habitat loss and modification and increased exposure to toxic chemicals. Among Pacific salmon species, Chinook salmon have a complex and diverse life history (Quinn 2005). Ocean-type Chinook, the predominant life-history type in Puget Sound, spend considerably more time in rivers, estuaries and coastal marine waters during downstream migration than other salmon species, and thus are more susceptible to contaminant exposure.

Systematic, comprehensive sampling of outmigrant juvenile Chinook salmon in Puget Sound has not occurred, although data from several previous unrelated studies indicate that Chinook salmon from urban rivers and estuaries are exposed to contaminant above concentrations known to cause adverse effects (Stehr et al.2000, Johnson et al. 2007, Olson et al. 2008, Meador et al. 2010, Sloan et al. 2010). Below we summarize the potential adverse effects of contaminant exposure on growth, immnuno-competence and disease resistance, and reproductive development of outmigrant Chinook salmon from Puget Sound rivers and the nearshore.

Effects of Contaminant Exposure on Salmon Growth

Adequate energy reserves and normal growth are vital to juvenile fish survival, and also strongly influence reproductive potential of adult fish. Various studies (reviewed by Johnson et al. 2014) have documented that exposure to POPs can alter growth rates and condition in fish, particularly fish exposed to high levels (> 1-2 ug/L) of PCBs, PCDDs and chlorinated pesticides. However, Johnson et al. (2014) conclude that the effects of exposure to lower POPs concentrations, which are more representative of environmentally relevant concentrations, are less consistent, with some studies reporting enhanced fish growth at low POP exposures. In general, exposures to environmentally relevant levels of POPs were more likely to affect fish growth if exposures occur during early development. Exposure to low concentrations of POPs may also have neurological effects that impair foraging ability, reduce lipid content and alter energy metabolism, leading to reduced growth (see review by Johnson et al. 2014, and references therein). Petroleum-derived compounds (PAHs) also depress growth rate of juvenile salmon, which can affect their survival (Meador et al. 2006).

Short-term-exposure to low levels of copper reduces the olfactory capacity of salmon and, therefore, their ability to detect important olfactory cues from nearby prey and predators (Baldwin et al. 2003; Sandahl et al. 2007, McIntyre et al. 2008). Copper disrupts olfaction and olfactory-mediated behaviors in Chinook, coho and chum salmon, steelhead, Atlantic salmon, and rainbow trout (reviewed by Tierney et al. 2010, see also Baldwin et al. 2011). These findings support extrapolation of copper toxicity data across species and are relevant to both hatchery and wild fish. In addition to these behavioral effects, modeling by Mebane and Arthaud (2010) suggested that body size reductions due to chronic early life stage exposure to sublethal copper concentrations could reduce juvenile salmon survival and population recovery trajectories.

Several studies in Puget Sound document that growth is impaired for out-migrant juvenile Chinook salmon while migrating through urban estuaries and bays of Puget Sound (Casillas et al. 1995, 1998; Varanasi et al. 1993). The growth rates of juvenile Chinook salmon collected from urban estuaries (e.g., Hylebos and Duwamish Waterways) and held in the laboratory for 90 days were lower than those for fish from the corresponding hatcheries or from nonurban estuaries. Furthermore, concentrations of plasma hormones involved in the regulation of growth in fish, such as thyroxine (T4), triiodothyronine (T3), and insulin- like growth factor (IGF), were altered in salmon from urban estuaries in comparison with hormone levels in hatchery or non-urban fish (Casillas et al., unpublished data). Thus exposure to contaminants may interfere with the endocrine modulation of growth in juvenile salmon, reducing overall growth.

Additionally, laboratory exposure experiments using sediment extracts from contaminated Puget Sound sites and model toxic compounds indicated that exposure to toxic contaminants may suppress growth or alter the metabolism of juvenile Chinook salmon (Varanasi et al. 1993, Casillas et al., 1998, Meador et al. 2006). In studies by Casillas et al. (1998), there was some uncertainty regarding the concentrations of PAHs required to suppress growth of juvenile salmon because fish exposed to PAHs alone at concentrations comparable to those present in the Hylebos Waterway did not exhibit consistent reductions in growth in all treatment groups, although growth was reduced consistently in fish exposed to sediment extracts containing PAHs in combination with PCBs and other contaminants. Meador et al. (2006) dosed juvenile Chinook salmon with PAHs at 5 different concentrations in feed encompassing PAH concentrations measured in stomach contents of juvenile salmon from Pacific Northwest estuaries. Significant differences in mean fish weight, and whole body lipids were detected at the two highest doses. At the lowest doses, variability in fish weights increased significantly. Additionally some significant alterations in plasma chemistry enzymes were observed at the second lowest and higher doses. These studies indicate effects of PAHs on fish growth and energy balance but also suggest that other compounds present in contaminated Puget Sound estuaries, such PCBs, are contributing significantly to growth reductions that have been observed in field collected fish; however, more work is needed to determine the relative importance of various compounds in generating this effect.

Effects of Contaminant Exposure on Immuno-competence and Disease Susceptibility

A properly functioning immune system is an important fitness trait that is vital for both individual survival and population productivity (Segner et al., 2012). Contaminant exposure can alter the immune system, either alone (Arkoosh et al., 2010; Arkoosh et al., 2000; Arkoosh et al., 2001) or in conjunction with other stressors (Jacobson et al., 2003), resulting in an increase in susceptibility to naturally occurring pathogens that cause lethal diseases, potentially leading to population level effects (Arkoosh et al., 1998; Loge et al., 2005; Spromberg and Meador, 2005).

Exposure to environmentally relevant concentrations of petroleum-derived compounds such as PAHs, industrial contaminants such as PCBs and flame retardants such as PBDEs suppress the immune system, rendering juvenile Chinook salmon more vulnerable to naturally occurring pathogens (Arkoosh and Collier, 2002; Arkoosh et al. 1994, 1998, 2001, 2010). Arkoosh et al. (1998) demonstrated that Chinook salmon from an urban estuary were more susceptible to bacteria-induced mortality from naturally occurring marine pathogens than were fish from the corresponding hatchery upstream from the urban-estuary, and fish from a nonurban estuary and its corresponding hatchery (Figure 1).

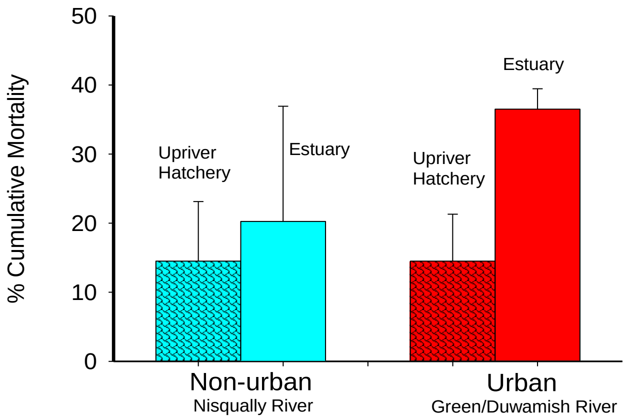

Figure 1. Cumulative mortality of juvenile Chinook salmon from an urban and nonurban estuary and their corresponding hatcheries four days after exposure to the marine pathogen Vibro anguillarum.

Adapted from Arkoosh, M.R. et al., Trans. Am. Fish. Soc., 127, 360–374, 1998; results for 2 -6 X 10-5 dilution of V. anguillarum.

Follow-up laboratory exposure studies with sediment extracts and contaminant model mixtures determined that contaminants such as PCBs and PAHs, apart from other estuarine variables specifically associated with the Duwamish and Hylebos Waterways, could independently suppress immune function and increase disease susceptibility in juvenile Chinook salmon (Arkoosh et al., 1994, 2001). More recently, studies have documented that exposure to PBDEs also influence disease resistance (Arkoosh et al. 2010). Though an adverse health effects threshold for PBDEs has yet to be determined, Arkoosh et al. (2010) demonstrated that juvenile salmon fed an environmentally relevant concentration of PBDE congeners were more susceptible to the marine pathogen *Listonella anguillarum*.

Effects of Contaminant Exposure on Reproductive Development

Several environmental contaminants, especially chemicals specifically produced to mimic hormones (e.g., ethynylestradiol in birth control pills), are known to disrupt the endocrine system and affect the reproduction, development and other hormonal functions of fish and wildlife. However, chemicals with relatively low hormonal activity can also pose a health risk because they persist in the aquatic environment (e.g., PAHs and PCBs) or are more persistent in tissues (e.g., PCBs.). There is evidence that juvenile Chinook salmon are exposed to estrogenic contaminants in estuarine and nearshore waters that can affect their reproductive development. Peck et al. (2011) documented higher plasma levels of estrogen-inducible yolk protein, vitellogenin (VTG), in field caught Chinook salmon at sites such as Elliott Bay and the mouth of the Snohomish River than non-exposed hatchery control fish. Juvenile Chinook salmon with elevated VTG during a sensitive early life stage could experience delayed reproductive effects such as those observed in independent studies on flounder or rainbow trout (Hashimoto et al. 2000 and Bennetau-Pelissero et al. 2001)

Hypotheses

The study addresses the hypothesis that chemicals released into the Puget Sound from human activities and development reduces the health and productivity of salmon and their food supply. We hypothesize that toxic contaminant inputs have increased, reducing the marine survival of salmon through reductions in growth and resistance to disease, and behavioral changes as outlined in Puget Sound Hypotheses and Preliminary Recommendations Report (Schmidt et. al. 2012). Specific sub-hypothesis include:

- Exposure to contaminants in freshwater habitats causes latent reductions in marine survival of juvenile salmon.
- Exposure to contaminants in estuarine and marine waters reduces the marine survival of juvenile salmon migrating through the Puget Sound to the Pacific Ocean.

Additional Cross-referenced Hypotheses

Hypothesis 3: Size-selective mortality is an important process regulating survival at one or more life stages of salmon and steelhead: Larger body size at certain life stages confers higher survival to adulthood. – *Increased contaminant input to Puget Sound may reduce growth of salmon and their early marine survival, especially in urban watersheds and their associated marine bays.*

Hypothesis 4: Outmigration timing influences the magnitude effect of competition, predation, and environmental variation on survival in the Salish Sea. – *Increased contaminant inputs may alter the smoltification processes and outmigration timing, which in turn may affect the magnitude effect of competition, predation, and environmental variation on early marine survival.*

Hypothesis 12: Food supply limits growth, and thus survival, during critical periods of early marine rearing. – *Increased contaminant input to Puget Sound, especially the Main and South basins, may affect the quality and quantity of salmon's food supply.*

Hypothesis 13. Predation by larger fish and marine mammals has increased on salmon and steelhead, respectively. And, the potential effect of bird predation represents a significant knowledge gap. – *Contaminant related reductions in growth, swimming speed, and immune-competence, may increase predation by larger fish, birds, and marine mammals.*

Hypothesis 14: Infectious and parasitic diseases are causing direct and indirect mortality. - *Contaminant related reductions in immune-competence may increase susceptibility to infectious and parasitic diseases.*

Approach

This study is designed to evaluate the extent and magnitude of exposure of juvenile Chinook salmon to well-known and abundant toxic chemicals in their environment, as the fish migrate from their juvenile fresh water habitats to marine systems. Overall, the larger project will estimate exposure of salmon to these chemicals in 1) the lower reaches of the major rivers entering Puget Sound, 2) the marine shorelines associated with major rivers and 3) the offshore marine basins of Puget Sound. Collectively, the river/ nearshore systems represent a wide range of potential contaminant conditions from highly urbanized (Duwamish River/Elliott Bay; and Hylebos Waterway/Commencement Bay), to moderately urbanized (Snohomish River/Port Gardner), to primarily agricultural (Skagit River/Skagit Bay) and mostly rural, undeveloped (Nisqually River/ Nisqually Reach) watersheds. Likewise, the four basins Admiralty Inlet, Whidbey, South Sound and the Main basins represent a continuum from less to more contaminated marine food webs respectively. The river and estuarine portions of this project is funded by a National Estuary grant from the Washington Department of Ecology and the Salish Sea Marine Survival Project will fund the chemical analyses for the offshore portion. Additionally, contaminant tissue residues measured in fish samples will be compared with published adverse effects thresholds to evaluate the potential health effects on juvenile salmon growth, disease resistance, thyroid levels, all of which may affect marine survival.

At the river and nearshore marine sampling areas, juvenile salmon will be collected by beach seine, generally following the procedures described in the Puget Sound Protocols (PSEP 1990), Varanasi et al. (1993) and Roegner et al. (2009). The sampling will target unmarked, presumably wild Chinook salmon, but marked hatchery Chinook may also be collected as necessary to obtain sufficient tissue for analyses. At the offshore marine basins, fish will be collected at a midwater trawl.

At each sampling site, we will collect unmarked, presumably wild juvenile Chinook salmon, to create 4 - 5 composite samples each of whole fish (less stomachs), stomach contents, and gill tissue (river and nearshore sites only) as described in Varanasi et al. (1993), Stein et al. (1995) and Stehr et al. (2000). Tissues from five to ten fish will be combined in each composite sample. Chemical analyses will include stomach contents for measurement of PAHs, gill tissue for copper, zinc, lead, nickel and cadmium, whole bodies (less stomach contents and gills) for measurement of bioaccumulative contaminants including PCBs, PBDEs, DDTs, and other organochlorine pesticides. Fish length and weight data, tissue samples for genetic stock identification, and otoliths and scale for aging will also be collected. Samples will be maintained on ice during the necropsy procedure, and then transferred to -20° C or colder freezers for storage at the NWFSC laboratory in Seattle. Additional biological samples (e.g., bile for measurement of PAHs metabolites, and blood to monitor exposure to estrogenic compounds) will be collected when possible and archived for future analyses if funding becomes available. We will also work with other Puget Sound researchers to identify opportunities for assistance with fish and sample collection that could reduce costs and to increase the number of areas sampled.

Whole bodies (less stomach contents) and stomach contents of juvenile salmon will be analyzed for persistent bioaccumulative toxics (PBTs) or polycyclic aromatic compounds (PAHs) using a gas chromatography/mass spectrometry (GC/MS) method (Sloan et al. 2004, 2014). This is the same analytical method that has been used to measure levels of these contaminants in other components of WDFW's Vital Signs monitoring program, which ensures data continuity. As part of a performance-based quality assurance program, [a method blank and standard reference materials (SRMs)] will be analyzed with each set of field samples and the results of the quality control samples will meet established laboratory criteria (Sloan et al. 2006). Gill samples of juvenile salmon will be analyzed for selected metals that have been identified as stormwater contaminants in Puget Sound: copper, zinc, lead, cadmium and nickel. All metal analyses will be completed by ICP/MS following standard EPA Protocols for ICP/MS and individual metals.

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12. Salish Sea salmon and steelhead survival trends

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The following describes the approach being applied currently in a U.S.-Canada retrospective coho salmon study that is part of the Salish Sea Marine Survival Project. The intent is to replicate this approach with Chinook salmon, and possibly other salmon species later in the project. Puget Sound steelhead are being similarly assessed, as described in the Puget Sound Steelhead Marine Survival Research Work Plan.

Overview

The commonality in patterns of survival and abundance among Salish Sea stocks compared to survival and abundance trends of stocks outside the region suggest that in many cases, overall survival is strongly impacted during the period when salmon reside in the Salish Sea.

Our long-term objectives are to use a combination of retrospective analyses for multiple species of salmon plus steelhead in the Salish Sea to address the following questions:

1. What are the marine survival trends for Salish Sea salmon and steelhead populations? How do these trends compare to nearby populations outside of the Salish Sea (i. e., control group)?
2. Does survival differ for stocks entering the Salish Sea within different sub-basins (in particular, comparing oceanographic basins of Puget Sound to the Strait of Georgia)? If so, where, when, and to what degree has it varied?
3. Does marine survival more strongly predict adult returns than freshwater survival?
4. How much does marine survival differ between hatchery stocks and naturally spawning populations?
5. Does variation in body size, smolt migration timing, or other life-history characters affect marine survival?
6. Is the production of salmon limited by the carrying capacity of the Salish Sea? What ecosystem indicators best predict marine survival?

These questions can help narrow down the scale and possible sources of mortality, and thereby identify the most likely causes of increased mortality in the Salish Sea. Questions (1) and (2) are vital for determining the spatial and temporal scales of the problem. Question (3) will help determine the degree to which freshwater or marine mortality has contributed to recent low returns of salmon. Questions (4) and (5) evaluate the characteristics associated with freshwater rearing that may account for variability in the survival estimates and determine which characteristics are contributing uniquely to mortality (or are uniquely affected by the environment) in the Salish Sea. Question (6) evaluates environmental characteristics of the marine environment and how these characteristics contribute to mortality in the Salish Sea. For example, analysis of outmigration timing coupled with ecosystem indicators will help evaluate the match-mismatch hypothesis and determine the extent to which early marine survival is

[36] See the draft Puget Sound Steelhead Marine Survival Research Work Plan (2014).

affected by food availability (Cushing 1990). Questions (5) and (6) can point to potential threats to survival across the salmon life cycle, and will be addressed by using annual estimates of either population characteristics (5) or ecosystem variables (6) as predictors in a regression with marine survival as the response variable. Questions (4) and (6) also address concerns that because of the finite carrying capacity in the Salish Sea to produce salmon, the release of hatchery fish may be restricting the ability of the wild populations to recover.

Here, we propose a significant advance towards these long-term objectives by systematically examining the marine survival of coho salmon. Coho salmon are ideal candidates for an initial analysis because 1) coho salmon are broadly distributed across the Salish Sea and along the Pacific Coast, 2) they have the highest quality monitoring data, with weir counts and coded-wire tag (CWT) groups providing accurate estimates of adult returns, smolts, and population-specific harvest rates in Georgia Strait, Puget Sound and the Pacific Coast, and 3) their relatively simple adult life history streamlines analysis and enables a more accurate forecast compared to species with more complex life histories. Furthermore, previous analyses of coho salmon data have shown consistent regional patterns of smolt-to-adult survival for hatchery CWT groups (Irvine et al. 2013; Teo et al. 2009; Beetz 2009), an alarming decline of coho salmon marine survival in the Strait of George (Beamish et al. 2010) and suggest that early marine survival patterns may be related to food availability (Araujo et al. 2013). Future work on Chinook, pink, chum, and sockeye will follow from the framework developed with coho and as the collaboration grows.

In this assessment, **we will address questions 1-4 of our long-term objectives** by:

A. Regional comparisons of coho smolt-to-adult survival trends, in an effort to isolate early marine mortality experienced in the Salish Sea (Salish Sea vs. outer coast) and understand differences between the two primary basins in the Salish Sea (Puget Sound vs. Strait of Georgia).
B. Comparing hatchery and wild smolt-to-adult (mostly marine) survival.
C. Comparing freshwater and marine survival rates in wild stocks in order to determine which has a stronger influence on population dynamics.

We advocate two strategies that are at the core of this proposal:

1. Use smolt outmigrant trapping data combined with adult harvest and spawner escapement data to estimate pre-smolt and smolt-to-adult survival. This strategy incorporates smolt body size, life history types, and outmigration timing, which will be used to understand freshwater dependencies of marine survival.
2. Use of hatchery release data combined with adult harvest and spawner escapement data. Hatchery stocks generally have short freshwater and estuarine residency, and most of the mortality can be inferred to occur following entry into the marine environment. Survival rates for these stocks can be determined from analysis of CWT groups or cohort analysis of hatchery releases.

Data Collection and Analysis

All techniques assess survival by examining changes in the abundance of cohorts measured at different stages. For this study, data include:

Table 1*: Data to collect*

Life Stage	Natural-origin stocks	Hatchery stocks
Spawner – smolt (freshwater)	• Spawner abundance • Spawner sex ratio • Fecundity • Juvenile counts, size, timing at traps • Trap capture efficiency	• Size, timing, location of releases • Number of releases
Update Early marine survival (ocean entry to September) in the Strait of Georgia	• CPUE and other results from trawl surveys • CPUE, adipose clip rates, CWT recoveries standard SOG trawl June/July. • CPUE, adipose clip rates, CWT recoveries standard SOG trawl September. • Hatchery release numbers and marking rates BC and Washington State	• Same process as for natural-origin stocks
Smolt – adult return (primarily marine)	• Abundance of outmigrants OR outmigrant CWT count • Age structure of returning adults (including jacks) • Harvest rate (CWT analysis) • Spawner abundance OR Spawner CWT counts • Hatchery stray rate	• Number of CWT releases • Age structure of returning adults(including jacks) • Harvest rate (CWT analysis) • CWT counts to hatchery rack • Counts of coded-wire tagged adults • Hatchery stray rate

US and Canadian scientists will develop a uniform data compilation format and analysis approach. Survival data sets will be evaluated for utility, compiled, and analyzed as described above. Each collaborator will be responsible for developing and documenting their respective datasets. Appropriate data sets for evaluating outmigration, including size and timing, will also be identified for future examination of hypotheses concerning size-selective mortality, match-mismatch, life-history variation, and inter-species comparisons. Other relevant data, such as that from nearshore and marine capture, will also be discussed in the context of developing a uniform compilation format and population data resource table in preparation for future analyses.

Stock/population selection is part of the survival analysis process. The work will attempt to be as inclusive as possible among the three stock groupings necessary for this analysis: Puget Sound, Strait of Georgia and other (control). However, stock selection will largely be driven by the quantity and quality of available data. For hatchery stocks, we will include those with consistent tagging and release strategies and adequate fishery sampling across years. For naturally spawning populations, we will target those stocks with either CWT or accurate counts of adults and smolts coupled with a CWT hatchery indicator for ocean harvest. See Table 2 for a preliminary list of stocks.

- Data will be synthesized to estimate the following parameters:*Adult equivalents*: the number of returns expected in the absence of harvest, i.e., escapement/(1-harvest rate), adjusted for different return ages and stray rates.
- *Marine (smolt to adult) survival :*: adult equivalents/(outmigrants or hatchery releases)
- *Marine survival of CWT stocks*: CWT adult equivalents/release size
- *Freshwater survival of natural origin stocks*: outmigrants/females*fecundity, adjusted for trap efficiency of outmigrants
- *Fates of eggs*: Eggs in a cohort lost in freshwater or marine waters
  Freshwater: eggs*(1-freshwater survival)
  Marine: outmigrants*(1-marine survival).

Current data sources include: Washington Department of Fish and Wildlife (WDFW), Puget Sound Tribes, and Department of Fisheries and Oceans Canada (DFO) enhancement and stock assessment, Regional Mark Recovery Program, and the PSC Technical Committees.

Table 2. Stock Selection (preliminary list). Natural-origin and hatchery coho stocks and the approximate number of years that marine survival data are available for each stock as of 2013.

Basin	Natural-origin	Hatchery-origin
Strait of Georgia Group		
Strait of Georgia	Black Creek (25)	
		Big Qualicum (30) Chilliwack (25) Inch (25) Quinsam (30)
Puget Sound Group		
Strait of Juan de Fuca	Snow Creek (21)	Dungeness (12) Lower Elwha (10)
Northern Straits	---	Kendall Cr (28)
Whidbey Basin	Baker (Skagit - 17) Snohomish (e.g., SF Skykomish - 29)	Marblemount (Skagit – 28) Wallace (28) Tulalip (32)
Hood Canal	Big Beef (29)	Big Quilcene (22) George Adams (27)
S. Puget Sound	Deschutes (22)	Voigts Creek (27) Kalama Cr (21) Minter (11)
Control Group (from outside the Salish Sea)		

Johnstone Strait	Keogh (25)	
West Coast Vancouver Island	Carnation Creek (30)	Robertson Creek (25)
WA Coast	Bingham Creek (29)	Sol Duc (15)
		Cook Creek (13)
		Bingham (28)
		Forks Creek (23)
Lower Columbia	Upper Cowlitz (8)	Cowlitz River (27)
		Lewis River S (22)
		Lewis River N (21)

What was done prior to initiating this work?

In Washington, state, federal, tribal and academic scientists participating in the Salish Sea Marine Survival Project began creating a catalog of the amount and type of data available for wild and hatchery populations in Puget Sound and the Strait of Juan de Fuca. Additionally, case studies comparing freshwater to marine survival were performed (US Salish Sea Technical Team 2012). This information will help establish the data compilation and assessment building blocks for this study. In Canada, coho smolt survival data for Strait of Georgia were recently analyzed in Irvine et al. (2013). These time series will be updated and expanded to include populations on the West Coast of Vancouver Island and Johnstone Strait. Escapement summaries from DFO's nuSEDS database will be assembled with a view to developing a time series of wild coho escapements to the Strait of Georgia. In addition, in Canada, examining factors regulating the marine survival of coho salmon has been part of a major marine sampling program since 1998. Numerous papers have been published that demonstrate that the coho from the Strait of Georgia remain in this inland sea region through to October/November of their first marine year (Chittenden et al.2009), that brood year strength for these coho over the past decade has been mostly determined during their first marine summer in the Strait of Georgia (Beamish et al. 2008, 2010a), and that there is a linkage between marine survival and growth during their first marine summer (Beamish et al. 2004, 2010a). Furthermore, variations in trends between hatchery and wild coho salmon and potential interactions with juvenile pink salmon have been documented (Beamish et al, 2008, 2010a, 2010b). The key indices developed for coho salmon in the entering the Strait of Georgia over this time period will be updated and data from other regions will be examined to determine if similar time series can be developed.

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13.1 Life-history characteristics and outmigrant abundance relative to marine survival

Principal Investigators: Joe Anderson (WDFW), Correigh Greene (NOAA), Josh Chamberlain (NOAA), Mara Zimmerman (WDFW) [Neala Kendall (WDFW) for steelhead[37]]

Chinook, coho, and steelhead will be analyzed to address:

- Does variation in body size, smolt migration timing, or other life-history characteristics associated with freshwater rearing affect marine survival?
- Does outmigrant abundance affect marine survival? Is the production of salmon limited by the carrying capacity of the Salish Sea? Does increased abundance protect salmon from predation or other effects?

This work will first be performed retrospectively, but the datasets will be updated over the course of the project where it is considered appropriate. Data on wild and hatchery life-history characteristics of stocks in Puget Sound (and potentially some Strait of Georgia stocks) will be analyzed with reference to marine survival trends over time. This work will be performed to determine whether certain characteristics account for variability in the marine survival estimates and or are contributing uniquely to mortality (or are uniquely affected by the environment) in the Salish Sea. Characteristics within and among species will be compared. Hypotheses concerning spatial variation in mortality, size-selective mortality, match-mismatch, and life-history variation (e.g., portfolio effect) will be examined. This analysis will also compare changes in hatchery and wild smolt outmigrant abundance and marine survival rates to examine the marine carrying capacity hypothesis. This analysis may include developing enhanced life-cycle models that capture life-history variation at outmigration better than current approaches.

Outmigration timing and size trend data will also be evaluated to:

- Evaluate life-history variation (and diversity) throughout Puget Sound.
- Determine the extent to which inter-annual variability in outmigrant timing and size is correlated among species and life-history trajectories.
- Determine whether outmigration timing (and size) has changed over time and whether there is a correlation with changes in marine survival.
- (Potentially) Analyze temporal trends in nearshore usage and associated size structure, where data are available

[37] See the Puget Sound Steelhead Marine Survival Research Work Plan. Contact Long Live the Kings for more information (mschmidt@lltk.org).

13.2 Life cycle modeling, and freshwater habitat capacity for affiliated study

Principal Investigator: Correigh Greene (NOAA)

The effect of freshwater capacity on marine survival

Several studies across the Pacific Northwest point to the importance of life history variation (e.g., variation in size, outmigration timing, and age structure) in influencing the productivity and resilience of salmon populations in response to environmental variation (Moore et al. 2009, Greene et al. 2010, Schindler et al. 2011, Thorson et al. 2013). Much of this variation is produced in freshwater before salmon enter marine waters, but the consequences of this variation in marine waters (and Puget Sound in particular) is not known. Understanding the extent to which variation in growth, migration, and survival of different life history types in freshwater and marine habitats is important to determine the extent to which changes in survival within Puget Sound affect adult returns. As a simple example, consider the life history of coho salmon, which can leave freshwater as subyearlings (0+), yearlings (1+), and even as 2-year olds in rare cases. If marine survival greatly differs between 0+ and 1+ individuals as might be expected based on hypotheses of size-dependent mortality, changes in the frequency of these life history types resulting from processes in freshwater could have a similar magnitude as changes in marine survival of the “typical” (1+) outmigrant year class.

Addressing these types of questions requires a synthesis of abundance and age structure data, in a way that can project changes in life history attributes. We propose a rigorous analysis of different life history components for two intensively monitored fish populations within Puget Sound: Chinook and coho salmon in the Skagit River data into life cycle models that can be used to test for the relative importance of various life history variables (e.g., age-specific or size-specific marine survival rate, frequency of yearling outmigrants). Both populations have an extensive history of status monitoring at multiple life stages and complementary watershed habitat data. Marine survival rates can also be estimated for these species. The long-term monitoring data demonstrate juvenile life history variation for both species. Coho salmon may migrate as subyearlings or yearlings, and Chinook salmon may migrate as one of three subyearling types with variable residency in freshwater and estuary, or as yearlings. Within both watersheds, salmon populations are primarily naturally spawning, and demonstrate an upper limit to outmigration abundance, i.e. a juvenile carrying capacity.

Evaluating freshwater habitat capacity

The ultimate goal of salmon recovery efforts is to rebuild populations to levels that are healthy and support fisheries. Rebuilding wild populations requires taking full advantage of the habitat features of watersheds to not only increase abundance, but also to improve productivity and diversity within a population. Thus, understanding how various habitat features influence production and carrying capacity of watersheds, and how life history variation of outmigrants responds to these habitat factors, is critical to ensuring that available habitat is fully utilized. In turn, a better understanding of the success of life history types as they grow and survive in marine waters is important for setting escapement goals that are directly tied to the productive potential of a watershed.

We propose to show how these concepts can be applied to improve conservation efforts using two species within Puget Sound: coho and Chinook salmon in the Skagit River. Both populations have an extensive history of status monitoring at multiple life stages and complementary watershed habitat data. The long-term monitoring data demonstrate juvenile life history variation for both species. Coho and Chinook salmon may migrate as one of three sub-yearling life history types with variable residency in freshwater and estuary, or as yearlings. Salmon populations are primarily naturally spawning, and demonstrate an upper limit to outmigration abundance, i.e. a juvenile carrying capacity. These data-rich stocks should provide an opportunity to predict habitat-based population responses in a variety of systems in the Pacific Northwest constrained by poorer data. Consequently, both species should provide good tests for examining how habitat availability influences escapement of returning adults, applicable to a wide array of systems across the Pacific Northwest.

Habitat capacity models:

- Synthesis of data. Both populations have a wealth of data on adult returns, juveniles rearing within the river, life history variation of juveniles, and outmigrant timing, size and abundance. Population data require some organization to determine parameters for life cycle modeling. In addition, habitat data for the Skagit has been collected, but needs to be synthesized at the watershed level to generate habitat parameters that will be incorporated into the model. These include existing habitat databases such as GIS layers developed by the Skagit River System Cooperative as well as on-the-ground measurements that need to be synthesized at reach or greater scales. Relevant biological data include mainstem electroshocking, a study of stream-resident fish, and several monitoring datasets of outmigrants from three tributaries as well as the mainstem as well as data on spawning distributions. These tasks will be carried out by a contracted statistician.

- Life cycle modeling. Chinook and coho already have a life cycle model constructed in SLAM that will be modified to better incorporate habitat information and updated population data. Scenarios run using these models will be incorporate several novel features. First, we will evaluate the influence of habitat diversity on multiple life history decisions by salmon and consequences of changes in local abundance upon juvenile production. Hence, the modeling should be able to incorporate limiting factors at a number of life stages, including adult spawning, early juvenile rearing, and overwintering. Second, we will examine the sensitivity of early marine survival to freshwater and estuarine based changes in productivity and capacity, and thereby evaluate the degree to which freshwater environments indirectly influence marine survival and consequent adult returns. Finally, we will use these models to help inform monitoring and management decisions in the face of lack of data on life history variation or their habitats. We will examine this issue by comparing scenarios that vary amounts of life history diversity, thereby demonstrating its relative importance, and by varying habitat amounts, thereby demonstrating how systems with differing habitat availability than the Skagit River might be affected. Updates to the model and additional runs will be carried out by the contracted statistician.

14.1 Developing ecosystem indicators to inform geographic variation in marine survival rates

Principal Investigators: Correigh Greene, Peter Lawson, and Jason Hall (NOAA)

Fisheries stocks are known for their high recruitment variability (Rothschild 2000) and the resultant difficulty in forecasting stock size to support sustainable harvest management. These challenges are highlighted in Pacific salmon stocks, whose variability in marine survival continues to challenge managers forecasting returns to spawning rivers. This variability has sometimes resulted in poor forecasts of adult returns, a situation that can complicate conservation and constrain commercial, tribal, and recreational fishing. Under-forecasts result in excessive fishing restrictions (and disgruntled fishers), while over-forecasts often result in worsening conditions for the stock and future restrictions on fishing. These circumstances are especially complicated in the Pacific Northwest because some stocks are listed as Threatened or Endangered under the Endangered Species Act, and are managed in the context of a mixed stock fishery under international (US and Canada) and tribal treaty rights.

In light of variation in marine survival, much interest has developed across the Pacific Coast in using ecosystem indicators to improve predictions of productivity and adult abundance. For example, returns of Chinook salmon stocks from the Sacramento River system appear strongly tied to upwelling, wind curl, and euphausiid abundance at outmigration (Wells et al. 2007), while returns of Oregon coast coho salmon and Columbia River Chinook salmon can be effectively predicted by a suite of ecosystem indicators (Burke et al. 2013, Rupp et al. 2012) describing conditions experienced during early marine residence. The utility of these indicators depends upon the spatial variation in indicators. Hence, while coastal systems exhibit relative uniformity in climatic and oceanographic conditions, geomorphic variation in complex estuarine and nearshore environments like Puget Sound and the inland seas of Alaska modify climate and oceanography patterns. Limited connectivity to open ocean and increased influence of terrestrial and freshwater processes reduce the direct effect of marine conditions and introduce time lags as oceanic waters gradually work their way inland. This is especially important in restricted areas like South Puget Sound, connected only through a narrow inlet 200 km from the open ocean.

In Puget Sound, anadromous salmon stocks spawn in six sub-basins, each with its distinct geomorphology and oceanography (Strickland 1983, Moore et al. 2008), thereby creating the potential for strong spatial structuring of productivity patterns. Indeed, coastal ecosystem indicators do not readily predict marine survival and productivity of stocks spawning within Puget Sound. Likewise, marine survival of stocks entering different basins of Puget Sound does not necessarily track survival rates from other basins (Fig. 1). Hence, the ability of ecosystem indicators to reduce uncertainty in forecasts of adult returns across Puget Sound appears to require spatial variation. We propose to produce and test a spatially variable framework of ecosystem indicators that can be used by harvest managers to forecast adult salmon returns. Specifically, we will:

- Develop a suite of indicators describing conditions within Puget Sound's sub-basins as smolts enter seawater. Do this in conjunction with Canadian indicators development for the Strait of Georgia.
- Combine sub-basin indicators with ecosystem indicators of the Northwest region.

- With Strait of Georgia data, establish the indicators dataset as the primary data catalog for the Salish Sea Marine Survival Project.
- Test these indicators for their ability to reduce uncertainty in predictions of marine survival.
- Examine the potential for improved forecasts to reduce management constraints.
- Develop tools that harvest managers in Puget Sound can use to forecast marine survival and adult returns.
- Convene a workshop to show managers how these tools can be used.

Approach

Conceptual framework. Previous efforts to integrate ecosystem indicators along the Pacific coast have supported the hypothesis that conditions during initial stages of marine migration directly affect marine survival, but multiple indicators are informative given that marine survival can be influenced by different ecosystem attributes in any given year (Greene et al. 2005, Burke et al. 2013). Based on our knowledge of Puget Sound climate and oceanography (Moore et al. 2008), we also predict a hierarchical organization to indicators: regional climate and ocean characteristics influence background conditions for fish from all sub-basins and at multiple life stages, but conditions within sub-basins during early ocean entry can greatly influence survival. We will build on the existing suite of regional ecosystem indicators for the Northern California Current (Rupp et al. 2012, Burke et al. 2013) by integrating and testing sub-basin specific indicators in the context of previously developed coastal indicators.

Indicator selection. Previous efforts have funded the development and evaluation of ecosystem indicators to forecast marine survival and adult returns on the Pacific coast (Table 1). Rupp et al. (2012) used a variety of climate and oceanographic measurements, and Burke et al. (2013) examined predictors that included climate, oceanographic, prey and growth, predator, and cohort size indicators. This suite of indicators, when used as individual predictors in regression models or when assimilated using various data reduction procedures, can greatly reduce uncertainty in both marine survival rates of Oregon Coast coho salmon (Rupp et al. 2012) and adult returns of Chinook salmon to the Columbia River (Burke et al. 2013). Efforts to utilize these indicators for stocks spawning within Puget Sound have had mixed results, informing marine survival of some stocks but offering little improvement of survival estimates for others.

In addition to these indicators describing conditions for the northwest coastal region, a number of long-term monitoring efforts have produced ecosystem indicators of conditions within Puget Sound's sub-basins (Table 1). Following Burke et al. (2013), we divide these into climate and weather patterns, oceanographic measurements, prey and growth environment, cohort strength, and potential predators. All datasets have greater than ten years of data, and monitoring of these indicators is expected to be continued into the foreseeable future. Indicators in the list include metrics that are naturally variable as well as those that are sensitive to anthropogenic stressors, including climate change.

We will summarize these indicators following two data reduction methodologies. The non-parametric ranking procedure used initially for coastal indicators is simple to perform and understand, effective in informing marine survival, and easy for managers to use. However, annual updating results in changes to previous rankings because long-term averages of indicator anomalies are recalculated, and an additional year is subsequently ranked. Data reduction using PCA and related multivariate techniques (Burke et al. 2013) produce indices that do not necessarily have to be re-ranked, but may reduce information content provided by variation in multiple indicators. We will examine both methodologies, summarizing data for each sub-basin. Additional regional indicators not captured in the California Current suite will be added to these using similar procedures.

Marine survival estimates. Pacific salmon stocks are managed using run forecasts of adult returns that are specific to spawning populations, and these forecasts are made by local harvest managers. While many of these forecasts are based on autocorrelations of previous cohorts or younger age classes, forecasts for most stocks do not currently integrate ecosystem indicators. Nevertheless, the spatial structure of stocks can allow for the use of ecosystem indicators that are spatially variable.

Both coho salmon (Beetz et al. 2009) and Chinook salmon (Greene et al. 2005) stocks have attracted interest with respect to linkages with ecosystem indicators. Within Puget Sound we will compile and update datasets from 39 stocks of Coho salmon and Chinook salmon that are closely monitored by Washington Department of Fish and Wildlife (WDFW) and tribes (Table 2). These include multiple natural-origin stocks as well as hatchery stocks. Hatchery stocks include groups marked with coded-wire tags, so marine survival can be estimated using standard mark-recapture techniques, with recaptures in fisheries being used to estimate harvest (e.g., Bernard and Clark 1996, Teo et al. 2009). Survival of natural-origin stocks is based on cohort reconstructions that account for freshwater survival measured at outmigrant traps, and adjust for harvest using indicator hatchery stocks (e.g., Zimmerman 2007). Much of these survival data will be aggregated and analyzed via the **12. Salish Sea salmon and steelhead survival trends** research activity, described previously (Coho survival dataset available in summer 2014, Chinook in spring 2015)**.** These dataset updates will enable us to conduct similar analyses using adult Chinook return numbers as done by Burke et al. (2013) to take advantage of additional Chinook salmon data with longer time series.

We will examine each species separately, but utilize the statistical power afforded by multiple stocks and years to develop statistical models accounting for year and basin, and determine whether models with ecosystem indicators can both perform better than these simple models and can improve forecasts for a subset of years. We will examine several possible methods for testing how marine survival rates relate with combined effects of regional and sub-basin indicators, including using individual indicator as multiple predictors, and data reduction techniques that incorporate regional and sub-basin indices. For example, regional and sub-basin indices could be treated as independent variables in multivariate models (Burke et al. 2013) or general additive models (Rupp et al. 2012) of marine survival, or regional and sub-basin summaries could be combined into one metric (e.g., sums of indicator ranks from both regional and sub-basin sets). We will also examine the forecasting precision of a model average compared to a single forecast model (Greene et al. 2005, Rupp et al. 2012).

Technical input and review. Data inputs will depend on Canadian, Federal, state, and tribal sources. To insure that both indicator and survival data sets are acquired and used appropriately, we will seek technical review from scientific experts from Canada's Department of Fisheries and Oceans, the Northwest Fisheries Science Center, the Puget Sound Environmental Monitoring Program, WDFW, and tribal groups. Development of datasets will regularly be reviewed by this panel via telephone conferences.

Production of indicator tools and workshop. In the Pacific Northwest, forecasts of salmon recruiting to fisheries are made by individual co-managers (WDFW and tribes) and combined in a mixed stock fisheries model to determine tribal, US, and Canadian harvest allocations. The utility of our proposed approach depends on its adoption by multiple harvest managers. Therefore, in the second year of our project, we will produce a database of indicators formatted to allow rapid updating and simple reporting of relevant predictor indices. We will also host a workshop to discuss how improvements can be made to Coho and Chinook forecasts, and how these can improve fisheries management. During this workshop we will provide sub-basin specific and regional indicators datasets for general use.

Benefits

The results of this study will provide the framework for evaluating use of ecosystem indicators to forecast adult returns of salmon stocks to Puget Sound. In 2012, concerns about the lack of precision in forecasts were brought to the attention of NMFS by members of the PFMC's North of Falcon Process. In response, we led a workshop (Schmidt et al. 2013) to identify potential ecosystem indicators for adult return forecasting in the Puget Sound region, which attracted 50 biologists involved with harvest management and committed to improving forecasts. The proposed research will directly address these concerns by providing these scientists the proper tools: a suite of spatially relevant indicators, and verification that these indicators reduce uncertainty in forecasts of productivity and marine survival for their stocks of interest.

In turn, improved forecasts should benefit not only harvest management, but also additional needs associated with management of listed species in Puget Sound. Rupp et al. (2012) found only a limited benefit to reduced variability in forecasts of a single Coho salmon stock. We hypothesize that reducing the variability in a suite of stocks subject to a complex management regime will confer greater benefits because of the ability of single weak stocks to constrain harvest on multiple stocks, and dependence on indicators from larger stocks can lead to overharvest of smaller, less productive stocks. In addition, reduced bias in predictors may lead to improved outcomes. We propose to test this using a management strategy evaluation (MSE) model similar to that used by Rupp et al. 2012. From a recovery perspective, results will guide decision making by clarifying the role of marine processes on population dynamics, helping to identify alternative recovery strategies or set realistic expectations by describing the constraints on population growth imposed by marine mortality.

The ecosystem indicators dataset will also serve as the primary data catalog for the Salish Sea Marine Survival Project. These data will be used for ecosystem modeling and a variety of correlative analyses beyond the scope of the forecasting analyses described in this section.

Deliverables

FY 2014-2015

- Basin-specific indicators used in forecasts
- Indicators database
- Database tools for applying indicators to forecasts, so managers can readily adopt them.

FY 2015-2016

- Statistical examination of the efficacy of these indicators for predicting Chinook and coho salmon returns around Puget Sound
- Management strategy evaluation of the benefits of reduced variability and bias in forecasts in relation to management and conservation objectives.

- Outreach workshop with local managers at the Northwest Fisheries Science Center to demonstrate how ecosystem indicators can be used.

FY 2016-2018

- Continue to update, manage, and refine indicators database.

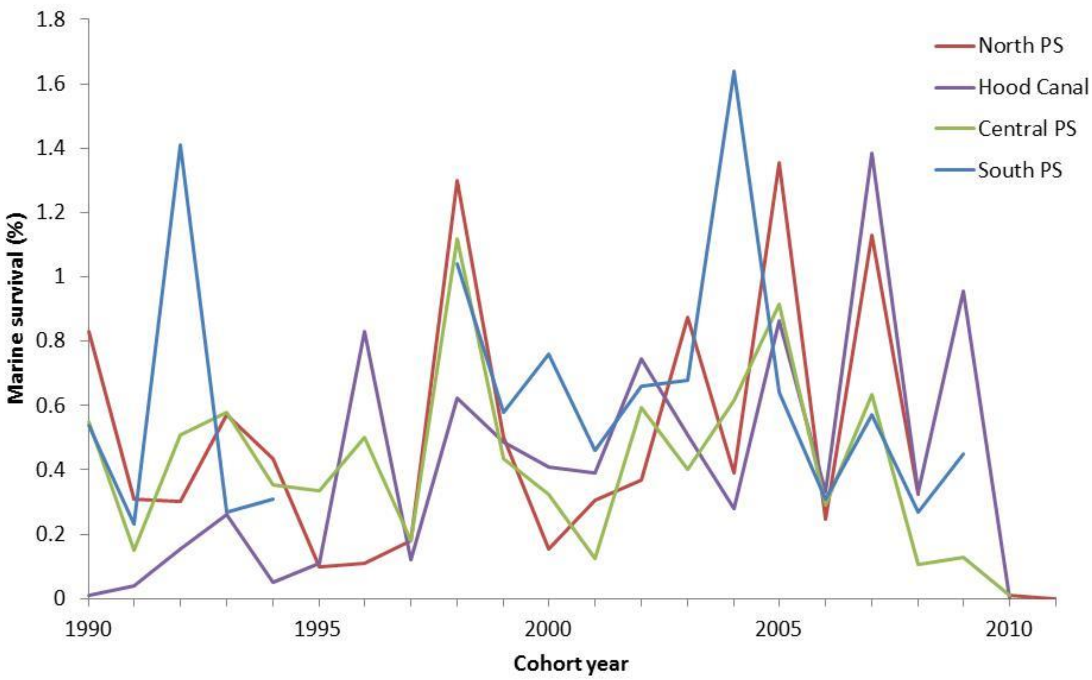

Figure 1. Marine survival of four different Chinook salmon hatchery stocks from different basins of Puget Sound. Correlations among stocks range from 0.01-0.78.

Statement of previous results

FATE proposal. Wainwright, T.C., P.W. Lawson, T. E. Helser, and W.T. Peterson. FY2009. Integrating ocean climate indices into Pacific salmon stock assessments.

Previous FATE funding focused on 1) improving coastal ecosystem indicators for Oregon Coast Natural Coho (OCN) salmon, 2) using those indicators to make forecasts in support of harvest management, and 3) testing how higher forecasting precision will likely improve future management. The first goal was accomplished by using generalized additive models (GAMs) to improve the relationships between annual recruitment of Coho salmon and climate and oceanographic indices of the California Current, ranging from local to very large spatial scale (e.g., coastal water temperature versus Pacific Decadal Oscillation). Sets of two- and three-indicator models were tested using best fit, cross validation, and hindcasting metrics. Forecasts from the best performing three-variable models were averaged to arrive at an ensemble mean forecast (Rupp et al. 2012). This model is now used to forecast OCN abundance as part of PFMC's annual preseason salmon process (Goal 2).

FATE funding was also used to produce a management strategy evaluation that addressed the more general question of whether improved forecasts can actually result in better management (Goal 3). Two management strategies were examined: 1) harvest was determined based on both a forecasted marine survival rate and parental spawner abundance (the strategy currently used), and 2) a forecast of preharvest adult abundance was used to achieve a constant spawner escapement goal. Performance of the first strategy was not greatly sensitive to forecasting precision, while performance of the second strategy depended on the target escapement goal and performance metric. These findings show that benefits to be gained from improved forecasting precision depend on the specific structure and goals of the management system (Rupp et al. 2012).

The techniques developed for these studies have clear application in Puget Sound, with its unique set of stocks, management structure, and goals. We propose to apply and extend the work of Rupp et al. (2012) by 1) examining a variety of models that integrate ecosystem indicators, 2) exploring the use of model averages to reduce forecast variance, and 3) testing how improved forecasts can enhance mixed stock management of Puget Sound salmon stocks. We predict that improved forecasting will have greater management benefits when multiple stocks are at risk of missing escapement goals and when productivities of different stocks do not strongly covary over time.

Table 1. Ecosystem indicators that can be used to analyze marine survival rates of Puget Sound salmon stocks.

Type	Northwest region	Puget Sound sub-basin
Climate and weather	Pacific Decadal Oscillation[1] Oceanic Nino Index[1] Date of spring transition[1] Upwelling Index[1] Sea level[1] Sea surface temperature[1]	Sea surface temperature[5] Precipitation and riverflow[5] Wind speed and direction[5]
Oceanography	Water temperature[1] Hypoxia[1] Salinity[1]	Water temperature[6] Dissolved oxygen[6] Salinity[6] Turbidity[6] Chlorophyll[6] $SiO_4:NO_x$[6] pH Stratification[10]
Prey and growth	Copepod biodiversity[1,2] Copepod community structure[1,2]	Zooplankton biomass, abundance, community structure[11]
	Winter ichthyoplankton[1]	
	Summer & fall length and weight in Central basin[3]	Length at outmigration[7]
	Summer & fall pelagic herring abundance[3]	Herring spawning biomass[8]
Cohort strength	Summer and fall pelagic salmon abundance[3]	Outmigrants and hatchery releases (see Table 2)
Predators	Orca population size[4]	Winter seabird predators[9]

[1] Ocean ecosystem indicators of salmon marine survival in the Northern California Current (17 years, http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/).

[2] Copepod survey, West Coast of British Columbia (28 years, Mackas et al. 2004).

[3] British Columbia Department of Fisheries and Oceans survey of Puget Sound (12 years, Sweeting et al. 2011).

[4] Total population size and biomass of resident pods (37 years, Krahn et al. 2004, updated annually at http://www.orcanetwork.org/Main/index.php?categories_file=Babies).

[5] Puget Sound weather station data, J. Hall (20 years, unpublished)

[6] Puget Sound water quality monitoring (35 years, Moore et al. 2008, http://www.ecy.wa.gov/programs/eap/mar_wat/)

[7] Washington Department of Fish and Wildlife and tribal fish datasets (see Table 2)

[8] Washington Department of Fish and Wildlife herring spawning surveys (35 years)

[9] Washington Department of Fish and Wildlife marine bird aerial survey (21 years, http://wdfw.wa.gov/mapping/psamp/index.html)

[10] See research activities, 14.5 Analyzing long-term stratification datasets as a proxy for primary production, 14.6 Analyzing primary production variability in relation to stratification, part one - observational view, 14.7 Analyzing primary production variability in relation to stratification, part two - model view

[11] See research activities, 14.2 Analyzing JEMS zooplankton time series and other zooplankton data relative to physical controls and salmon survival, 14.3 Retrospective analysis of zooplankton datasets

Table 2. Natural-origin and hatchery stocks of Coho and Chinook salmon and the approximate number of years that marine survival data are available for each stock as of 2013. Datasets are based on efforts by WDFW and tribal programs.*

Sub-basin	Origin	Coho salmon	Chinook salmon
Strait of Juan de Fuca	Natural-origin	Snow Creek (21)	Dungeness (8)
	Hatchery	Dungeness (12) Lower Elwha (10)	Dungeness (12) Lower Elwha (10)
Northern Straits	Natural-origin	---	Nooksack (10)
	Hatchery	Kendall Cr (28) Skookum (30)	Kendall Cr (28) Skookum (30)
Whidbey Basin	Natural-origin	Baker (17) SF Skykomish (29)	Skagit (18) Stillaguamish (10) Skykomish (13) Snoqualmie (12)
	Hatchery	Marblemount (28) Wallace (28)	Marblemount (28)
Central Basin	Natural-origin	Green River (14) Cedar River (14)	Green River (13) Cedar River (14)
	Hatchery	Soos Creek (33) Voigts Creek (27)	Soos Creek (36) Issaquah (11)

			Voigts Creek (27)
Hood Canal	Natural-origin	Big Beef (29)	---
	Hatchery	Big Quilcene (22)	Hoodsport (23)
		George Adams (27)	George Adams (27)
S. Puget Sound	Natural-origin	Deschutes (22)	Nisqually (4)
	Hatchery	Kalama Cr (21)	Kalama Cr (21)
		Minter (11)	

*The precise list of stocks will be dependent upon the results of 12. Salish Sea salmon and steelhead survival trends, above.

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14.2 Analyzing JEMS zooplankton time series and other zooplankton data relative to physical controls and salmon survival

Principal Investigator: Julie Keister (U. Washington)

This study will utilize a time series of zooplankton data collected in the Strait of Juan de Fuca (see JEMS site labeled on figure 1 of appendices“**2. Zooplankton: Establishing a Puget Sound-wide zooplankton sampling program**) to identify the primary environmental variability that correlates with changes in zooplankton communities and subsequent salmon returns. Zooplankton samples have been collected monthly since 2003 (75-cm diameter, 150-µm mesh vertical nets) during research cruises conducted by the University of Washington (UW) Puget Sound Regional Synthesis Model (PRISM) program, (http://www.prism.washington.edu/home), and the Washington Department of Ecology as part of the Joint Effort to Monitor the Strait of Juan de Fuca (JEMS).

This extant time series presents a perfect opportunity for an exploration of zooplankton correlations to salmon growth and survival. Samples through 2010 have been taxonomically analyzed, but analysis and interpretation of the remaining archived samples has not been funded. We propose to conduct the laboratory identification and statistical analysis of the archived JEMS zooplankton samples and compare the data to concurrent time series of physical, biological, and climate data, with the objective of assessing the primary physical factors that control zooplankton variability in this dynamic, and economically important, region of the Pacific Northwest. This study will provide information that is presently lacking in this under-studied region, including data on the variability of zooplankton, a description of seasonal cycles, inter-annual variability, and relationships to climate that have profound regional implications to fisheries and the fishing communities in optimizing economic benefits. This data will then be compared to the salmon survival data resulting from research activity “**12. Salish Sea salmon and steelhead survival trends**”. As part of this activity, a single year, region-to-region comparison between zooplankton data and salmon SARs/survival trends using data collected by NOAA in 2011 throughout Puget Sound may also be analyzed.

Temporal changes in total zooplankton biomass, community structure (species composition), and abundances of individual taxa will be compared to long-term environmental data and to salmon SARs that are available over the same time period. Synchronies among the data, as well as changes in amplitude and timing of major fluctuations, will be assessed using a combination of time series and multivariate analyses. Recommendations of the Scientific Committee on Ocean Research (SCOR) Working Group #125 (“Global Comparisons of Zooplankton Time Series”) will be followed.

Relationships among individual variables (for example, temperature and abundance of specific taxa) will be examined using standard time series correlation methods. Given that the time series is relatively short (currently ten years), determining statistical significance of multi-year fluctuations is not a realistic goal, but interannual signals in the data can be related to environmental variations and salmon survival. Community analysis techniques, such as ordinations (e.g. Non-Metric Multidimensional Scaling) and cluster analyses, will be used to explore temporal changes in the zooplankton community in relation to biological and physical variables. Where appropriate, multiple regressions may be performed to examine the factors which explain the variability in zooplankton.

Climate indices such as the Pacific Decadal Oscillation index (Mantua et al. 1997), Multivariate El Niño-Southern Oscillation index (MEI), Northern Pacific Oscillation, and upwelling indices, are publicly available and will be assembled from their various web sources. Wind data will be obtained from the National Data Buoy Center (NDBC). River flows are provided by the United States Geological Survey and Environment Canada. Geostrophic exchange velocity will be calculated as described in Newton et al. (2003). Temperature, salinity, fluorescence, and dissolved oxygen are measured with each zooplankton sample and are available from several oceanographic buoys in Puget Sound (http://orca.ocean.washington.edu/data.html). Bulk chlorophyll and nutrient samples are collected from discrete depths and processed by the WDOE. Salmon SAR/marine survival time series data (primarily for Chinook and coho) will be utilized from research activity "**12. Salish Sea salmon and steelhead survival trends"**.

In 2011, NOAA was funded by the EPA to profile the marine environment throughout Puget Sound; sampling occurred from April to September and included physical, chemical, microbial, plankton, and fish collections, including salmon growth metrics. The zooplankton sampling was conducted in a similar manner to the proposed approach. While most of the zooplankton samples have been analyzed for species composition and abundance, the resulting data have not been compared to salmon marine survival rates/SARs for those fish outmigrating through Puget Sound in 2011. SAR data for the 2011 coho outmigrants is expected to be completely processed by mid- to late-2014. Standard correlation methods will be used to perform the comparison between the zooplankton data and coho SAR data.

14.3 Retrospective analysis of zooplankton datasets

Investigators: Correigh Greene (NOAA), Jeff Cordell (U. Washington), Casey Rice (NOAA), Julie Keister (U. Washington)

Puget Sound's deep bathymetry makes the pelagic zone the largest component of the Sound's marine habitat. It is therefore not surprising that the pelagic ecosystem is at the center of the Sound's complex marine food web. When marine nutrients mix with riverine inputs at estuaries, high primary and secondary productivity fuels forage fish and salmon populations and prompted Strickland (1983) to term Puget Sound "The Fertile Fjord". As a consequence, the pelagic ecosystem is highly valued for its ecosystem services for recreational and commercial fishing, shellfish aquaculture, boating and diving, and its tribal cultural heritage. While Puget Sound's pelagic zone is critical to many fish and wildlife species including salmon, it is one of the least understood components of the Puget Sound's ecosystem. Zooplankton are a dominant feature of the pelagic system and their ecology has likely been significantly affected by many natural and anthropogenic influences including climate and water quality changes, fisheries, and introduced exotic species that have greatly altered other west coast waters. Given the evidence for strong bottom-up ecosystem dynamics in Puget Sound (Harvey et al. 2012) and the important roles zooplankton play in food webs, understanding the stability of zooplankton communities should provide insight into the stability of higher trophic levels.

A number of observations have raised concern for the ecological health of Puget Sound's pelagic ecosystem. Herring and smelt, the dominant forage fish of Puget Sound, may be declining in some regions of Puget Sound. Many populations of Pacific salmon that use Puget Sound pelagic zone are listed as Threatened under the Endangered Species Act (Chinook and chum salmon, and steelhead), or Species of Concern (coho salmon). Sea bird populations, which depend on forage fish and juvenile salmon living in the pelagic zone, show evidence of declines (PSP 2010). In addition, incidents such as high abundances of jellyfish in various parts of Puget Sound (Rice et al. 2012), harmful algal blooms, and hypoxia, all of which have been interpreted as ecological warning signs (Anderson et al. 2002, Cope and Roberts 2012), have focused our concern of the current ecological health of Puget Sound's pelagic habitats.

Exotic zooplankton species have begun to appear in Puget Sound. A warm-water species of copepod never recorded north of central California (*Labidocera jollae*) was found during a 2011 food web study in Hood Canal (J. Cordell, unpublished), and in the latest of a series of Sea Grant-supported quadrennial surveys of estuaries along the Pacific coast of the US and Canada another highly invasive copepod species was found in abundance in Samish Bay, northern Puget Sound (*Oithona davisae*—J. Cordell, unpublished). These are probably not the last non-native plankton species to appear in Puget Sound, because of climate change and because foreign ballast water containing many live organisms continues to be discharged into Puget Sound (Cordell et al. 2010, Lawrence and Cordell 2011). It is important to know when and if new species become established, given the profound ecosystem level effects of planktonic invaders elsewhere in the region (e.g., San Francisco Bay, see Bollens et al. 2011).

Recently, Carpenter et al. 2011 found that increased variation in zooplankton communities served as a harbinger of pelagic food web reorganization. This promising approach could in theory be used as an ecologically based warning sign in Puget Sound for potential impacts of ocean acidification, invasion, and other stressors, but the lack of data on plankton communities and their spatial and temporal variation limits its potential utility. A firm understanding of what types of communities exist within Puget Sound, how they vary over time, and whether they have systematically changed over the last 40 years would provide a solid footing for monitoring the resilience of the pelagic food web, and conversely, whether regime changes in food web structure have or are likely to occur.

Despite the above-mentioned possibilities and concerns, zooplankton has been largely overlooked in research and monitoring in Puget Sound. Over the last forty years, only a handful of surveys of zooplankton composition exist for Puget Sound, and most of these are strongly restricted in space and/or time. Of the landscape scale efforts, only a fraction of the samples have been processed and analyzed. These factors seriously limit inferences that can be gleaned from existing data sets.

These limitations can be overcome. In 1973 and 1974, B. Frost (UW Oceanography) extensively sampled zooplankton bi-monthly across Puget Sound (Figure 1). Although the samples from this effort were only minimally processed and analyzed, they are still in existence and available for full analysis. More recently, NOAA Fisheries extensively sampled the Puget Sound nearshore pelagic community monthly in 2011 (Figure 2), and sampling is occurring Puget Sound wide in 2014 and 2015 (see study 2, Establishing a zooplankton monitoring program). Due to limited funding and the multiple other foci of the project, only a minimum number of samples were processed to characterize structure spatially (samples from only one month across the landscape) and temporally (samples from a limited set of sites across all months). Other sampling efforts have occurred within the last 10 years or are proposed for future monitoring (Fig. 1). We propose to improve analysis of Sound-wide samples collected in 1973, 1974, 2011, and 2014-2015 as well as facilitate comparisons of future sampling efforts to historical datasets, and thereby produce a comprehensive zooplankton dataset for Puget Sound.

Preliminary analysis of 2011 samples shows strong spatial structure that correlates with other components of the food web, and which exhibits greater predictability than time (months). These results have important implications for ecosystem management in Puget Sound, indicating that the health, target conditions, and vulnerability to stressors are not uniform across the sub-basins of Puget Sound. Further, these results raise questions about whether pelagic ecology has changed significantly over time. Comparisons of 2011 sites with spatially concordant samples collected three decades ago offers a unique opportunity to look for evidence of historical change in zooplankton communities, and characterize the nature of change over space, seasons, years, and decades. Additionally, matching sampling to future proposed efforts would allow us to determine whether patterns detected in recent data are likely to persist across years. These efforts would greatly advance our understanding of pelagic ecology in Puget Sound, and provide invaluable information for improved assessment and monitoring of the Puget Sound ecosystem.

[IN FALL 2014, UW STAFF LEARENED THAT THE FROST SAMPLE COLLECTION WAS NOT AS EXTENSIVE AS PREVIOUSLY THOUGHT, AND DOES NOT OVERLAP WELL WITH MORE RECENT SAMPLING EFFORTS. THEREFORE, THIS HISTORIC TO PRESENT COMPARISON HAS BEEN ELIMINATED, UNLESS NEW INFORMATION ARISES THAT LEAD TO A DIFFERENT CONCLUSION REGARDING OUR ABILITY TO COMPLETE THIS WORK. INSTEAD, ONLY THE 2011 SAMPLES WILL BE FULLY ANALYZED AND COMPARED TO JEMS STATION SAMPLES AND PUGET SOUND-WIDE ZOOPLANKTON SAMPLES FROM 2014 AND 2015]

We propose to:

1. Improve spatial and temporal extent and resolution of zooplankton community datasets by fully processing ~~and comparing~~ 2011 samples ~~with Frost's collections from the 1970s~~.

2. Collect additional years of data from a subset of sites in the ~~Frost and~~ 2011 datasets to determine the degree to which zooplankton composition and biomass varies over both space and time (to be performed as part of research activity **2. Zooplankton: Establishing a Puget Sound-wide zooplankton sampling program**.
3. Add hydroacoustic information to plankton sampling to determine how representative plankton samples are as a function of depth, and density of the plankton characterized by hydroacoustics.
4. Compare compositional shifts to data sets from the coastal ocean and California Current, which are known to be highly dynamic in responses to temperature and other climatic forcings.

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14.4 Analyzing qualitative historic zooplankton dataset from WDFW herring spawning surveys

Principal Investigators: Iris Kemp (LLTK), Julie Keister (NOAA)

Data from plankton tows that occurred coincident with WDFW herring spawning surveys are being evaluated. The presence/absence and relative dominance of zooplankton, by taxonomic category, and some phytoplankton and fish larvae data were collected over a 20-year period (1975-1994 and a few samples from 1997 and 1999). Surveys typically spanned the January-May period each year. Samples from June-December also exist but are less consistent. In early years plankton tows were largely opportunistic; beyond that, tows were done at fixed sites fairly close to shore within each herring spawning survey region. Surveyed locations span from the Canadian border down to Olympia, out in the Straits to Dungeness Bay, and, in a few years, Willapa Bay and Grays Harbor. A second set of plankton data was collected at fixed mid-channel sites during herring-larval surveys in South Puget Sound from 1975-1979.

The majority of tows were made just offshore of the marine vegetation beds being sampled for herring spawn. A 0.5 meter plankton net (mesh size 0.5 mm) was towed at 5-6 feet (~1.5-1.8 m) depth for 5 minutes at 2 knots (~1 m/s) behind a small (~13 ft/4 m) outboard zodiac survey vessel. Catches were preserved with formalin in quart jars and were processed by Dan Penttila within a few weeks of the survey. Samples were separated into broad taxonomic categories and abundance of each taxon within the sample was qualitatively assessed. Numerically dominant/co-dominant taxa were noted. Fish larvae (herring, sandlance, smelt) were enumerated and larval lengths were recorded to the nearest mm.

None of these data have been analyzed or published prior to this effort. Dan Penttila (retired, WDFW) and WDFW are credited for establishing this dataset.

While this is largely a qualitative dataset, the data could provide a description of plankton presence/absence trends over time (seasonally, interannually) and space (regionally). There is also potential to measure larval forage fish length distributions over time and space. These data may give insight to plankton response to large-scale ecosystem shifts (e.g., PDO regime shift) within Puget Sound. Additionally, trends found in these data will be analyzed with respect to trends in Puget Sound salmon marine survival. If bottom-up factors drive salmon marine survival, we might expect trends in certain plankton taxa (e.g., crab larvae) to correlate with trends in salmon growth and survival.

These data will be paired with the results of studies 1 and 2 analyzed in single and multi-factor regression analyses comparing ecosystem factors and individual and population characteristics to population specific, stage-specific survival trends.

14.5 Analyzing long-term stratification datasets as a proxy for primary production

Principal Investigators: Neil Banas, Parker MacCready, and Ryan McCabe (U. Washington)

Stratification will be analyzed for its utility as a proxy for primary production. It also has more historical data than chlorophyll, and its modeling in future scenarios is more robust. A retrospective analyses of density stratification documented in the Collias reports from 1952-1966 Puget Sound surveys will be conducted; those observations from 1952-1966 period will be compared with those from ORCA buoys from 2005-present; and this information will be compared with Department of Ecology monthly survey data to determine if monthly sampling is adequate for documenting seasonal, inter-annual and longer timescale trends and variations in Puget Sound properties. Seasonal and inter-annual variation and long-term stratification trends will be compared to salmon marine survival trends and to climate indices such as the PDO. A template for the analysis is the wonderful papers by Stephanie Moore, while she was working with Nate Mantua.

Year 1: Collias/ORCA stratification analysis (research scientist R McCabe, 2 mos)

Year 2: DOE stratification analysis (McCabe, 2 mos)

14.6 Analyzing primary production variability in relation to stratification, part one - observational view

Principal Investigators: Neil Banas, Parker MacCready, and Ryan McCabe (U. Washington)

Existing ORCA records will be used to conduct analyses of phytoplankton production rates, timing, and variability to assess interannual and inter-basin variation. In addition, spatial and temporal variations in the relationship between bloom timing and stratification timing will be assessed, building on A.3.4. Results will be compared to salmon marine survival time series.

Year 1: ORCA analysis (Banas, 3 mos)

14.7 Analyzing primary production variability in relation to stratification, part two - model view

Principal Investigators: Neil Banas, Parker MacCready, and Ryan McCabe (U. Washington)

Rationale: A biophysical model will give a much more comprehensive view of primary production variation in space and time than can be inferred from existing ORCA data, although the ORCA data is absolutely essential for validation. This validation needs to be focused on the processes of particular concern to this project, rather than simply a skill assessment of model salinity or phytoplankton in general, because the processes of concern here—spring bloom timing, primary production dynamics at marginal light levels—are known weak spots of contemporary NPZ (nutrient-phytoplankton-zooplankton) models.

Extrapolating from recent work on plankton phenology across the North Atlantic and Pacific, it appears likely that interannual variations in bloom timing and growing season length will prove to be even more important to the dynamics of large zooplankton than interannual variations in total chlorophyll (Varpe et al. 2007, Mackas et al. 2012). Getting bloom timing right may require that we include a representation of phytoplankton physiological adaptation to changing light conditions: that is, it may be that a fixed light response (such as all current PNW models that we know of use) is too inflexible and needs to be replaced by a dynamic carbon:chlorophyll ratio or a scheme like that used by Wirtz et al. (2013) in the North Sea. The Coastal Modeling Group is now beginning a major, two-year Salish Sea biogeochemical modeling project through the Washington Ocean Acidification Center that will include the development of a basic NPZ model for Puget Sound. However, it would be risky to assume that the validation effort this work will entail—focused on bulk biogeochemical balances—total chlorophyll, nitrate, oxygen, and their impact on carbon budgets—will identify and resolve the issues with spring bloom timing most important to large zooplankton and salmon.

The flip side of this problem is that once we identify a model formulation that correctly reproduces early spring phytoplankton dynamics in one model system, that process understanding and mathematical formulation can be directly ported to another model system, such as Atlantis.

Year 1: Updating of CMG Salish Sea model physics (match from WOAC: McCabe, 4 mos)

Year 1-2: Porting of CMG coastal plankton model to Salish Sea, validation of seasonal cycle (match from WOAC: Banas, 3+2 mos)

Year 2: Validation of spring bloom timing and growing season length in relation to stratification against ORCA data; iterative improvements to phytoplankton growth scheme as necessary; comprehensive model view of interannual and interbasin variation in primary production (Banas, 3 mos + McCabe 2 mos)

15.1 Refining the existing ewe ecosystem model and run scenarios for coarse analyses of salmon survival drivers

Principle Investigator: Chris Harvey (NOAA)

(This work will be performed in an opportunistic fashion as the primary modeling focus is on establishing the end-to-end ecosystem model, described in 15.2)

A Puget Sound Central Basin food web model was developed collaboratively by numerous scientists from NOAA, State of Washington agencies, and from the University of Washington; the lead developer is Chris Harvey at NOAA. It was made in the Ecopath with Ecosim (EwE) software, which first creates a mass-balanced food web of functional groups linked through predator-prey interactions (Ecopath) and then allows the user to perturb the food web in a dynamic simulation framework (Ecosim). The model domain is the central basin of Puget Sound, specifically marine waters from approximately Whidbey Island in the north to the Tacoma Narrows in the south. As EwE has essentially no spatial resolution, the model domain is essentially a single well-mixed box, although the developers have used some features of the model to impose some spatial dynamics (e.g., habitat effects related to eelgrass beds). The current model food web is composed of over 65 functional groups, ranging from phytoplankton to marine mammals, and also includes 15 different fishing gear types.

The EwE software is not especially well-suited to simulating groups like Pacific salmon because the software does not handle complex life histories well, nor (as noted above) is it particularly well suited to handle spatial dynamics such as migrations and habitat switches that are characteristic of salmon. Thus, salmon have not been a major focus in research to date using this model (see References). Until now, three major groups of salmon have existed in the model: "wild" salmon, "hatchery" salmon, and pink salmon. Because of the aforementioned shortcomings of the EwE software for simulating salmon ecology, the salmon groups were simplified from the outset, rather than exhaustively parameterizing them. Thus, the "wild" and "hatchery" groups are respective aggregates of naturally and hatchery-reared Chinook, coho, and chum salmon from populations in the Central Basin and the South Sound (which must migrate through the Central Basin and thus interact with its food web and fisheries). Each group's parameters represent weighted averages of biomass, production rates, consumption rates, harvest rates, and diets from the three species. This masks our ability to compare effects of simulated ecosystem changes or management actions on Chinook salmon.

To better address questions and research needs related to salmon, the following changes will be made to the Puget Sound Central Basin food web model:

1. **Disaggregating salmon groups.** Existing "wild" and "hatchery" groups will be separated by subyearling migrants (less than 80-100mm in length) (pinks, chum, and most chinook and some coho), yearling+ migrants (greater than 80-100mm in length) (Chinook, coho, sockeye), and steelhead (150-200mm in length). The subyearling migrants are expected to have longer residence in Puget Sound and more usage of shorelines, while the others would have shorter residence, particularly in shallower waters. This will translate into different suites of predators and prey for the three groups. Assumptions will have to be made about the relative importance of each species in the diets of its predators. Model simulations will be run to compare the aggregated and disaggregated salmon groups' responses to system perturbations to see if

model performance and sensitivity differ (and if so, how). At this time, the resident life-history for Chinook and coho will not be isolated, although that could occur in the future.

2. **Adding spatial heterogeneity.** As noted above, the EwE software takes little account of spatial dynamics. It does, however, have a seldom-used module, Ecospace, that allows users to create simple grid-based maps of the model system and assign habitat types, spatial productivity patterns, and crude migration dynamics. Each functional group can have affinities assigned to each habitat type, such that some habitats benefit growth or fitness while others are neutral, competed for, or actively avoided. A highly stylized, simplified Ecospace model will be developed that features nearshore/offshore habitat differences and also allows salmon to migrate out of the current model domain, through the Strait of Juan de Fuca, and into the Pacific Ocean. This may include a distinct domain for the west coast of Vancouver Island as well.

3. **New model scenarios.** The research represented in the "References" section below includes work on general food web structure and sensitivity; the role of eelgrass; the role of bald eagles as top predators; and the potential effects of ocean acidification. At the request of the Salish Sea Marine Survival Technical Team, scenarios will be established that are germane to salmon-related questions and appropriate for a coarsely scaled model like this. These will mainly be scenarios that simulate changes in system state, to either directly reflect changes to the food web or mimic the impact drivers such as temperature changes, toxics, disease, and ocean acidification may have on the system. This effort can inform the value of further investigating particular factors and how they may be affecting salmon and steelhead survival. Example questions that would be asked of the model are as follows:
    a. How have historic declines in gadoid populations affected juvenile salmon?
    b. How do changes in forage fish biomass affect juvenile salmon and steelhead?
    c. What is the effect of the recent increase in harbor seals, sea lions, and harbor porpoises on juvenile salmon and steelhead?
    d. Why have pink and chum salmon increased while Chinook, coho and steelhead have declined? Does this have to do with prey differences, residence time or both?
    e. What is the effect of the recent increases in bald eagles on juvenile salmon?
    f. What is the role of eelgrass in juvenile salmon survival?

Future Activities

A similar EwE model was developed for the Strait of Georgia. Therefore, the proposed U.S.-Canada modeling workgroup will discuss the value of aligning the two EwE models vs. performing other ecosystem modeling efforts in a thorough modeling assessment. For example, the EwE modeling limitations may lead the workgroup to conclude it's not worth expending more resources to improve them. Puget Sound/U.S. scientists have tentatively concluded that EwE limitations are an issue. Its spatial resolution is, at best, crude, and it does a poor job of simulating complex life histories. Moreover, it makes no attempt to simulate seasonal dynamics, and it is also not linked to physical, biogeochemical, or transboundary drivers and processes, which limits our ability to understand landscape-level processes and anthropogenic impacts such as land use changes, eutrophication, and stormwater inputs. Therefore, the U.S. scientists currently propose the development of a Salish Sea-scaled model in the Atlantis software. This model is at an early stage of development, and a more detailed discussion weighing the merits of developing the Atlantis model for the entire Salish Sea will be had by the proposed U.S.-Canada modeling workgroup. See Modeling Activity #3 for more information.

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15.2 Developing an end-to-end, spatiotemporal model for Puget Sound

Principle Investigators: Chris Harvey (NOAA), Brandon Sackmann (contractor), Tarang Khangaonkar (PNNL), Isaac Kaplan (NOAA), and Neil Banas (U. Washington)

Complex patterns of circulation, water chemistry, and primary productivity affect each of Puget Sound's sub-basins in different (but potentially interacting) ways, and those processes in turn influence populations of valued resources such as salmon, forage fish, marine mammals, and seabirds: affecting our ability to manage, restore and protect living marine resources. Given the diversity and complexity of bottom-up and top-down forces that interactively influence Puget Sound, a spatiotemporal ecosystem model is of great potential value, particularly an "end-to-end" ecosystem model that can integrate a broad range of oceanographic, biological, and social drivers, currencies, and scales. Contemporary models also help us develop ecosystem monitoring programs and test various management strategies.

We propose to develop an end-to-end ecosystem model of Puget Sound and use it to examine how bottom-up processes, driven largely by circulation patterns, relate to spatiotemporal differences in the abundance of lower and middle trophic level species in Puget Sound. The value of this activity will extend beyond a more refined understanding of the salmon-Salish Sea relationship. It will also contribute to the foundation for the ecosystem-based management effort currently underway in Puget Sound, informing us about the interactions of multiple species and Puget Sound characteristics recognized as "vital sign" in indicators of the system's health by the Puget Sound Partnership (PSP 2012).

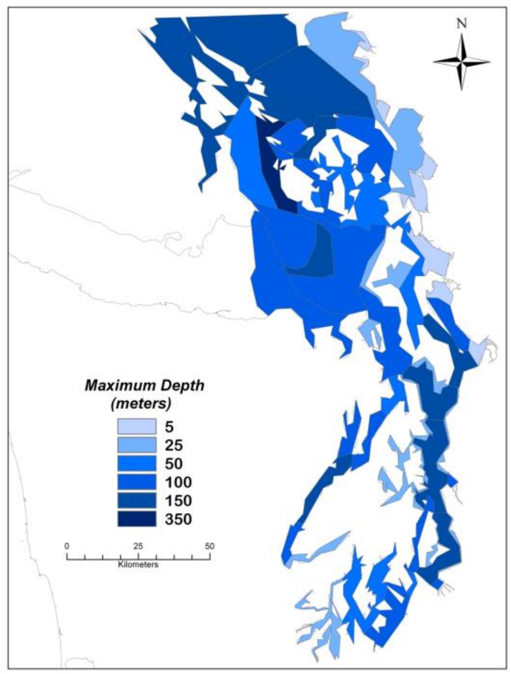

Figure 1. One possible configuration of an Atlantis model of the Puget Sound region. Polygons have up to 6 depth layers, and derive from bathymetry, circulation patterns, species distributions, and habitat characteristics.

Specific questions to be examined are:

1. How do short- and long-term changes in circulation and water chemistry affect the salmon, steelhead (and, other relevant species) in Puget Sound?
2. How sensitive are bottom-up processes to the effects of human activities in Puget Sound, relative to natural variability?

We will address these questions by coupling oceanographic models of Puget Sound with the Atlantis ecosystem modeling software. Atlantis was developed primarily by Dr. Beth Fulton and colleagues for evaluating marine ecosystem-based management in Australia, but its use has expanded globally (Fulton et al. 2011). Atlantis integrates circulation patterns; nutrient cycling, with biological feedbacks; food web interactions; benthic habitat effects; fisheries; and management and monitoring efforts. Simulations are spatially explicit (Fig. 1) and three-dimensional, with multiple depth layers and sediment. Three-dimensional fluxes of water, salinity, and other variable are input from oceanographic models. Food webs span from phytoplankton and bacteria to marine mammals; movements can be described as localized diffusion and/or daily, seasonal or annual migrations. Fishing fleets can be modeled simply or as dynamic actors responding to spatial factors, regulations, and economics. During a model simulation, a monitoring and assessment routine collects "data" so that indicators can be used to inform decision rules and management strategies can be compared.

Approach

The following approach will be taken:

1. Puget Sound Atlantis box geometry (completed). Prior work at the NWFSC (in consultation with Dr. Neil Banas, University of Washington Applied Physics Lab) resulted in a 3-D representation of Puget Sound, with polygonal cells representing regions characterized by discrete bathymetry, circulation, habitat, community structure, and/or management practices. There are 61 cells, each with a minimum of 2 and a maximum of 7 depth layer including a sediment layer (Fig. 1). Cells at the northern and northwestern extremes of the model domain are boundary boxes, which allow us to simulate linked processes that occur outside of the model domain.

2. ALTERNATIVE 1 - Develop oceanographic submodel (Year 1). Integral and PNNL will leverage previously computed hourly output from hydrodynamic and water quality solutions from the Puget Sound Georgia Basin (PSGB) model (Khangaonkar et al., 2012b) for calendar years 2006 and 2070 to create input data products needed to underlie the Puget Sound Atlantis ecosystem model. Specifically, PNNL will develop hourly volume fluxes across selected cross sections corresponding to boundaries of the Atlantis model cells internal to the greater PSGB model domain. Volume fluxes will be defined by layer, across each specified boundary, over a 10-layer sigma stretched grid on an hourly time step. Integral will use the output from the PSGB model to generate a complete set of initial condition setup files and time-varying forcing input files for volume fluxes, temperature, salinity, and other key water quality parameters that adhere to specifications outlined in the Atlantis end user documentation. Nutrient loading estimates from all major point and non-point sources have been developed and summarized separately by WA Department of Ecology (Khangaonkar et al., 2012a; Mohamedali et al., 2011). Using this dataset, developed in part to support initial development of the PSGB model, Integral will prepare point and non-point source input files for incorporation into Atlantis.

3. ALTERNATIVE 2 - - Develop oceanographic submodel (Year 1). (a) We will spatially integrate multi-year time series of 3-D fluxes of water, heat and salinity as projected by an existing, well validated Regional Ocean Modeling System (ROMS) model of Puget Sound, called MoSSea (Sutherland et al. 2011) to match the box geometry of the Atlantis model domain (e.g., Fig. 1). (b) We will use the ROMS fields to drive a spatial model of nutrients, phytoplankton, zooplankton, detritus, and oxygen ("NPZDO"). This will follow a model framework developed in ROMS for the Washington-Oregon outer coast by the UW Coastal Modeling Group (Banas et al. 2009; see *http://faculty.washington.edu/sarahgid/PNWTOX/*). Puget Sound-specific adjustments will be made using observations from Washington Dept. of Ecology monitoring and the Hood Canal Dissolved Oxygen Program (see *http://faculty.washington.edu/banasn/models/lynch/* for an adaptation of the coastal model to Lynch Cove in lower Hood Canal). The adjusted NPZDO model will be coupled to the Atlantis food web submodel to link the abiotic and biotic components at the base of the food web.

4. Develop food web submodel (Year 1) NWFSC will follow similar protocols to those they have used to develop Atlantis models of the California Current (Brand et al., 2007; Horne et al., 2010; Kaplan et al., 2012) and Gulf of California (Ainsworth et al., 2012), and that they have also used to support development of Atlantis models for Chesapeake Bay (http://chesapeakebay.noaa.gov/ecosystem-modeling/chesapeake-atlantis-model-). Key food web components in all marine habitats of Puget Sound have already been identified and aggregated into 60 functional groups, based on consultation with federal, state, tribal and academic biologists; these groups range from microbial groups to marine mammals (similar to food web diagram in Fig. 2). Basin-specific parameters related to abundance, mortality, growth, maturation, reproduction, feeding, harvest, movement, and habitat use will be derived from literature and consultation with experts; this process has already begun through previous food web modeling in the main basin of Puget Sound (Harvey et al., 2010; Harvey et al., 2012a; Plummer et al., 2013). Model tuning and calibration will follow the methods outlined by Horne et al. (2010) and practices developed at the NWFSC by Kaplan and colleagues over the past 7 years. When establishing and populating these fields, we will consider the interplay between this modeling and the proposed monitoring/field assessment efforts that are part of or associated with the Salish Sea Marine Survival Project as a whole.

4. Run simulations to address questions, above (Year 2) The second step will be the running of simulations to explicitly address the two questions outlined above at the scale of individual basins as well as the whole model domain:

A. <u>How do short- and long-term changes in circulation and water chemistry affect the salmon, steelhead (and, other relevant species) in Puget Sound?</u> We will run multi-year simulations in which we examine the effect of the mean seasonal cycle and interannual variation in large-scale circulation patterns on abundance and production of key lower and middle trophic level groups in each basin (from here, we can identify mechanisms relevant to long-term change). Focal groups will include zooplankton (particularly crustacean and gelatinous functional groups), forage fish (including Pacific herring *Clupea pallasi*), and the early marine stages of salmon and steelhead. We will also impose short-term, localized changes in circulation and water chemistry and track their effects on the system. Such perturbations will include hypoxia events in regions of Hood Canal and South Puget Sound where they have been observed frequently, and seasonal changes in freshwater inputs, as might be associated with droughts or changes in winter precipitation patterns. Other changes to be considered include: a) the effects of of pCO_2/pH (ocean acidification) and its synergistic impacts (with low oxygen, warming, and eutrophication or combined effects with toxics), b) toxics, including trophic transfers and spatial exposure based on land cover and toxic inputs, and c) heterosigma events.

B. <u>How sensitive are bottom-up processes to the effects of human activities in Puget Sound, relative to natural variability?</u> Following on the previous question, we will examine how management actions might be used to mitigate the impacts of circulation and water quality changes across a range of spatial and temporal scales. Focus will be on determining if natural and anthropogenic perturbations have additive or interactive effects (for example, if eutrophication impacts are substantially greater or less than expected given changes in circulation). We will also examine the magnitude of management actions required to mitigate the impacts of these natural and anthropogenic drivers on ecosystem health and services, and whether or not stringent management actions to maintain various ecosystem attributes imply tradeoffs in other sectors or conservation objectives (a detailed example of a tradeoff analysis using Atlantis is in Fulton et al. 2007).

5. Simulated climate change scenario (Year 2). Because the PSGB circulation model we may use to drive Atlantis (Khangaonkar et al., 2012b) can simulate circulation patterns and freshwater inputs based on future climate projections (see step 2, alternative 1, above), we can generate hypothetical comparisons of present vs. future climate impacts on community structure. We will drive Atlantis simulations with continuous loops of annual circulation patterns based on either a contemporary year (2006) or a projected future year (2070); future dynamics will be based on regional hydrology projections based on downscaled climate model information obtained from the University of Washington's Climate Impacts Group, nutrient loading projections developed in collaboration with the Washington Department of Ecology (Roberts et al., in prep.), and land use estimates from Oregon State University's Alternative Futures Project (http://envision.bioe.orst.edu/StudyAreas/PugetSound/index.html). These climate driven loops will serve as an initial baseline for comparisons and will provide a basis to hypothesize which food web components and ecosystem services are potentially sensitive to climate change. We will also replicate the indicator assessment described above (see step 4) to test whether indicator performance is robust to long-term climate variation, or if other indicators may be more useful as the underlying environment changes.

This project will provide a much clearer spatiotemporal framework in which to examine the processes that tie bottom-up processes, including factors such as eutrophication and hypoxia, to the production of forage fish and salmonids. The modeling framework will place several of the Puget Sound Partnership's vital sign indicators into the context of factors that can be managed (e.g., nutrient inputs, fishery harvests) but that must be managed against the backdrop of natural variation. It will enable us to examine individual basins of Puget Sound, as well as how basins influence one another through vectors such as circulation and species migrations. We will write peer-reviewed publications for each of the questions outlined above.

The same model would also be applicable to numerous other Puget Sound research and management efforts concerning species of concern like groundfish, marine mammals, and seabirds; moreover, it could serve as a central "operating model" that is often used in processes such as management strategy evaluation (MSE), integrated ecosystem assessments (IEA), and analyses within the so-called DPSIR framework. It would represent effective mechanistic bridging of the MoSSea model of circulation, via a well-validated model of plankton dynamics, to the higher trophic levels; this is significant not just because Puget Sound is heavily forced by lower trophic level processes (Strickland 1983), but also because many contemporary ecosystem models tend to badly oversimplify processes at the base of the food web. Finally, it may be a key step in modeling the impacts of ocean acidification in Puget Sound; Kaplan, Harvey, Fulton and colleagues at the NWFSC are currently working on a NOAA-funded project to add an ocean acidification module to Atlantis models of the California Current ecosystem, and that capability could be extended to the Puget Sound model as well.

This effort will be well integrated with the other Salish Sea Marine Survival Project Activities and the Puget Sound Partnership's Puget Sound Ecosystem Monitoring Program via their Modeling Workgroup. If there is a decision at the U.S.-Canada level to develop this model for the entire Salish Sea, the scope, participation and costs will be adjusted accordingly.

Deliverables

- An ecosystem model for collaborative use between the PIs, the Marine Survival Project Technical Team, the Puget Sound Partnership, and its affiliates to use in ecosystem-based management and IEA in Puget Sound

- A NOAA technical memorandum describing the development and parameterization of the model (steps 1, 2 and 3 of the Approach outlined above)

- Manuscripts describing the results of steps 4 and 5, above.

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