CANADIAN SALISH SEA MARINE SURVIVAL PROGRAM

2015 PROGRAM SUMMARY

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Section 1: 2015 Program Overview

The following is a 2015 year-end report of the Salish Sea Marine Survival Project: 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, carried out between 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 33 projects in 2015 conducted by 30 partners with a total expenditure of $3.388 Million for non-federal projects[1]. Field studies will continue during 2016 and 2017, while 2018 will be dedicated to assimilation of results, analysis and dissemination of key findings.

Background

The Project is based on three broad concepts that impact salmon, which have been ranked in order of significance:

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

2015 Canadian Program

Table 1 below provides a brief overview of the Canadian SSMSP projects implemented during 2015. Key findings from each project are provided in more detail in Section 2.

Bottom-Up Sampling Program and Individual Studies

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

[1] See 2015 SSMSP Project report (pdf format) on www.psf.ca

identifying critical growth periods for salmon and understanding the primary factors affecting growth during those periods.

- Individual bottom-up studies build off of 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, namely 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.

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.

SSMSP-funded programs to monitor forage fish include the DFO juvenile herring survey and a hydroacoustic survey carried out by the Institute of Oceanography in Sidney. Juvenile salmon studies are led by DFO, with freshwater, beach seine, purse seine, small boat trawl and Ricker trawl surveys occurring in the Cowichan, Big Qualicum and Fraser watersheds. These studies are 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.

Marine survival, migration pathways and residency are assessed using PIT tag and acoustic tagging methodologies. These programs are led by the BC Conservation Foundation, University of British Columbia, Kintama and University of Victoria.

Top-Down and Other Studies

The Canadian major top-down studies for 2015 include assessment of the impacts of seal and fish 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, we have carried out some hatchery manipulation studies, involving alternative times of release of Chinook into the Strait of Georgia. Another large scale study involves the use of parental-based tagging (PBT) to identify genetic, physiological, phenotypic and environmental factors affecting fitness of hatchery coho, to quantify family-specific post-fishery to spawning survival rates of hatchery coho, and to estimate the contribution of hatchery Coho Salmon to southern BC fisheries.

Table 1. SSMSP 2015 Projects

Proponent	PIs	Title	Category	Project Outline
OCEANOGRAPHY				
Buoys				
Sea This Consulting	Stephanie King	High temporal resolution monitoring of surface chlorophyll in the Salish Sea	Biological Oceanography	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 and one with a nitrate sensor to provide continuous measurements for 2015. Spatial context for the fluorometer time series is provided with satellite imagery during the spring bloom.
Citizen Science Program				
ONC Innovation Centre	Ryan Flagg	Citizen Fishers (application)	Biological Oceanography	This project developed a tablet application during 2014/2015 to allow for immediate download of citizen science CTD data to the ONC central database via WiFi. This allows data to be easily transmitted and stored in Oceans 2.0 data system at UVic and allow scientists from all over the world to download this data easily and for free.
ONC Innovation Centre	Ryan Flagg	Initial Instrument Set-up & Data User Services Support	Biological Oceanography	This project was for citizen science instrument set up and data services support during 2015- including digital infrastructure support, user services support (including manual correction of data) and ongoing management support.
ONC Innovation Centre	Ryan Flagg	Engineeer Support Package	Biological Oceanography	This project was for citizen science engineering support in 2015 – and included pre-deployment dry and wet testing, assembly and maintenance, shipping and receiving, and instrument calibrations.
Vancouver Island University	Brian Kingzett	Deep Bay Vessel	Biological Oceanography	The Deep Bay vessel from VIU was utilized for the Baynes Sound citizen science sampling program during 2015.
Multiple	Oline Luinenberg /Colin Novak	Citizen Science Boats	Biological Oceanography	A total of 8 additional citizen science vessels were outfitted during 2015 (Lund, Powell River, Sechelt, Vancouver, Cowichan, Victoria, Nanaimo/Qualicum, Campbell River). Boats made 20 trips over 2015 and gathered oceanographic data from the Strait using a CTD and secchi disk.

				They also collected phytoplankton and nutrient samples. We also loaned an additional CTD to Hakai for their citizen science sampling program in Johnstone Strait.
Linda White	Linda White	Nutrients	Biological Oceanography	Linda White at IOS analysed the nutrient samples collected from citizen science vessels during 2015.
Satellite Imagery				
University of Victoria	Maycira Costa	Spatial temporal analysis chlorophyll, turbidity and sea surface temperature of the Salish Sea: an integration of satellite imagery and data from vessels of opportunity	Biological Oceanography	This study aims to elucidate the relationship between the interannual and seasonal variability of productivity and turbidity in the Salish Sea and regional environmental forcing and global climatic indices. The data set and 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 and SST products based on MODIS (available since 2002) and Sentinel-3 (launched in 2015) ocean colour satellites. Next they will define the integration method to use data acquired from vessel of opportunities (BC Ferry/ONC continuous FerryBoxes and Ferry ocean Colour Observation Systems – FOCOS, continuous above-water reflectance from moving ferries crossing the Salish Sea, and citizen science boats) to calibrate and validate satellite imagery and products.
Ocean Acidity				
Vancouver Island University	Helen Gurney-Smith	Coupling state-of-the-art chemical oceanography with biological relevance: examining phyto- and zooplankton populations in a dynamic coastal environment	Biological Oceanography	This study aims to determine patterns between oceanographic processes and the quality and quantity of salmon prey items and lower trophic levels, thereby assisting in determinations of salmon productivity drivers. The work couples high resolution chemical oceanographic monitoring with phyto- and zooplankton analysis in the northern Strait of Georgia (Quadra Island) to determine: (1) the variability and intensity of corrosive surface ocean conditions (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) if the incidence and 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 analysis during 2015.
Cowichan Oceanography				

DFO (IOS)	Svein Vagle	Observation of temporal and spatial variability of water-column physical chemical and biological properties in Cowichan Bay	Biological Oceanography	Objectives of this study were to obtain spatial and temporal water property data for Cowichan Bay during the important fish migration period from April to August and augment these data with shorter term (order of hours from small boats), medium term (order of several months from acoustic monitoring) and 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 and coho early marine survival. Funding for 2015 included costs to continue use of three moorings in Cowichan Bay and equipment leases for 1) an upward pointing Acoustic Zooplankton and Fish Profiler (AZFP) that monitored the water-column for both juvenile salmon, zooplankton, phytoplankton, and larger predatory fish between April and June 2015, and 2) an Imagenex digital multi-frequency imaging sonar mounted from smaller boats to survey the fish habitat near-shore and to observe the spatial variability in the biomass in the bay.
Zooplankton				
DFO	Ian Perry	Zooplankton and ichthyoplankton status and trends in the northern Salish Sea	Zooplankton	The objective of this program is to identify the seasonal patterns of variability in zoo/ichthyoplankton species composition, abundance and biomass in the Strait of Georgia and 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 and biomass of the zoo/ichthyoplankton has on the growth and early marine survival of juvenile salmon. SSMSP is covering the cost for a number of vessel charters 2015-2016 to augment (in time and space) the current DFO zooplankton collection program (Peter Chandler and Ricker surveys) and zooplankton analysis at IOS of these samples as well as zooplankton samples collected by the citizen science boats for 2015-2017.
Forage Fish				
DFO (IOS) and UVic	Stephane Gauthier	Forage Fish	Forage Fish	The short term objective of this project is to develop a time series of robust acoustic indicators of productivity for forage and demersal species in the Strait of Georgia and establish potential links to juvenile salmon survival. The long term objective will be to use these indicators within a management context to understand and forecast marine survival of juvenile salmon based on validated ecosystem considerations. SSMSP is funding a post doc in Gauthier lab 2016-2017

DFO	Jennifer Boldt	Juvenile Herring Survey	Forage Fish	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. SSMSP will cover part of the costs of the juvenile herring surveys for the next 3 years 2015-2018.
JUVENILE SALMON STUDIES				
Freshwater Studies- Rotary screw trap				
Key Mills Construction		Cowichan Chinook downstream survival	Juvenile Salmon	Key Mills was responsible for the construction/operation of a Rotary Screw Trap on Cowichan River in 2015.
Cowichan Tribes		Cowichan Chinook downstream survival	Juvenile Salmon	Cowichan Tribes took care of the operation/monitoring of a Rotary Screw Trap on Cowichan River in 2015.
J A Taylor & Associates		Cowichan Chinook downstream survival	Juvenile Salmon	JA Taylor and associates carried out the data analysis of results from the Rotary Screw Trap study in 2015. This study provided an estimate of in-river mortality of hatchery chinook smolts.
PIT tagging studies to assess freshwater and marine survival				
BC Conservation Foundation	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	Juvenile Salmon	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 and locations throughout their first year of life, 2) apply PIT tags to wild and hatchery fish which are 60 mm and greater (fork length) at each location 3) construct and operate PIT tag detection arrays at the Cowichan River counting fence and 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, and by microtrolling (to catch sub-legals) during 2015 and PIT tagged. Tag recoveries for each group will occur over several years due to multiple age classes of returning adults.

University of Victoria	Francis Juanes, Will Duguid (PhD student)	Variation in juvenile Cowichan River Chinook salmon distribution, diet, and growth rate in relation to tidal mixing and water column stratification	Juvenile Salmon	Aims of this project (2015-2016) are to identify the biophysical attributes of epipelagic habitats that may be of particular importance to juvenile Chinook and Coho salmon in their first marine year (hotspots) and identify candidate areas in the Salish Sea meeting this description. They will also determine if, and how, distribution of juvenile Chinook and Coho salmon with respect to gradients in water column stratification and tidal mixing may be modulating the effect of bottom up (temperature, food availability) and 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.
Juvenile salmon projects-DFO				
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	Juvenile Salmon	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 and chinook and determining which individuals do not appear to survive over time. Information has been collected 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. In 2015, smolt samples of coho and 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 and Big Qualicum). The latter is required to obtain samples of wild coho and Chinook during their downstream migration. Samples were also taken using purse seines, CCGS Neocaligus on a monthly basis from April to August (Cowichan Bay and Fraser River Plume), and the CCGS WE Ricker in July and September.
Zotec Services	Carol Cooper	Plankton & Stomach Analysis	Juvenile Salmon	Zotec Services carries out stomach content analyses and zooplankton analyses for collections from Cowichan Bay and elsewhere (Puntledge/Big Q) as part of the juvenile salmon studies of Trudel et al. (listed above)
PREDATION STUDIES				

University of British Columbia	Austen Thomas, Andrew Trites, Ben Nelson	Juvenile salmon predation by harbour seals	Predation	During 2015 a study was carried out to assess seal predation on hatchery coho smolts from Big Q hatchery. Costs were for1) design and building of a seal capture platform and PIT tag detection haulout, 2) deploying RFID tags (seal "beanie") and GPS-accelerometer tags on harbour seals, 3) calculating a harbour seal smolt predation rate from PIT tag detections, and 4) generating maps of spatial predation risk from combined RFID and spatial data.
BC Conservation Foundation	Kevin Pellet & Hatchery Staff at Big Q	BQR tagging project	Predation	Costs were for PIT-tagging coho smolts at Big Q hatchery for the seal predation project described above.
DFO	Dick Beamish	Fish Predation Studies		During 2015, gillnetting was carried out in both Cowichan Bay and Qualicum Bay to sample for fish predators.
ACOUSTIC TAGGING STUDIES				
University of British Columbia	Scott Hinch, Tony Farrell, Kristi Miller	Physiological and environmental factors affecting the migratory behaviour and survival of sockeye and steelhead salmon smolts	Acoustic tagging	These studies continue time series of acoustic telemetry-derived estimates of salmon smolts migration rates and survival in the Salish Sea, enabling an among-year retrospective analysis examining impacts of environmental and physiological factors, and 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 and gill biopsy outmigrating smolts, 2) assess gill and blood biomarkers for pathogen presence/load, osmoregulatory preparedness, and growth potential for tagged outmigrant smolts and relate these biomarkers to migration rate and survival, 3) conduct retrospective analyses of existing and new telemetry data for Chilko sockeye salmon (2010-2016) to relate migration rate and survival of smolts in the Salish Sea to fish size, migration behaviour (migrating timing and rate), and oceanographic and riverine conditions, 4) conduct retrospective analyses of existing and new telemetry data across sockeye and steelhead stocks to define meso-scale migration routes of smolts and 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 and orientation) and oceanography on resulting marine

				distributions and migration routes. High water levels prevented tagging of Chilko sockeye during 2015, so Seymour steelhead were tagged instead. Chilko sockeye will be tagged during 2016.
Kintama Research Services	Dave Welch	Comparative Marine Survival of Seymour Steelhead and Testing Performance of 180 kHz Small Acoustic Tags in the Salish Sea	Acoustic tagging	Aims of this project were to a) provide expanded baseline survival data for Seymour steelhead in 2015 that may be compared to past published data and address uncertainty as to whether or not survival in the small section of the Salish Sea north of the NSOG sub-array (and south of the Discovery Islands) is more consistent with survival measurements for the lower Strait of Georgia or the Discovery Passage/Johnstone Strait/Queen Charlotte Strait region, b) evaluate the detection efficiency of the proposed new VR4 sub-array in the Discovery Islands for 180 kHz tags using the existing POST sub-array geometry and c) evaluate the improved performance possible as a result of retro-fitting Vemco acoustic receivers with a sold-state acoustic amplifier to increase tag detection range, and thereby reduce the future cost of achieving a given level of scientific precision on measurements of survival or residence time.
HARMFUL ALGAE				
Microthalassia Consultants Inc.	Nicky Haigh	Salish Sea Harmful Algae Bloom Monitoring	Harmful Algae study	Assessment of harmful algal bloom status in the Strait of Georgia: seasonal extent and interannual variability of blooms in area and vertical distribution of HAB species in the water column, associated with environmental factors such as nutrients, temperature and salinity. Costs so far have been for lab work carried out by S. Esenkulova (PSF hired technician)
SALMON HABITAT				
University of Victoria	Maycira Costa	Spatial temporal extent of kelp canopy area: satellite method development for two study areas with different water turbidity characteristics, and further evaluation for a larger scale mapping project.	Salmon Habitat	This short pilot project (3 months) was carried out during 2015 to evaluate and define methodologies to use satellite imagery (present and historical) to map the aerial extent of kelp beds on BC coastal waters. Costs were primarily for a short term research assistant and technician. The project was successful and will therefore be expanded during 2016. Overall goal is to determine how kelp beds have changed over time and space, and where we may wish to focus restoration efforts.

University of Victoria	Laura Kennedy	The effects of eelgrass density on prey availability for juvenile salmon	Salmon Habitat	The objectives of this SSMSP funded MSc project were 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.
Seachange	Nikki Wright	Eelgrass Restoration from 2013-2015	Salmon Habitat	The purpose of this project (2015-2016) 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. These objectives are: 1. Increase and restore critical marine salmon corridors; 2. Strengthen partnerships with governments, First Nations and funding agencies to promote restoration of eelgrass habitats over time and, 3. Continue stewardship of eelgrass habitats within fourteen coastal communities.
Forage Fish	Ramona De Graaf	Beach Spawning Forage Fish of the Salish Sea	Nearshore Habitat	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. Objectives of this SSMSP funded work are to: 1. Determine the spatial extent of spawning habitat and suitable habitats for surf smelt and Pacific sand lance in the Salish Sea 2. Protection of forage fish resources (secondary capacity) in the Salish Sea 3. Development of operational statements and best management practices for forage fish spawning/rearing habitats and marine riparian habitats for local government and stakeholders.
Project Watershed	Bill Heath	Bull kelp and eelgrass restoration research in Baynes Sound and Lambert Channel	Salmon Habitat	Two key projects were funded: "Eelgrass and Kelp Restoration, Courtenay (K'omoks) Estuary" and the "Collaborative Bull Kelp Restoration Project". The former project aimed to increase subtidal eel grass habitat area for juvenile salmonids and spawning herring and to examine the bull kelp restoration potential in K'omoks Bay and adjacent Cape Lazo area and Royston wrecks. The second project aimed to replant approximately 1400 m^2 of kelp habitat through seeded line at Maude Reef in Ford Cove on Hornby Island and in Northern Baynes Sound in collaboration with Project Watershed. They also collected biological and environmental data to assess limiting factors to kelp and eelgrass restoration.

Trend Analyses and Modeling

Trend analyses and modeling provides the primary, integrated data evaluation framework for the entire project. Several of the primary activities in this section (salmon survival trends, ecosystem indicators, and ecosystem modeling) are being developed and implemented with significant collaboration between U.S. and Canadian scientists. Canadian modeling projects are being implemented during 2016.

Section 2: Overview of Key Progress/Findings

A. Bottom Up Programs

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.

A1. Oceanography

Under the oceanography category, we had 6 key programs in 2015. These included satellite monitoring of the Salish Sea, oceanographic buoy monitoring, the citizen science program, moorings in Cowichan Bay, monitoring of ocean acidity in the northern Strait of Georgia, and a phytoplankton monitoring program. Timing of the spring bloom was early in 2015, occurring around February 20, and was noted by all our programs using very different methodologies.

Short overviews of the key findings for each project are noted below.

A1.1 Citizen Science Program

Team: PSF (Pearsall, Novak, Luinenberg, Esenkulova, Curran), Svein Vagle, Jane Eert, Mike Dempsey, Kelly Young, (all DFO), Citizen scientists in Lund, Powell River, Victoria, Nanaimo, Baynes Sound, Cowichan, Campbell River, Ladysmith, Steveston, nutrient analyst Linda White (contractor), Ocean Networks Canada.

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 "small vessel fleet" which would utilize community vessels to collect oceanographic data during the spring and neap tides at specific locations in coastal waters of the Strait of Georgia. These 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 in one day, providing data at a spatial and temporal degree that has not been realized 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

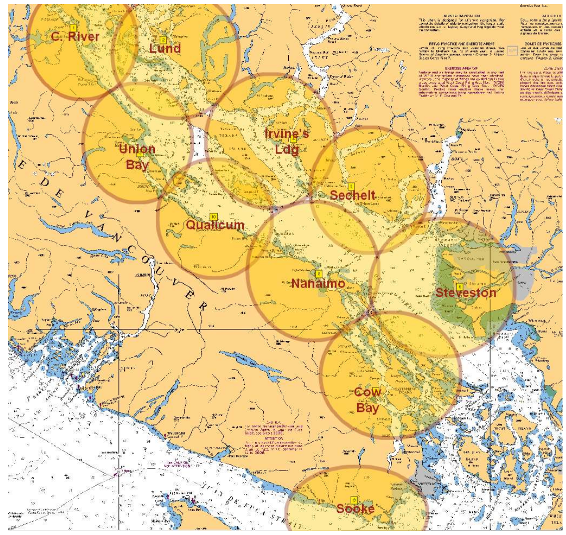


Figure 1. Citizen science coverage of the Strait of Georgia- concept diagram by Dr. Eddy Carmack

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 fluorescence (a proxy for 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 assess water turbidity. The data collected from this part of our 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 our 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 our examination of the spatial and temporal occurrence of harmful algal blooms (HABs) throughout the Strait of Georgia. HABs are a significant problem in the coastal waters of British Columbia and annually cause millions dollars in losses to salmon (salmon mortality) and shellfish (harvest closures) aquaculture industries. Currently, SSMSP is the only governmentally supported project that systematically collect data and observations on harmful algae in BC providing unique information to examine the links: physical oceanography-phytoplankton dynamics-effects on higher trophic levels. Water samples collected throughout the Strait are analyzed back at the lab with a compound microscope: phytoplankton biomass is estimated, dominant species and harmful algae species are identified and enumerated. Data on sample analysis is promptly available.

- See the following link for details: https://www.youtube.com/watch?v=bgdr2wkVhWk

Status:

The program was begun in February 2015, with all vessel operators fully trained to carry out the program on the first “shakedown” cruises. PSF staff trained all the citizen scientists, and a PSF videographer developed a training video.

On February 27 2015 a Citizen science symposium was held at Deep Bay Marine Station was held so that all the citizen scientists could get together with the scientists that developed the program, discuss routes, use of the tablet, and provide feedback.

Overall, boats sampled 20 days in the Strait of Georgia. In the case of poor weather conditions, sampling dates varied by 1-2 days either side of the proposed date. The dates were chosen based on spring/neap tides, and the sample locations were decided upon by oceanographers at the Institute of Ocean Sciences, Sidney.

Currently, the program has vessels outfitted and actively sampling the Strait of Georgia from Campbell River, Deep Bay, Qualicum, Cowichan Bay, Victoria, Lund, Powell River, Sechelt and Steveston. The number of sampling stations and distances in each sampling developed by the oceanographic science team proved to be unrealistic to accomplish in a reasonable day at sea for some of the areas (Baynes Sound, Nanaimo/Qualicum, Irvine’s/Sechelt and Victoria). In early March, and after some discussion at the citizen science symposium, these areas were modified to ensure crew success and participation. In May, water quality concerns by First Nations in Ladysmith Harbour resulted in PSF technicians including 5 additional stations in Ladysmith for sampling as part of the program. The figure below shows the overall coverage of the Strait of Georgia:

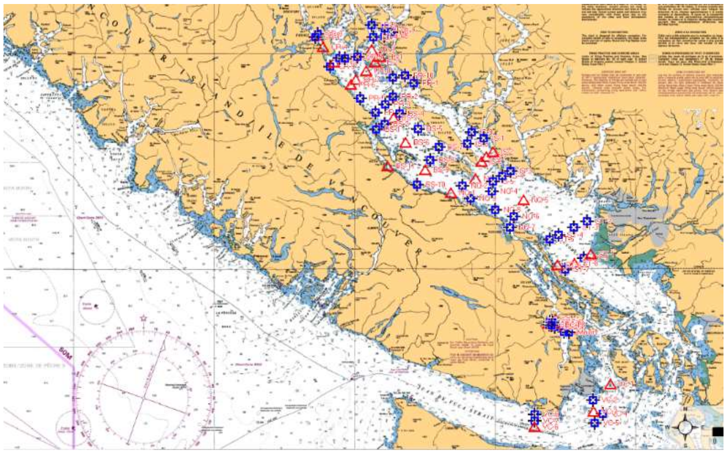


Figure 2. 2015 Citizen Science Coverage of the Strait of Georgia

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 total, over 2000 CTD casts were performed during 2015, and the following samples collected:

- Nutrients- 1300 samples, 100% processed
- Chlorophyll a- 99 samples, 100% processed
- Phytoplankton-1400 samples, 85% processed
- Zooplankton- 110 zooplankton samples from Baynes Sound and Irvine-Sechelt, 50% processed

The table below show the total number of CTD casts performed for each vessel:

		Lund	Powell	Sechelt	Baynes	Nanaimo	Campbell	Steveston	Victoria	Cowichan	Ladysmith	TOTAL
total casts:		379	280	150	245	192	254	88	141	332	90	**2075**
average casts per trip:		17	15	9	14	11	13	11	11	21	15	**104**

Many different products are being produced, such as 2D and 3D plots, plots of boat drift, and nutrients by area. Some example products are shown below:

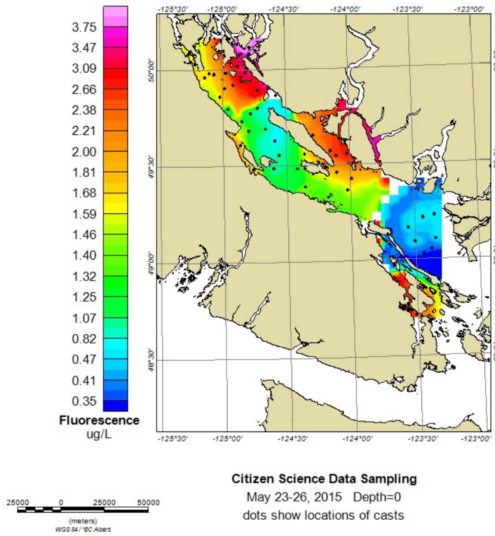


Figure 3. 2D example plot- chlorophyll fluorescence in the Strait of Georgia

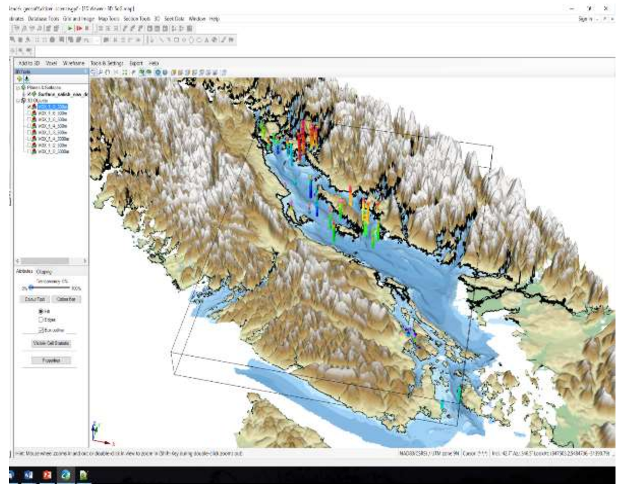


Figure 4. 3D example plot- fluorescence

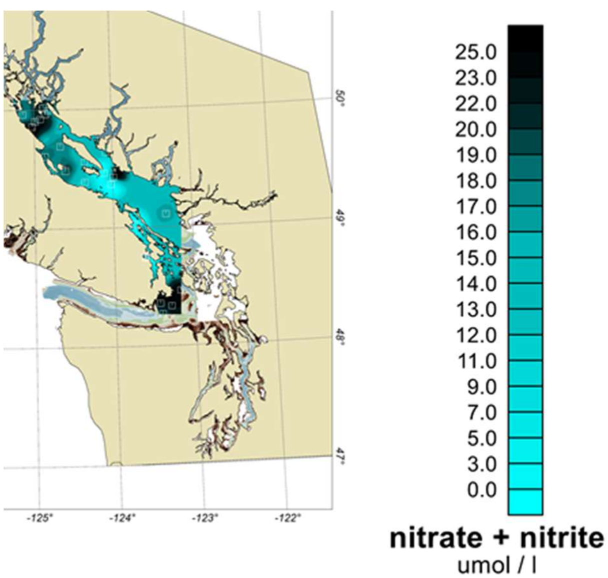


Figure 5. Nutrients in the surface waters of the Strait of Georgia- Nitrate and Nitrite

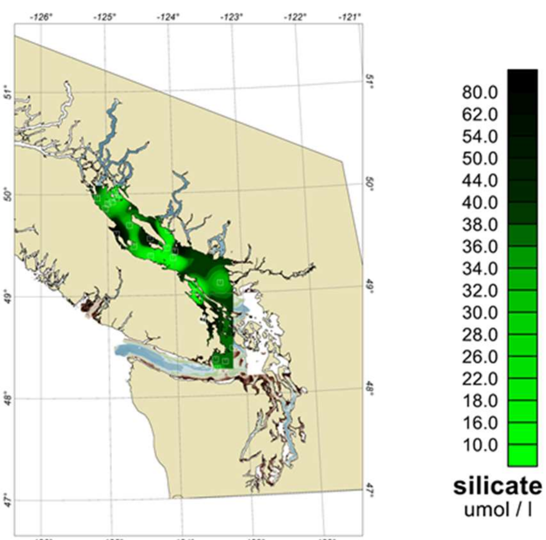


Figure 6. Nutrients in the surface waters of the Strait of Georgia- silicates

We are currently compiling and adding B.C. ferry data and data from other cruises from PBS and IOS to this collection. Other ongoing work is to calibrate the fluorometers with the on-site chlorophyll collections, to include analysis of the secchi data, to compare the results for spring and neap periods and to compare this data with data archives from IOS for 1980s and 1990s (during the periods of better coho/chinook production until the mid-1990 decline).

All data are freely available on the Strait of Georgia Data centre (www.sogdatacentre.ca) and Oceans 2.0 (at Ocean Networks Canada, oceannetworks.ca).

Changes to the program during 2016 include the following:

- The Victoria vessel was removed so that there is greater focus upon the Strait proper. To this end, we modified the route of the Stevesteon patrol, and added a boat out of Galiano Island.
- We are currently implementing a program to include measurements of ocean acidity with Dr. Wiley Evans (Hakai Institute). Water sampling for ocean acidity testing will be done on the Baynes Sound and Powell River routes from June 2016 onwards.

A1.2 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 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 aiming to address 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 and 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 and Preliminary Results:
This project started in July 2015 and is on-going.

Chlorophyll climatology (2003-2014) indicates the seasonality in the central Salish Sea, where lower values (<5.0 mg m^{-3}) are present at both beginning and end of year corresponding to winter conditions, and higher chlorophyll (*chla)* values (10.0-20.0 mg $^{-3}$) are present in the spring and summer periods. Further, often fall bloom occurs where chlorophyll concentrations exceeding 5.0 mg m^{-3} occurred every year with the exception of 2007. Typically, *chla* values in the northern Salish Sea region are lower than 3.0 mg m^{-3} during winter months.

The results from their yearly analysis (2003-2015) of MODIS-Aqua image indicated that the spring bloom initiation, on average, occurs on March 29 (day=88 ±4 days) and on March 20 (day=80 ±4 days) for the central and north Salish Sea, respectively. However, 2005 and 2015 had the earliest bloom initiation dates with the central region blooming on February 22 and 21 (±4 days), respectively, and the northern region approximately one week later on March 2 (±4 days).

The spring bloom is generally followed by a lower magnitude late summer or fall bloom.

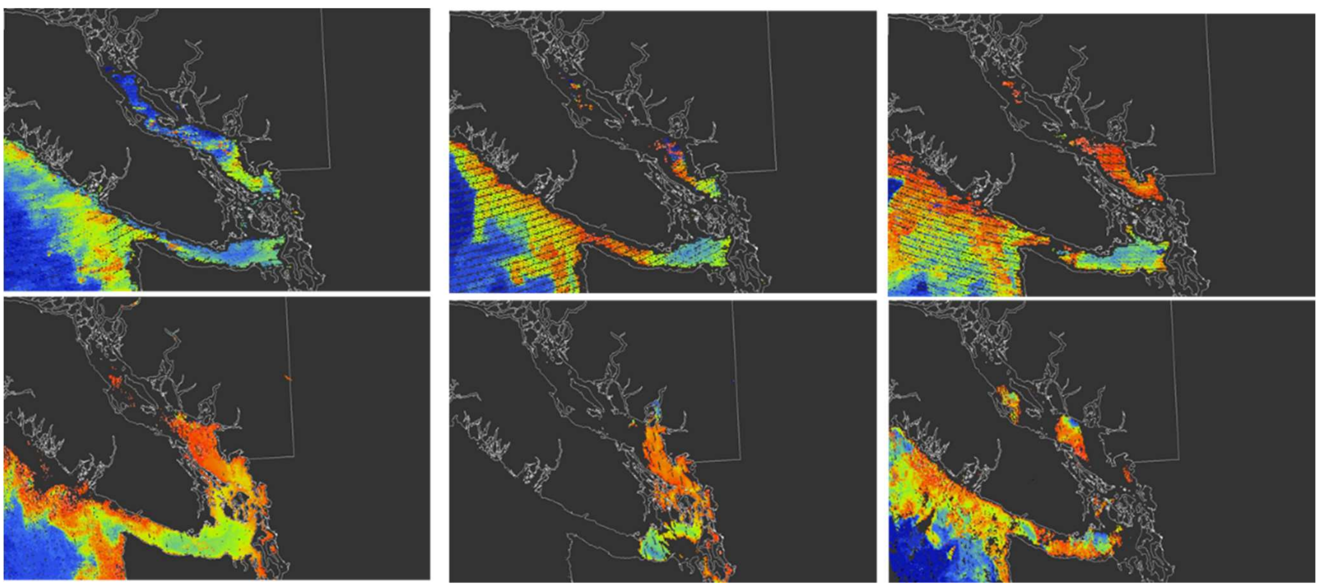


Figure 1. Development of spring bloom (red) n the Strait of Georgia March 2015. Satellite imagery.

Specifically, this work addresses the general hypothesis that the size and survival of juvenile salmon is related to the time of juvenile marine entry, the time of the zooplankton bloom, and the related phytoplankton bloom (i.e., a Match/Mismatch hypothesis). Progress as related to the two key objectives is as follows:

- Objective 1: Derive fifteen years of spatial-temporal improved biogeochemical and SST products based on present (MODIS - available since 2002) and future (Sentinel-3 to be launched in 2015) ocean colour satellites. This is an on-going activity. Costa *et al.* will introduce imagery from VIIRS, which has been recently defined by NASA as calibrated for deriving chlorophyll products.
- Objective 2. Define integration method to use data acquired from vessels of opportunity (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. This is an

on-going activity. They have advanced in several fronts. An initial planning phase started in September 2015, which has involved an extensive review of the SAS Solar tracker instrument documentation with involvement with the manufacturer Satlantic. Additional planning work has been carried out in the lab with engineered drawings of the two ships of opportunity, provided by BC ferries, to establish accurate measurements of both vessels. With these drawing, Costa *et al.* were able to accurately determine a set of optimal locations to install the instruments. This step has been followed by Measurements for testing data quality for the potential locations we have established as being optimal for instrument setup. In regard to the involvement of the citizen science boats, they have decided to first test the methods with data acquired by ferry passengers. They have started to purchase the tablets to carry out tests with data acquired by Ferry passengers.

The next steps will be the incorporation with VIIRS and Sentinel-3 imagery analysis, and in parallel they will integrate data acquired by other SSMSP programs in the imagery analysis. Specifically, these data will include phytoplankton composition, chlorophyll concentrations, and zooplankton. They will also evaluate the data collected by the citizen science boats. A post doc is being hired by Maycira Costa at University of Victoria in 2016 to integrate and assimilate the oceanographic and biological information.

A1.3 High temporal resolution monitoring of surface water properties in the Salish Sea

Team: Stephanie King, Managing Director, Sea This Consulting, Jim Gower, DFO

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 Figure 1 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.

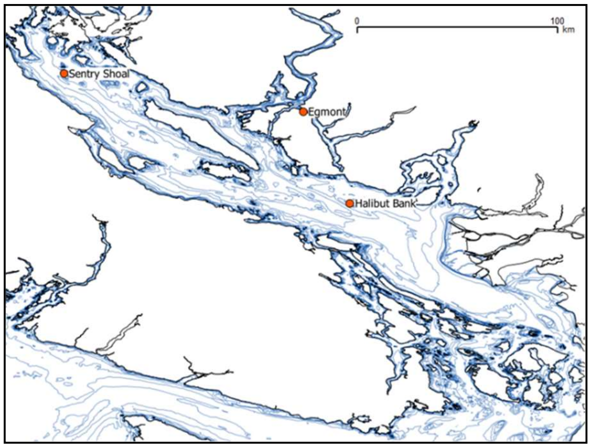


Figure 1. Three proposed sampling sites for chlorophyll fluorescence time series in the Salish Sea.

Status and Preliminary Results:

Oceanographic sensors were deployed and maintained from the beginning of 2015 onward at Halibut Bank and Sentry Shoal, and in the spring only at Egmont. High temporal resolution time series were collected for chlorophyll fluorescence, turbidity, temperature, salinity and nitrate with very few interruptions due to fouling. Key results include 1) a clear start to the spring bloom on Feb. 21 in the northern Strait and on Mar. 7 in the southern Strait; 2) demonstration of seeding from inlets using buoy data and satellite imagery; 3) promising results from the new nitrate sensor show that nitrate can be monitored autonomously and can help explain phytoplankton variability in the Strait.

The buoy monitoring program will support testing several of the SSMSP key hypotheses relating to prey availability, productivity and the health of the ecosystem. The high temporal resolution dataset gives context to the periodic sampling by the DFO and Citizen Science SSMSP monitoring.

The originally proposed objectives were met for this project. At Halibut Bank, a time series of chlorophyll fluorescence, turbidity and temperature has been maintained since January (Figure 2). At Sentry Shoal, chlorophyll fluorescence, turbidity and temperature have been monitored since February, and nitrate and salinity since April (Figure 3). At Egmont, chlorophyll fluorescence was monitored from January to April (Figure 4).

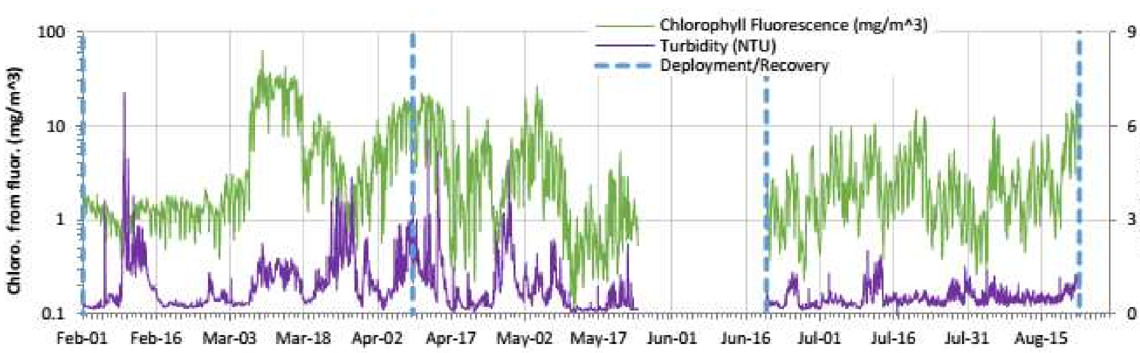


Figure 2. Chlorophyll fluorescence and turbidity at Halibut Bank in 2015. Blue vertical lines mark when instruments were serviced. Data in late May and early June were removed due to fouling. The spring bloom started on Mar. 7 and reached a peak of almost 50 mg/m3 on Mar. 9. Intermittent increases in turbidity were likely from the Fraser River plume. The chlorophyll fluorescence shows a strong daily cycle from non-photochemical quenching.

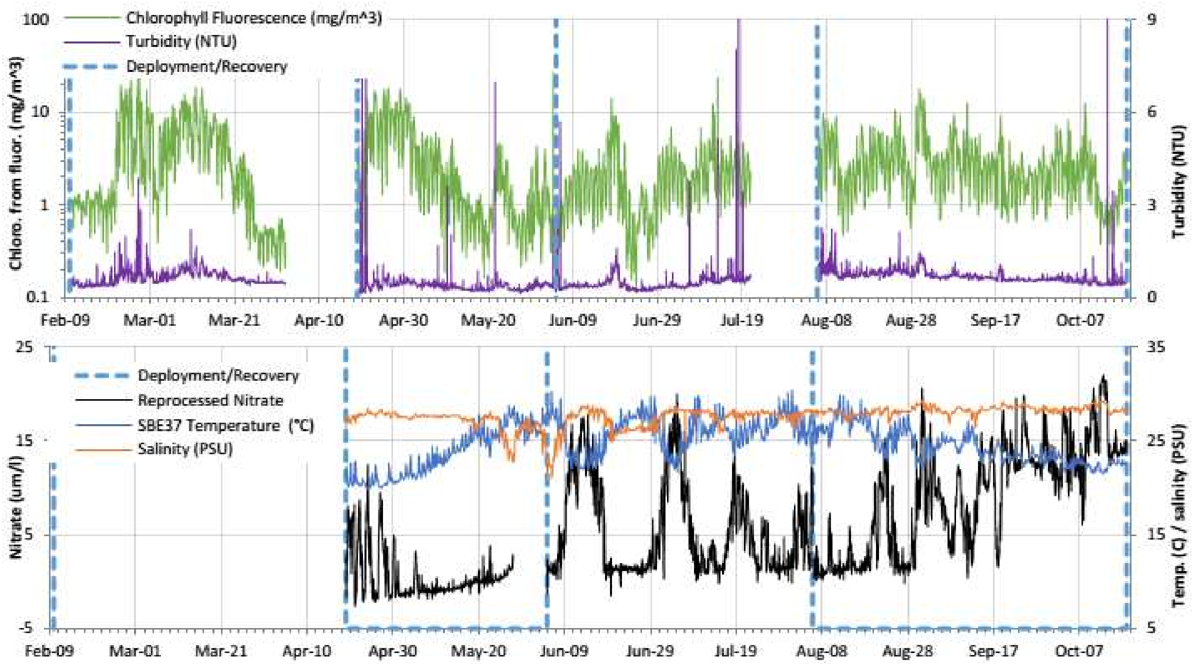


Figure 3. Chlorophyll fluorescence and turbidity (top) and nitrate, temperature and salinity (bottom) at Sentry Shoal in 2015. Blue vertical lines mark when instruments were serviced. Fouled data were removed leaving gaps in fluorescence and turbidity data (top) in April and late July, and gaps in the nitrate data (bottom, black series) in late May. No fouling was observed in the temperature and salinity data (bottom, blue and orange series).

The spring bloom started on Feb. 21 and reached a peak of almost 35 mg/m3 on Feb. 26. The turbidity series (top, purple series) showed no influence from river runoff and varied mainly with chlorophyll (top, green series). Several high nitrate events occurred through the summer and at the same time as high salinity and low temperatures. These events were usually followed by increases in chlorophyll. The chlorophyll fluorescence shows a strong daily cycle from non-photochemical quenching.

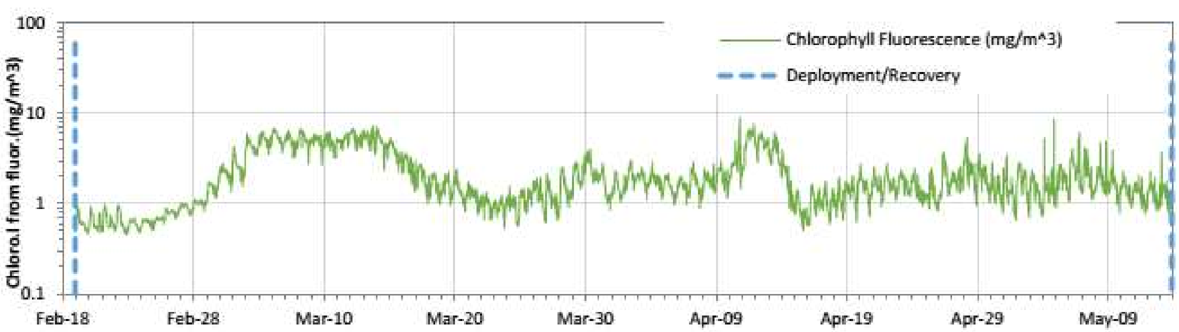


Figure 4. Chlorophyll fluorescence in the spring 2015 at Egmont. Fluorescence increased in late February and early March. The spring bloom lasted from about Mar. 5 to 14 with concentrations between 5 and 9 mg/m3. The time series shows daily dips explained by non-photochemical quenching.

Fluorescence Line Height (FLH) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua satellite was used to provide spatial context for in situ measurements (Figure 5). FLH has a linear relationship with chlorophyll at concentrations below about 20 mg/m3 and tends to perform better than the standard satellite chlorophyll products, with less confusing signal from aerosols, sediment and dissolved organic matter.

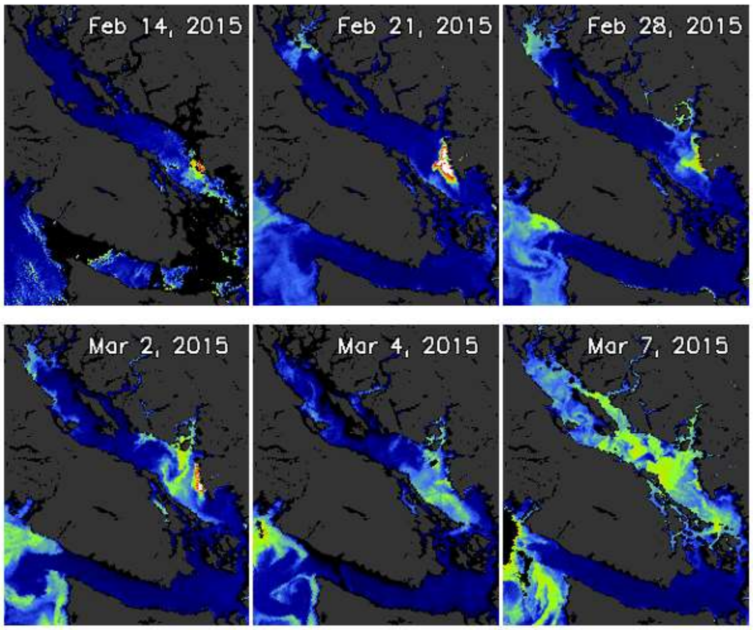


Figure 5. Fluorescence Line Height (FLH) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua satellite was processed from level1B data. Compared to standard chlorophyll products, FLH performs well in BC coastal waters with less confusing signal from aerosols, sediment and dissolved organic matter.

In situ chlorophyll fluorescence at Sentry Shoal shows a rapid increase on Feb. 21 which is confirmed by satellite image on the same day. A small, bright patch imaged on Feb. 14 in Desolation Sound indicates possible seeding of the early bloom in the northern Strait. The FLH image from Feb. 28 suggests seeding from Howe Sound and also shows a bloom in Sechelt Inlet. The Egmont fluorometer measured increased fluorescence between March 1 and 5 as the Sechelt bloom moved into Jervis Inlet. This was also observed in the Mar. 2 and 4 satellite images. The Halibut Bank data show the spring bloom starting on Mar. 7, the same day that MODIS confirmed the spring bloom covering most of the Strait.

The monitoring program was carried out as planned. Fouling was an issue and several additional anti-fouling measures, such as applying copper tape to the instruments and attaching a copper painted screen to the SUNA housing, were tested and implemented. The aluminum housings are now painted to reduce corrosion. The deployment schedule for 2016 will also be changed to accommodate shorter deployments in the spring/summer and longer deployments in the fall/winter.

A1.4 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 are continuing in spring-summer 2015.

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 has become 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) is being 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, will provide 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 will be 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 will also work 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.

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:

Moorings have been deployed in Cowichan Bay and Satellite Channel continuously since June 2014 and until the spring/summer of 2016 to measure water movement and type (Temperature, Salinity, acoustical Doppler current profiler) and productivity (Fluorometers). These data will be interpreted during the winter of 2015/2016 before the end of the project. The location for the three moorings are shown below. An ADCP (measuring currents and 300 kHz backscatter) was deployed at the station MCBN shown below.

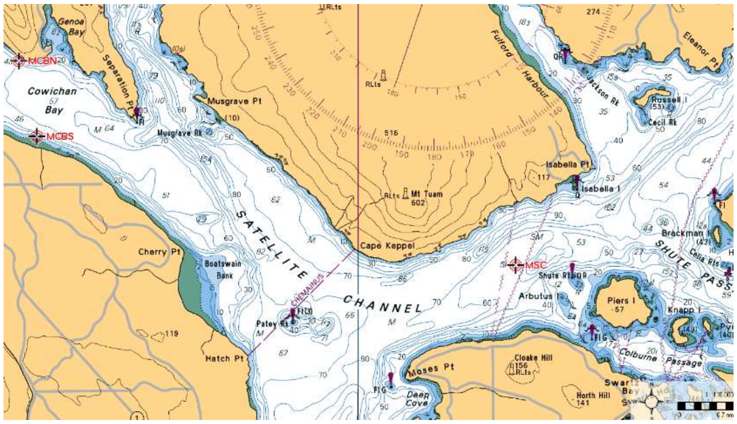


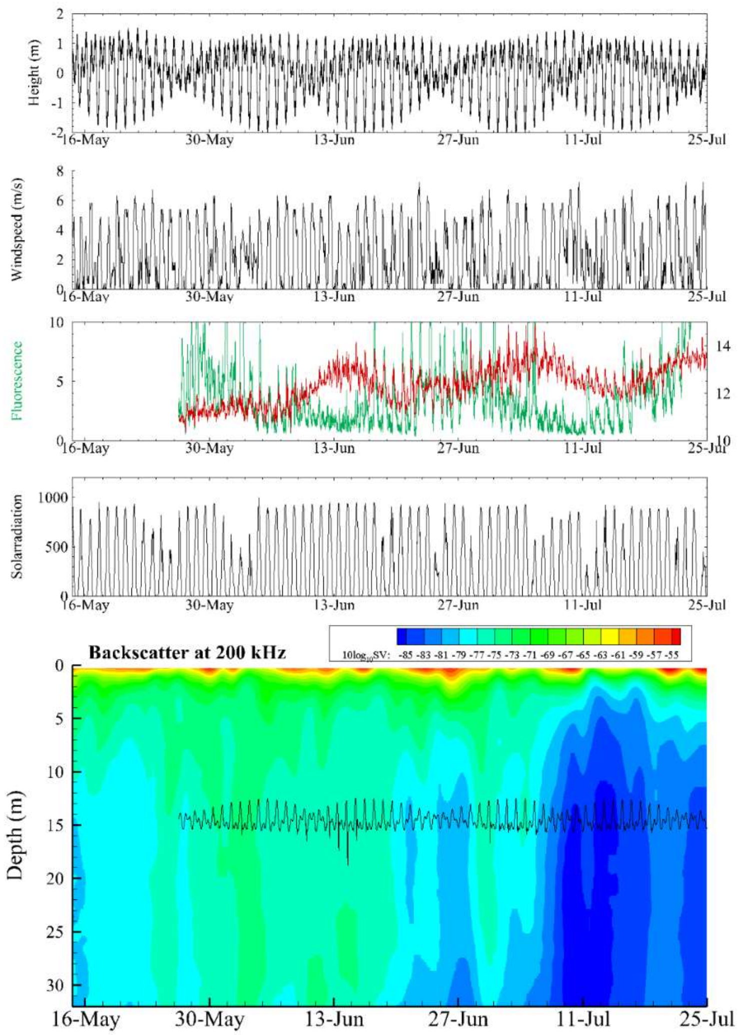
Figure1.Location of moorings in Cowichan Bay

The two boats used for PSF research in Cowichan Bay and surrounding waters were serviced in January and are now both fully operational. Since January 2015, a number of missions have been made to collect depth profiles of temperature, salinity, oxygen, and fluorescence at 13 stations in and around Cowichan Bay. These data have been downloaded to ONC as part of the Citizen Science program. Net tows and nutrient sampling have also been parts of this research. A 100 kHz sidescan sonar system has been tested in Patricia Bay, and used in Cowichan Bay in mid June.

From May 16, 2015 to July 24, 2015 a 4-frequency (125, 200, 455 and 769 kHz) backscatter sonar system was deployed in Cowichan Bay to continuously identify and count fish targets and function of time and water-column depth. This state-of-the-art multi-frequency backscatter sonar system (AZFP) provides multi-frequency data which will be used in an attempt to identify target sizes. These data will also be echo-integrated to obtain time-series of zooplankton and perhaps phytoplankton abundance. In addition, the data will allow for identification of seals to investigate fish-seal interactions in the area being investigated.

A 300 kHz Imagenex sonar system was delivered by the end of May. The 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 figures below show examples of data from MCBN and AZFP moorings:



Tides from pressure sensor and AZFP showing neap and spring tides.

Wind speed from sensor on sawmill dock showing the strong diurnal summer signal.

Fluorescence (green) and temperature (red) at approximate depth of 15 m (see black line in bottom panel).

Solar radiation from weather station on sawmill dock.

Averaged backscatter at 200 kHz referenced from the ocean surface.

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.

A1.5 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 and Preliminary Results:

In December 2014 chemical oceanographic monitoring equipment was installed at the 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. A SAMI pH meter was also deployed at the site between February to April 2015 to provide a concurrent measure of pH to validate the full chemical monitoring suite. Carbon dioxide standards are run automatically daily to continually calibrate the system, and the system is operating stably since installation.

The shellfish raft for biological deployment was constructed late January / early February, from which all plankton measurements would be taken. By February 2015 the team had developed protocols for sampling both quantitatively and qualitatively for phyto- and zooplankton.

Plankton sampling began at the Quadra Island site on 16 February 2015. Twice per week the following samples were 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 – see sections below)
- Zooplankton quantitative horizontal surface tow, 250µm plankton mesh
- Phytoplankton qualitative vertical tow, 20µm plankton mesh (see sections below)
- Phytoplankton quantitative surface sample, no filtering

Oceanographic data is emailed to Dr. Wiley Evans for processing once a week. This data is then analyzed to calculate calcium carbonate variables, as seen in Figure 1 below.

The data has revealed large and rapid variations in ocean conditions, such as important calcium carbonate saturation states, and linkages to coastal processes such as upwelling. There were extended periods of fall/winter corrosive conditions and The fall and 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. Further testing will be carried out to examine the annual pattern and to determine whether there are anthropogenic influences. The sharp decrease in carbon dioxide and subsequent increase in aragonite saturations in late February to early March, were early indicators of the early spring phytoplankton bloom observed in the Salish Sea this year. Subsequent rapid changes in aragonite saturations and carbon dioxide levels were also observed, and it will be interesting to compare these results to phytoplankton and zooplankton data once fully analyzed.

Phytoplankton and zooplankton production were correlated to oceanographic changes, and blooms in 2015 showed that there may have been one mismatch (early spring bloom late February / early March) and one matched the timing of peak migration of sockeye passing through the area. Diatoms dominated the percentage composition of samples, including mechanically harmful species, but levels of toxic harmful algae had low precedence. This work will be ongoing until August 2016.

This project aligns with the Salish Sea Marine Survival Project hypotheses related to prey availability (food supply, productivity, timing of food availability), metabolic effects (impacts of temperature on prey species) and ocean acidification (observed ranges, impact on productivity, impact on *Heterosigma*, harmful algal species in general, synergistic impacts with temperature). This project identified peaks in primary and secondary productivity which will assist in determining timing of hatchery release and factors for wild survival return forecasting (match-mismatch). In terms of harmful algal species, very few toxic species were observed and therefore this is unlikely to have impacted salmon populations moving through the northern Strait of Georgia. Migrating salmon may have encountered mechanically harmful (*Chaetoceros* species), which combined with warmer than average observed water temperatures may impact survival and therefore returns. In addition, the observed fluctuations in calcium carbonate chemistry and subsequent zooplankton analysis (underway) may provide valuable information on future climate scenarios on the quantity and quality of prey species.

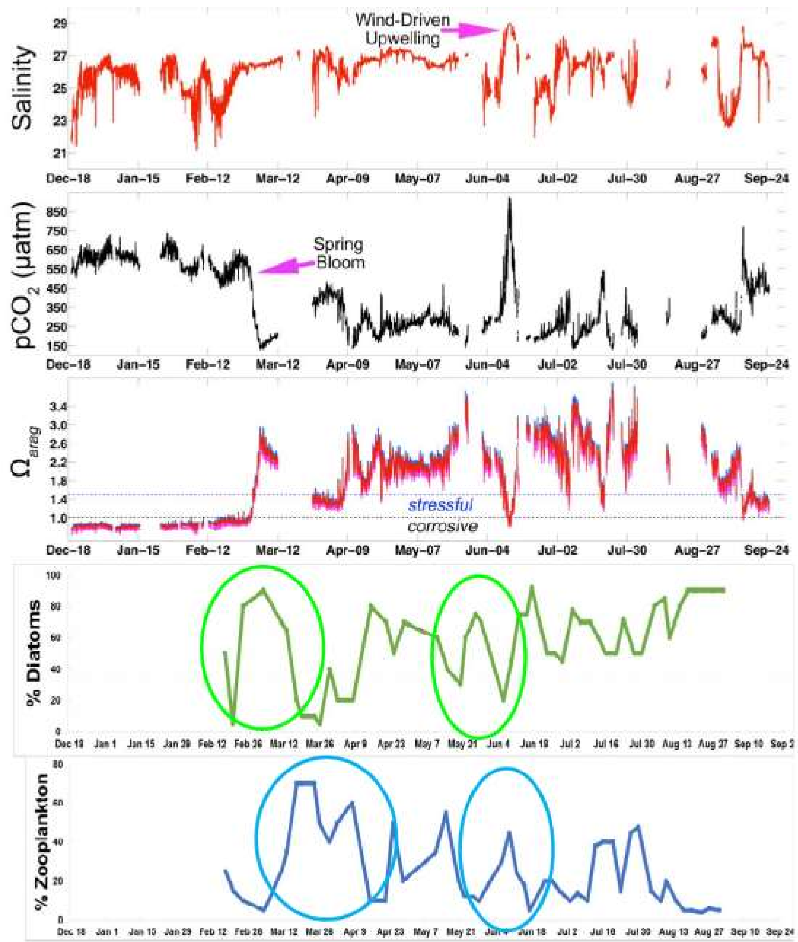


Figure 1 - Sea surface temperature (SST; °C), sea surface salinity (SSS), CO2 partial pressure (pCO2; µatm), and the saturation state of aragonite (Ωarag) from December 18, 2014 to September 24, 2015. Diatom, zooplankton and harmful algal data as percentage (%) constituents of plankton tow sampling from February 17 to August 31, 2015.

A2. Zooplankton and Ichthyoplankton

A2.1 Zooplankton and ichthyoplankton status and trends in the northern Salish Sea

Team: Dr. 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.

The central question being investigated by this project is "what physical oceanographic and plankton processes control the seasonal and interannual variability in zooplankton timing, amount and composition". This question directly relates to the Salish Sea Marine Survival Program investigations of marine versus freshwater survival of juvenile salmon in this region, in particular to questions of: whether there is a critical period and/or a critical size for juvenile salmon to survive; the availability of plankton prey to fish; whether there is a match or mismatch in the timing of plankton food supply and fish predation; and questions of the quality and availability of plankton prey for these fish.

This project will leverage existing DFO resources and programs sampling zoo/ichthyoplankton in these areas, and add 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., and in the Canadian program only certain larger vessels are capable of conducting oblique tows (therefore reducing both spatial and temporal coverage for these samples).

The main project research questions are as follows:

1. What are the seasonal patterns of zoo/ichthyoplankton species composition, abundance, and biomass in the northern Salish Sea areas?
2. How do these properties vary with changes in physical conditions?
3. How do variations in these properties influence the marine growth and survival of juvenile salmon in these areas?

To answer these questions, the project has a three tiered approach:

1) use of existing DFO surveys to provide a "backbone" of stations throughout the Strait of Georgia to obtain seasonal information on zooplankton trends, composition, and abundance;

2) use of a smaller charter vessel to sample the same and supplementary stations to provide information at times in between the DFO surveys;
3) Citizen Science vessels to sample selected locations at higher frequency (e.g. approximately weekly)

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 and Findings to Date:

The objectives of this project for 2015 were fully met. This included setting up the survey program and collecting a record number of samples in the Strait of Georgia (424 samples). The Canadian team performed mostly vertical zooplankton tows, but oblique tows were also carried out on selected surveys.

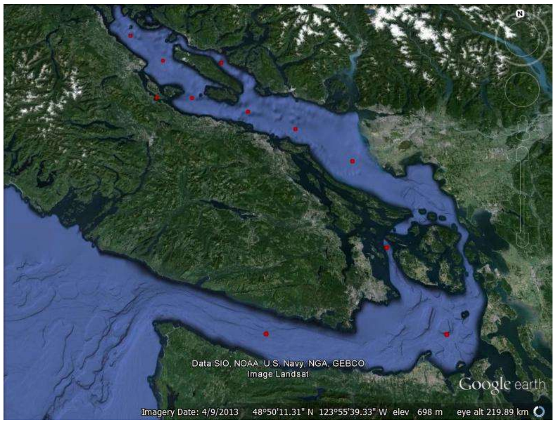
Sampling was conducted at approximately 20 locations in the Strait of Georgia, every two weeks from mid-February to mid-October 2015. This represents the most intensive zooplankton sampling in the Strait of Georgia ever carried out. Surveys were conducted using a sequence of platforms, including DFO survey vessels, a charter survey vessel, and two citizen science vessels. Seven 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 424 zooplankton samples were collected; about half have been analysed to full taxonomic resolution as of December 2015 (with analyses continuing). Phytoplankton samples collected bi-weekly from Citizen Science vessels (based in Baynes Sound and the Sunshine Coast) have been analysed for taxonomic composition and results posted to BaseCamp.

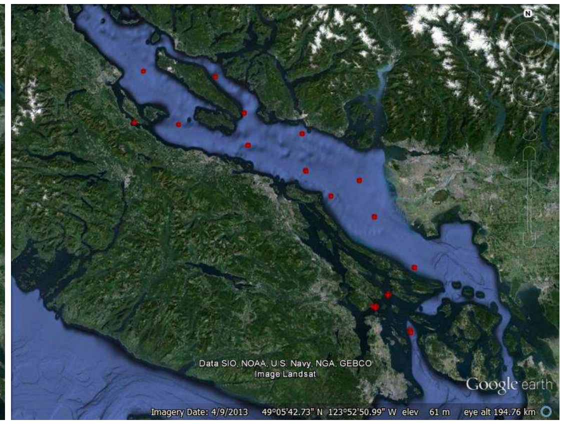
The total number of samples collected from these charter vessel surveys, DFO vessel surveys, and Citizen Science surveys, related to the Salish Sea Marine Survival Project is shown below:

Project	**# Processed**	**# Unprocessed**	**Total**
DFO-Charter	75	25	100
DFO-Chandler	28	12	40
DFO-IOS	27	19	46
DFO-PBS	1	95	96
Other SOO (CRD, NOAA)	3	8	11
Citizen Science	56	55	111
Cowichan Bay	20	19	39
TOTAL	**210**	**233**	**443**

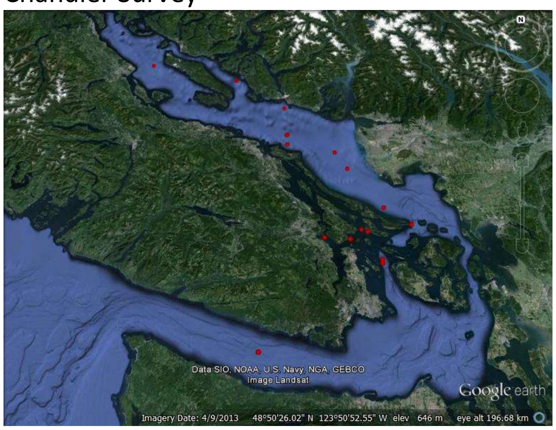
Sample locations are provided below:



Chandler Survey

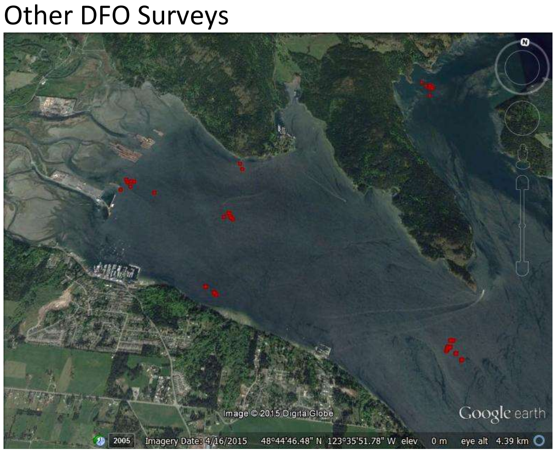


Charter Survey

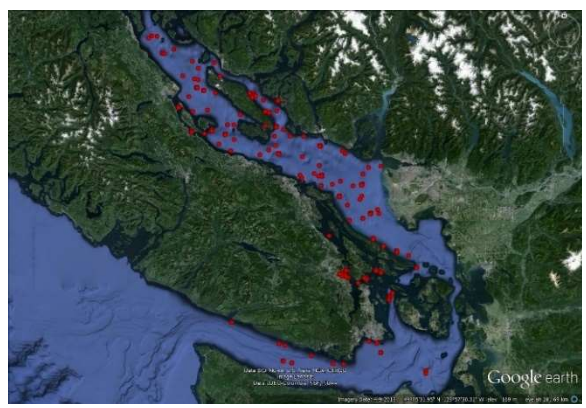


Other DFO Surveys

Citizen Science Surveys (Baynes Sound, Irvine)



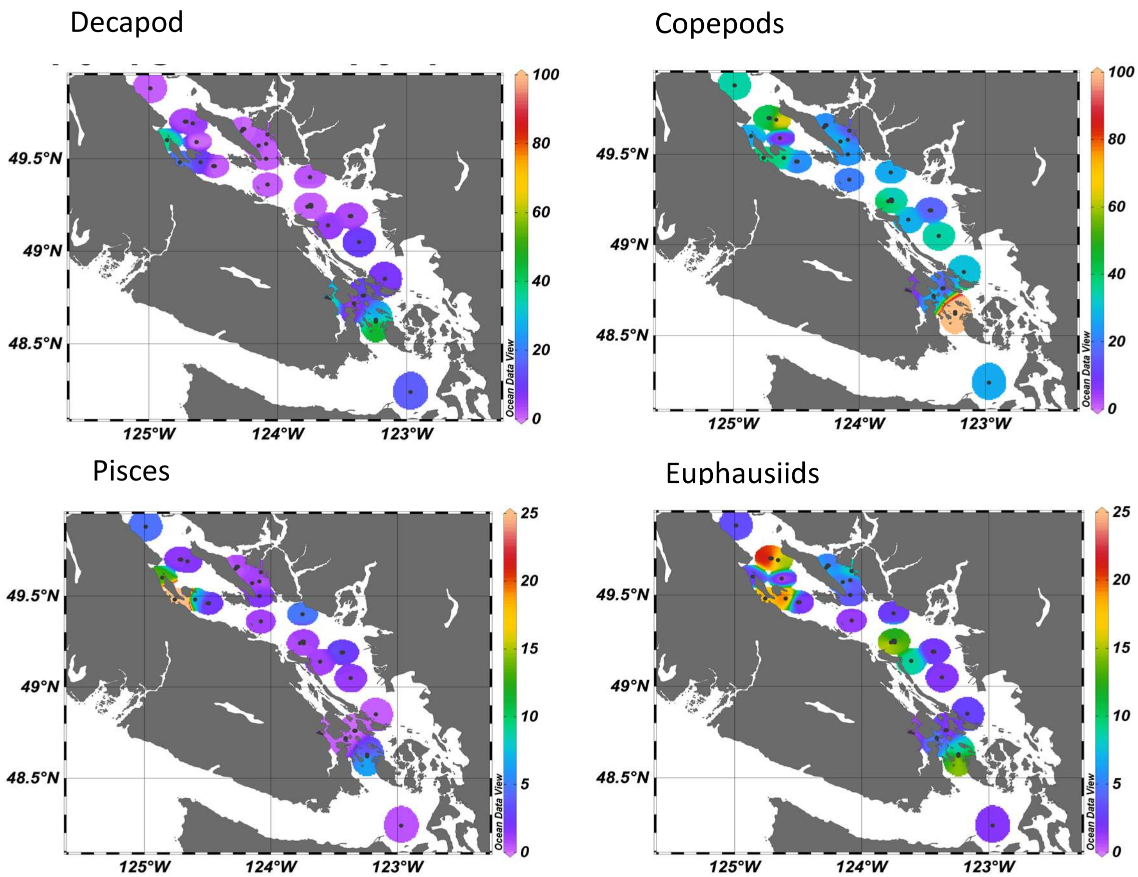
Cowichan Bay Surveys



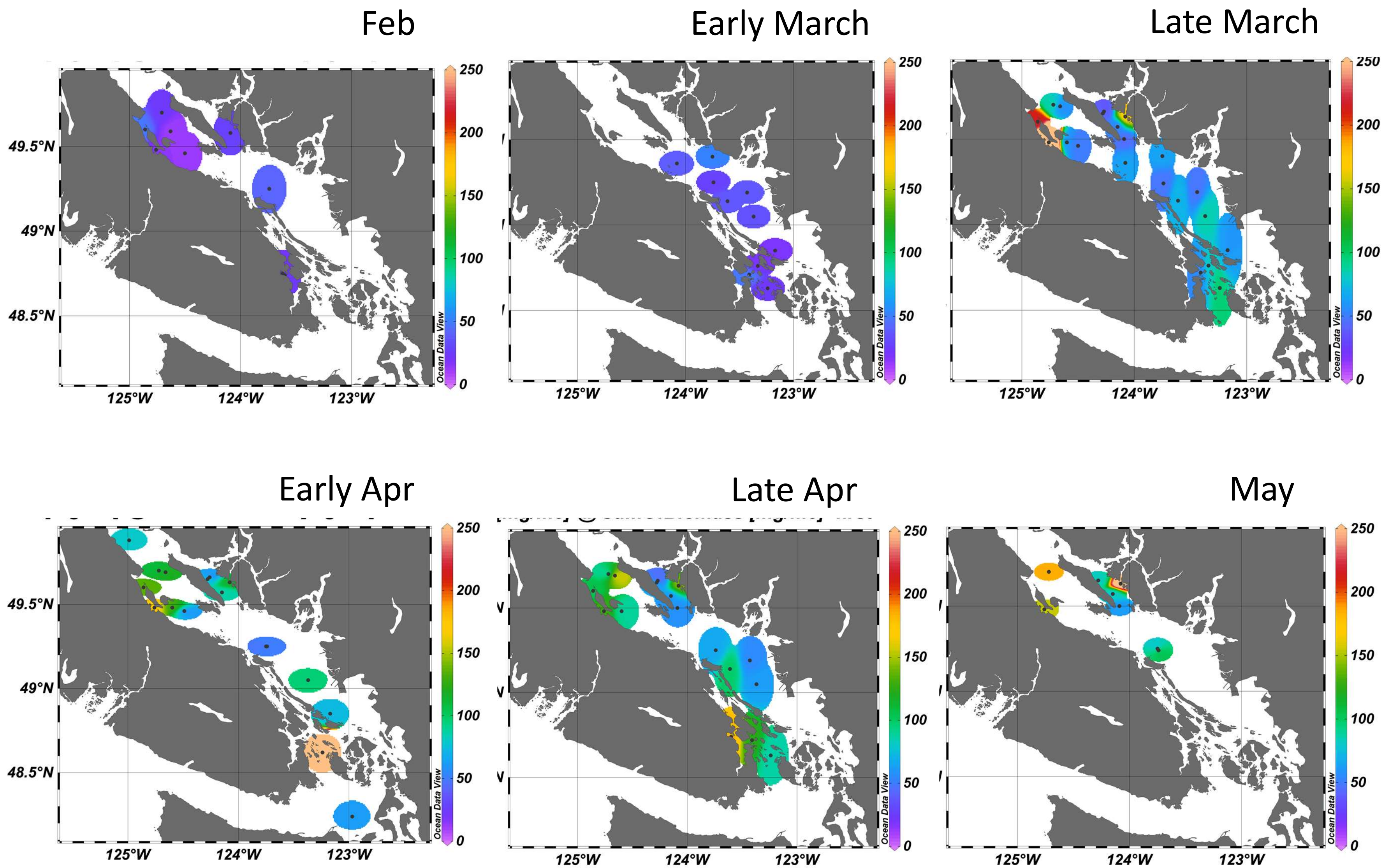
Entire Strait of Georgia Coverage 2015

Some preliminary data are provided below. Data analysis is not yet complete so these results will be updated in summer 2016.

Biomass (mg/m3) of selected groups; All to-date samples combined:



Spring biweekly biomass (mg/m^3):



This has been the most intensive plankton sampling effort ever carried out in the Strait of Georgia. The collection of data allowed for examination of the summer warming in the Strait of Georgia this year, which was in part influenced by the unusually warm ocean waters on the west coast of North America. It also allowed for identification of the early spring phytoplankton bloom. The PIs noted that the biomass size spectra show dominance of plankton in the 20-25 mm range in all seasons.

The CTD and chlorophyll fluorescence data have all been quality controlled and archived in the IOS database. These data provide oceanographers with more frequent information about the physical properties of the Strait of Georgia than are obtained from the 3-5 DFO-led surveys per year in this region. The Chl-a data helped to identify problems with the analyses of chlorophyll being conducted by the citizen science program so that adjustments could be made. CTD fluorescence and chl-a data can also be used by other SSMSP projects relying on models, e.g. by providing chl-a data from the Halibut Bank buoy to assist in buoy fluorometer calibrations, and for use in groundtruthing the satellite data.

The researchers identified the timing of the spring phytoplankton bloom as being unusually early in 2015, and identified the timing of peaks in spring and summer zooplankton biomass and species composition. A bloom of small zooplankton occurred early (mid-March) in the northern Strait of Georgia, followed a few weeks later (early May) by the main bloom throughout the Strait. Time series of zooplankton believed to be key prey items for juvenile salmon (based on analyses of salmon gut contents by other SSMSP projects) have been developed. Analyses of collected samples are still underway, but enough data covering the entire seasonal cycle from selected locations are available to provide to SSMSP projects studying fish distributions, feeding, and growth. Statistical comparisons of plankton biomass anomalies with trends in salmon survival and with large-scale atmospheric climate indices are underway.

A training workshop was conducted by two DFO staff for the plankton lab of the University of Washington, with the purpose of ensuring coordination of taxonomic identifications between U.S. and Canadian components of the Salish Sea program, and to exchange knowledge of unusual and interesting plankton appearing in the samples.

Finally, an “Information Bulletin” was prepared and circulated on behalf of the program, identifying the timing of the spring phytoplankton bloom in the southern Strait of Georgia in 2015.

This sampling will be repeated in 2016.

A3. Forage Fish- Canada

A3.1 Acoustically derived indicators of demersal and forage species productivity in the Strait of Georgia, and their link to the survival of juvenile salmon.

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 potential 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 potential 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, began work on the hydroacoustic data set on March 1 2016 and is hosted in Dr. John Dower's lab at UVic.
- A two-week acoustic survey has been conducted in the Strait of Georgia during Mar 14-27, 2016. Collected acoustic data from this survey has been pre-processed.
- Dr. Lu Guan will attend an echoview training during May 23-27, 2016, after that she will start intensive data process and analysis.

A3.2 Strait of Georgia juvenile herring and nearshore pelagic ecosystem survey.
Team: Jennifer Boldt (lead), Research Scientist, Fisheries and Oceans Canada (DFO), Pacific Biological Station (PBS), Matt Thompson, Technician, DFO, PBS, Charles Fort, Biologist, DFO, PBS, Carol Cooper, Taxonomist Contractor, Zotec services, Doug Henderson, Skipper and Fisher Contractor, Dr. Marc Trudel, Research Scientist, DFO, PBS, Dr. Stéphane Gauthier, Research Scientist, DFO, Institute of Ocean Sciences, Dr. Kyle Garver, Research Scientist, DFO, PBS, Jaclyn Cleary, Biologist, DFO, PBS.

Objectives:

- Update age-0 Pacific 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 Salmon, which generally switch to piscivory early in their marine life, are likely 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 and Findings to Date:

Research activity for this project is proceeding as planned. The key accomplishments of this project include the following:

1. Completion of the 2014 and 2015 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.
2. In addition to completing surveys, a time series of the relative biomass and abundance of age-0 herring was updated (Figure 2). They identified suitable data and statistical methods for estimating an index (and associated variance) of the relative biomass or abundance of age-0 herring.
3. 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 (68% of variability), (Figure 3) and
    b.) to some runs of Chinook Salmon survival (explaining up to 47% of the variability). (Figure 4)

4. The annual variation in herring lengths, weights, and fish condition (length-weight residuals) were examined and herring condition increased after 1997, with positive residuals since ~2005, which may have implications for the quality of prey consumed by juvenile Chinook Salmon.

Key lessons learned include the following:

- The SOG juvenile herring survey provides a valuable data set that may be used to estimate the relative biomass (abundance) of age-0 herring. This provides a potential leading indicator of recruitment to the adult herring population and may provide an indicator of prey availability to predators in the SOG, such as Chinook Salmon.
- They recommend that sampling of core stations and transects continue, following consistent and standardized practices and with more accurate measures of depth where samples are collected. To reduce CVs, more transects should be sampled, however, trade-offs between lower CVs and higher costs would need to be considered.
- They also recommend that multiple indices are calculated (catch weight, CPUE, and abundance) using a two-stage method and the less conservative formulae (Thompson 1992) for estimating variance. Given a consistent approach to sampling and index calculations, the herring indices can be used to explore other research questions that might elucidate factors affecting herring survival and recruitment, as well as the survival of predators.
- Next steps might include more in-depth analyses of the relationship between the relative biomass of age-0 herring and Chinook Salmon survival and perhaps juvenile Chinook Salmon diets in the SOG.

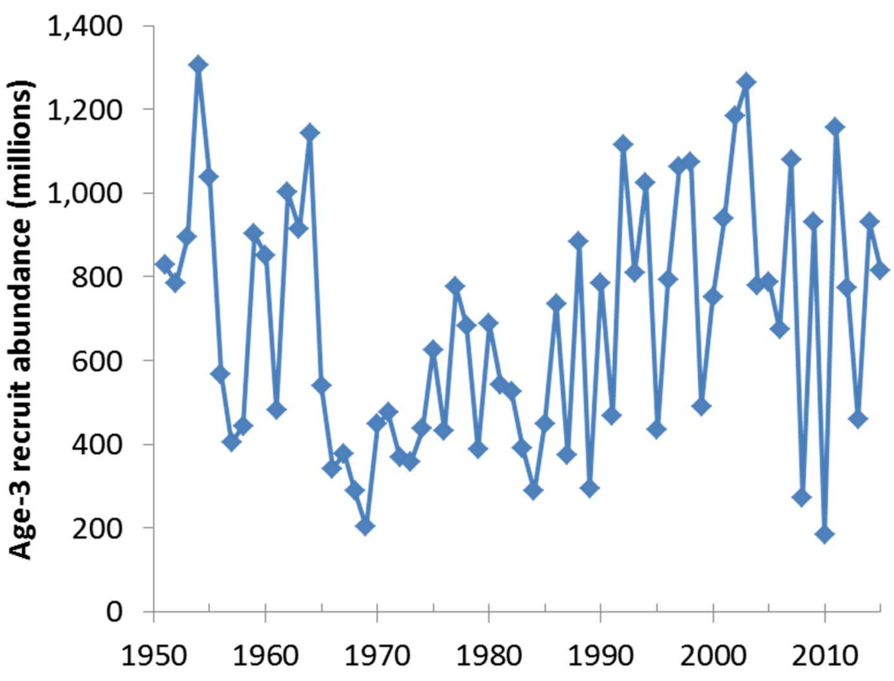


Figure 1. Pacific Herring Recruits, 1951-2015 (DFO) Stock Assessment Output

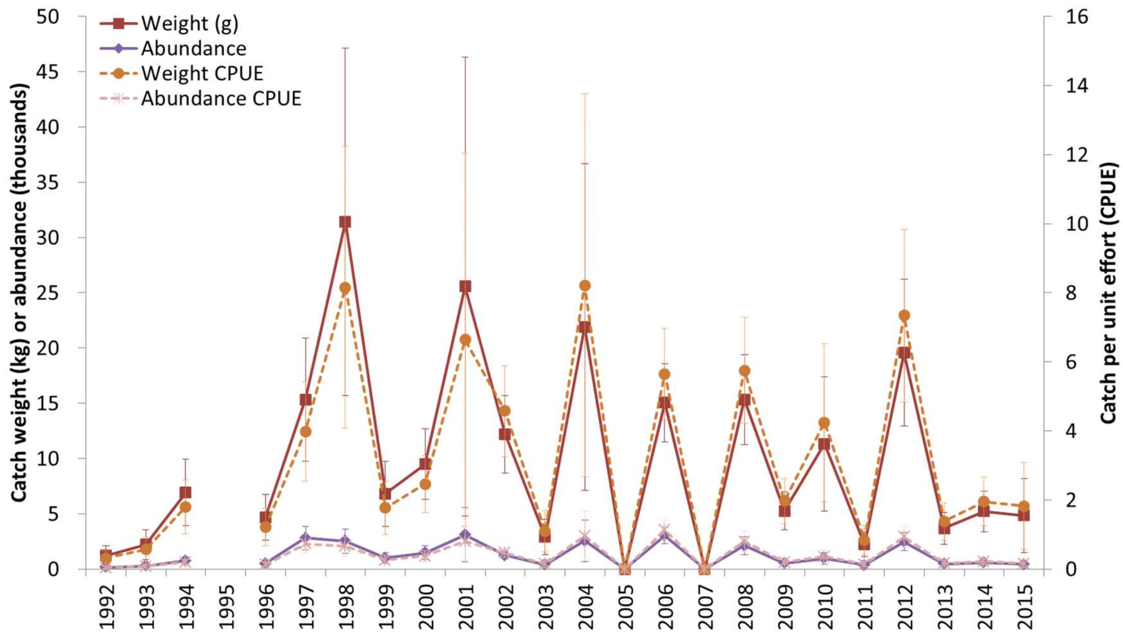


Figure 2. Survey Catch Weights & CPUE (se) Age-0 Herring

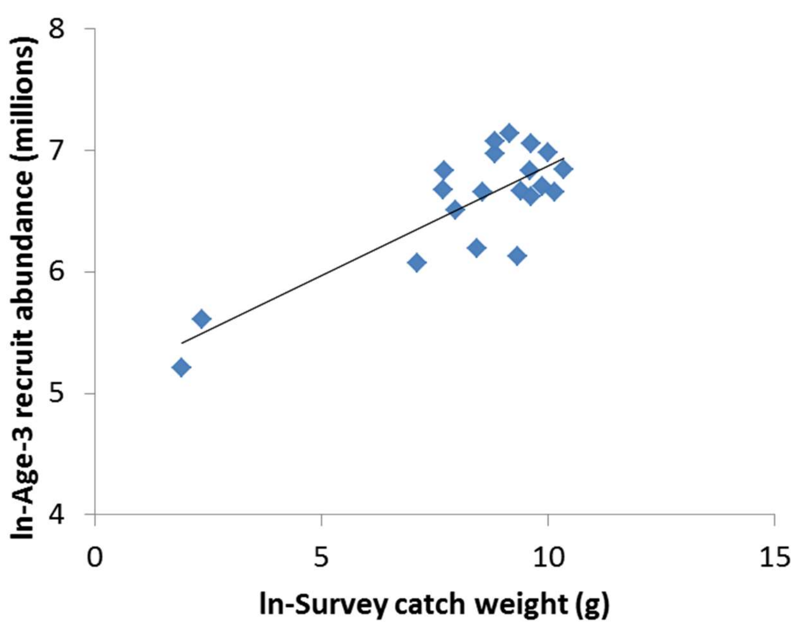


Figure 3. Age-3 Recruits from Stock Assessment vs. Age-0 Survey Catches (with 3 year lag)

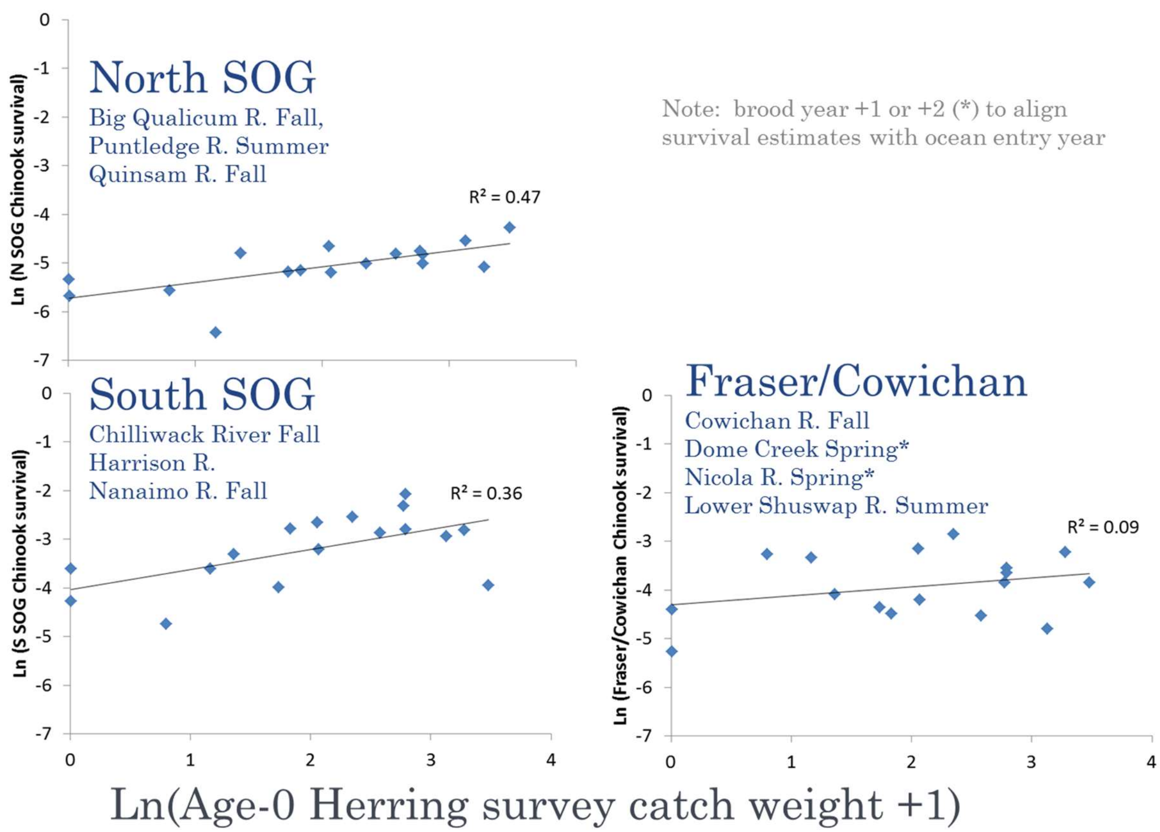


Figure 4. Chinook Salmon Survival vs.Age-0 Herring Survey Catches, 1992-2009

A4. Juvenile salmon - Canada

A4.1 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, estuary, and early marine off-shore periods of life.

Background:

Both rotary screw trap and PIT (passive integrated transponder) tagging methods were 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. If it is concluded that hatchery smolts released a significant distance upstream from the estuary experience high losses prior to saltwater entry, a follow-up study could be implemented to determine if lower river hatchery releases improve overall and river return survival.

The RST work was supplemented with a freshwater PIT tagging study carried out by BCCF during 2015. Hatchery chinook were PIT- tagged and released at the usual release location, and their survival estimated using a radio-frequency identification array (RFID, i.e., an antennae) 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/size. 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 were tagged in the hatchery, in the river, by beach seine in the shallow nearshore and estuary, by purse seine in deep nearshore waters, and then by microtrolling in coastal waters off the Cowichan watershed.

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 and Preliminary Findings:

Rotary Screw Trap

There is a high level of mortality (98%) during the first two years of life of Cowichan Hatchery chinook salmon, with many possible reasons. This project examined the level of mortality in the initial stage associated with the hatchery fry releases, between the release in the upper river and their arrival downstream to the lower river where they reside for up to 2 months.

As in 2014, they used a rotary screw trap to catch a sample of the hatchery chinook moving downstream. The proportion of the run that were caught is estimated by releasing a small group of stained chinook just upstream of the trap, far enough so that they are randomly distributed. The proportion of the stained release caught in the RST provides a value for trap efficiency, and is used to expand the number of hatchery chinook to estimate the number that arrived to this location. This result is compared to the number of released chinook fry to estimate the mortality rate. This was accomplished for both the early and late releases.

Two groups of Cowichan Hatchery Chinook were released on April 22nd (348,485 CWT) and May 20th (465,438 CWT). A rotary screw trap was operated between April 8th and May 30th 2015 to monitor wild salmonid juvenile migration and to recover and estimate the population of hatchery chinook smolts that successfully migrated to the lower river (40 kms downstream). 9940 dye marked fish were released April 23rd approximately 1 km above the RST to estimate the trap efficiency and 4746 dye marked fish were released May 20th.

Trap efficiency during the two releases was estimated at 27.2% and 19.9%, respectively. Based on this data, they estimated that 65.5K chinook fry (95% CI 63.3K-67.8K) had arrived in the lower river from the early release group of 338.5K. Similarly, 49.7K chinook fry (46.7K-52.8K) arrived in the lower river from the late release group of 460.4K. Thus, they estimated that **19.4%** of the early release and **10.8%** of the late release represent the portion of the population that arrived in the lower river during the extent of this project. The data from the late release in 2014, using much poorer quality data, indicated a survival rate of 15-20%, similar to 2015.

Several factors are confounding the results. Although the trap efficiency was much higher that our target of 5%, they expected a higher level of trap efficiency with the late release over the early release due to a lower rate of water discharge. Second, they were forced to terminate field operations due to low water, with hatchery release chinook still being caught. In addition, early release chinook were still being caught when the late release was initiated so all hatchery chinook caught after that date were deemed to be from the late release.

The mechanism for the low survival rate is unknown and will need to be studied. Possible factors include:

- Residualization/slow migration rate
- Freshwater based predation (non-native brown trout)

This project provided evidence to support the hypothesis that a high level of mortality is occurring in the freshwater phase of hatchery reared fry. This stage of the life history occurs in the period after release in the upper reach of the Cowichan River, to the lower river upstream of tidal influence. Further investigation is warranted to compare this result to other similar studies to examine whether there are unique influences in the Cowichan River, and/or whether this observation is common to other situations. Further investigation within the Cowichan is warranted to identify whether the observation is due to hatchery release practices, habitat degradation, predator communities or other hypotheses.

PIT tagging

Freshwater

- Despite very low spring flows, in-river migration timing and rearing behavior appeared to be similar to 2014 (normal flows).
- Migrating hatchery Chinook from the release site to the lower river appeared to endure a high degree of mortality. Estimated survival using detection of PIT tags was 22% at the RST and 27% at the PIT array. (Release site to tide-water at Tzouhalem Road Bridges, 46 km). Thus the PIT tagging results showed similarly high mortality rates in the freshwater phase of juvenile Cowichan chinook life history as found using the Rotary Screw Trap.
- Migrating wild Chinook also experienced significant mortality although survival appeared to be 2X higher than hatchery fish (estimated at 49% over 41 km)
- Freshwater growth rates were calculated at 0.70 mm/day in 2015 compared to 0.60 mm/day in 2014. This difference was not statistically significant but suggests growth was good despite above average river temps and low flows during 2015.

Early Marine

- The size distribution of fish tagged in freshwater matched that of recaptures in the marine environment. This suggests there is little evidence for size-selective mortality during in-river migration and the transition to salt water.
- Marine recaptures were disproportionality associated with fish tagged in the lower reaches of the river. The survival estimate for hatchery fish migrating from the release site to the lower river (46 km) was only 14%.
- Similarly, survival of wild fish was estimated at 27% over 41 km. These survival estimates are about 55% of those based on in-river detections suggesting that fish which come from upper river habitats experience disproportionality higher mortality rates in the early marine environment.
- These observations collectively place a higher value on smolts originating in the lower Cowichan River despite similar abundance throughout 40 km+ of habitat (BCCF snorkel data 2014).

Outer Marine

- Micro trolling was proven to be effective for catching significant numbers of first and second year juvenile Chinook with limited bycatch. Catch per hour averaged 8 fish and was as high as 12. This has opened the door for studying juvenile Chinook in the 120 mm+ range using low-cost and highly mobile fishing platforms. The utility of this tool should be discussed for other work, not just application of PIT tags.
- Sansum Narrows was identified as a “hot spot” for rearing juvenile Chinook and Coho. DNA results indicated this area is shared by many different stocks suggesting it may be a good candidate for fine-scale study. Areas with similar characteristics (i.e. tidal mixing) should be explored to see if juvenile Chinook/Coho are disproportionally abundant in these areas.

In-River Detections – Returning Tags

- 15 unique PIT tags were detected in fall 2015 returning Chinook. 9 were at the counting fence and 7 at Skutz Falls. Of the 7 at Skutz Falls, only 1 was detected at the fence. This suggests about 63 tagged fish returned in 2015.

- Although the detection efficiency was disappointingly low, this indicates that the study design is sound and should produce a reliable estimate of marine survival by stage as the majority of returns are yet to come.
- Tag returns were distributed throughout each tagging stage including hatchery releases, in-river tagging, purse seining and micro trolling.
- Low detection efficiency is linked to radio frequency "noise" that limits the ability of the equipment to listen for the tag response and decode the tag identifier.
- An investigation of noise sources is currently underway. It is believed that altering antenna design at the counting fence will improve detection efficiency in 2016 to acceptable levels (>95%).

In spring 2016 SSMSP released funds to purchase a Biomark "Stout" PIT tag detection array. This array promises a significant improvement in read range (from 20 cm to 60 cm) and reduced radio frequency interference. Instead of one long antenna, this system is comprised of 6 smaller rectangular antennas laid end on end to span the wetted width. Two complete spans comprised of 12 antennas total and separated by 30 m will greatly improve tag detections. The system has been installed permanently in the Cowichan River in May 2016 and will operate year round. This makes it possible to record the juvenile fish PIT-tagged in freshwater as they leave the river, and to detect returning adults in the lower river independent of counting fence operation (which may not be operated in the fall of 2016 due to additional budget cuts and a lack of support from Cowichan Tribes).

A4.2 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 , Tom Iwanicki -MSc Student - 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 and scale circulus spacing as non-lethal methods 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 and circulus spacing based growth rate indices, 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 in US Salish Sea Technical Team (2012):

- Food supply limits growth, and thus survival, during critical periods of early marine rearing and
- 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 ratio and scale circulus spacing as indices 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. RNA:DNA ratio and outer scale circulus spacing 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 and/or circulus spacing based 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:

- 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 and Preliminary Results:
Field work was carried out at 5 sites (Saanich Inlet, Cowichan Bay, Satellite Channel, Sansum Narrows, and Maple Bay) from 6 July to 23 October (a total of 60 Field Days). Fieldwork concluded on 23 October and data analysis and field sample processing is in progress.

They captured 474 juvenile salmon (369 Chinook, 92 Coho, 12 Coho/Chinook hybrids and 1 Chum salmon) in 1459 individually logged 7-10 minute fishing events (15,905 hooks deployed). They conducted concurrent biological and physical oceanographic sampling including 59 pairs of water samples (surface and 10 m) for harmful algal bloom assessment; CTD casts and vertical zooplankton tows during both the flood and ebb tide on each sampling day (120 of each in total); and temperature loggers deployed at 5m intervals from 5 to 30 m on each fishing event. Captured salmon were measured, examined for parasites, sampled for stomach contents using gastric lavage, sampled for scales, and had a small muscle biopsy removed for RNA/DNA ratio based growth rate analysis (frozen in liquid nitrogen); Passive integrated transponder (PIT) tags were applied to 350 juvenile Chinook salmon as part of a BCCF led cohort survival study.

They also conducted a laboratory study to inter-calibrate the RNA/DNA based growth rate index with alternative indicators of recent growth (plasma IGF-1 and scale circulus spacing) and to compare the integration times of these alternative indices.

The specific relevance of their preliminary results to the comprehensive list of SSMSP Hypotheses is 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 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.

Their preliminary data are consistent with the hypothesis that juvenile Chinook salmon prefer areas which are more stratified, possibly due to more predictable prey distribution and/or due to the ability to select optimum temperature strata for growth. When they have completed analysis of their catch data by depth and temperature (based on temperature loggers deployed while fishing) they will hopefully be able to express this preference quantitatively. Their field collected muscle biopsies and scales may also allow us to relate the recent growth of juvenile Chinook to physical oceanography at the time and site of capture.

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. For example, in 2015 they had much lower catch rates that the BCCF microtrolling PIT tagging crews who focused their efforts on deeper strata where Chinook CPUE was

highest (they fished throughout the water column in order to detect depth distribution). Despite their lower CPUE, the proportion of Cowichan Chinook in their catch (59%) was twice that of the BCCF crews. They discovered that Cowichan Chinook CPUE was highest somewhat shallower than overall Chinook CPUE. This information can inform PIT tagging efforts in future years.

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 (for example, does a breakdown of stratification in the fall suddenly reduce availability of zooplankton prey, resulting in the onset of starvation).

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 our 2015 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 will allow them 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 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 across a gradient of water column stratification states and 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 we begin to test whether current, past of future conditions may be deleterious to their growth and survival. Preliminary data indicate differing depth distributions in Cowichan Chinook CPUE among study sites, with the most mixed site (Satellite Channel) having the least structured depth distribution.

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 stratified 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.

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 are also frequently observed in Sansum Narrows, and this group is considering the possibility of linking fine scale fish sampling and marine mammal distribution surveys and scat analysis during the 2016 season to investigate the possibility of focused seal predation at this site.

A4.3 Cohort Analysis and Marine Growth

Team: Marc Trudel (DFO-PBS), Chrys Neville (DFO-PBS), Oline Luinenberg (PSF), 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 will be 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.

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 we need to examine the factors affecting salmon growth in the marine environment.

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

Status and Preliminary Findings:

- Many juvenile Chinook salmon remain in the inner Cowichan Bay for an extended period of time. Purse seine fishing was extended into mid-August this year. The catches were lower than July but many Chinook were still captured and the largest catches still remained inside Cowichan Bay.
- Diet and feeding of juvenile Chinook salmon changes in the presence of harmful algae (higher incidence of empty stomach). This was seen in 2014 when harmful algae were observed. They cannot say if this reduction in feeding (increase in empty stomachs) is due to a change in the fish behaviour or a change in food abundance. There was a reduction in their primary diet item (crab larvae) during these periods of time.
- The level of growth hormones in juvenile coho is higher at the north end of the Strait of Georgia than at the lower end, and also higher in even years when there are lots of juvenile pink around. The growth appears to be related to herring in the diet: high growth when they are feeding on herring, and lower growth when they are feeding on crab larvae (data from 2012-2014 – work done in collaboration with B. Beckman). Growth was lower in the Strait in 2013 for coho and chum – they are still waiting for the results on sockeye. One consideration was whether this might explain the poor performance of Fraser River sockeye this year.
- YOY herring were big this year and silvered up earlier than normal. They observed YOY herring in the first purse seines off BQR. Typically, at this time of year they tend to see few of these and more larval herring. This "larger" size persisted through September. Results from herring survey in September has collaborated this with the largest YOY herring recorded in their time series this year.
- Juvenile chum salmon were also large early in the year and again first noted in sampling off BQR. Verbal reports from hatcheries on ECVI indicated earlier movement of these juveniles down river and likely cause for increased size.
- The feeding of all juvenile salmon in the Strait of Georgia this year was good. There was an increase in larval fish other than herring in many regions.
- Juvenile coho were also big, though they need to perform DNA analyses to determine their origin. The size of coho in the September survey were the largest in their 15-year time series for this time period. CWT were analyzed to confirm they had entered the ocean this year and also showed that there was the typical mix of SOG and Puget Sound stocks. DNA analysis will help finalize the proportion. In addition to size, there was a high number of jacks in the sample (7.5% of all males). The number was higher for hatchery fish (AD clipped, 9.5%) than wild (unclipped, 6.3%). Subsequent to their sampling, the hatcheries around the SOG have been reporting high jack return.

- There are some intriguing results with respect to fall catches of juvenile coho in 2013 and 2014. Chrys Neville observed the highest CPUE of juvenile coho in the Strait of Georgia in the fall of 2013, but that was not accompanied with high survival. They do not know why, but need to do DNA analyses to determine their origin (either the fish did not survive the winter, or the Strait was invaded by Puget Sound coho). The fall catches of coho were average in the Strait of Georgia in 2014, but returns were very poor. This may be due to the warm temperature anomalies this winter, spring and summer. They would suggest that the relationship seen between September abundance of coho and early marine survival is not as strong in the last couple of years. They have noted average (2014) to above average (2013) numbers but not the same response in total returns. This is complicated by a change in behaviour of the sub-adults with more of these available to sport fisheries in the SOG, changes in the hatchery/wild proportions (yet wild fish still not allowed to be retained in fishery although many caught), and changes in size. The size of the fish is increasing and they do not know how this is related to survival or distribution. In addition, the warm water off ECVI and huge harmful algal blooms are anomalies out of our experience to know how they may affect fish. Overall, in 2014 the fish appeared healthy and were growing very will (biggest until this year). Something happened to them after this point and the result is very variable returns to many systems in the SOG (some average and some poor to dismal).
- Pacific pomano were caught in Cowichan Bay during 2015. This species has not been seen before by their surveys in the SOG.
- Due to delays in funding during 2015, many of the laboratory analyses were delayed, including much of the DNA work. With the collaborative agreement finally in place, these studies are now underway and more results will be available in spring 2016.

A4.4 Acoustic Tagging

A4.4.1 Deployment and Maintenance of Fish Tracking Arrays in the Salish Sea

Team: KINTAMA Research Services (Nanaimo, BC), Dr. David Welch, Dr. Erin Rechisky, Paul Winchell

Objective:

To unambiguously measure migration rates and patterns, residence time, and survival in the Strait of Georgia and Johnstone Strait, and clarify where potential survival 'bottlenecks' (mortality hotspots) occur.

Background:

The existing array of acoustic receivers in the Fraser River, Salish Sea (northern Strait of Georgia, Juan de Fuca Strait) and Queen Charlotte Strait was used to produce the first early marine survival estimates for juvenile salmon in BC and Washington State. These arrays are currently being used to track juvenile salmon into the ocean as well as adults upon return to the Salish Sea. As the existing sub-array running from Comox to Powell River (termed NSOG) is situated at a location approximately 4/5ths of the length of the Strait of Georgia, it is not currently possible to estimate survival to the very northern end of the Salish Sea. To address the SSMSP primary objective of identifying significant factors affecting marine survival of salmonids in the Salish Sea, Kintama deployed a new sub-array in 2015, termed the Discovery Islands sub-array, sited at the northern end of the Strait of Georgia/Salish Sea. This sub-array consists of 43 VEMCO acoustic receivers (model VR4UWM, "VR4") (41 of these are on loan to the PSF from Canada's Ocean Tracking Network) deployed within the Discovery Islands and Johnstone Strait to monitor juvenile salmon migration and survival in the Salish Sea between the northern Strait of Georgia and the Broughton Archipelago. These new arrays allow researchers to unambiguously measure survival and residence times within the entire Strait of Georgia and Salish Sea, and through Johnstone Strait. The following figures provide more detail of the layout of this new sub-array.

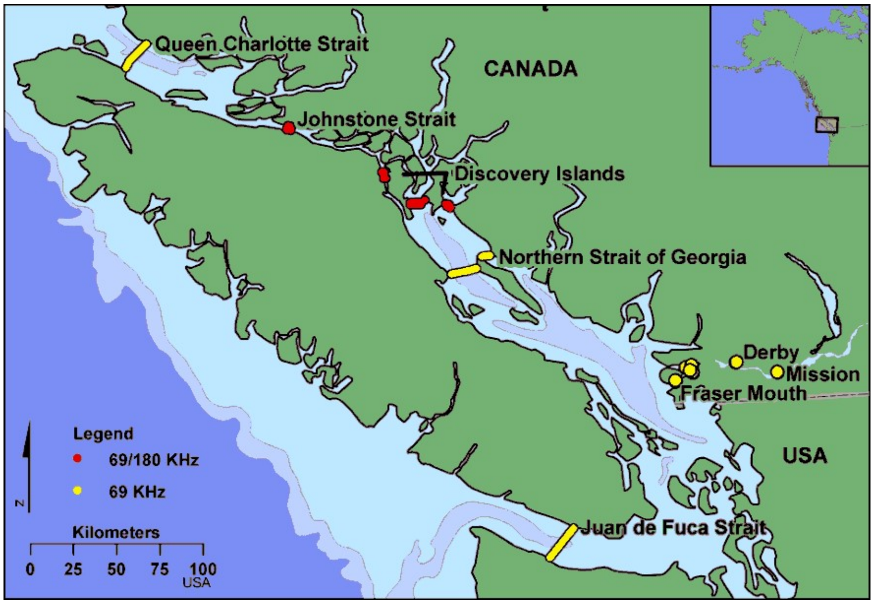


Figure 1. Map of all receiver sub-arrays available to track juvenile salmon in 2015. The red arrays indicate the new, dual frequency receivers deployed in 2015.

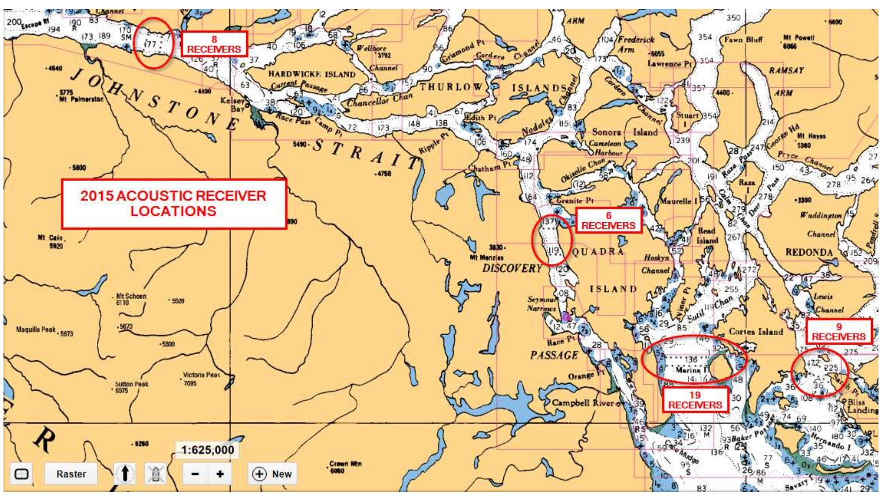


Figure 2. Overview of Discovery Islands (three components to the south) and Johnstone Strait sub-array deployment locations.

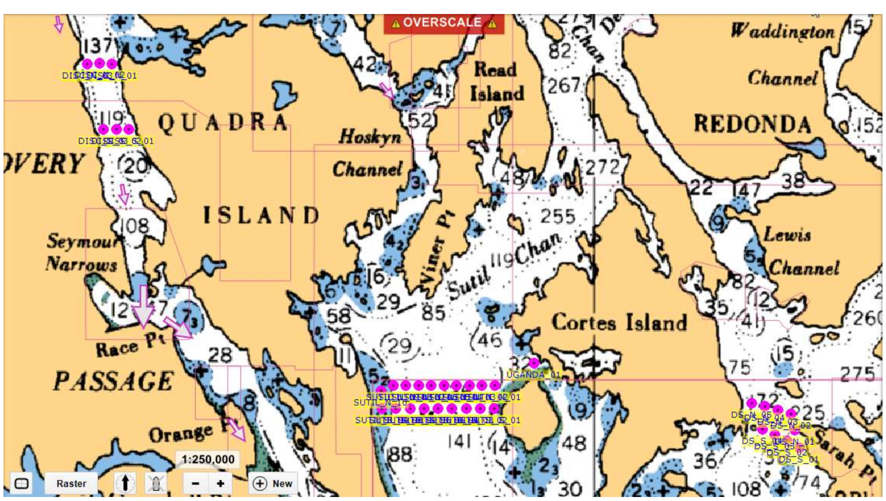


Figure 3. Three components of the Discovery Islands sub-array. Individual receiver positions are shown in magenta.

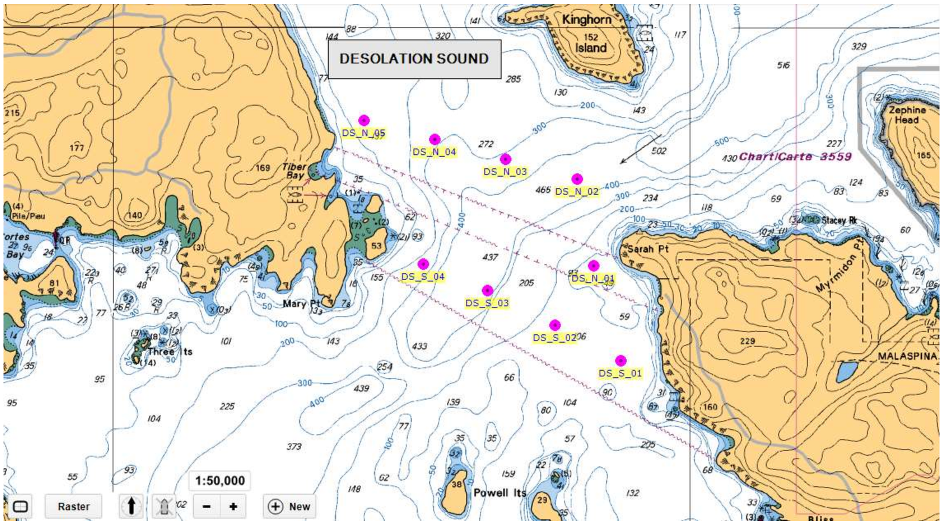


Figure 4. Desolation Sound component of the Discovery Islands sub-array. Individual receiver positions are shown in magenta.

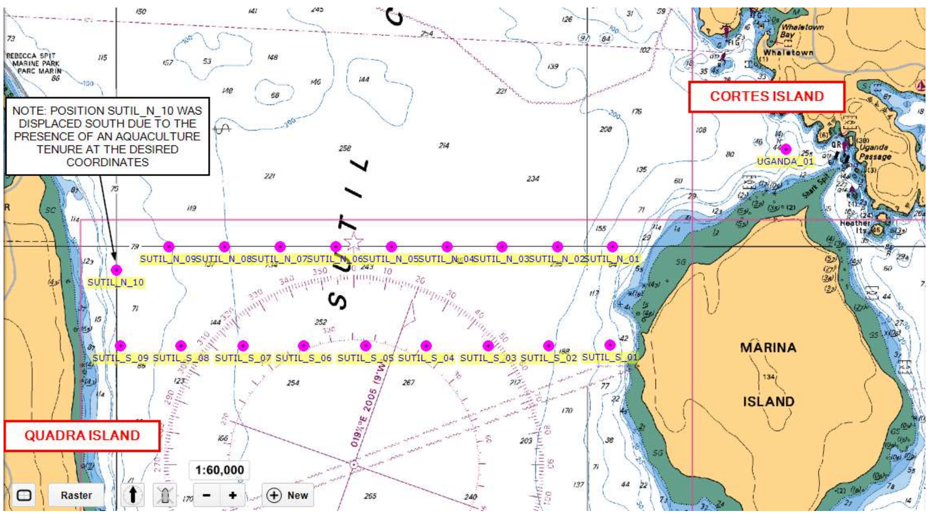


Figure 5. Sutil Channel and Uganda Passage components of the Discovery Islands sub-array. Individual receiver positions are shown in magenta. Note one deviation from the planned location.

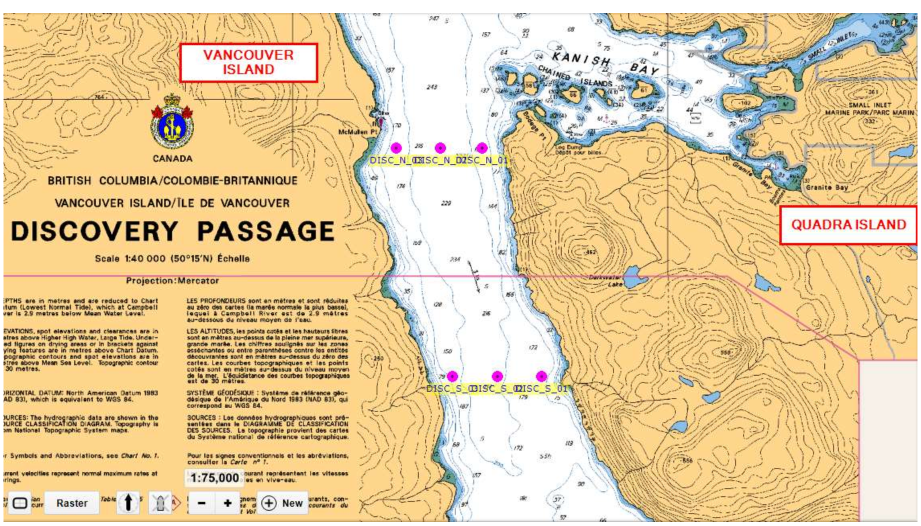


Figure 6. Discovery Passage component of the Discovery Islands sub-array. Individual receiver positions are shown in magenta.

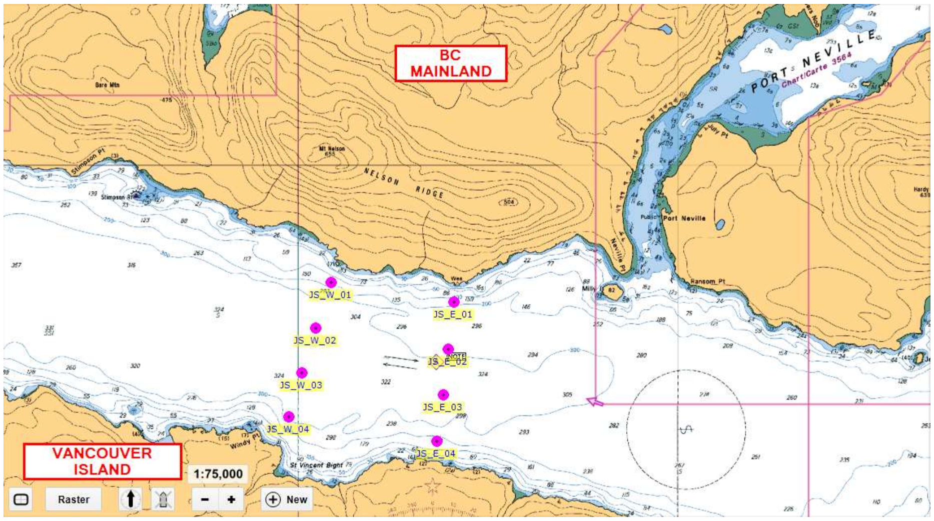


Figure 7. Johnstone Strait sub-array. Individual receiver positions are shown in magenta. Kintama VR4s are the two northern-most locations shown, and were deployed using acoustic releases and depth recorders.

Status:

During the spring of 2015, Kintama Research Services successfully deployed 43 VEMCO acoustic receivers (model VR4UWM, "VR4") within the Discovery Islands and Johnstone Strait to monitor juvenile salmon migration and survival in the Salish Sea between the northern Strait of Georgia and the Broughton Archipelago. These additional arrays will allow Kintama and other researchers to examine survival of tagged fish on a smaller scale between the previously existing arrays in the northern Strait of Georgia (NSOG) and Queen Charlotte Strait (QCS) and determine whether the increased mortality rate north of the NSOG array which we have seen in previous studies, occurs in the very northern 1/5 of the SoG or within the Discovery Island and Johnstone Strait (Figure 1 above).

Thirty-five VR4 receivers were deployed at or near the positions that were originally proposed (see figures 2-7 above). The six additional OTN VR4 receivers (along with two VR4s, floatation collars and anchoring systems which Kintama provided in-kind) were deployed in Johnstone Strait so that salmon smolts could be potentially detected at a location north of the Discovery Islands. As the Johnstone Strait sub-array became a priority, deployment of the five planned northern SoG stand-alone receivers to evaluate possible milling behavior was put on hold in 2015.

In summary, there are now five sub-arrays in which to detect acoustically tagged fish in the Salish Sea and Vancouver Island area, as well as 14 receivers in the lower Fraser River, which greatly increases spatial resolution and our ability to discern where mortality occurs throughout the Salish Sea. However, these arrays do not all detect the new high frequency acoustics tags (V5 or V4 tags, 180 Khz). The use of these high frequency and smaller acoustic tags are essential for research on juvenile salmon that are representative of the size range of naturally produced salmonids.

A4.4.2 Comparative Marine Survival of Seymour Steelhead and Testing Performance of 180 kHz Small Acoustic Tags in the Salish Sea

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

Objectives:

The key objectives of this study were to:

(a) Evaluate the detection efficiency of the 180 kHz tags on new dual frequency sub-arrays

(b) Provide survival data for Seymour River Hatchery steelhead in 2015

(c) Evaluate the improved performance of retro-fitting VEMCO acoustic receivers with a solid-state acoustic amplifier

Background:

Acoustic telemetry is a key research tool that has be used to determine when and where salmon smolts die in the Salish Sea, but transmitter size has limited past studies to studying larger smolts. A new suite of smaller transmitters has been recently developed, but they transmit on a different frequency than can be detected by receivers deployed in the Salish Sea as part of the POST array. Additionally, their smaller size means that battery life and acoustic output are reduced. To enable tracking of smaller smolts through the major salmon migratory route in the northern Salish Sea, the Pacific Salmon Foundation secured ~$0.5 million worth of compatible acoustic telemetry equipment from the Ocean Tracking Network (OTN), and the Salish Sea Marine Survival Project (SSMSP) provided Kintama with funding to design the geometry of two new subarrays using this equipment and then deploy them in the Discovery Islands (DI) and Johnstone Strait (JS) in the spring of 2015 (see Section A1.4). The receivers (VR4s) that make up these subarrays are dual-frequency- they are capable of detecting VEMCO's 69 kHz transmitters (e.g., V7, V9) as well as their newest, smallest 180 kHz transmitters (e.g., V4, V5). Since the smaller transmitters have a reduced detection range, and since subarrays used to detect them have not been tested in the ocean, Kintama and the PSF felt it was important to conduct a pilot study prior to implementing use of this smaller tag for studying early marine survival. Therefore, Kintama designed a study to test the performance of the new array design at detecting the V4 tags by double-tagging 50 Seymour River Hatchery steelhead smolts with V4-1H and V9-1H tags and then tracking them through the array. The V9 tags have higher acoustic power and were expected to have excellent detection efficiency which could be used to compare with the smaller V4 tag. The V9 tags in conjunction with the newly deployed subarrays also allowed Kintama to assess survival on a finer scale than previously possible in the northern Salish Sea.

Therefore, Kintama's second objective was to measure early marine survival of Seymour steelhead smolts using the existing Salish Sea sub-arrays as well as the newly deployed subarrays. This would allow them to partition survival for a key BC stock into Salish Sea survival (from release to the start of the Discovery Islands) and survival in the northern Vancouver Island region (from the Discovery Islands subarray to Johnstone Strait to the existing Queen Charlotte Strait subarray). Similar to most other salmon species, a profound decline in marine survival of BC steelhead stocks occurred starting in ocean entry years 1989/90 over a widespread region including the Strait of Georgia and Queen Charlotte Strait. The early marine movements and survival of Seymour steelhead smolts formed a major focus of work completed using the prototype acoustic telemetry array from 2006 to 2009 and will provide an excellent data set which can be used as a baseline against which more refined survival estimates using an expanded telemetry array can be compared. This data will allow Kintama to objectively establish where steelhead "mortality hotspots" occur during the first month at sea.

The third objective of this study which was mostly funded by in-kind support but used the same double-tagged fish, was to evaluate the performance of VEMCO VR2W-69 kHz and VR2W-180 kHz acoustic receivers which were retro-fitted with a Kintama-designed and manufactured solid-state acoustic amplifier ("lens"). If successful, it will be possible to design an improved second generation acoustic telemetry array that will be more cost effective than the previous and will deliver substantially better scientific data yields while at the same time allowing researchers to tag a wider distribution of smolt sizes and/or reduce smolt tag burden. During 2015 they field tested the performance of amplified receivers relative to the standard Vemco receivers by pairing amplified and standard VR2W-69 kHz and VR2W-180 kHz receivers and then compared the efficacy of the receivers (amplified and non-amplified) to pick up the larger and smaller tags implanted into the steelhead smolts.

Status and Preliminary Findings:

On May 13-14, 2015, Kintama double-tagged 50 hatchery-reared Seymour River (North Vancouver) summer steelhead smolts with VEMCO V9-1H (69 kHz) and V4-1L (180 kHz) acoustic transmitters. These 50 double-tagged steelhead smolts were then held with about 150 untagged smolts, aka "decoys". On June 8th, 20 of these fish were surgically implanted with V7 transmitters as part of the amplifier test.

Figure 1. VEMCO V9-1H (69 kHz) and V4-1L (180 kHz) acoustic transmitters.

Figure 2. A Seymour River summer steelhead smolt implanted with acoustic transmitters.

Kintama also completed the design and initial manufacture of new solid state acoustic amplifiers, which can potentially boost the detection range of 69 kHz and 180 kHz transmitters (tags). To test the amplifiers, they deployed two pairs of standard and amplified receivers (one pair of each frequency) near seven existing NSOG stations in Malaspina Strait east of Texada Island. Once the test array was in position, the double tagged steelhead were released. The double tagged (and V7 tagged) steelhead smolts were successfully transported and released into Malaspina Strait early on June 16 to migrate over Salish Sea acoustic arrays (Figure 3). The release site was 18.5 km south of Kintama's test subarray and smolts were expected to migrate north. For the deployment of Kintama's test array and the transport of the double-tagged steelhead, Kintama chartered the vessel Denman Isle. The Denman Isle is a Canadian Fishing

Company (Canfisco) vessel, and was also used by Kintama for the deployment of the DI and JS sub-arrays in April/May 2015.

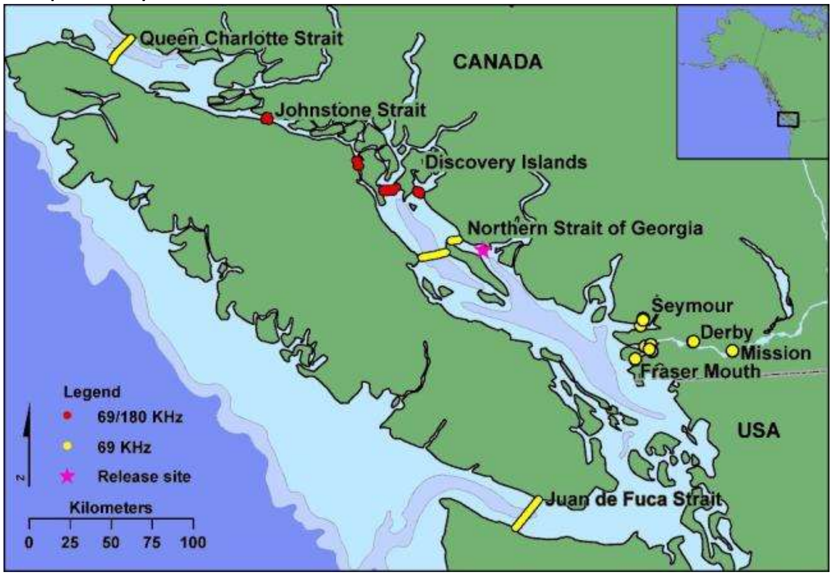


Figure 3. Map of the acoustic array and release location of double-tagged Seymour River steelhead. The 69/180 kHz test subarray at Malaspina Strait is not shown, but was deployed ~550 m south of the eastern section of the Northern Strait of Georgia subarray.

There were a few minor changes to their originally proposed work:

- They initially presented early marine survival in the SoG as the first objective because OTN receivers had not yet been negotiated, and they planned to release the tagged Seymour steelhead smolts at the conventional release location in West Vancouver. With the deployment of the new dual-frequency subarrays and transporting of the fish, their primary objective shifted to testing the performance of the subarrays at detecting 180 kHz tags.
- They proposed to design and test the new lenses on 180 kHz receivers, but expanded this to include lenses for the 69 kHz receivers as well. (No cost implications for this Salish Sea Marine Survival Project).
- They originally proposed to deploy a 180 kHz test array near to and along the full length of the northern Strait of Georgia (NSOG) array; however, they deployed 180 kHz and 69 kHz receivers in Malaspina Strait on the east side of Texada Island only.
- The manufacture of the mold used to fabricate the amplifiers was delayed into June, and as a result the smolts were held at the hatchery until mid-June until the amplifiers could be fabricated and then deployed in Malaspina Strait. The day after the Malaspina subarray was deployed, the tagged smolts were transported and released.
- Because the test array was deployed in Malaspina Strait, they transported the tagged steelhead from the hatchery to Malaspina Strait. The advantage of this is that it should have reduced the mortality that occurs between the typical release site at the DFO West Vancouver Lab (WVL) and the NSOG array (steelhead are never released at the hatchery), and limit the section of the NSOG array which must be instrumented with amplified receivers. Although this means that they will not be able to report survival between the WVL and NSOG, releasing the smolts in Malaspina Strait means they will be able to estimate survival with more precision in the critical area in the northern Strait of Georgia between the NSOG array and the new Discovery Islands sub-array, and between the Discovery Islands sub-array and the new Johnstone Strait sub- array (and to the Queen Charlotte Strait sub-array). As Professor Scott Hinch's (UBC) tagging

operations were moved to Seymour Hatchery in 2015 due to the inability to catch large sockeye smolts up at Chilko Lake (because the DFO weir could not be deployed due to high lake levels), survival estimates for Seymour steelhead from the conventional WVL release site to the NSOG sub-array will still be available from the SSMSP-funded UBC study.

The 69 KHz V9-1H transmitters had 100% detection efficiency at the NSOG and Discovery Islands subarrays (Table 1). Detection was also 100% at the Johnstone Strait subarray. The performance at the Malaspina subarray was reasonable (DE=79%, SE=6.6%; 2 of the 7 receivers were only partially operational). The V4 180 KHz transmitters performed well at the Discovery Islands subarray in the period before their batteries were expected to begin expiry (DE=74%; SE=10%; Table 1). Since the subarray was fully functional and the tags were operating within their warranted lifespan, Kintama considers this to be a reasonable estimate of what can be achieved with the V4 tags.

Table 1. Detection efficiency by time interval calculated for V9-1H and V4-1H tags implanted in Seymour River steelhead smolts in 2015. Time intervals were defined by the predicted dates of battery expiry for the V4 tags as provided by the tag manufacturer.

			V9-1H		V4-1H	
Subarray	**Time Period**	**N Present**	**N Detected**	**DE (SE)**	**N Detected**	**DE (SE)**
Malaspina Strait	Before expiry	33	25	0.76 (0.075)	11	0.33 (0.082)
	<50% expired	4	4	1 (0)	0	0 (0)
	>50% expired	1	1	1 (0)	0	0 (0)
Discovery Islands	Before expiry	19	19	1 (0)	14	0.74 (0.101)
	<50% expired	11	11	1 (0)	7	0.64 (0.145)
	>50% expired	12	12	1 (0)	3	0.25 (0.125)

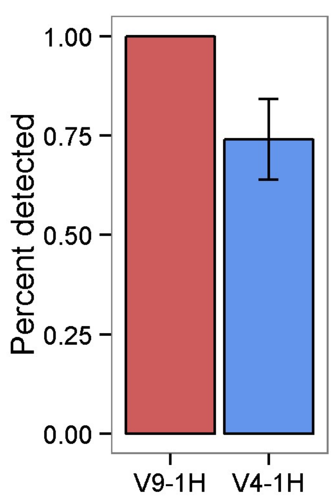


Figure 4. Detection efficiency of V9-1H and V4-1H VEMCO acoustic tags at the Discovery Islands subarray. These detections were recorded before the earliestdate of V4 tag expiry as provided by the manufacturer.

Table 2. Detection efficiency and survival calculated for V9-1H tags implanted in Seymour River steelhead smolts in 2015. N=number, DE=detection efficiency, SE=standard error, Ssegment=survival in the segments between release and Malaspina, and then between each set of subarrays; Scumulative=survival from release to each subarray; NSOG=Northern Strait of Georgia. [a]Total does not include 4 fish that were detected on the west side of NSOG after migrating around the southern end of Texada Island. [a]Preliminary estimate.

Subarray	N Present	N Detected	DE (SE)	$S_{segment}$(SE)	$S_{cumulative}$(SE)
Malaspina Strait	38[a]	30	0.79 (0.066)	0.84 (0.052)	0.84 (0.052)
NSOG	42	42	1 (0)	1 (0)	0.84 (0.052)
Discovery Islands	32	32	1 (0)	0.76 (0.066)	0.64 (0.068)
Johnstone Strait	23	23	1 (0)[a]	0.72 (0.079)	0.46 (0.07)

Survival of Seymour steelhead between release and NSOG was 84% (Figure 5). It then dropped slightly between NSOG and DI (76%) and again in the final segment DI to JS (72%). Cumulative survival over the ~170 km from release to Johnstone Strait was 46% (Figure 6). Although mortality was lowest in the first segment after release, the short distance over which it occurred (~20 km) means that survival rate per km was lower than in subsequent segments.

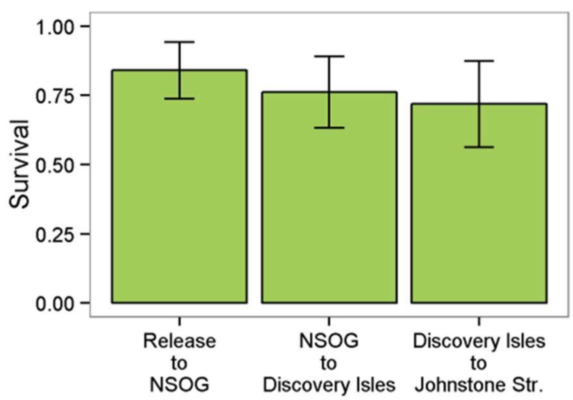


Figure 5. Segment-specific survival estimates (95% CIs) for Seymour River steelhead smolts released in Malaspina Strait in 2015 and implanted with V9 tags.

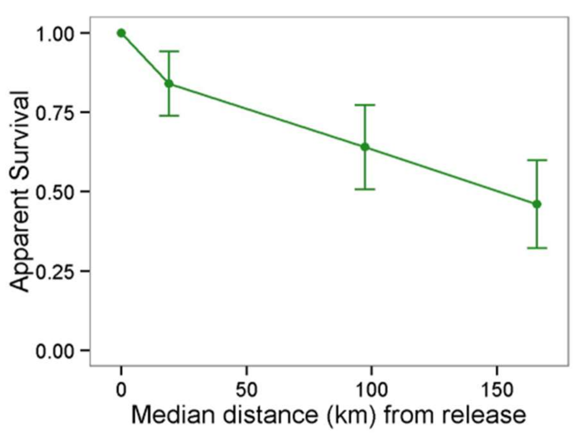


Figure 6. Cumulative survival estimates (95% CIs) with distance for Seymour River steelhead smolts released in Malaspina Strait in 2015 and implanted with V9 tags.

Their evaluation of VEMCO acoustic receivers retrofitted with a solid-state acoustic amplifier to increase tag detection range, is still in progress.

In summary:

- Kintama double tagged Seymour River steelhead smolts with 69 kHz and 180 kHz transmitters in order to test the performance of the smaller 180 kHz tag which has a shorter range. This was the first test of this new tag in the ocean and they had very good results: the high power 69 KHz tags had 100% detection rate and the smaller 180 kHz tags had a 74% detection rate.
- Because of the effectiveness of the new dual frequency array design, 180 kHz tags can now be applied to smaller salmon smolts in order to estimate early marine survival in the Salish Sea with statistical confidence levels about as tight as past work using 69 kHz tags. (Note that 180 kHz tags can currently only be detected at Discovery Islands & Johnstone Strait).
- The finer scale array showed more evidence of smolts milling, with at least some smolt tags doubling back to the NSOG sub-array from the Discovery Islands sub-array, a behaviour not previously seen. An animation of the movements of the Seymour River steelhead smolts released in 2015 is available on their website (http://kintama.com/visualizations/).

A4.4.3 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:

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.

This group is addressing a number of key hypotheses:

- Factors operate at different levels – survival can be affected by <u>different areas encountered </u>(that vary in ecosystem/community factors)
- Smolts in poor condition will have poorer survival
- Diseased smolts will have poorer survival (and assumed predation)

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 and Preliminary Findings:

Short-term objectives

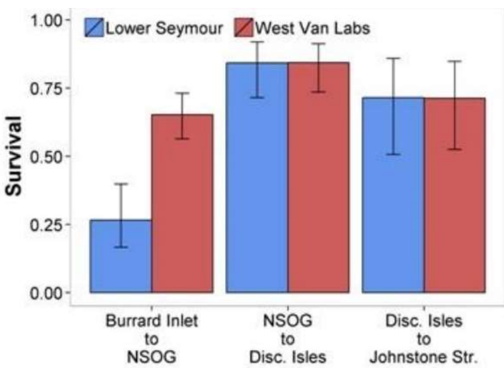
1) **Tagging and gill biopsy sampling outmigrating smolts:** Acoustic transmitters (300 V7s) were ordered from Vemco and received in March 2015. From January to March, 2015, UBC had numerous phone and email discussions with DFO in regards to using the Chilko field camp and coordinating project logistics in order to capture and tag outmigrating Chilko sockeye smolts. Animal care and fish collection permits were also obtained during this time. In March 2015, UBC researchers attended the annual Tsilhquot'in National Government (TNG) Fisheries Forum in Williams Lake to discuss research aims for First Nations and DFO. In particular, PhD student Nathan Furey presented past, current, and future Chilko sockeye smolt research, including those of the SSMSP. In April 2015, Steve Healy became a new MSc student in their group and would lead the field study this spring. He had been their lab assistant for the past 2 years. Using their salmon rearing lab facilities at UBC, Steve was trained in conducting surgeries to implant smolts with acoustic transmitters by PhD student Nathan Furey. In March and April, technician Andrew Lotto set up the rearing lab to house smolts for holding and tagging-effect studies. In mid-April, a crew of four UBC researchers left for Chilko Lake to capture and tag sockeye salmon smolts. During the first week, the freshwater receiver array was deployed in the Chilko and Chilcotin Rivers.

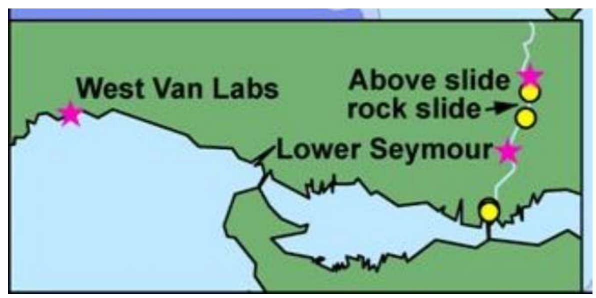
Due to unprecedented high water levels, DFO was unable to deploy its counting fence in the Chilko River. The fence and associated trap box normally enable us to obtain the relatively rare 2 year smolts (only 1-5% of the smolt run are 2 year olds) which are the only ones large enough for their tags. DFO deployed rotary screw traps in an attempt to continue to examine smolt numbers but they were ineffective at capturing any 2-year old smolts. For two weeks the UBC research crew attempted to beach and pole seining in multiple locales to obtain appropriately sized smolts. In the end, only 6 smolts large enough to tag were captured, tagged, and released in the Chilko River. By the end of the first week of May few smolts were being observed migrating and few were found in bull trout stomachs (part of a parallel smolt predation study) indicating the smolt run was nearly complete. The UBC crew departed Chilko during the 2nd week of May and recovered the deployed receivers.

Because tag battery life can be reduced with long-term storage, they wanted to ensure that as many tags as possible that were in their possession were released this year. There were no other freshwater capture sites/stocks that they could access this spring to obtain two year old sockeye smolts, so they rapidly modified their tagging strategy. In 2016, their study had planned to tag and release steelhead salmon smolts which share a migration route and have a similar coastal life history as Fraser sockeye smolts, so they initiated a dialogue with the Seymour Steelhead Society, facilitated by Kintama (who they knew were obtaining Seymour steelhead smolts for a tagging/infrastructure experiment being funded by the SSMSP) to obtain and tag hatchery Seymour steelhead. These smolts are even larger than two year old sockeye so there are no concerns about tag burden. In total, 274 Seymour steelhead smolts were tagged and released during the third week of May 2015. The release locales included: 30 tagged fish released in the Seymour River above the new rockslide, 84 tagged fish released in the lower Seymour near the estuary, and 160 tagged fish released at West Vancouver near Point Atkinson. This release strategy was used because recent studies identified Burrard Inlet as having high risk of mortality for steelhead smolts (Balfry et al. 2011), and they wanted to ensure as many smolts as possible reached the OTN marine acoustic arrays to facilitate our objectives of linking initial physiological state to travel rates and fate. The change from Chilko sockeye to Seymour steelhead this spring did not change their broader objectives, as Seymour smolts were going to be targeted next year (they simply moved the project ahead a year), and they still plan on tagging Chilko sockeye smolts next year.

Initial data analysis by Kintama has resulted in the plot below showing survival for Seymour steelhead 1) transported and released in the lower Seymour River and 2) transported and released at the West Van Lab by the Hinch et al group. There appears to be a large survival deficit evident in Burrard Inlet. The lower Seymour released fish only traveled an extra 18 km from the second narrows bridge to the lab but had only 40% survival to NSOG of the fish that were released at the lab. (The figure below excludes mortality in the river; see the detection site at the mouth in the cropped map below.)

Thus, there appears to be a mortality hotspot in the early marine life history of Seymour steelhead. The group are interested in investigating this in further detail during 2016.





2) Assess gill biomarkers: Of the smolts tagged, 168 (6 Chilko sockeye and 162 Seymour steelhead) had small gill biopsies taken to assess smolt physiological condition (presence and load of pathogens, and regulation of biomarkers) and link physiological state to survival and behaviour as determined by acoustic telemetry. In addition, 80 Seymour steelhead that were brought back to UBC will have gill clips taken as part of the lab-holding study. A summer undergraduate research assistant (Jeremy Lotto) has been hired to be trained in the lab work necessary to process these samples, which will occur in the late summer and fall. In addition, 100+ gill samples were also obtained from one year Chilko smolts in order to assess physiological condition and compare to previous years. Lastly, a tagging study in 2013 on Chilko sockeye smolts also obtained gill samples (they have not been processed or related to telemetry data) and those will be made available for this project to provide an additional year of data to link physiological state and survival.

***3)* Conduct retrospective analyses (on migration rate and survival):** Nathan Furey (UBC PhD student) and Erin Rechisky (Kintama) have compiled all Chilko sockeye smolt telemetry data to date (2010-2014 tagging studies) into a single database. Sources of environmental/oceanographic data to pair with telemetry data are in the process of being identified and downloaded, and will currently include lighthouse data (DFO), Strait of Georgia oceanographic buoys (DFO), and river temperature and water height (Environment Canada). They are also currently searching for remote sensing products in order to add further variables.

***4)* Conduct retrospective analyses (on movement patterns and migration routes)**: All telemetry data for retrospective movement analyses have been organized and processed to define movement/migration behaviours at the Northern Strait of Georgia (NSOG) array. In total, they have organized data from >850 combined sockeye and steelhead smolts tagged between 2004 and 2013, and have determined any lateral (east-west) movements at the NSOG array. Analyses to determine most common migratory behaviors and how they are related to survival, as well as this project's write-up, are currently in progress.

5) **Develop individual-based models (IBM):** They are currently in discussions with oceanographers (Neil Banas and Mike Foreman) to determine the best data formats and temporal scale and ranges to use for development of an IBM for the smolt outmigration. A proof-of-concept model (using only 10 day's worth of oceanographic data) has been constructed using the proposed framework, thus showing the utility of the NetLogo software for use with large-scale oceanographic models. Moving from such a small time frame (10 days) to a few months (required for the entire outmigration) requires larger files and thus they are working with collaborators to set up a file transfer system.

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.

Status:

The CAHS program is ongoing.

B. Top Down 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 2015 include assessment of the impacts of seal and fish 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 have carried out some hatchery manipulation studies, involving alternative times of release of Chinook into the Strait of Georgia.

B.1 Disease & Health- Strategic Salmon Health Initiative

Team: Kristi Miller-Saunders (DFO-PBS), Karia Kaukinen (DFO-PBS), Amy Tabata (DFO-PBS)

The SSHI is a collaboration between Genome BC, the Department of Fisheries and Oceans lead by Dr. Kristi Miller-Saunders, and the Pacific Salmon Foundation. This study has successfully demonstrated the use of new genomic technology in Dr. Miller's lab. During the past three years, samples of wild Pacific salmon, hatchery-reared Pacific salmon, and aquaculture-reared Atlantic salmon have been collected and will now be analyzed.

This program aims to identify stressors that may undermine early marine survival. The fish collected are being integrated into genomic studies that utilize assessments of the physiological condition of fish to identify stressors that may undermine early marine survival and microbe monitoring research to identify what microbes, if any, may be important in early marine survival.

Researchers are using novel genomic approaches that utilize physiological assessments to identify potential stressors and monitor dozens of microbes to identify pathogens that might be of greatest import. 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.

However, knowing what microbes are present doesn't mean disease is present. To assess the risk of disease, we also need to know whether disease will be expressed if wild salmon are exposed. To do that, we need to understand the migration patterns (rate, proximity to a microbe source, duration of exposure) and behaviour of individual fish. This can be studied using acoustic tags implanted in juvenile salmon (see details on the acoustic tracking programs above).

Status:
This work is ongoing.

B.2 Harmful Algal Program

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

Objectives:

To determine the seasonality, magnitude, and annual variations of phytoplankton blooms in the Strait of Georgia; examine the impacts of harmful algal blooms on juvenile salmon.

Background:

Harmful algal blooms (HABs) are one of the leading cases of caged salmon's mortality in BC. HABs cause million dollar losses to salmon aquaculture industry every year, yet the effects of HABs on the wild fish in BC is unknown (and have not been studied). A pilot project looking into the possible effects of HABs on wild juvenile salmon was initiated under SSMSP in 2014, as part of a juvenile salmon study in Cowichan Bay. Unique observations (juvenile salmon significantly reducing feeding during blooms, evidence that *Heterosigma akashiwo* blooms might be affecting wild salmon) lead to the expansion of the project, which is now fully implemented with phytoplankton being sampled throughout the Strait of Georgia (as part of the Citizen Science Program).

Phytoplankton samples are collected bi-weekly from February to October at ~70 locations in the Strait of Georgia. Samples are collected from surface waters at most of the stations and at the depths of (5, 10, and 20 m) at 10 priority stations. Phytoplankton data containing information on biomass level, dominant species and its abundance, percentages of phytoplankton constituent groups (diatoms, dinoflagellates, silicoflagellates, raphydophites, nanoplankton, zooplankton), and harmful algae abundance is readily available to all SSMSP researchers on the basecamp website. 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.

The key hypotheses that are being addressed are:

- Phytoplankton dynamics regulate zooplankton dynamics and subsequently affect the availability of the salmon food. The link phytoplankton-zooplankton might not be linear as some toxic algae have a significant negative impact on zooplankton productivity
- Harmful algae directly affect salmon survival: toxic algae through acute or chronic toxicity and mechanically harmful algae through gill damage

Lab studies on cultivating harmful algae and assessing exposed fish (or assay) for physiological response utilizing molecular technics 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 and Preliminary Findings:

Phytoplankton samples collected by the Citizen Science Project, and from DFO cruises, as well as from purse and beach seine events in Cowichan Bay and the area around the Big Qualicum River are routinely identified. Some ongoing smaller citizen science projects to assess water quality in Ladysmith Harbour and around Salt Spring Island also collect phytoplankton samples. The information about blooms is posted a Facebook page titled "Phytoplankton - Citizen Science Program" and also to two BaseCamp sites associated with both the Citizen Science program and the Cowichan studies.

Over 2500 samples have been analyzed to date.

Major findings of 2014:

- Three major blooms were observed in Cowichan Bay – one toxic bloom (*Heterosigma akashiwo*) and two diatom blooms

- During the *H. akashiwo* bloom (Fig. 1 and 2), Chinook juveniles caught by purse seine displayed lethargic behavior as well as a dramatic (25 fold) increase in mortality of individuals after a PIT-tagging procedure.

Figure 1– Bloom of Heterosigma akashiwo in Cowichan Bay, 2014.

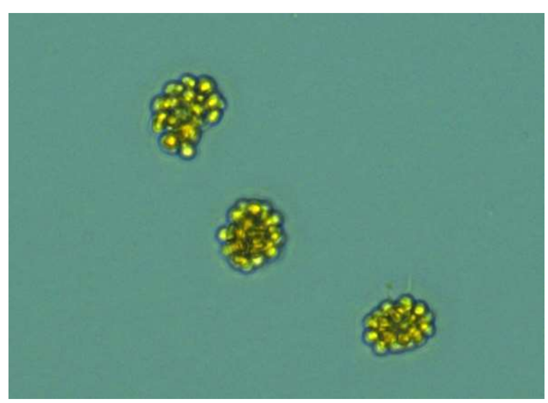


Figure 2– Cells of Heterosigma akashiwo.

- During diatom blooms Chinook salmon had lower catch rates AND ate significantly less (50% + of empty stomachs).
- Salmon diet shifted during a bloom. Crab larvae abundance (the most important in the diet of juvenile Chinook salmon) in stomachs decreased dramatically after the toxic algae bloom.

Major findings of 2015:

- Annual spring phytoplankton bloom was recorded very early in 2015 at all, but Campbell River, sampled areas. Spring bloom was observed in mid-March, however there were no late February and early March cruises, so the beginning of the bloom could have been missed.
- At all sampled locations, spring bloom was caused by the diatom *Skeletonema costatum*.
- It appears that the northern part of the Strait of Georgia was more productive from July to September than the central and southern parts (Fig. 5).
- The year of 2015 had were very favorable conditions for juvenile salmon as it was unusually quiet in terms of harmful algal blooms (it was the quietest year since the start of the Harmful Algae Monitoring Program [HAMP] run by Nicky Haigh for the finfish aquaculture industry for over 15 years).
- There was an unusual prevalence of diatoms in the summer 2015 across the Strait (as opposed to a more common shift to dinoflagellates).
- Occasional cells of *Alexandrium* spp. (most species from this genus cause Paralytic Shellfish Poisoning) were seen in some samples at most of the locations, persistent and notably higher concentrations (up to ~18 cells per mL which is extremely high in respect of PSP) were observed in Cowichan Bay and Ladysmith sites in June samples.
- Moderate and high levels of the mechanically harmful diatoms *Chaetoceros convolutus/concavicorne* were observed in Cowichan Bay, Baynes Sound Campbell River, Lund, Powell River, and Irvine's Sechelt at the end of May and beginning of June. Cowichan Bay, Campbell River, and Lund appear to be the most affected locations.
- Histology analysis of juvenile salmon gills obtained in Cowichan Bay post *Chaetoceros convolutus/concavicorne* bloom appeared to show signs of damage.

In summary, this project provide reference *in situ* data for other studies (*i.e.* fluorescence, Chl a, modelling) and has found evidence that harmful algal blooms affect wild salmon (in the same way as they affect caged salmon) in enclosed bays.

B3. Predation Studies

B3.1. Seal Predation

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. There are two main projects being carried out to answer these questions.

B3.1.1 Impacts of seals on Pacific salmon in Cowichan Bay

Team: Ben Nelson and Andrew Trites (Marine Mammal Research Unit, University of BC)

Background:

Since the 1970s, native stocks of Chinook and coho salmon have declined throughout the Strait of Georgia (SOG), despite sizable reductions in harvest from commercial and recreational sources. Coinciding with the decline of these species are rapid increases in populations of pinnipeds native to the SOG, including Steller sea lions, California sea lions and harbour seals.

Salmonids are a significant dietary component of seals and sea lions in the SOG, particularly in estuaries where adult salmon return to their natal steams. There is also direct scientific evidence of seals preying on out-migrating juvenile salmon during the spring. Such predation in combination with habitat loss, fishery removals, declining prey abundance and climate regime shifts may explain the dramatic declines in salmon abundance in the SOG. However, the trends in pinniped abundance have led some scientists to speculate that predation on salmon by marine mammals may be particularly significant and may be impeding recovery.

This team have been assessing the impact of seals on salmonids in Cowichan Bay by counting the number of predators in the Cowichan Bay, quantifying predation events from visual observations, and determining diets from morphological and genetic analysis of fecal samples. These data were collected over 2013 and 2014 and now will be used in a model being developed by PhD student Ben Nelson to test whether pinnipeds are inhibiting the recovery of commercially and recreationally important stocks of chinook and coho salmon in the Strait of Georgia.

Key goals of this project are to:

1. Estimate the number of juvenile salmon consumed by seals (2012-2013)
2. Use models to infer mortality dynamics- where and when is mortality of chinook and coho occurring, and what is the potential impacts on the populations in the Strait of Georgia?

Status and Preliminary Findings:

Analyses and modeling is ongoing in the Marine Mammals Research Unit at the University of B.C.

The key findings to date are:[2]

- Based on an average yearly estimate of coho smolt production of 15.5 million for the period 1998-2007, the seal consumption model predicts that the harbour seal mean annual consumption of coho for 2012 and 2013 is as follows:
    - 2012: 6.2 million coho eaten, **40%** of the population (CV= 1.02)
    - 2013: 10.3 million coho eaten, **67%** of the population (CV= 0.61)
- Based on an estimated 2010 chinook smolt production of ~ 66 million, the seal consumption model predicts that the harbour seal mean annual consumption of chinook for 2012 and 2013 is as follows:
    - 2012: 26.1 million chinook eaten, **39.5%** of the population (CV= 0.48)
    - 2013: 28.3 million chinook eaten, **43.0%** of the population (CV= 0.84)
- Thus, it appears that Harbour seal predation is likely responsible for a significant amount of natural mortality in the early marine stage for both chinook and coho salmon in the Strait of Georgia;
- Seal predation is highest when juvenile fish are between 115-145mm in length, and

[2] Some of these results pre-date the SSMSP commencement but were funded by PSF during the development of the SSMSP and collaboration with UBC.

- Consumption estimates and mortality may be biased high due to emphasis on "estuary seals" because of the locations where diet data were sampled.
- Future sampling should expand throughout the Strait and include open water/rocky reef habitat

B3.1.2 Mapping and quantifying juvenile salmon predation by harbour seals using seal-mounted PIT tag scanners (RFID tag) and GPS/accelerometers coordinated with the release of PIT tagged coho smolts

Team: Dr. Andrew Trites, Professor, Marine Mammal Research Unit, University of British Columbia, Austen Thomas, PhD Candidate, Marine Mammal Research Unit, University of British Columbia, Dr. Brian Battaile, Statistical Consultant, United States Geological Survey (USGS), Hassen Allegue, Msc student, Marine Mammal Research Unit, University of British Columbia, Steven Jeffries, Research Scientist, Washington Department of Fish and Wildlife, Dr. Martin Haulena, Head Veterinarian, Vancouver Aquarium, Todd Lindstrom, Senior Engineer, Wildlife Computers Inc., Brandon Russell, Research Technician, Marine Mammal Research Unit, University of British Columbia, Kevin Pellett, Fisheries Biologist, BC Conservation Foundation

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. However, rates of predation and the relative spatial and temporal vulnerabilities of smolts to predation by seals are unknown. This study aims to track harbour seals to estimate rates of predation on coho smolts, and will identify when and where predation is occurring.

Over the past 3 years the team has developed a satellite-linked PIT tag scanner that is designed to quantify the number of PIT tagged fish ingested by harbour seals. These radio-frequency detectors tags are suitable to be affixed to the heads of harbour seals, and the internal PIT tag scanner is activated when seals attempt to capture fish (head-strikes), thereby detecting the presence of PIT tagged fish in the mouths of the seals. PIT tag detections are logged by the instrument and then transmitted via the ARGOS satellite network, providing the number of tags consumed and the complete PIT tag identification number.

Figure 1. PIT tag scanner on Vancouver Aquarium seal

A second monitor pack has also been developed which incorporates a GPS and 3D accelerometers and will allow for reconstruction of the fine-scale movements of individuals, to determine the locations and the ways in which seals are consuming the juvenile coho. The data collected by the seals will be used to create maps of spatial predation risk needed to identify predation ‘hot spots’ during the critical period of smolt outmigration. The aim of this study is to test whether harbour seals could be responsible for high salmon mortality in the Salish Sea, and will provide resource managers with important information needed to design mitigation strategies for seal predation.

The BC Conservation Foundation was responsible for PIT tagging hatchery coho at the Big Qualicum River hatchery, and Austen Thomas and his team are responsible for tagging seals.

Status and Preliminary Findings:

Half-duplex PIT tags were implanted in 36,900 coho smolts at the Big Qualicum hatchery more than one month prior to the release of 381,800 total coho smolts in early May 2015 (9.7% tagging rate). Twenty harbour seals were captured prior to the fish release and outfitted with RFID tags (the PIT tag scanners) in addition to back mounted GPS/3D accelerometers (used for reconstructing seal movements). Seals were tagged in the mouth of the Big Qualicum River (9 animals), in addition to nearby rocky haul-out sites (11 animals). The purpose of this design was to determine a coho smolt predation rate for the animals that likely specialize on out migrating smolts, versus those seals that likely feed in other areas and represent the larger portion of the seal population.

Coho smolts were released from Big Qualicum hatchery on Monday May 4, 2015. Researchers received detections from 4 of the 20 seals, and each transmitted multiple PIT tag identifications. This demonstrates that these seals were consuming Big Qualicum coho smolts. All of the seals with PIT tag detections were animals tagged in the estuary, and haulout observations indicate these animals stayed in the estuary during smolt outmigration. Corrected counts of harbour seals in the area indicate that the number of seals using the river was ~96 individuals.

Based on the timing of PIT tag detections, seal predation on smolts occurs primarily at dusk and midnight. During peak outmigration, the per seal smolt predation rates suggested that seals consume ~1kg coho smolts per night. This equals ~½ of their daily energy needs, indicating that smolt consumption is only part of the daily foraging pattern.

Extending these data only to the ~96 seals using the river, seals consumed **~6.2%** of the out-migrating coho population. Note that this estimate is substantially lower than the estimate provided by the seal consumption method, above. The two estimates may be reconciled as follows: 6% of the juvenile salmon entering the Strait (from hatcheries) may be eaten by estuary specialists (as in this study). Another 34% of mortality of smolts may occur from high numbers of seals feeding throughout the Strait of Georgia, giving a total of 40% overall seal-related mortality. At this time, however, recall that the seal consumption model remains to be validated by more representative sampling of scats throughout the Strait.

Integration of an accelerometer trigger into the RFID tags extended battery life of the tags from 2 weeks to 2-6 months. PIT tag detections continued for over 3 weeks after the release date. Future work will explore alternative ways of doing the population level data expansion.

The backpack GPS unit recorded the seal location information and began transmitting the locations (from the whole deployment) on July 1. This was done to prevent collisions between satellite transmissions of the head mounted tag and the back mounted tag. The location information and PIT tag detections are being used to determine how many smolts were consumed, and when and where that predation primarily occurred.

According to preliminary spatial distribution data, 16 of 20 harbour seals seemed to use a relatively limited area around their main haul-out sites whereas 4 harbour seals traveled long distance (>100 km) and transited between multiple haul-out sites. The seals that consumed PIT tag smolts seemed to forage mainly in Big Qualicum estuary while traveling back and forth between their respectively haul-out sites and the estuary. The seals that did not consume PIT tag smolts have different distribution patterns than seals that consumed PIT tag smolts and Big Qualicum estuary was not their main foraging spot.

B3.2 Fish Predation

Team: Dick Beamish (DFO-PBS, retired), Joy Wade (contractor), Dave Preikshot (Madrone Environmental), Lana Fitzpatrick (DFO-PBS)

Objective:

To determine the extent of predation by predatory fish on juvenile salmonids in Cowichan and Qualicum estuaries.

Background:

Pacific salmon experience heavy and highly variable losses in the ocean, with natural mortality rates generally exceeding 90-95% during their marine life. Most of this mortality is thought to occur in coastal marine ecosystems during two critical periods: an early predation-based mortality that occurs during the first few weeks following ocean entry, and a starvation-based mortality period during the first fall and winter at sea.

Figure 1. Predation studies- gillnetting, bird observations, bird scat collections

This project aims to whether fish predation of juvenile Chinook and coho accounts for a significant level of mortality in this early marine period. Sampling is carried out primarily at night-time, at a variety of depths, and using a variety of fishing gear including gillnet, trawl and purse seine surveys in both the area of Cowichan Bay and Big Qualicum River.

Status and Findings:

A gillnetting survey was carried out weekly from April 26 to June 19th 2015 in the estuaries of Cowichan Bay and Big Qualicum River.

Week (2015)	Location	# Trips
May 3-9th	Qualicum	1
May 10-16th	Qualicum	1
	Cowichan	1
May 17th -23rd	Qualicum	1
	Cowichan	1
May 24th -30th	Qualicum	1
	Cowichan	1
May 31st – June 6th	Qualicum	1
	Cowichan	1
June 7th- 13th	Qualicum	1
	Cowichan	1
June 14th- 20th	Qualicum	1
	Cowichan	1
Total # nights fishing		**13**

The PIs:

- Confirmed the absence of fish predators in Cowichan Bay during smolt outmigration.
- Determined that there were few fish predators in Big Qualicum estuary during smolt outmigration.
- Confirmed that predators can be captured with the fishing gear used.

The absence of fish predators in the surface and bottom gillnet sets in Cowichan Bay estuary were consistent with the study conducted in 2014. Similar results were found for Big Qualicum estuary. Because it was possible that large abundances of predators arrived after they had finished fishing, they made several sets in the early morning, late afternoon and evening. Large abundances of Pacific salmon juveniles were present in the vicinity of the gillnets indicating that the potential food source was there. Seals were observed actively feeding at both locations.

B3.3 Bird Predation

Team: Joy Wade (contractor, Fundy Aquatic Services Inc. (and local volunteers)

To date, there has been little effort to characterize the abundance and diversity of bird species at the time of smolt outmigration from the Cowichan River in either the river or the estuary. The purpose of this project has therefore been to collect preliminary data on the abundance and diversity of the non-passerine birds in this area through a citizen science based project.

In addition, scat have been collected from known piscivorous birds for DNA analysis at a future date. It is believed that such an analysis will be able to determine which species of salmon are being consumed if any.

Status:
This project was piloted in 2014, and although this study was not continued in 2015, there may be continuation of studies in 2016

B4. Nearshore Habitat Studies

B4.1 Spatial temporal extent of kelp canopy area: satellite method development for two study areas with different water turbidity characteristics, and further evaluation for a larger scale mapping project.

Team : Dr. Maycira Costa, MSc. Jennifer O'Neill, MSc Justin Dell Beluz

Objective:
To carry out a pilot study to demonstrate the use of satellite optical imagery to map the canopy distribution of kelp *Nereocystis leutkeana.*

Background:
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. In BC, the Ministry of Environment has conducted kelp surveys in specific areas along the BC coast since the 1970s using transects and infrared aerial photos. Other localized initiatives of kelp inventory have started recently, for example in Mayne Island and Gabriola Island. A proposed alternative to transect and aerial photos is the use of optical remote imagery acquired by satellites which can be more cost- and time- effective, nearly instantaneously and with high frequency; with the added potential for automation. Additionally, the historical distribution of kelp can potentially be derived from imagery acquired by the Landsat series, starting in 1972 up to now, with SPOT series, and more recently with high spatial resolution satellites, such as WorldView 2 and 3. Given proper methodology is developed for accurate retrievals of kelp canopy bed extent, satellite technology can be used to describe the special temporal dynamic of this ecosystem. The best scenario would also combine ground sampling not only for calibration of satellite data but also for higher scale understanding of the in situ dynamics of this ecosystem.

This was a short pilot project (3 months) aimed to evaluate and define methodologies to use satellite imagery (present and historical) to map the aerial extent of kelp beds in BC coastal waters. The long-term goal is to apply the developed methods to the BC coastal waters and work together with local communities and First Nations in collaboration with SeaChange Society to improve data collection and the use of satellite imagery.

Status and Findings:
This project addresses habitat used by juvenile fish and as such will contribute to the understanding of the role of the marine environment on the survival of salmon in the Salish Sea. The need of a kelp (*Nereocystis*) distribution map was one of the main outcomes from the Salmon Habitat meeting in July 2014. This was a short pilot project aiming to evaluate and define methodologies to use satellite imagery to map the aerial extent of kelp beds on BC coastal waters.

Mayne Island was selected as the focal study site for the pilot project because of its wealth of historical *Nereocystis* distribution data and detailed local knowledge of collaborator, Leanna Boyer of the Mayne Island Conservancy Society. Mayne Island is situated in the Southern Gulf Islands between Vancouver and Victoria, British Columbia, within the Strait of Georgia (Figure 1). Portions of the island and its surrounding marine habitat are situated within the Gulf Islands National Park Region of Canada (GINPRC). *Nereocystis* beds are found in the many rocky bays and fringing reefs of the island and eelgrass forms both flat and fringing beds in several shallow sandy bays. The Mayne Island Conservation Society together with SeaChange Marine Conservation Society, have been mapping the eelgrass and kelp distribution from 2008 to present and 2010 to present respectively, via citizen science / community mapping efforts.

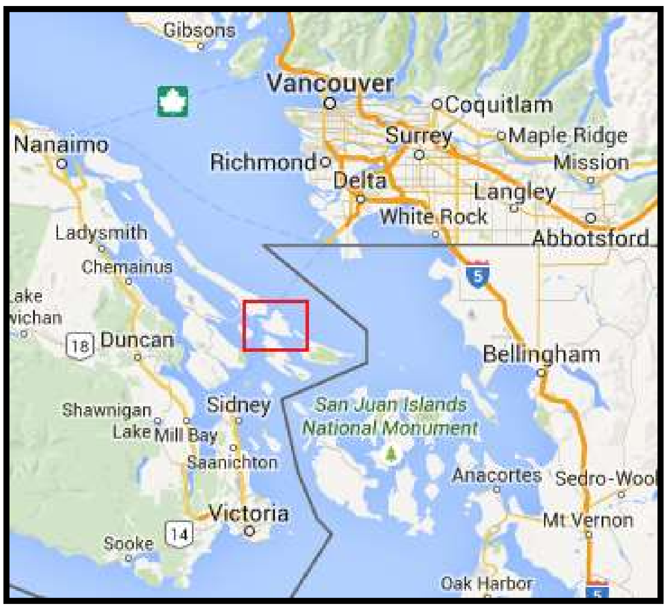


Figure 1. Location of pilot study site, Mayne Island, within red box.

This pilot study demonstrates the use of satellite optical imagery, specifically WorldView-2 and SPOT 6, to map the canopy distribution of kelp *Nereocystis leutkeana*. The best kelp map product attained in this study was produced from the SPOT-6 image, with the selected variable set of principle component PC2 and PC3 after image preprocessing steps of geo-rectification, atmospheric correction, masking of land and depth below 30 m, and the statistical image processing steps of principle components analysis and variable reduction.

The comparison of the satellite derived kelp map with the in situ kelp survey showed the high effectiveness of the developed procedures.

The coverage of the derived kelp map product is dependent on the availability of cloud-free, low tide imagery, acquired during peak kelp growth months of August through September. The accuracy of the kelp map product is dependent on (1) atmospheric conditions, (2) sea surface conditions, (3) the acquisition angle of the sensor, and (4) noise introduced by the optical sensor itself.

It is important to highlight the difficultly in comparing satellite derived kelp maps with in situ survey data given (1) the mobility of kelp beds at the surface with changing water depth and current direction throughout tidal cycles; (2) the fast growth rate of *Nereocystis* rapidly changing the standing crop of kelp between the time of image acquisition and the time of kelp survey; (3) locational error intrinsic in field surveys due to occasional human error, the accuracy level of the GPS, and availability of satellites to the GPS unit; and (4) full characterization of the reflectance of what could be false-positives

This pilot project was completed and has now been expanded for 2016. The long-term goal 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.

B4.2 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, we 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 and key findings:

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 for 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.

In April/May 2015 Ms. Kennedy sampled several seagrass habitats in the Comox Estuary for seagrass biomass and invertebrate abundance. She also collected plankton and juvenile salmon. Juvenile chum was the dominant salmonid present, so her project results focussed on the diet of chum salmon only.

Key findings were:

- Chum salmon do not seem to rely on food from eelgrass ecosystems in the Comox estuary
- Prey abundance increases with increasing eelgrass density
- Eelgrass density does not appear to change the suite of available invertebrate prey, but presence of eelgrass does (i.e. very few prey are found in unvegetated habitat, and many different types are found when eelgrass is present).
- Little is known about how salmon utilize estuarine habitat
- More research is needed to understand how salmon interact with the estuarine environment, and how they might benefit from productive, healthy near-shore ecosystems.

B4.3 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.
These objectives are:

1. Increase and restore critical marine salmon corridors;
2. Strengthen partnerships with governments, First Nations and funding agencies to promote restoration of eelgrass habitats over time and,
3. Continue stewardship of eelgrass habitats within fourteen coastal communities.

Background:

The objective of eelgrass restoration in the Salish Sea is to recover nearshore eelgrass habitats (*Zostera marina*) damaged or destroyed by historical log handling practices. Eelgrass meadows have been reduced in densities and area extent in the Salish Sea, limiting the amount of critical habitat accessible for out-migrating salmon species and other marine wildlife that use the nearshore for nourishment, shelter and metabolic growth. Because there is a dearth of research data about the limiting factors of these impacted marine subtidal environments, it is necessary to field test adaptive management and to begin applied scientific research on strategies to increase habitat recovery. Key objectives for this study include:

Eighteen sites are presently monitored for transplant density and coverage. For 2015 and 2016, the goal is to continue and expand this work. Three new components to the project have been 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.

Key sites 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 is taken of all monitored and newly transplanted sites.

Eelgrass and riparian vegetation is 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*) continues 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 are conducted in consultation with First Nations. Where possible, training in habitat mapping and restoration is occurring 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.

Diminishing kelp habitats, such as *Nereocystis spp.* are also of concern. A symposium of fifty scientists, conservation organizations and First Nations gathered in February, 2015 to address the challenges facing nearshore habitats, including forage fish spawning areas, eelgrass and kelp habitats in the Salish Sea. A newsletter was established, and data for each habitat type will be posted on the Strait of Georgia Data Centre web site.

Status and Key Findings:

A total of over 1875 m^2 of eelgrass habitat was restored in the Salish Sea from 2013-2015. During the summer and fall months of 2014-2015, 11 transplants totalling 1100m^2 were installed within the Salish Sea. Many of the sites were identified by surveying the presence/absence of eelgrass surrounding the sixteen islands within the Islands Trust Areas from 2012-2014. HOBO units were placed in several locations to monitor light availability and temperature over time.

The following objectives as listed in the Contribution Agreement with the Pacific Salmon Foundation have been met or exceeded:

Goal 1: Increase and restore critical marine salmon corridors.

Objectives:

a): Survey potential restoration sites with SCWG Community Coordinators and Science Advisor: Potential restoration sites were identified from eelgrass inventories (2012-2014), partially funded by PSF. Sites were also identified using anecdotal information from local community members. The sites were then ground-truthed with SCUBA divers, an underwater camera and GPS units. A decision-making matrix for site selection was formally created by a University of Victoria Environmental Studies student to support field work and to disseminate site selection methodology to others.

b): Obtain permits from Dept. of Fisheries and Oceans and other agencies where applicable: Under the revised Fisheries Act, no permits from DFO are required for eelgrass restoration work.

c): In collaboration with DFO, SCWG Science Advisor and Community Coordinators, transplant small test plots in 4 suitable sites within the Georgia Basin in the first year; increase area of restoration at each site in the second year based on monitoring results: A total of 11 transplants occurred during the summer and fall of 2014, an increase from the 9 sites restored in 2013.

Goal 2: Strengthen partnerships with governments, First Nations and funding agencies to promote restoration of eelgrass habitats over time.

Objectives:

a): Renew and establish new partnerships with local government agencies and staff: Partnerships were initiated or maintained with Islands Trust, Squamish Sechelt and Tsleil-Waututh First Nations, the Cowichan and Sechelt Regional Districts, and Central Saanich municipality.

b): Continue to work within the SCWG on strategies to further eelgrass restoration within the Georgia Basin: SCWG Coordinators in Squamish, Sechelt, Cowichan, Salt Spring, Gabriola and Pender Islands, and Maple Bay supported restoration work by coordinating logistics and volunteers.

c): Continue to attend conferences and workshops in both Canada and Washington State to strengthen collaborations towards net gain in marine salmon habitats within the Georgia Basin.

Project Coordinator presented at the Salmonid Habitat Conference in Vancouver Washington and at numerous workshops and community meetings, such as the Cowichan and Saanich Inlet Round Tables.

Goal 3: Continue stewardship of eelgrass habitats within fourteen coastal communities.
Objectives:
a): Recruit volunteers in training workshops and restoration activities: A total of 165 volunteers were directly involved with the eelgrass restoration in 2014.

B4.4 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 in the Salish Sea (extensive program in Puget Sound)
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 Canada's 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.

Status:
Spawning surveys by Sea Watch and Community Monitoring Efforts have been conducted for 9 years. In total, there have been ~275 beaches monitored with 42-44 positive for Pacific Sandlance and 48 for surf smelt. In total 30+km 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.

With respect to the Forage Fish Spawning Habitat Suitability Model, 11 Islands Trust islands have been monitored and project is ongoing; the Lower Mainland project has been completed; and Burrard Inlet and Howe Sound projects are beginning in 2016. Ongoing research is being carried out into the 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.

Other areas of progress include the development of a Lower Mainland Beach Spawning Forage Fish 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.

B4.5 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:

Ongoing during 2016- see summary below under "Collaborative Bull Kelp Restoration Project".

B4.6 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 past few 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.

The key hypothesis under consideration for this project is: reduction of estuary eelgrass and/or kelp habitat in specific sub-basins of the Strait of Georgia correlates with lower marine survival of juvenile salmonids.

Objectives of this project include:

1. Replanting approximately 1400 m^2 of kelp habitat through seeded line at Maude Reef in Ford Cove on Hornby Island.
2. 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)
3. 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.
4. 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).
5. Collaborative research with DFO Science partner, Dr. Ianson of IOS, and Island Scallops Ltd on carbon cycling and ocean acidification (ecological services of kelp);
6. 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 and Key Findings:

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 for both projects "Eelgrass and Kelp Restoration, Courtenay (K'omoks) Estuary" and the "Collaborative Bull Kelp Restoration Project" 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.

B4.7 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. We 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:

This project was begun in fall 2015.

B4.8 Remote Sensing Methodology to examine the relationships between eelgrass distribution, upland land use and water quality.

Team: Dr. Maycira Costa, UVic

Objective:

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.

Status:

Project started in October, 2015 and is on-going. They are currently in an organization phase for partners and data compilation.

B5. Hatchery –Wild Interactions

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.

B5.1 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.

Funding from the PSF will support 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.

B5.2 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. This project will increase the marking rate of hatchery Chinook juveniles to ~100%, which will allow for full identification of hatchery returns in other concurrent studies. The increased CWT release also improves the information on coastwide exploitation, survival and distribution for this indicator, which can provide valuable inferences for wild Chinook stocks in Lower Georgia Strait.

B5.3 EPIC4- Parental-based Tagging of Hatchery Coho salmon- Activity 3. Efficacy of hatcheries.

Team: Beacham (leader), Davidson, Withler, Devlin, Naish, Bernatchez, and Willis.

Objectives:

- 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.

Background:

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.

Status:

Funding for this project was secured through Genome Canada, and the preliminary work to collect genetic samples began in 2014. SSMSP funding contributes to Activity 3. 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.

C. Trend Analyses and Modeling

Trend analyses and modeling will provide the evaluation framework for the entire project. Existing and new data are brought together to assess 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 determinants. Historical data will also be used to look for general ecosystem regime shifts that may correlate with changes in salmon and steelhead survival. To ensure lasting value and the ability to evaluate new information as we learn, these activities will be aligned with the proposed suite of research activities involving the collection of new data.

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

Both joint coho and joint chinook retrospective survival studies are complete: the former has been published while the manuscript for the joint chinook retrospective survival study is currently under submission. The strategy for determining the suite of ecosystem indicators to be assessed throughout the Salish Sea has been determined. Furthermore, modellers from the United States and Canada have discussed approaches and target outcomes to ensure efforts are well aligned.

C1. Canadian Modeling Studies

In Canada two modelling efforts are underway:

C1.1 Salish Sea Marine Ecosystem Modeling

Team: Angelica Pena, IOS; Ken Denman (OCN), ret; post-doc (to be hired)

Status:

Angelica Pena is currently advertising for a postdoctoral researcher in the area of marine ecosystem modelling. The incumbent will work to implement an individual-based-model (IBM), representing 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.

See the following link for information on the ROMS model:
https://www.pices.int/publications/scientific_reports/report36/49-54-modeling-of-biogeochemical.pdf

C1.2. 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

Objective:

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.

Background:

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 model will be based on an extant historic Ecopath model of the Strait of Georgia prepared by the Principal Investigator which was constructed for the Ecosystem Research Initiative by Fisheries and Oceans Canada in 2010-2012 (Masson and Perry 2015)[3]. This model is described in a technical report (Preikshot et al. 2012)[4] and a peer reviewed publication (Preikshot et al. 2013)[5]. Time series for species in the historic model will be updated to include improved or newly available stock assessment data as well as improving biomass estimates for species modelled in aggregated groups. The existing model would be enhanced to include information on the ecosystem interactions of Coho and Chinook Salmon in the Strait as determined from investigations by colleagues working on the Salish Sea Marine Survival Program, e.g.,

- marine mammal interactions based on research by Ben Nelson and Austen Thomas,
- juvenile chinook salmon interactions based on survey work by Marc Trudel, Chrys Neville and Richard Beamish.

The model will also include updated information on phytoplankton and zooplankton productivity collected by colleagues at the Institute for ocean Sciences as part of the Strait of Georgia Ecosystem Research Initiative, e.g., phytoplankton bloom timing (Allen and Wolfe 2015)[6], variation in zooplankton production (El-Sabaawi et al. 2015 and Mackas et al 2015)[7].

The historic model will cover the period from 1970 to 2016. The Ecopath model will emulate historic species dynamics by fitting hindcasts of biomass, mortality rates and fisheries yields to reference time series data from surveys and stock assessments. The modelled data will be fitted to reference time series in a three step process;

- account for extractions by fisheries and inputs from hatcheries,

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[3] Masson, D. and R.I. Perry. 2013. The Strait of Georgia Ecosystem Research Initiative: An overview. Progress in Oceanography 115: 1-5.

[4] Preikshot, D. C.M. Neville, and R.J. Beamish. 2012. Data and Parameters Used in a Strait of Georgia Ecosystem Model. Can. Tech Rep. Fish. Aquat. Sci. 3005.

[5] Preikshot, D. R.J. Beamish, and C.M. Neville. 2013. A Dynamic Model Describing Ecosystem-Level Changes in the Strait of Georgia From 1960 to 2010. Progress in Oceanography 115: 28-40.

[6] Allen, S.E. and M.E. Wolfe. 2015. Hindcast of the timing of the spring phytoplankton bloom in the Strait of Georgia, 1968–2010. Progress in Oceanography 115: 6-13.

[7] El-Sabaawi, R., M. Trudel, and A. Mazumder. 2015. Zooplankton stable isotopes as integrators of bottom-up variability in coastal margins: A case study from the Strait of Georgia and adjacent coastal regions. Progress in Oceanography 115: 76-89.

Mackas, D., M. Galbraith, D. Faust, D. Masson, K. Young, W. Shaw, S. Romaine, M. Trudel, J. Dower, R. Campbel, A. Sastrid, E.A. Bornhold Pechter, E. Pakhomov, R. El-Sabaawi. 2015. Zooplankton time series from the Strait of Georgia: Results from year-round sampling at deep water locations, 1990–2010. Progress in Oceanography 115: 129-159.

- estimate predator-prey, i.e., ‘top-down’ and ‘bottom-up’ interaction for predator prey linkages in the model,
- estimate historic variation in annual average primary production anomalies (PPAs).

Status: Project approved and begun April 1 2016.