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 final year will be used to convert the research results into general conclusions, reporting, and management actions.

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].

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]).

[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).

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

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. 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

[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.

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 will have 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 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.

[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.

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 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.

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[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.

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).

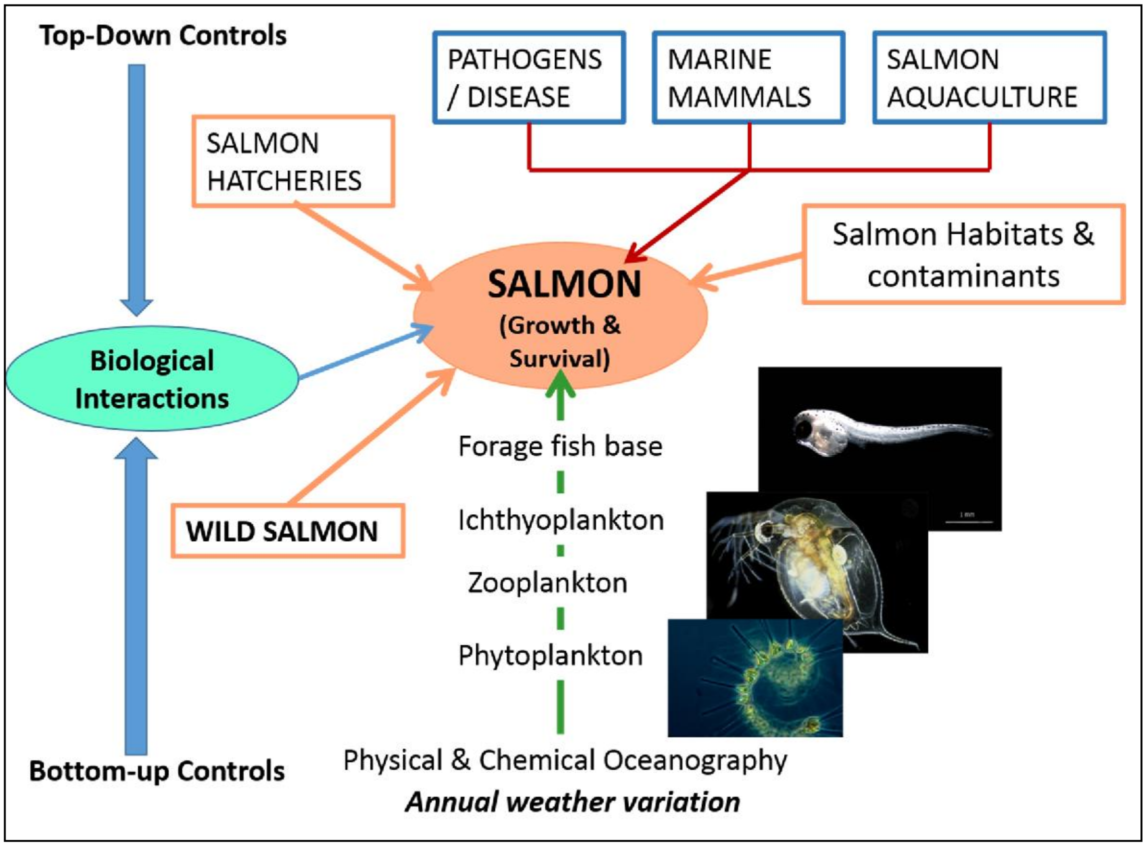


Figure 2. A schematic of the factors addressed annually within the Salish Sea Marine Survival Project. In aggregate, studies within each of these components makes up the SSMSP.

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.

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.

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.

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 project sites: for example, in Canada, we have developed a communication site for Canada's Citizen Science program; a Nearshore Habitat working group site for those involved in forage fish habitat, and kelp and eelgrass restoration; as well as sites for sharing results of studies such as the Cowichan Research study site. We also have joint US-Canada sites 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 will 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. The first retreats occurred in 2013 and 2014. Two larger workshops will occur to ensure good communication with the broader community: 1) mid-way through the project, in 2016, to discuss progress, findings and determine whether any strategic shifts should be made in research implementation; and 2) 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 will be 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 will be 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. US-Canada Operating and Alignment Summary (2015)
2. Puget Sound Marine Survival Research Plan Version 1: 2014-2015 Research Details (2014)
3. Research Work Plan: Marine Survival of Puget Sound Steelhead (2014)
4. Marine Survival of Salmon & Steelhead in the Salish Sea: Hypotheses and Preliminary Research Recommendations for Puget Sound (2012)
5. Strait of Georgia Chinook and Coho Proposal (2009)

There also are a number of meeting summaries from the US-Canada planning and co-ordination retreats (2013 & 2014):

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

There is also a Primary Publications section on this website including the recent publication: Mara S. Zimmerman, James R. Irvine, Meghan O'Neill, Joseph H. Anderson, Correigh M. Greene, Joshua Weinheimer, Marc Trudel & Kit Rawson (2015) "Spatial and Temporal Patterns in Smolt Survival of Wild and Hatchery Coho Salmon in the Salish Sea, Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 7:1, 116-134".

SECTION 3: PROGRAM PLANNING FOR 2015

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. Criteria used to assess proposals are provided in Table 3.

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 2015 Program

The following table describes the Strait of Georgia research studies approved for funding in November 2014.

Table 4. Funded Canadian SSMSP Program for 2015-2016

Legend: Active, Pending, Concept - Not Fleshed Out

CATEGORY	Principle Investigators	Title	2015	2016	Comments
Oceanography	R. Flagg, ONC	Citizen Fishers (Application)	Active	Active	Development of a tablet application to allow for immediate download of CTD data to the ONC central database via WiFi. This will allow data to be easily transmitted and stored in Oceans 2.0 data system at UVic and allow scientists from all over the world will be able to download this data easily and for free. Project approved at full value.
Oceanography	R. Flagg, ONC	Citizen Science Instrument Set up and Data Services Support	Active	Active	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. Project approved at full value.
Oceanography	R. Flagg, ONC	Citizen Science Engineering Support	Active	Active	Citizen Science Engineering Support – includes pre-deployment dry and wet testing, assembly and maintenance, shipping and receiving, instrument calibrations. 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	Concept - Not Fleshed Out	Project only partially funded. $25K will be provided to cover the costs of a technician to process sediment trap samples collected from 2008-2012 at a single NSoG mooring site. This will enable the development of a quantitative description of the physical environment and timing and relative magnitude of phytoplankton and zooplankton blooms, which can then be compared with marine survival of juvenile fish during the same period. These samples were collected during a DFO study but never fully processed.
Oceanography	S. King, Consultant	High temporal resolution monitoring of surface chlorophyll in the Salish Sea	Active	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. Project approved at full value.

CATEGORY	Principle Investigators	Title	2015	2016	Comments
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.			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. Project approved at full value.
Oceanography	S. Vagle, IOS	Observations of temporal and spatial variability of water-column physical chemical and biological properties in Cowichan Bay: Fundamental parameters to understand fish habitat and survival			Objectives are to obtain spatial and temporal water property data for Cowichan Bay during the important fish migration period from April to August and augment these data with shorter term (order of hours from small boats), medium term (order of several months from acoustic monitoring) and order of years (from oceanographic moorings). Ultimate aim is to interpret the biological observations to determine the primary factors controlling chinook and coho early marine survival. Project approved at full value.
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 2015.
Oceanography	Linda White, Consultant	Nutrients			Linda White will be analysing the nutrient samples collected from citizen science vessels.
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.

CATEGORY	Principle Investigators	Title	2015	2016	Comments
					Project approved at full value.
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. Project approved at reduced value, after some discussion and re-submission of the budget.
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- will begin Nov 2015 to be ready for the cruises planned for 2016. Project approved at full value. However, the costs will likely be reduced as PSF is working with Mitacs to assist with matching funding towards student costs for SSMSP
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 will cover part of the costs of the juvenile herring surveys for the next 3 years. Project approved at full value.
In-River	M. Sheng, DFO	Cowichan River Chinook hatchery smolt assessment May 2015			Costs are for construction/operation of a Rotary Screw Trap on Cowichan River. The aim of this study is to provide an estimate of in-river mortality of hatchery smolts. Project approved at full value. (based on data need)

CATEGORY	Principle Investigators	Title	2015	2016	Comments
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 will also be assisting BCCF in their Cowichan PIT tag project (see above) and will be helping to apply as many PIT tags as possible to Cowichan Chinook salmon during the latter part of their first summer at sea as part of a cohort study to determine the critical mortality period for this stock. Project approved at full value. Collaborating with the Avid Anglers and Sidney Anglers.
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 2015 and 2016, and Seymour steelhead in 2016) migration rates and survival in the Salish Sea, enabling an among-year retrospective analysis examining impacts of environmental and physiological factors, and allowing for better understanding of the relative roles of freshwater versus coastal marine environments as locales of mortality. Short-term objectives are to 1) tag and gill biopsy outmigrating smolts, 2) assess gill and blood biomarkers for pathogen presence/load, osmoregulatory preparedness, and growth potential for tagged outmigrant smolts and relate these biomarkers to migration rate and survival, 3) conduct retrospective analyses of existing and new telemetry data for Chilko sockeye salmon (2010-2016) to relate migration rate and survival of smolts in the Salish Sea to fish size, migration behaviour (migrating timing and rate), and oceanographic and riverine conditions, 4) conduct retrospective analyses of existing and new telemetry data across sockeye and steelhead stocks to define meso-scale migration routes of smolts and relate these migration routes to subsequent survival, 5) develop individual-based models (IBM) to simulate smolt migrations in the Salish Sea to better understand the relative influence of movement behaviours (navigation and orientation) and oceanography on resulting marine distributions and migration routes Project approved at full value. PSF has asked that Fraser (Inch Creek) coho are also tagged as part of this project during 2016- we are also working with Mitacs to bring the student costs down, as this project utilizes PhD, MSc and post-doctoral students.
Juvenile Salmon	Welch, Rechisky, Kintama	Deployment and Maintenance of Fish Tracking Arrays in the Salish Sea			Project under discussion. Approval for costs for deployment of the acoustic receivers on loan from Canada's Ocean Tracking Network.

CATEGORY	Principle Investigators	Title	2015	2016	Comments
Juvenile Salmon	Welch, Rechisky, Kintama	Comparative Marine Survival of Seymour Steelhead and Testing Performance of 180 kHz Small Acoustic Tags in the Salish Sea			Aims of this project are to a) provide expanded baseline survival data for Seymour steelhead in 2015 that may be compared to past published data and address uncertainty as to whether or not survival in the small section of the Salish Sea north of the NSOG sub-array (and south of the Discovery Islands) is more consistent with survival measurements for the lower Strait of Georgia or the Discovery Passage/Johnstone Strait/Queen Charlotte Strait region, b) evaluate the detection efficiency of the proposed new VR4 sub-array in the Discovery Islands for 180 kHz tags using the existing POST sub-array geometry and c) evaluate the improved performance possible as a result of retro-fitting Vemco acoustic receivers with a sold-state acoustic amplifier to increase tag detection range, and thereby reduce the future cost of achieving a given level of scientific precision on measurements of survival or residence time. Costs are for part of this project. Project approved at full value after correction (reduction) of vessel costs paid directly by PSF.
Juvenile Salmon	BCCF	A PIT tag based method to investigate survival of Cowichan River Chinook throughout various stages in their first year of marine life			Study aims are to determine survival of Cowichan Chinook at different stages of their first year of marine life. Fish will be captured in-river, by beach seines, by purse seine, and by microtrolling (to catch sub-legals). Latter method will need extra assistance and will employ the help of citizen scientists, the Avid Anglers, and Will Duguid, UVic (see below). Objectives are to: 1) capture juvenile Cowichan Chinook at a series of key times and locations throughout their first year of life, 2) apply PIT tags to wild and hatchery fish which are 60 mm and greater (fork length) at each location (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. (If funds are available we may also allow for BCCF installation of a fixed full stream antenna in the lower Cowichan River to detect tags year round- this is not currently part of this budget.), 4) scan brood stock for tags upon capture, 5) calculate the relative survival for each tag group. Tag recoveries for each group will occur over several years due to multiple age classes of returning adults. Project approved at full value.
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.
Juvenile Salmon	M. Trudel, C. Neville &K.	Understanding the factors limiting the recruitment of Pacific salmon in the Strait			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 to

CATEGORY	Principle Investigators	Title	2015	2016	Comments
	Miller (PBS-DFO)	of Georgia – From patterns to processes			be 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 will be 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 will 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. Project approved.
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)
Juvenile Salmon	PSF	PIT tag readers			Cost of PIT tag readers for use by Trudel et al.'s juvenile salmon study above, and for Avid Anglers when micro-trolling for Chinook and coho (part of the BCCF Cowichan study above)
Juvenile Salmon	PSF	Acoustic Tags			Purchase of acoustic tags to be employed by Hinch et al. (project above)
Predation	J.Wade, Consultant	Determining the Role of Piscivorous Birds in Salmon Predation Bird in the Cowichan River system and Southern Gulf Island Rookeries			Project was not approved for 2015. Studies to assess level of predation by birds and fish will be resumed in 2016 but budgetary concerns have resulted in deferral of this project in 2015.
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			Costs are for a seal predation study on coho smolts at Big Q hatchery. Costs are for 1) design and building of a seal capture platform and PIT tag detection haulout, 2) deploying RFID tags (seal "beanie") and GPS-accelerometer tags on harbour seals, 3) calculating a harbour seal smolt predation rate from PIT tag detections, and 4) generating maps of spatial predation risk from combined RFID and spatial data. Project approved at full value. PSF has extensive investment into this project due to support for Austen Thomas (PhD candidate) and development of the seal 'beanies'.

CATEGORY	Principle Investigators	Title	2015	2016	Comments
Predation	K. Pellet & Hatchery Staff at Big Q	BQR tagging project			Costs are for PIT-tagging coho smolts at Big Q hatchery for the seal predation project described above.
Predation	PSF	PIT tag purchase			Cost are for PIT tags purchased for BCCF's coho PIT tagging project outlined above.
Harmful Algae Blooms Study (HABS)	N. Haigh, Consultant, 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. Costs are simply for N. Haigh oversight of the project- lab work will be carried out by S. Esenkulova (PSF hired technician) Project approved and work will be done by S. Esenkulova, PSF tech
HABS	K. Miller-Saunders, DFO	Cumulative Impacts of harmful algal blooms and microbes on wild salmon			Project is not approved for 2015. Further discussion and proposal development is required before this proposal is re-evaluated for 2016.
Contaminants	P. Ross, Van Aqua	Pacific salmon at risk: evaluating the impacts of pollutants of concern in Strait of Georgia salmon habitat			Proposal was not funded. We will work with Peter Ross to produce a more focused proposal for 2016. In the interim, we are collecting appropriate samples from juvenile salmon during 2015 and storing these so that they may be analyzed for contaminants at a later date.
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. Project approved.
Nearshore Habitat	M. Costa, UVic	Spatial temporal extent of kelp canopy area: satellite method development for two study areas with different water turbidity characteristics, and further evaluation for a larger scale mapping project.			This is a short pilot project (3 months) aiming to evaluate and define methodologies to use satellite imagery (present and historical) to map the aerial extent of kelp beds on BC coastal waters. Costs are primarily for a short term research assistant and technician. If successful, this project will be expanded and will allow us to determine how kelp beds have changed over time and space, and where we may wish to focus restoration efforts. Project approved.
Nearshore Habitat	R. De Graaf	Systematic spawning surveys for surf smelt and			Funded after some proposal amendments

CATEGORY	Principle Investigators	Title	2015	2016	Comments
		Pacific sand lance in the Salish Sea.			
Nearshore Habitat	R. De Graaf	"Salish Sea Citizens' Science Forage Fish Initiative": Beach spawning forage fish spawning surveys.			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.			Funded after some proposal amendments
Nearshore Habitat	R. De Graaf	Howe Sound Forage Fish Habitat Assessments – Mapping Critical Marine Forage Fish Habitats			Funded after some proposal amendments
Modeling	K. Denman (Uvic & Canada's Ocean Network)	Modeling the Salish Sea			Costs are for a post doc (to begin January 2015). He/she 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, but costs will be 50% lower as we are working with Mitacs to assist in matching funding for SSMSP students. On-going funding will be required.
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.

SECTION 4: DESCRIPTIONS OF RESEARCH ACTIVITIES

The 2015-2016 project activities are described in the following sections. Complete proposals are also provided in the adjoining document "Error! Reference source not found." available on the project website www.marinesurvivalproject.com.

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.

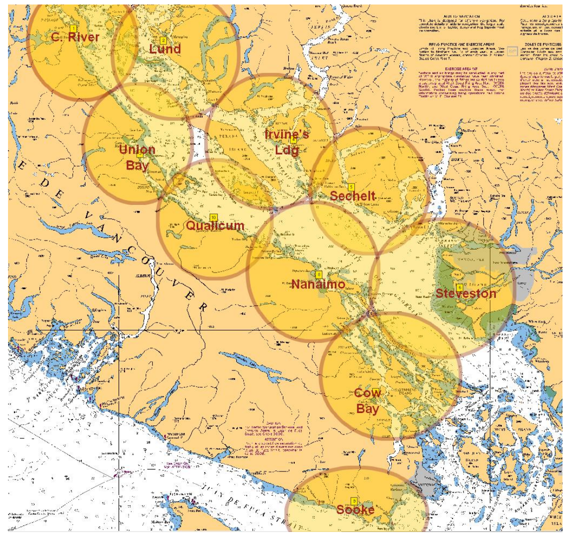
Citizen Science Program

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

This program was originally proposed by Dr. Eddy Carmack, retired scientist from the Institute of Ocean Sciences, Sidney. His concept was the creation of a "mosquito fleet" which would utilize fishing vessels to collect oceanographic data during the spring and neap tides at specific locations in coastal waters of the Strait of Georgia. This retirees or interested persons would take on a role as citizen scientists, collecting information in different areas of the Strait on the same days each week over a period of months, such that the entire Strait could be fully sampled, providing data at a spatial and temporal degree that has not been realized or possible before. PSF has partnered with DFO, and with Ocean Networks Canada (ONC) to assist with program management for the citizen science program.

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

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



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

The work done on the vessels Elvis and Dr. Carmack’s vessel Wicklow in the Cowichan during 2013 and 2014 served to test equipment and refine the methodology for this program. Currently, the program has vessels outfitted and actively sampling the Strait of Georgia from Campbell River, Deep Bay, Qualicum, Cowichan Bay, Victoria, Lund, Powell River, Sechelt. We are now searching for a vessel from Steveston or Silva Bay, Gabriola Island.

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. Proposals 1-3 in Appendix 2 are from ONC and related to the work to 1) develop the app, 2) engineering services for the CTDs, and 3) 2) data services (storage, QA/QC and data retrieval).

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

The fifth is the collection of water samples to identify phytoplankton, as part of our examination of the spatial and temporal 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.

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.

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 will address specific knowledge gaps in spatial-temporal biogeochemistry of the Salish Sea by using synergistic methods that include (i) ocean colour satellite imagery, (ii) sensors aboard vessels of opportunity (FerryBox and FOCOS-BC Ferries), (iii) *in situ* data from research cruises, and (iv) *in situ* data collected from citizen science boats. A fifteen year remote sensing data set will allow them 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.

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

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 Johanneson'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.

Buoys

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

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

King and her team will continuously monitor phytoplankton for two years (2015-2016) using fluorometers deployed at three locations in the Salish Sea. Sampling locations are at three locations as shown in Figure 3 and will provide data in the relatively data-poor central and northern parts of the Strait of Georgia (Halibut Bank, Sentry Shoal), as well as at the mouth of a coastal inlet (Egmont). Two additional sensors have been deployed on the Sentry Shoal Buoy: SBE-37 MicroCAT, a temperature and conductivity sensor and the Satlantic SUNA V2, an optical nitrate sensor. Both have been deployed at the surface to provide a continuous time series of temperature, salinity and nitrate from April 2015.

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

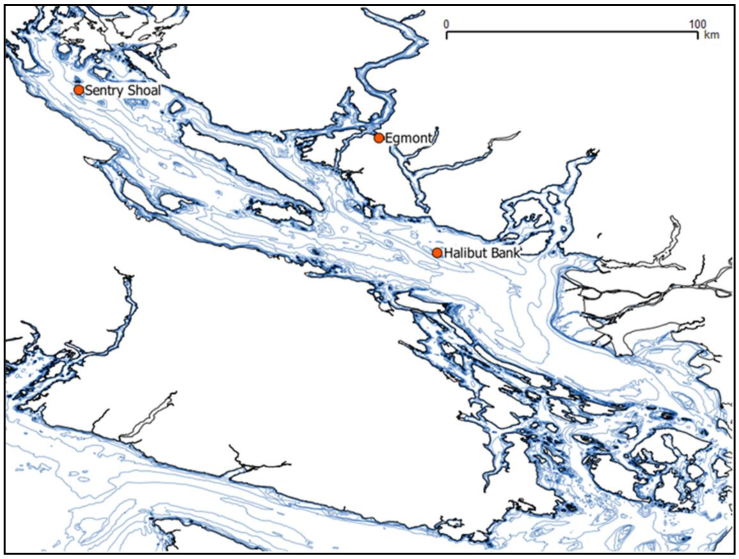


Figure 3. Three proposed sampling sites for chlorophyll fluorescence time series in the Salish Sea.

Cowichan Bay Oceanographic Studies

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

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

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

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

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

Early marine habitat use is a critical component to the Cowichan Bay study, and thus the team will also work with Nikki Wright from the Seachange Conservation Working Group to interpret multibeam data collected by CHS in the area in the spring of 2014, locate and use available bottom classification data sets, and to make surveys along the shore of Cowichan Bay using both available video and acoustical systems and the Imagenex imaging sonar.

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

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.

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 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) if 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) if the incidence and magnitude of harmful algal species is correlated to ocean conditions

This information 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.

1.2 ZOOPLANKTON AND ICHTHYOPLANKTON

Zooplankton and Ichthyoplankton

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

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

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

The short-term 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 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.

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.

1.3 FORAGE FISH

Herring

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.

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.

Hydroacoustics

Team: Stéphane Gauthier (DFO), Marc Trudel (DFO), Chrys Neville, Research Biologist, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, Chelsea Stanley, Acoustic Research Technician, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, Moira Galbraith, Zooplankton Taxonomist, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, Chris Grandin, Research Biologist, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, Dr. Jennifer Boldt, Research Scientist, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, Postdoctoral fellow (Visiting Scientist in government laboratory)

Stephane Gautier supervised a pelagic ecosystem survey of the Strait of Georgia (SoG) in March 2014 based on acoustic-trawl methods. Another survey is scheduled for March 2016, with anticipated follow up in June/July and again in March 2017. In addition to these surveys, acoustic data are now routinely collected as part of DFO's juvenile salmon trawl program occurring in the area. This project is to host a qualified postdoctoral fellow for 2 years to oversee those surveys and focus on this rich acoustic dataset. The objective will be to develop a series of acoustic indices of productivity for forage fish species such as herring, mesopelagic fish, euphausiids, zooplankton, and ichtyoplankton within the SoG. Demersal species distribution and abundance are also explored as part of these surveys (e.g. Pacific Hake and Walleye Pollock). Acoustic indicators will be developed using robust multi-frequency techniques in conjunction with mark identification fishing (trawls). A multiple opening and closing net system (the Hydrobios multinet) will be used to sample smaller organisms (zooplankton, euphausiids, and larval fish). Along with existing time-series of forage species catch from trawl surveys, the acoustic indicators of productivity will be investigated for potential links to juvenile salmon survival. Data and results from this study will be closely integrated with the other projects that focus on juvenile salmon survival in the area.

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, Don Elliot, Cowichan Tribes.

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

Previous work to determine the marine survival of Cowichan chinook have made assumptions that all hatchery fish released 40 kms upstream from the estuary in the Cowichan River survive and enter the estuary. This assumption is unlikely to be valid, and thus, a Rotary Screw Trap (RST) has been operated by DFO and Cowichan hatchery staff during 2014 and 2015 in the mainstem of the Lower Cowichan River to allow for a mark-capture population estimate on hatchery released fish. If it is concluded that hatchery smolts released a significant distance upstream from the estuary experience high losses prior to saltwater entry, a follow-up study could be implemented to determine if lower river hatchery releases improve overall and river return survival.

The RST work is being supplemented with a freshwater PIT tagging study during 2015. Hatchery chinook are PIT- tagged and released at the usual hatchery release location, and their survival will be estimated using a RFID array at the bottom of the Cowichan River, which records each PIT tag as the fish crosses the array. The survival estimate using this method can be compared with that from the RST.

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

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

The key hypotheses that are being addressed are as follows:

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

Cohort Analysis and Marine Growth

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

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.

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

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

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

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

*Hypotheses that predict that faster growing fish have higher survival

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

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

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

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

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

Figure 3. Beach Seining in Cowichan Bay

Figure 6. Sorting Fish Caught by Purse Seine

Figure 4. Purse Seining in Cowichan Bay

These analyses will be performed in collaboration with the University of Victoria (Francis Juanes-otoliths, Rana El-Sabaawi-Fatty Acids, and Asit Mazumder-Stable Isotopes & Fatty Acids), the West

Vancouver Laboratory (Ian Forster-Fatty Acids), the Pacific Biological Station (Strahan Tucker-Cesium Analyses, Fatty Acids & Stable Isotopes, Stewart Johnson-Fatty Acids & RNA:DNA ratio).

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

Figure 7. 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

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

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

12. Food supply limits growth, and thus survival, during critical periods of early marine rearing (including Hypothesis 12c – that growth is limited by the metabolic effects of temperature); and

13. Predation on juvenile salmon (by birds, seals, and/or marine fish) has increased.

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

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

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

5. Accurate and repeatable RNA:DNA ratios can be obtained from juvenile Chinook salmon in their first marine summer using a non-lethal muscle biopsy;
6. These RNA:DNA ratios are strongly correlated with recent individual specific growth rates; and
7. The relationship between RNA:DNA ratios and recent specific growth rate is as strong as, or stronger than, the relationship between growth rate and insulin-like growth factor (IGF-1) concentration.

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

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

Acoustic Tagging

Deployment and Maintenance of Fish Tracking Arrays in the Salish Sea

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

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

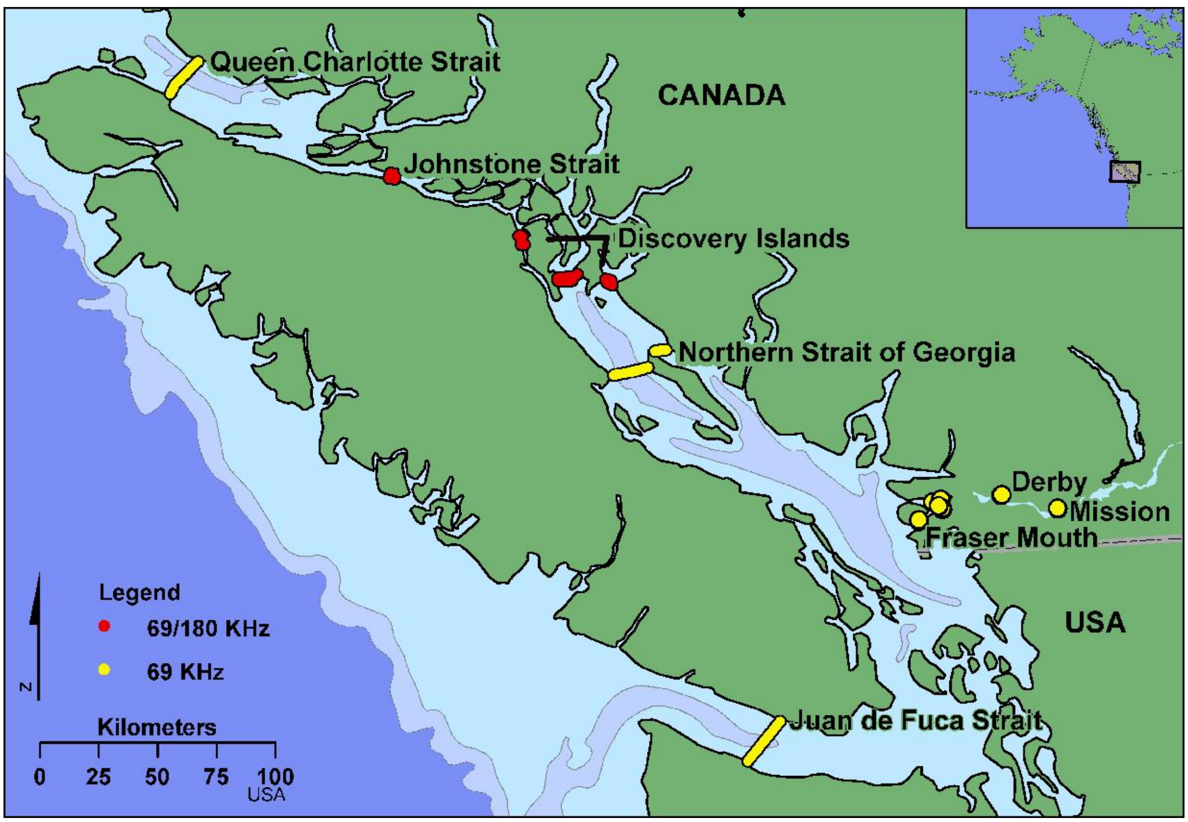


Figure 8. Map of all receiver sub-arrays available to track juvenile salmon in 2015. The red arrays indicate the new, dual frequency receivers deployed in 2015.

The following figures provide more detail of the layout of this new sub-array.

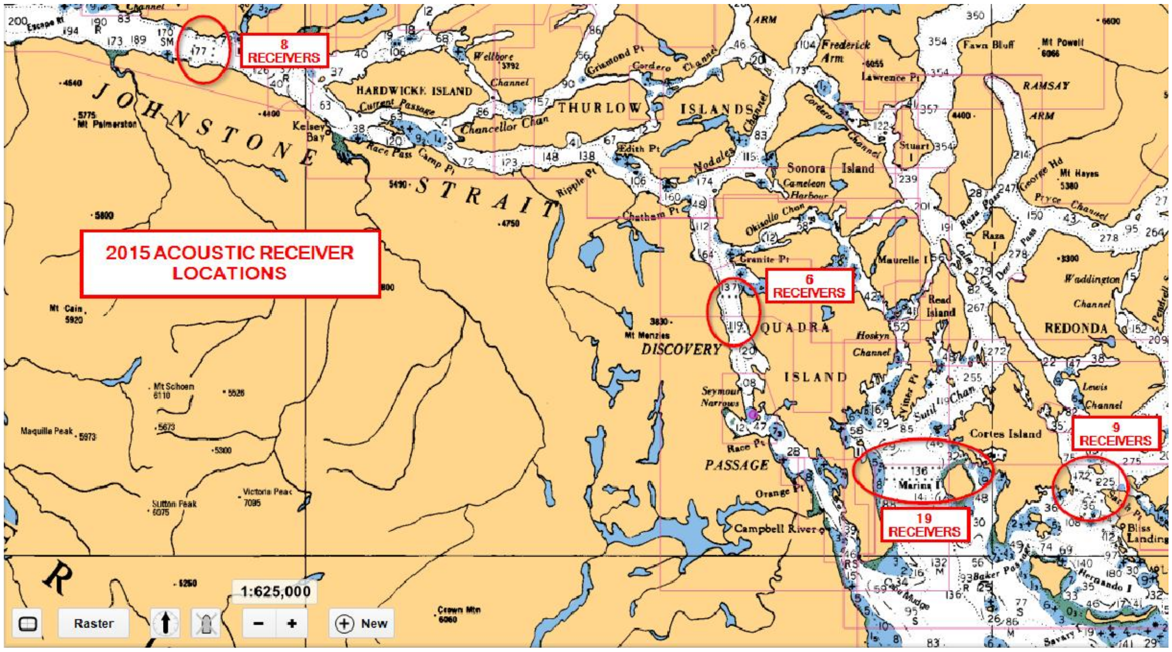


Figure 9. Overview of Discovery Islands (three components to the south) and Johnstone Strait sub-array deployment locations.

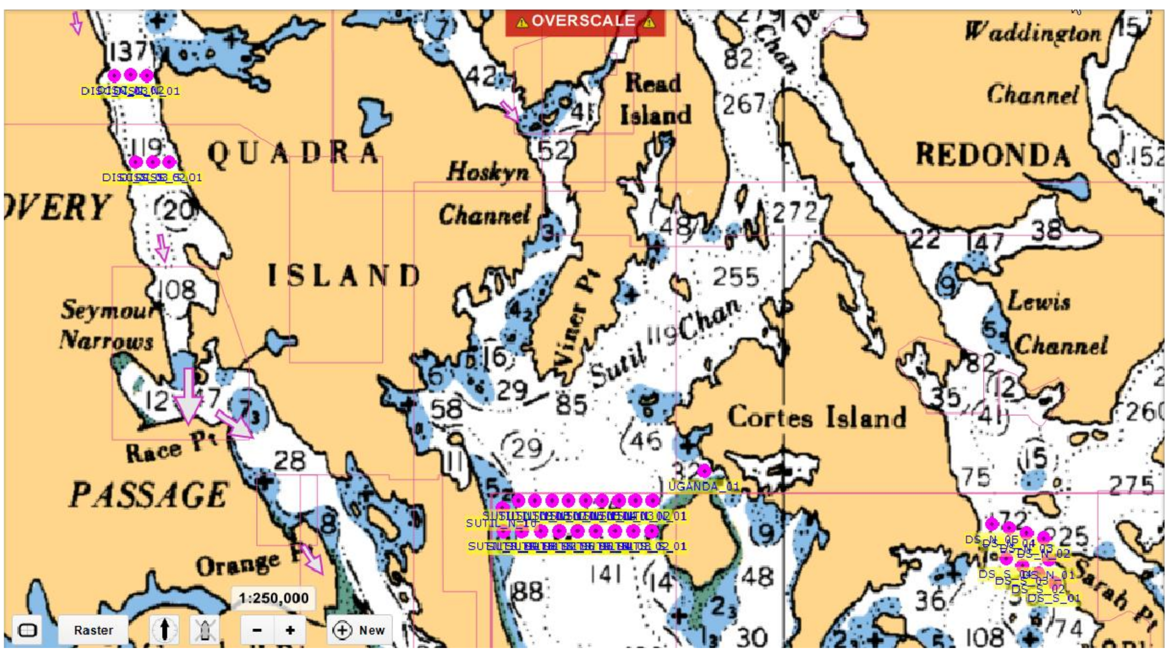


Figure 10. Three components of the Discovery Islands sub-array. Individual receiver positions are shown in magenta.

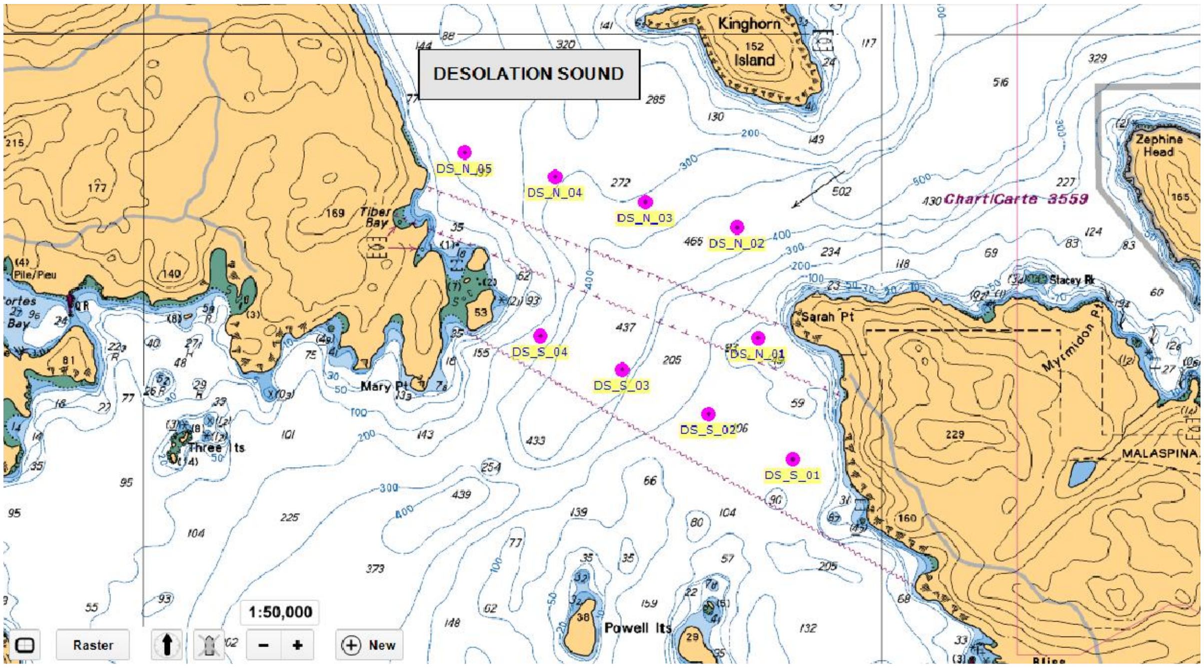


Figure 11. Desolation Sound component of the Discovery Islands sub-array. Individual receiver positions are shown in magenta.

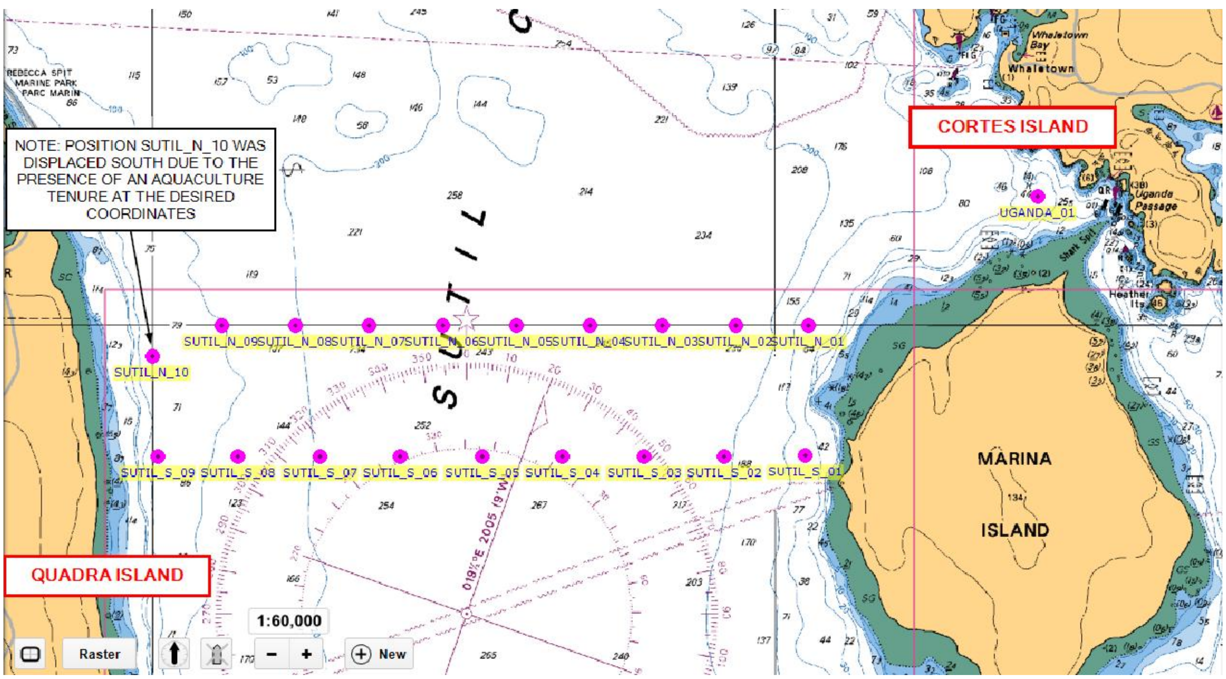


Figure 12. Sutil Channel and Uganda Passage components of the Discovery Islands sub-array. Individual receiver positions are shown in magenta. Note one deviation from the planned location.

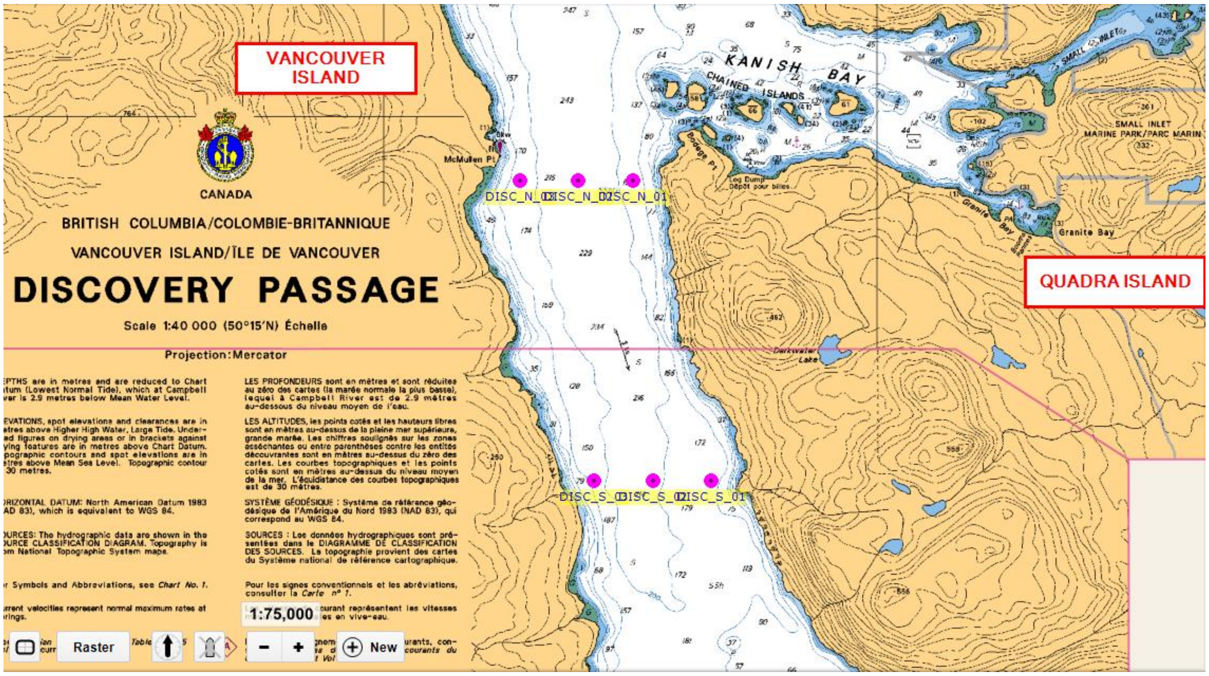


Figure 13. Discovery Passage component of the Discovery Islands sub-array. Individual receiver positions are shown in magenta.

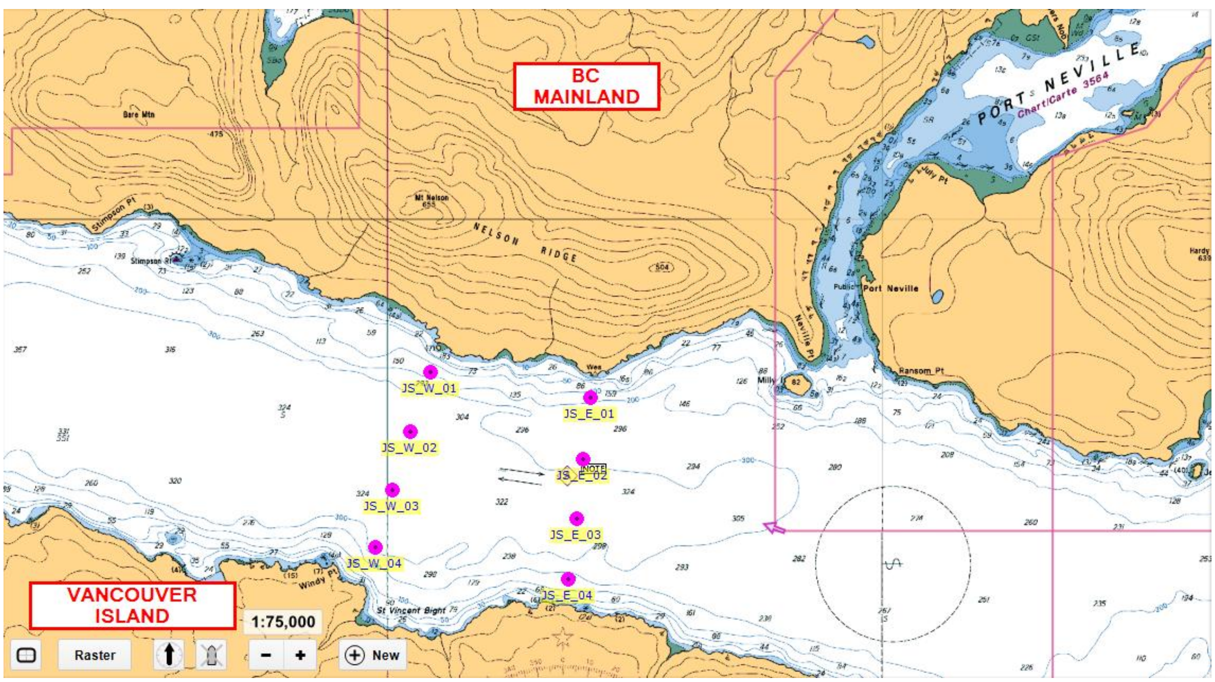


Figure 14. Johnstone Strait sub-array. Individual receiver positions are shown in magenta. Kintama VR4s are the two northern-most locations shown, and were deployed using acoustic releases and depth recorders.

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)

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

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

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

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

A profound decline in marine survival of BC steelhead stocks occurred starting in ocean entry years 1989/90 over a widespread region including the Strait of Georgia and Queen Charlotte Strait. In this project, Kintama are measuring early marine survival of Seymour steelhead smolts using the existing Salish Sea sub-arrays as well as the new Discovery Islands sub-array, which will allow them to partition survival for a key BC stock into Salish Sea survival (from release to the start of the Discovery Islands) and survival in the northern Vancouver Island region (from the Discovery Islands sub-array to the existing Queen Charlotte Strait sub-array). The early marine movements and survival of Seymour steelhead smolts formed a major focus of work completed using the prototype (POST) acoustic telemetry array from 2006 to 2009 and will provide an excellent data set which can be used to form a baseline against which more refined survival estimates using an expanded telemetry array can be compared. This data will allow Kintama to objectively establish where steelhead “mortality hotspots” occur during the first month at sea.

The second key objective is to develop baseline “engineering measurements” that will allow the design of an improved second generation acoustic telemetry array that will be more cost effective than the current POST prototype and will deliver substantially better scientific data yields while at the same time allowing researchers to tag a wider distribution of smolt sizes and/or reduce smolt tag burden. To do this, Kintama are testing the efficacy of the Starit of Georgia receivers to pick up smaller 180KHz transmitting acoustic tags, and will test how well a solid-state amplifier (currently being developed by Kintama) can be used to boost detection of those small tags. During 2015 they will test the performance of amplified receivers relative to the typical Vemco receivers by pairing amplified and normal 180 kHz VR2 receivers close to the 19 Northern Strait of Georgia receiver locations instrumented with VR3 receivers (which detect 69 kHz acoustic tags only). The comparison will be achieved by double tagging Seymour steelhead smolts with VEMCO V9-1H (69 kHz, larger sized acoustic tags) and V4-1L (180 kHz, small acoustic transmitters) and comparing the efficacy of the receivers (amplified and non-amplified) to pick up these larger and smaller tags.

The key objectives of this study are to:

(a) Develop objective calculations of how well an upgraded array with the capability to monitor smaller, more "modern", tags will perform,
(b) Establish the cost of developing a 180 kHz marine telemetry platform,
(c) Find the optimal (best possible) array design for a given cost

Other studies

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

SSMSP is providing partial support to continue work on juvenile salmon ecology in Campbell River. The CAHS project focuses primarily on improving the returns of Coho reared at the Quinsam Hatchery in Campbell River BC. There are many components including: characterizing plankton dynamics; evaluating which measured environmental indicators correlate with the timing and composition of plankton blooms; providing a program that is a tool to assist in predicting the strength or weakness of a brood year far in advance of the return so that pro-active management measures can be implemented; as well as collaboration and knowledge-transfer between governmental, non-governmental and First Nations organizations. Funds to CAHS allowed for continued plankton identification and analysis during 2015.

1.5 NEARSHORE HABITAT

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

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

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. Specifically in BC, the Ministry of Environment has conducted kelp surveys in specific areas along the BC coast since the 70s using transects and infrared aerial photos. Other localized initiatives of kelp inventory have started recently, for example in Mayne Island and Gabriola Island. A proposed alternative to transect and aerial photos is the use of optical remote imagery acquired by satellites which can capture data from large and sometimes inaccessible areas cost- and time- effectively, nearly instantly, and with high frequency, with the added potential for automation. Additionally, the historical distribution of kelp can potentially be derived from imagery acquired by the Landsat series, starting in 1972 up to now, with SPOT series, and more recently with high spatial resolution satellites, such as WorldView 2 and 3. Given proper methodology is developed for accurate retrievals of kelp canopy bed extent, satellite technology can be used to describe the special temporal dynamic of this ecosystem. The best scenario would also combine ground sampling not only for calibration of satellite data but also for higher scale understanding of the in situ dynamics of this ecosystem.

This is a short pilot project (3 months) aiming 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 long-term goal is to apply the developed methods to the BC coastal waters and work together with local communities and First Nations in collaboration with SeaChange to improve data collection and the use of satellite imagery.

Evaluating seagrasses as habitats for juvenile salmon

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

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

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

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. Eelgrass and riparian vegetation will be mapped in areas considered critical nearshore and coastal nursery habitats for salmon in the southern and central areas of the Salish Sea. Restoration of eelgrass (*Zostera marina*) will continue using a well- established science based methodology. Riparian shoreline areas will be restored where feasible. Activities in all locations will be conducted in consultation with First Nations. Where possible, training in habitat mapping and restoration will occur in these communities to increase capacity to conserve nearshore marine habitats. Presentations, field tours and school programs focused on the high value of nearshore salmonid habitats will continue to be an important stewardship component of this project.

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

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.

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.

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.

Other projects in the Nearshore Habitat category that are under evaluation include the following:

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

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

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

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

Team: Dr. Maycira Costa, UVic

We are also in discussions with Dr. Maycira Costa, UVic, with respect to using remote sensing methods to assess changes in eelgrass distribution, concomitant with changes in upland land use and water quality.

Top-down Studies

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

The Canadian major top-down studies for 2015 include assessment of the impacts of seal and fish predators on juvenile coho and Chinook, analysis of the spatial and temporal occurrence of harmful algal blooms, and an examination of microbe loads on juvenile salmon. Additionally, the Canadian side will be carrying out some hatchery manipulation studies, involving alternative times of release of Chinook into the Strait of Georgia. Samples of juvenile salmon will be collected from the Strait for future contaminants analysis, but this program will be more fully developed during 2016.

1.6 DISEASE & HEALTH

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

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.

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

Researchers are using novel genomic approaches that utilize physiological assessments to identify potential stressors and monitor dozens of microbes to identify pathogens that might be of greatest import. The sampling program utilizes a trajectory from freshwater through the first 9 months of marine residence, and thus the conditional state of fish can be monitored even before they enter the Salish Sea. Prior analyses have suggested that salmon pre-condition can be highly predictive of survival as they move into new stressful environments.

1.7 HARMFUL ALGAE IN COWICHAN BAY

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

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

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

1.8 PREDATION STUDIES

Seal Predation

Impacts of seals on Pacific salmon in Cowichan Bay during spring, summer and fall 2014

Team: Ben Nelson and Andrew Trites (UBC)

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

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

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

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

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

High rates of predation by harbour seals on salmon smolts may explain the decline and lack of recovery of coho and Chinook salmon in the Salish Sea. However, rates of predation and the relative spatial and temporal vulnerabilities of smolts to predation by seals are unknown. This study aims to track harbour seals to estimate rates of predation on coho smolts, and will identify when and where predation is occurring.

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

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

BCCF is responsible for PIT tagging hatchery coho out of Big Qualicum River hatchery, and Austen Thomas and his team are responsible for tagging seals.

Fish Predation

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

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

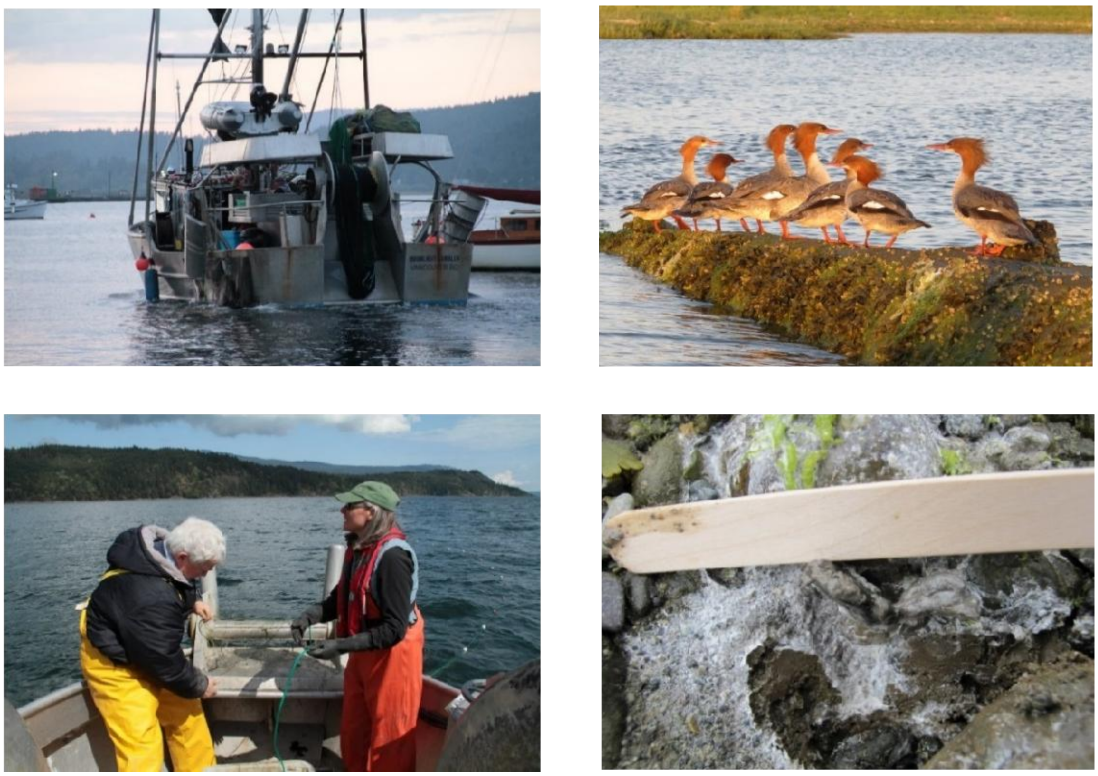


Figure 15. Predation studies- gillnetting, bird observations, bird scat collections

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

Bird Predation

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

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

In addition, scat have been collected from known piscivorous birds for DNA analysis at a future date. It is believed that such an analysis will be able to determine which species of salmon are being consumed if any. This project was piloted in 2014, and although this study was not continued in 2015, there may be continuation of studies in 2016.

1.9 CONTAMINANTS

A contaminants program is being developed during 2015, for the 2016-2017 funding cycle.

1.10 STRAIT OF GEORGIA COHO HATCHERY RELEASE STUDIES

Team: Salmon Enhancement Program, DFO (Mel Sheng, Dave Willis, Ryan Galbraith).

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.

Funding from the PSF will support the costs associated with extended rearing and coded wire tagging of these experimental releases. This study is being conducted at multiple locations around the Strait of Georgia over a period of several years.

Cowichan River Chinook Salmon Coded Wire Tag Application

The Cowichan River Chinook population was historically one of the larger Chinook stocks in the Salish Sea. This hatchery stock is a Pacific Salmon Treaty indicator stock, which is used to provide information that is critical to the management of wild Chinook salmon in Lower Georgia Strait. The PSF has been supporting several initiatives relating to Cowichan River Chinook studies, including genetic-based hatchery-wild interaction work. This project will increase the marking rate of hatchery Chinook juveniles to ~100%, which will allow for full identification of hatchery returns in other concurrent studies. The increased CWT release also improves the information on coastwide exploitation, survival and distribution for this indicator, which can provide valuable inferences for wild Chinook stocks in Lower Georgia Strait.

Genomic studies in Coho salmon (EPIC4)

As part of a joint project with DFO (Science Branch), Genome BC, and Genome Canada, genomic tools will be used to study genetic variation in Southern BC coho salmon (wild and hatchery produced), the genetic effects of intensive hatchery production studied in four BC major hatcheries, and examine whether marine survival in coho salmon has a genetic basis that could be utilized to improve production. PSF will support this research but the developers of this program were Dr. Willie Davidson (Simon Fraser University) and Dr. Louis Bernatchez (Laval University). Full funding for this project has been secured through the partners, and the preliminary work to collect genetic samples began in 2014.

In the original Strait of Georgia program developed in 2009, the science panel had recommended a significant reduction in the number of hatchery coho smolts released in the Strait. However, since then, the Department of Fisheries and Oceans has made significant reductions in smolts released, from 6.75M in 2009 to a planned release of just over 4M in 2016 (~40 % reduction). Further reductions for the SSMSP are not anticipated.

1.11 HATCHERY-AQUACULTURE INTERACTIONS PROGRAM

This project will address concerns about salmon aquaculture in the northern Strait of Georgia and lower Johnstone Strait. The focus of this research is on Fraser River sockeye salmon exposure to open-net pen salmon farms during their emigration from the Strait of Georgia; but it will also involve Chinook and coho salmon of interest to the SSMSP. Following recent discussions with the BC Salmon Farmers Association; they will participate in the SSMSP and the details of the research program are still being developed.

Trend Analyses and Modeling

Trend analyses and modeling is a priority to provide a data evaluation framework for past and future data, consolidate existing data, combine the effects of multiple factors, better identify information gaps, and help narrow the field of likely survival drivers. Historical data and modeling are being used to evaluate survival and it's variation 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 are also being used to look for general ecosystem regime shifts that may correlate with changes in salmon and steelhead survival since the 1980s. These activities are aligned with the proposed suite of research activities involving the collection of new data.

Each research activity in this section is being developed and implemented with significant collaboration between U.S. and Canadian scientists. There is currently significant agreement between U.S. and Canadian scientists on the value of evaluating salmon survival trends and establishing a suite of ecosystem indicators that identify and provide a mechanism for simultaneously evaluating multiple metrics. There is also significant agreement that advancing ecosystem modeling is imperative to our understanding of cumulative effects; however, the scientists concluded that initial efforts should focus on improving the modeled relationship between physical parameters through secondary production (zooplankton). There is less agreement on the value of evaluating the effects of outmigration timing and size relative to survival (associated with the hypothesis that changes to life-history variation is related to the decline in marine survival of Chinook and coho). Currently, the U.S. intends to invest more in evaluating this, while the

Canadians largely reference a recent publication by Dr. James Irvine indicating no apparent difference in survival of hatchery coho with various release and outmigration times (2013)[8].

Survival trends U.S.-Canada alignment: High

Chinook, coho, and steelhead are being analyzed to address:

1. What are the marine survival trends[9] for Salish Sea Chinook and coho and Puget Sound steelhead populations? How do these trends compare to nearby populations outside of the Salish Sea (i. e., control group)?
2. Does survival differ for stocks entering the Salish Sea within different sub-basins (in particular, comparing oceanographic basins of Puget Sound to the Strait of Georgia)? If so, where, when, and to what degree has it varied?
3. How much does marine survival differ between hatchery stocks and naturally spawning populations?

This work is being performed retrospectively, but the datasets will be updated over the course of the project. Outmigration and adult return estimates for most Salish Sea and some Washington and B.C. coastal stocks are included, providing a comprehensive picture of marine survival in this region. Early marine abundance/CPUE data from the Ricker marine trawl surveys and from future marine trawl or seine surveys are being included to directly assess early marine survival where practical. To some extent, freshwater survival will be analyzed for wild stocks to express the degree to which freshwater vs. marine mortality contributes to salmon returns. This effort provides the framework and foundation for ongoing[10] and proposed analysis and modeling activities, listed below. Participants are also interested in using the outcome of this work as a template for a long-term assessment program.

U.S.-Canada expert task teams have been developed for coho and for Chinook (steelhead was U.S. only). To facilitate across species comparisons, an assessment format was established first by the coho survival task team and has been replicated for Chinook and steelhead.

Life-history characteristics relative to survival U.S.-Canada Alignment: Moderate

Salish Sea Chinook and coho, and Puget Sound steelhead will be analyzed to address:

- Does variation in body size, smolt migration timing, or other life-history characteristics associated with freshwater rearing affect marine survival?
- Does outmigrant abundance affect marine survival?
- Does migration duration/residence time in the Salish Sea affect survival (comparing Strait of Georgia vs Puget Sound coho)?

This work will first be performed retrospectively, but the datasets will be updated over the course of the project where it is considered appropriate. Data on wild and hatchery steelhead life-history characteristics of stocks in Puget Sound (and potentially some Strait of Georgia stocks) will be analyzed with reference to

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

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

[10] For example, FRAM (Pacific Fisheries Management Council, Fisheries Regulation Assessment Model).

marine survival trends over time. This work will be performed to determine whether certain characteristics account for variability in the marine survival estimates and or are contributing uniquely to mortality (or are uniquely affected by the environment) in the Salish Sea. Characteristics within and among species will be compared. Hypotheses concerning spatial variation in mortality, size-selective mortality, match-mismatch, and life-history variation will be examined. This analysis will also compare changes in hatchery and wild smolt outmigrant abundance and marine survival rates to examine the marine carrying capacity hypothesis. This analysis may include developing enhanced life-cycle models that capture life-history variation better than current approaches. The U.S.-Canada Chinook and coho survival task teams and others will work together to complete this assessment. This may be merged to occur simultaneously with the ecosystem indicators effort, described below, because of the need to evaluate both life-history characteristics and their environment simultaneously to assess hypotheses such as match-mismatch. Per the overview of the Trends Analyses and Modeling section, there is less agreement regarding the relative value of additional work in this area (U.S. greater than Canada because of Irvine 2013 findings), influencing the level of investment by each party in work in this area.

Ecosystem indicators: stoplight modeling, single & multi-variant analyses, & other approaches U.S.-Canada alignment: High

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

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

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

End-to-end, spatiotemporal ecosystem model for the Salish Sea U.S.-Canada alignment: High – Moderate

End-to-end modeling (ecosystem modeling, from physical characteristics through the biotic trophic levels) alignment is focused on concurrence around key information gaps/needs and associated output. Better establishing the NPZ (nutrient-phytoplankton-zooplankton) and bio-energetics for salmon feeding and growth are top priorities throughout the Salish Sea. Establishing ecosystem models is occurring in a slightly different fashion on both sides of the border. The Canadians are currently merging two existing models for the Strait of Georgia to establish links from circulation through to the salmon, prioritizing understanding effects on feeding behavior. The Americans are focused on acquiring funding to develop a full, end-to-end Atlantis ecosystem model of Puget Sound. In the interim, the Americans are using assessing physical data for input into the Salish Sea circulation model (MoSSea), and evaluating whether atmospheric and stratification datasets illustrate ecosystem change consistent with high and low marine survival periods of coho. They are also creating the basis for incorporating zooplankton data into circulation models.

Program Gaps

Key identified program gaps in Canada include: contaminants, Pacific herring recruitment, forage fish biomass estimation, and inter-specific competition between salmonids, including interactions of hatchery and wild salmon within the Salish Sea. In the case of the contaminants program, we will solicit a more focused proposal during 2015: in the interim we are making sure to collect appropriate samples during 2015 field studies and will be storing these in an appropriate method for future contaminants analysis. During 2015, we have addressed concerns for continued monitoring of juvenile herring recruitment in the Strait of Georgia and hired a post-doctoral fellow to research the use of hydroacoustic surveys to estimate the biomass of forage fishes in the Strait (in collaboration with UVic and DFO Science). The inter-specific interaction of salmon species and with hatchery fish remains to be developed.

Both Canadian and US scientists continue to assess whether large-scale experiments or manipulations can be used effectively as a tool in this research project, as recommended by the November 2012 Workshop Advisory Panel and as discussed in the two subsequent Salish Sea Marine Survival Project, U.S.-Canada Retreats (2013 and 2014). These are most relevant to assessing top-down effects such as predator-prey interactions and competition, but are broadly applicable. The Canadians are currently considering future experiments to assess impacts of harmful algae, herring recruitment, interspecific competition, and are evaluating kelp restoration with before and after assessments. Discussions will continue at both the international and national level regarding the applicability of this type of work.