SALISH SEA

MARINE SURVIVAL PROJECT

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SECTION 1: OVERVIEW

The Salish Sea Marine Survival Project is a multi-disciplinary, ecosystem-based research effort to determine the most significant factors affecting juvenile salmon and steelhead survival in the Salish Sea marine environment. The project is coordinated by nonprofits, Seattle-based Long Live the Kings (LLTK) and Vancouver-based Pacific Salmon Foundation (PSF), and involves over 150 scientists and technical staff from over 40 Federal and State agencies, Tribes, academia, and nonprofit organizations. It was initiated in response to significant declines in Chinook, coho and steelhead marine survival relative to other regions in the Pacific Northwest; apparent changes in the Salish Sea marine ecosystem over the same time period; and increasing evidence that overall marine survival is largely dependent upon the growth and survival of juvenile salmon after they first enter the marine environment.

Planning associated with this trans-boundary initiative began in 2012, and the five-year research phase began in 2014. 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 30-40 projects in 2015 and 2016 conducted by over 30 partners with a total expenditure of approximately $6.5M. Field studies will continue during 2017, while 2018 will be dedicated to assimilation of results, analysis and dissemination of key findings.

The final year will be used to convert the research results into general conclusions, reporting, and management actions. This report provides an overview of the Canadian program for 2017-2018, and is an update of a similar overview report for 2015-2016 studies (Salish Sea-Strait of Georgia Marine Survival Research Plan 2015-2016; see http://marinesurvivalproject.com/resources/).

Objectives

The primary objective of the Salish Sea Marine Survival Project is to determine the principal factors affecting the survival of juvenile salmon and steelhead in the Salish Sea. In Canada these studies are intended to:

- Re-build production of wild Pacific salmon and steelhead through a program that is ecosystem-based, considers hatchery effectiveness, and engages communities.
- Promote sustainable fisheries and increase their value to B.C. communities, and
- Provide a foundation for long-term monitoring of Salish Sea and salmon health.

Ultimately, the research results and subsequent management actions may also benefit other marine life in the Salish Sea, such as the southern resident killer whales[1].

[1] The Southern Resident Killer Whale population is listed as 'endangered' under Canada's Species at Risk Act (http://www.registrelep-sararegistry.gc.ca/default.asp?lang=En&n=A9748209-1).

Scope and Geographic Range

The geographic range of this project includes the entire Salish Sea, the body of water that extends from the north end of the Strait of Georgia and Desolation Sound to the south end of the Puget Sound and west to the mouth of the Strait of Juan de Fuca (i.e., the inland marine waters of southern British Columbia, Canada and northern Washington State[2]).

The interaction between salmonids with environments in the Salish Sea is complex. This study is being approached from an ecosystem context requiring experts from multiple disciplines. Chinook, coho and steelhead are the species of greatest concern given significant declines in their smolt[3]-to-adult survival (the primary measure of marine survival) since the mid-1990s. However, chum, pink and sockeye will be included to the extent practicable given potential for shared survival determinates; inter-species competition; the recent extraordinary variation in survival of these species, and the associated effects on local fisheries.

The Project's focus will be on factors affecting juvenile salmon and steelhead while they are in the Salish Sea. Understanding the condition of fish entering the Salish Sea marine environment will also be included to assess whether conditions prior to their marine residence affect survival in the Salish Sea. Resident Chinook and coho salmon will be studied as these fish stay within the Salish Sea through adulthood and may provide a clue to how salmon respond to variations in marine conditions. However, it will be more difficult to determine whether conditions in the Salish Sea and the impacts on juvenile salmon, also affect the survival of salmon in the open north Pacific Ocean after they leave the Salish Sea (i.e., Is survival in the North Pacific contingent on the conditions these salmon encounter in their earlier life phases?). Conditions in the North Pacific will not be included other than the large scale climate systems that annually influence weather conditions in the Salish Sea.

Figure 1. Topographic map of the Salish Sea

Within the Salish Sea, a number of changes over time have likely contributed to the decline in catch of these Chinook and coho. Before the decline in catches (1980s and into 1990s), fishing pressures exceeded those sustainable for Chinook and coho salmon produced from natural habitats. Compounding this, the marine survival rates of hatchery and natural Chinook and coho declined steadily through that period.

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[2] See map: http://staff.wwu.edu/stefan/SalishSea.htm

[3] A "smolt" is the stage of a juvenile salmon's life when it is physiologically capable of adapting to saltwater. In this stage, the juvenile becomes silvery (losing it dark bars) and begins migration out of freshwater habitats.

The combination of excessive fishing pressures and declining survival rates accelerated the decline in abundance of Chinook and coho salmon. However, reductions in fishing pressure and significant investments in hatchery production during the past 20 years within the Strait have failed to recover local natural populations or sustain associated fisheries.

While scientific and public consultations identified many changes in the Salish Sea over past decades, there was little agreement or understanding on the causes of the salmon declines. It was also apparent that we lack scientific consensus in Canada or the United States on processes presently determining the annual production of Chinook and coho salmon in the Salish Sea.

However, in preparing for this research, a short list of the primary concerns and knowledge gaps has been identified:

- Causes of early marine mortality are largely unknown (there is consensus that mortality rates are highest in the first few months in the sea but little agreement on the mechanisms);
- Changes in the marine ecosystems of the Salish Sea have been numerous, widespread, and significant;
- There is a lack of understanding as to why hatchery-produced salmon have also shown poor survival and have not been able to sustain local fisheries. It is likely that production from the major hatcheries is competing with wild fish.
- Information collected through annual oceanographic surveys have seldom been linked with data on Pacific salmon production or its' variability; and
- Research to-date has lacked a conceptual foundation or plan designed to understand the production of Pacific salmon within the Salish Sea (despite an abundance of researchers, laboratories, and ships).[4]

Conceptual Development of the Study

The lack of consensus on causation could have been anticipated when attempting to assess changes in just a few specific species within a complex natural ecosystem. However, we know that two broad categories of effects need to be studied. In ecological terms, these categories are referred to as "**bottom up**" (the annual variation in environmental conditions) versus "**top down**" (biological factors). But in reality, these categories interact in natural ecosystems to generate the annual variations that we observe in salmon abundance, distribution, and growth.

'Bottom-up' control simply means the food that the young fish need is a determining factor. The mechanism involves annual weather conditions and effects mediated through the lower levels of the biological production chain. Initially environmental conditions influence the timing, intensity, spatial extent, and duration of phytoplankton blooms (e.g., winter wind and spring sunlight determine the timing of spring blooms of phytoplankton). Once the primary production (phytoplankton) is initiated, energy is

[4] A comprehensive source for publications related to the Strait of Georgia and Pacific salmon can be accessed at the Strait of Georgia Data Centre (www.sogdatacentre.ca) containing over 10,800 references.

passed through to higher levels (zooplankton and ichthyoplankton (fish eggs and larvae)), upward to small forage fishes and onward to juvenile salmon.

'Top-down' control refers to a variety of biological factors that directly limit survival of salmon and therefore their abundance (i.e., what kills juvenile salmon in the Salish Sea). Mortality likely occurs through predation, pathogens and disease expression, competition for food, and human developments including habitat loss, shore-line modifications, and aquaculture. Each of these factors may act singularly but usually the effects involve multiple factors that vary in time, space, and opportunity.

While none of these factors are new insights, they are recurring concerns, and most have not been thoroughly explored for Pacific salmon within the Strait of Georgia and Juan de Fuca.

The challenge then in developing the SSMSP was how to separate the effects of multiple factors to identify the primary determinants of salmon production and, subsequently, what mitigation measures may be possible to improve annual production.

If environmental conditions and bottom-up processes primarily control Chinook and coho production, then recommendations for how to restore and sustain production will be fundamentally different than if top-down biological processes are the primary controls.

Further, biological interactions may have very different consequences depending on what the productivity of the environment is during a particular time and place. This point is not widely appreciated but could be very important. For example, the consequences of interactions between hatchery and natural juveniles may vary widely depending on the abundance and availability of food for juvenile salmonids (i.e., competition for food would be much greater during poorer environmental conditions with resultant poor food production).

Setting Goals for Salmon Recovery

If the marine environment in the Strait of Georgia has changed dramatically over the last 30 years, it is unclear whether the abundances in the 1970/80's are reasonable expectations for future recovery goals. Modeling studies at the University of British Columbia (UBC) have suggested that recovery may only be possible to about one half of past levels[5,6].

Such models can be an informative representation of natural processes and can identify key sensitivities or unknowns in the development of mitigation plans. However, given our state of knowledge and the numerous interactions possible, it is inappropriate to use them to recommend specific recovery goals at

[5] Source: Martell, S.J., Beattie, A.I., Walters, C.J., Nayar, T., Briese, R., 2002. Simulating fisheries management strategies in the Gulf of Georgia ecosystem using Ecopath with Ecosim. In: Pitcher. T., Cochrane, K. (Eds.), The Use of Ecosystem Models to Investigate Multispecies Management Strategies for Capture Fisheries. Fisheries Centre Research Reports 10(2), pp. 16–23

[6] Recovery to 50% of the past production would still be a very successful program and provide for sustainable fisheries operating at lower but appropriate harvest rates.

this time. *The SSMSP should more appropriately be considered the beginning of an adaptive management process to restore salmon production over time.* The process would include: establishing interim actions and production targets, monitoring responses at a level of detail required to assess actions, and adapting to what is learned. Such a process will likely be more immediately informative for coho salmon due to their 3-year life cycle, but is applicable to Chinook salmon. This course of action will also directly engage communities and user groups in establishing restoration goals and making key decisions.

Hypotheses for SSMSP

Science advisors to the SSMSP broadly agree that the primary hypotheses to investigate include, in order of significance:

A. Bottom-up processes — annual environmental conditions that determine the food for salmons and therefore result in the variation in size and growth rate of juvenile salmonids.
B. Top-down processes - biological processes that directly determined the survival of salmonids. Predation is likely the direct cause of mortality, but fish condition may be compromised by other biological factors, increasing their susceptibility to predation (e.g., disease, hatchery versus wild competition).
C. Additional in-direct factors exacerbating these ecological processes, including habitat loss, and contaminants, and interactions with aquaculture.

In actuality, each of these factors interact each year but to differing degrees. Consequently, to explain the annual variation we observe, requires monitoring each of the factors each year. The Project will build out from the condition of juvenile salmon in-river, to estuary environments and habitats used by salmon, and into the near-shore waters in order to identify very local effects occurring within more global factors. The differentiation of where effects are most influential will be important to identify mitigation opportunities versus longer-term adaptation of Pacific salmon to environmental conditions that are changing over time.

The SSMSP will build from extensive past research, identify hypotheses presently under consideration and develop research and monitoring programs to test these. By measuring many factors simultaneously, the SSMSP will allow consideration of multiple hypotheses within and between years. The Project proposes three years of comprehensive and integrated research and analysis, followed by the development of adaptive management actions to rebuild salmon production and sustainable fisheries.

Table 1 below shows the key hypotheses that have been compiled by the Canadian researchers. The complete list of detailed hypotheses for both Canada and the US is listed on the SSMSP website including an indication of whether each hypothesis is being addressed in the US only, Canada only or by both.

The important differences of the SSMSP from previous research efforts is the scope of topics considered simultaneously and the breadth of collaboration involved. The SSMSP benefits from a depth of past research (literally thousands of studies and report, see www.sogdatacentre.ca). But this history covers almost one hundred years of projects and has failed to provide an understanding of the ecological controls/mechanisms that determine the annual production of Pacific salmon within the Strait of Georgia (also true for the geographic area encompassed by the Salish Sea). This is not a comment about the quality of research conducted but the context within which it was conducted. Many individual studies address specific species in a particular time/area and for short periods of years. In a complex and open ecosystem such as the Salish Sea, studying a species without consideration of its broader environment will naturally limit the inferences and understanding that can result. This limitation is the fundamental observation that the Science Team addressed in developing the scope of the SSMSP. Put simply, the SSMP will endeavor to study everything at once that could be hypothesized to impact the annual production of Pacific salmon within the Salish Sea (Figure 2).

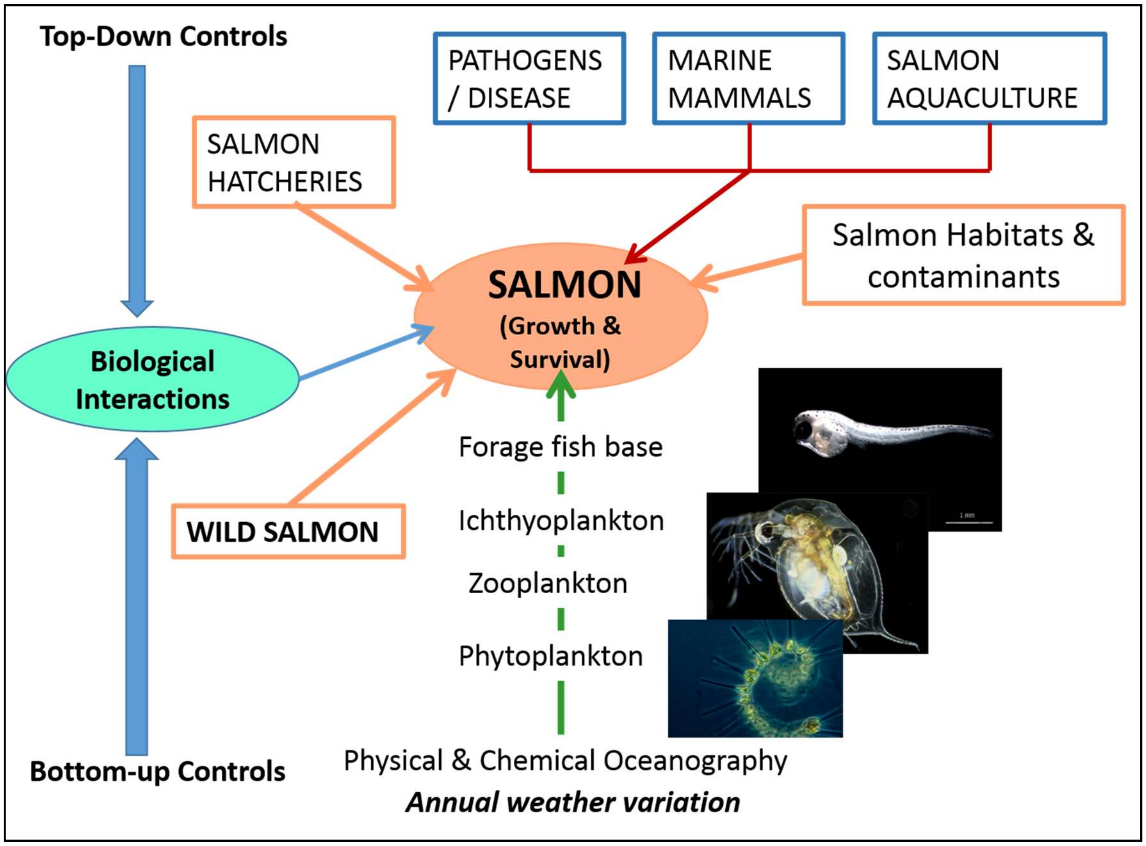


Figure 2. A schematic of the factors addressed annually within the Salish Sea Marine Survival Project. In aggregate, studies within each of these components makes up the SSMSP.

Short descriptions of each of the individual studies are available in Section 4 of this document, while the full original proposals for each project are available as an appendix on the SSMSP website.

However, a project of this scope obviously creates issues of its own, for example:

1) Duration of the Project (an extended commitment of resources and its total cost);
2) Building the collaboration to conduct the studies and sustain that effort over time, and
3) Coordination of each program within the overall Project (domestic and international).

While undertaking the breadth of studies is necessary to understand the mechanisms that determine salmon production in a year, we acknowledge that the scope of work cannot be sustained for many years. However, this scope of work is also a unique attribute of this Project. The SSMSP is a five-year project including one year of planning and testing methods, three years of research intended to cover the full scope of study, and one year for completion of analyses and initial reporting. The Pacific Salmon Foundation has secured the funds for the five years but we fully acknowledge that restoration and management actions will require more time. Therefore, a major objective of this effort is to ensure that ecological monitoring within the Salish Sea continues after the SSMSP so that the health of these ecosystems are no longer neglected.

The ability to undertake the scope of this initiative required building a research network with government laboratories (with Science Branch, Dept. Fisheries and Oceans, Canada), First Nations, universities, non-government organizations, and local communities. The network has been built over the past few years and is based on the common objective of promoting sustainable fisheries and salmon production within the Salish Sea. Organizations with the expertise to deliver specific components of the Project were invited to participate and prepare research proposals for technical review and subsequent funding. The SSMSP did not use an open solicitation of research proposals in order that we could ensure the greatest coverage of the study components within the available funds.

Table 1. Possible mechanisms controlling brood year strength in the marine environment for Pacific salmon.

Hypothesis	Explanation	Prediction	Potential Metrics
Critical periods	Marine survival is thought to be set during two (or more) critical periods/windows	Total marine survival is largely determined during the early marine life stage.	Survival rates determined by tagging fish in the river and in the ocean with PIT-tags; Size-selective mortality determined from otoliths
		Total marine survival is correlated to winter survival.	Survival rates determined by tagging fish in the river and in the ocean with PIT-tags; Size-selective mortality determined from otoliths
Smolt condition	Conditions in the freshwater environment affect the ability of the smolt to survive in the marine environment	Size dependent survival of smolts. Hatchery fish have lower marine survival than wild fish	Back-calculated size at ocean entry; Smolt size; Lipid concentration/composition; use of otoliths, PIT tagging approaches
		Physiologically prepared smolts have higher survival	Predation risk experiments; Size-selective mortality determined from otoliths Genomic profile of smolts; NaK-ATPase
Prey availability	Fish that grow quickly survive better because they can escape predators or survive winter better	Marine survival increases with prey production.	Zooplankton biomass; Ichthyoplankton biomass; herring/sandlance recruitment; Stable isotopes of carbon as a proxy for productivity; Diet
		Growth and food consumption rates increase with prey production.	Feeding rate determine using cesium; Growth determined with RNA:DNA ratio, otolith and/or IGF
Density-dependence	Prey availability becomes limiting as the numbers of smolts increase and/or prey production is poor/decreases	Marine survival decreases with increasing smolt abundance. [For instance, changes in pink salmon abundance between odd-even years].	CPUE of competitors; Marine survival; Prey availability/quality
		Growth and food consumption rates are inversely related to the abundance of competitors.	Feeding rate determined using cesium; Growth determined with RNA:DNA ratio, otolith and/or IGF; CPUE of competitors

Match-mismatch	The timing of ocean entry is thought to have evolved to coincide with the timing of prey production	Smolts that enter during the peak of prey availability perform better.	Marine survival from different release groups (PIT-tags and CWT); Ocean entry time from otoliths. Sampling for prey production timing and quantity/quality.
Junk-food/Prey-quality	Growth of juvenile salmon is affected by the nutritional content of their food.	Marine survival and growth increases with the availability of preferred (fat/nutritious) prey.	Growth determined with RNA:DNA ratio, otoliths and/or IGF; Lipid concentration/composition in zooplankton/ichthyoplankton; Stable isotopes of nitrogen; Carbon-to-nitrogen ratio in plankton
Winter starvation	Winter is a critical period due to low food availability and low temperatures.	Fish that do not reach a critical size, growth, or lipid concentration prior to the winter do not survive.	Survival rates determined by tagging fish in the river and in the ocean with PIT-tags; Size-selective mortality determined from otoliths; Predation risk and starvation experiments
Predation-intensity	Predation is a direct cause of mortality.	Mortality rates increases with the abundance of predators.	Abundance of piscivorous fish; Frequency of salmon in the stomachs of fish predators; size of salmon in the stomach of predators; Predator distribution (day-night, light-dark) and response to salmon availability.
Buffering-capacity	The probability of being detected by predators decreases with the abundance of alternative prey.	Mortality rates decreases with increasing abundance of forage fish [or other prey items such as euphausiids].	Abundance of piscivorous fish and forage fish from nighttime surveys; Predator distribution (day-night, light-dark)
Disease-susceptibility	Infected fish may be more susceptible to predators or simply die from the infection	Mortality increases with increasing parasite or pathogen loads.	Pathogen surveys using DNA assays to monitor for presence and load of disease agents; supported by challenge tests to assess impacts of specific pathogens and/or synergistic effects of multiple pathogens.

US-Canada Coordination and Alignment

Possibly the greatest challenge in managing the project will be in the coordination of the many components within Canada and the United States. The analogy of the weakest link in a chain is appropriate. While this issue is recognized, minimizing the impact of it falls to the Project managers to track progress by each organization and, where possible, to foresee problems. For example, ensuring comparability of sampling has been addressed by developing sampling protocols for specific tasks; communication between researchers has been addressed through workgroups, internet communication sites, and annual international workshops; and Project managers are in weekly communication throughout the year.

At the international level, the primary concern has been alignment of the research programs. Alignment has been monitored under three broad categories:

1. **Bottom-up Sampling Program and Individual Studies**
    - A fully integrated sampling program examines the condition of salmon and steelhead as they out-migrate while simultaneously evaluating the physical and biological (plankton) characteristics of the Salish Sea. This includes identifying critical growth periods and understanding the primary mechanisms affecting growth.

      U.S. – Canada alignment is high

    - Individual bottom-up studies build off of this sampling framework to hone our understanding of the relationship between salmon and their prey, and to build out from the fish and their prey to the factors driving prey availability, such as temperature, habitat availability, ocean acidification, runoff, and wastewater. Many of these studies are to test specific mechanisms, new ideas and may focus on particular areas/issues of interest. Thus, a distributed approach among U.S. & Canadian scientists is applied to cover more ground.

      U.S.-Canada alignment is moderate

2. **Top down Studies -** Targeted studies evaluate predation (what eats salmon and steelhead) and other potential contributing factors, including disease, toxic chemicals, competition between hatchery and wild fish, harmful algae, and aquaculture impacts. A distributed approach among U.S. and Canadian scientists is applied to address unique/local issues and cover more ground depending on local issues/areas of interest, although we are working to align the contaminant studies, and there is overlap with approaches to assess marine mammal predation.

   U.S.-Canada alignment is moderate

3. **Trend Analyses and Modeling -** Existing and new data are brought together to analyze and model relationships between salmon and their ecosystem, to evaluate the cumulative effects of multiple factors, and to model factors ultimately driving survival over time. This work establishes the platform for integrated data analyses for the entire project. The work includes survival trends, ecosystem indicators development and ecosystem modeling.

   U.S. – Canada alignment is moderate-high

In summary, the fundamental differences of the SSMSP from past research are:

a) The scope and integration of individual studies;
b) The collaboration of researchers and organizations to facilitate the scope of studies (building collaboration and research network); and
c) The integration of individual studies into an understanding of the mechanisms determining the survival of Pacific salmon in our near-shore marine waters.

SECTION 2: PROJECT MANAGEMENT

There are three levels of management within the SSMSP. The base level of consideration is a Science Team composed of local experts (Table 2) who advised on the factors to be considered and reviewed the research proposals prepared before any individual project is funded.

Drs. Riddell and Pearsall will be responsible for tracking research activities, monitoring progress, producing overviews for the science team and the Foundation's Oversight Committee, and providing feedback to the various scientists, First Nations and community groups involved. The Pacific Salmon Foundation will provide administrative and financial services to the project.

Table 2. Science Team for Canadian portions of SSMSP.

Brian Riddell (Project Lead)	CEO/President, Pacific Salmon Foundation	Background, Research Scientist in salmon assessment and genetics, and fisheries management.
Isobel Pearsall (Project Coordinator)	Research Scientist, Pacific Salmon Foundation	Responsible to oversee the project, managing staff and volunteers, science coordination and planning. Lead for Strait of Georgia Data Centre, UBC
Richard (Dick) Beamish, Fisheries Research	DFO Science (retired)	Extensive experience in fish, fisheries, and the Strait of Georgia[7].
Ken Denman, Oceanography and Climate	DFO Science (retired)	Adjunct Professor, School of Earth and Ocean Sciences at University of Victoria, and past Chief Scientist with Ocean Networks Canada.
Ian Perry, Fisheries Oceanography	DFO Science, Research Scientist	Head of Zooplankton Ecology and Ecosystems, DFO Science, and Adjunct Professor, UBC
Andrew Trites, Marine Mammologist	Professor, UBC	Director, Marine Mammal Research Unit at UBC, and Research Director of the North Pacific Universities Marine Mammal Research Consortium.
Tony Farrell, Fish Physiology	Professor, UBC	Canada Research Chair in Fish Physiology, Culture and Conservation (since 2010)
Carl Walters, Fisheries & Modelling	Professor Emeritus, UBC	Zoology and Fisheries, specialist in fisheries stock assessment, adaptive management, and ecosystem modeling
Marc Trudel, Fish Ecology	DFO Science, Research Scientist	Head, Salmon Marine Interactions Section at the Pacific Biological Station. Adjunct Department of Biology, UVic
Kristi Miller-Saunders, Molecular Genetics	DFO, Research Scientist	Head, Molecular Genetics Laboratory at Pacific Biological Station, and an adjunct Professor in the Department of Forest Sciences at UBC
Mel Sheng	DFO, Salmonid Enhancement Program, Biologist	Operations Section Head for DFO's South Coast Area, Salmon Enhancement Program

[7] Author "The Sea Among Us, the amazing Strait of Georgia", by RA Beamish and G. MacFarlane. 2014. Harbour Publishing.

At the second level of management, the PSF's Board of Directors (list available at www.psf.ca) has formed a SSMSP Oversight Committee to monitor the conduct and administration of the project. Terms of reference for this committee have been set as:

- Provide financial oversight of the use and accountability of funds used in the project, and monitor fund raising and cash flow during this project;
- Report annually on the progress of this research on achieving its stated objectives as presented within the original project description, and recommend corrections to actions or objectives as determined by this committee;
- Communicate effectively on results to funders, government agencies, and the public as appropriate; and
- Support the integration of programs between PSF and Long Live the Kings (US host agency) as this project proceeds.

Periodic meetings with the science team will allow for information exchange with the Oversight Committee and allow feedback on direction of research and funding.

The third level of project management involves the coordination of research planning and projects between countries. The responsibility for the coordination rests with the Pacific Salmon Foundation (Vancouver, BC) and Long Live the Kings (LLTK, Seattle, WA). Coordination has been facilitated by development of sampling protocols and data standards, development of secure websites for communication and data sharing (BaseCamp software), creation of a Project website for document sharing, research up-dates, and public access (www.marinesurvivalproject.com), and annual workshops to review research progress and planning for future works.

Collaboration and Communication

LLTK and PSF are responsible for developing and maintaining collaboration and communication. The primary tools for facilitating collaboration include: a web-based project management utility called Basecamp to allow for communications and support data sharing; facilitated meetings and conference calls, workgroup contact management, and annual U.S.-Canada workshops to discuss progress, findings, continued alignment, and next steps. Both project coordinators have developed several different Basecamp online projects: for example, in Canada, we have developed a communication project for Canada's Citizen Science program; a Nearshore Habitat working group project for those involved in forage fish habitat, and kelp and eelgrass restoration; as well as projects for sharing results of studies such as the Cowichan Research study. We also have joint US-Canada projects for Communications, Project Management, and Web Development.

Communications activities led by PSF and LLTK for this project include: a project web site and social media outlets; a media library including photos, videos, and stories; project logo and brand elements management; partnering with reporters to capture the research; coordinating with the public relations departments of all participating groups; and in-house publications to report on project progress. Participating scientists will disseminate their results at workshops and via peer-reviewed publications.

All participating scientists and managers continue to convene at annual U.S.-Canada Retreats over the course of the project to facilitate alignment, promote cross talk, compare outcomes, and discuss next steps. So far, four US-Canada retreats occurred in 2013, 2014, 2015 and 2016. A larger workshop will occur to ensure good communication with the broader community in 2018, at completion of the research phase (2014-2017).

The project website (www.marinesurvivalproject.com) is a continual work-in-progress as updates and new additions are included.

Information Management and Infrastructure

Complex research projects are often deficient in allocating resources for knowledge management. Knowledge management includes the organization of new information, the integration of current knowledge, and the development of an analytic framework for the testing of competing hypotheses (i.e. decision support). Further, models of ecosystem behaviour need to be designed to account for variation in both space and time. Only recently has increased computing power been combined with analytical and visualization tools (e.g., Google earth, HectaresBC) to provide for calculations at meaningful resolutions and within reasonable time frames.

Another function of the infrastructure system is to create communication products. When communications are made to politicians and the public, the messages must be clear and understandable. A well-structured knowledge management infrastructure and an effective presentation system will significantly enhance the credibility of project presentations.

To this end, we have adopted a number of guidelines and activities around data sharing and infrastructure. These include:

1. Data will be stored to allow open access and peer review.
2. A ‘core’ collection of data sets will be made available for use by all members of the research teams (e.g., historical catch or spawning escapement data, hatchery releases).
3. Open source software will be encouraged.
4. UBC provides the server “hub” and programming support for the project via the Strait of Georgia Data Centre (www.sogdatacentre.ca). Other open-access data systems in use include Oceans 2.0 at the University of Victoria, and BaseCamp, a project management site where photographs, videography and researcher observations are freely available for use by all project participants. Other open access data systems may be used by the US side.
5. Data will be stored outside of government systems to enable open access and reduce costs.
6. All data will be spatially referenced with attached metadata.

Data Sharing and Publications

With many researchers involved in an international project, the topic of data sharing and publication rights has been an interest. One goal of the Salish Sea Marine Survival Project is to make ecosystem data developed through this effort comparable across the Salish Sea and readily available and usable for a variety of analyses, with a life extending beyond this project. Therefore, all relevant datasets produced via the SSMSP have been requested as deliverables (in addition to technical reports, manuscripts or other types of reports) from individual projects. All data collected within the SSMSP will be open to all participants with the exception that some specific agreements require time allowances for first publication.

All data and reports from the SSMSP are made available to the public via the Strait of Georgia Data Centre and the SSMSP website. Guidance has been provided to researchers with respect to how to acknowledge the SSMSP, and reports are numbered sequentially so that all the products from the program can be tracked over time.

Background Reports

The following reports are available on the project website, as are the descriptions, hypotheses and background information regarding the Salish Sea Marine Survival research effort:

1. Salish Sea – Strait of Georgia Marine Survival Research Plan 2015-2016
2. Puget Sound Steelhead Marine Survival: 2015-2017 Research Plan (2015)
3. US-Canada Operating and Alignment Summary (2015)
4. PSF Strait of Georgia SSMSP Backgrounder 2015
5. Canadian SSMSP Status and Findings to Date 2015
6. Puget Sound Marine Survival Research Plan Version 1: 2014-2015 Research Details (2014)
7. Research Work Plan: Marine Survival of Puget Sound Steelhead (2014)
8. Marine Survival of Salmon & Steelhead in the Salish Sea: Hypotheses and Preliminary Research Recommendations for Puget Sound (2012)
9. Strait of Georgia Chinook and Coho Proposal (2009)
10. Comprehensive list of hypotheses

There also are a number of meeting summaries from the US-Canada planning and co-ordination retreats (2013-2016):

1. 2015 US – Canada Science Retreat Report (2016)
2. 2014 US – Canada Planning and Coordination Retreat (2015)
3. 2013 US – Canada Planning and Coordination Retreat (2014)
4. 2012 Research Planning and Ecosystem Indicators Workshop Series Presentations and Results & Recommendations Report (2013)

There is also a Primary Publications section on this website. This includes the following publications to date:

- Duguid & Juanes (2017) Microtrolling: an economical method to nonlethally sample and tag juvenile Pacific salmon at sea. DOI: 10.1080/00028487.2016.1256835
- Berejikian et al. (2016) Predator-prey interactions between harbor seals and migrating steelhead trout smolts revealed by acoustic telemetry. DOI: 10.3354/meps11579
- Thomas et al. (2016) Harbour seals target juvenile salmon of conservation concern. DOI: 10.1139/cjfas-2015-0558

- Moore et al. (2015) Multi-population analysis of Puget Sound steelhead survival and migration behavior. DOI: 10.3354/meps11460
- Zimmerman et al. (2015) Spatial and temporal patterns in smolt survival of wild and hatchery coho salmon in the Salish Sea. DOI: 10.1080/19425120.2015.1012246

Finally, a number of technical reports have been produced from this project to date:

- MacCready & Banas (2016) Linking Puget Sound primary production to stratification and atmospheric drivers on seasonal to inter-decadal scales. SSMSP Technical Report.
- Kemp & Keister (2015) Zooplankton community patterns in Puget Sound: description of a 20-year qualitative dataset. SSMSP Technical Report.
- O'Neill et al. (2015) Toxic contaminants in juvenile Chinook salmon (Oncorhynchus tshawytscha) migrating through estuary, nearshore and offshore habitats of Puget Sound. SSMSP Technical Report.
- Pearson et al. (2015) Identifying potential juvenile steelhead predators in the marine waters of the Salish Sea. SSMSP Technical Report.
- Wade, J. (2014) Citizen science bird survey in the Cowichan Valley in support of the Pacific Salmon Foundation's Salish Sea Program 2014. Can. Manuscr. Rep. Fish. Aquat. Sci. 3044: iv + 30 p.

SECTION 3: PROGRAM PLANNING FOR 2017-2018

In 2014, Canada intentionally focused work on juvenile salmon sampling in the Cowichan Bay as a test site for developing sampling guidance for application at other future sites. Lessons learned allowed for development of the full 2015 program. The 2015 program and associated budgets were developed through a solicited proposal process, and evaluation of proposals by the Canadian science team. The Science Team recommended that a full set of projects should be continued for 3 full years, with intense and simultaneous data collection for the bottom-up, top-down and other studies. Most of the accepted proposals were for a 2-year duration.

In the fall of 2016, additional projects were considered by the Science Team for both the final year of field studies in 2017, and the analytical/modeling studies for 2017-2018. In many cases, the projects under consideration were simply one-year continuation studies to allow for 3 full years of data collation. However, new proposals were also solicited and developed based on the findings from studies carried out in 2015 and 2016. The Science Team met several times during 2016 to assess and rank new proposals. Criteria used to assess proposals are provided in Table 3.

Discussions at both the Canadian SSMSP Retreat in November 2016, and the US-Canada Retreat in December 2016 also resulted in a number of recommendations. Overall, the SSMSP has enabled the collation of huge amounts of data, and the level of integration both within Canada and transboundary has increased greatly over the past few years. As groups are made aware of the different data collections, there is, for example, increasing cross-calibration of oceanographic data sets, and validation of models and satellite imagery products. The Canadian data are being made openly available on the Strait of Georgia Data Centre portal (www.sogdatacentre.ca).

Most emphasis is currently on how to integrate the information collected to date. The Canadian researchers are being encouraged to collaborate, work in teams, and to focus on publications. To this end, we have decided to create a number of workgroups. These will include the following:

- ✓ Biological Oceanography & Environmental Parameters
- ✓ Zooplankton, Ichthyoplankton & Forage Fish
- ✓ Juvenile Salmon
- ✓ Predation
- ✓ Nearshore Habitat
- ✓ Analysis and Modeling

We have assigned a lead person for each workgroup, and will encourage and facilitate meetings (amongst Canadian researchers and transboundary) over 2017 and 2018.

Additionally, it is apparent that some PIS require increased capacity to enable them to achieve timely sample processing and analysis. Other PIS require statistical or GIS capacity so we are identifying individuals that can assist with these requirements during 2017.

Table 3. Criteria used in project evaluation.

Criteria	Weighting
Applicability and relevance • Is this proposal a core element of the SSMSP as agreed by the Science Team? • Are the stated objectives and expected deliverables (outputs) relevant to the goals of the SSMSP? • Will this work result in outcomes that assist us in accepting/eliminating hypotheses related to the production of chinook and coho in the Salish Sea?	30%
Scientific merit and technical quality • Are the research objectives and expected deliverables/outputs of the proposal clearly stated? • Are the research objectives and expected deliverables/outputs of the proposal achievable? • What is the significance of this project- how important is the proposed activity to advancing knowledge or understanding? Does it show innovation?	20%
Sound research methodology • Is the work plan adequate? Is it clearly described and well defined? • Are the scheduled tasks and methods adequate to the stated objectives? • Is it clear how the data will be managed, analyzed, and archived?	20%
Budget estimation • Is the budget reasonable for the proposed goals, activities and expected deliverables? • Are all budget lines adequately justified, including specific equipment, supply cost, estimates of number of hour/pay scale for personnel (e.g. students; other personnel), travel, and publication cost? • Does the narrative adequately justify the requested funding, including support for in-kind contributions and funding committed from other sources?	15%
Collaboration and Integration • Does this proposal show adequate integration and collaboration with other proposed/ongoing projects and other PIs?	10%
Reporting • Has the author clearly stated how the results will be disseminated to enhance scientific and technological understanding?	5%

Recommended 2017-2018 Program

The following table describes the Strait of Georgia research studies approved for funding in November 2016. 2017 marks the final year for field studies, and programs accepted for 2018 are primarily focussed on data assimilation, modelling and synthesis. Details of these programs are provided in the next section of this document.

For results to date for continuing programs, please see the following documents that are on the project website (www.marinesurvivalproject.com):

- Canadian SSMSP Status and Findings to Date 2015
- Canadian SSMSP Status and Findings to Date 2016

Overall, our key goals for 2017 are as follows:

1. Continue a third (and final) year of the complete sampling program. This will involve the following key collections: citizen science, buoys, satellite imagery, zooplankton program, herring studies, juvenile salmon studies, genomic studies, and completion of the seal predation studies.
2. Fund a number of additional projects for 2017 including the following:

   -Funding modeling programs for a) Dr. Susan Allen (UBC), b) Dr. Villy Christensen (UBC) and C) Dr. Angelica Pena (IOS).

   -Provide funding to John Dower's lab at UVic for analysis of herring energy content. Given the importance of herring to juvenile coho and chinook diets, this collaboration will be useful.

   -Provide funding to Dr. Brian Hunt's lab at UBC for a post-doc who will establish a mechanistic understanding of the phytoplankton-zooplankton relationship in the Salish Sea, focusing specifically on trophic pathways among these lower trophic levels. An understanding of these trophic pathways is essential to a mechanistic understanding of zooplankton response to changing ocean conditions, and the processes that drive salmon early marine survival.

   -Fund a new Cowichan River Predation study, to identify predators within the Cowichan River basin (bird, mammals, & fishes) that may be responsible for the high level of river mortality of Cowichan Chinook. The release of Chinook from the Cowichan Hatchery will be modified to three release dates at different flows rates to provide analytic contrast with flow and estimated survival.

   -Fund two new acoustic tagging programs with Kintama, UVic, DFO.

      a) acoustic tagging study of Cowichan Chinook rearing in the Gulf Islands (Sept. through October, 2017).
      b) A Study to Measure Fine-scale Movements and Residency of Free-Ranging Salmon Smolts near Okisollo Channel Salmon Farms.

See Section 4 below for details of these studies.

3. Fund individuals who have collated large amounts of data to analyze their data, collaborate with other researchers, and publish. This will include funding to Will Duguid (UVic) to complete his PhD work, and to BCCF to continue monitoring the Biomark array for returning PIT tagged fish.

4. Establish the workgroups, assign a leader for each group, and facilitate meetings. We will also facilitate meetings for the workgroup leaders so that they can integrate activities.
5. Increase GIS and Statistical capacity.
6. Continue collaborations with other parties such as DFO, Hakai, UBC, Ocean Networks Canada etc.

Table 4. Funded Canadian SSMSP Program for 2017-2018

Legend: Active (green cells)

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Oceanography	R. Flagg, ONC	Citizen Science Instrument Set up and Data Services Support	Active		2017 Citizen Science Instrument Set up and Data Services Support- including digital infrastructure support, user services support (including manual correction of data) and ongoing management support. Covers the final year of the citizen science program. Project approved at full value.
Oceanography	R. Flagg, ONC	Citizen Science Engineering Support	Active		Citizen Science Engineering Support – includes pre-deployment dry and wet testing, assembly and maintenance, shipping and receiving, instrument calibrations. Covers the final year of the citizen science program. Project approved at full value.
Oceanography	S. Johannessen, DFO	The effects of food availability and physical circulation on early marine survival of juvenile salmon in the Strait of Georgia	Active	Active	This project addresses the hypothesis of bottom-up control on early marine survival by testing to see whether an indicator of food timing and availability is related to the health of juvenile salmon. They will develop an indicator of food availability, based on the timing and composition of phytoplankton and zooplankton fecal pellets / eggs and sinking organic matter captured in sediment traps, and then compare this with the health of juvenile salmon, as measured by researchers at the Pacific Biological Station. Project approved at full value. Project ends March 2018.
Oceanography	S. King, Consultant	High temporal resolution monitoring of surface chlorophyll in the Salish Sea	Active		The work will describe the fine-scale temporal variability of surface chlorophyll in the Salish Sea and be used by ecosystem scientists to understand the factors limiting salmon productivity. Three existing buoys will be equipped (Halibut Bank buoy, Egmont, Sentry Shoal) with fluorometers and one with a nitrate sensor to provide continuous measurements. Spatial context for fluorometer time series will be provided with satellite imagery during the spring bloom. Covers a final year of mooring data collection. Project approved at full value.
Oceanography	H. Gurney-Smith VIU	Coupling state-of-the-art chemical oceanography with biological relevance: examining phyto- and zooplankton populations in a dynamic coastal environment.	Active		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. Work will couple 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. The $20K from SSMSP is to pay for her phytoplankton and harmful algae analysis. Funding covers the final year of this study. Project approved at full value.

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Oceanography	PSF, DFO	Citizen Science Boats			Running costs for 9 citizen science vessels. Includes equipment costs and predicted costs for the daily stipend, gas costs, some insurance top-ups, for each boat for 18-20 trips in 2017. Covers the final year of the citizen science program.
Oceanography	Shapna Mazumder, UVic	Nutrient Analysis			Shapna Mazumder will be analysing the nutrient samples collected from citizen science vessels for our final year of activities (2017).
Remote Sensing	M. Costa, UVIC	Spatial temporal analysis chlorophyll, turbidity and sea surface temperature of the Salish Sea: an integration of satellite imagery and data from vessels of opportunity.			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. They will 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. 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. Funding covers the final year of this study. Project approved at full value(collaboration with Mitacs for student funding).
Phytoplankton/ Zooplankton	Karyn Suchy, UVic	Phytoplankton and zooplankton phenology in the Salish Sea by integrating satellite products with historical and present zooplankton data			Objectives of this study are: 1. Examine the synchrony of phytoplankton and zooplankton phenology in the Salish Sea by integrating satellite products with historical and present zooplankton data 2. Investigate the response of phytoplankton and zooplankton to different climate drivers (e.g. regional environmental forcing including SST, wind, cloud cover, global climatic indices) in the Salish SeaExamine the synchrony of phytoplankton and zooplankton phenology in the Salish Sea by integrating satellite products with historical and present zooplankton data Investigate the response of phytoplankton and zooplankton to different climate drivers (e.g. regional environmental forcing including SST, wind, cloud cover, global climatic indices) in the Salish Sea • This is an important project that will integrate several different data sources. • Work began summer 2016 and significant progress has been made on objective 1. For objective 2, various data sets will be integrated, including: CTD data (IOS), phytoplankton abundance and chl-a data (citizen science data), buoy data (Stephanie), HPLC (Angelica, Nina) and the juvenile salmon data

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Phytoplankton/ Zooplankton	Brian Hunt and Post-doc, UBC	The trophic structure of the Salish Sea plankton food web: defining functional groups, energy pathways, and a mechanistic interface between bio-chemical and fish centric ecosystem models			The proposed project aims to establish a mechanistic understanding of the phytoplankton/zooplankton relationship in the Salish Sea, focusing specifically on trophic pathways among these lower trophic levels. Physical-chemical conditions drive phytoplankton bloom timing, taxonomic composition, size structure, and quality as food items. How the zooplankton respond to changes in these phytoplankton parameters is determined by their functional trophic group and the resulting trophic pathways, e.g., the contributions of the microbial vs. classical food chains (large diatoms -> copepods -> fish). An understanding of these trophic pathways is essential to a mechanistic understanding of zooplankton response to changing ocean conditions, and the processes that drive salmon early marine survival. The proposed project will explicitly build on and complement Dr. Karyn Suchy's research project "Synchronicity between phytoplankton and zooplankton phenology", aimed at identifying the seasonal patterns and interannual variability in phytoplankton and zooplankton abundance, biomass and composition in the Salish Sea. The addition of knowledge of trophic pathways will inform how changing zooplankton community structure impacts energy transfer to salmon and other fish species. Project approved- post-doc TBD will begin spring 2017
Zooplankton	I.Perry, DFO	Zooplankton and ichthyoplankton status and trends in the northern Salish Sea			The objective of this program is to identify the seasonal patterns of variability in zoo/ichthyoplankton species composition, abundance and biomass in the Strait of Georgia and how they relate to changes in physical conditions. 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. Costs are for a number of vessel charters that will 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. Funding covers the final year of this study. Project approved at full value.
Forage fish	S. Gautier, DFO	Acoustically derived indicators of demersal and forage species productivity in the Strait of Georgia, and their link to the survival of juvenile salmon.			The short term objective 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. Costs are for a post doc in Gauthier lab- Lu Guan began spring 2016. Funding covers the final year of this study. Project approved at full value (collaboration with Mitacs for student funding).

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Forage fish	J. Boldt, DFO	Strait of Georgia juvenile herring and nearshore pelagic ecosystem survey			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 agreed to cover part of the costs of the juvenile herring surveys for 2015-2017. Funding covers the final year of this study. Project approved at full value.
Forage fish	J. Dower & Emma Pascoe, UVic	Spatiotemporal variability in lipid profiles of young-of-the-year herring from the Strait of Georgia			The current objectives of the project are: 1) Short term: to quantify seasonal and interannual variability in the condition, growth, and nutritional value of young-of the-year herring from the Strait of Georgia from 2013-2016. 2) Longer term: to explore how variability in the food quality represented by forage fish affects the growth and survival of higher trophic level predators such as salmon, and how bottom-up forcing affects the trophic transfer efficiency in coastal BC ecosystems. Project is funded for work in 2017. Project approved at full value.
Juvenile Salmon	F. Juanes (UVic) and W. Duguid (UVic)	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 micro-trolling and RNA:DNA ratio based growth rate indices			Aims of this project 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 has also assisted BCCF in their Cowichan PIT tag project (see above). Funding covers the final two years of this Duguid's PhD to allow for further field studies, write up, analysis and publication. Project approved at full value (collaboration with Mitacs for student funding).
Juvenile Salmon	Hinch, Farrell, Miller, Cooke (UBC, DFO)	Physiological and environmental factors affecting the migratory behaviour and survival of sockeye and steelhead salmon smolts			These studies continue time series of acoustic telemetry-derived estimates of salmon smolts (Chilko sockeye in 2016 and 2017, and Seymour steelhead in 2015) 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

CATEGORY	Principle Investigators	Title	2017	2018	Comments
					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 Funding covers the final year of this study. Project approved at full value (collaboration with Mitacs for student funding).
Juvenile Salmon	Welch, Rechisky, Kintama	Deployment and Maintenance of Fish Tracking Arrays in the Salish Sea			Approval for costs for data retrieval from the acoustic receivers on loan from Canada's Ocean Tracking Network and others on loan from Kintama. These receivers have been deployed in the Discovery Islands area, and allow for much finer resolution of migration and survival patterns of tagged sockeye and steelhead (tagged in Hinch et al. study, noted above). In 2017, Kintama will also carry out studies in Cowichan Bay and Discovery Islands. The former study will involve double tagging 50 age-0 Chinook captured by microtrolling with both a PIT tag and high power V9 acoustic tag in fall (early Sept-early October) of 2017. A total of seven receiver moorings in the southern Gulf Islands (SGI; three sub-arrays) will be deployed in the approaches to Cowichan Bay. Mobile tracking will be used to monitor fish movements and fate within the Southern Gulf islands. Fish tagged in this study may also be detected at arrays in Northern Strait of Georgia, Discovery Islands, Johnstone Strait, Queen Charlotte Strait and Juan de Fuca Strait. This study should inform us on residence time of these fish in Sansum Narrows and around the Gulf Islands (with acoustic tags), survival in the Salish Sea and exit out of the Strait (with acoustic tags), and survival back to Cowichan River (with PIT tags). This study will be carried out with Will Duguid and Francis Juanes at UVic. The latter study will be a direct examination of survival of Chilko sockeye in the Discovery Island region, as well as information on migration routes and time spent in the areas of fish farms. Information will be derived from the 300 Chilko sockeye that are acoustically tagged in the Hinch study (above) as well as an additional 120 sockeye that will be tagged by the Hakai Group, as well as several additional receivers that will be deployed in this region in Okisollo channel and 100m from fish farms. Latter project is currently being developed.
Juvenile Salmon	BCCF	A PIT tag based method to investigate survival of Cowichan River Chinook			Study has been carried out since 2015 and aims to determine survival of Cowichan Chinook at different stages of their first year of marine life. Fish have been captured each year in-river, by beach seines, by purse seine, and by microtrolling (to catch sub-

CATEGORY	Principle Investigators	Title	2017	2018	Comments
		throughout various stages in their first year of marine life			legals). Objectives of project have been 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 (18,000 PIT tags available), 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. Tag recoveries for each group occur over several years due to multiple age classes of returning adults. 2017 PIT tagging will likely occur for fish caught during microtrolling only- TBD Spring 2017.
Juvenile Salmon	Clements, Avid Anglers	Support Avid Anglers biological sampling and DNA analysis of chinook and coho encounters in the Strait of Georgia area.			Project approved for 2017 for analysis of coho DNA.
Juvenile Salmon	M. Trudel, C. Neville &K. Miller (PBS-DFO)	Understanding the factors limiting the recruitment of Pacific salmon in the Strait of Georgia – From patterns to processes			The primary objectives of the juvenile salmon studies are to understand the factors currently limiting the abundance of salmon in the Salish Sea. This will be achieved by testing a series of hypotheses that may explain trends in marine survivals. Methods being used will be cohort analysis, following several cohorts of coho and chinook and determining which individuals do not appear to survive over time. Information will be 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. Smolt samples of coho and Chinook salmon are 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 are also be 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. Funding covers the final year of this study. Project approved at full value.
Juvenile Salmon	C. Cooper, Consultant	Plankton & Stomach Analysis			Costs are for 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) Funding covers the final year of this study. Project approved at full value.
Juvenile Salmon	PSF	PIT tag readers			Cost of PIT tag readers for use by BCCF PIT tagging study (above). Funding covers the final year of this study. Project approved at full value.

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Juvenile Salmon	PSF	Acoustic Tags			Purchase of acoustic tags to be employed by Hinch et al. (project above). Approved for the final year of acoustic tagging studies in 2017.
Predation	A. Trites, A. Thomas, H. Allegue	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			The goal of this research is to 1) estimate the numbers of chinook and coho smolts consumed in the Strait of Georgia by harbour seals, 2) evaluate their impact on salmon recovery, and 3) propose ways to mitigate the impact of seals. Specific questions for 2016-2018 are: 1)Are the diets we determined from scats largely collected from harbour seals resting in estuaries representative of seal diets throughout the Strait of Georgia? 2) Are our estimates of diets biased due to the methods we used to reconstruct them (i.e., from DNA and frequency of occurrence of hard parts)? 3) Do seals that feed on smolts employ specialized foraging strategies, or are they behaviourally no different from the seals that do not consume smolts? Project approved at full value and will be completed by 2018.
Predation	BCCF/DFO/UBC	Cowichan River Predation Study			A predation study is being developed to determine the causes of juvenile Chinook predation on the Cowichan River. Project was developed in response to 2014-2016 Rotary Screw Trap and PIT tagging studies on Cowichan River, showing high levels (upto 80%) mortality of juvenile Chinook in river. Project approved for 2017 for BCCF costs and UBC MSc student (under Andrew Trites). Project is coordinated by Kevin Pellet DFO.
Harmful Algae Blooms Study (HABS)	S.Esenkulova, PSF	Salish Sea Harmful Algae Bloom Monitoring			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. Project approved for final year of study.
Nearshore Habitat	N. Wright, Seachange Group	Estuarine and Coastal Restoration in the Salish Sea			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. This project is part of the bottom-up approach to improving food webs and nearshore habitats for juvenile salmon within the context of the Salish Sea Marine Survival Project. Funding covers the final year of this study. Project approved at full value.
Nearshore Habitat	M. Costa, UVic & Natasha Nahirnick (MSc student)	Spatial-temporal extent of eelgrass habitats & relationship with associated adjacency catchment area land use change: remote sensing approach using aerial phots & satellite imagery (1950-present)			The goal of this project is to quantify the temporal and spatial dynamics of eelgrass habitats and associated adjacency catchment area land use change over time to further understand temporal changes and associated disturbance/environmental forcing. Funding covers the final year of this study (with Mitacs funding for MSc Student, Natasha Nahirnick). Project approved at full value.

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Nearshore Habitat	M. Costa, UVic & Sarah Schroeder	Spatial temporal distribution of *Nereocystis luetkeana* (bull kelp) & use by juvenile salmonids in the Salish Sea			Objectives of this project are: (1) to define the surface extent of bull kelp beds by using satellite imagery (present and historical) associated with sea-kayak surveys for several regions of the Gulf Islands (Salt Spring, Saturna, North and South Pender, and Mayne), and Comox and Cowichan estuaries, in collaboration with several environmental stewardship community organizations and First Nation groups. (2) To initiate a robust study on the use of kelp habitat by juvenile salmon in the Salish Sea. Funding covers the final year of this study (with Mitacs funding for MSc Student, Sarah Schroeder). Project approved at full value.
Nearshore Habitat	Bill Heath, Sheryl Bisgrove & Braeden Schiltroth	Restoration Research on Kelp Forest Habitats in the Salish Sea			1) Estimate the extent of kelp forest cover/loss in the northern Salish Sea in recent decades and identify sites in need of restoration that would be of benefit to juvenile salmon 2) Identify kelp stocks capable of growing at sites with stressful conditions (high temperature and/or low pH) by correlating sites that have retained kelp with recorded oceanographic conditions available from online databases (e.g. lighthouse SST databases on DFO Pacific website). 3) Compare bull kelp growth and survival, faunal (fish and invertebrate) presence and detailed oceanographic conditions at 5 experimental sites and at a reference site. Funding covers the final year of this study. Project approved at full value.
Nearshore Habitat	Nile Creek Enhancement Society & Andrew MacInnis (Cooper Beauchesne & Associates Ltd.)	Eelgrass Mapping, Fish Monitoring, and Habitat Data Collection			The overall objective of this project is to quantify the amount and relative importance of eelgrass habitat in the Nile Creek area to juvenile salmon. In 2017, the project will collect a second year of data to monitor changes in eelgrass habitat, the use of that habitat by juvenile salmon and other fish, and the testing of alternative methods for quantifying nearshore habitat types towards the objective of identifying areas where restoration might be beneficial. While small in scope, the data collected by this project may also contribute towards the factors operate at different levels, critical period, and prey availability hypotheses of the SSMSP. Funding covers the final year of this study. Project approved at full value.
Nearshore Habitat	R. De Graaf	Systematic spawning surveys for surf smelt and Pacific sand lance in the Salish Sea.			Sea Watch society's projects focus on the declining habitat quality for two key forage fish species, surf smelt & Pacific sand lance, & coastal marine rearing habitat for juvenile salmon. Objectives of this SSMSP funded work are to: 1. Determine the spatial extent of spawning habitat & suitable habitats for surf smelt & Pacific sand lance in the Salish Sea
Nearshore Habitat	R. De Graaf	"Salish Sea Citizens' Science Forage Fish Initiative": Beach			

CATEGORY	Principle Investigators	Title	2017	2018	Comments
		spawning forage fish spawning surveys.			2. Protection of forage fish resources (secondary capacity) in the Salish Sea 3. Development of operational statements & best management practices for forage fish spawning/rearing habitats & marine riparian habitats for local government & stakeholders. Funded after some proposal amendments Funded after some proposal amendments
Nearshore Habitat	R. De Graaf	Salish Sea Forage Fish Habitat Assessments - Mapping Critical Marine Forage Fish Habitats of the Southern Gulf Islands, Island Trust and National Marine Conservation Areas.			
Nearshore Habitat	R. De Graaf	Howe Sound Forage Fish Habitat Assessments – Mapping Critical Marine Forage Fish Habitats			
Modeling	K. Denman (Uvic & Canada's Ocean Network)	Modeling the Salish Sea			Costs are for a post doc (starting spring 2017). He will be responsible for running the ROMS circulation model of the SoG with Angelica's planktonic food web model embedded, adding an IBM component (Individual Based Model) to track migrating juvenile salmon (currents + prescribed swimming). and possibly coupling high resolution FVCOM models (similar to developed by Mike Foreman) to the ROMS model. Project approved at full value (with Mitacs funding)
Modeling	V. Christensen (IOF, UBC), 2 post-docs, Carl Walters and others	Environmental productivity of the Salish Sea: trends, impacts and projections			This group intends to develop a coupled biogeochemical model and food web model to evaluate how the combination of changes in environmental productivity, food web structure and human impacts (notably through fishing) has changed in the Salish Sea over three and a half decades. Project is funded for 5 years of study.
Modeling	S. Allen (UBC) & Elise Olson (post doc UBC)	Spatial and Temporal Variability of Primary and Secondary Production in the Salish Sea from a Coupled Model (SalishSeaCast with SMELT)			A previous, one-dimensional model for the southern Strait of Georgia has been used to accurately forecast the spring bloom, and determine the interannual variability in phytoplankton and carbon cycles in the Strait. Under this project we propose to investigate the physical factors (wind, freshwater flux, clouds, mixing regions, turbid regions) leading to spatial and temporal variations in primary and secondary productivity. This understanding will then allow us to suggest how the productivity of the Strait has changed and how it may change in the future. Key Research Questions are: 1. What processes control primary and secondary productivity in the Salish Sea and how do they, and thus productivity, vary spatially, seasonally and interannually? And 2. Given what we know about past conditions in the Sea and what is forecast for the future, what do these results imply about past and future primary and secondary productivity. Funding is for 2 years for post doc.

CATEGORY	Principle Investigators	Title	2017	2018	Comments
Disease	K. Miller (DFO) & B. Riddell (PSF)	Strategic Salmon Health Initiative (SSHI)			The main objective of the Strategic Salmon Health Initiative (SSHI) is to determine what pathogens/diseases, if any, may be undermining the productivity and performance of BC salmon, their evolutionary history, and the potential role of exchanges between wild and cultured salmon. A current objective is to develop molecular methods to recognize early developing disease states. Funding is for xxx
Wild-Hatchery Interactions	SEP (D. Willis, M. Sheng, R. Galbraith)	Strait of Georgia Coho hatchery release studies			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. Project approved for final year of study.
Wild-Hatchery Interactions	Willy Davidson, SFU	EPIC4 (Enhancing Production in Coho: Culture, Community, Catch) -Activity 3. To assess the ability of fish hatcheries to conserve Coho Salmon & enhance their numbers			As part of a joint project proposal with Genome Canada, parental based tagging (PBT) of hatchery coho stocks in Southern BC will be utilized to genotype the majority of hatchery coho smolts released into the Salish Sea. This work will permit subsequent identification of clipped juveniles and adults by stock and year of origin, release strategy, and parentage history, and may allow for detailed investigations of differences in early marine distribution patterns of different hatchery coho stocks. Project approved for final year of study.
Data	I.Pearsall (PSF) & T. Curran (PSF)	Strait of Georgia Data Centre			Funding is continued for development and maintenance of the Strait of Georgia Data Centre. This is particularly important for the modelling projects and ecosystem indicators (US-Can) projects that are underway.

SECTION 4: DESCRIPTIONS OF RESEARCH ACTIVITIES

The 2017-2018 project activities are described in the following sections.

1. 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. A sampling program has been implemented in an integrated fashion in the Strait of Georgia and Puget Sound. This Salish Sea-wide sampling program will examine the condition of salmon and steelhead as they outmigrate while simultaneously evaluating the physical and biological (plankton) characteristics of the Salish Sea. This includes identifying critical growth periods for salmon and understanding the primary factors affecting growth during those periods.

The sampling program builds out from specific watersheds within the Strait of Georgia and Puget Sound. In the Strait of Georgia, the key watersheds of interest are the Cowichan, Puntledge, Fraser, and Big Qualicum Rivers. Several of the key 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.

1.1 PHYSICAL CHARACTERISTICS AND PHYTOPLANKTON PRODUCTION

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

Citizen Science Program

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

Objective:

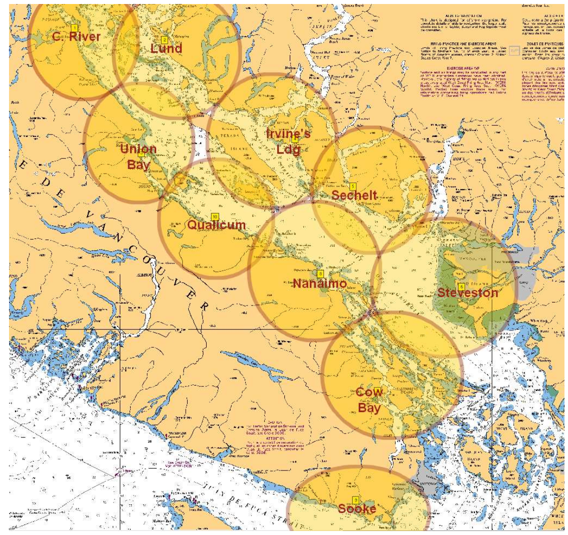
To allow for oceanographic sampling and monitoring in the Strait of Georgia at a spatial scale not possible before.

Background:

This program was originally proposed by Dr. Eddy Carmack, retired scientist from the Institute of Ocean Sciences, Sidney. His concept was the creation of a "mosquito fleet" which would utilize fishing vessels to collect oceanographic data during the spring and neap tides at specific locations in coastal waters of the Strait of Georgia. 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, providing data at a spatial and temporal degree that has not been realized or possible before. PSF has partnered with DFO, and with Ocean Networks Canada (ONC) to assist with program management for the citizen science program.

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

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



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

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

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

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

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

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

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

Status:

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

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

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

Data are currently being utilized by several of the other programs. The final year of collection will be in 2017: data analysis for all 3 years will be done over summer/fall 2017 by UBC. All data are available from the Strait of Georgia Data Centre.

Remote Sensing

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

Objective:

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

Background:

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

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

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

Status:

This project was initiated Fall 2015 and time-series imagery analysis is ongoing. An NSERC USRA student is working on the data-integration component of the project. Work will be completed on this project during 2017.

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

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

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

Next steps in this project for 2017 include the following:

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

Sediment Traps

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

Objective:

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

Background:

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

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

Status:

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

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

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

Objective:

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

Background:

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

Under SSMSP funding, King and her team have been continusouly monitoring phytoplankton since 2015 using fluorometers deployed at three locations in the Salish Sea. Sampling locations are at three locations as shown in **Error! Reference source not found.** and 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 since April 2015.

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

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

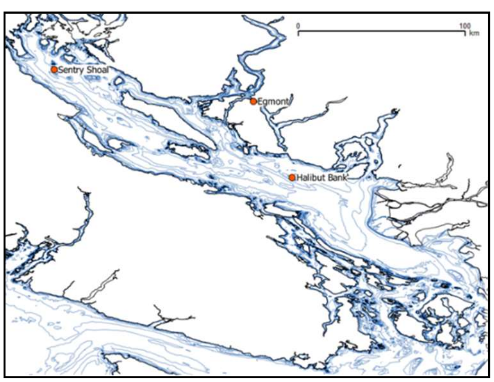


Figure 1. The three sampling sites for chlorophyll fluorescence time series in the Salish Sea.

Status:

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

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

Cowichan Bay Oceanographic Studies

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

Objective:

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

Background:

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

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

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

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

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

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

Status:

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

During 2017: work will be continued based on Sounder and Moorings Data includes:

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

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

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

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

Objective:

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

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

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

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

Background:

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

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

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

Status:

The project has been active since 17 March 2015. The monitoring station has been successfully initiated and represents a long-term opportunity for chemical and biological monitoring on multiple trophic levels in the northern Salish Sea. Sampling and analysis protocols have been developed and zooplankton development and analysis is now in line with that of other SSMSP partners for comparable reporting. Chemical oceanographic data is now available in near real-time, and plankton analysis is up to date. Monitoring is continuing in 2017. Currently two papers are in preparation: one paper detailing the first year of chemical oceanographic data and the second on the plankton productivity, for submission in early 2017. Plans are underway by the lead PI to develop a coastal monitoring data program, of which the PSF would be a partner. Specific recommendations include continuance of monitoring and the inclusion of a biomass component.

The trophic structure of the Salish Sea plankton food web: defining functional groups, energy pathways, and a mechanistic interface between bio-chemical and fish centric ecosystem models. NEW for 2017-2018

Team: Brian Hunt (IOF, Hakai Institute), Ian Perry (DFO), Karyn Suchy (UVic), Ian Forster (DFO), Evgeny Pakhomov (IOF), Jennifer Boldt (DFO), Villy Christensen (IOF), Chrys Neville (DFO).

Objective:

Zooplankton are the interface between basal food web processes (physics-chemistry-phytoplankton) and salmon, either through direct consumption or indirectly through forage fish (e.g., herring) pathways. Filling an essential data gap, the proposed project aims to establish a mechanistic understanding of the phytoplanktonzooplankton relationship in the Salish Sea, focusing specifically on trophic pathways among these lower trophic levels.

Background:

Physical-chemical conditions drive phytoplankton bloom timing, taxonomic composition, size structure, and quality as food items. How the zooplankton respond to changes in these phytoplankton parameters is determined by their functional trophic group and the resulting trophic pathways, e.g., the contributions of the microbial vs. classical food chains (large diatoms -> copepods -> fish). An understanding of these trophic pathways is essential to a mechanistic understanding of zooplankton response to changing ocean conditions, and the processes that drive salmon early marine survival. The proposed project will explicitly build on and complement Dr. Karyn Suchy's research project "Synchronicity between phytoplankton and zooplankton phenology", aimed at identifying the seasonal patterns and interannual variability in phytoplankton and zooplankton abundance, biomass and composition in the Salish Sea. The addition of knowledge of trophic pathways will inform how changing zooplankton community structure impacts energy transfer to salmon and other fish species.

Approach:

Trophic linkages between phytoplankton groups and zooplankton species / groups will be determined using a three-part biochemical approach:

- Fatty acid analysis to measure the contribution of phytoplankton group specific pathways to the zooplankton food web, and the energy content and food quality of zooplankton prey species;
- Stable carbon (δ13C) and nitrogen (δ15N) isotope analysis of bulk tissues bulk tissues to identify zooplankton trophic level, trophic niche space, and assign trophic functional groups that define food-web linkages.
- δ13C analysis of amino acids to measure food web pathways

The post-doctoral fellow will:

- Manage the sample collections in 2017, assisting in field programs where necessary; • Coordinate the laboratory analysis, and be responsible for running the fatty acid analysis;
- Conduct the statistical analysis of biochemical data to identify food web pathways, and develop a compartmentalized food web framework;
- Liaise directly with the ecosystem modelling group in the development of an operational zooplankton interface between the biochemical and food web model components.

Specific outcomes:

A comprehensive analysis of the plankton food web in the Salish Sea has never been conducted before. This proposed project will:

1) Empirically establish food web interactions among lower trophic levels in the Salish Sea;
2) Develop a compartmentalized food web framework that captures the primary functional feeding groups and energy pathways;
3) Work directly with the ecosystem modelling team to incorporate the identified plankton food web structure into the existing Salish Sea model and update the model as appropriate to achieve mass-balance.

Status:

Project approved. Once a suitable PDF is hired, the project is expected to begin spring 2017. Funding is for 2 years of study.

1.2 ZOOPLANKTON AND ICHTHYOPLANKTON

Zooplankton and ichthyoplankton status and trends in the northern Salish Sea

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

Objective:

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

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

Background:

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

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

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

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

Status:

Sampling has been conducted at a number of core locations in the Strait of Georgia, approximately every two weeks from mid-February to mid-October for 2015 and 2016. This project represents the most intensive zooplankton sampling program in the Strait of Georgia, ever, and will be continued during 2017.

Data from this project are undergoing statistical analyses during 2017. They are also being integrated with data from satellites to examine the role of physical and lowest trophic level (phytoplankton) biological processes on zoo/ichthyoplankton characteristics (e.g. species composition, timing, abundance, biomass). A new Post-Doctoral Fellow in the Pakhomov Lab at UBC will conduct further analyses of the zooplankton community and its responses to environmental variations during 2017. Comparisons have begun with marine survival data for Strait of Georgia Coho populations. The next steps are to compare with Strait of

Georgia Chinook marine survival data and with detailed data on the distributions and conditions of juvenile salmon in the Strait of Georgia.

1.3 FORAGE FISH

Strait of Georgia juvenile herring and nearshore pelagic ecosystem survey.

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

Objectives:

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

Background:

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

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

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

Status:

Completion of the 2014, 2015, and 2016 Strait of Georgia (SOG) juvenile herring and nearshore pelagic ecosystem survey – a long-term monitoring program including the collection of age-0 herring and Three Spine Stickleback samples, zooplankton biomass data, and physical environmental measurements in the SOG during the fall has occurred, and the survey will be carried out for one final year under SSMSP funding in 2017.

Spatiotemporal variability in lipid profiles of young-of-the-year herring from the Strait of Georgia. NEW for 2017

Team: Dr. John Dower and Emma Pascoe, UVic

Objectives:

Short term: to quantify seasonal and interannual variability in the condition, growth, and nutritional value of young-of the-year herring from the Strait of Georgia from 2013-2016.
Longer term: to explore how variability in the food quality represented by forage fish affects the growth and survival of higher trophic level predators such as salmon, and how bottom-up forcing affects the trophic transfer efficiency in coastal BC ecosystems.

Background and Status:

Juvenile herring are a key prey item of many predators, including Pacific salmon. Here they explore spatial and interannual patterns in lipid content of young-of-the-year (YOY) herring from the Strait of Georgia (SoG).

This work fits under the SSMSP "Junk-food/Prey quality" hypothesis, which proposes that the growth of juvenile salmon is affected by the nutritional content of their food, and that marine survival and growth increases with the availability of preferred (fat/nutritious) prey. To date, however, the degree to which prey such as YOY herring vary in their condition and, hence, nutritional quality between years has not been quantified.

John Dower has fish from four years (2013-2016) that were collected as by-catch during DFO trawl surveys. Their goal is to quantify patterns of spatial and temporal variation in total lipids and lipids classes across years in the SoG. Lipid data will be compared with data on growth and condition measured using otolith microstructure, RNA:DNA ratios and Fulton's K.

This work is being carried out during 2017.

Hydroacoustics

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

Objectives:

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

- To develop acoustic indicators of productivity (relative/absolute biomass estimates) for salmon predators and prey

- To examine abundance & spatial distribution of the defined species/assemblages, and explore their potential links to oceanographic and environmental factors
- To test hypotheses that relate the abundance and distribution of the defined species/species assemblages to the marine survival of juvenile salmon

Background & Status:

Stéphane Gauthier supervised a pelagic ecosystem survey of the Strait of Georgia (SoG) in March 2014, March 2016 and July 2016 based on acoustic-trawl methods. 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 Mitacs postdoctoral fellow (Lu Guan, University of Victoria) has been focussing on this rich acoustic dataset and will continue this work during 2017. 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.

1.4 JUVENILE SALMON

Freshwater and Marine Survival

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

Objectives:

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

Background:

Both rotary screw trap and PIT tagging methods have been used to compare freshwater and marine survival at different stages in the life history of Cowichan chinook since 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. To test this assumption a Rotary Screw Trap (RST) was operated by DFO and Cowichan hatchery staff during 2014, 2015 and 2016 in the mainstem of the Lower Cowichan River to allow for a mark-capture population estimate on hatchery released fish.

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

In 2015 and 2016 groups of hatchery smolts were released at multiple locations further downstream in the river to determine if migration success rate improves. Hatchery chinook were PIT- tagged and released at the usual hatchery release location, and their survival estimated using a RFID array at the bottom of the Cowichan River, which records each PIT tag as the fish crosses the array. The survival estimate using this method was compared with that from the RST. Results tallied very well, and showed that approximately 80% of the juvenile hatchery chinook died during their migration down the river. This work will be continued during 2017.

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

Cowichan chinook are thus tagged 1. In hatchery, 2. In freshwater, 3. By beach seine, 4. By purse seine, 5. By microtrolling. Microtrolling (catching fish using specialized trolling equipment aimed at catching juveniles as they move offshore) will be used to capture sublegal juveniles in the marine environment. This is a novel method, piloted by Will Duguid, PhD candidate at UVic during 2014.

The 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:

These studies have provided evidence of high mortality of downstream migrating wild and hatchery Chinook smolts and this has been corroborated by the RST studies. After three years of RST studies, this project was not continued for 2017: however, the PIT tagging study is being continued for a final year in 2017. This will involve continuation of PIT tagging in river, in Cowichan Bay and during microtrolling.

There is also mounting evidence that predation accounts for the majority of losses based on abnormal tag behavior on multiple arrays as well as photographic evidence of animals interacting with detection fields. This has led to the development of a predation study on Cowichan River for 2017.

Freshwater

- A significant bottleneck to freshwater production was discovered in 2016. It appears that both hatchery and wild Chinook can endure high rates of loss during their downstream migration as “fingerling” smolts. There is some evidence to suggest depredation by aquatic and terrestrial species. Further investigation of which species (birds/mammals/fish) or mechanisms (low flow) are responsible is warranted. It is unknown if similar losses are occurring in other watersheds but a literature review of similar tagging studies (acoustic/radio) and species (Sockeye/Steelhead) may put Cowichan results in perspective. A study of predation on the Cowichan River is currently being developed by Kevin Pellett (DFO), BCCF, and UBC (Andrew Trites). See the Predation section below.

- Repeating the downstream survival experiment for at least hatchery origin Cowichan River Chinook in 2017 would be highly informative and cost effective with the mainstem detection array now in place (<10 K). Ideally, releases could be conducted at varying flow targets ranging from 5 to 40 m3/s (subject to lake storage levels, spring precipitation and fish size at date). This project is currently being developed and will be funded for 2017.

- Improving the proportion of returning adults scanned for PIT tags (to account for fishery and other losses) should be a priority for 2017. Temporary arrays deployed in the lower river (north/south arm) during the first half of the season (Sept 1-Oct 15) would be a cost-effective solution. This is being considered for 2017.

Marine

- PIT tag application rates in-river and in Cowichan Bay were substantial in 2015 and 2016. The largest gaps in the current study are:

1) Micro troll targets of Cowichan fish were only achieved in 1 of 3 years, 2) Few age 2 Cowichan fish were tagged overall and the return rate of those that were appears to be biased high (resident?). Tagging age 2 Cowichan fish outside of the Gulf Islands area would shed light on mortality rates during the first winter at sea and would likely result in a significant number of in-river detections.

- Fish tagged in 2014 and 2015 will be large enough that some will be harvested in 2017 sport fisheries. Opportunities to recover tags in areas known for high rates of Cowichan interception (e.g. Campbell River) are being explored. The most cost effective option would be to provide lodges/guides with hand scanners and offer a substantial reward for each tag ($100).

- An acoustic tagging project to further investigate survival and behavior within the highly utilized Sansum Narrows area has been developed and funded for 2017 (see acoustic tracking studies, below). A small number of tags are likely to provide a large amount of data given an expected residency period extending through early October combined with narrow channel widths which support high detection rates.

- A mobile high-power PIT tag detection antenna was developed to assist with seal scat studies on Burial Island. 8 PIT tags were detected from Cowichan tagging activities suggesting this technique has merit.

Opportunities to increase the number of haul-outs scanned are being explored for 2017 although tag retention at the sites following winter storms may be low.

- Given that PIT tags will be applied by purse seine and micro trolling in 2017 we are considering the development of a haulout detection array at Burial Island. A prototype was operated in 2016 but did not result in any detections due to low coverage. Up to 60 animals per day appear to use the area and larger antennas may be able to sample an area suitable for 10-20.

Cohort Analysis and Marine Growth

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

Objective:

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

Background:

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

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

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

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

*Hypotheses that predict that faster growing fish have higher survival

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

In order to determine whether or not there is a specific component of the population that disappears over time during their first year at sea, salmon smolts are collected as they leave freshwater and subsequently in the marine environment. Fish sampling surveys for both coho and chinook have been carried out in four main locations through the Strait of Georgia since 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. This work will be continued in 2017.

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

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

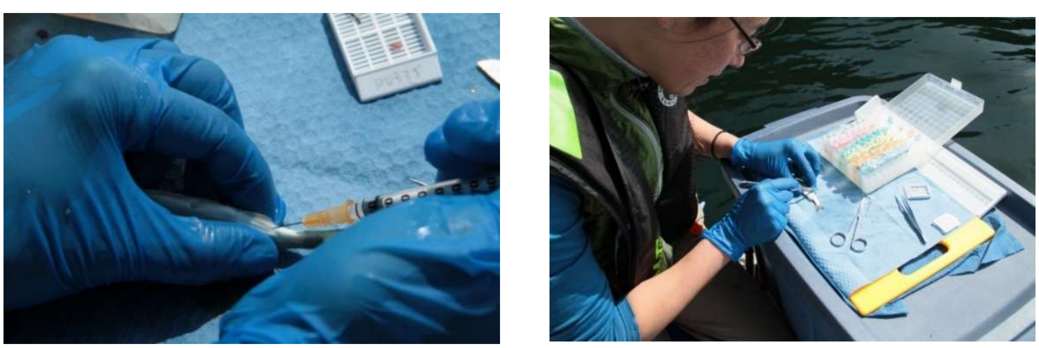


Figure 4. Collecting samples (tissues, blood, DNA etc) for genomics and physiology studies

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

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

Objective:

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

Background:

The complex topography of the Salish Sea results in dramatic spatial variability in water column stratification and mixing. This variability, and how juvenile Coho and Chinook salmon respond to it, may modulate the effects of bottom up and top down regulators of survival during the first marine year. Despite this, studies of juvenile Chinook and Coho salmon in the latter part of their first marine summer have generally been conducted at a relatively coarse spatial (and temporal) scale, partly due to the high cost and logistical challenges of current sampling methods (Trawl and Purse Seine). This project uses modified recreational fishing gear (microtrolling) to economically assess the distribution, diet and growth of juvenile Cowichan River Chinook salmon at high spatial and temporal resolution from July to October of their first marine summer. Systematic sampling of fish and biophysical oceanographic parameters at sites with differing degrees of tidal mixing and water column stratification will test whether Cowichan Chinook salmon utilize biological "hot spots." This project complements the PIT tagging based Cowichan Chinook salmon cohort survival study led by BCCF through the application of PIT tags to juvenile Chinook salmon (see above).

The general objective of the research project is to test whether juvenile Chinook Salmon distribution, diet, and growth in the Salish Sea is structured at spatial and temporal scales finer than those resolved by existing sampling programs. Furthermore, we aim to characterize mechanisms responsible for fine scale structure in habitat quality and assess the importance of these patterns for bottom up and top down factors controlling survival. Three specific objectives supporting this general objective are outlined below:

> Objective 1: Assess whether distribution, diet, and growth of juvenile Chinook Salmon varies predictably with fine scale physical and biological oceanography within the Southern Gulf Islands of the Salish Sea (field data collected in 2015 – proposed work consists of analysis, reporting and synthesis with other SSMSP projects).
>
> Objective 2: Elucidate the mechanisms and possible survival implications of utilization of tidally mediated foraging hotspots by juvenile Chinook Salmon (field data collected in 2015 and 2016 – proposed work consists of analysis, reporting and synthesis with SSMSP projects).
>
> Objective 3: Develop and validate a method to use long term averages of temporally sparse but spatially high resolution remote sensing data (Landsat TIR) to index juvenile salmon habitat quality (convergent front probability and water column stratification), and relate this index to CPUE and growth (IGF-1) of juvenile Chinook Salmon caught in trawl surveys.

Status:

Most of the data collection for these objectives has been carried out during 2015 and 2016. During 2017, focus will be on analysis and publication, as well as involvement in the Kintama Project "" listed below.

Acoustic Tagging Studies 2017

1. A Study to Measure Fine-scale Movements and Residency of Free-Ranging Salmon Smolts near Okisollo Channel Salmon Farms NEW for 2017

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

Earlier research indicated that sockeye primarily migrate out of the Strait of Georgia using the northern exit and that survival was lower in the area lying between Texada Island and northern Queen Charlotte Strait than in the Strait of Georgia, which has important implications if correct. However, these findings were limited because (1) only two-year-old sockeye smolts were studied, and (2) survival in the northern region included a composite of three areas: (a) the Strait of Georgia north of Texada Island, (b) the Discovery Islands & Johnstone Strait, and (c) Queen Charlotte Strait (including the Broughton Archipelago). It is unclear whether these earlier findings also applied to one-year-old smolts, or whether lower survival rates in the north might be caused by elevated mortality rates in the most northern part of Strait of Georgia or further north in the region containing fish farms.

In 2015 Kintama designed and deployed two new subarrays intended to allowing tracking one-year old sockeye smolts. Tests indicated that the new design allowed tracking of 180 kHz tagged one-year old smolts with acceptably high detection efficiency, and also yielded comparative survival estimates for smolts migrating east and west of Quadra Island. The results suggest that steelhead smolts travelling east of Quadra, through the maze of waterways including fish farms, had lower survival than smolts travelling west of Quadra via Discovery Passage. In 2017, they will deploy temporary subarrays in Hoskyn & Okisollo Channels, and develop data on smolt residence times and survival rates in this region and establish telemetry equipment performance that can be used to inform a scale-up to a larger tracking array in future. The results should be useful for refining a proposal, TEFFS, that can be used to rigorously test whether fish farm exposure reduces smolt survival as well as provide further biological insight into the marine ecology of sockeye smolts in southern British Columbia waters.

This project is under development and will be carried out during 2017.

2. Measuring Life-Cycle Survival, Movements, and Migration Timing of Age-0 Cowichan Chinook Salmon Tagged in the Southern Gulf Islands in Fall 2017. NEW for 2017

Team: Kintama, BCCF and Will Duguid (UVic).

Neville et al. (2015) report results for two studies in which a combined total of 70 juvenile Chinook Salmon were acoustically tagged in the Southern Gulf Islands in July of 2008. Only one of these fish was ever detected again, leaving the Salish Sea through the Strait of Juan de Fuca, leading the authors to conclude that very high mortality of these juvenile Chinook Salmon occurred within the Salish Sea.

Microtrolling conducted by the University of Victoria (Will Duguid et al.) from 2014-2016 in the Southern Gulf Islands near Cowichan Bay has suggested that Juvenile Chinook Salmon are abundant in this area through September before abruptly disappearing in October. In 2014-2016, 60-65% of juvenile Chinook caught by UVic crews in late summer and fall were of Cowichan River origin; (Duguid, unpublished data). Average fork length of Cowichan-origin fish in September was 158 mm in 2014, 190 mm in 2015, and 195 mm in 2016. Juvenile fish ≥140mm are candidates for double tagging with a low power V9 acoustic tag and a PIT tag, while juveniles >170mm FL are capable of being tagged with a high power V9, and juveniles ≥180mm FL can be implanted with a very long-lived high power V9 tag. The V9 tag has considerable programming flexibility which determines detection range, tag life, and therefore array costs. Roughly speaking, high power V9 tags have about an 800m detection range from receivers and low power tags have a 400m detection range. Kintama has substantial experience with these tags which they have implanted into Cultus and Sakinaw Lake Sockeye, and successfully measured the entire survival post-tagging until adult return 2 years later.

They are proposing to double tag 50 age-0 Chinook captured by microtrolling with both a PIT tag and high power V9 acoustic tag in fall (early Sept-early October) of 2017. A total of seven receiver moorings in the southern Gulf Islands (three sub-arrays) will be deployed in the approaches to Cowichan Bay. Mobile tracking will be used to monitor fish movements and fate within the Southern Gulf islands. Fish tagged in this study may also be detected at arrays in Northern Strait of Georgia, Discovery Islands, Johnstone Strait, Queen Charlotte Strait and Juan de Fuca Strait.

Objectives are to determine residence time (time to exit) and survival with high confidence using high power tags. The broader Discovery Island & Ocean Tracking Network receiver arrays would then measure residence time and survival in the Salish Sea and direction of exit (Queen Charlotte Strait/Juan de Fuca Strait). The use of high power tags with a nominal five-month battery life will provide high probability of detection of fish by these arrays through at least mid-February of 2018.

The additional PIT tags in these fish will allow for identification of survival to adult river entry when these fish return to their natal river, and return timing which can be determined from the PIT tag array installed in the lower Cowichan river. Finally, using the smolt to adult return rate (SAR) for Cowichan Chinook, they could indirectly determine early marine survival during the first summer in the Cowichan Bay area. This approach would therefore parse out the stage-specific survival of Chinook smolts for the entire migratory life history of Chinook, the first time this will have been done anywhere.

Mobile tracking of live fish near the tagging site (Southern Gulf Islands) will provide a direct test of the hypothesis of tidally mediated use of foraging hotspots that has been investigated and supported by microtrolling work conducted by UVic from 2014-2016. Mobile surveys for stationary tags near seal haul-outs throughout the Gulf Islands will also facilitate assessment of intensity of seal predation, as has been done for Steelhead in Puget Sound. Collecting a tissue sample at the time of tagging will allow for subsequent genomic profiling for multiple diseases, and relation of health status to subsequent fate.

This project is currently under development and will be carried out during 2017.

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:

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

Using small acoustic transmitters, the behaviour and fate of Chilko sockeye (2016 and 2017) and Seymour steelhead (2015) smolts are being tracked from release through the Salish Sea. The condition of these same smolts is assessed prior to transmitter implantation and release through the use of biomarkers for pathogen presence and load, presence of immune- or stress-related responses, and growth potential, to better understand the links between condition during initial outmigration and survival and behaviour in the early marine environment. Retrospective analyses on a large database generated from ~10 years of acoustic telemetry studies will determine how migratory behaviour and survival are influenced by oceanographic conditions recorded in the Salish Sea. Lastly, individual-based models (IBM) will be developed to simulate smolt migrations by combining various movement behaviours of smolts with fine-scale ocean simulation models to provide potential migratory pathways through the Salish Sea, and a means of testing what navigation and/or orientation behaviours smolts use in the early marine environment. Together these studies will help to provide a mechanistic understanding of salmon smolt migrations to better understand trends in productivity and survival.

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

Migration route was found to influence subsequent survival, particularly for steelhead, indicating that area encountered is an important component of the migration experience. For sockeye, both outmigration timing (particularly Chilko sockeye) and residency were correlated with survival. For neither sockeye nor steelhead did size influence survival, albeit this might be due to the small size range of smolts tagged.

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

These migration routes are to be analyzed in greater detail during 2017, as well as the impact on survival (see Kintama project 1 above).

2. Top Down and Other Studies

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

The Canadian major top-down studies for 2017 include a study to complete the assessment of the impacts of seal predators on juvenile coho and Chinook, analysis of the spatial and temporal occurrence of harmful algal blooms, and an examination of microbe loads on juvenile salmon. Additionally, the Canadian side are carrying out some hatchery manipulation studies, involving alternative times of release of Chinook into the Strait of Georgia.

2.1 DISEASE & HEALTH

Team: Kristi Miller-Saunders (DFO-PBS), Karia Kaukinen (DFO-PBS), Amy Tabata (DFO-PBS), Strahan Tucker (DFO-PBS), Genome Canada, and many others.

Objective:

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

Background:

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

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

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

SSMSP will continue to fund SSHI activities for 2017 and 2018.

2.2 HARMFUL ALGAL PROGRAM

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

Objectives:

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

Background:

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

High-resolution, in situ data on phytoplankton dynamics in the Strait of Georgia has been collected in 2015 and 2016 and has provided a solid foundation for understanding bottom-up control of zooplankton and herbivories fish dynamics (bottom-up control for salmonids). With an additional data from 2017 (a year not affected by El Nino), it will be possible to establish a statistically significant links between phytoplankton and environmental characteristics in the SoG. Having enough zooplankton data, will enable to investigate environment-phytoplankton-zooplankton relationship and (in cases when zooplankton sampling is limited) to anticipate/forecast trends of juvenile fish food abundance based on environmental/phytoplankton data.

2.3 PREDATION STUDIES

Predation by Harbour Seals on Salmon Smolts – Study Completion

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

Objective:

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

Background:

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

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

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

The 2016-2017 work plan includes the following:

- Collect harbour seal scats every two weeks for 8 months from 5 sites (April – November 2016)
- Undertake DNA analysis and measure size of salmon otoliths recovered from 2016 harbour seal scats
- Compare 2016 diet findings with samples collected in previous years from estuaries to determine if diets vary significantly by region in the Strait of Georgia
- Recalculate estimates of mortality on salmon smolts caused by harbour seals in the Strait of Georgia
- Compare *biomass reconstruction* estimates of diet for 210 samples collected in 2016 with estimates obtained using two other methods—frequency of occurrence and DNA metabarcoding
- Assess the biases of the three diet reconstruction methods (from simulations and data), and recalculate (if necessary) estimates of mortality on salmon smolts caused by harbour seals in the Strait of Georgia
- Process the acceleration data collected by the 20 tagged seals using specialized animal behaviour software to determine and compare time-activity budgets between seals that ate smolts and those that did not
- Calculate the foraging efficiencies of the two groups of seals to assess whether targeting smolts is energetically beneficial or inconsequential
- Assess whether seals that feed on smolts employ specialized foraging strategies or are behaviourally not different from the seals that do not consume smolts—and identify mitigation strategies that could be employed to reduce predation risk on salmon smolts.

Cowichan River Predation Study

Team: Kevin Pellett, DFO; BCCF; Andrew Trites and Zachary Sherker, MSc Student, UBC

Objectives:

1) Investigate predation by river otters, mergansers, raccoons, Brown Trout primarily on hatchery Chinook
2) Repeat multi-site tag releases to investigate downstream survival at three discharge levels
3) Continue PIT tag applications to wild and hatchery fish in Cowichan Bay on the purse seiner
4) Continue PIT tag applications to wild and hatchery fish in Sansum/Maple Bay via micro trolling
5) Continue to scan fall returns for PIT tags and continue to develop escapement methodology change (PSC objective)

Secondary Objectives

6) Possibly monitor Burial Island and/or other haul outs for PIT tags
7) Consider tagging age 2 Chinook outside of Gulf Islands

Background and Status:

Results from 2016 studies revealed high rates of loss for both hatchery and wild Chinook smolts during their freshwater migration down the Cowichan River. Losses appeared to be linear and predation is strongly suspected. A work plan for 2017 is currently being developed by DFO, BCCF and UBC, to further investigate these losses on two fronts. The first is to estimate survival at varying discharge levels to test the hypotheses that higher spring flows improve survival. The second hypothesis is that predation by otters, raccoons or mergansers are the mechanism of loss. Additionally, trout are also suspected predators but will not covered in this project (there is likelihood that a project may be undertaken by Cowichan Tribes to assess level of brown trout predation on juvenile Cowichan chinook).

This project will involve DFO, BCCF and a master's student from UBC and is funded for 2017-2018.

2.4 NEARSHORE HABITAT STUDIES

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

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

Objectives:

The objectives of the expanded full project for 2016-2017 are: (1) to define the surface extent of bull kelp beds by using satellite imagery (present and historical) associated with sea-kayak surveys for several regions of the Gulf Islands (Salt Spring, Saturna, North and South Pender, and Mayne), and Comox and Cowichan estuaries, in collaboration with several environmental stewardship community organizations and First Nation groups. (2) To initiate a robust study on the use of kelp habitat by juvenile salmon in the Salish Sea.

Background:

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

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

Status:

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

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

Estuarine and Coastal Restoration in the Salish Sea

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

Objective:

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

Background & Status:

This project is part of the bottom-up approach to improving food webs and nearshore habitats for juvenile salmon within the context of the Salish Sea Marine Survival Project.

SeaChange is entering the last of five years of marine nearshore conservation work as part of the Pacific Salmon Foundation's Salish Sea Marine Survival Project. Eelgrass inventories, restoration, monitoring, research and public education have been integral to conservation activities. The overarching goal is to increase marine native eelgrass habitat for all species of salmon within the Salish Sea through a bottom-up approach to improving food webs and nearshore habitats.

The scope of work for 2016-2017 will be the following:

Monitoring

- Monitor 20 restoration sites and designate those which would benefit from more transplant shoots.
- Complete monitoring data for all 23 eelgrass transplant sites (including water temperature, velocity, sediment loads, and light attenuation).
- Create synthesis report for all conservation work from 2013-2017 inclusive.
- Receive completed sediment composition and chemistry analyses and reports from sediment samples by Ecotox Lab, Simon Fraser University – Drs. Vicki Marlatt and Leah Bendall, supervisors.

Restoration

- During the summer and fall of 2017, complete expansion of existing restoration sites.
- Monitor sites 6 months after transplanting.

Research

- Continue research of eelgrass habitats with the University of British Columbia's with Dr. Mary O'Conner and the University of Simon Fraser with Dr. Sheryl Bisgrove. Subjects of research: Effects of non-point pollution on eelgrass food webs in Boundary Bay, and effects of multiple stressors, including log storage, continuing the work already supervised by Dr. Leah Bendell at SFU.

Community Outreach

- Continue partnerships with BC Parks and other agencies and stewardship groups to increase net gain of salmonid nearshore habitats.
- Continue networking to create an alliance of nearshore habitat conservationists within communities surrounding the Salish Sea.
- Continue outreach educational programs in coastal communities.
- Attend related conferences and make formal presentations whenever possible.

Locations of successful restoration sites are:

1. Genoa Bay, Cowichan Estuary
2. Maple Bay
3. Mill Bay
4. Saanich Inlet
5. Tod Inlet

6-10. Sechelt Inlet
11-13. Gabriola Island
14. Madrona Bay, Salt Spring Island
15. Wallace Island (BC Park)
16. Montague Harbour, Galiano Island (BC Park)
17-18. Burrard Inlet
19. Mayne Island
20. North Pender Island

A video library will be created to demonstrate the status of eelgrass recovery within each transplant site, including “before” and “after” restoration videos for each year. This library, in conjunction with the monitoring data that will be stored in the Strait of Georgia Base Camp site, will serve as a basis for research students to continue investigations into eelgrass recovery over time in degraded environments. It is the hope of this organization to continue marine nearshore restoration after the Salish Sea Marine Survival Project has concluded.

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:

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.

Background & Status:

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

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

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

Project is completed in 2017 and results will be forthcoming.

Eelgrass and Kelp Restoration

Restoration Research on Kelp Forest Habitats in the Salish Sea

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

Objectives:

Objectives of this project include the following:

1) Estimate the extent of kelp forest cover/loss in the northern Salish Sea in recent decades and identify sites in need of restoration that would be of benefit to juvenile salmon

2) Identify kelp stocks capable of growing at sites with stressful conditions (high temperature and/or low pH) by correlating sites that have retained kelp with recorded oceanographic conditions available from online databases (e.g. lighthouse SST databases on DFO Pacific website).

3) Compare bull kelp growth and survival, faunal (fish and invertebrate) presence and detailed oceanographic conditions at 5 experimental sites and at a reference site.

4) Examine the effect of density thinning of sea urchins on kelp abundance at a monitoring site.

Longer term objectives:

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

Background & Status:

This project addresses restoration research on critical nearshore bull kelp habitats for use by juvenile salmon in the Salish Sea. It builds upon and extends the findings of research funded by the SSMP in 2015 and 2016 (Heath et al. 2015, 2016) which has developed: 1) an experimental system for environmental sampling as well as planting and analysis of bull kelp performance in the field; 2) the role of prolonged warm temperatures (>16C) and herbivore grazing in restricting bull kelp survival; 3) participation in a population genetic study of *Nereocystis luetkeana;* 4) assessing thermal tolerances of different bull kelp populations; 5) identification of habitat sites utilized by salmon that have suffered losses or reductions in bull kelp and are therefore in need of restoration.

In 2017, the experimental kelp system will be used to study the growth and survival of bull kelp originating from Sansum Narrows (S. Gulf Islands) area at 3 planted sites with varying depth and wave/current exposure. At a reference site on S. Denman Island, thinning of red and green sea urchin densities as needed will be examined as a treatment for restoring a small natural kelp bed. Differences in thermal tolerances of kelp growing in "hot" or "cool" zones will be compared in the Bisgrove lab at Simon Fraser University. Kelp from 2 sites in each zone will be sampled; spore release from reproductive sori will be quantified and subsequent growth, development, and stress responses during exposure to thermal stress will be assessed.

Eelgrass Mapping, Fish Monitoring, and Habitat Data Collection

Team: Nile Creek Enhancement Society & Andrew MacInnis (Cooper Beauchesne and Associates Ltd.)

Objectives:

The project has three short term objectives:

. Annual mapping of the tidal and shallow subtidal eelgrass beds within the confines of the seaward boundary of the extensive lagoons on the Bowser/Deep Bay foreshore. The data will be compared to existing baseline data to assist in monitoring changes that are occurring to nearshore habitats.

a. Identify resident and transient fish species and their life stages that are using the eelgrass beds and lagoons seasonally to assist in determining the contribution of this habitat to the local ecosystem. The data on fish use will assist in understanding interactions within the ecosystem and how it supports salmonids and other valuable fish locally.

b. Develop a map of nearshore habitats using a combination of high resolution orthophotos and recreational grade side scan sonar. The habitat map would then be used to quantify what habitats are available, if there are any important habitats with limited availability, and potentially where habitat enhancements might have the greatest benefit in the nearshore area. This mapping will also allow creation of baseline data for quantification of changes in nearshore habitats over time.

The long-term objective of this project is to use the quantitative information both locally (NCES) and within larger efforts in protecting eelgrass and nearshore habitat (e.g., Seagrass Conservation Working Group) within the Salish Sea. In particular, the information will be used as a basis will provide the basis for the designation of the area around the Bowser Lagoons as a protected zone for the benefit of all organisms that use this habitat.

Background and Status:

This project will assist protection and enhancement of highly valued productive marine habitat for Pacific salmonids. Eelgrass beds provide habitat complexity in locations where bull kelp used to proliferate in adjacent waters. Because of this and in their own right, eelgrass bed are valuable habitat for forage fish. They are also a highly valued and necessary nursery and rearing habitat for juvenile salmonids, providing the food and protection they need after leaving their natal streams and before leaving for their migration.

By mapping eelgrass beds, providing an inventory of seasonal organism use, and completing detailed habitat maps, changes will be documented to facilitate protection and enhancement.

In 2017, the project will add to the existing baseline data for use in monitoring change and organism use over time. The success of artificial and natural production of fish is dependent on many factors, which include the provision of good quality habitat. It is expected that information generated through this project will assist in protecting and enhancing efforts to ensure the production of healthy populations of fish. Furthermore, it is expected that the provision of this scientific information will provide the basis for the designation of the area as a protected zone for the benefit of all organisms that use this habitat. To this extent it will support efforts to maintain and restore habitat for the benefit of salmonids and other organisms within the coastal nearshore food chain.

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

Principal Investigator: Dr. Maycira Costa, UVic

Objective:

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

Background:

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

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

Status:

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

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

2.5 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.

Delayed release of hatchery coho and Chinook salmon

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

Status:

Funding from the PSF supports the costs associated with extended rearing and coded wire tagging of these experimental releases. This study is being conducted at multiple locations around the Strait of Georgia over a period of several years. 2017 will be the final year that the SSMSP will fund delayed releases.

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

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

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

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

The key objectives are as follows:

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

Status:

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

- Activity 3.1. Estimate of Coho Salmon produced from specific hatcheries to capture fisheries – Sampling
- Samples were obtained from 22 locations, with fin clips collected from a total of about 5,200 Coho Salmon during 2015 sampling. They completed data collection on about 2,500 adult three-year-old returning Coho salmon at Inch Creek hatchery. The 2015 sampling of Inch Coho salmon represents the fourth generation of Inch Coho salmon sampled in the study since its inception in 2006.

- Activity 3.2. Estimate of Coho Salmon produced from specific hatcheries to capture fisheries – Genotyping
- All samples collected from the 2014 hatchery broodstock sampling (approximately 5,500 individuals representing all of the DFO hatcheries in BC) have been genotyped, as well as available samples from the 2006, 2009, and 2012 broodstock at the Inch Creek hatchery, and approximately 200 individuals from the 2012 Inch Creek hatchery that contained coded-wire tags.

- Activity 3.3. Estimate of Coho Salmon produced from specific hatcheries to capture fisheries – Data Analysis
- Analysis of population structure for 20 populations indicated a regional population structure, with Fraser River populations clustered together, as did populations from the southern mainland of British Columbia, the east coast of Vancouver Island, and the west coast of Vancouver Island.

- Activity 3.4. Family-specific marine survival rates of hatchery Coho Salmon – Sampling
- The sampling is well underway. This activity depends on the results from Activity 3.1.

- Activity 3.5. Family-specific marine survival rates of hatchery Coho Salmon – Genotyping
- This activity also depends on the results from Activity 3.1. It will commence in Q3.

- Activity 3.6. Family-specific marine survival rates of hatchery Coho Salmon – Data Analysis
  The data analyses for this is scheduled to begin in Q3.

EPIC4 will be funded for 2017 and 2018.

3. Trend Analyses and Modeling

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

Several of the primary activities 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.).

In Canada three modelling efforts are underway:

Salish Sea Marine Ecosystem Modeling ***NEW for 2017-2018***

Team: Angelica Pena, IOS; Ken Denman, ret; Olivier Riche (postdoc)

Background and Status:

Angelica Pena and her postdoctoral research scientist Olivier Riche will be working to implement an individual-based-model (IBM), representing larval and juvenile salmon, into an existing Salish Sea plankton ecosystem ROMS model to simulate their migration and feeding behaviour in the Strait of Georgia. Research will be conducted at the Institute Ocean Sciences in Sidney, British Columbia, Canada. Olivier is beginning this work in spring 2017.

Combined effects of environmental, food web and human impacts on salmon in the Salish Sea ***NEW for 2017-2018***

Team: Villy Christensen UBC), Carl Walters (UBC), Vijay Kumar, PDF (TBD), Jeroen Steenbeek, Joe Buszowski, Karsten Bolding and Jorn Bruggeman (Bolding and Bruggeman Aps, BB)

Background:

The Salish Sea Marine Survival Project has compiled a vast amount of data sources, and made clear the need to understand how the environmental productivity of the area has changed temporally and spatially over the last number of decades where there have been substantial changes in the marine survival of key salmon species. While previous studies have evaluated short-term productivity patterns for the Salish Sea, there has so far only been correlative studies to evaluate the relationship between long-term changes in environmental productivity and the productivity of higher trophic levels organisms (notably salmon) in the ecosystem. Through this initiative, they intend to develop a coupled hydrographic and biogeochemical model of the Salish Sea, and link this to a spatial food web model in order to evaluate how the combination of changes in environmental productivity, food web structure and human impacts (notably through fishing) has changed in the Salish Sea over recent decades.
The study will extend over the time period for which there is sufficient observations to reliably evaluate how environmental productivity has changed along with the consequential impacts throughout the ecosystem, and we anticipate that this will be back to 1979 or earlier. The project participants will work across disciplines to develop an end-to-end model of the Salish Sea focused on SSMSP's primary objective of assessing if "bottom-up processes driven by annual environmental conditions are the primary determinate of salmon production via early marine survival."

The overarching hypothesis is that the environmental productivity of the Salish Sea is changing over time (e.g., inter-decadal) and that such changes can be amplified through the food web, potentially leading to stronger effects on upper-trophic level species, such as notably Chinook and coho salmon.

They assume that the only practical way to evaluate how environmental productivity is impacting biological productivity over long time spans is through modelling, i.e. data assimilation of large quantities of environmental, biological, ecological and fisheries data. They also assume that this is best done through a combination of hydrographic, biogeochemical and food web models, and that spatial patterns in productivity in the Salish Sea are important enough to warrant an explicit spatial dimension to the analysis.

Rather than evaluate this using indirect environmental or climate indicators, (e.g., PDO, wind at YVR), they will,

- seek to explain why the environmental productivity is varying,
- evaluate the spatial patterns of productivity over time,
- quantify how the changes propagate through the food web, and
- evaluate how anthropogenic impacts (notably through fishing) have interacted with environmental productivity changes and food web effects over time to impact population trends for notably Chinook and coho salmon in the Salish Sea
- evaluate alternative management scenarios in coordination with the Atlantis modelling group for Puget Sound.

Status:

Project was begun spring 2017. The first post-doc, Vijay Kumar, will begin in September 2017.

Spatial and Temporal Variability of Primary and Secondary Production in the Salish Sea from a Coupled Model (SalishSeaCast with SMELT) NEW for 2017-2018

Team: Susan Allen, UBC and postdoc Elise Olson

Objectives:
The objectives of this project are as follows:

Major Model Improvements
- Finish the light-dependence parametrization for the Fraser River plume
- Add the carbon cycle and oxygen to the model (funded elsewhere)
- Evaluate the model based on SSMSP mosquito fleet and other data

Analysis
- Complete a cluster analysis to seek regions that behave similarly
- In major regions, or regions targeted by other SSMSP projects, evaluate the controls on productivity, their seasonal and interannual variations

Provide Results Set for other Users
- Produce a full hindcast of the SalishSea from Sep 2014, make results available on web via their erddap server (salishsea.eoas.ubc.ca/erddap/)
- Continue to run forecasts and make the results available on the web

Background:

Under the NSERC Network of Centres of Excellence MEOPAR (Marine Environment Observation, Prediction And Response) Susan Allen and her team have configured a coupled bio-physics model for the Salish Sea called SalishSeaCast. The model is run daily with high resolution winds and other meteorological forcing, river forcing from over 150 rivers, and temperature, salinity and sea surface at the open boundaries. The physical model is coupled to SMELT (Salishsea Ecosystem Model of Lower Trophic dynamics). The biological model reproduces the expected seasonal cycles in growth, the vertical distribution of phytoplankton, the large spatial gradients between the Strait of Georgia and Juan de Fuca Strait.

A previous, one-dimensional model for the southern Strait of Georgia has been used to accurately forecast the spring bloom, and determine the interannual variability in phytoplankton and carbon cycles in the Strait. Under this project they propose to investigate the physical factors (wind, freshwater flux, clouds, mixing regions, turbid regions) leading to spatial and temporal variations in primary and secondary productivity. This understanding will then allow us to suggest how the productivity of the Strait has changed and how it may change in the future.

The Key Research Questions are:

1. What processes control primary and secondary productivity in the Salish Sea and how do they, and thus productivity, vary spatially, seasonally and interannually? and
2. Given what we know about past conditions in the Sea and what is forecast for the future, what do these results imply about past and future primary and secondary productivity.

The model results fields will be provided on the web for other scientists to use.

Status:
Project was begun January 2017.