CANADIAN SALISH SEA MARINE SURVIVAL PROGRAM

2016 PROGRAM SUMMARY

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with contributions from the SSMSP scientists

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Section 1: 2016 Program Overview

The following is a 2016 year-end report of the Salish Sea Marine Survival Project in Canada: the joint U.S. – Canada effort to determine the primary factors affecting the survival of juvenile salmon and steelhead in the Salish Sea marine environment.

The project is a five-year project (2014-2018). The full Canadian research program was implemented in 2015, developed and tailored based on lessons learned during 2014. In the Salish Sea, work has focused primarily on the Cowichan, Puntledge, Big Qualicum and Fraser watersheds, and the marine waters of the Strait of Georgia. In total, the Pacific Salmon Foundation managed 40 projects in 2016 conducted by over 30 partners with a total expenditure of $3.2M. Field studies will continue during 2017, while 2018 will be dedicated to assimilation of results, analysis and dissemination of key findings.

This report provides a short overview of the 2016 Canadian program and key findings to date.

Background

The Project is based on three broad concepts that impact salmon:

1. Bottom-up processes—including weather, water, and plankton—that drive juvenile Chinook, coho and forage fish prey availability have changed, and salmon are not able to compensate. This is limiting salmon growth and survival.
2. Top-down processes have also changed. Primarily, there are more predators eating steelhead, resident salmon and larger forage fish.
3. Additional factors are exacerbating these ecological shifts, including toxics, disease, competition, and the cumulative effect of significant top-down and bottom-up shifts occurring simultaneously.

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.

Accomplishments and Progress to Date related to initial 3 Key Objectives

The project was begun with 3 key initial objectives. We note the progress to date related to these objectives, listed below.

Objective 1: Re-build the production of wild Pacific salmon and steelhead through a program that is ecosystem-based, considers hatchery effectiveness, and engages communities

- The Salish Sea Marine Survival Project is currently in the process of active data acquisition to enable us to work towards this goal; a comprehensive modelling and analytical framework has been implemented and will be led by Dr. Villy Christensen, ecosystem modeler at UBC;
- We have completed a second year of the complete field program; most of these core projects will be continued for another year, after which time we will be focusing on data compilation, analysis and modeling, and reporting out on our findings;

- The core projects of the SSMSP were initiated by the SSMSP Science Team and developed by scientists from government, academia, and local community groups in BC;
- We are carrying out hatchery manipulation studies to help us examine hatchery effectiveness; we are engaging communities in nearshore habitat studies including restoration and monitoring; we are working to clarify the impact of harbour seals and other predators on juvenile salmon; we are assessing the health of juvenile salmon; we are collecting information on ecosystem indicators and carrying out modeling studies and analyses to better understand the changes that have occurred in the Strait, as well as how to ameliorate conditions for coho and Chinook salmon;
- We are working with our US partners and aligning our efforts cross-border.

Objective 2: Promote sustainable fisheries and increase their value to communities

- We will be engaging in community meetings around the Strait of Georgia in 2017-2019, informing local communities about the findings from the program as a whole;
- We will be producing media releases and local newspaper articles about local sustainable fisheries

Objective 3: Provide a foundation for long-term monitoring of Salish Sea and salmon health

- We have set up a highly successful citizen science program for oceanographic monitoring, and during 2016 we are also monitoring ocean acidity, in addition to water temperatures, salinity, oxygen content and nutrient content of the waters of the Strait;
- We have developed the Strait of Georgia Data Centre, which serves as a repository for ocean ecosystem data and is being actively developed;
- We are collaborating increasingly with partners such as Seachange, Hakai and SeaWatch Society that carry out monitoring programs for eelgrass, kelp and forage fish habitat;
- We are partnering with Genome Canada for their Strategic Salmon Health Initiative- working to characterize salmon health throughout BC hatcheries, aquaculture facilities and of wild fish within the Strait of Georgia;
- We have built strong ties with the new UBC Institute for the Oceans and Fisheries; one of our goals is that some of our programs will be continued after 2018 under this organization, while others may be continued by Hakai.
- One project specific to defining ecological indicators for Puget Sound, the Strait of Georgia, and Juan de Fuca Strait has commenced.

Overview of 2016 projects

The key studies that were carried out in 2016, are briefly:

Bottom down studies:

- Oceanographic monitoring projects including citizen science boats, buoys, satellite imagery, localized moorings in Cowichan Bay and zooplankton monitoring: overall, these projects are collecting information at time and space scales never achieved before.
- Juvenile herring surveys and forage fish assessments (using hydroacoustic methods for the latter).
- Juvenile salmon sampling in freshwater and early marine life around Cowichan Bay, Qualicum Bay, Fraser River and in the Discovery Islands. These studies continue to incorporate in-river sampling, beach seining, purse seining and trawl sampling.

Top down studies:

- These include assessments of harmful algae, continued studies of seal predation (these include seal scat collections from areas of the Strait that were not studied in earlier assessments, such as mainland inlets, and central Strait) and the Strategic Salmon Health Initiative.
- With respect to the latter, researchers are using novel genomic approaches to identify potential stressors and monitor dozens of microbes to identify pathogens that might be of greatest importance. The sampling program samples fish from freshwater through the first 9 months of marine residence, and thus their conditional state can be monitored even before they enter the Salish Sea. Prior analyses have suggested that salmon pre-condition can be highly predictive of survival as they move into new stressful environments. Over 26,000 wild, enhancement hatchery and aquaculture salmon are currently being analyzed to discover the microbes present in BC salmon and their spatial and temporal distributions within and among species and cultured and wild stocks.

Other:

- We are also carrying out a number of projects focused on nearshore habitat research, monitoring and restoration. These includes eelgrass planting, assessment of upland land use impacts on eelgrass, satellite methods for assessing kelp distributions and identification of kelp strains that may be most successful for restoration under climate change and in warming waters.
- We are carrying out some hatchery manipulation studies: these consist of 3 years of delayed release studies at Quinsam and Big Qualicum hatcheries. Additionally, we are partnering with EPIC4 and are contributing towards a large-scale initiative to characterize all coho genetics in hatcheries.
- We have begun modeling initiatives using historical data as well as cross border studies of ecosystem indicators.
  - A compilation of ecosystem indicators is being carried out cross-border and a combination of statistical models will be used to determine which are most useful as indicators for salmon survival. Those indicators will be used within a modeling framework to evaluate retrospective survival as well as to predict future trends.
  - Villy Christensen will head up the Salish Sea modeling initiative at UBC.

Table 1 below provides a listing of each project carried out during 2016, lead scientists, title, the main objectives and key findings in each case. More details on each specific project activity and results to date are provided in Section 3 below.

TABLE 1. CANADIAN SSMSP 2016 PROJECTS

Proponent	PIs	Title	Project Outline	Progress/Findings
OCEANOGRAPHY				
Sea This Consulting	Stephanie King	High temporal resolution monitoring of surface chlorophyll in the Salish Sea	The project examines the fine-scale temporal variability of surface chlorophyll in the Salish Sea which can be used by ecosystem scientists to understand the factors limiting salmon productivity. Three existing buoys have been equipped (Halibut Bank buoy, Egmont, Sentry Shoal) with fluorometers & one with a nitrate sensor to provide continuous measurements since 2015. Spatial context for the fluorometer time series is provided with satellite imagery during the spring bloom.	• The data show dramatic variability in the timing & magnitude of the spring bloom with the earliest & highest concentration bloom observed in 2015 & the latest bloom observed in 2011. The spring bloom in 2016 was about average in terms of timing but had a relatively low concentration. • There is a correlation between seeding from inlets & an early spring bloom (by ~1 month, 2003 to 2016). • The spring bloom in the south Strait is 5 days earlier on average compared to the north Strait • Nitrate concentration can be monitored autonomously & is a factor explaining phytoplankton bloom timing • Continuous monitoring patterns of blooms in the SoG since 2011 will be related to zooplankton phenology (Suchy project, below) and ultimately to juvenile salmon survival.
ONC Innovation Centre	Ryan Flagg	Citizen Fishers (application) Initial Instrument Set-up & Data User Services, & Engineer Support	The citizen science program is collecting oceanographic information in the Strait of Georgia at a spatial & temporal scale that has not been achieved before. ONC developed a tablet application during 2014/2015 to allow for immediate download of citizen science CTD data to the ONC central database via WiFi. The tablet has required several modifications & improvements over 2016. ONC also takes care of citizen science instrument set up & data services support - including digital infrastructure support, user services support (including manual correction of data) & ongoing management support. They also took care of engineering support in 2016 – & included pre-deployment dry & wet testing,	• 2015 & 2016 data are stored at ONC's Oceans 2.0 & freely available for download. • Modifications were made to the tablet during 2016. • These data are being used by modelers & other SSMSP scientists.

Proponent	PIs	Title	Project Outline	Progress/Findings
			assembly & maintenance, shipping & receiving, & instrument calibrations.	
Multiple	Isobel Pearsall/ Colin Novak	Citizen Science Boats	This program utilized 9 citizen science vessels in 2016 (Lund, Powell River, Sechelt, Vancouver, Cowichan, Galiano, Ladysmith, Nanaimo/ Qualicum, Campbell River). Boats made 22 trips over 2016 & gathered oceanographic data from the Strait using a CTD & secchi disk. They also collected phytoplankton & nutrient samples. We also loaned an additional CTD to Hakai for their citizen science sampling program in Johnstone Strait. Hakai are interested in collaborating & sharing data. Rich Pawlowicz, Oceanography at UBC & student Janet Lam have evaluated & improved the data collection process & citizen science data.	• The secchi disk spreadsheet, CTD data, chl-a data & nutrient data are all available on the Strait of Georgia Data Centre. • These data are being used in many programs including: calibration of Susan Allen's SoG biological model, Karen Suchy's phytoplankton-zooplankton phenology (see below), Svetlana Esenkulova's assessment of phytoplankton species & prevalence of harmful algae, calibration for Maycira Costa's satellite imagery etc.
University of British Columbia	Janet Lam and Rich Pawlowicz	Analysis of 2015 and 2016 Citizen Science Data	All the citizen science data for 2015 & 2016 was error checked & sensor & processing issues identified by Rich Pawlowicz & student Janet Lam at UBC.	• Solutions posed to issues have been sent to ONC & are being incorporated into their program (above). • Rich (and students) will continue to analyze the data over 2016-2017.
University of Victoria	Shapna Mazumder	Nutrients	Shapna Mazumder at UVic analysed the nutrient samples collected from citizen science vessels during 2016.	• Data analysis is ongoing.
DFO (IOS)	Mary Steel	Chlorophyll a	Mary Steel at IOS analysed the chla samples collected from citizen science vessels during 2016.	• Data set has been made available & is uploaded to SoG data centre.
University of Victoria	Maycira Costa	Spatial temporal analysis chlorophyll, turbidity & sea surface temperature of the Salish Sea: an integration of satellite imagery & data from vessels of opportunity	This study aims to elucidate the relationship between the interannual & seasonal variability of productivity & turbidity in the Salish Sea & regional environmental forcing & global climatic indices. The data set & analysis can be further used in collaboration with fisheries biologists to access relationships with juvenile salmon marine survival. Costa et al are deriving fifteen years of spatial-temporal improved biogeochemical & SST products based on MODIS (available since 2002) & Sentinel-3 (launched in 2015) ocean colour satellites.	• During 2016 they added sensors to two BC ferries as part of their FOCOS program, so now have data that is being used to calibrate & validate satellite imagery • Products provide a 2002-2016 phytoplankton phenology in the Strait of Georgia. These data will be invaluable to the modeling efforts of Villy Christensen (see below).

Proponent	PIs	Title	Project Outline	Progress/Findings
University of Victoria & DFO	Karyn Suchy (post doc), Ian Perry, Maycira Costa	Phytoplankton and zooplankton phenology in the Salish Sea by integrating satellite products with historical and present zooplankton data	Objectives of this study are: 1. Examine the synchrony of phytoplankton and zooplankton phenology in the Salish Sea by integrating satellite products with historical and present zooplankton data 2. Investigate the response of phytoplankton and zooplankton to different climate drivers (e.g. regional environmental forcing including SST, wind, cloud cover, global climatic indices) in the Salish Sea	• This is an important project that will integrate several different data sources. • Work began summer 2016 and significant progress has been made on objective 1. • For objective 2, various data sets will be integrated, including: CTD data (IOS), phytoplankton abundance and chl-a data (citizen science data), buoy data (Stephanie), HPLC (Angelica, Nina) and the juvenile salmon data
Vancouver Island University	Helen Gurney-Smith	Coupling state-of-the-art chemical oceanography with biological relevance: examining phyto- & zooplankton populations in a dynamic coastal environment	This study aims to determine patterns between oceanographic processes & the quality & quantity of salmon prey items & lower trophic levels, thereby assisting in determinations of salmon productivity drivers. The work couples high resolution chemical oceanographic monitoring with phyto- & zooplankton analysis in the northern Strait of Georgia (Quadra Island) to determine: (1) the variability & intensity of corrosive surface ocean conditions (2) the effect of changing ocean conditions on the species & abundance of phyto- & zooplankton species in the northern Strait of Georgia; & (3) if the incidence & magnitude of harmful algal species is correlated to ocean conditions. This work is primarily funded by Tula Foundation but we provided funding for her phytoplankton & some zooplankton analysis during 2015 & 2016.	• Project ongoing during 2016 despite Helen's departure to St. Andrews. She will continue to oversee the project and samples will be analyzed by Tamara Russell, VIU • Results will be available after receipt of final project report Dec 2016. • Overall, it is apparent that there are extended periods of corrosive conditions during winter months. The severity has likely increased compared to pre-Industrial times. This may have impacts on overall coastal ocean productivity, with a potentially reduced 'biological window' during the spring / summer. Further years of data will be used to ascertain if this is the case.
DFO (IOS)	Svein Vagle	Observation of temporal & spatial variability of water-column physical chemical & biological properties in Cowichan Bay	Objectives of this study were to obtain spatial & temporal water property data for Cowichan Bay during the important fish migration period from April to August & augment these data with shorter term (order of hours from small boats), medium term (order of several months from acoustic monitoring) & order of years (from oceanographic moorings). The ultimate aim of this study is to interpret the biological observations to determine the primary factors controlling chinook & coho	• Mooring data collected throughout year show strong temporal (seasonal, tidal, diurnal) & spatial (1-10 km) variability in T,S, Fluorescence and acoustic backscatter. • Benthic settlement (Zooplankton?) varies seasonally. • Chlorophyll fluorescence (Phytoplankton growth) shows both a spring bloom (within bay) and tidal-modulated (in-channel) production regimes.

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			early marine survival. There were no costs associated with this ongoing program during 2016.	• Vertical migration of Zooplankton (grazing?) shows a strong seasonal modulation. The acoustic backscatter also shows wind-generated and bottom flux bubbles, fish and signatures of seals. • Fish and seals show regular patterns of vertical disposition, but are mutually exclusive (No evidence of frenzy feeding). • Seals show daily patterns in density and depth that varies seasonally. • Vagle & co-authors (e.g. Eddy Carmack) are currently working on a publication.
DFO (IOS)	Sophie Johanesson	Analysis of Sediment Trap Data from the Northern Strait of Georgia	The ultimate aim of this project is to relate juvenile fish health & survival to the timing & extent of blooms & ultimately to the physical forcing that drives the productivity. If there is a strong link between the timing of available food & the health of the outmigrating smolts, that will indicate a strong bottom-up control on survival. If timing turns out to be critical, then a possible next step would be to change the timing of the release of hatchery-raised smolts. Smolts could be released at staggered times, with tags linked to release date, so that the survival rate of smolts released at different times could be assessed.	• Analysis is underway of sediment trap data collected during 2008-2012. • By the end of the fiscal year, they will have a time series of phytoplankton & relative zooplankton biomass (inferred from fecal pellets) in the northern Strait of Georgia for 2008 – 2014 that can be combined with their existing time series of the chemical composition of sinking organic matter. • From these data they will assess the timing & quality of food for zooplankton & hence for juvenile salmon. They will compare the sediment trap record of food availability with indicators of juvenile salmon health as reported by the salmon group at the Pacific Biological Station & St. Andrew's Research Station (Marc Trudel, Rusty Sweeting).
ZOOPLANKTON & ICHTHYOPLANKTON				
DFO	Ian Perry	Zooplankton & ichthyoplankton status & trends in the northern Salish Sea	The objective of this program is to identify the seasonal patterns of variability in zoo/ichthyoplankton species composition, abundance & biomass in the Strait of Georgia & how they relate to changes in physical conditions. The ultimate aim is to identify the effect that changes in seasonal patterns of the species composition, abundance & biomass of the zoo/ichthyoplankton	2015 zooplankton samples are fully analyzed. 10% of 2016 samples analyzed to date. Key findings to date: • 2015 was a warm year, with an early spring phytoplankton bloom: copepods dominated abundance, euphausiids & amphipods dominated biomass; 2016 analyses underway

Proponent	PIs	Title	Project Outline	Progress/Findings
			has on the growth & early marine survival of juvenile salmon. SSMSP covered the cost for a number of vessel charters in 2015-2016 to augment (in time & space) the current DFO zooplankton collection program (Peter Chandler & Ricker surveys) & zooplankton analysis at IOS of these samples as well as zooplankton samples collected by the citizen science boats for 2015-2017.	• Spatial variability of zooplankton abundance/ biomass was high, with maxima occurring at different locations in each season • (Complex) relationships of euphausids, amphipods, decapods in central Strait of Georgia with NPGO, & to a lesser extent PDO • Statistically significant (weak) positive relationships between marine survival of Strait of Georgia Coho populations with Class Malacostraca (euphausids, decapods, amphipods, etc.) abundance & biomass in Central Strait of Georgia (1990-2010)
FORAGE FISH				
DFO (IOS) & UVic	Stephane Gauthier	Forage Fish	The short-term objective of this project is to develop a time series of robust acoustic indicators of productivity for forage & demersal species in the Strait of Georgia & establish potential links to juvenile salmon survival. The long term objective will be to use these indicators within a management context to understand & forecast marine survival of juvenile salmon based on validated ecosystem considerations. SSMSP is funding a post doc in Gauthier lab 2016-2017.	This project officially started in the March 2016. During the past six months, they have completed two Strait of Georgia Bio-acoustic Surveys in March & July. The March survey focused on dominant pelagic & demersal fish species in the SoG (e.g. Pacific hake, walleye pollock & Pacific herring) by conducting mark-identification fishing (trawls), while the July survey focused on plankton (e.g. zooplankton, euphausiids & larval fish) by conducting mark-identification sampling using hydrobios multinet & MOCNESS plankton net. Based on acoustic data collected in March- 2016 survey, they developed calculation methods to estimate biomass (indicator of productivity) & map biomass distributions for dominant fish species (Pacific hake, walleye pollock & Pacific herring). The method of biomass estimation will be applied to the other surveys to develop time series dataset for further analysis. The preliminary analysis on March-2016 survey shows the relatively separation in biomass distribution of hake, pollock & herring in the

Proponent	PIs	Title	Project Outline	Progress/Findings
				strait: biomass of Pacific hake was more distributed in the central-northern SoG, biomass of walleye pollock was more distributed in southern-central SoG, while biomass of Pacific herring was more aggregated along the shore.
DFO	Jennifer Boldt	Juvenile Herring Survey	The current objectives of the survey are to 1) estimate the relative abundance & distribution of juvenile herring in the SOG as a potential indicator of herring recruitment & as a potential indicator of prey availability to salmonid & other predators, 2) monitor the distribution & relative abundance & collect samples of nearshore pelagic fish in the Strait of Georgia, 3) monitor the distribution & relative abundance & biomass of the zooplankton community, 4) measure physical environmental variables that may affect the distribution of fish & zooplankton species, & eventually 5) understand trends in temporal & spatial variability in community composition & diversity.	• Bottom-up factors appear to affect age-0 herring • There may be some indications of density dependence • The date of most herring spawn relative to spring bloom affects both abundance & condition of age-0 herring. • After 2005, most spawning to occur prior to spring bloom • Salmon predators may not affect abundance but may influence condition of age-0 herring; may have implications for survival • Salmon competitors may not negatively affect age-0 herring
JUVENILE SALMON STUDIES- FROM FRESHWATER TO MARINE				
Key Mills Construction		Cowichan Chinook downstream survival	Key Mills was responsible for the construction/operation of a Rotary Screw Trap on Cowichan River in both 2015 & 2016.	See below
Cowichan Tribes		Cowichan Chinook downstream survival	Cowichan Tribes took care of the operation/monitoring of a Rotary Screw Trap on Cowichan River in both 2015 & 2016.	See below
J A Taylor & Associates		Cowichan Chinook downstream survival	JA Taylor & associates carried out the data analysis of results from the Rotary Screw Trap study in both 2015 & 2016. This study provided an estimate of in-river mortality of hatchery chinook smolts, which was surprisingly high. In 2015 the RST data from Cowichan Chinook showed 85% - 90% mortality between release & the lower river. In 2016 project was repeated, & a key question addressed was to determine how the FW mortality changes between different release locations?	The results from this study reiterated the low in-river survival of Cowichan hatchery chinook and showed that survival increases when the chinook fry are released at locations downstream from the standard site. Results from this study will be considered in future years when the Cowichan River Hatchery reviews its annual program, & will likely result in a change in hatchery release locations to the lower river.

Proponent	PIs	Title	Project Outline	Progress/Findings
BCCF	Kevin Pellet, Craig Wightman, James Craig	A PIT tag based method to investigate survival of Cowichan River Chinook throughout various stages in their first year of marine life	Study aims are to determine survival of Cowichan Chinook at different stages of their first year of marine life. Objectives are to: 1) capture juvenile Cowichan Chinook at a series of key times & locations throughout their first year of life, 2) apply PIT tags to wild & hatchery fish which are 60 mm & greater (fork length) at each location 3) construct & operate PIT tag detection arrays at the Cowichan River counting fence & Skutz Falls fishway to detect tags in retuning adults, 4) scan brood stock for tags upon capture, 5) calculate the relative survival for each tag group. Fish were captured in-river, by beach seines, by purse seine, & by microtrolling (to catch sub-legals) during both 2015 & 2016 & PIT tagged. Tag recoveries for each group will occur over several years due to multiple age classes of returning adults. During 2016 BCCF also installed the state of the art Biomark in-river array which has excellent detection of both smolts leaving the system & adults returning.	From their study, we are starting to have an understanding of the high levels of in-river mortality, the causes (e.g. raccoons, otters) of this predation mortality, as well as the fact that most mortality appears to occur in-river or soon after fish enter salt water. This group have collected a huge amount of information about the early life history of juvenile salmon both in-river and in the early marine period. Mortaltiy in river appears to occur constantly along the river and accounts for about 80% of mortality of hatchery and wild chinook. PIT tag returns to the new BIOMARK array show highest returns to date for fish PIT tagged when microtrolling (ie most mortality occurring in-river and in Cowichan Bay.
University of Victoria	Francis Juanes, Will Duguid (PhD student)	Variation in juvenile Cowichan River Chinook salmon distribution, diet, & growth rate in relation to tidal mixing & water column stratification	Aims of this project (2015-2016) are to identify the biophysical attributes of epipelagic habitats that may be of particular importance to juvenile Chinook & Coho salmon in their first marine year (hotspots) & identify candidate areas in the Salish Sea meeting this description. They will also determine if, & how, distribution of juvenile Chinook & Coho salmon with respect to gradients in water column stratification & tidal mixing may be modulating the effect of bottom up (temperature, food availability) & top down (predators) regulators of marine survival. Duguid is also assisting BCCF in their Cowichan PIT tag project (see above) applying as many PIT tags as possible to Cowichan Chinook salmon during the latter part of their first summer at sea as part of a cohort study to determine the critical mortality period for this stock.	Key findings include the following: •Very fine scale habitat variability may be important for diet, growth & predator exposure of juvenile Chinook • Some evidence for abrupt outmigration in October • Lack of evidence for decline in abundance or differential hatchery mortality during summer • Failure to reach a size facilitating piscivory on YOY herring may slow growth. A potential mechanism linking match-mismatch & critical size-critical period hypotheses? Herring availability and the size of the chinook relative to juvenile herring may be crucial factors.

Proponent	PIs	Title	Project Outline	Progress/Findings
DFO	Marc Trudel, Chrys Neville, Kristi Miller	Understanding the factors limiting the recruitment of Pacific salmon in the Strait of Georgia – From patterns to processes	The primary objectives of the juvenile salmon studies are to understand the factors currently limiting the abundance of salmon in the Salish Sea. This will be achieved by testing a series of hypotheses that may explain trends in marine survivals. Methods currently being used are cohort analysis, following several cohorts of coho & chinook & determining which individuals do not appear to survive over time. Information has been collected on ocean entry time & size, growth (using otoliths), RNA:DNA ratios, IGF, bioenergetics, diet (using stomach contents & isotopes), fatty acids (in both zooplankton prey & juvenile salmon), presence/absence of competitors & presence of microbes. In 2015, smolt samples of coho & Chinook salmon were obtained from selected hatcheries at the moment of release, as well as a few selected sites through beach seining (i.e. Cowichan River & Big Qualicum). The latter is required to obtain samples of wild coho & Chinook during their downstream migration. Samples were also taken using purse seines, CCGS Neocaligus on a monthly basis from April to August (Cowichan Bay & Fraser River Plume), & the CCGS WE Ricker in July & September.	Project is ongoing with lab analyses underway now that funding delays are over. Huge amounts of information have been collected by these programs. Now the goal is to complete the lab studies and begin analyses.
Zotec Services	Carol Cooper	Plankton & Stomach Analysis	Zotec Services carries out stomach content analyses & zooplankton analyses for collections from Cowichan Bay & elsewhere (Puntledge/Big Q) as part of the juvenile salmon studies of Trudel et al. (listed above)	Ongoing. Timely processing allows for fast data transfer to the Neville lab (above).
Raincoast	Andy Rosenberg, Dave Scott, Misty McDuffee, Lia Chalifor	Characterizing juvenile salmon species abundance, growth and habitat use in the Fraser River estuary.	Monitoring in the Fraser estuary fills a critical gap that will help characterize recruitment and survival patterns of juvenile salmon migrating into Georgia Strait and the Salish Sea. The project will provide extensive new quantitative information on juvenile salmon presence, timing, use of estuary habitats across the outmigration period, potential differences between populations, and between	This study has provided new information on juvenile salmon movement, outmigration timing, and distribution in the Fraser River estuary. They found that fish abundance and diversity was much greater in eelgrass than in sand flat and marsh habitats. They captured a total of 725 juvenile salmon, of which the majority were juvenile Chinook

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			hatchery and wild Chinook. Additionally, Genetic Stock ID will provide new and important information on how specific populations use the estuary over various spatial and temporal scales.	(n=516) captured in marsh habitats (n=437). They also collected a total of 289 fin clips from juvenile Chinook for genetic stock identification and retained 258 juvenile Chinook for otolith microstructure analysis. Data analysis is ongoing.
PREDATION STUDIES				
University of British Columbia & DFO	Sheena Majewski, Andrew Trites	Juvenile salmon predation by harbour seals	The goal of this research is to 1) estimate the numbers of chinook and coho smolts consumed in the Strait of Georgia by harbour seals, 2) evaluate their impact on salmon recovery, and 3) propose ways to mitigate the impact of seals.	Collections of scats were made in 2016 at several sites around the Strait. Processing and prioritization of samples for genetics and hard-part analysis is ongoing so results from this study will be available in late 2017
University of British Columbia	Hassen Allegue, Austen Thomas & Andrew Trites	Habour seal fine-scale foraging behaviour during the out-migration of salmon smolts from Big Qualicum River	Hassen's MSc thesis has used data from the 2015 RFID & GPS-accelerometer tags used on harbour seals around Big Qualicum hatchery to generate maps of spatial predation risk from combined RFID & spatial data.The key questions he is asking are: (1) Seal Foraging hotspots- where are they? (2) Seal Foraging behaviour: how is it affected by smolt migrations?	Results show 3 different foraging strategies: Estuary seals, which forage at dusk & focussed on coho smolts leaving the Big Q hatchery; Intermediate Strategy, feeding in estuary & further afield, & a Non-estuary feeding strategy. Depth of foraging & spatial scale of foraging varied widely. Foraging hotspots were identified around the Big Q area, & it was noted that the estuary is an important foraging hotspot with seals focused on feeding on emigrating smolts.
University of British Columbia	Ben Nelson & Andrew Trites	Impacts of seals on salmon in Cowichan Bay during spring, summer & fall 2014	The primary objective of this study was to estimate monthly proportions of juvenile & adult salmon in the harbour seal diet through analysis of seal fecal material ("scats") collected from Cowichan Bay, British Columbia during 2014. Secondary objectives include estimating the local abundance of harbour seals in Cowichan Bay through visual surveys, & documenting & describing seal foraging behavior in the area.	Study & report completed. The most immediate influence this project will have on achieving the objectives of the Salish Sea Marine Survival project is by increasing the sample size of the dataset used to describe harbour seal diet in the Strait of Georgia. By adding these 2014 samples to the 1,258 collected by Thomas et al. (2016) from 2012-2013, the total sample count increases by 23%. These samples, in addition to those recently gathered in 2015 & 2016 (Allegue, unpublished data; Majewski, unpublished data), are critical to understanding how spatial & inter-annual variability in the harbour seal diet may influence the modelling approaches used to

Proponent	PIs	Title	Project Outline	Progress/Findings
				quantify the impacts of seal predation on species of high conservation concern.
ACOUSTIC TAGGING STUDIES				
University of British Columbia	Scott Hinch, Tony Farrell, Kristi Miller	Physiological & environmental factors affecting the migratory behaviour & survival of sockeye & steelhead salmon smolts	These studies continue time series of acoustic telemetry-derived estimates of salmon smolts migration rates & survival in the Salish Sea, enabling an among-year retrospective analysis examining impacts of environmental & physiological factors, & allowing for better understanding of the relative roles of freshwater versus coastal marine environments as locales of mortality. Short-term objectives are to 1) tag & gill biopsy outmigrating smolts, 2) assess gill & blood biomarkers for pathogen presence/load, osmoregulatory preparedness, & growth potential for tagged outmigrant smolts & relate these biomarkers to migration rate & survival, 3) conduct retrospective analyses of existing & new telemetry data for Chilko sockeye salmon (2010-2016) to relate migration rate & survival of smolts in the Salish Sea to fish size, migration behaviour (migrating timing & rate), & oceanographic & riverine conditions, 4) conduct retrospective analyses of existing & new telemetry data across sockeye & steelhead stocks to define meso-scale migration routes of smolts & relate these migration routes to subsequent survival, 5) develop individual-based models (IBM) to simulate smolt migrations in the Salish Sea to better understand the relative influence of movement behaviours (navigation & orientation) & oceanography on resulting marine distributions & migration routes.	In 2016 water levels allowed for tagging of Chilco sockeye. This year both 1 and 2 year olds were tagged. Findings to date from this project include: -Using acoustic telemetry, it appears that Burrard Inlet may be a mortality hotspot for juvenile Seymour steelhead smolts as they migrate to the Strait of Georgia. -Survival of juvenile Seymour steelhead through the Strait of Georgia was dependent upon the migratory route used. Steelhead showed higher use of Discovery Passage, and experienced significantly higher survival - For the first time, V4 tags were used on wild sockeye salmon smolts (Chilko population) in 2016 to compare telemetry-based estimates of survival between age-one & age-two smolts. -One and two year-old smolts showed similar patterns of mortality but one year-olds tended to show higher survival overall. This could be related to higher levels of predation on the larger smolts. - Wild sockeye smolts were found to find safety in numbers when migrating downstream towards the Salish Sea. When these juvenile fish were migrating with many others, their chance of survival was high. But juvenile fish travelling alone or in small packs were likely to perish.
Kintama Research Services	Dave Welch, Erin Rechisky	Use of acoustic tagging methods to determine the behavior, migration routes, residency &	In 2016, they conducted a small acoustic telemetry pilot study on juvenile Chilko River Chinook with the following objectives: a) Provide freshwater survival estimates for Chilko River yearling Chinook smolts from	• Study allowed an assessment of Chilco Chinook survival from release to the mouth of the Fraser River showing higher mortality in the tributaries and high survival in the lower Fraser (similar results as found for Chilco sockeye).

Proponent	PIs	Title	Project Outline	Progress/Findings
		survival of juvenile wild salmon migrating around salmon farms within the Discovery Island region	release in the Chilko River to the lower Fraser River, & compare this to past published data for other species & populations originating from the Fraser River. b) For Chilko River Chinook smolts that migrate north after ocean entry during the hypothesized timeframe, fill in the critical uncertainty regarding residence time of upper Fraser River Chinook in the Strait of Georgia. c) For Chilko River Chinook smolts that migrate north after ocean entry during the hypothesized timeframe, provide estimated survival in the Strait of Georgia & Discovery Islands & compare to past published data	• Migration time from the Fraser Estuary to Texada was approx. 1 week. • Early marine survival could not be assessed as only 1 Chilco chinook (of 100 tagged) was picked up in the marine environment. The transmitters are capable of being detected at multiple sites in the Fraser River basin & in the Discovery Islands & Johnstone Strait; however, they cannot be detected on the sub-arrays in the Strait of Georgia, Juan de Fuca & Queen Charlotte Strait. Thus, if the chinook exited the Strait through the northern route, they would have been recorded on the receivers there, but could not be picked on the Juan de Fuca receiver line. So we do not know if they exited south, remained in the Strait or perished.
DISEASE AND MICROBES				
DFO, Genome BC, UVic etc	Kristi Miller	Strategic Salmon Health Initiative	The main objective of the Strategic Salmon Health Initiative (SSHI) is to determine what pathogens/diseases, if any, may be undermining the productivity and performance of BC salmon, their evolutionary history, and the potential role of exchanges between wild and cultured salmon. A current objective is to develop molecular methods to recognize early developing disease states	Kristi has been assessing hundreds of hatchery, wild and aquaculture salmon samples for microbes. Results are forthcoming. She is also developing the use of Viral Disease Development biomarkers which work across salmon species and salmon tissues to allow one to recognize early developing disease states in salmon.
HARMFUL ALGAE MONITORING				
Microthalassia Consultants Inc. & PSF	Svetlana Esenkulova & Nicky Haigh	Salish Sea Harmful Algae Bloom Monitoring	Assessment of harmful algal bloom status in the Strait of Georgia: seasonal extent & interannual variability of blooms in area & vertical distribution of HAB species in the water column, associated with environmental factors such as nutrients, temperature & salinity. Costs so far have been for lab work carried out by S. Esenkulova (PSF hired technician)	• The Spring phytoplankton bloom in 2016 started much later than bloom in 2015 & its composition was very different. Last year, the majority of spring bloom was comprised of one species (diatom *Skeletonema costatum*) but this year it was a mix of species (diatoms - *Thalassiosira* spp., *Chaetoceros* spp., & *Skeletonema costatum*). • Dinoflagellates (second major group after diatoms) started to appear unusually early in a

Proponent	PIs	Title	Project Outline	Progress/Findings
				season. For example, most of the areas sampled by the Citizen Scientists in the Strait of Georgia at the end of March had some cells of *Alexandrium* spp. (causes Paralytic Shellfish Poisoning) which is more common for summer months. • Silicoflagellates were almost absent in 2015 but are very common & sometimes abundant in 2016 samples. In July 2016, there were several records of moderate concentration of toxic non-skeletal *Dictyocha*. • It appears that general phytoplankton dynamics in the Strait are closely linked to primary physical oceanographic parameters & the weather but the exact temporal patterns are more localized.
NEARSHORE HABITAT STUDIES				
University of Victoria	Sarah Schroeder & Maycira Costa	Spatial temporal distribution of *Nereocystis luetkeana* (bull kelp) & use by juvenile salmonids in the Salish Sea	Objectives of this project are: (1) to define the surface extent of bull kelp beds by using satellite imagery (present and historical) associated with sea-kayak surveys for several regions of the Gulf Islands (Salt Spring, Saturna, North and South Pender, and Mayne), and Comox and Cowichan estuaries, in collaboration with several environmental stewardship community organizations and First Nation groups. (2) To initiate a robust study on the use of kelp habitat by juvenile salmon in the Salish Sea.	-This project was begun in early summer 2016 with a new MSc graduate student, Sarah Schroeder, in the Costa Lab. In the summer of 2016 an intense field survey was conducted in Cowichan Bay, Mayne Island, and Pender Island in collaboration with SeaChange and local communities. Digital manipulation of the WorldView 3 image shows a strong ability to map kelp beds. Imagery analysis is ongoing as is the kelp bed sea kayak survey processing. -The next steps will focus on data integration with the other nearshore habitat projects. Also, planned collaboration with Hakai Institute will allow this project expand to a larger spatial scale, which is required to understand the health of the nearshore habitat in the BC coast. This will be important to understand trends in the large-scale distribution of kelp habitats, which are known to provide shelter and food to numerous species including Coho and Chinook salmon.

Proponent	PIs	Title	Project Outline	Progress/Findings
University of Victoria	Natasha Nahirnick & Maycira Costa	Spatial-temporal extent of eelgrass habitats & relationship with associated adjacency catchment area land use change: remote sensing approach using aerial phots & satellite imagery (1950-present)	The goal of this project is to quantify the temporal and spatial dynamics of eelgrass habitats and associated adjacency catchment area land use change over time to further understand temporal changes and associated disturbance/environmental forcing.	Data were collected for a long-term eelgrass mapping methodology using historic aerial photography from 1932-2014. Using a drone to validate remote sensing imagery, Natasha has validated results from Village Bay, Mayne Island. Further investigation will examine the possible impact of shoreline & watershed alterations on eelgrass distribution at several study sites around Mayne Island & Saturna Island. This will be a very useful technology to allow us to compare current and past eelgrass distributions, and to determine the possible causes of change.
University of Victoria	Laura Kennedy	The effects of eelgrass density on prey availability for juvenile salmon	The objectives of this SSMSP funded MSc project were to determine the impact of eelgrass density on invertebrate communities, & to determine the importance of prey originating from eelgrass ecosystems to juvenile salmon diets.	Project is complete and the thesis is being written up at present. Basic finding is that eelgrass is very important to juvenile salmon and stable isotope signatures suggest that much of their diet originates there.
Seachange	Nikki Wright	Eelgrass Restoration from 2013-2015	The purpose of this project (2015-2016) is to continue to restore estuarine & coastal ecosystem resiliency & health in the Salish Sea for all species of salmonids & the marine food web upon which they depend. These objectives are: 1. Increase & restore critical marine salmon corridors; 2.Strengthen partnerships with governments, First Nations & funding agencies to promote restoration of eelgrass habitats over time &, 3. Continue stewardship of eelgrass habitats within fourteen coastal communities.	• 2013: 7 sites; 775m² restored • 2016 : 23 sites, 27,000 shoots (2,700 m²) transplanted, monitored every 6 mo. • Boundary Bay, 13 islands within Islands Trust, Oak Bay mapped • 4 marine riparian sites restored • 1 underwater debris removal in Cowichan estuary • Research of sediment, water quality & suspended sediments • They will continue research of contaminants & wood waste in sediments for site selection/mitigation
University of Victoria	Josie Iacarella	Juvenile salmon association with eelgrass vs. non-eelgrass habitat	There are two key studies that make up Josie's post doc: 1) Assessing the impacts of human disturbance to eelgrass fish communities across BC coast (using data from 9 regions, 89 sites) and 2) Assessing the role of eelgrass in juvenile salmon early life histories relative to unvegetated habitats (5 sites).	Results to date: 1.Evidence of decreased species richness and biotic homogenization of eelgrass fishes in highly disturbed regions (e.g. sites within Fraser Estuary, Comox Estuary, southern Vancouver Island).

Proponent	PIs	Title	Project Outline	Progress/Findings
				2.Rockfish species were an indicator species of low disturbance regions whereas threespine stickleback were most associated with high disturbance regions. 3.Juvenile salmon use eelgrass habitat more than vegetated habitats, and were most often found to have harpacticoid copepods in their diets – a species associated with eelgrass. Josie has brought together a community of persons interested in eelgrass research: the "Eelgrass Fishes Network" was established to facilitate a collaborative effort in surveying eelgrass fishes across the coast of BC in summer 2016, and hope to continue studies in 2017.
Simon Fraser University, Comox Valley Project Watershed Society, Nile Creek Enhance-ment Society	Bill Heath, Sheryl Bisgrove, Braeden Schiltroth etc.	Restoration Research on Kelp Forest Habitats in the Salish Sea	1) Estimate the extent of kelp forest cover/loss in the northern Salish Sea in recent decades and identify sites in need of restoration that would be of benefit to juvenile salmon 2) Identify kelp stocks capable of growing at sites with stressful conditions (high temperature and/or low pH) by correlating sites that have retained kelp with recorded oceanographic conditions available from online databases (e.g. lighthouse SST databases on DFO Pacific website). 3) Compare bull kelp growth and survival, faunal (fish and invertebrate) presence and detailed oceanographic conditions at 5 experimental sites and at a reference site. 4) Examine the effect of density thinning of sea urchins on kelp abundance at a monitoring site. Longer term objectives: 1) To identify sources of thermal stress-resilient genetic stocks of bull kelp (*Nereocystis luetkeana*) in the Salish Sea that can be grown in significant quantities to restore historical kelp beds as habitat for refuge and feeding of juvenile salmon.	This study made progress toward the SSMSP objective of identifying significant factors affecting the early marine survival of salmon in the Salish Sea, particularly in the central Strait of Georgia. It has focused on the factors limiting the distribution of bull kelp *(Nereocystis luetkeana)* beds in Lambert Channel and Baynes Sound, a critical nearshore habitat for refuge and feeding of juvenile salmon. A significant database was diversified and expanded on kelp performance under varying conditions at several study sites (including depth, temperature, light intensity, salinity, pH, turbidity and chlorophyll; and under grazing pressure from various herbivore species). Participation in a population genetics study of bull kelp is enhancing understanding of genetic structure of this species which will be a valuable tool in habitat restoration work.

Proponent	PIs	Title	Project Outline	Progress/Findings
Sea Watch Society	Ramona De Graaf	Beach Spawning Forage Fish of the Salish Sea	Sea Watch society's projects focus on the declining habitat quality for two key forage fish species, surf smelt & Pacific sand lance, & coastal marine rearing habitat for juvenile salmon. Objectives of this SSMSP funded work are to: 1. Determine the spatial extent of spawning habitat & suitable habitats for surf smelt & Pacific sand lance in the Salish Sea 2. Protection of forage fish resources (secondary capacity) in the Salish Sea 3. Development of operational statements & best management practices for forage fish spawning/rearing habitats & marine riparian habitats for local government & stakeholders.	Spawning Surveys by Sea Watch and Community Monitoring Efforts have been carried out for over 10 years. In total, approximately 280 beaches monitored. Of these, 50 are positive for Pacific Sand lance, 52 for Surf smelt, and 4 mixed Surf smelt/Pacific sand lance. Over 30km of spawning beds have been monitored. In addition, studies have been underway to elucidate the Surf smelt spawning stock structure- both in the summer, winter and year-round. Strait of Georgia Surf smelt spawning stock structure is similar to that in Puget Sound with summer, fall/winter and year-round spawning. Work continues to define the geographic boundaries and/or overlap of these stocks within the Strait. With respect to the Forage Fish Spawning Habitat Suitability Model, 12 Islands Trust islands have been completed and project is ongoing with 3-4 islands being undertaken for 2017-2018. Working with partners in Puget Sound, a beach condition model has been completed. This model has been applied to English Bay/Burrard Inlet.
HATCHERY-WILD INTERACTIONS				
Simon Fraser University	Willy Davidson	EPIC4 (Enhancing Production in Coho: Culture, Community, Catch) -Activity 3. To assess the ability of fish hatcheries to conserve Coho Salmon & enhance their numbers	As part of a joint project proposal with Genome Canada, parental based tagging (PBT) of hatchery coho stocks in Southern BC will be utilized to genotype the majority of hatchery coho smolts released into the Salish Sea. This work will permit subsequent identification of clipped juveniles and adults by stock and year of origin, release strategy, and parentage history, and may allow for detailed investigations of differences in early marine distribution patterns of different hatchery coho stocks.	Hatchery broodstocks sampled in 2014 & 2015, totaling over 12,000 individuals, have been genotyped at approximately 380 SNPs. Strong regional structuring of populations has been observed, & high levels of accuracy of assignments of individuals to specific hatcheries or geographic regions has been achieved.

Proponent	PIs	Title	Project Outline	Progress/Findings
SEP (DFO)	Mel Sheng	Delayed hatchery release studies for coho and chinook	This study has two main objectives of exploring release strategies that may improve the marine survival rates and distribution of hatchery coho and Chinook salmon, as well as reducing competition in the early marine environment between hatchery and wild salmon. Five hatcheries (Big Qualicum, Quinsam, Seymour, Inch and Chilliwack) will hold trial groups of Chinook and/or coho salmon in the hatchery beyond the traditional release timing of May through to late June/early July, which is several weeks after most wild juveniles, will have entered the marine environment.	Ongoing- results will first be available in 2017.
MODELING AND ANALYSIS				
DFO (IOS)	Angelica Pena and Ken Denman	Salish Sea Marine Ecosystem Modeling	Angelica Pena is currently advertising for a post doctoral research scientist position in the area of marine ecosystem modelling. The incumbent will work to implement an individual-based-model (IBM), representing larval and juvenile salmon, into an existing Salish Sea plankton ecosystem ROMS model to simulate their migration and feeding behaviour in the Strait of Georgia. Research will be conducted at the Institute Ocean Sciences in Sidney, British Columbia, Canada.	Post doc is expected to begin Spring 2017
Madrone Environm ental	Dave Preikshot	Forecasting near and long-term ecosystem changes influencing the population dynamics of adult and juvenile Chinook and Coho Salmon in the Strait of Georgia	The long term objectives of this project are as follows: -to provide the research community with a model that can be used to explore hypotheses of how the Strait of Georgia ecosystem function, particularly in Coho and Chinook Salmon and other upper trophic level species with significant economic, cultural and biological significance, -to identify significant data gaps and research priorities to improve long-term monitoring and thus our ability to sustainably manage wild populations of Coho and Chinook Salmon in the strait of Georgia	Dave had two contracts during 2016 and amassed some of the seabird and other datasets.

Proponent	PIs	Title	Project Outline	Progress/Findings
			-to provide management with strategic ecosystem level advice that can be used to identify achievable goals for wild Coho and Chinook Salmon populations in the Strait of Georgia.	
UBC	Villy Christensen	Environmental productivity of the Salish Sea: trends, impacts and projections	The Salish Sea Marine Survival Project has compiled a vast amount of data sources, and made clear the need to understand how the environmental productivity of the Sea has changed through the time period for which there is sufficient observations to reliably evaluate how environmental productivity has changed along with the consequential impacts throughout the ecosystem. While previous studies have evaluated short-term productivity patterns for the Salish Sea, there has so far only been correlative studies to evaluate the relationship between long-term changes in environmental productivity and the productivity of higher trophic levels organisms (notably salmon) in the ecosystem. Through this initiative, they intend to develop a coupled biogeochemical model and food web model to evaluate how the combination of changes in environmental productivity, food web structure and human impacts (notably through fishing) has changed in the Salish Sea over three and a half decades.	One post-doc is beginning work on this project June 2017: a second will be hired later in 2017. Project will also involve Dr. Carl Walters, UBC, and others.

Section 2: Overview of 2016 Project Development, Coordination and Communications

2016 Project Development and Coordination

The following are the project development and coordination activities that have been completed over the 2016. This list includes some work that is being carried out in co-ordination with our SSMSP Project Partner, Long Live the Kings (LLTK) in the US:

- Maintained an up-to-date comprehensive website describing the project, background, purpose and details of research activities (www.marinesurvivalproject.com). This site will continue to be the primary mechanism for encapsulating critical details about the project and communicating with the interested public.
- Held frequent meetings between the US and Canadian project coordinators, Michael Schmidt and Isobel Pearsall.
- Held management and fundraising meetings between key LLTK and PSF staff.
- Continued to maintain the project pages in the Basecamp web-based project management utility for key research activities. This site serves as an active project coordination utility. The utility allows for sharing calendars, resources, raw data, key findings and supports general communications among researchers.
- Completed the report from the 2015 US-Canada Retreat describing research status, findings, and project needs (available on the resources page of marinesurvivalproject.com.)
- Organized a number of cross-border Webex meetings for strategic planning around modeling initiatives and ecosystem indicator analysis and data aggregation.
- Held a joint US-Canada Salish Sea Leadership Roundtable meeting April 13th 2016. Leaders from 23 federal, state, tribal, academic and nonprofit entities convened for a roundtable discussion about the value of and potential for a sustained U.S.-Canada, science-based effort that supports the management and recovery of our shared Salish Sea ecosystem.
- Held the third annual winter retreat for key project participants in Bellingham Dec 1-2, 2016.
- PSF Implemented the complete 2016 Research program, including: oceanography, the citizen science program, zooplankton sampling, YOY herring survey, juvenile salmon sampling, telemetry studies, genomics, habitat restoration, marine mammal studies and modeling.
- PSF executed a number of new awards. New funding was made available for the 2016-2017 funding period for the following studies: sediment traps, seal predation; mictrotrolling; Cowichan freshwater mortality (Rotary Screw trap); PIT tagging studies; juvenile salmon species abundance, growth and habitat use in the Fraser River estuary; acoustic tagging and tracking of Chilko Chinook; restoration research on kelp habitats; Ecopath/Ecosim modeling.
- PSF finalised the “SSMSP 2015 Summary & 2016 Program Overview” report for the PSF Oversight committee. Meetings with PSF Oversight committee, SSMSP Science Team and PSF Directors to discuss and determine the 2016 program.
- PSF organized and held the 2016 Canadian retreat November 21-22 2016

- PSF continued development of the Strait of Georgia Data Centre, including metadata creation for existing data portals providing ecosystem information in the Strait of Georgia and collation of US-Canada ecosystem indicators.
- PSF collated information from all project leads on 1) data sets collected by their program, 2) current collaborations with other PIs (Canadian and US), 3) publications (current or potential).
- PSF collated mid-year and final-year reports from all PIS. Year end reports for 2016 will be collated into a 2016 Overview document for the SSMSP website as well as the 2016 Year End report for PSC

2016 Communications

The following are the communications activities that have been completed over the reporting period. These include communications activities that are ongoing with our project partner, Long Live the Kings, Seattle.

- PSF presented the project as the primary theme of their 2016 Gala Event as well as at their various fundraising dinners throughout B.C. SSMSP was also highlighted at PSF's spring and fall PSF Major Donors Circle, and at various boat and fishing tradeshows across BC where PSF attended. LLTK also presented the project as primary theme for their 2016 annual dinner in April.
- PSF and LLTK continue to moderate the various BaseCamp sites, including a communications resources site for project participants to help them communicate about the project (includes stock presentations, photos, video, language/messaging resources, etc.).
- PSF and LTTK hosted three full sessions at the 2016 Salish Sea Ecosystem Conference, Vancouver April 2016. A summary of the session was written as an article in Salish Sea Currents: https://www.eopugetsound.org/magazine/marine-survival-project
- PSF produced a number of videos detailing various SSMSP projects and uploaded to the PSF youtube site https://www.youtube.com/user/SalmonFoundation. PSF produced an overview video of SSMSP (shown at the Vancouver gala) which was shared via social channels.
- PSF highlighted SSMSP in the spring/summer Salmon Steward magazine, with an entire focus on SSMSP in the fall/winter Salmon Steward magazine.
- PSF provided blog coverage of various SSMP projects throughout the year on BC Outdoors, sportfishing BC.com and on the psf.ca blog with enhanced distribution via Twitter and Facebook.
- PSF received print coverage of the Citizen Science project by Tri-City News and BC Outdoors Magazine.
- PSF and LLTK updated the project website, www.marinesurvivalproject.com and organization web sites.
- LLTK and PSF updated fundraising media, including flyers, appeals, and 2-page project descriptions.
- LLTK and PSF continued to create photo and video stock with professional photographers. PSF continued to procure video and photographic footage of key activities, including drone footage of beach and purse seine activities.
- A Facebook page has been developed for the Harmful Algal Program: "Phytoplankton - Citizen Science Program"

- Canadian Project PIS have made presentations at numerous meetings including: State of the Ocean Meeting, Nanaimo, March 2016; Salish Sea Ecosystem Conference, Vancouver, BC, April 2016; MEOPAR Annual Scientific Meeting, Ottawa, September 2016; Eastern Pacific Oceanography Conference, Mt. Hood, Oregon, September 2016; International Ocean Optics Conference Victoria, BC, October 2016; Eelgrass Fish Network workshop, University of Victoria, November 2016; PICES, San Diego, USA, November 2016; Pan Ocean Remote Sensing Conference (PORSEC), Fortaleza, Brazil, November 2016; 3rd COCI Users & Science Team meeting, Canadian Space Agency, November 2016.
- Canadian PIs have created metadata and their data are being collated and are openly available on the Strait of Georgia Data centre. Eelgrass information has been posted on the websites of Nile Creek Enhancement Society, Project Watershed, and the SSMSP's BaseCamp site.

Section 3: Overview of Key Progress/Findings

A. Bottom Up Programs

Bottom-up processes—including weather, water, and plankton—drive what is available for juvenile salmon and steelhead to eat. Bottom-up research activities fall into two categories:

- A Salish Sea-wide sampling program examines 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.
- Individual bottom-up studies build off this sampling framework: to 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, such as temperature, habitat availability, ocean acidification, runoff, and wastewater.

The sampling program builds out from specific watersheds within the Strait of Georgia and Puget Sound. In the Strait of Georgia, the key watersheds of interest are the Cowichan, Puntledge, Fraser, and Big Qualicum Rivers. Several of the key Canadian programs have been designed to augment a backbone of oceanographic and biological sampling activities carried out by DFO each year in the Strait of Georgia.

A1 Physical characteristics and phytoplankton production- Canada

To collect data on the physical characteristics and primary production in the Strait of Georgia, a combined approach has been implemented, utilizing buoys, CTD casts from the Canadian "Citizen Science Program" and zooplankton sampling program, CTD casts from Canadian juvenile salmon sampling efforts, remote sensing methods, and data collected from ongoing monitoring efforts led by project partners (e.g., Canada's FerryBox and FOCOS-BC Ferries program). Similar variables are collected at most sites, with continuous information collected from buoys in a few key areas, together with time-specific information relevant to biological sampling events. Given that the physical monitoring approaches are distributed, with sampling inconsistently distributed in space and time, circulation models will be used to help expand the data and describe physical characteristics Salish Sea wide.

Citizen Science Program

Team: Mike Dempsey (DFO-IOS), Eddy Carmack (DFO-IOS), Jane Eert (DFO-IOS), Svein Vagle (DFO-IOS), Ryan Flagg (UVic), Marlene Jeffries (UVic), Benoît Pirenne (UVic), Jessica Stigant (UVic), Maia Hoeberechts (UVic), Adrian Round (UVic), Kelly Young (DFO-IOS), Linda White (DFO-IOS), Colin Novak (PSF), Svetlana Esenkulova (PSF) and the many citizen scientists around the Strait of Georgia.

Objective:

To allow for oceanographic sampling and monitoring in the Strait of Georgia at a spatial scale not possible before.

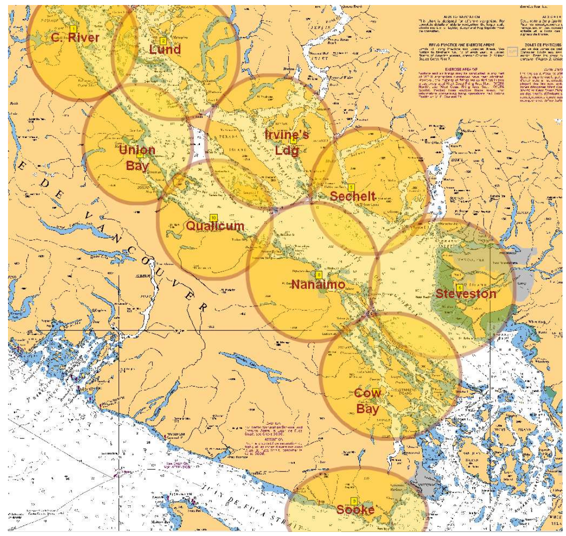
Background:

This program was originally proposed by Dr. Eddy Carmack, retired scientist from the Institute of Ocean Sciences, Sidney. His concept was the creation of a "mosquito fleet" which would utilize fishing vessels to collect oceanographic data during the spring and neap tides at specific locations in coastal waters of the

Strait of Georgia. This retirees or interested persons would take on a role as citizen scientists, collecting information in different areas of the Strait on the same days each week over a period of months, such that the entire Strait could be fully sampled, providing data at a spatial and temporal degree that has not been realized or possible before. PSF has partnered with DFO, and with Ocean Networks Canada (ONC) to assist with program management for the citizen science program.

IOS scientists initially divided the Salish Sea into overlapping areas that they suggested could be covered by a small boat in one or two days of sampling effort. These include:

- Campbell River
- Union Bay
- Qualicum
- Nanaimo
- Cowichan Bay
- Sooke
- Lund
- Irvine's Landing
- Sechelt
- Steveston



Having citizen scientists make oceanographic measurements in each of these areas, on the same day one to three times a month between February and October, allows for complete coverage of the Strait of Georgia. The data collected will allow us to assess annual variation in the physical/chemical oceanography in the entire Salish Sea and to estimate phytoplankton biomass. These data will be very useful to modeling initiatives, and for understanding spatial and temporal changes in productivity of the Strait.

The work done on the vessels Elvis and Dr. Carmack's vessel Wicklow in the Cowichan during 2013 and 2014 served to test equipment and refine the methodology for this program.

- The main workhorse for the oceanographic measurements is a CTD (Conductivity, Temperature, Depth) instrument which collects and stores electronic measurements of the water properties. The instrument we are using, an RBR Concerto CTD measures these properties 6 times a second as it descends through the water column from surface to maximum depth. Attached to the CTD are two auxiliary instruments: a fluorometer which measures chlorophyll content and an optode which measures oxygen content. Fluorescence is an indicator of plankton productivity (algae growth), while oxygen is used both to trace the movement of water masses and to detect areas with low flush rates.

- Along with the CTD profiles water samples are taken for nutrients dissolved in the seawater – these samples are analysed back in the lab. Nutrients are used to identify water from certain sources (like rivers), to diagnose the limiting factors for growth of plankton and track the movement of water masses.

- The third element is a small plankton net intended to capture zooplankton. This net is lowered to a maximum of 150m and brought up at a specified speed to capture plankton. A flowmeter in the mouth of the net will measure the volume of water that flowed through. Once back on board, the net is washed down with filtered seawater and the zooplankton collected from the cod end and preserved in formalin. Again these samples are returned to the lab for analysis of abundance and species found. Currently, zooplankton samples are collected from the Baynes Sound and Sechelt boats only.

- The fourth element is the use of a secchi disk which is used to asses water turbidity. The data collected from this part of the project will also be included as part of an international program to collect secchi disk measurements. A recent study of global phytoplankton abundance over the last century concluded that global phytoplankton concentrations have declined due to rising sea surface temperatures as a consequence of current climate change and prompted the development of an international effort to examine this www.secchidisk.org. Each of the citizen scientists has been provided with a tablet, and will download the free Android 'Secchi' application which will allow them to contribute these measurements.

- The fifth is the collection of water samples to identify phytoplankton, as part of the examination of the spatial and temporal prevalence of harmful algae throughout the Strait of Georgia. Water samples containing phytoplankton are analyzed back at the lab and examined for harmful algal blooms.

Status:

The program was begun in February 2015, with all vessel operators fully trained to carry out the program on the first “shakedown” cruises. During 2015, the program had vessels outfitted and actively sampling the Strait of Georgia from Campbell River, Deep Bay, Qualicum, Cowichan Bay, Victoria, Lund, Powell River, Sechelt and Steveston.

Ocean Networks Canada has provided a smart phone application for sample data transfer so that data can be transmitted directly to ONC, undergo QA/QC, archived and made freely available over the internet. For the first two months of the project, CTD data transfers from the instrument to the tablet and from tablet to ONC data centre created some problems, but initial issues were resolved by the ONC technical team.

In 2016 some changes were made to the program: the Victoria vessel was not continued as this area showed little seasonal variation oceanographically; instead it was replaced by a new vessel sampling out of Galiano Island. During 2016 we also implemented sampling for ocean acidity measurements on the Baynes Sound and Powell River vessels. This work was carried out in partnership with Wiley Evans of the Hakai Institute. PSF also supported a summer student in Dr. Rich Pawlowicz’s lab at UBC to analyse the CTD data.

Boats sampled the waters of the Strait of Georgia over 22 sample dates and collected the following information:

- 1,369 stations sampled
- 1,506 nutrient samples collected
- 1,958 phytoplankton samples collected
- 342 chlorophyll samples collected
- 2,689 Secchi recordings collected
- 60 zooplankton samples collected

The phytoplankton samples are 60% analyzed (by Svetlana Esenkulova, PSF), the zooplankton around 15% analyzed (at IOS), and the chlorophyll samples are fully analyzed (at IOS). The nutrient analysis is underway at the Mazumder Lab at UVic. Janet Lam, student at UBC, examined the data and provided constructive feedback to ONC for improving the sensors and data processing. These suggestions have been implemented by ONC. Changes and modifications were made during 2016 to the app used on all vessels. Data are currently being utilized by several of the other programs. The final year of collection will be in 2017: data analysis for all 3 years will be done over summer/fall 2017 by UBC. All data are available from the Strait of Georgia Data Centre.

Remote Sensing

Team: Dr. Maycira Costa, University of Victoria (UVic), Dr. Akash Sastri, Staff Scientist, Plankton Dynamics & Biogeochemistry Ocean Networks Canada , Dr. Lyse Godbout, DFO/PBS, Justin Dell Beluz, contractor, UVic, Tyson Carswell, contractor, UVic.

Objective:

The goal of this project is to determine the spatial-temporal dynamics of Salish Sea in the last fifteen years using remote sensing and data acquired from vessels of opportunities to test hypotheses on spatial and time domain fluctuations in the phytoplankton bloom phenology (timing, duration, and amplitude) and water turbidity and environmental physical drivers.

Background:

SSMSP is utilizing a number of different approaches to examine bottom-up processes, including those that provide information at various time and spatial scales. Satellites, radiometers, and other optical sensors aboard of vessels of opportunity and buoys can allow for continuous and sustained data collection. Operational ocean colour satellites such as MODIS-Aqua and the upcoming Sentinel-3 provide a great opportunity for continuous data acquisition at high temporal resolution, and provide the data required for a long-term monitoring program in the Salish Sea.

Maycira Costa is addressing specific knowledge gaps in spatial-temporal biogeochemistry of the Salish Sea by using synergistic methods that include (i) ocean colour satellite imagery, (ii) sensors aboard vessels of opportunity (FerryBox and FOCOS-BC Ferries), (iii) *in situ* data from research cruises, and (iv) *in situ* data collected from citizen science boats. A fifteen year remote sensing data set will allow her group to analyze the spatial-temporal phytoplankton bloom phenology of the Salish Sea in relationship to environmental time series data (SST, Fraser discharge, turbidity, wind, light availability) and global climate indices.

This project will allow the researchers to contribute to one of the primary objectives of the *Salish Sea Marine Survival Project (SSMSP),* which is to determine if the *"*bottom-up processes driven by annual environmental conditions are the primary determinate of salmon production via early marine survival". The proposal will also contribute to the "trend analysis and modeling" component of the SSMS project by providing spatial temporal data that can be used to initiate and/or provide parameterization for the models.

Status:

This project was initiated Fall 2015 and time-series imagery analysis is ongoing. An NSERC USRA student is working on the data-integration component of the project. Data has been compiled from a number of different sources, and Costa et al are defining a method to evaluate and pre-define spatial-temporal biogeochemical provinces in the Salish Sea. The data being analysed include spatial temporal Chla data from (1) ONC ferrybox systems aboard the BC Ferries, (2) the Institute of Ocean Sciences (IOS) public database, (3) Dr. Ian Perry data collected every two weeks as part of the PSF project, (4) Citizen Science Project (boats) data collected in 2015 and 2016, (5) Svetlana Esenkulova microscopy data Feb-Oct biweekly, ~1300 samples for 2015 and daily 2016, (6) buoy data acquired by Stephanie King.

The time-series of satellite imagery (2002-2016) has allowed for the understanding of the phytoplankton dynamics in the Salish Sea with an annual characterized spring bloom generally occurring at the end of March in the Central Salish Sea and middle of March in the North Salish Sea, except in 2005 and 2015 when the bloom happened two month earlier. The spring bloom is generally followed by a lower magnitude late summer or fall bloom. Specifically, this work addresses the general hypothesis that the size of the salmon return is, to some extent, related to the time of juvenile marine entry and the time of the zooplankton bloom and its related phytoplankton bloom.

- Objective 1: Derive fifteen years of spatial-temporal improved biogeochemical based on present MODIS - available since 2002 and Sentinel-3 (available since June 2016) ocean colour satellites.

Progress: Sentinel-3 imagery is in the processing and evaluation phase. Empirical orthogonal function temporal method is applied to the chlorophyll satellite-derived products for better spatial representation of the data. Satellite-derived chlorophyll concentrations and zooplankton data are combine to examine the synchrony of phytoplankton and zooplankton phenology in the North and Central Salish Sea from 2002-2016. This will be part of the foundation data to help improving the accuracy of adult return forecasts.

- Objective 2. Define integration method to use data acquired from vessel of opportunities (BC Ferry/ONC unattended continues FerryBoxes and Ferry ocean Colour Observation Systems - FOCOS unattended continuous above-water reflectance from moving ferries crossing the Salish Sea, and citizen science boats) to calibrate and validate satellite imagery and products.

Progress: FOCOS was installed, tested, and now is operational. The citizen science program “water colour” was successfully done in the spring and summer as part of the Coastal naturalist program in the Queen of Oak Bay. Data is now under analysis. BC ferries wants to incorporate “water colour” as part of their environmental awareness program in the spring and summer. They would like to add this program to the PSF citizen science boats. All the technology developed in Objective 2 is successfully used in Objective 1.

In summary, the results of this project to date are as follows:

- Empirical orthogonal function temporal method is applied to the chlorophyll derived products for better spatial representation of the data.
- Sensors to measure water leaving radiance successfully installed in two BC ferries. The data is used for validation of atmospheric corrected satellite imagery; MODIS and Sentinel-3
- Chlorophyll climatology (2002-2016) indicates the seasonality in the Central Salish Sea. Bloom initiation on average happens on March 29 (±4 days) and on March 20 (±4 days) for the Central and North Salish Sea, respectively. The chla climatology also indicates that, for both the Central and Northern regions, late summer and fall blooms occur.
- In 2014, 2015, and 2016, bloom initiation happened on April 2, Feb 21, and March 8 in the Central region, and April 10, Feb 21, and March 16 in the North region. This indicated an early bloom condition in 2015 and 2014, and normal bloom conditions in 2016.
- Satellite-derived chlorophyll concentrations and zooplankton data are combine to examine the synchrony of phytoplankton and zooplankton phenology in the North and Central Salish Sea from 2002-2016. Initial results indicate relationship between zooplankton abundance anomaly and time of bloom initiation.

A post-doc, Dr. Suchy, in collaboration with Costa and Perry will also focus on investigating the level of synchronicity between phytoplankton and zooplankton phenology in the Salish Sea. Time-series data for phytoplankton from satellite imagery, buoy data, ferry data, citizen science data, and research cruise data will be coupled with historical and present zooplankton data. By looking at long-term spatial data of phytoplankton and zooplankton, they can identify their response to different climate drivers (e.g. SST, wind). Ultimately, changes in the seasonal patterns of these lower trophic levels will provide insight into their influence on the growth, survival, and overall return strength of salmon populations in the region. Karyn began work in July 2016 and is focused on two major objectives:

Objective 1: Examine the synchrony of phytoplankton and zooplankton phenology in the Northern/ Central Salish Sea from 2002-2016 by integrating satellite products with historical and present zooplankton data. Sub-regions of focus: North and central due to optimal; data availability. Environmental drives to be considered: chlorophyll satellite-derived data, zooplankton data (abundance biomass class size, life stages), satellite-derived SST, satellite-derived PAR, Fraser runoff, mixing layer from DFO database, wind data, PDO, NPGO, SOI.

Objective 2 – Examine the influence of local environmental drivers on phytoplankton and zooplankton in the Salish Sea from 2014-2016. Sub-regions of focus: Johnstone Strait, Northern SoG, Baynes Sound (?), Central SoG, Southern SoG, Tidal Mixing, and Juan du Fuca. Environmental drivers: chlorophyll satellite-derived data and citizen science boats, zooplankton data (abundance biomass class size, life stages), satellite-derived SST, satellite-derived PAR, Fraser runoff, mixing layer from DFO database, wind data.

Next steps in this project for 2017 include the following:

1. Data integration with fish telemetry data: Nathan Furey will work on integration of the chlorophyll-derived satellite data and zooplankton (Perry) with the fish telemetry data.
2. Satellite-derived data for the UBC model initiative: The satellite data will be an important component of the modeling phase. Data requested for the modeling initiative is from 1998 to present. Costa et al will integrate data from 1998-2002 from the SeaWifs satellite with the present time series.
3. Data integration with Chrys Neville was discussed and will be fostered in 2017. Ideally a Post-doc student could be supported with PSF and MITACS funds to address this component of data integration.

Sediment Traps

Team: Sophia Johannessen Research Scientist, DFO Institute of Ocean Sciences, Richard Thomson Research Scientist, DFO Institute of Ocean Sciences, Robie Macdonald Research Scientist Emeritus, DFO Institute of Ocean Sciences, Louis Hobson Professor Emeritus, University of Victoria, Marc Trudel Research Scientist, DFO, Pacific Biological Station

Objective:

The ultimate aim of this project is to relate juvenile fish health and survival to the timing and extent of blooms and ultimately to the physical forcing that drives the productivity.

Background:

The survival of juvenile salmon during their first year in marine waters may be strongly affected by the quality, quantity and timing of food available in the Strait of Georgia. Sophie Johannessen's team wish to develop an indicator that links physical conditions (stratification, circulation, winds) with the timing and magnitude of phytoplankton blooms, the response by zooplankton, and the health of juvenile salmon. Past data have been collected from sediment traps placed on a mooring in the northern Strait of Georgia, providing a continuous record of sinking particles. This project will analyze four years of existing geochemical samples and data from the northern Strait to assist in the development of a quantitative description of the relationship between timing and relative magnitude of phytoplankton and zooplankton blooms, as compared with marine survival of juvenile fish during the same period.

If successful, the number of moorings, and associated sensors, may be increased in the future, and studies will be developed to also relate ocean circulation and stratification and associated meteorological conditions (winds and cloud cover) with the timing and extent of blooms. The ultimate aim of this project is to relate juvenile fish health and survival to the timing and extent of blooms and ultimately to the physical forcing that drives the productivity.

Status:

This study began in summer 2016 and is in progress. It is leveraged against DFO research dating back to 2008, but the portion of the project funded by SSMSP only began this year. By the end of the fiscal year (April 2017), they will have a time series of phytoplankton and relative zooplankton biomass (inferred from fecal pellets) in the northern Strait of Georgia for 2008 – 2014 that can be combined with their existing time series of the chemical composition of sinking organic matter. From these data, they will assess the timing and quality of food for zooplankton and hence for juvenile salmon. They will compare the sediment trap record of food availability with indicators of juvenile salmon health as reported by the salmon group at the Pacific Biological Station and St. Andrew's Research Station (Marc Trudel, Rusty Sweeting).

Possible next steps include the following:

- If they find a strong link between the timing of available food and the health of the outmigrating smolts, that will indicate a strong bottom-up control on survival. If timing turns out to be critical, then a possible next step would be to change the timing of the release of hatchery-raised smolts. Smolts could be released at staggered times, with tags linked to release date, so that the survival rate of smolts released at different times could be assessed.
- If this study shows a weak link with the health of smolts, or if the link seems to be present in some years but not in others, that result would support the hypothesis that, since the main population decline in the 1970s, the number of coho and chinook salmon has been so low that the fish are vulnerable to every stressor. Preliminary results from other project support this hypothesis. If that is the case, then a possible management response would be to reduce all the stressors within local control (low river discharge during outmigration or return, contaminant discharge into rivers, habitat destruction, fishing, releasing juveniles from hatcheries too early to catch the main biomass peak of zooplankton). This would give the fish a better chance to be resilient to long-term climate change and to recover from the rapid decline in the 1970s.
- This activity will be associated with juvenile salmon studies, once their time series is complete. The other collaborators (Marc Trudel, Rusty Sweeting) are still willing to carry out the collaborative work. The jellyfish time series collected incidentally as part of this project might turn out to be useful too. They intend to pursue a collaboration with fisheries and zooplankton researchers to determine whether amphipods associated with jellyfish might provide food for juvenile salmon and explain some of the variability in their survival (idea proposed by Dick Beamish).

High temporal resolution monitoring of surface water properties in the Salish Sea

Team: Stephanie King, Managing Director, Sea This Consulting, Jim Gower, DFO, Terence Learmonth, Sea-going technician, Sea This Consulting

Objective:

To provide data that can be used by ecosystem scientists and modelers to describe bottom-up processes impacting juvenile salmon.

Background:

Phytoplankton bloom timing and concentration is a major driver of the marine ecosystem and potentially one of the keys to understanding the growth and survival of juvenile salmon in the Salish Sea. High temporal resolution time series are required to adequately characterize phytoplankton variability and explain how blooms impact food availability for salmon.

King and her team will continuously monitor phytoplankton for two years (2015-2016) using fluorometers deployed at three locations in the Salish Sea. Sampling locations are at three locations as shown in **Error! Reference source not found.** and will provide data in the relatively data-poor central and northern parts of the Strait of Georgia (Halibut Bank, Sentry Shoal), as well as at the mouth of a coastal inlet (Egmont). Two additional sensors have been deployed on the Sentry Shoal Buoy: SBE-37 MicroCAT, a temperature and conductivity sensor and the Satlantic SUNA V2, an optical nitrate sensor. Both have been deployed at the surface to provide a continuous time series of temperature, salinity and nitrate from April 2015.

The fluorescence time series builds on data collected as part of the Fisheries and Ocean's Strait of Georgia Ecosystem Research Initiative (ERI) during which fluorometers were deployed at Halibut Bank and Egmont.

The buoy monitoring program supports testing several of the SSMSP key hypotheses relating to prey availability, productivity and the health of the ecosystem. The high temporal resolution dataset is complementary to the periodic sampling done by SSMSP Citizen Science monitoring and DFO surveys.

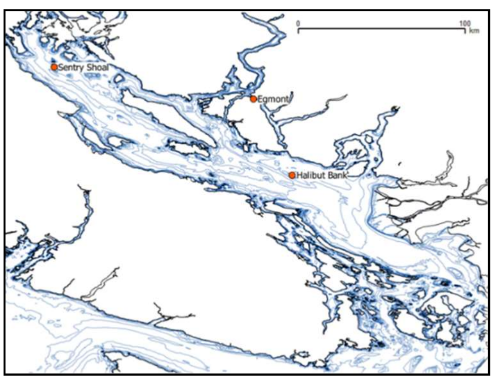


Figure 1. The three sampling sites for chlorophyll fluorescence time series in the Salish Sea.

Status:

Oceanographic sensors were deployed and maintained in 2015 and 2016 at Halibut Bank and Sentry Shoal, and in the spring at Egmont. High temporal resolution time series were collected for chlorophyll fluorescence, turbidity, temperature, salinity and nitrate. The SSMSP project initiated monitoring at Sentry Shoal and extended the time series at Halibut Bank and Egmont which now run from 2011 to 2016 and 2010 to 2016, respectively.

Key results from the monitoring include:

1) The buoy data can be used to describe the timing and magnitude of the spring bloom in the northern (waters to the northwest of the center of Texada Island) and central (waters from the center of Texada to 49°N) Strait in 2015 and 2016

2) Buoy data and satellite data confirm seeding from inlets in 2015.

3) There is a correlation between seeding from inlets and an early spring bloom (by ~1 month, 2003 to 2016)
4) The in situ chlorophyll fluorescence data and satellite FLH agree
5) The spring bloom in the central Strait is 5 days earlier on average compared to in the north
6) The SUNA nitrate sensor is an exciting new instrument for monitoring Nitrate concentration autonomously and is an important factor in informing phytoplankton bloom timing
7) A very unusual, bright, coccolithophore bloom was observed in 2016 in satellite imagery and in the turbidity time series at Halibut Bank

At Halibut Bank, time series for chlorophyll fluorescence, turbidity and temperature have been maintained since January 2011 (Figure 1). The quality and consistency in the dataset improved with the SSMSP funding starting in 2015 which allowed more frequent servicing trips and calibration. At Sentry Shoal, chlorophyll fluorescence, turbidity and temperature have been measured since 2015. This is the first high temporal resolution time series of surface conditions in the northern Strait, and the first high resolution time series of Nitrate in the Salish Sea (Figure 2). At Egmont, chlorophyll fluorescence has been monitored in the spring each year since 2010 to monitor potential seeding from inlets. In 2015, satellite imagery and buoy data confirmed seeding from Desolation Sound triggering a very early spring bloom in the northern Salish Sea on Feb. 21, and seeding from Howe Sound and Jervis Inlet initiating the bloom in the central Salish Sea on March 7 (Figure 3).

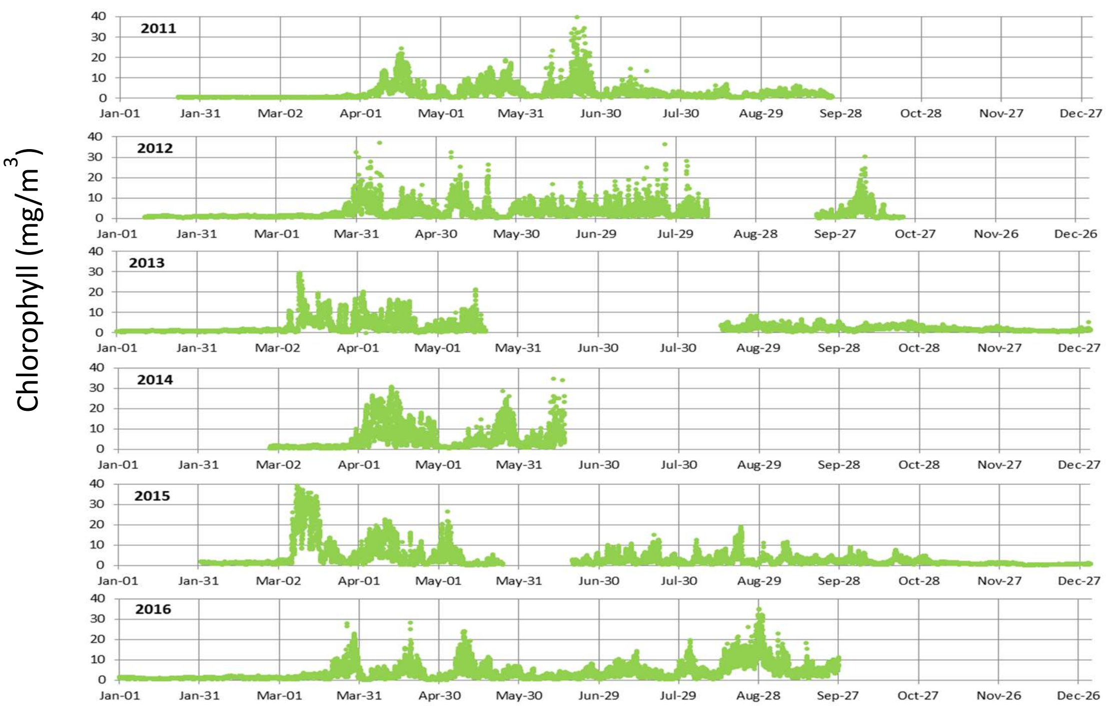


Figure 1. Annual surface chlorophyll fluorescence at Halibut Bank from 2011 (top) to 2016 (bottom). In 2013 and 2015 there was an early spring bloom. In 2015 the spring bloom was early with very high concentrations compared to other years. In 2016 the spring bloom timing was average, but low in magnitude. Concentrations were lower than normal in 2016 until a large bloom in late August.

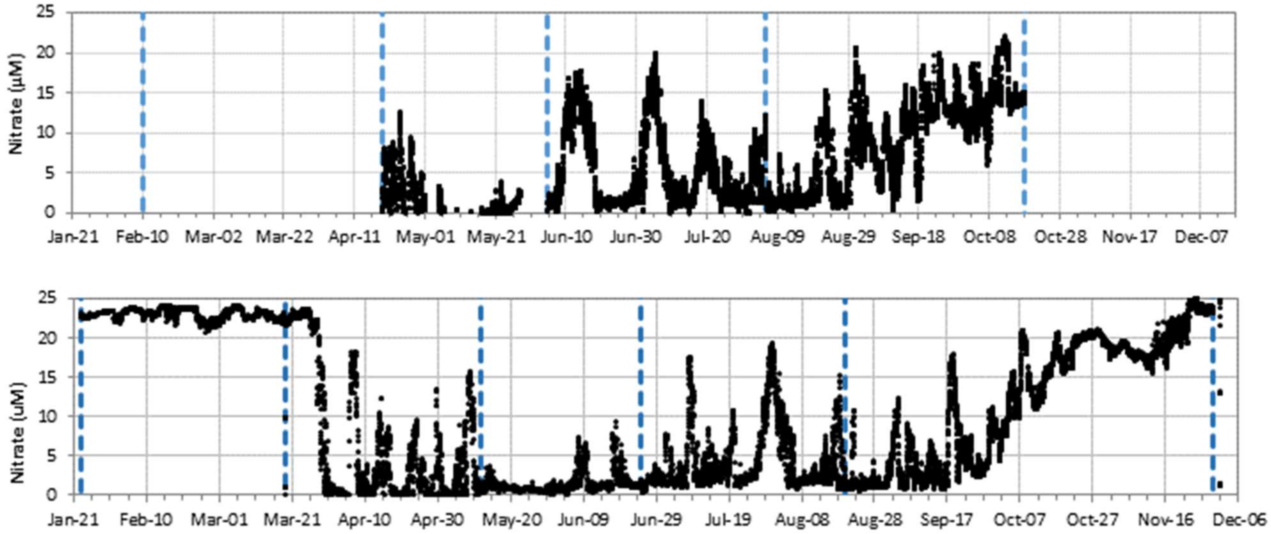
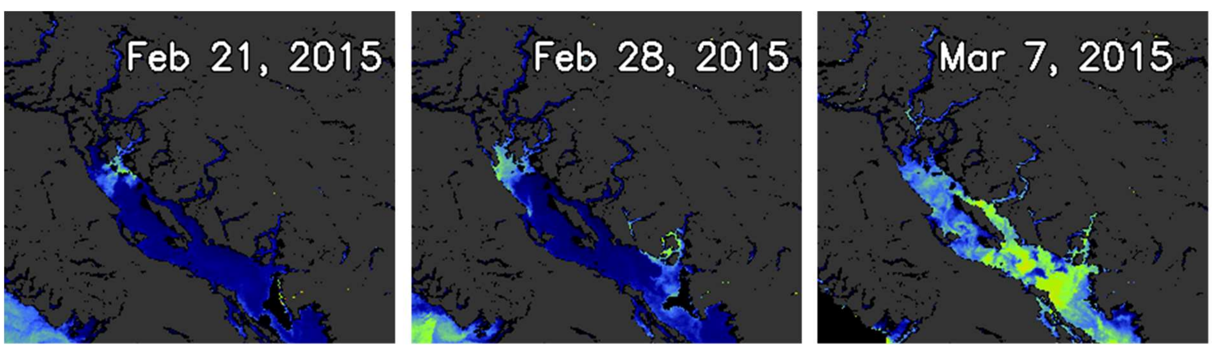


Figure 2. Nitrate time series (black) in 2015 (top) and 2016 (bottom) at Sentry Shoal. The vertical blue dashed lines show when the sensor was cleaned and/or calibrated. Note that calibrations were done with dionized water, but the data have not been compared to any in situ samples yet.



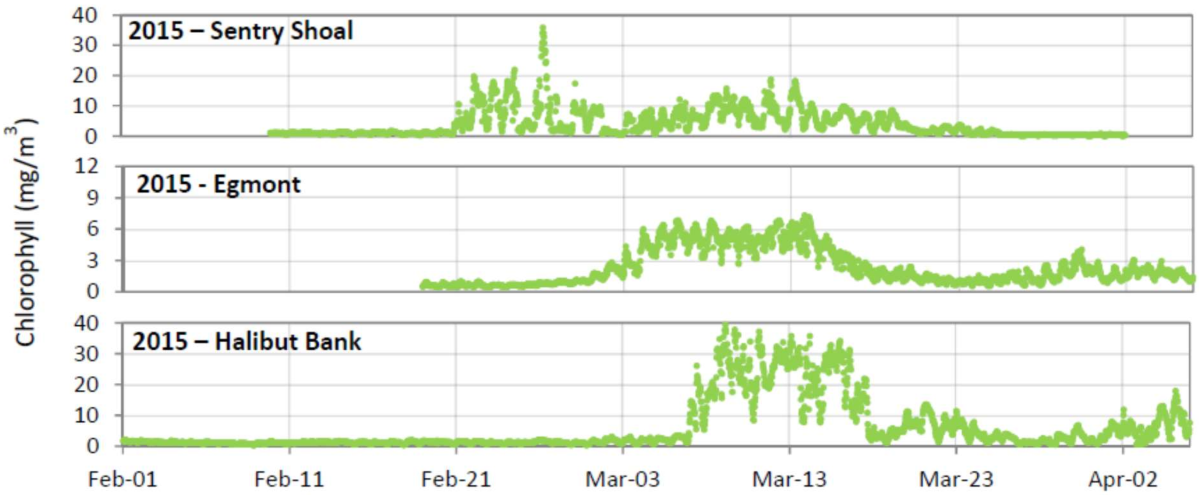


Figure 3. MODIS Fluorescence Line Height (FLH) image series from late February to early March 2015 shows early blooms in Desolation Sound, Sechelt Inlet and Howe Sound seeing followed by an early bloom in the Strait of Georgia. Sensors at Sentry Shoal (top plot) and Halibut Bank (bottom plot) confirm the bloom start dates of Feb. 21 and Mar. 7, respectively. The fluorometer at Egmont (middle plot) measured increased chlorophyll about 5 days before the spring bloom in the central Salish Sea.

Fluorescence Line Height (FLH) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua satellite was processed to provide spatial context for in situ measurements. FLH has a linear relationship with chlorophyll at concentrations below about 20 mg/m^3 and tends to perform better than the standard satellite chlorophyll products, with less confusing signal from aerosols, sediment and dissolved organic matter. Satellite imagery is useful for looking at spatial variability in blooms and has been used to establish a correlation between seeding from inlets and an early spring bloom in the Strait of Georgia. Seeding was observed in satellite imagery from 2004, 2005, 2007, 2008, 2009, 2013 and 2013. In years with no seeding (2003, 2006, 2010, 2011, 2012, 2014 and 2016) the bloom is later by about one month. Satellite imagery was also used to assess the difference in timing between the northern and central Salish Sea. The bloom is start date is 5 days earlier on average in the southern Strait compared to the northern Strait. There were only two years when the northern Strait was earlier than the southern Strait (2001 and 2015).

A very unusual coccolithophore bloom was observed in the Halibut Bank buoy data and satellite imagery in August 2016 (Figure 4). There are no other records of this type of event in the Strait of Georgia in recent years.

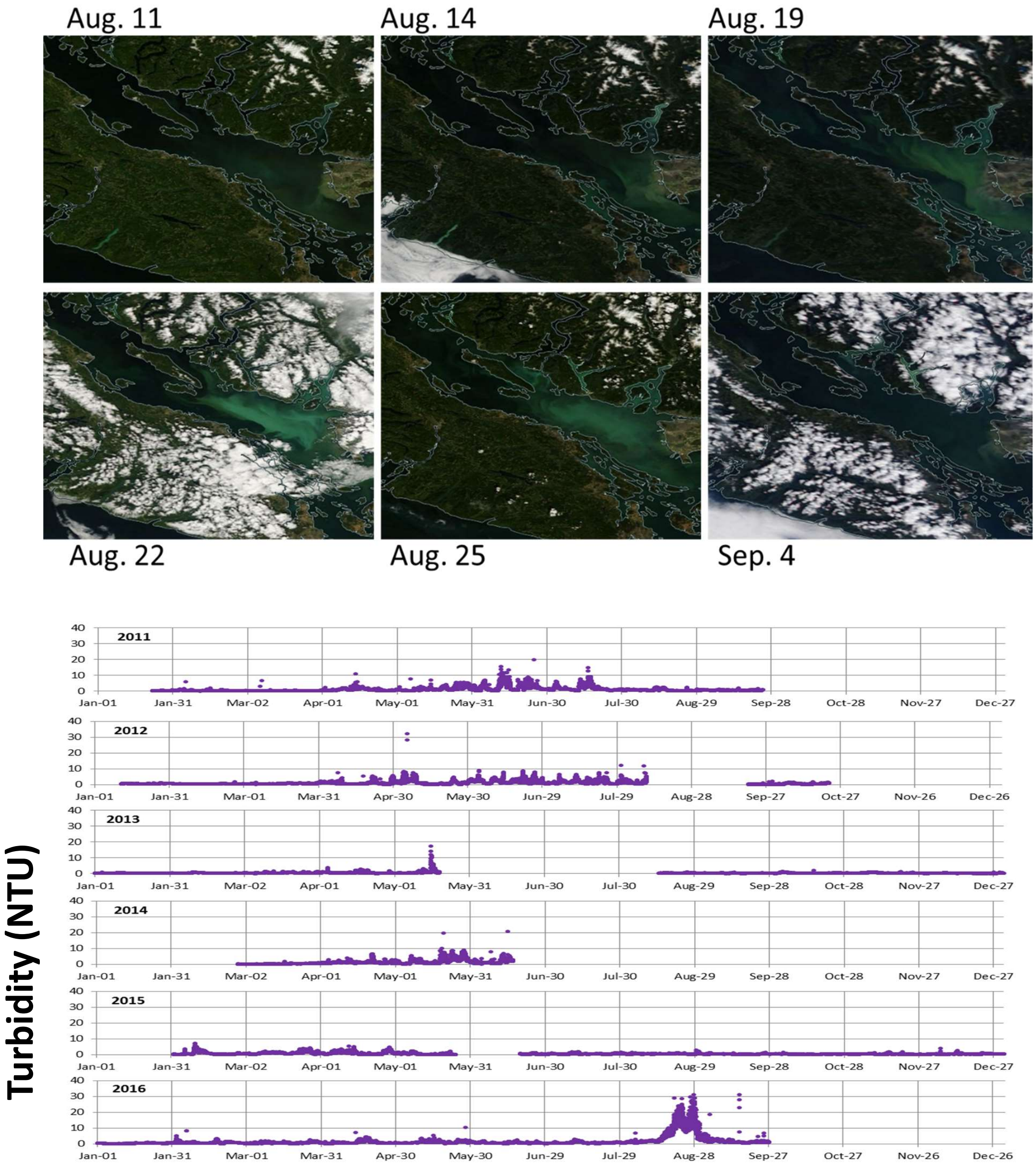


Figure 4. MODIS true colour imagery from NASA's Worldview (https://worldview.earthdata.nasa.gov/; top) show a coccolithophore bloom with the peak brightness on Aug. 22, 2016. The bloom lingered in inlets into September. The plots show the turbidity time series at Halibut Bank from 2011 to 2016. The largest signal in the time series is in August 2016 from the bloom.

Lessons learned include the following:

- Autonomous deployments are an effective method for monitoring surface conditions in the Strait. Fouling is a problem but can be mitigated with anti-fouling measures such as copper and shorter deployments during periods of high growth.

- The new SUNA nitrate sensor gives promising results and can be linked to bloom timing in the summer. Having multiple sensors at one site allows events to be explained in more detail. For example, a bloom in early August was initiated by a wind driven mixing event which mixed nitrate to the surface.

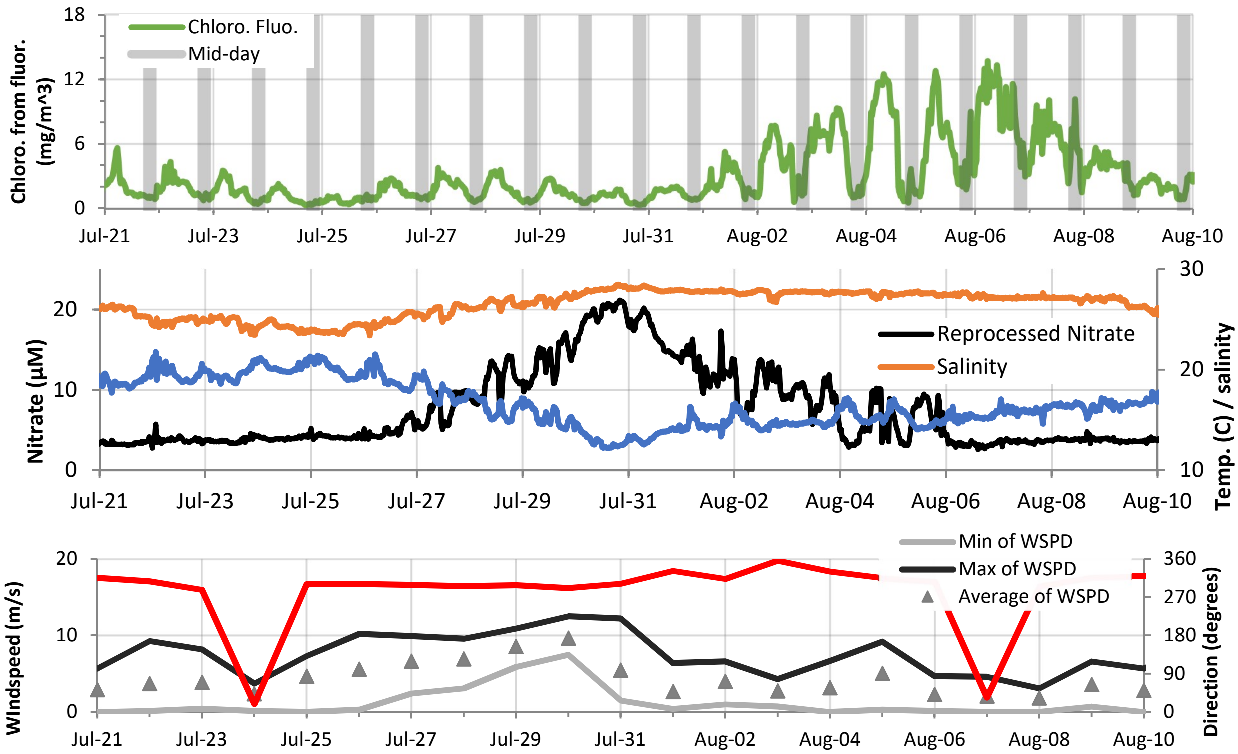


Figure 5. A strong and persistent north-northwest wind from July 26 to 31 (lower plot) initiated mixing as initiated by the decreased temperatures, increased salinity and increased nitrate (middle plot). The peak nitrate, reaching concentrations near to winter conditions, was followed by a plankton bloom several days later (top plot). Note the daily decrease in chlorophyll fluorescence from non-photochemical quenching. Times are in UTC. Wind data are averaged from the buoy data available on http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp.

High resolution measurements are needed to accurately characterize the ephemeral nature of conditions in the Strait. Furthermore, adding the northern monitoring site at Sentry Shoal in 2015 has demonstrated variability between different areas of the Strait. The time series at Halibut Bank and Egmont are now over 6 years in length and can be used to explain interannual variability that may be linked to juvenile salmon survival. For example, observations such as the very late spring bloom in 2011 or the relatively low biomass in 2016 may indicate unfavorable conditions for juvenile salmon entering the Strait.

The monitoring at the three locations will continue into 2017 and hopefully beyond. At Sentry Shoal, an exciting new collaboration with the Hakai Institute began in summer 2016 with the deployment of a SeaFET pH sensor on the Sentry Shoal buoy. Wiley Evens, Hakai will take over the field deployments in 2017 at the northern site with fluorometer support by Sea This Consulting. Sea This will maintain the sensors at the other locations.

Cowichan Bay Oceanographic Studies
Team: Svein Vagle (DFO-IOS), Mike Dempsey (DFO-IOS), Eddy Carmack (DFO-IOS), Jane Eert (DFO-IOS)

Objective:
The objective of this study is to obtain spatial and temporal water property data for Cowichan Bay during the important fish migration period from April to August. The aim is to understand nutrient cycling, variability in food supply (phytoplankton and zooplankton), the movement of fish, their predators, and ultimately the survival rate and the primary factors controlling this survival rate.

Background:
A repeat sampling grid covering Cowichan Bay and immediately connected waters was established in 2013 and was sampled on weekly intervals during April to June 2013, and from April to July 2014 for temperature, salinity, chlorophyll fluorescence, nutrients and zooplankton. These oceanographic studies are carried out concurrently with fisheries assessments by researchers from PBS and were continued in 2015 and 2016.

These data are augmented with both shorter term (order of hours from small boats), medium term (order of several months from acoustic mooring) and order of year (from oceanographic moorings). Three moorings were deployed in 2014 in Cowichan Bay and Satellite Channel with temperature, conductivity, pressure, and fluorescence sensors. The mooring program will extend until April 2016, and will tie together the weekly intense water-column sampling.

As a result of the 2013 and 2014 field work in Cowichan Bay it was clear that new approaches are desirable to monitor both the temporal and spatial variability in fish movement within Cowichan Bay. Specifically, researchers wish to determine whether the migrating juvenile salmon leave the river at certain times and migrate into the bay in certain locations, and to assess the interaction between the young salmon and their predators. An upward pointing Acoustic Zooplankton and Fish Profiler (AZFP) was used to monitor the water-column outside the river mouth for both juvenile salmon, zooplankton, phytoplankton, and larger predatory fish between April and June 2015.

The deployment of the AZFP, listed above, provides information on timing and species composition (e.g. the use of 4 frequencies will allow for identification of fish versus zooplankton versus phytoplankton). In addition, an Imagenex digital multi-frequency imaging sonar was mounted from smaller boats to survey the fish habitat near-shore and to observe the spatial variability in the biomass in the bay.

Early marine habitat use is a critical component to the Cowichan Bay study, and thus the team also worked with Nikki Wright from the Seachange Conservation Working Group to interpret multibeam data collected by CHS in the area in the spring of 2014, locate and use available bottom classification data sets, and to make surveys along the shore of Cowichan Bay using both available video and acoustical systems and the Imagenex imaging sonar. Eelgrass and bottom habitat surveys, originally scheduled for February were postponed to June and September 2015 so that the Imagenex system could be included in this work. Acoustic surveys took place using Wicklow and the two IOS boats.

The long-term objective is to be able to interpret the biological observations (phytoplankton, zooplankton, and fish abundance and species composition) in the Cowichan Bay area to determine the primary factors controlling Chinook and Coho early marine survival.

Status:

Data analysis for this project are ongoing. The above listed observations will be used with tidal information, solar radiation, wind information, fluorescence and nutrient information as well as current data and water mass properties from the different moorings and from the Citizen Science observations to look for correlations and relationships that relate to survival of Salish Sea wild and hatchery salmon.

Work in progress based on Sounder and Moorings Data includes:

- Identification and counts of individual fish targets as function of time
- Use of multi-frequency data and target strength information to attempt to identify size
- Echo-integration to obtain time-series of zooplankton, and perhaps phytoplankton abundance.
- Identification of seals as function of depth and time.
- Interpretation of the above findings using tidal, solar radiation, wind, fluorescence, nutrient, as well as current data and water mass properties from the moorings and from the Citizen Science observations.

Vagle, Carmack and co-workers will be submitting a manuscript this year.

Coupling state-of-the-art chemical oceanography with biological relevance: examining phyto- and zooplankton populations in a dynamic coastal environment.

Team: Dr. Helen Gurney-Smith, Research Scientist and Manager, Head of Shellfish Health and Husbandry Group, Centre for Shellfish Research, Vancouver Island University, Dr. Eric Peterson, President and Founder of the Tula Foundation, Dr. Wiley Evans, Research Associate, Pacific Marine Environmental Laboratory in Seattle Washington (National Oceanic and Atmospheric Administration) and the University of Alaska Fairbanks Ocean Acidification Research Centre in Fairbanks Alaska.

Objective:

This project aims to couple high resolution chemical oceanographic monitoring with phytoplankton and zooplankton analysis at a coastal site in the Northern Strait of Georgia to determine:

(1) the variability and intensity of corrosive surface ocean conditions (measured using state-of-the-art chemical oceanography monitoring equipment);

(2) the effect of changing ocean conditions on the species and abundance of phyto- and zooplankton species in the northern Strait of Georgia; and

(3) whether the incidence and magnitude of harmful algal species is correlated to ocean conditions

Background:

The timing and magnitude of salmon production is believed to be correlated with prey production, and therefore a timing shift in phytoplankton and prey production may be influencing the early marine survival of salmon in the Strait of Georgia. These changes in productivity may be influenced by the observed increased temperatures and suspected decreased pH within the Strait of Georgia. Atmospheric increases in anthropogenic carbon dioxide (CO_2) are creating massive changes in the marine carbonate system by increasing the concentration of hydrogen ions, and therefore lowering seawater pH, in the Earth's oceans. This is a phenomenon known as ocean acidification.

Additionally, the incidence of harmful algal blooms (HABs) has globally been on the increase and may be related to climate-driven species expansion, increased temperatures and the eutrophication of coastal waters. The chemical, physical and biological ocean conditions are therefore highly likely to impact the timing and magnitude of important food web dynamics for marine salmon.

This study will examine the chemical oceanography at a coastal site in the northern Strait of Georgia, together with impacts on harmful algae, species and abundance of phytoplankton and zooplankton. This study complements sediment trapping, satellite imagery of phytoplankton conditions, harmful algal monitoring programs and migratory research carried out by the SSMSP as well as contributing towards a Tula-led initiative examining the impacts of biological oceanography on salmon ecology in the Discovery Islands and Johnstone Strait.

Status:

Project setup / logistics data collection:

The project has been active since 17 March 2015. Since 2014 the group has been collecting chemical oceanographic data from their field site on Quadra Island in the Northern Strait of Georgia, Vancouver Island. Since deployment, this equipment has been monitoring sea surface, temperature, salinity, and calculating pH and calcium carbonate saturation states every 2 seconds. Plankton sampling began at the Quadra Island site on 16 February 2015. Twice per week the following samples have been taken from the nearshore site, in proximity to the shellfish raft and chemical monitoring equipment:

- Zooplankton quantitative vertical tow, 64µm plankton mesh (since changed to 250µm)
- Zooplankton quantitative horizontal surface tow, 250µm plankton mesh
- Phytoplankton qualitative vertical tow, 20µm plankton mesh (see sections below)
- Phytoplankton quantitative surface sample, no filtering

Data analysis:

Initially oceanographic data was being emailed to Dr. Wiley Evans for processing once a week, but data is now available in near real-time. This data is then analyzed to calculate calcium carbonate variables, as seen in Figure 2 below.

As it can be seen, the winter months had extended periods of considered corrosive aragonite saturation conditions, with water partial pressure carbon dioxide levels much higher than the global average of ~ 400µatm. Interestingly on average the water temperature over the annual cycle was around the global atmospheric mean of ~ 400µatm, but Figure 1 shows the rapid changes within the system. These long periods of increases of pCO2 levels are likely to be normally observed during the winter period, but that the severity is likely to be increased compared to pre-Industrial times. This may have impacts on overall coastal ocean productivity, with a potentially reduced 'biological window' during the spring / summer. Further years of data will be used to ascertain if this is the case.

All phytoplankton samples have been analyzed and up-to-date (Figures 2 and 3). Figure 2 shows phytoplankton and zooplankton percentage constituents of surface discrete samples (1m), and show a salmon migration mis-match even in early spring and then another zooplankton bloom later in the season which is when salmon were observed to be migrating through the northern Salish Sea area (Trudel and Hunt pers. comm.), prior to migration through the Discovery Islands and Johnstone Strait. As can be seen in Figure 2, the discrete surface (1m) plankton samples contained predominantly diatom species, and the majority of harmful species observed were also in the diatom Chaetoceros group so were mechanically rather than toxic; there was one occurrence of Heterosigma in June 2015. The increased snowfall of Winter 2015 will likely increase the amount of freshwater discharged into the Salish Sea, and therefore in Summer 2016 we may see increases in bloom production (Figure 5).

Zooplankton species identifications and protocols have now been developed, in line with that of I. Perry DFO, and will facilitate comparisons between groups in the SSMSP (Figure 4). To date, data shows monthly means from a limited number of samples but will be updated as more samples are processed. June and July 2015 samples were predominantly Chordata (Larvaceans) and May predominantly Arthropoda. Ordination analysis will be used in the future to examine changes over time and with chemical oceanographic state. Although it initially appeared in Figure 2 that there were peaks in zooplankton production at times of salmonid migration through the Salish Sea, further analysis of size classes (Figure 4) shows that the zooplankton available was very small, and therefore unlikely to be a highly nutritious food source prior to migration through the Johnstone Strait.

Summary and recommendations for next steps:
The monitoring station has been successfully initiated and represents a long-term opportunity for chemical and biological monitoring on multiple trophic levels in the northern Salish Sea. Sampling and analysis protocols have been developed and zooplankton development and analysis is now in line with that of other SSMSP partners for comparable reporting. Chemical oceanographic data is now available in near real-time, and plankton analysis is up to date. 2015 was an unusual year for plankton production in the Salish Sea, and further years of data will be required to determine any linkages between chemical fluctuations and biological productivity. Currently two papers are in preparation: one paper detailing the first year of chemical oceanographic data and the second on the plankton productivity, for submission in early 2017. Plans are underway by the lead PI to develop a coastal monitoring data program, of which the PSF would be a partner. Specific recommendations include continuance of monitoring and the inclusion of a biomass component.

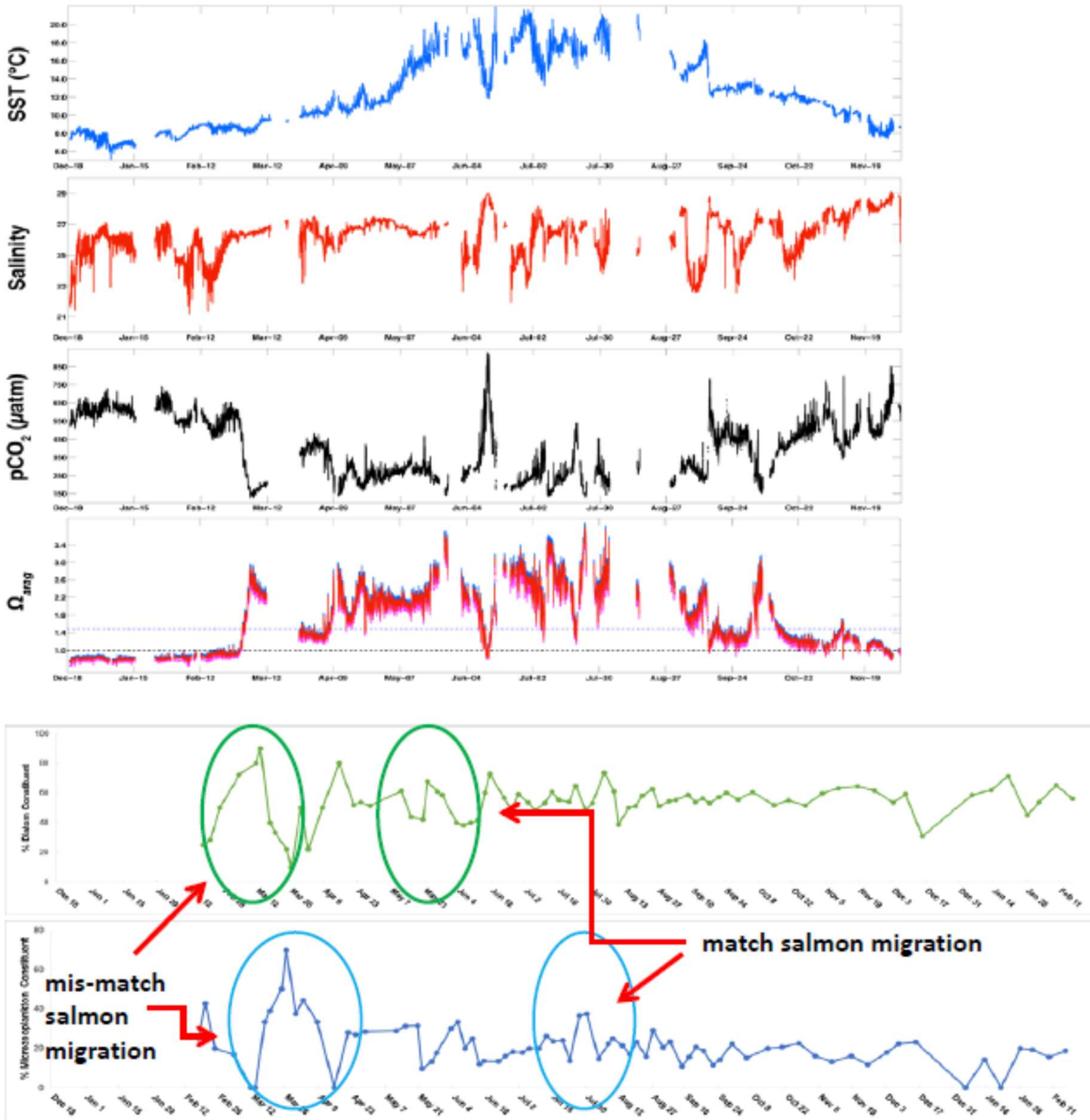


Figure 1 - Sea surface temperature (SST; °C), sea surface salinity (SSS), CO2 partial pressure (pCO2; µatm), and the saturation state of aragonite (Ωarag) from December 18, 2014 to December 4, 2015. Ωarag was calculated using three regional alkalinity-salinity relationships: those reported by Wootton and Pfister [2012; blue] and Ianson et al. [2003; magenta], and one constructed from the data reported by Murray et al. [2015; red]. Ωarag from the Murray et al. [2015] relationship falls in the middle of values calculated from the other two relationships; the data used for this relationship span a broader salinity range, were collected over two annual cycles, and are in closer proximity to Quadra Island. Owing to these reasons, this relationship is believed to currently be the best suited for this dataset. Blue and black horizontal lines in the Ωarag panel mark conditions that are stressful for early life stages of some bivalve species, and conditions that are corrosive for aragonite. Data shown are 5-min averages of 2-sec data. % Diatom and % Zooplankton constituent data taken from surface (1m) discrete samples from 17 February 2015 to 16 February 2016.

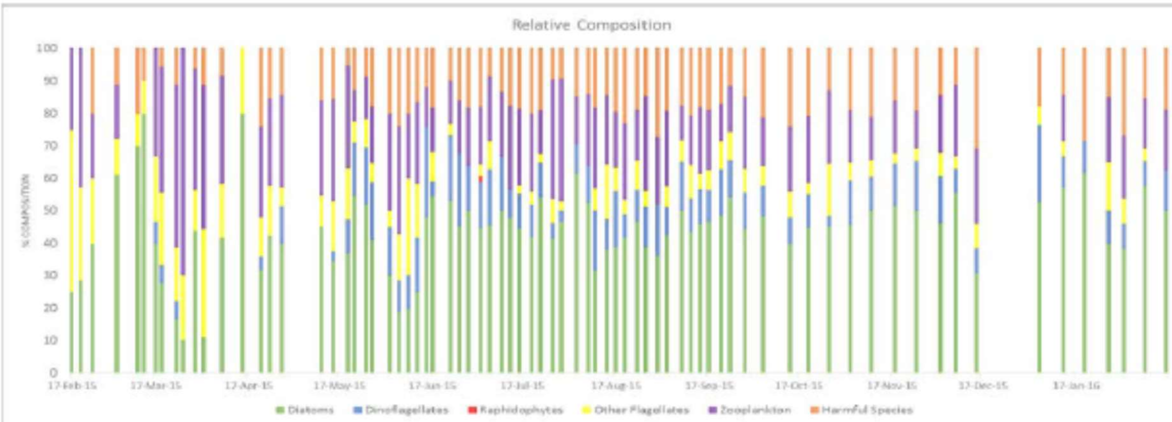


Figure 2 – Phytoplankton relative compositions from discrete samples (1m), from 17 February 2015 to 16 February 2016.

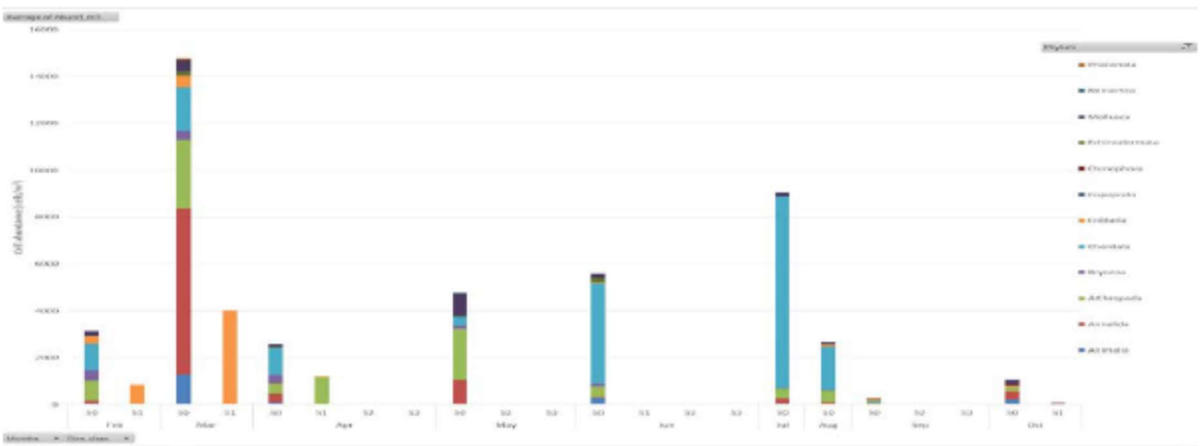


Figure 3 - Cell abundance (cells/m3) of the zooplankton phyla in size classes in the coastal water off of Quadra Island, 2015. Vertical tows of zooplankton data only (phytoplankton removed) from 64µm net from February to 22 June, 250µm net from 23 June onwards. Size fractioned samples as follows: S0 <2mm, S1 2-5mm, S2 5-10mm and S3 >10mm.

A2 Zooplankton and Ichthyoplankton – Canada

Zooplankton and ichthyoplankton status and trends in the northern Salish Sea

Team: Ian Perry, Research Scientist, Fisheries & Oceans Canada, Pacific Biological Station, Dr. Evgeny Pakhomov: Professor, Biological and Fisheries Oceanography, Earth and Ocean Sciences, University of British Columbia, Dr. John Dower: Associate Professor, Biology Department and School of Earth & Ocean Sciences, University of Victoria, Ms. Moira Galbraith: Research Biologist, Fisheries & Oceans Canada, Institute of Ocean Sciences, Dr. Brian Hunt: Research Associate, Earth and Ocean Sciences, University of British Columbia, Vancouver, Ms. Kelly Young: Research Biologist, Fisheries & Oceans Canada, Institute of Ocean Sciences

Objective:

The short-term goal is to identify the seasonal patterns of variability in zoo/ichthyoplankton species composition, abundance and biomass in the Strait of Georgia and Juan de Fuca Strait, and how they relate to changes in physical conditions.

Long-term, the aim is to identify the effect that changes in seasonal patterns of the species composition, abundance and biomass of the zoo/ichthyoplankton in these areas has on the growth and early marine survival of juvenile salmon and, ultimately, their influence on the overall return strength of these populations.

Background:

Zooplankton are the basis of the food web for juvenile salmon and the direct connection between bottom-up physical processes and salmon survival and growth. They are as a necessary component of a core bottom-up sampling program, and as central elements of both coupled physical-biological (e.g. NPZ) and food-web models. This project will provide a comprehensive zooplankton and ichthyoplankton sampling program to identify the seasonal status and trends of the species composition and biomass/abundance of these animals in the Strait of Georgia and Juan de Fuca areas. The sampling provides information regarding ecosystem variability and prey quantity and quality for outmigrating juvenile salmon.

This project leverages existing DFO resources and programs sampling zoo/ichthyoplankton in these areas, and adds additional surveys to sample in areas and at times that are currently not covered. This is comprised up from existing Chandler surveys from IOS, Ricker surveys that occur June, July and September in the SOG, from additional vessels chartered by Ian Perry, and from 3-4 boats that make up part of the Mosquito Fleet in Canada.

Both the U.S. and Canadians are utilizing a distributed approach to achieve a zooplankton sampling program with broad spatial (throughout Salish Sea) and temporal (monthly or greater during salmon outmigration) coverage. Methodologies and protocols among the US and Canadian scientists are similar. Sampling protocols for zooplankton have been shared to ensure relative consistency, and both sides will be utilizing vertical bongo net tows (to assess zooplankton in the entire water column, from just off the sea floor to the surface) as well oblique tows (in the top 10-30m to assess the salmon prey field). Oblique tows have proven difficult off of the smaller vessels used in the distributed, multi-party approach implemented in the U.S. Canadian collaborators are focused on utilizing one vessel to perform the oblique tows, with broad spatial coverage but fewer sampling events (once per month from April to September).

Although not a primary objective of this proposal, the samples taken can be made available for biochemical analyses (e.g. of lipids, fatty acids, stable isotopes) to provide a plankton baseline for biochemical analyses of juvenile salmon being proposed by other projects.

Status:

Sampling was conducted at 19 core locations in the Strait of Georgia, approximately every two weeks from mid-February to mid-October 2016. This continues the success of this project in 2015, which represented the most intensive zooplankton sampling program in the Strait of Georgia, ever. Surveys were conducted using a sequence of platforms, including DFO survey vessels, a charter survey vessel, and one citizen science vessel. Six of these surveys were conducted using a dedicated charter vessel, funded by this PSF grant. At each station, the following data and samples were collected: full depth CTD profile including fluorescence and oxygen; full depth zooplankton tow, using SCOR net with 236 µm black mesh; at selected stations, additional samples were collected for phytoplankton, chlorophyll, and salinity. A total of 316 zooplankton samples were collected; taxonomic identification in the laboratory is continuing as of the date of this report (5 December 2016).

Data from this project are undergoing statistical analyses. They are also being integrated with data from satellites to examine the role of physical and lowest trophic level (phytoplankton) biological processes on zoo/ichthyoplankton characteristics (e.g. species composition, timing, abundance, biomass). They plan to task a new Post-Doctoral Fellow in the Pakhomov Lab at UBC to conduct further analyses of the zooplankton community and its responses to environmental variations next year. Comparisons have begun with marine survival data for Strait of Georgia Coho populations. The next steps are to compare with Strait of Georgia Chinook marine survival data and with detailed data on the distributions and conditions of juvenile salmon in the Strait of Georgia (when these data are available). These latter collaborations are slow due to the problems encountered by that project.

Taxonomic analyses of all samples collected in 2015 have been completed, and data provided to the Salish Sea program database. Taxonomic analyses of the samples collected in 2016 are about 10% complete; they anticipate another 4 months (December 2016 to April 2017) to complete taxonomic identifications for all of the remaining 2016 samples. These taxonomic identifications will continue simultaneously with the 2017 zoo/ichthyoplankton surveys.

A3 Forage Fish- Canada

Strait of Georgia juvenile herring and nearshore pelagic ecosystem survey.

Team: Jennifer Boldt (lead), Research Scientist, Fisheries and Oceans Canada, Pacific Biological Station, Matt Thompson, Technician, DFO, Charles Fort, Biologist, DFO, Carol Cooper, Taxonomist Contractor, Zotec services, Doug Henderson, Skipper and Fisher Contractor, Dr. Marc Trudel, Research Scientist, Fisheries and Oceans Canada, Pacific Biological Station, Dr. Stéphane Gauthier, Research Scientist, Fisheries and Oceans Canada, Institute of Ocean Sciences, Dr. Kyle Garver, Research Scientist Pacific Biological Station, Nanaimo, BC.

Objectives:

- Update age-0 herring time series
- Identify suitable data and statistical methods for estimating an index (and associated variance) of the relative biomass or abundance of age-0 herring.
- Relate estimates to
  - age-3 herring abundance from stock assessment model,
  - Chinook salmon survival.
- Examine annual variation in herring lengths, weights, and fish condition (length-weight residuals).

Background:

The survival of salmon species in the North Pacific has been linked to food availability during their early life history and coho and Chinook, which are generally switching to piscivory early in their marine life, are likely strongly affected by the availability of prey fish when they enter the marine environment. In the Strait of Georgia, the marine survival of Chinook salmon is strongly correlated to the proportion of young-of-the-year herring in their diet (R. Sweeting, unpublished). Thus, understanding the factors affecting the recruitment dynamics of herring in the Strait of Georgia may be key to understanding the variability in the marine survival of coho and Chinook Salmon in the Strait of Georgia.

The main goal of this project is to continue long-term monitoring of the SOG nearshore pelagic ecosystem. The goals of the SOG juvenile herring and nearshore pelagic ecosystem survey are to provide an index of herring recruitment and prey availability to salmon and other predators, explore factors affecting herring distribution and survival, examine the temporal and spatial patterns in pelagic species composition, and gain a better understanding of the prevalence of aquatic viruses in Threespine Sticklebacks in the SOG.

The current objectives of the survey are to 1) estimate the relative abundance and distribution of juvenile herring in the SOG as a potential indicator of herring recruitment and as a potential indicator of prey availability to salmonid and other predators, 2) monitor the distribution and relative abundance and collect samples of nearshore pelagic fish in the Strait of Georgia, 3) monitor the distribution and relative abundance and biomass of the zooplankton community, 4) measure physical environmental variables that may affect the distribution of fish and zooplankton species, and eventually 5) understand trends in temporal and spatial variability in community composition and diversity. In addition, collaborative project objectives from survey-collected fish samples include: 6) screen Threespine Sticklebacks for the newly discovered threespine stickleback iridovirus (TSIV) that has caused mortality of sticklebacks in coastal waters of BC and 7) identify the prevalence and distribution of this virus and save any positive samples for future studies.

Status:

The key accomplishments of this project include the following:

1. In April 2016, funding was contributed by PSF and in-kind support was provided by DFO for the 2016 survey. The survey was successfully completed during September 7-20, 2016, with no weather delays. All 48 core stations on the 10 core transects were sampled. Fish and zooplankton samples were collected and are being processed. The age-0 herring abundance index will be updated once all fish samples are processed. Qualitative observations indicate roughly similar abundances of age-0 herring as observed in 2015. Interesting observations in 2016 include catches of anchovies along the Sunshine Coast and south of Dodd Narrows, as well as juvenile rockfish in many sets.
2. Completion of the 2014, 2015, and 2016 Strait of Georgia (SOG) juvenile herring and nearshore pelagic ecosystem survey – a long-term monitoring program including the collection of age-0 herring and Three Spine Stickleback samples, zooplankton biomass data, and physical environmental measurements in the SOG during the fall.
3. In addition to completing surveys, a time series of the relative biomass and abundance of age-0 herring was updated through 2015. They identified suitable data and statistical methods for estimating an index (and associated variance) of the relative biomass or abundance of age-0 herring. Estimates of age-0 catch weight CPUE varied annually, with no overall trend during 1992-2015. The age-0 herring index tended to peak every two or three years, with the peaks occurring in even years during 2004-2012. The index was relatively low and stable during 2013-2015, compared to the peaks within the time series. High estimates of variability are associated with peak estimates; the survey coefficient of variation (CV) is 0.47. The samples collected in 2016 are currently being processed.
4. The index of age-0 herring biomass may provide a leading indicator of recruitment to the adult herring population and of prey availability to Chinook Salmon in the SOG, as indicated by the positive correlations between the index of age-0 herring and:

   a.) age-3 herring recruit abundance 2.5 years later, as estimated by the age-structured stock assessment model (67% of variability), and b.) to some runs of Chinook Salmon survival (explaining up to 47% of the variability).

5. The annual variation in herring lengths, weights, and fish condition (length-weight residuals) were examined and herring condition increased since 1997, with positive residuals since ~2005, which may have implications for the quality of prey consumed by juvenile Chinook Salmon.
6. In 2015, sticklebacks collected from eight different transects were received by the Virology Lab. These fish were aseptically dissected and tissues are to be analyzed for the presence of threespine stickleback iridovirus (TSIV). A diagnostic assay has been developed and validated for TSIV and has proved to be specific and highly sensitive for detection of the virus. Anaylsis of the SOG sticklebacks is expected to be completed in 2016.
7. New analyses examining Juvenile Pacific Herring (*Clupea pallasi*) trophic linkages in the Strait of Georgia, British Columbia were presented at the 2016 PICES annual science conference, San Diego, Nov. 1-13, 2016, and at the Canadian and US-Canada SSMSP Retreat meetings in winter 2016.

Hydroacoustics

Team: Lu Guan, Mitacs posdocoral fellow (University of Victoria), Stéphane Gauthier (DFO), John Dower (University of Victoria), Marc Trudel (DFO), Chrys Neville (DFO), Chelsea Stanley (DFO) Moira Galbraith (DFO)Jennifer Boldt (DFO)

Objectives:

This research project is specifically to study the production of the prey and predators of juvenile salmon, and their links to the juvenile salmon survival in the SoG. Key objectives are:

- To develop acoustic indicators of productivity (relative/absolute biomass estimates) for salmon predators and prey
- To examine abundance & spatial distribution of the defined species/assemblages, and explore their potential links to oceanographic and environmental factors
- To test hypotheses that relate the abundance and distribution of the defined species/species assemblages to the marine survival of juvenile salmon

Background:

Stéphane Gauthier supervised a pelagic ecosystem survey of the Strait of Georgia (SoG) in March 2014 and 2016 based on acoustic-trawl methods. Another survey is scheduled for July 2016, and March 2017. In addition to these surveys, acoustic data are now routinely collected as part of DFO's juvenile salmon trawl program occurring in the area.

A newly appointed Mitacs postdoctoral fellow (Lu Guan, University of Victoria) will focus on this rich acoustic dataset. The objective will be to develop a series of acoustic indices of productivity for forage fish species such as herring, mesopelagic fish, euphausiids, zooplankton, and ichtyoplankton within the SoG. Demersal species distribution and abundance are also explored as part of these surveys (e.g. Pacific Hake and Walleye Pollock). Acoustic indicators will be developed using robust multi-frequency techniques in conjunction with mark identification fishing (trawls). A multiple opening and closing net system (the Hydrobios multinet) will be used to sample smaller organisms (zooplankton, euphausiids, and larval fish). Along with existing time-series of forage species catch from trawl surveys, the acoustic indicators of productivity will be investigated for potential links to juvenile salmon survival. Data and results from this study will be closely integrated with the other projects that focus on juvenile salmon survival in the area.

Status:
A qualified post-doc, Lu Guan, started working with the team in March 2016.

They completed two Strait of Georgia Bio-acoustic Surveys in March and July 2016. The March survey focused on dominant pelagic and demersal fish species in the Strait of Georgia (e.g. Pacific hake, walleye pollock and Pacific herring) by conducting mark-identification fishing (trawls), while the July survey focused on plankton (e.g. zooplankton, euphausiids and larval fish) by conducting mark-identification sampling using hydrobios multinet and MOCNESS plankton net.

Based on the acoustic data collected in March- 2016 survey, they developed calculation methods to estimate biomass (an indicator of productivity) and map biomass distributions for dominant fish species (Pacific hake, walleye pollock and Pacific herring). The method of biomass estimation will be applied to the other surveys to develop time series datasets for further analysis. The preliminary analysis of the March-2016 survey showed a separation in biomass distribution of hake, pollock and herring in the strait: biomass of Pacific hake was more distributed in the central-northern Strait, biomass of walleye pollock was more distributed in southern-central Strait, while biomass of Pacific herring was more aggregated along the shore. Analyses are ongoing.

A4 Juvenile salmon – Canada

Freshwater and Marine Survival
Team: BCCF (Kevin Pellet, James Craig, Wightman, Stenhouse, Dambourg, Atkinson), Mel Sheng DFO-PBS, Steve Baillie DFO-PBS, Don Elliott Cowichan Hatchery Manager, Dr. J. Taylor, Dave Key Key Mill Construction Ltd. dba Pisces Research Corps Elliot, Cowichan Tribes.

Objectives:
To determine the level of mortality of Cowichan chinook in both the freshwater and early marine periods of early life.

Background:
Both rotary screw trap and PIT tagging methods are being used to compare freshwater and marine survival at different stages in the life history of Cowichan chinook in 2015.

Previous work to determine the marine survival of Cowichan chinook have made assumptions that all hatchery fish released 40 kms upstream from the estuary in the Cowichan River survive and enter the estuary. This assumption is unlikely to be valid, and thus, a Rotary Screw Trap (RST) has been operated by DFO and Cowichan hatchery staff during 2014 and 2015 in the mainstem of the Lower Cowichan River to allow for a mark-capture population estimate on hatchery released fish

In the last 6 years, research has been undertaken to monitor the spatial and temporal distribution and ratio of hatchery and wild chinook entering the Cowichan Estuary and through their first months in the ocean. This information has been used to estimate the early marine survival of hatchery and wild chinook salmon from this system (Beamish et al. 20xx). The estimates assumed that all hatchery fish released 40 kms upstream from the estuary in the Cowichan River survive and enter the estuary. However, based on recent freshwater work, only 20% of the releases successfully migrate to the lower river.

In 2016, groups of Hatchery smolts will be release at multiple locations further downstream in the river to determine if migration success rate improves; the level of freshwater mortality will be determined by operating a Rotary Screw Trap (RST) in the mainstem of the Lower Cowichan River and conducting a mark-capture population estimate on CWT and PIT tagged hatchery released fish.

The RST work has been supplemented with a freshwater PIT tagging study during 2016. Hatchery chinook are PIT- tagged and released at the usual hatchery release location, and their survival will be estimated using a RFID array at the bottom of the Cowichan River, which records each PIT tag as the fish crosses the array. The survival estimate using this method can be compared with that from the RST.

PIT tagging is also used to assess marine mortality of the same hatchery population. Several previous research studies have attempted to investigate where mortality is occurring in the marine environment but few answers have resulted. The past approach has been to mark fish in freshwater using coded-wire tags (CWT) and recovering tags in fisheries and spawning populations. However, the use of CWT-marked groups limits survival estimates to total marine survival rates (juveniles tagged at release to recruitment pre-fishing) and says little about the sequence of mortality events. BCCF piloted the application and use of PIT tags in the marine environment during 2014. This method provides a means to estimate the survival of multiple tagged groups differentiated by their size and age when tagged during the early marine life stage: by applying PIT tags to fish captured in the marine environment over an extended period of time (e.g., 6 months following ocean entry) and at multiple locations, fewer tags are required as smolts become sub-adults and mortality rates likely decline accordingly. Passive tag technology allows a cost effective method for individually marking many fish without constraints of battery life. Tag recoveries are made in freshwater as fish return to spawn which greatly reduces the need to scan a broad geographic range for marked fish. Finally, the individual codes for each tag allow analysis of an infinite range of marking locations, times, species, and sizes down to fish measuring only 60 mm. Data will be collected in a way that allows many different hypotheses to be tested such that results from other ecosystem research projects can be linked to marine survival. If successful, this study could provide the empirical foundation which identifies the critical times (i.e., discrete life stage) and/or locations that determine survival in the marine environment.

Hatchery chinook are tagged 1. In hatchery, 2. In freshwater, 3. By beach seine, 4. By purse seine, 5. By microtrolling. Microtrolling (catching fish using specialized trolling equipment aimed at catching juveniles as they move offshore) will be used to capture sublegal juveniles in the marine environment. This is a novel method, piloted by Will Duguid, PhD candidate at UVic during 2014. The method is labour intensive, so it is proposed to achieve higher sample sizes by forming a collaboration with the "Avid Anglers" which will form a second citizen science project in the Strait of Georgia.

The key hypotheses that are being addressed are as follows:

A) The mortality rate in the early marine environment is initially high but subsides as fish grow and move offshore.
B) Survival to the adult stage is controlled mostly by mortality at a specific time and location within the first year of marine life.
C) The determinants of marine survival may be geographic and temporal. Fish of a similar size may experience significantly different survival based on when they occupy a specific habitat (early vs. late migrants).
D) Understanding how mortality is distributed in the marine environment will lead to the identification of causal factors in conjunction with other research activities.

Status:

Rotary Screw Trap

Field operations were started on 6-April-2016 and completed on 24-June-2016. A rotary screw trap was installed on the Cowichan River to catch a sample of downstream migrating salmon, including released hatchery origin chinook fry. Two paired releases have been completed, with the early release on 12-April and 28-April and the late release on 12-May and 25-May. One of the early groups and one of the late groups were released in the Road Pool, which is the normal location. The other early and late groups were each released in one of two other locations (Stoltz Bluff and Horseshoe Bend) mid-way down the Cowichan River.

Data analysis was conducted in July 2016. Results indicated that the chinook released in the normal Road Pool site experienced low freshwater survivals, similar to the work in 2015. The chinook released in the alternative locations experienced improved freshwater survivals.

PIT tagging

A total of 45,202 PIT tags have been applied to juvenile Cowichan River Chinook since spring 2014. Tag application rates have steadily increased over the study period as have detection probabilities in-river. Activities in 2016 were highly successful as tag targets were met or exceeded at all locations. In-river detections were dramatically improved for out-migrating juveniles while over 130 returning tags were detected in the fall.

Steady improvements in micro trolling locations and gear types have solidified the feasibility of this technique for targeting juvenile Cowichan River Chinook in the marine environment. Provided in-river detection systems are maintained, tag returns over the next 3-5 years are expected to provide the necessary data to satisfy project goals.

Key Findings:

Freshwater

One of the key findings to date is that in-river survival is lower than expected for both wild and hatchery Cowichan River Chinook. Preliminary results from the RST program in previous years have been validated with PIT tag detections in-river and in the early marine environment. Activities in 2016 focused on paired releases of wild/hatchery Chinook at five upstream locations. Subsequent detections at the permanent detection array (installed May 2016) revealed losses of 70-80% over a distance of 40 km with a very strong linear trend between sites. Incidental recaptures of PIT tagged Chinook in the early marine environment (Cowichan Bay/Sansum Narrows) showed a dramatically reduced probability of encountering fish tagged in upper reaches of the river in 2015 and 2016.

Abnormal instream detections were noted at a lower river side channel detection array in early June of 2016. Tags released in the mainstem were appearing to migrate into the bottom end of the side channel in clusters. A trail camera was deployed to test the hypothesis that tags were actually inside of another animal that consumed multiple tagged fish. A family of raccoons was captured on the camera within 8 hours of deployment and appeared to interact with the antennas in a way that would result in tag detections. Approximately 4,300 hatchery fish from the late release at Road Pool were estimated to have been consumed over a 15 day period. Abnormalities were discovered upon further analysis of other detection arrays including 12 tags detected 4.5 km upstream of their release location. A river otter, a raccoon and two mergansers were later captured on a trail camera at the mainstem array.

These observations provide evidence that:

1) Large losses were sustained by downstream migrating wild and hatchery Chinook smolts in 2016. Survival to the marine environment for the late hatchery release group was estimated at 12% (23,250 of 193,748).
2) RST work suggests this trend is observed in most/all years where hatchery Chinook survival was investigated
3) There is mounting evidence that predation accounts for the majority of losses based on abnormal tag behavior on multiple arrays as well as photographic evidence of animals interacting with detection fields.
4) A large portion of the marine survival estimate for hatchery fish released in the upper river can be attributed to freshwater losses in most or all years. They estimate that only 10-15% of the late hatchery release group (CWT indicator stock) made to the marine environment in 2016 assuming the rate of loss observed over the first 40 km continued through the last 7 km.
5) The hypothesis that larger smolts have a higher survival rate in freshwater is not supported by tag detections in the lower river.

Marine
Tag application targets were met in the early marine environment (Cowichan Bay) providing resolution in space and time. Recaptures of fish tagged in freshwater were not a primary objective of marine sampling activities due to anticipated low capture rates. However, 70 tags were recovered in 2016 allowing for a comparison of recapture rate (% of tags released) by river km. Results were highly correlated with tag detections in the lower river and lend further support to conclusions regarding low in-river survival.

Capture rates aboard the purse seiner in Cowichan Bay were high in 2016 resulting in the application of 7,912 tags over 5 days compared to the pre-season target of 5,000 tags over 6 days. As a result, beach seining activities were curtailed at 1,980 tags over 7 days (pre-season target 3,150) to conserve tags for micro trolling work. The sixth purse seining day was rescheduled for August 21 in Sansum Narrows/Maple Bay to support micro trolling work. Accordingly, 300 additional tags were deployed resulting in a season total of 8,212 tags aboard the Ocean Venture.

Micro trolling techniques were further refined from 2015 in order to target a higher proportion of Cowichan River Chinook. A significant amount of effort was placed in Maple Bay (63% of total) where Cowichan fish were regularly found in 2015 while the rest occurred in northern/southern Sansum Narrows (37%). 2015 results indicated that Cowichan fish occupied the smaller size bins of all juvenile Chinook captured and that smaller fish were generally found closer to the surface. 2016 activities focused on shallower depths (6-21 m) than 2015 (15-30 m) while terminal tackle was scaled down to spoons measuring 2.0 cm from 4.5 cm. An initial batch of 196 samples was run within one week to allow for calibration of tagging procedures (i.e. avoid tagging non-Cowichan). 139 samples (71%) came back with Cowichan as the first stock ID while the cumulative probabilities of all Cowichan ID's (more conservative estimate) was 68%. GSI work on the balance of DNA has yet to be conducted but estimate 1333 Cowichan fish were tagged during micro trolling/purse seining outside of the bay in 2016 (assuming a 68% Cowichan GSI). This exceeds the pre-season target of 1050 fish and the 2015 total of 431.

Returning Tags – Freshwater
Tag returns in 2015 were estimated at 63 based on a low detection efficiency of 14% in the lower river and 24% overall. An increased number of tags were expected to return in 2016 from multiple age classes in conjunction with improvements to detection equipment. In total, 134 returning tags were detected in 2016 with an estimated probability of detection exceeding 93%. The upstream sub-sample used to estimate detection efficiency was low at only 14 tags. This was a result of a large increase in flows during the migration period such that the upper threshold for fish using the primary fishway was exceeded on

October 15. Abnormally high rainfall during October was observed and this result is not expected to be consistent in future years. Antenna performance within the fishway was excellent with each tag detected an average of 36 times (range 14-100).

Several comments were received by BCCF staff from Tribes members concerned about the level of harvest occurring in the lower river during late September and early October (lawful and unlawful). Any returning adults removed from the population prior to passing the permanent array (river km 7) were not scanned for PIT tags (with the exception of hatchery brood) and represent lost data. Opportunities to install temporary arrays in the lower river should be explored in 2017 to account for these losses.

Key Data Outputs

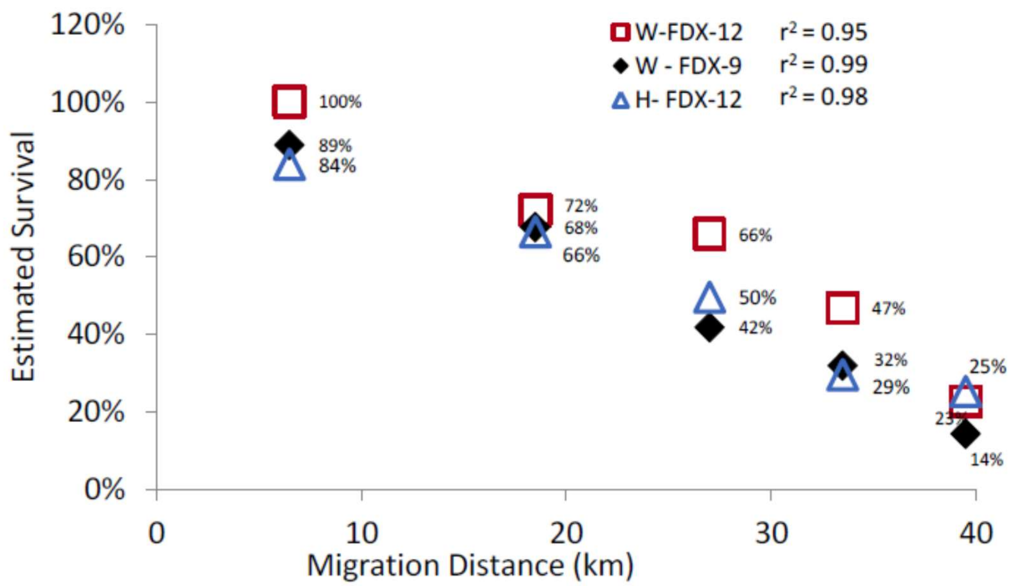


Figure 1. In-river survival estimates for three different groups of PIT tagged juvenile Chinook migrating from five different upstream locations in the mainstem Cowichan River, spring 2016. Note: these estimates are similar despite varying migration timing (up to 20 days apart) and origin (hatchery/wild).

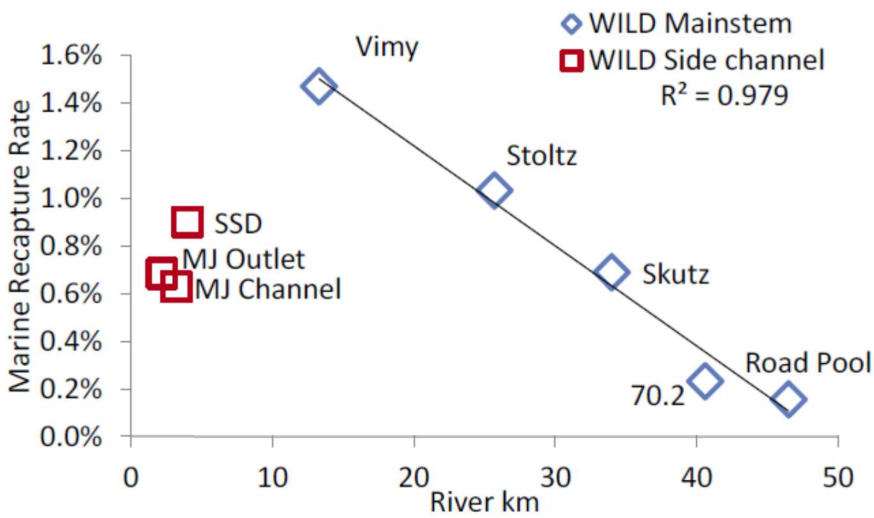


Figure 2. Relative marine recapture rates of wild Chinook PIT tagged at various locations in the Cowichan River watershed, spring 2016. These data have a strong correlation with in-river survival estimates (r^2=0.93) suggesting fish migrating shorter distances in freshwater are more likely to reach the early marine environment.

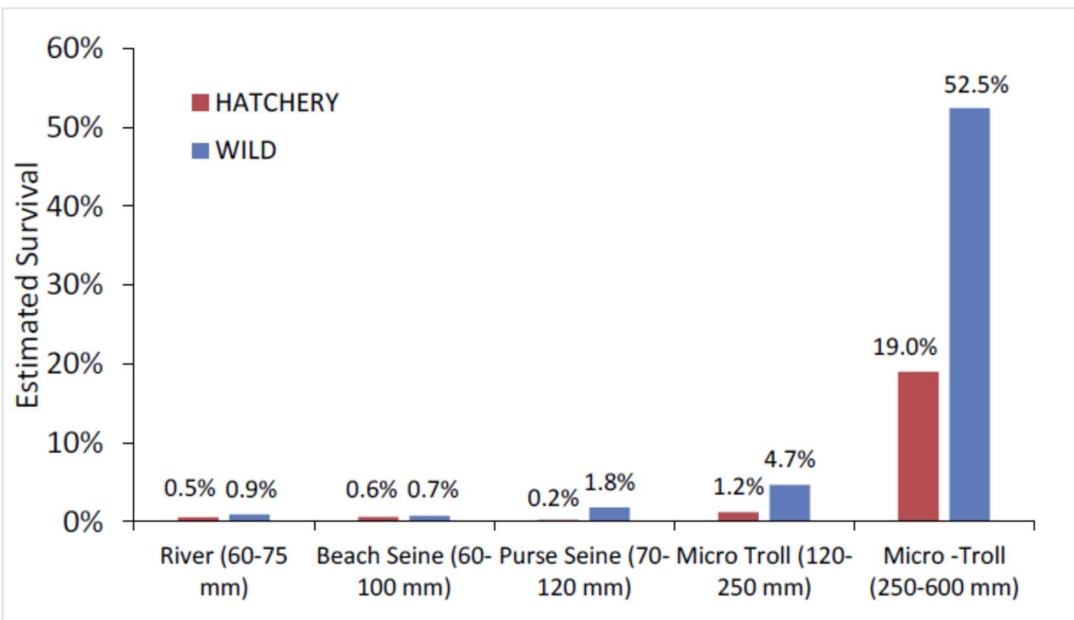


Figure 3. Estimated survival to adult return for juvenile Chinook implanted with PIT tags in 2014 and 2015. Note: returns are only representative to age 3 for fish tagged in 2014 and age 2 for 2015. The majority of returns are expected by age 4 which is fall 2019 for fish tagged in spring 2016.

Unexpected Outcomes:

1) Detection of tags inside of predators/scavengers (presumably raccoons based on trail camera photos) was unexpected as antennas were designed to scan for fish only. This opens the door to conducting future predation studies with terrestrial antennas.

2) Downstream migration survival was similarly low for both hatchery and wild Chinook based on lower tag detections and marine recaptures. Wild fish were expected to survive at a much higher rate based on the assumption hatchery fish would be disoriented upon release and be targeted by predators.
3) Early returns of age 2 and 3 tag groups suggest the marine survival bottle neck could exist at the age 1 micro troll stage (120-250 mm). The estimated marine survival of this group was expected to be 1050% compared to 2-10% for fish tagged in Cowichan Bay (see low/high end estimates in Figure 4 of the proposal) yet the current estimate is only 4.7%. This suggests that over 95% of the Cowichan Chinook tagged during micro trolling have yet to return or have perished. Age 3 returns in 2017 (from 2015 tagging) and age 2 returns (from 2016) will be highly informative relative to the objectives of this study.

Next steps:
Freshwater
- A significant bottleneck to freshwater production was discovered in 2016. It appears that both hatchery and wild Chinook can endure high rates of loss during their downstream migration as “fingerling” smolts. There is some evidence to suggest depredation by aquatic and terrestrial species. Further investigation of which species (birds/mammals/fish) or mechanisms (low flow) are responsible is warranted. It is unknown if similar losses are occurring in other watersheds but a literature review of similar tagging studies (acoustic/radio) and species (Sockeye/Steelhead) may put Cowichan results in perspective.
- Repeating the downstream survival experiment for at least hatchery origin Cowichan River Chinook in 2017 would be highly informative and cost effective with the mainstem detection array now in place (<10 K). Ideally, releases could be conducted at varying flow targets ranging from 5 to 40 m3/s (subject to lake storage levels, spring precipitation and fish size at date).
- Improving the proportion of returning adults scanned for PIT tags (to account for fishery and other losses) should be a priority for 2017. Temporary arrays deployed in the lower river (north/south arm) during the first half of the season (Sept 1-Oct 15) would be a cost effective solution.

Marine
- PIT tag application rates in-river and in Cowichan Bay were substantial in 2015 and 2016. The largest gaps in the current study are:
1) Micro troll targets of Cowichan fish were only achieved in 1 of 3 years, 2) Few age 2 Cowichan fish were tagged overall and the return rate of those that were appears to be biased high (resident?). Tagging age 2 Cowichan fish outside of the Gulf Islands area would shed light on mortality rates during the first winter at sea and would likely result in a significant number of in-river detections.
- Fish tagged in 2014 and 2015 will be large enough that some will be harvested in 2017 sport fisheries. Opportunities to recover tags in areas known for high rates of Cowichan interception (e.g. Campbell River) could be explored. The most cost effective option would be to provide lodges/guides with hand scanners and offer a substantial reward for each tag ($100).
- An acoustic tagging project to further investigate survival and behavior within the highly utilized Sansum Narrows area would be well placed. A small number of tags are likely to provide a large amount of data given an expected residency period extending through early October combined with narrow channel widths which support high detection rates.
- A mobile high-power PIT tag detection antenna was developed to assist with seal scat studies on Burial Island. 8 PIT tags were detected from Cowichan tagging activities suggesting this technique has merit. Opportunities to increase the number of haul-outs scanned could be explored for 2017 although tag retention at the sites following winter storms may be low.
- If additional PIT tags are applied by purse or micro trolling in 2017 it would be wise to develop a haulout detection array at Burial Island. A prototype was operated in 2016 but did not result in any detections

due to low coverage. Up to 60 animals per day appear to use the area and larger antennas may be able to sample an area suitable for 10-20.

Cohort Analysis and Marine Growth

Team: Marc Trudel (DFO-PBS), Chrys Neville (DFO-PBS), Carol Cooper (DFO-PBS), Svetlana Esenkulova (PSF), Dave Preikshot (Madrone Environmental), Lana Fitzpatrick (DFO-PBS), August Jones (PSF), Francis Juanes (Uvic), Rana El-Sabaawi (Uvic)-Fatty Acids, Azit Mazumder (Uvic)-Stable Isotopes & Fatty Acids, Ian Forster (West Van. Lab.)-Fatty Acids, Strahan Tucker (DFO-PBS) -Cesium Analyses, Fatty Acids & Stable Isotopes, Stewart Johnson (DFO-PBS)

Objective:

This project will focus directly on the key objectives of the Salish Sea Marine Survival Project by directly assessing the bottom-up and physiological factors limiting the recruitment of Chinook Salmon and Coho Salmon during their early marine life in the Strait of Georgia.

Background:

This project is divided into two specific components: 1) a cohort analysis to determine which segment of the population survive the early marine residency period, and 2) an empirical analysis to determine how ocean conditions affect the growth and bioenergetics of juvenile Chinook Salmon and Coho Salmon in the Strait of Georgia.

A) Cohort analysis: Assessing the cause of mortality can be a daunting task given the number of mortality agents that need to be examined simultaneously. An alternative approach is to determine whether or not there are specific smolt characteristics or traits that influence their success relative to other smolts. In this project, a cohort analysis will be used to test the *Critical-Size*, *Match-Mismatch*, and *Disease-Susceptibility* hypotheses (Table 1).

B) Marine growth: There are at least thirteen different mechanisms that have been proposed to explain the variability in smolt survival of juvenile Pacific salmon:

1. Ocean-productivity*	6. Smolt-quality	11. Harmful-blooms
2. Match-mismatch*	7. Critical-size*	12. Winter-starvation*
3. Predation-intensity*	8. Physiological-stress*	13. Predation-risk*
4. Buffer-capacity	9. Disease-susceptibility*	
5. Density-dependence*	10. Junk-food*	

*Hypotheses that predict that faster growing fish have higher survival

Although the specific mechanism affecting the marine survival of salmon differs among these hypotheses, they generally indicate that lower marine survival of Pacific salmon is associated with lower marine growth during their first year at sea (Peterman 1987; Beamish and Mahnken 2001). This indicates that to understand the effects of ocean conditions on Salish Sea salmon survival theyneed to examine the factors affecting salmon growth in the marine environment. In this project, an empirical approach is being used to test the *Ocean-Productivity*, *Match-Mismatch*, *Junk-Food*, and *Density-Dependence* hypotheses (Table 1).

In order to determine whether or not there is a specific component of the population that disappears over time during their first year at sea, salmon smolts are collected as they leave freshwater and subsequently in the marine environment. Fish sampling surveys for both coho and chinook are being carried out in four main locations through the Strait of Georgia in 2015: in the Cowichan, around Qualicum, Puntledge and the lower Fraser River. Given that both hatchery and wild salmon are being targeted, this study focuses on a potential combination of 12 species/populations/life history. Due to the uncertainty of the level of catch of the various stocks in the marine surveys, additional freshwater sampling is being conducted on the east coast of Vancouver Island systems and in the Fraser River to ensure matching samples are available from both freshwater and marine surveys.

These studies will be used to gain information on ocean entry time and size, growth (using otoliths, RNA: DNA ratios, IGF), bioenergetics, diet (using stomach contents and isotopes), fatty acids (in both zooplankton prey and juvenile salmon), presence/absence of competitors and presence of microbes. Thus, length, weight, stomach contents (diet), scales, otoliths and DNA samples will be collected. Fish will be provided to the genomics lab, blood samples will be taken, and tissues will be stored for contaminants analysis. All the juvenile Chinook salmon and coho salmon are scanned for coded-wire-tags (CWT) and PIT-tags (Chinook salmon only).

This project will collect complementary and compatible data to an ongoing sampling program in Puget Sound. This will provide an opportunity to expand the analyses to both regions and the number of populations that are examined simultaneously in regions that are subjected to similar climates but differing ocean conditions, and will therefore contribute to enhancing collaborative research between Canada and the United States to address a common concern for declining salmon resources. This project will also be coordinated with oceanographic sampling programs within the Salish Sea to obtain relevant data on the timing of phytoplankton and zooplankton production, and species composition.

Protocols for the U.S. and Canadian salmon sampling efforts have been shared cross border, and the sampling teams communicate about approaches with the focus on ensuring that the results can be compared. Regarding size, growth and size-selective mortality comparisons throughout the Salish Sea: Canada is assessing the effects of size-selective mortality and ocean entry timing using otolith microstructure recorded on the otoliths taken from smolts and juvenile salmon, whereas scale samples are predominantly used for this in the U.S. That said, both scale and otolith samples are being collected on each side of the border so that results can be calibrated across the Salish Sea (otoliths less so in Puget Sound wild Chinook because they are federally protected). Unlike Puget Sound, juvenile coho and Chinook salmon appear to migrate rapidly away from the nearshore areas in the Strait of Georgia. Therefore, Canada will not rely on an intensive beach seine effort to determine the extent of size-selective mortality. Offshore/midwater sampling in the Salish Sea is occurring via trawls and purse seines from April through August. Calibrating the collection approaches is not pertinent since both sides are not using CPUE as a primary determinant of survival. The CCGS WE Ricker cruises in July and September remain a critical component of midwater sampling efforts for the Strait of Georgia and Puget Sound.

Figure 1. Beach Seining Cowichan Bay

Figure 2. Purse seining in Cowichan Bay

Figure 3. Sorting fish caught in the purse seine

These analyses will be performed in collaboration with the University of Victoria (Francis Juanes-otoliths, Rana El-Sabaawi-Fatty Acids, and Asit Mazumder-Stable Isotopes & Fatty Acids), the West Vancouver Laboratory (Ian Forster-Fatty Acids), the Pacific Biological Station (Strahan Tucker-Cesium Analyses, Fatty Acids & Stable Isotopes, Stewart Johnson-Fatty Acids & RNA:DNA ratio).

Additional sampling beach seining and purse seining event have also occurred to provide additional samples for the live PIT-tagging project of BCCF (see above) and for genomics/health studies (see TOP DOWN studies).

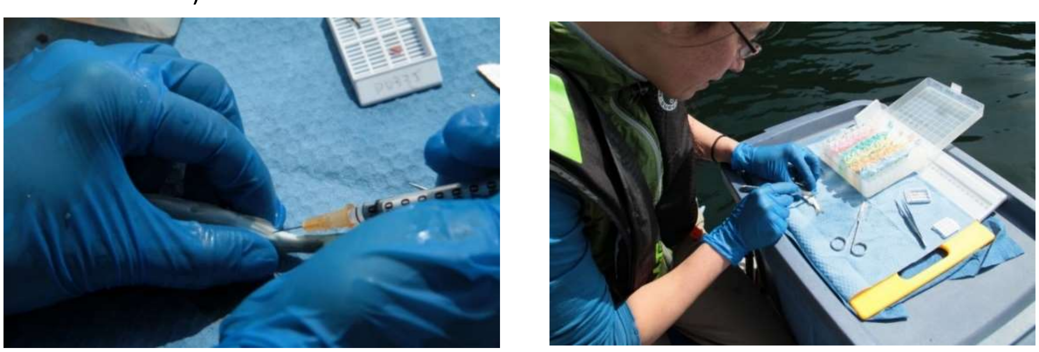


Figure 4. Collecting samples (tissues, blood, DNA etc) for genomics and physiology studies

Status:

1. The salmon ecology and physiology in the Strait of Georgia study has now completed 2 years of sampling from juveniles in freshwater through their early months in the ocean and into their first fall at sea.
2. The field objectives of 2016 were completely met with samples collected over time and space in both the Strait of Georgia and Puget Sound. They completed year 2 of field sampling including freshwater sampling at multiple locations on Vancouver Island and Fraser River, beach and purse seining in Cowichan Bay, purse seining off BQR and charter trawl surveys in SOG and Puget Sound in July and October. The loss of the WE Ricker as a workable platform in 2016 provided challenges. However, with the support of upper management in DFO, they were able to secure charter vessels to complete the required sampling in July and October in both basins, which provided samples in support of the Salish Sea Marine Survival Project in Canada and the United States.
3. With the CA agreement signed through March 2017, the DNA processing of samples from 2015 and 2016 now either completed or in progress. This is permitting subsequent analysis to progress.
4. Fatty acid and stable isotope analyses are ongoing with initial results from 2015 received.
5. Diet analysis completed on 2015 samples and in progress for 2016 samples.
6. Otolith analysis underway with protocol developed and 2015 in preparation for analysis

Key findings and results to date include the following:

The figure below shows the marine sampling locations for 2016.

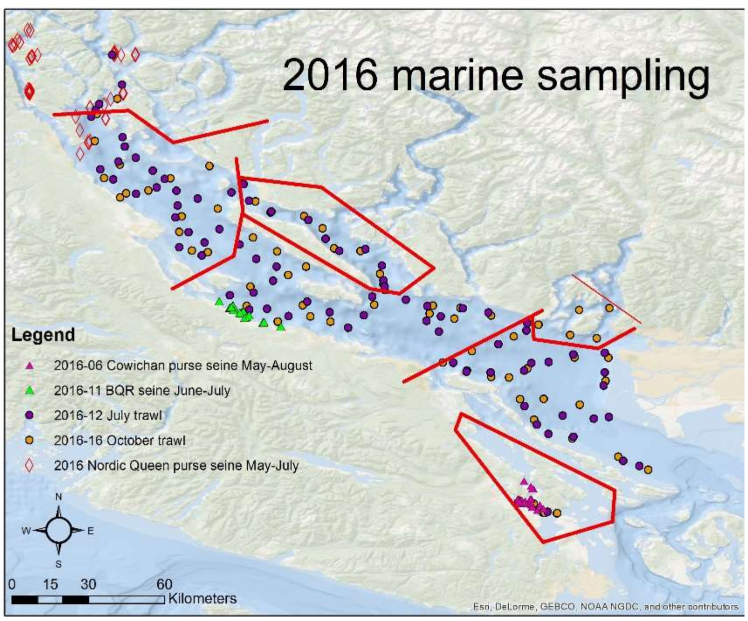


Figure 1. Map of marine sampling locations in 2016. Trawl surveys include sampling in Puget Sound that is not shown on attached figure. Sampling is similar to 2015.

Chinook and coho salmon were frozen (muscle or whole body) at -80°C for subsequent fatty acid, cesium, and stable isotope analyses based on the stock ID results.

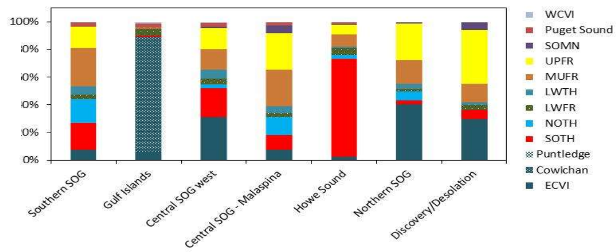
Diet analysis is being conducted on samples from all surveys.

Otoliths have been retained from all samples for analysis based on stock ID results.

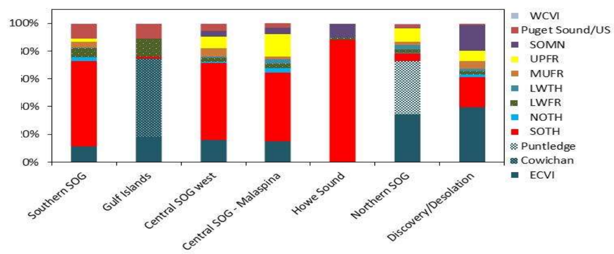
Associated freshwater samples were collected from Cowichan, BQR, Puntledge, Quinsam and the Fraser River (at source

DNA for stock analysis has been submitted for all marine captured Chinook salmon over the two-year period. Based on DNA results, several stocks of Chinook salmon have been identified to conduct more detailed fatty acid, stable isotope and cesium analyses. For 2015 these stocks include Cowichan, Big Qualicum River, Puntledge and the group of stocks originating from the South Thompson. Initial results from these analyses are now being received and it is anticipated that analysis of these first results will be completed in the early spring of 2017. Additional 2015 samples and samples from 2016 sampling will be processed between January and March of 2017.

July 2015



Sept 2015



July 2016

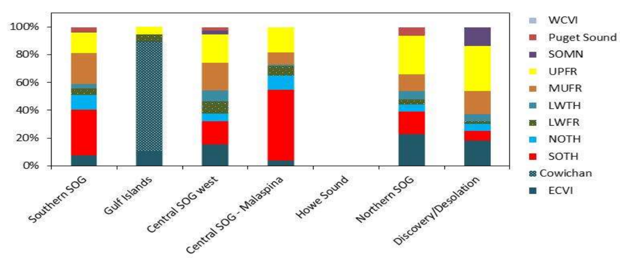


Figure 2. Results of DNA analysis on 2015 trawl captured Chinook salmon. The areas follow the regions outlined in Figure 1 (red lines). Results are summarized by key geographical regions. However, the proportion of Cowichan Chinook salmon captured in the Gulf Islands is shown in both surveys as they represent the majority of Chinook salmon captured in this region. In addition, in the September survey the proportion of Puntledge origin fish are shown for the northern Strait of Georgia region as they represent a large proportion of the ECVI group in this region.

The DNA analyses demonstrate that ECVI Chinook salmon and South Thompson Chinook salmon represent a large proportion of the fish captured in both regions. Other key stocks from the Fraser River are present, particularly in the July survey, and are available for comparison of initial results. The presence of relatively large numbers of UPFR Chinook in July 2015 and 2016 is unexpected. These fish in particular will be added to the analysis.

Over 2016, 2 staff members were trained in the preparation of otoliths for circuli reading and analysis. The otoliths from the juvenile Chinook salmon presented some challenges not experienced with sockeye salmon otoliths due to a higher proportion of crystalline otoliths and challenges in clearly identifying and in measuring circuli around the saltwater entry check. However, the process and protocol for preparing the otoliths has been finalized. For this developmental stage, otoliths from Cowichan River Chinook salmon captured prior to 2015 were used to ensure no loss of valuable otoliths as the techniques were developed. Currently, otoliths from 2015 study are being processed and the reading of the circuli from these otoliths will begin in January 2017. These otoliths will also be examined by Lance Campbell to identify ocean entry timing using otolith microchemistry to validate the visual checks being used in their analysis.

Analysis of the diet of Chinook salmon is indicating that the majority of the diet is composed of 4-6 key diet items. However, there is variation in the proportion of these diet items by area within the Strait of Georgia and possibly by stock or size of fish. This analysis is currently in progress but results of the initial two years of study are anticipated to be complete by the end of April 2017.

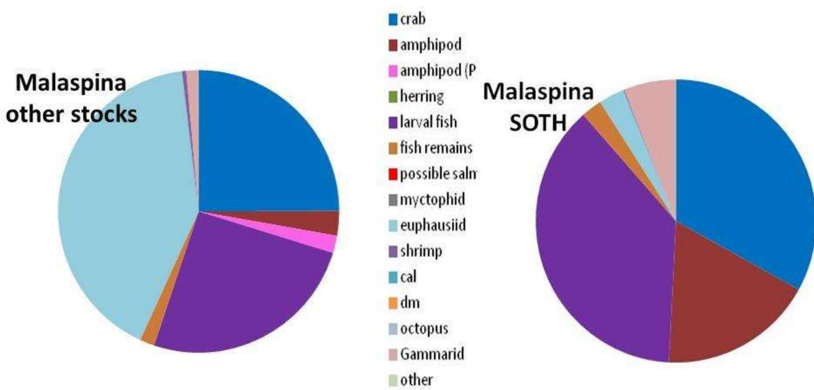


Figure 3. The common diet items in juvenile Chinook salmon are decapods (crab), amphipods, euphausiid, larval fish and herring. The importance of these prey items vary with season and area. For instance, this figure shows the diet of South Thompson Chinook salmon relative to other stocks caught in in Malaspina Strait, east of Texada Island, during our September trawl survey. Diet differences are apparent, with higher proportion of crab, amphipods, and larval fish in South Thompson Chinook salmon. It is not clear if the variation to increased amphipods and decreased euphausiids is stock base or size base. However, due to higher survival of the South Thompson fish, this will be investigated further.

Integration of diet and survival data with studies in Puget Sound is ongoing to improve our understanding of variability between the basins.

Diet results and laboratory analysis results from the first two years of juvenile salmon sampling in conjunction with results from studies examining the zooplankton production in the Strait of Georgia and fatty acid and stable isotope analysis of plankton samples and diet samples will be used to test the junk-food hypothesis and ocean productivity hypothesis.

The analysis being conducted on biological samples from 2015 and 2016 will provide information on the change in the condition of juvenile salmon over their first summer at sea. The juveniles captured in September and October are the survivors of the first marine summer. Therefore, variation between these fish and the fish in May and June will be an indicator of the requirements needed for survival. The results of the otolith analysis, fatty acid, stable isotope and cesium analysis will be used to test the critical size hypothesis, match-mismatch hypothesis, and density-dependence hypothesis.

Analysis of CWT recoveries from juvenile Coho and Chinook salmon in the Strait of Georgia was conducted for all surveys between 1998 and 2015. The results of this analysis were presented at the Salish Sea Conference in May. A report on the results is currently being prepared for submission to the SSMSP.

Field activities occurred as planned with the exception of a delay in the fall trawl survey due to requirement for trawl charter. However, survey successfully captured juvenile Chinook and coho salmon throughout the study area (see Figure 1 above).

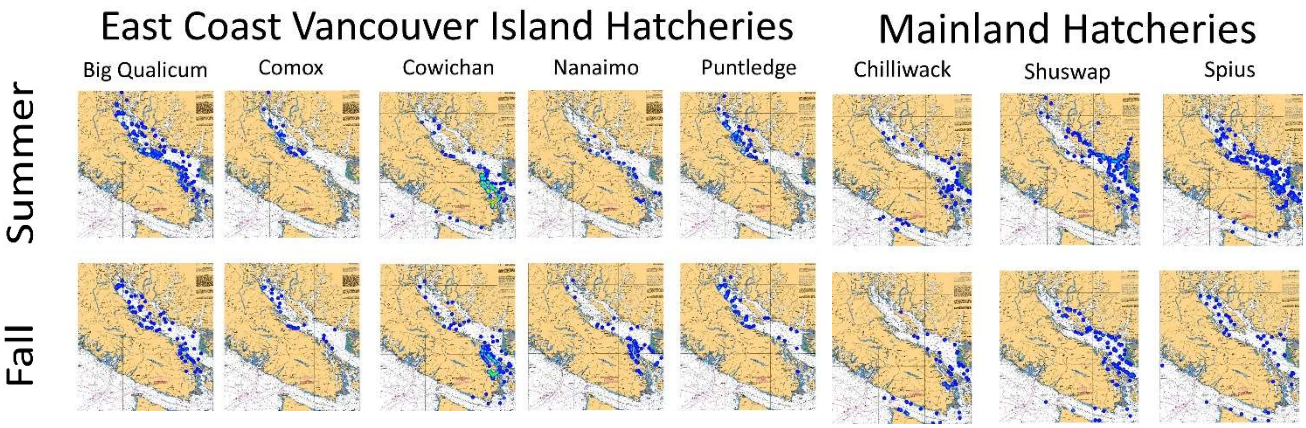


Figure 4. Analysis of CWT recovered from juvenile Chinook salmon 1998-2015. This figure shows ECVI hatcheries and three mainland (Fraser River) hatcheries. Since DNA is only available for this work from about 2008, the CWT results can be used to examine change in distribution over time as well as validate results from the DNA analysis.

The laboratory objectives for 2016 are on track to be completed. DNA from 2015 was submitted in March and April of 2016 and all results have been received (see Figure 2 above). DNA from 2016 is partially completed with additional samples from coho and Chinook to be submitted prior to January 2017. Samples for fatty acid and stable isotope analysis were selected based on DNA results. Laboratory analysis was initiated in September 2016 for 2015 samples. Initial results are now available with about 30% of the samples from 2015 processed.

The analysis of circuli spacing from otoliths will begin in January 2017. The training of staff to effectively prepare juvenile Chinook otoliths required more time than anticipated, however the result of ensuring that a correct protocol was developed will ensure fewer otoliths are damaged during the preparation process. Currently the preparation of Cowichan otoliths from 2015 that have been selected for fatty acid and stable isotope analyses are being completed. Detailed analysis of these otoliths will begin in January.

Stable isotope analyses have been performed on a subset of the juvenile Chinook salmon caught in 2015 (Figure 5). The increase in the carbon and nitrogen isotopic signature observed in South Thompson Chinook salmon indicates the transition from freshwater-derived nutrients to marine-derived nutrients. This was not apparent in other stocks due to their larger size at capture. The higher carbon isotopic ratio of Puntledge Chinook salmon suggests that these fish are feeding in different regions of the Strait. This is supported by the CWT recovery data (Figure 4), which shows a more northerly distribution. The proportion of fish and shift to piscivory will be inferred once stable isotopes are determined in both zooplankton and larval fish.

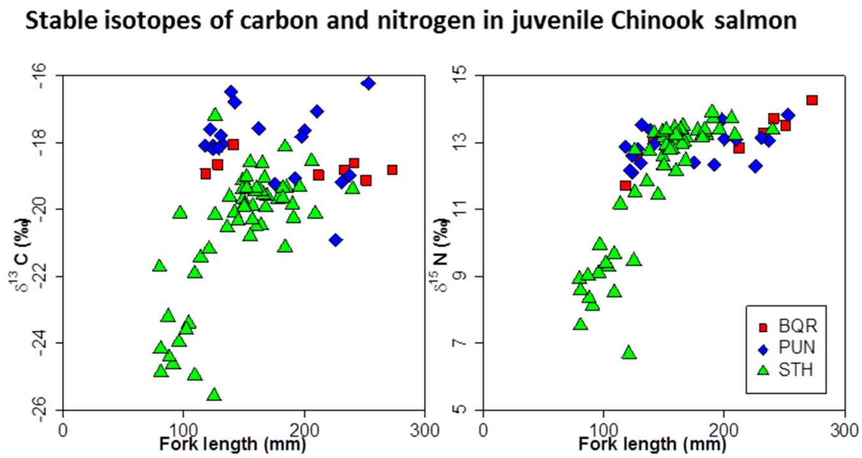


Figure 5. Stable isotopes of carbon and nitrogen in juvenile Chinook salmon originating from the Big Qualicum River (BQR), Puntledge (PUN), and South Thompson (STH) caught in the Strait of Georgia in 2015. Higher asymptotic values of carbon were observed in Puntledge Chinook salmon, suggesting that they are feeding in different regions of the Strait or feeding on different prey items.

Summary of samples collected in 2016: This represents fish that have been sampled or are available for sampling in the laboratory.

	ECVI Freshwater	Mission RST/Fraser	Cowichan Beach seine	Cowichan Purse Seine	BQR purse seine	Discovery purse seine	July trawl	October trawl
Chinook salmon	500	1100	209	1058	400	200	1117	600
Coho salmon	366	213	45	422	238	262	900	322
Chum salmon	217		110	277	286	476	452	156
Pink salmon				106	524	361	392	182
Sockeye salmon		2300		115	344	2500	214	23

Characterizing juvenile salmon species abundance, growth and habitat use in the Fraser River estuary.
Team: Misty MacDuffee, Raincoast, David Scott, Raincoast, Andy Rosenberger, Raincoast, Lia Chalifour, M.Sc. Student, (UVIc), Dr. Josie Iacarella, Post Doctoral Fellow, UVic & Pacific Salmon Foundation

Objective:
This project will characterize the juvenile salmon species utilizing the Fraser River estuary, including the timing of outmigration and sub-basin origin of Chinook fry and smolts; temporal patterns of abundance and growth and residency; and determine whether there are differences between wild and hatchery juveniles.

Background:
Estuarine habitats provision food and refuge for juvenile salmon during a critical period of growth and development. Juvenile salmon from 56 Conservation Units migrate through the Fraser estuary annually, yet their timing and habitat preferences are understood only at a very coarse scale. Although the Fraser continues to support salmon, the estuary has been highly modified by human activity, and many populations are experiencing substantial declines in abundance. Monitoring in the Fraser estuary fills a critical gap that will help characterize recruitment and survival patterns of juvenile salmon migrating into Georgia Strait and the Salish Sea. The project will provide extensive new quantitative information on juvenile salmon presence, timing, use of estuary habitats across the outmigration period, potential differences between populations, and between hatchery and wild Chinook. Additionally, Genetic Stock ID will provide new and important information on how specific populations use the estuary over various spatial and temporal scales

This group are conducting a spatio-temporally extensive juvenile salmon monitoring program throughout the Fraser River delta over the course of a year. They will survey salmon at 22 sites across Roberts and Sturgeon Banks, which encompass three habitat types. Sites will be sampled biweekly during the outmigration using beach and purse seine methods. Non-lethal fin clips will be taken from juvenile Chinook for genetic stock ID and a subsample retained for otolith analysis. They will determine (1) the population origin and growth rate of Chinook fry and smolts across the estuary and the outmigration season, (2) the outmigration, residency time, and size of juvenile salmon species, and (3) the occurrence and abundance of juvenile salmon species between Banks and habitat types in relation to abiotic and biotic variables.

Status:

Project was begun March 2016. Progress with respect to their objectives is as follows:

Objective 1: Their main objective for year one was to complete a successful field season investigating juvenile salmon habitat preferences in the Fraser estuary. This year has provided new information on juvenile salmon movement, timing, and distribution in the Fraser estuary and will be further refined with the second year of field work.

Objective 2: They are communicating with DFO regarding otoliths, other outmigration timing projects on the Fraser, and awaiting genetic stock analyses. They also collaborate with the Eelgrass Fishes Network, and believe that these efforts will result in their data providing a greater contribution to collective efforts.

Objective 3: Preliminary data analysis began in the fall of 2016, and they will continue this analysis into the spring and early summer of 2017, with the additions of a second season of sampling, genetic stock identification and otolith growth analysis.

Summary of results to date:

To date Raincoast has completed their first field season and successfully surveyed fish communities at sites located throughout the Fraser River estuary. In their first year of sampling they conducted ten rounds of sampling at 17 sites, and captured 33,441 fish of 39 species. They found that fish abundance and diversity was much greater in eelgrass (abundance=26930, species=30), than in sand flat (abundance=4019, species = 21) and marsh habitats (abundance=2492, species=18). They captured a total of 725 juvenile salmon, of which the majority were juvenile Chinook (n=516) captured in marsh habitats (n=437). They also collected a total of 289 fin clips from juvenile Chinook for genetic stock identification and retained 258 juvenile Chinook for otolith microstructure analysis.

Variation in juvenile Cowichan River Chinook salmon distribution, diet, and growth rate in relation to tidal mixing and water column stratification: validation of a novel high spatial and temporal resolution approach utilizing microtrolling and RNA:DNA ratio based growth rate indices

Team: Francis Juanes - Fisheries Ecology and Marine Conservation Group, Department of Biology, University of Victoria, Will Duguid MSc – PhD Student - Fisheries Ecology and Marine Conservation Group, Department of Biology, University of Victoria

Objective:

To assess the distribution, diet and growth of juvenile Cowichan River Chinook salmon at high spatial and temporal resolution from July to October of their first marine summer. Systematic sampling of fish and biophysical oceanographic parameters at sites with differing degrees of tidal mixing and water column stratification will test whether Cowichan Chinook salmon utilize biological “hot spots.”

Background:

The complex topography of the Salish Sea results in dramatic spatial variability in water column stratification and mixing. This variability, and how juvenile Coho and Chinook salmon respond to it, may modulate the effects of bottom up and top down regulators of survival during the first marine year. Despite this, studies of juvenile Chinook and Coho salmon in the latter part of their first marine summer have generally been conducted at a relatively coarse spatial (and temporal) scale, partly due to the high cost and logistical challenges of current sampling methods (Trawl and Purse Seine). This project uses modified recreational fishing gear (microtrolling) to economically assess the distribution, diet and growth of juvenile Cowichan River Chinook salmon at high spatial and temporal resolution from July to October of their first marine summer. Systematic sampling of fish and biophysical oceanographic parameters at sites with differing degrees of tidal mixing and water column stratification will test whether Cowichan Chinook salmon utilize biological "hot spots." This project complements the PIT tagging based Cowichan Chinook salmon cohort survival study led by BCCF through the application of PIT tags to juvenile Chinook salmon (see above). They will also assess the feasibility of using RNA to DNA ratios as a non-lethal method to derive an index of the recent growth rate of individual juvenile Chinook salmon in the field. A controlled laboratory study will be used to calibrate the RNA to DNA ratio based growth rate index, and will also facilitate calculation of medium term PIT tagging associated mortality and tag retention estimates.

The results of this study will refine the ability of Salish Sea researchers to address two overarching hypotheses regarding juvenile Pacific salmon survival. These correspond to hypotheses 12 and 13 in US Salish Sea Technical Team (2012):

12. Food supply limits growth, and thus survival, during critical periods of early marine rearing (including Hypothesis 12c – that growth is limited by the metabolic effects of temperature); and
13. Predation on juvenile salmon (by birds, seals, and/or marine fish) has increased.

The monitoring approaches to test these hypotheses (eg. zooplankton and icthyoplankton surveys to assess food availability and predator diet and telemetry studies to assess predation pressure) are only valuable if they can be linked to habitat use by juvenile salmon in space and time. This work will test a number of specific hypotheses that will help to refine these linkages:

1. Epipelagic habitat in the Salish Sea varies at fine spatial scales (10s to 1000s of meters) in temperature profile (stratification), food (zooplankton) availability, and ability to support growth of juvenile Chinook and Coho salmon;
2. Juvenile Chinook and Coho salmon in the latter part of their first summer at sea are significantly more abundant in epipelagic habitat that supports more rapid growth (biological hotspots);
3. Juvenile Chinook salmon occupying such biological hotspots grow faster than those in lower quality epipelagic habitat; and
4. Depth distribution of juvenile Chinook and Coho salmon differs between areas with differing water temperature and degree of water column stratification, potentially reflecting trade-offs between foraging success and optimal metabolic rates.

To support field work to test the hypotheses above, they will also conduct a controlled laboratory study to assess the value of RNA:DNA ratios as an index of growth in juvenile Chinook salmon; testing the following hypotheses:

5. Accurate and repeatable RNA:DNA ratios can be obtained from juvenile Chinook salmon in their first marine summer using a non-lethal muscle biopsy;
6. These RNA:DNA ratios are strongly correlated with recent individual specific growth rates; and

7. The relationship between RNA:DNA ratios and recent specific growth rate is as strong as, or stronger than, the relationship between growth rate and insulin-like growth factor (IGF-1) concentration.

If they are successful in obtaining good RNA:DNA growth rate index data for a significant sample of PIT tagged fish, this will add value to the BCCF PIT tagging based cohort study by allowing the researchers to test if:

8. Growth rate of juvenile Chinook salmon during the latter part of the first marine summer is related to the likelihood of surviving to adulthood.

Status:

Their 2014 feasibility study and first full year of field work microtrolling for Chinook Salmon in the vicinity of Cowichan Bay (2015) identified tidally mediated areas of high CPUE in Sansum Narrows and Maple Bay.

During 2016, they expanded on the 2015 project employing a novel, non-lethal sampling methodology (microtrolling) to investigate how distribution, diet, and growth of juvenile Chinook and Coho salmon varied at fine scales in relation to spatiotemporal variability in physical and biological oceanography. They conducted 31 days of fish sampling between July and November (ongoing) in the vicinity of Cowichan Bay, with an additional two days of reconnaissance in Juan de Fuca Strait near Sooke; sampling 901 juvenile salmon (834 Chinook, 54 Coho, 4 Chum and 9 Pink salmon). They conducted physical oceanographic sampling concurrently with fish sampling; deploying temperature loggers at 5m intervals from 5 to 30 m and a light meter at 5 m on each fishing event, and conducting daily CTD casts to 90 m. Captured salmon were measured, examined for parasites, sampled for stomach contents using gastric lavage, and sampled for scales for genetic stock ID and growth trajectory analysis. Passive integrated transponder (PIT) tags were applied to 661 juvenile salmon as part of a BCCF led cohort survival study. They worked with Svein Vagle (IOS) to conduct three days of hydroacoustic surveys (200 kHz sonar and 300 kHz ADCP) through near complete tidal cycles at Sansum Narrows (2 days) and Maple Bay (1 day). They also conducted two days of intensive plankton sampling sub-hourly through the tidal cycle. Finally, they contributed to ongoing DFO seal diet studies by collecting seal scat and scanning for PIT Tags at Burial Island.

The SSMSP funded work conducted by their group in 2016 is still very much in progress. Their most recent field day was on 28 November and data analysis and processing of samples from both the field and laboratory work are ongoing. This report therefore serves as an interim rather than final project report. Field and laboratory activities in 2016 were completed successfully as described in their project proposal. Preliminary results of their 2016 field and lab work are promising, and they are confident that the final research products, combined with results of work completed in 2015, will make a valuable contribution towards the objectives of the Salish Sea Marine Survival Project.

The specific relevance of their research and preliminary results to the comprehensive list of SSMSP Hypotheses are outlined below:

Water Quality – Prey Availability

In order to understand how changes in circulation or other physical properties of the water column may have impacted juvenile salmon survival in recent decades, it is necessary to understand how the behavior of juvenile Chinook and Coho salmon interacts with water column properties to influence patterns of diet, growth and distribution. Their work is bringing together physical and biological oceanography with fish size, diet, and growth rate (circulus spacing) data at a previously unachievably fine scale. They are conducting this work within an area (the Southern Gulf Islands) that is characterized by pronounced variability in water column properties (well mixed and well stratified regions and turbulent tidal features). The lessons they learn within this study system will hopefully be applicable to the broader Salish Sea and will facilitate interpretation of likely responses by juvenile salmon to long term changes in physical and biological oceanography.

Critical Period

Their work is relevant to the critical period hypothesis on a number of levels. They are applying PIT tags in support of the BCCF led Cowichan Chinook cohort survival study, thereby contributing to a direct test of the critical period hypothesis. The data they are collecting is also valuable to help optimize sampling efforts for this cohort survival study.

Their work is also relevant to the critical period hypothesis in that they are conducting longitudinal sampling throughout a period when most other fish and oceanographic sampling projects have wound down. This is the period that precedes the second key mortality period of the 'Critical Size, Critical Period' hypothesis as outlined by Beamish and Mahnken (2001). If juvenile Chinook and Coho salmon do experience a physiologically induced mortality in the winter due to failure to achieve adequate growth during the summer, investigation of their habitat use, diet and growth through the late summer and fall could help elucidate proximate causes of this mortality.

Their preliminary results are suggesting that only individuals at the larger end of the size distribution of juvenile Chinook salmon are able to utilize young of the year (YOY) herring, the primary forage fish in their study area. Those fish that do not show evidence of piscivory are also showing evidence of slower growth (based on scale circulus spacing) raising the prospect that they could be permanently left behind by an important prey resource. The hypothesis that bottom up effects in the spring could set a growth trajectory for both juvenile herring and juvenile Chinook Salmon that could result in winter starvation of the latter nicely links the match-mismatch and critical period-critical growth hypotheses, two key foci of the SSMSP. John Dower (UVic) calls this the "Ghost of Mismatch Past" hypothesis.

Critical Growth

Their work is relevant to the critical growth hypothesis for the reasons as described in the paragraph above. In addition, by developing and validating tools for assessing recent growth of field caught fish (scale circulus spacing) they are refining the toolkit that may be used by other Salish Sea researchers to study the factors affecting growth of juvenile Chinook salmon.

Finally, by obtaining scale samples from fish that are also being PIT tagged, it may be possible to compare the recent pre-tagging growth of those fish which successfully return to the river to those which do not. This would provide a direct, albeit small scale, test of the critical growth hypothesis that was independent of absolute fish size at the time of capture.

Residency

Cowichan Chinook salmon are an example of a resident population in that they are thought to spend the whole of their first summer within the Southern Gulf Islands (Beamish et al. 2012). Understanding in detail how they utilize this habitat during their first summer at sea and comparing this to how transient populations utilize this habitat and how they perform outside it (for example data from the DFO high seas salmon survey) may help elucidate mechanisms leading to out of phase survival dynamics of resident and non-resident Salish Sea salmon populations. Their preliminary data already suggest different depth distribution for Cowichan and non-Cowichan Chinook in the Southern Gulf Islands, with Cowichan Chinook occupying shallower depths and having a diet more dominated by zooplankton prey.

Prey Availability: food supply

Their work is one of the only projects in the SSMSP to directly link prey availability to juvenile salmon presence, diet and growth. When they have completed zooplankton samples and stomach content analysis they will be able to relate prey availability to juvenile Chinook CPUE, stomach fullness, stomach contents, and recent growth for the same site and date. When combined with concurrent physical oceanographic data this may allow us to understand whether fish are seeking out certain water column attributes and what the consequences of these attributes are for their feeding success and potentially their recent growth. In turn these data will hopefully contribute to our understanding of broad spatial and temporal scale (years) patterns in food availability for juvenile salmon in the Salish Sea.

Metabolic Effects

Their work contributes to testing the metabolic effects hypothesis by directly measuring temperature at the depth, time and site of capture for all juvenile salmon. This will provide the highest possible resolution data of the temperatures actually experienced by juvenile salmon through the season from the warmest period of the year well into fall cooling and the breakdown of stratification. It will also provide evidence as to whether juvenile salmon actively select preferred temperatures. Only by understanding what temperatures the salmon actually experience can they begin to test whether current, past of future conditions may be deleterious to their growth and survival. They will be sharing their thermistor data with Dave Beauchamp so that he can assess its relevance to his ongoing bioenergetic monitoring work.

Density Dependence and Competition

Their work is seeking to understand how juvenile Chinook and Coho salmon are using their environment at fine scales in the latter part of their first summer at sea. If juvenile salmon are concentrated in areas that provide optimal foraging opportunities and/or optimal temperature strata, and/or if they are concentrated at foraging hotspots such as tidal jets, this has implications for possible competition effects. Use of limited foraging areas can result in density dependent effects that may not be detectable when prey abundance or growth are measured at large spatial scales (Walters and Juanes, 1993). Understanding fine scale habitat use is therefore necessary to interpret the likelihood of density dependent effects.

Winter Starvation

As discussed under 'Critical Period' hypothesis

Predation Intensity

Just as the use of restricted foraging areas has the potential to increase density dependent effects (see discussion above) it may also multiply predation pressure if predators key in on these areas (trophic focusing). Their preliminary results provide some evidence of concentration in optimal foraging areas. For example, a CPUE "hotspot" appears to be present in a backeddy of the tidal jet at Sansum Narrows during the late flood tide. This hotspot could be a result of vertical advection and/or horizontal concentration of zooplankton and/or forage fish which are in turn being targeted by juvenile salmon. Seals may take advantage of this concentration to prey on both juvenile salmon and forage fish.

Acoustic Tagging Studies

1. Use of Telemetry to Investigate Residence Time and Survival of Fraser River Chinook Salmon in the Strait of Georgia

Team: KINTAMA, Dr. David Welch, Dr. Erin Rechisky, Paul Winchell

Objective:

In 2016, Kintama conducted a small acoustic telemetry pilot study on juvenile Chilko River Chinook with the following objectives:

d) Provide freshwater survival estimates for Chilko River yearling Chinook smolts from release in the Chilko River to the lower Fraser River, and compare this to past published data for other species and populations originating from the Fraser River.

e) For Chilko River Chinook smolts that migrate north after ocean entry during the hypothesized timeframe, fill in the critical uncertainty regarding residence time of upper Fraser River Chinook in the Strait of Georgia.

f) For Chilko River Chinook smolts that migrate north after ocean entry during the hypothesized timeframe, provide estimated survival in the Strait of Georgia and Discovery Islands and compare to past published data (Welch et al. 2009; Chittenden et al. 2010; Balfry et al. 2011; Welch et al. 2011; Melnychuk et al. 2013; Neville et al. 2015; Clark et al. in press).

Background:

Marine survival of Fraser River Chinook salmon stocks has decreased to ~1% in recent decades and lack of information on downstream and early marine survival hampers their effective management. As part of an effort to establish an indicator stock for management of middle Fraser River summer run 5_2 Chinook salmon, the Pacific Salmon Commission provided funding to develop a coded wire tag (CWT) indicator project for Chilko River Chinook in 2014. In February 2016, Brian Riddell (PSF) approached Kintama and DFO Salmonid Enhancement Program (SEP) managers to conduct a telemetry study on hatchery reared smolts from this program which were going to be released in April 2016.

Thus, Kintama had a unique opportunity to acoustic tag and monitor these fish as they migrate downstream and into the ocean. They took advantage of this opportunity for several reasons: 1) there is a paucity of information on Fraser River Chinook migratory behavior, residence time, and early marine survival in the Strait of Georgia, 2) few populations of mid-upper Fraser River yearling Chinook salmon are presently accessible for tagging, 3) acoustic tags small enough to be used in this population are now available for use and can be detected with reasonable efficiency on acoustic sub-arrays in the Discovery Islands and Johnstone Strait, and 4) this study will provide information on post-release and downstream mortality of the 5_2 yearling summer Chinook run.

Status:

They successfully conducted a small acoustic telemetry pilot study on hatchery-origin Chilko River Chinook, using 100 acoustic-tagged smolts to 1) estimate freshwater survival, 2) investigate residence timing in the Strait of Georgia, and 3) begin to investigate early marine survival. Because acoustic receiver arrays capable of detecting smolts implanted with small 180 kHz acoustic tags only monitor the northern exit from the Strait of Georgia (SOG), residence time and early marine survival could only be potentially estimated if smolts migrated north before tag batteries expired five months after ocean entry.

Freshwater survival of acoustic-tagged Chinook to the Fraser River mouth (49%) was comparable to other populations or species which migrate the same distance downstream; however, their downstream migration rate (only 18 km/day) was dramatically slower than that of wild Chilko Lake sockeye, which migrate rapidly to the ocean after exit from Chilko Lake (100-170 km/day). Thus, Chinook smolts took more than one month on average to reach the SOG, in contrast to wild Chilko Lake sockeye which generally take under a week. It is unknown whether this behavioural difference is the result of their hatchery origin and transport to Chilko Lake.

Only one fish was subsequently detected in the SOG and none were detected exiting the SOG. Combined with the results from trawl surveys, the complete lack of detections in the Discovery Islands and Johnstone Strait suggest that Chilko Chinook do not migrate directly north after river exit. Instead, they likely remain in the SOG for at least several months.

With only a single fish detected in the SOG, they were not able to estimate early-marine survival or residence time. It is unclear if smolts eventually exited the Strait via the southern route, died during their summer residence, or simply ceased migration to reside in the SOG. This uncertainly can be resolved by either 1) increasing the number of tagged smolts released and instrumenting the southern exit from the SOG with acoustic receivers capable of detecting 180 kHz tags, or 2) capturing larger juvenile salmon in the SOG later in the season (by microtrolling or seine) and implanting them with longer-lived, low-frequency tags that are compatible with all of the receivers in the greater Salish Sea area.

2.Physiological and environmental factors affecting the migratory behaviour and survival of sockeye and steelhead salmon smolts

Team: Scott Hinch (University of British Columbia), Tony Farrell (University of British Columbia), Kristi Miller (Fisheries and Oceans Canada), and Steve Cooke (Carleton University)

Objective:

This team will combine novel methodologies (biotelemetry, biomarkers, simulation models, etc.) simultaneously to examine a variety of factors influencing the migratory behaviour and survival of sockeye and steelhead smolts in the Salish Sea.

Background:

This team will combine novel methodologies (biotelemetry, biomarkers, simulation models, etc.) simultaneously to examine a variety of factors influencing the migratory behaviour and survival of sockeye and steelhead smolts in the Salish Sea.

Using small acoustic transmitters, the behaviour and fate of Chilko sockeye (2016) and Seymour steelhead (2015) smolts will be tracked from release through the Salish Sea. The condition of these same smolts will be assessed prior to transmitter implantation and release through the use of biomarkers for pathogen presence and load, presence of immune- or stress-related responses, and growth potential, to better understand the links between condition during initial outmigration and survival and behaviour in the early marine environment. Retrospective analyses on a large database generated from ~10 years of acoustic telemetry studies will determine how migratory behaviour and survival are influenced by oceanographic conditions recorded in the Salish Sea. Lastly, individual-based models (IBM) will be developed to simulate smolt migrations by combining various movement behaviours of smolts with fine-scale ocean simulation models to provide potential migratory pathways through the Salish Sea, and a means of testing what navigation and/or orientation behaviours smolts use in the early marine environment. Together these studies will help to provide a mechanistic understanding of salmon smolt migrations to better understand trends in productivity and survival.

Status:

1) Tagging and gill biopsy sampling outmigrating smolts:

Seymour steelhead: In May 2015, 243 age-one hatchery steelhead smolts were tagged at the Seymour River Hatchery in North Vancouver and released at two locations to test route- and location-specific survival across outmigration. The early marine period was associated with poor overall survival (9-27% over 400km), and the Seymour River and Burrard Inlet were noted as regions of particularly low survival for migrating smolts. New acoustic receivers around the Discovery Islands revealed smolts showed higher use of Discovery Passage, with survival for this route being ~two times as high compared to channels to the east. Migration rates became faster and more variable through the Discovery Islands to Johnstone strait region, and complex milling patterns were noted in this region, suggesting the influence of strong currents impacting migration movements through this part of the Salish Sea. Lab work for genomics of non-lethal gill biopsies was completed in the Spring 2016, and analyses are currently in the initial phases.

Chilko sockeye: In April/May 2016, 300 Chilko sockeye salmon smolts were tagged with acoustic transmitters. 200 age-one smolts were tagged (for the first time) with Vemco V4 transmitters. An additional 100 age-two smolts were tagged with V7 transmitters. In addition, non-lethal gill biopsies were taken from 100 age-one smolts and 89 age-two smolts for use in Objective 2. They just recently were given access to detections of these smolts on marine arrays in the Salish Sea, including new arrays in the Discovery Islands and Johnstone Strait. As these data are new, all results are preliminary.

2) Assess gill biomarkers:

Seymour steelhead: 162 non-lethal gill biopsies were taken from tagged Seymour River steelhead smolts in 2015, and these were processed using genomic techniques at Dr. Kristi Miller's lab at the Pacific Biological Station (DFO) in Nanaimo in spring 2016.

Chilko sockeye: Gill clips taken from Chilko sockeye salmon smolts are currently being processed at Dr. Kristi Miller's lab, and will be completed by early 2017.

3) Conduct retrospective analyses on survival: Databases of smolt detections are being maintained. In addition, freshwater conditions (temperature and flow) during Chilko smolt outmigrations 2010-2014 have been downloaded. They are currently in the process of obtaining freshwater conditions for 2016. In addition, they are currently discussing best methods of acquiring primary productivity and zooplankton information from Drs. Maycira Costa and Ian Perry.

4) Conduct retrospective analyses on migration routes: This activity has been completed and published (see following sections 4 – 7 below for details). However, further analyses are now being completed on defining routes and route-specific survival for both Seymour steelhead and Chilko sockeye, utilizing detections on the new arrays in Discovery Islands and Johnstone Strait that were not available for the retrospective analyses.

5) Develop individual-based models (IBM): They are in discussions with Dr. Susan Allen regarding her new bio-physical model of the Salish Sea (SMELT), to determine the model's applicability to their aims, and its limitations.

Outcomes:

1) Tagging and gill biopsy sampling outmigrating smolts: This research aims to address the hypotheses "factors operate at different levels", "critical size/smolt condition," "outmigration timing," and "disease-predation" within the SSMSP.

Preliminary results from 2016 Chilko sockeye suggest that the upper Chilko and Chilcotin Rivers are a potential mortality hotspot, as well as when smolts initially enter the Strait of Georgia. In addition, it (at least qualitatively) appears that sockeye preferentially use Discovery Passage on their way to Johnstone Strait. Migration data are currently being analyzed to assess the influence of smolt size and age, microbes and biomarkers, and timing on migration success.

2) Assess gill biomarkers: This research aims to address the hypotheses "Critical size/smolt condition," "critical growth," and "disease-predation" within the SSMSP. Laboratory work was only recently completed for Seymour steelhead, and this work is currently in progress for 2016 Chilko sockeye samples. For Seymour steelhead, it appears there are links between biomarkers and survival, but data are too preliminary to give any further detail.

3) Conduct retrospective analyses on survival: N/A (in progress)

4) Conduct retrospective analyses on migration routes: This research addresses the hypotheses labeled as "factors operate at different levels," "critical size," "outmigration timing," and "residency," within the SSMSP. Migration route was found to influence subsequent survival, particularly for steelhead, indicating that area encountered is an important component of the migration experience. For sockeye, both outmigration timing (particularly Chilko sockeye) and residency were correlated with survival. For neither sockeye nor steelhead did size influence survival, albeit this might be due to the small size range of smolts tagged.

They were surprised by the proportion of both species (20-40% of sockeye and 30-50% of steelhead) that exhibited westward movements in the Strait of Georgia, evidence of "milling" by fairly large contingents of both species. Quantifying use of the Salish Sea and migration routes through it can help to identify factors influencing survival, and by using telemetry they are able to partition survival into smaller geographic areas, and thereby reducing uncertainty in the role of the marine environment.

They are still currently analyzing migration route and survival for 2015 Seymour steelhead and 2016 Chilko sockeye. For Seymour steelhead, however, they saw improved survival for smolts travelling via Discovery Passage (relative to those using Sutil Channel). This was also the route used more often by steelhead. Route taken around Texada Island (i.e. Malaspina Strait vs broader Strait of Georgia) did not impact survival, as was found in the retrospective analyses conducted across years and populations. This probably speaks to the annual variability in spatiotemporal conditions important to steelhead in the Strait of Georgia.

5) Develop individual-based models (IBM): N/A

Other studies

Elan Downey, Centre for Aquatic Health Sciences (CAHS), Campbell River

SSMSP is providing partial support to continue work on juvenile salmon ecology in Campbell River. The CAHS project focuses primarily on improving the returns of Coho reared at the Quinsam Hatchery in

Campbell River BC. There are many components including: characterizing plankton dynamics; evaluating which measured environmental indicators correlate with the timing and composition of plankton blooms; providing a program that is a tool to assist in predicting the strength or weakness of a brood year far in advance of the return so that pro-active management measures can be implemented; as well as collaboration and knowledge-transfer between governmental, non-governmental and First Nations organizations. Funds to CAHS allowed for continued plankton identification and analysis during 2015-2016.

Status:
The CAHS program is ongoing.

B. Top Down and Other Studies

U.S. and Canadian scientists agree that a unified understanding of the mechanistic association between Salish Sea bottom-up processes and juvenile salmon survival is vital. However, LLTK, PSF and affiliated scientists have initially determined that less U.S.-Canada alignment may be of value when investigating the multitude of other factors that may be contributing to juvenile salmon mortality in the Salish Sea. To more broadly evaluate these factors, the U.S. and Canadian scientists will have more flexibility to focus on specific species, approaches, geographic areas, and distinct survival drivers. The results will then be shared, incorporated into cumulative factors and other comprehensive analyses, and will inform next steps in research on both sides of the border.

The Canadian major top-down studies for 2016 include assessment of the impacts of seal predators on juvenile coho and Chinook, analysis of the spatial and temporal occurrence of harmful algal blooms, and an examination of microbe loads on juvenile salmon. Additionally, the Canadian side are carrying out some hatchery manipulation studies, involving alternative times of release of Chinook into the Strait of Georgia.

Top-down studies in the US have focused on contaminants for Chinook (PSC funding), and beyond the Southern Endowment funded work, contaminants, disease and predation as part of a comprehensive, predominantly top-down Puget Sound steelhead marine survival research effort, funded with Washington State appropriations.

B1 Disease & Health- Canada
Team: Kristi Miller-Saunders (DFO-PBS), Karia Kaukinen (DFO-PBS), Amy Tabata (DFO-PBS)

Objective:
The main objective of the Strategic Salmon Health Initiative (SSHI) is to determine what pathogens/diseases, if any, may be undermining the productivity and performance of BC salmon, their evolutionary history, and the potential role of exchanges between wild and cultured salmon.

Background:
Samples collected from the juvenile sampling study (described above) are used for a variety of physiological and genomic studies, involving a number of researchers from UVic and DFO.

Researchers are using novel genomic approaches that utilize the activity of the genes to conductphysiological assessments to identify potential stressors and diseases impacting salmon and apply quantitative assays to monitor dozens of infectious agents to identify viruses, bacteria and microparasites undermining salmon health and survival. The sampling program utilizes a trajectory from freshwater through the first 9 months of marine residence, and thus the conditional state of fish can be monitored even before they enter the Salish Sea. Prior analyses have suggested that salmon pre-condition can be highly predictive of survival as they move into new stressful environments.

In the previous phase of the project, the team developed and analytically validated a high throughput molecular-based infectious agent monitoring platform to detect and quantitative 46 pathogens known or suspected to cause disease in salmon world-wide simultaneously in 96 fish. This platform is being applied to over 26,000 wild, enhancement hatchery and aquaculture salmon in the current phase of the project (2b) to discover the microbes present in BC salmon and their spatial and temporal distributions within and among species and cultured and wild stocks. Multiple metrics to assess physiological and organismal impacts are being merged with the microbe data to discern the pathogenic potential of each microbe.

Status:

Phase 2b funding from Genome BC was signed off in April 2016, and research has progressed quickly. In May, the SSHI team announced the novel finding of Heart and Skeletal Muscle Inflammatory (HSMI) disease on one of the four salmon farms that were sampled over the entire ocean production cycle by the SSHI researchers. While the disease was diagnosed using the world-recognized pathological standard of inflammatory lesions in heart and skeletal muscle tissue, the researchers were also able to show that, as in other parts of the world, piscine orthoreovirus (PRV) was associated with the disease both statistically and through its distribution within the tissues and infected cells, and that clinical signs of the disease were also present. A manuscript on this finding, led by PSF-supported veterinary pathologist Emiliano Di Cicco, is now in the final stages of review for publication. PRV has been the subject of an ongoing court case, and these data are now being carefully examined by policy makers within DFO.

The SSHI team obtained 900 samples of farmed salmon through the DFO Audit program, and has completed the infectious agent monitoring and histopathology data collection on these fish; these data are now being analyzed by Postdoctoral fellows (supported by PSF and MITACS) conducting epidemiological research at University of Prince Edward Island (UPEI) to identify linkages between infectious agents and pathology on farms. One finding of note is a higher incident and diversity of infectious agents observed in farmed Chinook versus farmed Atlantic salmon.

A smolt out-migration study was undertaken encompassing infectious agent monitoring of >1,800 Chinook Salmon and is presently being analyzed and incorporated into a manuscript. The manuscript will describe potential pathogens infecting outmigrating Fraser River Chinook smolts emanating from freshwater hatcheries and transmitted in the early marine environment (first 9 months) and will show that half of the 32 microbes detected originated in freshwater. Moreover the study identifies a half dozen microbes that show seasonal shifts in prevalence and load in the ocean consistent with the potential for impact on the migratory salmon.

A study linking acoustic tracking and microbe and host transcription profiling funded through NSERC co-funding found that Sockeye smolts with enhanced anti-viral immune activation and infection with the IHN virus suffered high migratory failure during early down-stream migration (Jeffries et al. 2014). A follow-up study was undertaken and showed that fish carrying the IHN virus were 34 times more likely to be eaten by resident bull trout in the clear waters of the Chilcotin River, which may explain the early high losses associated with this virus; this work is part of a PhD thesis being defended in July 2016. A similar study on predation by Rhinoceros Auklets also carried out by the team also showed that infection status was associated with increased risk of predation. Together, these data suggest that 1) predators may increase the overall health of salmon populations by removing infected individuals and reducing risk of transmission, 2) sub-lethal impacts of infection that impact salmon performance (e.g. swimming, schooling, behavior, visual acuity, etc) likely puts them at greater risk of predation, perhaps even during early stages of disease development, and 3) if predators preferentially remove infected individuals, it will be quite rare to sample migratory fish in a late-stage of disease, making it very difficult to utilize classical diagnostic approaches to understand disease impacts on wild fish.

With co-funding from the DFO Genomic Research and Development Initiative, the SSHI team has added to their arsenal of host biomarkers a panel of genes that together can predict the development of a viral disease (VDD) state and can distinguish fish that are latent carriers of salmon viruses from those that are undergoing active, disease causing infections. This VDD panel has been validated to work across multiple viral species, salmon species, and salmon tissues, and can even predict the presence of a systemic viral disease state based on sampling of non-destructive gill tissue. Moreover, it works in the presence of numerous co-infecting organisms and can distinguish viral from bacterial infections. This disruptive technology moves the molecular monitoring program of the SSHI from pathogen detection to disease detection and will be expanded to recognize bacterial disease states and those brought on by different classes of microparasites.

B2 Harmful Algal Program - Canada

Team: Svetlana Esenkulova (PSF), Nicky Haigh (HAMP)

Objectives:

To determine the prevalence of harmful algal blooms in the Strait of Georgia and their impact on juvenile salmon.

Background:

The harmful algae program was developed during 2014 with a pilot study in Cowichan Bay. This program is now fully implemented with collections of phytoplankton taking place throughout the Strait of Georgia in the citizen science program. Samples are being collected from stations from February to November, primarily from surface waters, but at a number of depths (surface, 5, 10, 20m) from 3-4 priority stations. Phytoplankton data collected are biomass estimation, identification and enumeration of dominant species, % of constituent groups (diatoms, dinoflagellates, silicoflagellates, raphydophites, nanoplankton, zooplankton), and identification and enumeration of all harmful algae. The water quality data collected concurrently with the phytoplankton samples will be used to determine the conditions that appear to promote the development of harmful algal blooms.

Lab studies to assess the conditions that promote development of harmful toxins are currently under development. The field project may be augmented in 2016 with studies to assess whether juvenile fish are able to actively avoid blooms in marine waters.

Status:

Based on thousands of samples (collected bi-monthly from February to October at ~80 sites) in 2015 and 2016, they have unprecedented, high-resolution data on phytoplankton dynamics in the Strait of Georgia. Phytoplankton biomass and composition were strikingly different in 2015 and 2016, and appear to be closely associated with nutrients and environmental parameters. There is a clear synchrony in phytoplankton dynamics across the Strait, however it differs significantly on location-scale. They observed effects of harmful algae on juvenile salmon in Cowichan Bay in 2014, 2015, 2016 and the effects were consistent with these confirmed on salmon farms in BC and papers worldwide.

2015

An unusually early spring phytoplankton bloom in 2015 was associated with higher than normal water temperatures in the Strait of Georgia and early snowmelt. Lower summer biomass and dominance of diatoms (low dinoflagellates contribution, silicoflagellates, and raphidophytes) were associated with lower than usual river discharges and rainfall in summer. The year of 2015 was unusually quiet in terms of harmful algal blooms: there were no toxic blooms to salmon throughout the sampling period; moderate and high levels of *Chaetoceros convolutus/concavicorne* (mechanically harmful to salmon) were observed in Cowichan Bay, Baynes Sound, Campbell River, Lund, Powell River, and Irvines Sechelt at the end of May and beginning of June.

2016 (ongoing)

In 2016, the spring bloom was recorded several weeks later than in 2015; it was comprised by a mixture of species (*Thalassiosira* spp., *Skeletonema costatum*, *Chaetoceros* spp.), whereas the spring bloom of 2015 was comprised mostly by one species (*Skeletonema costatum)*. The phytoplankton composition (in terms of groups: diatoms, dinoflagellates, etc.) in 2016 was more normal then in 2015. The year of 2016 was somewhat unfavorable in terms of harmful algal blooms: there were elevated levels of non-skeletal *Dictyocha* (toxic to salmon) observed after periods of heavy rains in some areas, moderate blooms of *Rhizosolenia setigera* (mechanically harmful), low-moderate levels of *Heterosigma akashiwo* (toxic) in few areas in late August/early September samples. There were several non-harmful blooms (*Ditylum brightwellii*, coccolithophores) observed in summer.

Outcomes:

- High-resolution, in situ data on phytoplankton dynamics in the Strait of Georgia, 2015 and 2016, provided a solid foundation for understanding bottom-up control of zooplankton and herbivories fish dynamics (bottom-up control for salmonids). With an additional data from 2017 (a year not affected by El Nino), it will be possible to establish a statistically significant links between phytoplankton and environmental characteristics in the SoG. Having enough zooplankton data, will enable to investigate environment-phytoplankton-zooplankton relationship and (in cases when zooplankton sampling is limited) to anticipate/forecast trends of juvenile fish food abundance based on environmental/phytoplankton data.
- Studying effects of harmful algae on wild juvenile salmon in the Cowichan Bay 2014-2016 (top-down study) provided a body of evidence that wild salmon is negatively affected by harmful algae in the same way as the aquaculture salmon in BC (harmful algae directly affect salmon survival: toxic algae through acute or chronic toxicity and mechanically harmful algae through gill damage).
- Unexpected outcomes: juvenile salmonids significantly reduced feeding and their diets were somewhat unusual during high biomass (very thick) non-harmful blooms.
- Collected data, observations, and analysis of phytoplankton dynamics (including harmful algal blooms) could potentially increase hatchery salmon survival through timing of the hatchery releases with favorable phytoplankton conditions. Continuing phytoplankton monitoring program (e.g. Citizen Science Program or smaller scale program in important to juvenile salmon areas) provides information (both bottom-up and top-down in terms of phytoplankton effects on juvenile salmon) that can improve the accuracy of adult returns forecasting and reducing uncertainty around the role of the marine environment in overall productivity.

B3 Predation Studies- Canada

Predation by Harbour Seals on Salmon Smolts — Study Completion

Team: Dr. Andrew Trites, UBC; Dr. Austen Thomas, Smith-Root,; Sheena Majewski, Pacific Biological Station; Dr. Ruth Joy, SMRU Consulting; Dr. Dom Tollit, SMRU Consulting

Objective:

To determine the prevalence of juvenile salmon, particularly coho and chinook, in the diets of seals in the Strait of Georgia, and to clarify the impact that the current seal population is having on coho and chinook populations.

Background:

High rates of predation by harbour seals on salmon smolts may explain the decline and lack of recovery of coho and Chinook salmon in the Salish Sea. They have tested this hypothesis using models to estimate predation rates from the frequency of occurrence of smolt remains contained in the faeces of harbour seals in estuaries. They also directly measured predation near Big Qualicum River by capturing 20 adult harbour seals and equipping them with biologging tags. Preliminary results indicate that 20% of harbour seals in the Strait of Georgia may be eating over half of the smolts that enter these coastal waters. These high rates of predation require validation using additional diet data from non-estuary sites, and an independent method to reconstruct diets. Foraging behaviours of the few seals they recorded exploiting smolts also needs further investigation to determine whether these individuals used specific foraging strategies targeting smolts, or whether they were behaviorally no different from the seals that did not consume smolts. They will assess behavioural differences using the 3D accelerometry data recorded by the 20 tagged seals, and will address major uncertainties in their estimates of predation by collecting additional seal scats in 2016 from non-estuary sites. They will also compare their 2016 estimates of diet derived from DNA metabarcoding and hard-part frequency-of-occurrence with a third method—biomass reconstruction. This research will complete their study and ensure robust estimates of predation and a fuller understanding of the predatory behaviour of seals — information that is needed to design mitigation strategies.

The long-term goals of this research are to 1) estimate the numbers of chinook and coho smolts consumed in the Strait of Georgia by harbour seals, 2) evaluate their impact on salmon recovery, and 3) propose ways to mitigate the impact of seals.

The short-term objectives of the 2016-2017 project are to 1) address major uncertainties in their estimates of predation in terms of where scats were collected and the methods they used to reconstruct diets, and to 2) complete their analysis of the foraging behaviours of seals that eat smolts and those that do not to identify ways in which predation risk might be reduced. These studies will ensure robust estimates of predation and will provide a fuller understanding of the predatory behaviour of seals — information needed to design mitigation strategies.

The 2016-2017 work plan includes the following:

- Collect harbour seal scats every two weeks for 8 months from 5 sites (April – November 2016)
- Undertake DNA analysis and measure size of salmon otoliths recovered from 2016 harbour seal scats
- Compare 2016 diet findings with samples collected in previous years from estuaries to determine if diets vary significantly by region in the Strait of Georgia
- Recalculate estimates of mortality on salmon smolts caused by harbour seals in the Strait of Georgia
- Compare *biomass reconstruction* estimates of diet for 210 samples collected in 2016 with estimates obtained using two other methods—frequency of occurrence and DNA metabarcoding

• Assess the biases of the three diet reconstruction methods (from simulations and data), and recalculate (if necessary) estimates of mortality on salmon smolts caused by harbour seals in the Strait of Georgia
• Process the acceleration data collected by the 20 tagged seals using specialized animal behaviour software to determine and compare time-activity budgets between seals that ate smolts and those that did not
• Calculate the foraging efficiencies of the two groups of seals to assess whether targeting smolts is energetically beneficial or inconsequential
• Assess whether seals that feed on smolts employ specialized foraging strategies or are behaviourally not different from the seals that do not consume smolts—and identify mitigation strategies that could be employed to reduce predation risk on salmon smolts.

Status:
During 2016, they completed the main sample collection phase of the project. The samples are currently being processed for genetic and hard parts analysis with the goal that analysis can start in February.

In total, 1176 Harbour seal scats were collected at "non-estuary" sites throughout the SOG, and 407 at estuary sites (Cowichan Bay). The collection sites varied somewhat from those initially proposed due to sample availability and logistics but they were able to get good spatial and temporal coverage. They are planning to collect more sample next spring to address concerns over lower sample numbers in April/May and will run the samples collected in April/May 2015 during the tagging study to increase their spring sample numbers.

Overall progress was as follows:

- Setup of field sampling program for diet study, including reconnaissance for suitable sites. Completed first season of sample collection.
- Collected 1176 samples between May and November at non-estuary sites and 407 at estuary sites (Cowichan Bay) to extend the existing time series of estuary site data.
- Their main challenge was low sample availability during the spring due to a combination of seal behavior (less time spent hauled out than during pupping and moulting later in the sampling period) and tide/weather conditions (samples more likely to be washed away by tides and rain and fewer possible sample days due to high winds). To address the lower numbers of spring samples they adjusted their sampling locations to include better spring collection sites; they will also include samples collected in April/May 2015 during tagging near Little Qualicum in their analysis, and conduct additional sampling in April/May 2017.
- Locations of collection sites were adjusted based on ground truthing and PSF input; they extended their coverage to additional sites and collected sea lion scats when present.

B4 Nearshore Habitat Studies- Canada

Spatial temporal distribution of Nereocystis luetkeana (bull kelp) and use by juvenile salmonids in the Salish Sea

Team: Maycira Costa, UVic; Nikki Wright, SeaChange Marine Conservation Society; Leanna Boyer, SeaChange Marine Conservation Society; Sarah Schroeder, Graduate student, UVic; and various collaborators

Objectives:
The objectives of the expanded full project for 2016-2017 are: (1) to define the surface extent of bull kelp beds by using satellite imagery (present and historical) associated with sea-kayak surveys for several

regions of the Gulf Islands (Salt Spring, Saturna, North and South Pender, and Mayne), and Comox and Cowichan estuaries, in collaboration with several environmental stewardship community organizations and First Nation groups. (2) To initiate a robust study on the use of kelp habitat by juvenile salmon in the Salish Sea.

Background:

Kelp, specifically *Nereocystis luekeana* (bull kelp), form extensive forests in rocky habitats along the subtidal zone of the coast of British Columbia. Kelp forests provide important habitat for juvenile salmon attracting their preferred food and providing protection from predators. Of particular interest to the Salish Sea Marine Survival Project (SSMSP), kelp habitats have been shown to provide optimal feeding and refuge conditions for Chinook and Coho in the Strait of Juan de Fuca (Shaffer, 2003). Declines of Cowichan juvenile Chinook are largely attributed to their high mortality within the first four months in the southern Gulf Islands. One method of improving Chinook production is to find a way of improving kelp production (Beamish et al. 2011). However, there is a dearth of information of the existing populations and distribution of these kelp habitats in the southern Gulf Islands. As such, the need for kelp bed distribution for the Salish Sea was one of the main data gaps identified at the Salmon Habitat meeting in July 2014. Other research initiatives related to this proposal are the successful Kelp Mapping project using Satellite Technology and the Estuarine and Coastal Restoration in the Salish Sea.

At present, the majority of kelp mapping is conducted manually via transects and aerial photography. Though effective, the strategy is labour-intensive, requires large time investment, and is limited by the areas surveyed. During 2015 Costa et al. carried out a successful short pilot project (3 months) to evaluate and define methodologies to use satellite imagery (present and historical) to map the aerial extent of kelp beds on BC coastal waters. The 2015 pilot project is now finished and the full project goal for 2016-2017 is to apply the developed methods to the BC coastal waters and work together with local communities and First Nations in collaboration with SeaChange to improve data collection and the use of satellite imagery.

Status:

This project was begun in early summer 2016 with a new MSc graduate student, Sarah Schroeder, in the Costa Lab. In the summer of 2016 an intense field survey was conducted in Cowichan Bay, Mayne Island, and Pender Island in collaboration with SeaChange and local communities. Satellite imagery from Spot 7 (6 m spatial resolution) and WorldView 3 (2 m spatial resolution) satellites were acquired at the time of sea kayak field survey. Further, after receiving the acquired imagery, a second phase of field survey was conducted in August/September to better characterize the main nearshore habitats.

Digital manipulation of the WorldView 3 image shows a strong ability to map kelp beds. The DigitalGlobe historical archive was surveyed and images acquired from 2004 to present will be requested for free as part of a submitted application to DigitalGlobe.

Imagery analysis is ongoing as is the kelp bed sea kayak survey processing.

The next steps will focus on data integration with the other nearshore habitat projects. Also, planned collaboration with Hakai Institute will allow this project expand to a larger spatial scale, which is required to understand the health of the nearshore habitat in the BC coast. This will be important to understand trends in the large-scale distribution of kelp habitats, which are known to provide shelter and food to numerous species including Coho and Chinook salmon. This project may provide the scientific basis to quantify changes in a long temporal scale, which are deemed important for understanding environmental dynamics and provide rationales for regulations.

Evaluating seagrasses as habitats for juvenile salmon

Team: Laura Kennedy, MSc student, UVic, Dr. Rana El-Sabaawi, UVic, Dr. Francis Juanes, UVic.

Objectives:

To determine the impact of eelgrass density on invertebrate communities, and to determine the importance of prey originating from eelgrass ecosystems to juvenile salmon diets.

Background:

The primary goal of the SSMSP is to identify the most significant factors affecting the marine survival of juvenile salmon in the Salish Sea marine environment. Currently, they do not understand how juvenile salmon in the Salish Sea use nearshore environments in their early marine life, and how habitat complexity, degradation, or restoration of nearshore environments affects the availability of important juvenile salmon habitats. Shore development and climate change have led to the loss and degradation of nearshore ecosystems including seagrasses, which have been shown to be critical for juvenile salmon in many coastal ecosystems. The goal of this study is to assess the value of seagrass ecosystems as foraging grounds for juvenile salmon, and to quantify the effects of seagrass damage and restoration on the availability of high quality salmon diets.

Status:

Ms. Kennedy's project had two objectives: 1. to compare the availability of invertebrates along a gradient of seagrass health, and 2. to assess whether seagrass meadows provide prey for juvenile salmon. A pilot in the Cowichan Bay estuary showed that the seagrass habitats in the bay were not suitable objective 1 (no discernable seagrass gradients, and most meadows only accessible using snorkeling surveys). As a result, her sampling location was moved to the Comox estuary, which has a high abundance of accessible seagrass habitat containing a gradient of dense to sparse beds.

Laura has now successfully completed her MSc at the University of Victoria. Her study showed that eelgrass habitat supported a variety of prey items for juvenile salmon. Prey abundances increased with increasing eelgrass abundance, but did not change in composition across eelgrass density. Juvenile Chum and Chinook salmon diet was dominated by approximately 80% of benthic diet items, all found in eelgrass habitat, supporting the hypothesis that eelgrass habitat can provide foraging grounds for juvenile salmon. Juvenile Chum salmon isotope signatures closely reflected those of eelgrass invertebrates, indicating juvenile Chum salmon utilized eelgrass invertebrates from the Comox Estuary, BC.

Lessons learned include:

- Eelgrass habitat may provide important foraging grounds for juvenile salmon. Higher-density eelgrass habitat provides increased prey abundance, but even sparse habitat may be an important habitat feature, as it may provide a unique invertebrate community targeted by juvenile salmon.
- Eelgrass habitat should be protected in near-shore habitats, especially those frequented by juvenile salmon, or close to salmon-bearing streams. Restoration practices should continue, with increased monitoring of the status of natural and restored to better understand how the success of these habitats can influence juvenile salmon feeding.

This project reduces uncertainty around the role of near-shore habitat for juvenile salmon. Specifically, it indicates that the conservation of eelgrass habitat may protect foraging opportunities for juvenile Pacific salmon during a vulnerable life history stage, when growth is critical.

Estuarine and Coastal Restoration in the Salish Sea

Team: Nikki Wright, Executive Director, SeaChange Marine Conservation Society, Leanna Boyer, B.Sc., M.A. Jamie Smith, WCB SCUBA diver, photographer, videographer, Justin Bland, WCB SCUBA diver, Sarah Verstegen, WCB SCUBA diver, dive tender, SeaChange Operations Manager, Keith Erickson, R.P. Bio, Galiano Conservancy Association, Anuradha Rao, B.A.Sc., M.Sc., R.P. Bio., David F. Polster, B.Sc., M.Sc., R.P. Bio. , Doug Biffard

Objective:

The purpose of this project is to continue to restore estuarine and coastal ecosystem resiliency and health in the Salish Sea for all species of salmonids and the marine food web upon which they depend.

Background:

This project is part of the bottom-up approach to improving food webs and nearshore habitats for juvenile salmon within the context of the Salish Sea Marine Survival Project. Eighteen sites are presently monitored for transplant density and coverage.

For 2015 and 2016, the goal was to continue and expand this work. Three new components to the project will be added. The first is to add monitoring devices within their transplant sites to understand such parameters as annual sediment flows, water velocities, light availability and temperature. The second is to restore nearshore riparian vegetation in areas identified as critical nearshore marine habitats for juvenile salmon. The third is to begin research through a local university or college on mitigation methods that can be utilized to increase eelgrass growth in former log boom areas on a small landscape scale.

Sites so far identified for the above works are the Cowichan Estuary and Genoa Bay, Squamish River Estuary, Salt Spring Island (Burgoyne Bay), and Burrard and Sechelt Inlets. Video footage will be taken of all monitored and newly transplanted sites.

Eelgrass and riparian vegetation will be mapped in areas considered critical nearshore and coastal nursery habitats for salmon in the southern and central areas of the Salish Sea. Restoration of eelgrass (*Zostera marina*) will continue using a well- established science based methodology. Riparian shoreline areas will be restored where feasible. Environmental indicators used to gauge the project's success will include the number of potential restoration sites located through inventories, area increase in eelgrass habitat as measured in meters square, measurement of transplanted eelgrass shoot densities and metres square of nearshore riparian areas restored.

Activities in all locations will be conducted in consultation with First Nations. Where possible, training in habitat mapping and restoration will occur in these communities to increase capacity to conserve nearshore marine habitats. Presentations, field tours and school programs focused on the high value of nearshore salmonid habitats will continue to be an important stewardship component of this project.

Status:

Eelgrass (*Zostera marina*) restoration and conservation in the Salish Sea aligns with the SSSMSP objectives by 1) identifying management actions to increase the survival of Salish Sea wild and hatchery salmon and steelhead, and 2) reducing uncertainty of the role of the nearshore marine environment for salmon and steelhead survival. The project addresses both objectives by monitoring all critical nearshore salmon habitats of eelgrass transplant sites every 6 months for area extent and shoot density, monitoring water quality, sediment characteristics and quality, and advancing research of organics in sediments that might be limiting factors for eelgrass survival in former log storage areas.

In 2015, seven transplants were undertaken; totaling 581m², and four marine riparian areas were restored. In 2016, eleven transplants were completed, totaling 866m². Three of the eleven sites are in BC Provincial Parks, as backshore development threats are reduced through protected area designation.

Because there is a dearth of research data about the limiting factors of the impacts of log storage on these impacted marine subtidal environments to salmon habitat, a student was recruited, under the supervision of Dr. Leah Bendall, (Dept. of Marine Ecology and Ecotoxicology Simon Fraser University) to research levels of organics and sulfides in sediments affecting eelgrass productivity.

Eelgrass conservation activities included presentations during conferences and to municipalities and the public. Eelgrass surveys were undertaken in Boundary Bay, in collaboration with Friends of Semiahmoo Bay, and the Oak Bay Municipality. Maps were created of both areas to use for education and developing public policy conservation actions.

Monitoring data from 2014 through 2016 of all 23 transplant sites will be posted on the Strait of Georgia Data Centre. Video, photos and data are presently being collated and will be placed on a Google platform to make the restoration story and its relevance to salmon survival accessible to the public.

Leveraged funding for 2015-16 totaled $313,620.

A new collaboration was developed with the Hakai Institute so that research, especially that which can be applied in the field to improve conservation and can be shared amongst researchers and practitioners.

Summary of key results:

- A total of 9,238m² of eelgrass habitat was restored during 2015-6. Site locations included Sechelt , Burrard and Saanich Inlets, Cowichan Bay (Genoa Bay), Maple Bay, Squamish, Mill Bay, Pender and Mayne Islands, and three sites within BC Parks (Montague Harbour, Wallace and Gambier Islands).
- Four marine riparian areas (Tod, Burrard and Sechelt Inlets and Mayne Island) were re-vegetated to increase salmon feeding grounds and forage fish spawning areas on the nearshore.
- HOBO units and sediment traps were installed in Genoa and Mill Bays and Squamish estuary; sediment samples were collected from 23 transplant sites.
- 50km² was mapped in Boundary Bay and an Eelgrass Report was produced for the Municipality of Oak Bay after eelgrass habitat was mapped surrounding the township.
- A total of 170 community volunteers of all ages participated in restoration activities.
- Over 2500 people heard about the value of eelgrass habitats to salmon survival during several conferences, presentations and public tours. Educational brochures were produced in partnership with Parks Canada.
- Videos of all "before and after transplant" sites are available for viewing.
- SeaChange is participating in the newly rejuvenated Burrard Inlet Water Quality Working Committee as they feel they can contribute to improving water quality for salmon through restoration of eelgrass habitats and water quality monitoring.

Habitat and spawning surveys for surf smelt and Pacific sand lance in the Salish Sea.
Team: Ramona C. de Graaf, BSc. MSc., Jackie Woodruff, GPS/GIS Manager

Objectives:

Objectives of this work are to:

4. Determine the spatial extent of spawning habitat and suitable habitats for surf smelt and Pacific sand lance in the Salish Sea
5. Protection of forage fish resources (secondary capacity) in the Salish Sea
6. Development of operational statements and best management practices for forage fish spawning/rearing habitats and marine riparian habitats for local government and stakeholders.

Background:
Sea Watch society's projects focus on the declining habitat quality for two key forage fish species, surf smelt and Pacific sand lance, and coastal marine rearing habitat for juvenile salmon.

These projects seek to advance the goal of the SSMSP to support the recovery of wild salmon and sustainable fisheries by identifying major factors affecting the survival of juvenile salmon in the Salish Sea by undertaking research activities that protect and restore critical salmon habitats. Critical salmon habitats include those habitats that support spawning and rearing of prey species vital to salmon recruitment as defined by WA State ecosystem-based management principles for forage fish management and the BC Wild Salmon Policy.

Along shoreline units that have been heavily degraded, restoration/enhancement recommendations will be made to aid habitat restoration projects to recover and protect declining Strait of Georgia surf smelt stocks, protect Pacific sand lance spawning habitats, and enhance juvenile salmon coastal rearing habitats. The maps and data will also assist in allocation of oil spill remediation resources. Such a project is vitally important to protect and conserve critical marine fish habitats within the project locations.

Status:
Spawning Surveys by Sea Watch and Community Monitoring Efforts have been carried out for over 10 years. In total, approximately 280 beaches monitored. Of these, 50 are positive for Pacific Sand lance, 52 for Surf smelt, and 4 mixed Surf smelt/Pacific sand lance. Over 30km of spawning beds have been monitored. In addition, studies have been underway to elucidate the Surf smelt spawning stock structure- both in the summer, winter and year-round. Strait of Georgia Surf smelt spawning stock structure is similar to that in Puget Sound with summer, fall/winter and year-round spawning. Work continues to define the geographic boundaries and/or overlap of these stocks within the Strait.

With respect to the Forage Fish Spawning Habitat Suitability Model, 12 Islands Trust islands have been completed and project is ongoing with 3-4 islands being undertaken for 2017-2018. The Lower Mainland project consists of Howe Sound; English Bay/Burrard Inlet; and Delta/Surrey. The Howe Sound project was delayed and will recommence in 2017. The other components of the Lower Mainland project have been completed.

Working with partners in Puget Sound, a beach condition model has been completed. The matric allows for the consistent assessment and scoring of marine shorlines as to their current condition (health) of marine shorelines which are important as spawning/rearing habitats for Surf smelt, Pacific sand lance and neustonic insect prey for juvenile salmonids. This model has been applied to English Bay/Burrard Inlet. A technical report and potential journal publication of the model is being pursued with project partners.

Other areas of progress include the development of the English Bay/Burrard Inlet Surf smelt Habitat Technical Review and Restoration Plan. This Plan will provide science-based recommendations to

- Protect critical forage fish resources
- Prioritize marine shoreline habitat Prioritize restoration areas

- Model the impact of sea level rise on setting conservation targets
- Prioritize enhancement of marine riparian vegetation

Further Case Studies will include Denman Island and the Capital Regional District.

Eelgrass and Kelp Restoration

Restoration Research on Kelp Forest Habitats in the Salish Sea

Team: William Heath, Ph.D (Nile Creek Enhancement Society & Project Watershed Society); Sherryl Bisgrove, Ph.D (Simon Fraser University), Braeden Schiltroth (MITACS student SFU)

Objectives:

Objectives of this project include the following:

1) Estimate the extent of kelp forest cover/loss in the northern Salish Sea in recent decades and identify sites in need of restoration that would be of benefit to juvenile salmon
2) Identify kelp stocks capable of growing at sites with stressful conditions (high temperature and/or low pH) by correlating sites that have retained kelp with recorded oceanographic conditions available from online databases (e.g. lighthouse SST databases on DFO Pacific website).
3) Compare bull kelp growth and survival, faunal (fish and invertebrate) presence and detailed oceanographic conditions at 5 experimental sites and at a reference site.
4) Examine the effect of density thinning of sea urchins on kelp abundance at a monitoring site.

Longer term objectives:
1) To identify sources of thermal stress-resilient genetic stocks of bull kelp (*Nereocystis luetkeana*) in the Salish Sea that can be grown in significant quantities to restore historical kelp beds as habitat for refuge and feeding of juvenile salmon.

Background:

This project is aimed at restoration research on critical nearshore bull kelp habitats for use by juvenile salmon in the Salish Sea. It builds upon and extends the findings of research funded by the SSMP in 2015 (Heath et al. 2015) which has established: 1) an experimental system for environmental sampling as well as planting and analysis of bull kelp performance in the field; 2) the role of prolonged warm temperatures (>16C) and herbivore grazing in restricting bull kelp survival; and 3) methods for assessing stress-resiliency of bull kelp populations.

In 2016, the extent of kelp forest cover/loss in the northern Salish Sea in recent decades will be estimated and sites will be identified for potential restoration that would be of significant benefit to juvenile salmon.

The experimental kelp system will be used to compare the growth and survival of bull kelp originating from Sansum Narrows (S. Gulf Islands) and Campbell River areas at 5 planted sites. At a long-term monitoring site on S. Denman Island, thinning of red and green sea urchin densities will be examined as a treatment for restoring a natural kelp bed that has diminished, but persisted.

Status:

Diving observations and sonde casts were conducted on February 22, March 29, May 2, 24 and 25, June 11, 27, July 23, 24, August 16 and October 10, 2016.

The growth of the bull kelp was excellent (2-5m) at the Maude Reef grid and outer sites, but slower at the other sites, following the pattern observed last year. They noted some *Nereocystis* settlement and growth on their mooring lines at three sites. They also found a culture line at Cape Lazo shoal that had broken loose at one end, but was heavily stocked with “wild” bull kelp. Development of the kelp plants proceeded to maturity with sori production at Maude and Cape Lazo sites during June and July, lasting until October 11 at Maude Reef outer site (last visit). Water temperatures remained in a favourable range (under 18 C) during this period, in contrast to conditions in 2014 and 2015.

Genetic samples for a collaborative population genetics study with Dr Filipe Alberto were collected from seven sites, including three of their experimental sites, as well as Sansum Narrows, Quadra Island, Stanley Park and northeast Vancouver Island. Preliminary results regarding genetic variability of bull kelp populations from California to Alaska suggest that the populations in the central Strait of Georgia are genetically different from those in the Strait of Juan de Fuca. Using sea surface temperature data from NOAA’s thermal satellite imagery they identified a large “hot zone” in the central Strait of Georgia and a “cold zone” in the Strait of Juan de Fuca. Kelp collected from two sites situated in the cold (French Beach) and warm zones (Stanley Park) zones are now being tested for thermal tolerance in the lab at SFU. Additional sites of future interest include: Stanley Park, Comox/Denman Island, Campbell River, Mayne Island, Sansum Narrows, Victoria, and French Beach near the Jordan River in the Strait of Juan De Fuca. Preliminary testing revealed that spore release was higher from reproductive sori collected form Stanley Park, compared to French beach. Additionally, they found that gametophyte development differed during exposure to warm (20°C) and cold (10°C) temperatures for both Stanley Park and French Beach populations. Finally, they are collaborating with Rob Underhill and Stephanie Hurst of the Mayne Island Conservancy Society who have been monitoring kelp populations around Mayne Island. This area represents a site where kelp is exposed to temperatures that are slightly cooler that Stanley Park but warmer than sites in the Strait of Juan de Fuca.

Eelgrass and Kelp Restoration, Courtenay (K’omoks) Estuary

Team: Kathryn Clouston, Comox Valley Project Watershed Society

Background:

Bull kelp (*Nereocystis luetkeana*) and eelgrass beds (*Zostera marina*) are productive ecosystems for salmonids, hosting a myriad of marine plant and animal forms. These critical ecosystems have been reduced in size thus limiting foraging and refuge areas due to many negative impacts. This group initiated the mapping of existing and historical eelgrass and kelp beds in the K’omoks Estuary using high resolution digital aerial photos and interviews from elder residents. This has allowed identification of sites with a high probability for recolonization.

In cooperation with the Nile Creek Enhancement Society, Project Watershed plans to put in a 60 m^2 kelp bed using a 15 m seeded line outplanting in the subtidal area near the proposed eelgrass bed being planted this summer providing valuable additional habitat for all types of salmonids as well as some forage fish and other species.

Expected results include:

1. Increase subtidal eel grass habitat area for juvenile salmonids and spawning herring by 1000 sq. m. / 2015
2. Monitor the three previous eelgrass transplants near Royston Wrecks and continue monitoring and assessing success / 2015 – 2016

3. Planting of 60m^2 seeded kelp line at Royston wrecks area for bull kelp restoration potential in K'omoks Bay and adjacent Cape Lazo area in collaboration with NCES./2015
4. Assessing the potential and feasibility of a kelp grow line at Royston wrecks to determine whether an expanded outplanting of bull kelp is feasible at this site to add significant habitat complexity for outmigrating salmon smolts from the Courtenay River/2015
5. Collection of scientific data on: a) water temperature and light intensity at the kelp and eelgrass sites for interpretation of environmental conditions affecting kelp and eelgrass habitat performance during the growing season; and b) restoration performance in the estuary through surveys of eelgrass and bull kelp distribution using rigorous mapping techniques./2015-2016

Status:

Project is ongoing, see status results for next project "Collaborative Bull Kelp Restoration Project" below.

Collaborative Bull Kelp Restoration Project

Team: Diane Sampson and the Nile Creek Enhancement Society

Background:

Bull kelp forest habitat has been in steady decline within mid- Strait of Georgia, including Lambert Channel and Baynes Sound, as well as other coastal regions east of Vancouver Island for the last several decades. Although the causes of decline are still being elucidated and have resulted in patchy habitat through many parts of the Salish Sea, this phenomenon is seemingly widespread on the Pacific coast of North America.

Aims of this project include:

- Replanting approximately 1400 m2 of kelp habitat through seeded line at Maude Reef in Ford Cove on Hornby Island.
- Planting of seeded line at Northern Baynes Sound in collaboration with Project Watershed; connection with Island Scallops on large site of seeded lines at Bowser scallop tenure, through additional collection of data at this site. (see project above)
- Scientific data collection of environmental conditions, growth and habitat interactions in 2015-6 during the growth of the season's planting at Maude Reef, Northern Baynes Sound and Bowser and naturally occurring kelp bed at Denman Island.
- Completion of analysis of daily SST and salinity database for Chrome Island Light to include decadal averages for the 1970s and the 1990s, to add to work completed on the 1960s, 1980s and 2000s already reported in a recent report by this group to PSF (Heath et al. 2015).
- Collaborative research with DFO Science partner, Dr. Ianson of IOS, and Island Scallops Ltd on carbon cycling and ocean acidification (ecological services of kelp);
- Facilitation of communications between experts and practitioners in this field and initiation of planning for further research and restoration work (this will, hopefully, include securing a Post-Grad Research student).

Status:

A key accomplishment of this research activity was that the main research site at Maude Reef, Hornby Island, produced a large biomass (several thousand kilograms) of bull kelp that was studied by divers and extensively sampled for a wide range of environmental conditions. In addition, a second experimental site was deployed and studied in north Baynes Sound and although not as successful in kelp production, it was useful in improving knowledge of herbivore interactions with kelp restoration efforts. A small natural bed at Denman island was also sampled as a reference site. The project was conducted during on the warmest spring and summer periods ever recorded and provided an opportunity to study the effects of temperature stress and herbivore grazing as limitations to bull kelp distribution in an important area of the Salish Sea.

This study made progress toward the SSMSP objective of identifying significant factors affecting the early marine survival of salmon in the Salish Sea, particularly in the central Strait of Georgia. It has focused on the factors limiting the distribution of bull kelp (*Nereocystis luetkeana*) beds in Lambert Channel and Baynes Sound, a critical nearshore habitat for refuge and feeding of juvenile salmon. A significant database was diversified and expanded on kelp performance under varying conditions at several study sites (including temperature, light intensity, salinity, pH, turbidity and chlorophyll; and under grazing pressure from various herbivore species).

In summary the key findings are as follows:

1. Transplanting sub-tidal eelgrass is effective in restoring estuarine habitat areas to improve connectivity.
2. Natural bull kelp beds decreased in study area in 2015.
3. Experimental single-line kelp systems are effective for testing feasibility of restoration sites and environmental data collection (kelp grew at Royston; grazed at PW-1).
4. Large biomass of bull kelp can be reliably cultured for restoration (at Maude Reef grid site).
5. Limiting factors to bull kelp survival:
    - Prolonged (>35 days) temperatures >16C;
    - Grazing pressure from sea urchins and kelp crabs;
    - Competition from other algae for substrate.

Diversity and structure of coastal eelgrass communities and their importance for maintaining juvenile Pacific salmon

Team: Dr. Josie Iacarella, post-doc, UVic, and Dr. Julia Baum, UVic.

Background:

On the coast of British Columbia, both eelgrass meadows and Pacific salmon species are declining, yet eelgrass community dynamics and reliance of juvenile salmon on these communities are poorly understood. They will assemble the first large-scale dataset from monitoring efforts of coastal BC organizations in order to assess eelgrass community diversity and structure across environmental and human disturbance gradients (including boating, fishing, and non-native species). The final outcome of this research will be an index of eelgrass ecosystem health for all monitored meadows based on their ability to provide ecosystem services including provision of habitat for juveniles of salmon and other commercially-important fishes.

Status:

Since beginning her Postdoctoral Fellowship in November, 2016, Josie assembled a working group of 20+ individuals who are involved in surveying fishes across the coast of BC. Partner organizations and groups include: Nootka Sound Watershed Society, Parks Canada, West Coast Aquatic, Uu-a-thluk, Raincoast Conservation Foundation, Hakai Institute, Project Watershed Society, Nile Creek Enhancement Society, UBC labs, and the UVic Baum lab. The working group has been framed within a larger network that is forming, Seagrass BC, led by Hakai Institute and SeaChange Marine Conservation Society.

In February, they held a workshop for working group partners to discuss research questions and field methods. They decided to focus on 2 projects: (1) an assessment of juvenile salmon use of eelgrass vs. non-eelgrass habitats throughout the outmigration period, paired with gut content analysis and invertebrate prey surveys at the paired habitat sites, and (2) an assessment of fish diversity in eelgrass habitats across coastal gradients of human disturbance.

The juvenile salmon project was conducted in 5 regions (Tahsis Inlet, Bedwell Estuary, Fraser Estuary, Bowser Lagoons, and Koeye Estuary). The surveys began end of April/early May and continued through the summer, generally on a biweekly basis. They conducted beach or purse seines (depending on the region), invertebrate dip net sweeps, and collected some salmon juveniles (species and amount depending on region). They will use these data to compare abundances of juvenile salmon and their invertebrate prey in eelgrass vs. non-eelgrass (generally sandy or rocky) habitats; gut content analysis will be used to determine if the prey collected in each habitat matches what the juvenile salmon are consuming.

The fish diversity project was conducted from mid-June through July 2016 in 12 regions spanning the mainland from the Fraser Estuary – Calvert Island – Skeena Estuary, and covering a large spatial extent of Vancouver Island. This project involves a one-time survey of approximately 6-12 eelgrass sites per region. They sampled beach seining sites and characterized the eelgrass meadows (e.g. shoot density, percent cover, epiphyte load). Following the surveys, Josie and an Honour's student at UVic gathered functional trait information on the fishes that are caught (including morphometric analysis), and worked to quantify human disturbance levels at the surveyed sites. Human disturbance includes measures of distance to human-made structures, boating activity levels, and adjacent human population densities; they will also be preparing eelgrass samples to analyze δ^{15}N to determine if they can distinguish anthropogenic nutrient inputs from natural inputs. Josie will also be assessing whether there is evidence of biotic homogenization (reduced beta-diversity) of fish communities among regions with higher levels of human disturbance.

Status:

The Eelgrass Fishes Network was established to facilitate a collaborative effort in surveying eelgrass fishes across the coast of BC in summer 2016. Two workshops were held with 20+ attendees, the first to discuss research questions and survey methods, and the second to review preliminary analyses and plan publications. Network partners collaborated on two projects, (1) the impact of human disturbance on diversity of eelgrass fishes (one-time survey, 9 regions with a total of 89 sites), and (2) the role of eelgrass versus non-eelgrass habitats for juvenile salmon diets and refuge (generally biweekly surveys April – August, 5 regions with two sites each).

In terms of results, there is evidence of decreased species richness and biotic homogenization of eelgrass fishes in highly disturbed regions (sites within Fraser Estuary, Comox Estuary, southern Vancouver Island). Rockfish species, in particular, were an indicator species of low disturbance regions (sites within Clayoquot Sound, Barkley Sound, Central Coast, and Skeena Estuary), whereas threespine stickleback were most associated with high disturbance regions. The higher diversity (within and among sites) of the fish community and the importance of commercially-valuable rockfish species within the community at low disturbance sites exemplifies the need to maintain eelgrass habitat in low disturbance areas.

In addition, the results generally indicate that juvenile salmon use eelgrass habitat more than vegetated habitats, and were most often found to have harpacticoid copepods in their diets – a species associated with eelgrass. The role of eelgrass for juvenile salmon appears to vary by region, potentially in part dependent on the scale of the estuary (e.g. Fraser Estuary versus Bowser Lagoons).

This project contributes to a better understanding of (1) whether coastal human activities are impacting fish communities and (2) the relative contribution of eelgrass habitat to the diet and refuge of juvenile salmon. The results will have implications for the importance of habitat restoration and protection of habitats in low human disturbance areas and/or key outmigration locations.

Josie has taken on a new post-doctoral position so this project was ended approximately 10 months earlier than expected (Jan 2017). However, Josie intends on completing two publication based on the results to date.

Remote Sensing Methodology to examine the relationships between eelgrass distribution, upland land use and water quality.
Principal Investigator: Dr. Maycira Costa, UVic

Objective:
The goal of this research is to use historic aerial photography and contemporary UAV imagery to investigate the long-term trends in eelgrass habitat distribution in the Salish Sea, and to investigate the potential impact of coastal development in the region on eelgrass habitats.

Background:
Nearshore marine habitats are of great ecological and economical importance. Specifically, eelgrass meadows are one of the most productive and sensitive nearshore habitats. Part of their importance is to provide shelter and food to numerous species including Coho and Chinook salmon, and forage fish such as sand lance and herring. These habitats are threatened by human activities. Specifically, in the Salish Sea, as human population continues to grow, eelgrass beds have been documented as decreasing. However, there is a lack of understanding of the relative threats that are causing the decrease of eelgrass beds in this region. Current mapping efforts are underway to identify the occurrence of eelgrass and potential restoration areas.

Aerial photography is a valuable tool for monitoring landscape and ecosystem change. Archived air photos may date back as far as the 1920s, providing the longest available time series in remote sensing data with high spatial resolution and tonal detail making it suitable for mapping temporal change in small habitat units such as seagrass meadows. The goal of this project is to quantify the temporal and spatial dynamics of eelgrass habitats and associated adjacency catchment area land use change over time to further understand temporal changes and associated disturbance/environmental forcing. They are analyzing a long time series of aerial photos (1950-2004) and more recent satellite images for defining eelgrass cover change and land use change in the drainage basin at different scales from the Gulf Islands National Park Reserve and adjacent areas.

Status:
Field work conducted for this project included acquisition of aerial photography of the study sites for 2016 using a small Unmanned Aerial Vehicle (UAV) (2 cm spatial resolution) to complete the time series and kayak survey in the spring/summer 2016. In Village Bay a total of 1.5 hectares of eelgrass was delineated using object segmentation on the UAV image.

The time series was used to define methodology for long-term eelgrass mapping methodology using historic aerial photography from 1932-2014. Initial results for Village Bay, Mayne Island, indicates some variability of the eelgrass habitats between years and associated temporal land cover change. Further investigation will examine the possible impact of shoreline and watershed alterations on eelgrass distribution at several study sites around Mayne Island and Saturna Island.

Progress so far:

- The time-series of aerial photos is organized and data quality and environmental variables dictated the areas where the study is focused.
- Aerial photos are digitally pre-processed and subjected to an object-oriented classification model for definition of temporal eelgrass beds. On-going analysis
- Aerial photos are being processed for classification of land use change products.
- Intense field work was conducted in the spring/summer of 2016 and included acquisition of aerial photography of the study sites for 2016 using a small Unmanned Aerial Vehicle (UAV) (2 cm spatial resolution) and sea kayak survey with underwater videography. On-going analysis.

After the first steps of this project, (1) data organization and meetings to collate/examine available data and (2) initial processing of the aerial photos, they decided that more detailed field data for the different focused study sites was deemed required for accomplishing their goals. An intense field data acquisition comprised of imagery acquired with an UAV (Unnamed Aerial Vehicle) and sea kayak-based videography was conducted at several sites in the Gulf Islands during the spring/summer of 2016. These data are presently under analysis to be integrated with the historical aerial photos. Given the large amount of acquired field data and the time required to conduct the analysis and integration with historical data, this project will continue until the end of 2017, but within the planned budget.

The next steps will involve data integration with the other nearshore habitat projects. Also, planned collaboration with Hakai Institute will allow this project expand to a larger spatial scale, which is required to understand the health of the nearshore habitat in the BC coast. This will be important to understand trends in the large -scale distribution of eelgrass habitats, which are known to provide shelter and food to numerous species including Coho and Chinook salmon. This project may provide the scientific basis to quantify changes in a long temporal scale, which are deemed important for understanding environmental dynamics and provide rationales for regulations.

B5 Hatchery –Wild Interactions-Canada

Team: Mel Sheng (SEP-DFO), Dave Willis (SEP- DFO), Ryan Galbraith (SEP- DFO), Matt Foy (SEP- DFO)

SEP and PSF have been working in partnership on several projects designed to assess hatchery-wild salmon interactions in the Salish Sea, as well as to improve understanding of the behaviour, marine distribution, habitat use and competition between hatchery and wild salmon. This work also investigates various means to produce hatchery fish that survive at higher rates in the marine environment, which could then allow for reductions in hatchery production while sustaining or improving adult salmon production.

Delayed release of hatchery coho and Chinook salmon

This study has two main objectives of exploring release strategies that may improve the marine survival rates and distribution of hatchery coho and Chinook salmon, as well as reducing competition in the early marine environment between hatchery and wild salmon. Five hatcheries (Big Qualicum, Quinsam, Seymour, Inch and Chilliwack) will hold trial groups of Chinook and/or coho salmon in the hatchery beyond the traditional release timing of May through to late June/early July, which is several weeks after most wild juveniles, will have entered the marine environment. Juvenile fish will be released at a size that is expected to be consistent with naturally occurring salmon in the ocean at that time. By holding hatchery salmon longer, a period of several weeks of potential competitive interactions is eliminated. In addition, both recent (Beamish) and historic (Bilton) scientific work has suggested that juvenile salmon that enter the Strait of Georgia later and larger and that are able to grow fast are able to survive at higher rates than those that enter earlier. Furthermore, studies on wild coho at Black Creek have demonstrated that wild coho that enter the marine environment later and larger can have a tendency to maintain an "inside" distribution with the Salish Sea. For hatchery coho, this means that they would be more susceptible to catch in the summer Georgia Strait sport fishery, which historically was as high as 1 million fish retained.

Status:

Funding from the PSF supports the costs associated with extended rearing and coded wire tagging of these experimental releases. This study is being conducted at multiple locations around the Strait of Georgia over a period of several years. During 2016, costs are for CWTs for an experimental late large release of Seymour River coho, and for food costs for delayed release cohorts of coho and Chinook at Quinsam and Big Q hatcheries. 100K chinook smolts from 2015 Brood at Quinsam and 60K at BQ Hatchery were coded wire tagged, reared starting in Jan-Feb 2016 and released in early June at Quinsam and in July 2016 at BQ River.

DFO will be responsible for the monitoring and analyses of marine exploitation and escapement to determine overall survival compared to standard production releases in May (i.e. Brood return years 2016 to 2020 will be analysed; most adult returns are 3 and 4 year olds).

The table below shows the delayed chinook and coho releases at Quinsam and BQ during 2016:

Facility	Species	Brood	Date of release	Total Released	# Tagged	Tag code	Ave. Weight (Gm)	Ave. Length (mm)	C.F.
Quinsam	CN	2015	June 29/2016	104,078	102,806	18-24-70	14.21	108.54	
Quinsam	Co	2014	June 29/2016	79,881	38,183	18-37-65 &18-37-66	35.91	151	
BQ	CN	2015	July 5-7 2016	109,000	61,800	18-32-69 & 18-27-67	18.6	115.2	1.21
BQ	Co	2014	Jun 20-22/16	106,290	42,144	18-62-04 & 18-35-84	30.17		

Cowichan River Chinook Salmon Coded Wire Tag Application

The Cowichan River Chinook population was historically one of the larger Chinook stocks in the Salish Sea. This hatchery stock is a Pacific Salmon Treaty indicator stock, which is used to provide information that is critical to the management of wild Chinook salmon in Lower Georgia Strait. The PSF has been supporting several initiatives relating to Cowichan River Chinook studies, including genetic-based hatchery-wild interaction work.

Rotary screw trap (RST) assessments conducted on the migration survival of hatchery smolts which were released 40 kms upstream of the mouth of Cowichan River in 2015 and 2016 (ie. Road Pool) found that only 20% of the releases could be accounted for in the RST located in the lower river. Based on these findings, DFO and Cowichan hatchery agreed to carry out paired release trials of CWT Chinook during 2016, one at the upper river and one at the lower river.

Status:
During 2016, CWTs were applied to 4 release groups of Cowichan hatchery chinook. These fish were released on two dates in April and two dates in May to make for 2 early and 2 late Cowichan chinook releases in-river. (Early and late groups were released at the Road Pool and approx. 20 kms downstream). In addition, approximately 140K CWT hatchery smolts were also released directly from Cowichan Hatchery May 24th to determine if overall adult survival improves compared to smolts released 40 and 20 kms upstream. The smolts were supplemented with river water 2-3 hours per day, 2-3 times per week for a month period before release to assist with imprinting.. The individual survival estimates for the upstream (Road Pool) versus downstream releases were 13.7% and 42.0%, respectively. It is recommended that the lower release sites be used in all future Cowichan Hatchery release plans.

Release Location	Release Date	Hatchery CWT release no.	Population estimate at RST in lower river	% survival
Stoltz	27 April	94,530	29,465	31.20%
Road Pool	9 May	94,034	10,093	10.70%
Horseshoe Bend	24 May	194,315	91,815	47.30%
Road Pool	20 June	193,748	29,422	15.20%
Total		576,627	160,796	27.90%

EPIC4- Parental-based Tagging of Hatchery Coho salmon- Activity 3. Efficacy of hatcheries.
Team: Beacham (leader), Davidson, Withler, Devlin, Naish, Bernatchez, and Willis.

As part of a joint project proposal with Genome Canada, parental based tagging (PBT) of hatchery coho stocks in Southern BC will be utilized to genotype the majority of hatchery coho smolts released into the Salish Sea. This work will permit subsequent identification of clipped juveniles and adults by stock and year of origin, release strategy, and parentage history, and may allow for detailed investigations of differences in early marine distribution patterns of different hatchery coho stocks. Furthermore, genetic based sampling of returning adults will allow for identification of genetic, physiological and environmental factors that affect family-specific survival rates of hatchery coho salmon, which may support provide a means to allow reduced hatchery coho production while sustaining or improving adult production.

The key objectives are as follows:

- To use parental-based tagging (PBT) to estimate the contribution of Coho Salmon from hatcheries to the fisheries in southern BC;
- To compare the use of PBT with the existing Coded Wire Tag (CWT) recovery system currently used;
- To use PBT to quantify family-specific post-fishery to spawning survival rates of hatchery Coho Salmon;
- To use genetic methods to identify genetic, physiological, phenotypic and environmental factors (e.g., water temperature) affecting fitness of hatchery Coho Salmon.

Status:

Funding for this project was secured through Genome Canada, and the preliminary work to collect genetic samples began in 2014. Specific updates for this activity are as follows:

Activity 3.1. Estimate of Coho Salmon produced from specific hatcheries to capture fisheries – Sampling

Samples were obtained from 22 locations, with fin clips collected from a total of about 5,200 Coho Salmon during 2015 sampling. They completed data collection on about 2,500 adult three-year-old returning Coho salmon at Inch Creek hatchery. The 2015 sampling of Inch Coho salmon represents the fourth generation of Inch Coho salmon sampled in the study since its inception in 2006.

Activity 3.2. Estimate of Coho Salmon produced from specific hatcheries to capture fisheries – Genotyping

All samples collected from the 2014 hatchery broodstock sampling (approximately 5,500 individuals representing all of the DFO hatcheries in BC) have been genotyped, as well as available samples from the 2006, 2009, and 2012 broodstock at the Inch Creek hatchery, and approximately 200 individuals from the 2012 Inch Creek hatchery that contained coded-wire tags.

Activity 3.3. Estimate of Coho Salmon produced from specific hatcheries to capture fisheries – Data Analysis

Analysis of population structure for 20 populations indicated a regional population structure, with Fraser River populations clustered together, as did populations from the southern mainland of British Columbia, the east coast of Vancouver Island, and the west coast of Vancouver Island.

Activity 3.4. Family-specific marine survival rates of hatchery Coho Salmon – Sampling

The sampling is well underway. This activity depends on the results from Activity 3.1.

Activity 3.5. Family-specific marine survival rates of hatchery Coho Salmon – Genotyping

This activity also depends on the results from Activity 3.1. It will commence in Q3.

Activity 3.6. Family-specific marine survival rates of hatchery Coho Salmon – Data Analysis

The data analyses for this is scheduled to begin in Q3.

Research Update from the DFO team: Genotypes were available from 1,025 individuals of known origin and known age from 10 populations, and 90.3% (926/1,025) of the individuals were subsequently assigned via parentage analysis (PBT). All 926 assignments via PBT were 100% accurate for both population of origin and age, with a baseline of 117 populations with multiple age classes available for assignment. The 9.7% of individuals unassigned via PBT were subsequently assigned via genetic stock identification (GSI) with an overall accuracy of 88.9% correct assignment to population of origin, with 2.0% incorrectly assigned to population, and 9.1% unassigned to population (probability ≥ 0.85 required for assignment). For 171 coded-wire tagged (CWT) individuals that returned to the Inch Creek hatchery in 2012, 94.7% of these fish were assigned to parents in the 2009 broodstock via PBT, and an additional 5.3% to the population via GSI (100.0% of the CWT individuals). For 1,393 Coho Salmon from 10 populations that were assigned via PBT, the overall accuracy of assignment to the correct population was 100%, and to correct broodyear within population was 100%.

A total of 19,725 Coho Salmon from 117 locations in southeast Alaska, British Columbia, and Puget Sound has been genotyped. With individuals displaying an assignment probability < 0.85 excluded from the analysis, regional assignment accuracy of individuals ranged from 81.0% (Stikine River, North Puget Sound) to 100.0% (Lower Thompson, North/South Thompson, Georgia Strait mainland south (Boundary

Bay), and Hood Canal), with an average accuracy of 98.3% over all 23 regions. The "errors or mis-assignments" will be a mixture of incorrect assignments plus straying, and thus actual assignment errors were less than those estimated.

C. 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 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 they learn, these activities will be aligned with the proposed suite of research activities involving the collection of new data.

Several of the primary activities (salmon survival trends, ecosystem indicators, and ecosystem modeling) are being developed and implemented with significant collaboration between U.S. and Canadian scientists.).

In Canada three specific modelling efforts are underway:

Salish Sea Marine Ecosystem Modeling
Team: Angelica Pena, IOS; Ken Denman, ret; post-doc (to be hired)

Status:
Dr. Angelica Pena is currently advertising for a post doctoral research scientist position in the area of marine ecosystem modelling. The incumbent will work to implement an individual-based-model (IBM), representing larval and juvenile salmon, into an existing Salish Sea plankton ecosystem ROMS model to simulate their migration and feeding behaviour in the Strait of Georgia. Research will be conducted at the Institute Ocean Sciences in Sidney, British Columbia, Canada.

Forecasting near and long-term ecosystem changes influencing the population dynamics of adult and juvenile Chinook and Coho Salmon in the Strait of Georgia
Team: Dave Preikshot, Madrone Environmental

A Strait of Georgia ecosystem model will be used to determine how environmental and trophic mechanisms have influenced wild Coho and Chinook Salmon in the Strait of Georgia and how management of hatchery and fisheries policies influenced these changes. These historic dynamics will be used to establish a baseline for forecasting scenarios in which the effects of management policies on wild Coho and Chinook Salmon populations will be assessed under potential future marine production scenarios developed from regional downscaled marine climate models. The four primary objectives of this research will be to;

- identify likely future patterns of environmental variation in response to climate change in the Strait of Georgia to the years 2040 and 2060,

- measure the direction, magnitude and variability of biomass, catch and mortality for Coho Salmon, Chinook Salmon and other commercially fished and managed species in response to simulated environmental change in the Strait of Georgia to the years 2040 and 2060,
- analyze the influence of harvest and other management policy changes on the direction, magnitude and variability of biomass, catch and mortality of Coho salmon, Chinook Salmon and other managed species.
- compare model predictions for Coho and Chinook Salmon dynamics with parallel upper trophic level modelling from colleagues investigating other basins of the Salish Sea.

The long term objectives of this project are as follows:

- to provide the research community with a model that can be used to explore hypotheses of how the Strait of Georgia ecosystem function, particularly in Coho and Chinook Salmon and other upper trophic level species with significant economic, cultural and biological significance,
- to identify significant data gaps and research priorities to improve long-term monitoring and thus our ability to sustainably manage wild populations of Coho and Chinook Salmon in the strait of Georgia
- to provide management with strategic ecosystem level advice that can be used to identify achievable goals for wild Coho and Chinook Salmon populations in the Strait of Georgia.

Status:

Project approved and begun April 1 2016. Dr. Preikshot made some progress in collating some data sets. This project will be rolled into the third modeling effort "Environmental productivity of the Salish Sea: trends, impacts and projections" Mitacs project, led by Villy Christensen, UBC.

Environmental productivity of the Salish Sea: trends, impacts and projections

Team: Villy Christensen, UBC, Dr. Carl Walters and post-docs.

The Salish Sea Marine Survival Project has compiled a vast amount of data sources, and made clear the need to understand how the environmental productivity of the Sea has changed through the time period for which there are sufficient observations to reliably evaluate how environmental productivity has changed along with the consequential impacts throughout the ecosystem. While previous studies have evaluated short-term productivity patterns for the Salish Sea, there has so far only been correlative studies to evaluate the relationship between long-term changes in environmental productivity and the productivity of higher trophic levels organisms (notably salmon) in the ecosystem.

Through this initiative, the researchers intend to develop a coupled biogeochemical model and food web model to evaluate how the combination of changes in environmental productivity, food web structure and human impacts (notably through fishing) has changed in the Salish Sea over three and a half decades. Several post-docs will work to address the SSMSP's primary objective of assessing if "bottom-up processes driven by annual environmental conditions are the primary determinate of salmon production via early marine survival."

Status:

Project approved and has begun. A post-doc will begin June 2017 to develop a 3D biogeochemical model for the Salish Sea. This project will involve their obtaining environmental data covering the time period back to the 1970s/80s; transferring and implementing the ROMS model to WestGrid; model development and skill assessment; model tuning and validation; and publication.