SALISH SEA
MARINE SURVIVAL PROJECT

LLTK & PSF – January 2019

INTERIM FINAL REPORT
FOR THE PACIFIC SALMON COMMISSION

Overview

In 2014, the Pacific Salmon Foundation and Long Live the Kings (LLTK) launched the Salish Sea Marine Survival Project: a US-Canada research collaboration to determine the causes of poor juvenile Chinook, Coho, and steelhead survival in the Salish Sea. Sockeye have also been included in the Strait of Georgia. For the past five years over 200 scientists representing multiple disciplines have been engaged in this program; 60 federal, state, tribal, nonprofit, academic, and private entities are participating; over $20 million has been raised with an equal amount contributed in-kind by project collaborators; more than 90 studies have been initiated; and 25 articles have already been published in peer-reviewed journals. There are also a number of technical reports and affiliated publications associated with SSMSP. All reports/manuscripts are available at www.marinesurvivalproject.com/resources.

Research alignment throughout the Salish Sea has occurred by operating under a single overarching research framework, focusing on similar operational hypotheses, sharing results and evolving approaches in tandem, and aligning specific sampling approaches: especially, with bottom-up sampling (salmon/zooplankton/physical), where protocol were shared and reviewed by participants on each side of the border. Alignment continues with LLTK and PSF partnering to consider a common suite of ecosystem and salmon metrics, working on parallel and complementary modeling approaches, and assess a cohesive data management approach.

Overall, the research supported by this project is roughly 40% complete[1]. LLTK and PSF are working with partnering scientists through 2019 to get the work completed and synthesize results Salish Sea-wide. We expect to produce the final synthesis report in early 2020. We hope to work with the Pacific Salmon Commission on its release.

Already, the Salish Sea Marine Survival Project has made a significant contribution to our understanding of wild Pacific salmon, and should allow for implementation of management actions which will increase Chinook and Coho production. Ultimately, we believe that our results and subsequent management actions will also benefit other marine life in the Salish Sea, such as the southern resident killer whales.

Below is a brief review of what happened in 2018, followed by an update focused on highlights of findings to date. Final financials associated with PSC funding will be provided upon completion of all the work.

2018 in Review

Focus for Canadian SSMSP activities for 2018 was on completion of field projects, sample processing and analyses, and on synthesis activities. All field projects are now complete, and several final reports have been submitted. Other labs continue the process of sample analysis and data analysis (e.g. the Strait of Georgia Zooplankton and Juvenile Salmon Programs). Likewise, in the U.S., field activities are tapering down with sample processing, analysis and reporting being the focus. Puget Sound zooplankton monitoring has continued beyond the initial round of

[1] *Complete = finished through publication or completion of affiliated technical report.*

funding, and coordination responsibilities have been transferred to Washington Department of Fish and Wildlife. Funds for this program are now part of the Washington State Governor's Budget. If approved by the legislature, these funds will ensure this effort persists over the long term. Funds to support the synthesis phase of the SSMSP as well as next steps for indicators for forecasting, ecosystem modeling, pinniped research, and testing new hatchery release strategies are also in the budget.

Ongoing Canadian projects for 2018 included the following: PSF Citizen Science program, Maycira Costa's satellite imagery programs, Karyn Suchy's synchronicity between phytoplankton and zooplankton phenology program, EPIC 4, the Strategic Salmon Health Initiative (SSHI), PSF's Harmful Algal Bloom monitoring, Brian Hunt's project to examine the trophic structure of the Salish Sea plankton food web, the UBC Strait of Georgia Modeling program, the UBC Salish Sea Model, UBC Predation studies (seals and herons), and DFO-led Wild-Hatchery Interaction Studies (delayed release trials). For these projects, several graduate students are funded including David Costalago at UBC (salmon stable isotopes with Brian Hunt), Vijay Kumar at UBC (hydrographic Strait of Georgia modeling with Villy Christensen), Zachary Sherker at UBC (heron predation on salmon with Andrew Trites), Elise Olson at UBC (Salish Sea model with Susan Allen), Will Duguid at UVic (juvenile salmon studies with Francis Juanes), Karyn Suchy at UVic (bottom up processes with Maycira Costa), and Sarah Schroeder at Uvic (kelp studies with Maycira Costa). There are also a number of ongoing students working with DR. Kristi Miller on SSHI as well as several nearing completion in Scott Hinch's Lab at UBC. Ongoing, PSC-funded U.S. projects include work to understand the temporal and spatial dynamics of larval crab and how they affect Chinook growth (Beauchamp), quantifying the impacts of seals on Chinook and Coho (Nelson et al), work to determine what drives Chinook residency (Chamberlin, Campbell, O'Neil), an assessment of zooplankton prey quality and the analysis of longer-term zooplankton data (Keister et al), and an assessment of indicators of Chinook and Coho survival (Sobocinski). The status of all SSMSP Projects (Canadian and US) is provided in Appendix 2.

Modeling initiatives were ongoing through 2018, and Villy Christensen is working with his counterparts, Carl Walters and post docs to continue development of a full Strait of Georgia model. Progress continues at UBC and the food web modelling component will begin this fall. Likewise, in the Puget Sound Atlantis model (Morzaria, Kaplan, Harvey) is taking shape. The model is now parameterized. Model runs to test several hypotheses will begin within a month.

In 2017, PSF established focused workgroups for the following: Biological Oceanography & Environmental Parameters: zooplankton, ichthyoplankton & forage fish; juvenile salmon: predation, parasitism & pathogens; Nearshore Habitat and marine plants; and Analysis & Modeling. Workgroups continued to meet over 2018 to discuss progress with respect to the key SSMSP hypotheses: a juvenile salmon (Coho and Chinook focus) workgroup meeting was held May 2018, and a modelling workshop was carried out in September 2018 at UBC.

PSF and LLTK has established a Transboundary Synthesis Committee with lead science reps from the US and Canada. Through the Workgroup and Synthesis Committee efforts, focus is being placed on assimilation and integration of transboundary results. The Synthesis Committee is also charged with providing guidance on and, where possible, contributing to the development of one or more publications that synthesize key results affiliated with the project. The first meeting of the Transboundary Synthesis Committee occurred in April 2018, and the second was in November 2018. The goal of these meetings was to discuss findings and status of work, to finalize the approach to synthesis, and determine what actions must be done in 2019 to complete synthesis. We expect the synthesis to be completed in early 2020.

We continue to pursue some cross-border dataset comparisons. In spring 2018 we prioritized funding to allow for transboundary analyses e.g. otolith (size at seawater entry associated with survival) analysis has been expanded to include some additional Strait of Georgia rivers, thus otoliths were sent from Canada to Lance Campbell (WDFW). Funds were also set aside to allow for a transboundary comparison of zooplankton abundance and composition. Other transboundary comparisons include work by Austen Thomas and Ben Nelson who continue to

look at Harbor seal predation rates on Chinook and Coho, and a data manuscript is being completed that captures all the seal diet data from the various studies implemented under the SSMSP.

Isobel Pearsall, Michael Schmidt and Brian Riddell have drafted a narrative of key findings to date, provided below. Isobel Pearsall and Brian Riddell also developed a number of short information bulletins that serve to summarize key findings of PSF funded activities to donors, PSF board members and others. A very brief summary of these bulletins is provided in Appendix 3.[2]

Work continues with the Strait of Georgia Data Centre (www.sogdatacentre.ca) to collate datasets gathered under SSMSP, and time series for use by the modelers. Leaders of Coastal Restoration Fund (CRF) projects with Cowichan Tribes, Seachange and Project Watershed are also in discussion with SGDC to house their data. PSF (Drs. Riddell and Pearsall) began reporting out to communities around the Strait of Georgia in winter 2018. Community meetings were held in Powell River and Pender Harbour in December 2018 and were well attended. The next two community meetings will take place in New Westminster and West Vancouver in early February 2019. They have also developed a series of recommendations for priority legacy projects based upon the key findings identified during SSMSP.

Details of 2018 staffing, project management, and communications activities are found in Appendix 1.

Narrative of Findings to Date

The SSMSP was designed as an intensive, and short term, study of the Salish Sea ecosystem in an effort to: assess major components of the salmon ecosystem simultaneously; monitor the marine survival of Chinook, Coho and steelhead; and identify the major determinants of survival/production of these species. As findings come in, we have begun to develop a picture of what is happening to our juvenile salmon and steelhead as they traverse the Salish Sea marine environment.

Our salmon are dying in the Salish Sea

The journey for salmon and steelhead begins and ends in rivers; however, they spend a significant part of their lives in the ocean. This marine phase has enormous influence on the productivity of Salish Sea Chinook, Coho and steelhead. Further, studies suggest the greatest impact occurs soon after these fish enter saltwater as juveniles, in the Salish Sea before they make it to the open ocean:

1. The marine survival of Salish Sea Chinook[i], Coho[ii] and steelhead[iii] has declined up to tenfold since the 1980s and has remained low, a trend not shared by coastal populations.
2. We've witnessed many juvenile steelhead[iv] and Coho dying while they traverse the Salish Sea on their way to the ocean.
3. Juvenile Chinook that grow larger while in the Salish Sea have a greater chance of surviving to adulthood.[v]

Review of historical data on survival of multiple populations of Chinook and Coho salmon in the Salish Sea indicated that Chinook survival rates varied significantly within the Sea, but populations from nearby rivers tended to show similar patterns of survival. Meanwhile, Coho salmon demonstrated similar survival patterns throughout the Sea, regardless of river of origin. These observations are consistent with our sampling of oceanographic conditions within the Sea, and with the distribution patterns of juvenile Chinook and Coho salmon determined

[2] The complete documents can be accessed at:
https://www.dropbox.com/sh/kjc8wtycsact37b/AAAgwFHdBS4VuQIdmOouiudDa?dl=0

from trawl catches and DNA analyses to identify populations of origin. Chinook salmon revealed consistent patterns of distribution between years with specific populations consistently rearing in different areas of the Salish Sea. Coho salmon were more widely distributed and mixed.

Impacts begin in the freshwater

Impacts to salmon in the freshwater may ultimately play out in the marine environment. Because of this, our research begins with evaluating the condition of juvenile salmon in the river on their way to the Salish Sea.

NOAA scientists have recently shown that the release timing of hatchery Chinook throughout the Salish Sea has been consolidated into a short window.[vi] This could have implications. A pulse abundance of hatchery fish could lead to more competition for food and/or it could affect predator behavior.

In Canada, the BC Conservation Foundation (BCCF) carried out several studies to determine behavior and habitat preference of Chinook juveniles in the Cowichan River[vii]. These findings have led to a number of recommendations for in-stream restoration work, habitat restoration, and water management within the Cowichan basin.

BCCF noted that wild Chinook smolts make extensive use of freshwater habitats during early rearing. Habitats with peripheral instream and overhanging vegetation, and with suitable water velocities are important and required for Chinook fry in the early spring. *Recommendations for in-stream restoration will involve building new side channels with moderate to high flows, and improving existing habitat (e.g., riparian planting).*

PIT tag and Rotary Screw Trap studies carried out by BCCF, Cowichan Tribes and DFO showed that in some years freshwater survival in the Cowichan River was very much lower than commonly believed, and correlated with spring river flows[viii]. Downstream migration survival was similarly low for both hatchery and wild Chinook. River discharge was significantly higher during 2017 compared to 2016 (approximately 6X). Downstream survival from the highest (furthest up-stream) of 5 release sites was poor in 2016 (25%) but much higher in 2017 (71%). Hatchery fish were expected to have high in-river survival as they were thought to emigrate soon after release but the survival rates of hatchery and wild (tagged) Chinook were similar in each year. A surprising result that has significant implications of using hatchery fish as indicators of ***marine survival*** in annual DFO assessments.

Further studies in the Cowichan have shown that the freshwater survival appears to be related to the level of in-river predation[ix]. One surprise was the high level of predation by herons: 406 PIT tags were found under the heron rookery in Cowichan, and tag codes were traced back to all four tagging years (2014-2017) although 2016 represented over 50% of all detections. A small number of tags were from beach and purse seining operations while the majority (90%) were from Chinook tagged in-river, so most of this predation appears to be occurring in freshwater.

Based on these findings it was suggested that high hatchery losses could be reduced by simply moving the point of hatchery release, and this has resulted in a change in hatchery practices: Chinook from the Cowichan hatchery are no longer released in the Cowichan headwaters, but instead, are released in the lower river or directly from the hatchery. There has not been sufficient time to observe any change in estimates of marine survival.

For wild fish, the habitat is clearly supporting significant numbers of Chinook, but in low flow years a high proportion of the overall smolt production was lost during the downstream migration period. *Opportunities to limit losses, either through flow manipulations or predator management, should be considered.*

In Puget Sound, WDFW staff found high concentrations of contaminants in juvenile salmon migrating downriver.[x] Flame retardants were particularly high in Chinook in the lower Snohomish River and juvenile steelhead migrating out of the more rural Nisqually River. WDFW staff, along with the Nisqually Indian Tribe, Tulalip Tribes, NOAA, the Department of Ecology *are now working to isolate the sources of these contaminants, which are likely entering the rivers via wastewater treatment plants. LLTK is now working with these same partners on methods to reduce the amount of flame retardants affecting these fish.* The contaminants story continues in the marine environment: contaminant levels increase in juvenile Chinook salmon as they migrate through Puget Sound. LLTK is working with NOAA to complete a comprehensive model that will help explain how contaminants are reaching our salmon in Puget Sound and what the overall impact may be. This study has obvious value to British Columbia also.

Disease originating in rivers is also a concern for some populations. The US Geological Survey (USGS), in partnership with WDFW, several Puget Sound tribes, nonprofits, NOAA and the University of Washington, found very high levels of the parasite, *Nanophyetus salmincola*, in wild juvenile steelhead from the Nisqually and Green Rivers. This parasite is native to the Pacific Northwest region; however, at the levels observed it can reduce steelhead swimming performance, making them more susceptible to predation, or it can outright kill them.[xi] *USGS recently developed a new eDNA analysis tool to quickly identify the parasite in water samples, locate areas of high parasite concentrations in streams, and then remove the parasite host, a snail, to cut off the disease life cycle. USGS also developed a method to kill the parasite in hatcheries to prevent fish infections. Further, there are now funds in the Governor's budget for WDFW to treat water coming into Soos Creek Hatchery on the Green River, where high loads of nanophyetus were identified.* USGS staff are currently looking for hot spots of disease in the Nisqually River so actions can be taken to reduce its loads. The study of how disease may lead to higher marine mortality was investigated in depth in the Strait of Georgia via The Strategic Salmon Health Initiative. See the relevant section, below, for more information.

Estuarine and nearshore environments are important

SSMSP snorkel and underwater video studies in the Cowichan estuary and Denman/Hornby Island have observed the use of kelp beds by individuals and schools of juvenile salmon, forage fish and resident fish species (e.g. shiner perch, rockfish) and invertebrates (crabs, caprellid amphipods). Similarly, sampling in marsh channels, eelgrass and sand flats in the Fraser estuary across Roberts and Sturgeon banks showed highest total abundance and diversity of fish in eelgrass, followed by sand flat and marsh habitats. Of the estuarine habitats available, Chinook salmon particularly utilized the marsh channels but other estuarine and nearshore habitat types appear to be utilized in high density years. In the Fraser, the most abundant Chinook were small ocean-type Harrison Chinook which showed high residency and dependence on estuarine habitats for growth[xii].

In the Cowichan River, BCCF staff have also noted that the estuary was particularly important to smaller fry as compared to the stream rearing Chinook that left the river at a larger size[xiii]. High mortality rates for river-reared smolts in some years suggest that estuary reared counterparts could have a survival advantage in some years and may be an important component of annual Chinook production. *Estuaries in general play an important role for protection and rearing, especially of smaller fry, and allow for diversity in salmon production.*

Other studies in the Cowichan noted that hatchery-reared smolts were larger than wild smolts, ate larger prey, spent very little time in the estuary, and disappeared from the bay earlier, likely due to emigration or mortality[xiv]. The larger body size may be a disadvantage for hatchery smolts if it necessitates their leaving the estuary prematurely to meet energy needs; the onset of piscivory began at a fork length of approximately 74 mm, which was less than the average fork length of the hatchery (clipped) fish in this study. *Leaving the safety of nearshore habitats, especially those providing eelgrass and kelp cover may expose hatchery fish to increased predation risk and account for the low survival rates of hatchery fish compared to wild fish. (Additionally, their physiological adaptation to salt water is also being examined and may add physical stress that alone could be fatal.)*

Copepods were conspicuously absent from the diet of young Chinook salmon in Cowichan Bay[xv]. Continued log-booming activities in the north-western part of Cowichan Bay and the Cowichan River estuary have altered the substrate; the constant shedding from logs and lack of sunlight make the substrate inhospitable to eelgrass and the many organisms that live in eelgrass ecosystems including harpacticoid copepods, a favoured prey of Chinook Salmon smolts. Decomposing bark and wood on the bottom of the ocean also release toxins, such as log leachates, which are lethal to fish. Eliminating log booming and restoring eelgrass beds would improve salmon habitat quality in the Salish Sea.

Washington Department of Fish and Wildlife (WDFW) staff learned that small juvenile Chinook migrating out of North Puget Sound rivers (Nooksack and Skagit) early in the season have a much greater chance of surviving to return as adults when compared to populations from Mid and South Puget Sound (Cedar, Green, Puyallup).[xvi] Mid and South Puget Sound watersheds have limited estuary habitat compared to North Puget Sound rivers; this may be one reason small fish from those populations do not survive. This work is currently being extended to include more Strait of Georgia systems (otoliths were collected in 2017 and are being analyzed now). This will allow for a more complete transboundary analysis, and will examine whether a relationship between survival rates and presence of intact estuary habitats holds for the whole Salish Sea. *If this is the true, there will be a strong case for increased estuary protection and restoration.*

Meanwhile, Dr. Maycira Costa and students at UVic have been assessing the overall decline or degradation of eelgrass nursery areas in the Strait of Georgia over the period from 1932-2016, with increasing fragmentation and loss associated with shoreline activities and increased housing density[xvii]. Many of the correlations between eelgrass metrics and these potential human impacts are very high ($r>0.9$). The rate of eelgrass loss after 1975 has increased compared to the previous period. Dr. Josie Iacarella also identified that anthropogenic disturbance homogenizes seagrass fish communities and highlighted the importance of targeting conservation efforts in low anthropogenic disturbance areas, as well as managing anthropogenic impacts in high activity areas[xviii].

Project Watershed (Comox area) staff have examined current bull kelp distribution and noted that in the period from 2015 to present, bull kelp beds have been reduced or absent in many former bed areas in the northern Salish Sea but persist in Sansum Narrows, Dodds Narrows, Mayne Island, Saratoga Beach and Burrard Inlet side of Stanley Park. They are including kelp mapping from historical and recent aerial photographs (1970s to present) in a current Coast Restoration Fund (CRF) project. *Their work also provides information on habitat suitability for kelp restoration, as well as identifying critical factors limiting successful restoration.*

Other SSMSP studies of nearshore habitat suitability and spawning surveys for forage fish species such as surf smelt and sand lance in the Strait *have provided a list of priority areas for restoration that will aid local stakeholders in the challenge of protecting these fish species and local spawning beaches*.

Food is key to surviving the Salish Sea

BCCF and DFO's PIT tagging work suggest a 60-70% loss between May and September and a further critical bottleneck that occurs over the first winter[xix]. Our results seem to support the prevailing hypothesis of two critical periods – early (May-September) and late (over the winter between October and year 2). Importantly, this study provides the first demonstration of these periods and estimates of their relative magnitude … however, we fully expect this relationship to be site specific.

The PIT tag studies have also shown that hatchery survival is 50-60% less than wild whether the fish are tagged in-river, during beach seining, purse seining or during microtrolling. This is interesting as the hatchery are larger on average at each stage but alone does not seem to benefit these fish. Results will continue to accumulate for another 3 years as PIT tagged Chinook return to the Cowichan River. But to-date, over-winter survival seems to be the more important of the two survival periods.

Return rates were also investigated based on size at tagging. So far larger fish tagged on the purse seiner in 2015 have returned at a higher rate than smaller fish. However, returns have been recorded for all size classes tagged suggesting that it is not just large fish that survive. However, there is belief that smaller juveniles may return as older adults and we simply have not seen these tagged Chinook return yet, so analyses will continue as tags come back.

University of Washington, USGS, and WDFW scientist have found relationships between Chinook growth and survival. Size-selective mortality appears to matter toward the end of the summer rather than immediately[xx], as evidenced by relationships between late summer size and survival[xxi] and first year growth and survival[xxii]. To achieve the growth necessary for survival, juvenile Chinook and Coho salmon must eat a lot.[3] University of Washington (UW), USGS, and NOAA scientists, working with numerous collaborators throughout Puget Sound, learned that Chinook grow quickly in the Puget Sound offshore environment.[xxiii] Crab larvae and forage fish--primarily herring and Pacific sand lance and less so surf smelt--are particularly important to their diet in Puget Sound. [xxiv, xxv] UW scientists have also found that the type of copepods (small zooplankton) present in Puget Sound relates to the marine survival of many populations of Coho and Chinook.[xxvi] Similarly, DFO staff studying zooplankton showed a positive relationship between Strait of Georgia Coho survival and abundance of decapods (euphausiids, crab larvae and small shrimp) [xxvii].

Our understanding of the relationship between salmon and their prey is still evolving. USGS staff are assessing how the availability of crab larvae affects the feeding and growth of Chinook, and NOAA and UW scientists are working to pinpoint which herring populations contribute most to the diet of juvenile Chinook. In both cases, they are working to determine whether prey is at the right size and quantity at precisely the right time juvenile Chinook need them to grow quickly in Puget Sound. Further, academic, federal, tribal and state scientists from several entities are also working to better understand the relationships between the physical environment, plankton and salmon growth.

Finally, correlative analyses suggest pink salmon in Puget Sound (and possibly the Strait of Georgia) may be competing for food with Chinook and Coho in some years.[xxviii, xxix]

In the Strait of Georgia, the most common diet items in juvenile Chinook salmon are decapods (crab), amphipods, euphausiids, larval fish and herring. The importance of these prey items vary with season and area. UVic researchers have shown that fish and euphausiids became more important in Chinook diets over the course of the summer and crab became less important by fall[xxx]. Their preliminary results are suggesting that only individuals at the larger end of the size distribution of juvenile Chinook salmon are able to utilize young of the year (YOY) herring, the primary forage fish in their study area. Those fish that do not show evidence of piscivory are also showing evidence of slower growth (based on scale circulus spacing) raising the prospect that they could be permanently left behind by an important prey resource. The emerging hypothesis is that bottom-up effects in the spring could set a growth trajectory for both juvenile herring and juvenile Chinook salmon that could contribute to winter starvation of the latter. *A compounding issue has been the increase in body condition of Young-of-Year (YOY)*

[3] Unlike Chinook and Coho, steelhead spend very little time in Puget Sound (they don't seem to be foraging). Further, steelhead die at high rates in Puget Sound, and their mortality is not size dependent. Therefore, prey availability is not considered as critical.

herring since the 2000s; likely resulting in only the mouth gape of the largest juvenile Chinook able to prey on YOY herring.

Migration routes and abundances have impacts on survival

Results from acoustic telemetry of steelhead and sockeye smolts in the Strait of Georgia highlight spatial trends of survival across the Salish Sea and show that migration route can be important in migratory success. Telemetry studies have shown strong route-specific survival related to migratory route out of the Strait of Georgia for both steelhead and sockeye.

Data collected on over 850 sockeye salmon (*Oncorhynchus nerka*) and steelhead (*Oncorhynchus mykiss*) smolts detected at an array in the Strait of Georgia in 2004–2008 and 2010–2013 were analyzed to characterize migration routes and link movements to subsequent survival at an array 250 km further along the marine migration pathway[xxxi]. Both species exhibited disproportionate use of the most eastern route in the Strait of Georgia (Malaspina Strait). While many smolts moved across the northern Strait of Georgia acoustic array with no indication of long-term milling or large-scale east-to-west movements, large proportions (20–40% of sockeye and 30–50% of steelhead) exhibited a different behavior, apparently moving in a westward or counterclockwise pattern. Variability in migratory behavior for both species was linked to subsequent survival through the Strait of Georgia. Survival for both species was influenced by initial east-to-west location, and sockeye were further influenced by migration timing and duration of time spent near the northern Strait of Georgia array. Westward movements result in a net transport of smolts from Malaspina Strait to the Strait of Georgia, particularly for steelhead.

Analyses of movements of Seymour steelhead in the Discovery Islands region in 2015 indicates that these smolts (larger than other salmon) predominantly migrate through Discovery Passage, and this route was also associated with approximately twice the survival to the Johnstone Strait as compared to passages to the east (i.e. Sutil channel) [xxxii]. Similarly, survival of Chilko age-1 sockeye smolts through Discovery Passage was twice as high as through Sutil Channel. Although an interesting analysis accounting for distance or time travelled indicates that survival rates would be similar between the two channels if these variables were considered. Additionally, Burrard Inlet has been noted as a region of particularly poor survival for steelhead smolts, though what is causing this is still unclear. A relationship with seals has been suggested.

Further research could examine movements of smolts at fine scales and/or investigate additional factors such as distributions of food or predators to help determine why particular regions appear to be associated with high-risk. In 2017 and 2018, additional acoustic receivers were place on open-net pen salmon farms in the Discovery Island region to examine the response of wild smolts to these facilities[xxxiii]. These collaborations with industry, Hakai Foundation, UBC, and PSF provide essential information on the exposure of wild salmon smolts to pathogens shed from open-net pen farms. Juvenile sockeye migrated rapidly past the fish farms and were generally within detection range of farms for less than 20 minutes.

Significance of these studies also include the use of survival estimates for Chilko sockeye smolts (an indicator for all Fraser River sockeye) to improve forecasts of adult sockeye returns. If the significant portion of the marine survival occurs within the Salish Sea, then accounting for that loss in forecasts could significantly improve their accuracy.

Similar results were found for steelhead in Puget Sound, where segment specific mortality was apparent. Largely, mortality was higher in South and Central Puget Sound compared to other regions. Further, throughout Puget Sound, the greater the distance steelhead had to travel, the higher the mortality. Steelhead leaving Skagit River,

for example, experienced higher early marine survival when swimming through Deception Pass to the Strait of Juan de Fuca (39%) vs south around Whidbey Island(23%).[xxxiv]

Harbor seals are eating more salmon and steelhead

Moving up the food web, predation on Chinook, Coho, and steelhead may have significant survival consequences. Several studies are investigating the impacts of harbor seals. Harbor seal populations increased exponentially in both the Strait of Georgia and Puget Sound since the 1980's[xxxv], the same period over which Chinook, Coho, and steelhead marine survival declined. Research by UBC and DFO in the Strait of Georgia suggests harbor seals target Chinook, Coho, and sockeye salmon in the spring[xxxvi] and that ~40-47% of the out-migrating juvenile Chinook and Coho, respectively, in the Strait of Georgia are consumed by seals[xxxvii]. The same scientist from UBC, now at NOAA, estimated 20% of Puget Sound Chinook and 40% of Puget Sound Coho are consumed by seals[xxxviii]. Based upon the Strait of Georgia data, peak mortality of Chinook occurs in July, and it is estimated that seals take 61-83K adults annually**.** For Coho, peak mortality occurs in April and May, and losses to seals have increased 5-fold since the 1970s.

Other SSMSP research suggests juvenile steelhead are also being consumed by harbor seals within Puget Sound waters.[xxxix,xl] Steelhead are a very small proportion of the harbor seal diet, making the relationship between seals and steelhead difficult to assess. [xli] Yet, with so many harbor seals and so few steelhead, the percent of juvenile steelhead consumed by harbor seals could still be great. Other potential predators of steelhead include harbor porpoises, Caspian terns, and cormorants.[xlii] Chinook that remain in Puget Sound may also eat juvenile Chinook at significant levels.

In 2017, the SSMSP expanded the range of estuary focused sample efforts to examine predation in non-estuary areas of the Strait of Georgia[xliii]. In keeping with Strait of Georgia harbor seal diet studies conducted in the 1980s (Olesiuk et al. 1993) and recent estuary focused studies conducted 2012-14 (Thomas et al. 2017), they found that:

- harbor seals consumed a wide range of prey both inside & outside estuaries;
- gadids (primarily hake) and forage fish (primarily herring) are the most commonly consumed prey at most times of the year;
- salmon consumption increased in the fall period (driven by adult salmon returns to river estuaries);
- Chinook, Coho and sockeye smolts were consumed more than other salmonids in the spring, whereas chum was consumed more than other species in the fall;
- Consumption of salmonids was less in non-estuary areas than in estuaries.
- There is significant year to year variability in consumption of salmonids.

Given the information above, next steps are to recalculate the model estimates by Ben Nelson and others to include the new seal diet data from non-estuary sites in the Strait of Georgia. It is suggested that we will see a reduction from the estimates of ~40-47% of the out-migrating juvenile Chinook and Coho, respectively, in the Strait of Georgia consumed by seals. Further, work by Western Washington University suggests that males may have a higher tendency to consume juvenile salmon compared to females based upon overall differences in diet[xliv]

Scientists from WDFW, NOAA, the Nisqually Indian Tribe, Western Washington University, LLTK, and USGS are working to better assess the impact of harbor seals on salmon and steelhead in Puget Sound. We are also investigating factors that may exacerbate predation with an eye towards reducing predation impacts. These factors include:

- A lack of "buffer" prey: when preferred prey—bait fish such as herring, pacific sand lance and anchovies—are not available, seals may switch to salmon and steelhead.
- High concentrations of the *Nanophyetus salmincola* parasite may reduce the swimming performance of steelhead and increase their susceptibility to predation.
- Hatchery releases may impact predator behavior: large pulses of fish may attract predators or conversely buffer predation.
- The increase in ambient artificial light, combined with a reduction in turbidity throughout Puget Sound may improve the effectiveness of visual predators like seals.

The Salish Sea Marine Survival Project has also inspired a focused assessment to investigate the causes of high predation-based mortality of steelhead at the Hood Canal floating bridge.[xlv]

A major focus area for analysis currently is to incorporate the non-estuary dietary samples into the UBC feeding models and estimates of Chinook and Coho mortality rates. Since the majority of harbor seals are not resident in estuaries and salmonids are only seasonally available, we anticipate a reduction in the mortality rates estimated to-date; but the critical issue will be by how much?

Disease compounds the issues: The Strategic Salmon Health Initiative

The Strategic Salmon Health Initiative specifically addressed the hypothesis that infectious disease is impacting early marine survival of salmon in the Salish Sea. The project also addresses the potential that salmon aquaculture interactions may contribute to risk of disease in Pacific salmon smolts[xlvi].

The project has identified a number of infectious agents that are showing pathogenic potential in the Salish sea environment. In this past year, they identified eight novel salmon viruses from aquaculture and wild individuals showing molecular signs of disease, some also with unexplained pathological lesions. More information on where these viruses may have originated, whether they are detected in farmed and wild salmon, and their potential to associated with pathology in both is being pursued.

After the discovery of HSMI on a salmon farm in BC, they began conducting further analysis on Pacific salmon to determine if the PRV virus is associated with, and ultimately causative of HMSI disease in Pacific salmon. *Preliminary analysis of audit data suggests association between PRV and jaundice/anemia in Chinook salmon, matching findings in Norway for rainbow trout, and in Japan and Chile for Coho salmon.*

To date, their analyses have shown that bacterial agents (and diseases) are more commonly detected on farms than in migratory salmon, while fungal and protozoan parasites are more common in migratory salmon. Interestingly, only two "known" viruses have been detected in both farmed and wild fish (ENV and PRV). While still early in analyses, they have already determined that three of the novel viruses detected on farms are also detected in migratory salmon, most notably Chinook salmon. More work is required to assess whether there may be transmission potential from farmed to local wild salmon populations on the west coast, which is pertinent as industry expansion is anticipated along the BC coast.

They have also noted differences in disease profiles between hatchery and wild fish. Hatchery and wild Chinook salmon from the Cowichan carry divergent agent profiles in freshwater, with a generally high agent diversity in

wild fish owing to parasites with alternate invertebrate hosts. When the two converge in the early marine environment, they agent profiles are similar, but as hatchery fish move quickly from nearshore to inner bay environments, they hypothesize that they are exposed to and infected by a larger diversity of infective agents soon after entering the marine environment and could therefore be more impacted than wild salmon (Thakur et al. 2018).

Other key findings include the following:

- *Cryptobia salmonistica* was associated with higher rates of premature mortality of Fraser River Chinook salmon in both tracking and holding studies (Bass et al. 2018)
- In simultaneous tracking and holding studies on returning adult Chinook salmon, gill netting injury enhanced infective burdens. Infective burdens were associated with early mortality of held fish and faster migration, but reduced longevity, of tracked fish during river migration. Immune and blood properties were also correlated with infection and survival (Teffer et al. 2018)
- Juvenile sockeye salmon sampled in 2013, a year with very poor marine survival, had significantly higher infective burdens than in 2012, a year with average marine survival. These differences were present before fish left freshwater, and were attenuated during the first few weeks of marine residence but dissipated by the time fish reached Johnstone Strait. High levels of erythrocytic necrosis virus detected during early marine residence of sockeye salmon in 2013 (70%) relative to 2012 (11%), with subsequent drop in prevalence by Johnstone Strait only observed in 2013 (to 11%) provided the most explanatory power between years.
- Archived livers from adult sockeye salmon sampled in freshwater systems throughout BC were analysed for infectious agent profiles that would predate the expansion of the Atlantic salmon Aquaculture industry in the early 1990s. 23 agents were detected in the 30-35 year old samples, including many only recently identified in BC salmon, suggesting that most agents detected today were present before the industry expanded. A few agents that are detected in present day samples were not detected in samples from 1985-1992, including PRV (Thakur et al. In Revision).
- Sockeye smolt tracking studies have identified linkage between IHNV and migratory survival in the river, but it appears that predators, specifically Bull Trout, largely consume infected fish before they reach the Salish Sea (Furey and Hinch, 2017). Hence, their research is also demonstrating linkages between infection status and risk of predation, and the potential role that predators may play in removing infected individuals and thereby increasing the general health of the populations. Given the strong evidence that seals are consuming large numbers of smolts, one has to question whether infection status could enhance their risk of predation.

An overarching question with the SSMSP syntheses will be the interaction of factors in better understanding cumulative impacts of stressors. Stressors such as harmful algal blooms and low dissolved oxygen may act synergistically with disease development to ultimately cause mortality. For example, research on adult salmon has also demonstrated cumulative impacts of catch-release fisheries and disease development on survival (increasing pre-spawning mortality in sockeye and Chinook salmon).

Novel approaches to improve research and management

It is not only research results that steer a course toward salmon and ecosystem recovery. The cutting-edge tools and collaborative programs developed via the Salish Sea Marine Survival Project are critical to modernizing the way we manage our salmon and our overall ecosystem: from a historically segmented style to a comprehensive, holistic approach.

- Two complementary "end-to-end" ecosystem models, integrating physical and chemical water properties, food web structure, and human impacts are being developed by both UBC for the Strait of Georgia and NOAA and collaborators for Puget Sound. These models will be used to assess how changes in environmental productivity, food web structure and human impacts (notably through fishing) has changed in the Salish Sea over recent decades. These models will be used to assess factors impacting salmon survival, and are predicted to become fundamental decision support tools for Salish Sea ecosystem recovery.

- A collaborative monitoring program was created in 2014 to measure the abundance and composition of zooplankton throughout the Salish Sea, and similar approaches have been utilized in both the Strait of Georgia and Puget Sound. Zooplankton tell us how changes to the physical environment translate up the food web to salmon growth and survival. The zooplankton program may also contribute to our understanding of forage fish, crab, and other species dynamics; the transfer of contaminants through the food web; and much more. These resulting data inform harvest setting processes and can be used to optimize recovery strategies. In the US, UW is the principal investigator and WDFW the coordinator, with eleven other tribal, state, federal, county, and nonprofit entities providing sampling support. In Canada, DFO is the principal investigator.

- A suite of ecosystem indicators is being established at NOAA Northwest Fisheries Science Center (with significant support from project collaborators) that will better explain long-term associations between the Puget Sound ecosystem and salmon survival. These indicators will be used to improve salmon adult return forecasting. Refined Puget Sound indicators can then be used to accelerate the process of identifying indicators for Strait of Georgia stocks.

- Acoustic telemetry arrays have been deployed throughout the Salish Sea, with efforts in the Strait of Georgia led by OTN, Kintama and UBC, while those in Puget Sound are led by NOAA. These arrays listen for tagged juvenile salmon and steelhead, providing estimates of survival over time, and information on migration paths and rates.

- The development of PIT tag detectors affixed to seals provide the first ever direct estimation of predation rate of seals on juvenile salmon in the near-shore environment. Ultimately, our seal diet study and feeding studies provide estimates of the mortality on juvenile Chinook and Coho salmon in the Strait of Georgia, and then subsequently in Puget Sound.

- Satellite data on both sides of the border are being used to model the timing and magnitude of phytoplankton blooms and how bloom productivity impacts Salish Sea food webs; and have been extended to studies of eel grass and kelp changes in the Strait and to monitor their restoration.

- New genetic tools have been developed to detect disease earlier and more broadly because the tools aren't dependent upon overt signs of disease. As described earlier, a new eDNA platform has also been developed by USGS to cost-effectively detect the parasite *Nanophyetus salmincola*.

- Micro-trolling, a non-lethal, low-cost method of capturing juvenile salmon, was invented in the Strait of Georgia as part of the SSMSP and is now being employed in Puget Sound by USGS[xlvii]. Coupled with the application of PIT tags to juvenile fish, we have provided the first direct estimates of marine survival during the early marine rearing periods (2-4 months).

What's next for the Salish Sea Marine Survival Project, 2019/20?

Our goal is to synthesize results across the Salish Sea, provide recommendations to address the causes of poor marine survival, and institute ecosystem assessment processes by the end of 2020.

The U.S.-Canada Synthesis Committee will guide the process of synthesizing project results. Key synthesis products and management "white papers" will be developed by early 2020. Canadian and US workgroups will also continue to meet regularly to assimilate results and work on integrated journal publications.

PSF has hired a statistician on contract and a Geographic Information System (GIS) technician to assist with the analysis of the citizen science, harmful algae program data, and provide broad support for data assimilation and spatial analysis. PSF is currently holding a series of community meetings to report out on project findings, and LLTK continues to identify and act upon strategic opportunities to present to influencers. SSMSP participants continue to report out on results and findings at a large number of conferences and workshops, including the Salmon Ocean Ecology Conference, the State of the Pacific Ocean Meeting, the Salish Sea Ecosystem Conference, the Salmon Recovery Conference, etc. The SSMSP started from a series of public engagement evenings in 6 communities around the Strait of Georgia; and we promised to return with our results.

Drs. Riddell and Pearsall have developed a series of recommendations for the PSF Board of Directors in the form of a PSF SSMSP Legacy Program. This program is currently under further refinement and development. Some of the suggested recommendations are provided in Appendix 3. In the US, Michael Schmidt and Jacques White have worked with partners to develop next steps toward testing solutions. Much of this as come through the LLTK's participation on the Governor's Southern Resident Orca Task force, where the SSMSP has influenced over 20% of the recommendations from that group. Several million dollars of requests are embedded in the 2019-21 Governor's budget, affiliated with these recommendations.

Management Actions, Current and for Future Discussion

As research findings come in, some management actions are already resulting from the project, while other possible actions are under discussion and development. Highlights include:

US

1. LLTK participated on the Puget Sound Steelhead Recovery Team, and the marine survival findings had significant influence on the recovery strategies in the NOAA Fisheries Puget Sound Steelhead Recovery Plan. The recovery plan was submitted to the federal register in late 2018.
2. LLTK is also a member of the Governor's Southern Resident Orca Task Force and its prey workgroup. Here, the findings of the marine survival project have influenced over 20% of the recommendations for how to proceed[4], including novel hatchery management approaches, a focus on estuary habitat restoration, an ecosystem approach to predation management, forage fish recovery, zooplankton monitoring and revised NPDES permitting for wastewater treatment to include flame retardants.
3. LLTK participated in the National Fish and Wildlife Foundation planning for the Southern Resident Killer Whale program. Here too, the marine survival findings have affected their priorities in their request for proposals to increase the amount of Chinook salmon available to whales. At a local level, LLTK has influenced the San Juan Island Chinook recovery efforts, providing increased focus on herring and pacific sand lance recovery.
4. Work by LLTK and PSF has reached across the globe and influenced collective efforts to address Atlantic salmon survival issues via the Northern Hemisphere-wide initiative, International Year of the Salmon.

[4] Southern Resident Orca Task Force: Report and Recommendations (November 2018) https://www.governor.wa.gov/sites/default/files/OrcaTaskForce_reportandrecommendations_11.16.18.pdf

5. On the ground, experimental approaches are beginning to be tested at hatcheries to improve the marine survival of the Chinook they release and potentially reduce impacts to wild fish.
6. A state appropriations request has been made to filter the *nanophyetus* parasite from water at Soos Creek hatchery, a move that should cut the life-cycle of the parasite and reduce its intensity in the watershed.
7. LLTK is working with WDFW, the Tulalip Tribes and the Nisqually Indian Tribe to address high loads of flame retardants entering juvenile Snohomish Chinook and Nisqually steelhead.
8. LLTK is working with WDFW, NOAA and others to advance our understanding of pinniped impacts and broadly consider solutions to test from an ecosystem perspective given several factors may ameliorate or exacerbate pinniped predation.
9. LLTK will be convening a group to translate the results of the ecosystem indicators studies into tools for adult return forecasting.
10. Zooplankton, forage fish and estuaries are all receiving more attention from a salmon, orca and ecosystem recovery perspective, thanks in part to the SSMSP.

Canada

1. The Pacific Salmon Foundation has reviewed accomplishments under the Salish Sea Marine Survival Project and determined that the Foundation will establish as SSMSP Legacy program (the scope and investment has yet to be determined) to continue this research, maintain public focus on this environment, and sustain the international collaboration that has developed.
2. The Strategic Salmon Health Initiative (part of the SSMSP) underwent an independent science review (October 22-23, 2018) as required by Genome BC (a cofounder). This review is available if requested but was highly complimentary of the research to-date.
3. PSF has acted as the primary fundraiser in support of the Gulf of Alaskan salmon research expedition in Feb/March 2018 that is part of International Year of the Salmon. We have successfully raised sufficient funds ($1.1 M Cdn) and the Pacific Salmon Endowment Fund Society is now the primary sponsor of this research. We have also made application to the Northern Endowment Fund for partial support. The vessel left Vladivostok, Russia on January 10, 2018. The success and profile of the SSMSP by PSF was clearly a major reason for support received from donors.
4. PSF has initiated a series of public dialogues to report on the projects and outcomes of the SSMSP. Two dialogues were completed in November 2018, two more will occur in January 2019, and several more will be arranged within spring 2019.
5. PSF has organized a submission to DFO's Coastal Restoration Fund (Dec. 2018) to undertake an assessment of wetlands and marshes in the lower Fraser River and Fraser estuary, develop and inventory of recent assessments and GIS systems, and initiate development of a wetlands and estuary management and restoration plan. This proposal involves a collaboration of First Nations and several NGO's with come interest in Chinook salmon restoration and their critical habitats in the lower Fraser River region. This work was initiated within the SSMSP.
6. PSF is a partner in a successful research submission to the National Science and Engineering Council of Canada and DFO. This research will assess Chinook availability and feeding efficiency of Southern Resident Orcas in southern BC. The proposal was submitted through UBC (Dr. A. Trites) and buildings of our experience with acoustic tagging and receivers used within the SSMSP. The SSMSP arrays will be repositioned in spring 2019 and PSF will support the first application of 'predation tags' (new acoustics tags) in Canada.

7. Dr. Riddell has also been requested to participate in a DFO Technical Advisory committee on Chinook salmon availability and recovery of the SRKW. (SRKW Technical Working Group on Prey Availability and Accessibility).
8. Dr.'s Riddell and Miller-Saunders (Strategic Salmon Health Initiative, part of the SSMSP) will be involved in the Canadian Science Advisory Secretariat's review of Piscine-Reovirus and the risk of transmission to sockeye salmon. The review will be undertaken in late January, 2019.

Future actions may include the following:

- Discussion papers and meetings with the federal system on: potential for active management of harbor seals; review of habitat regulations for salmon habitats including log booms within estuaries, development of a hatchery science initiative including use of PIT tag technologies, delayed smolts releases, and application of DNA tools; establishment of SSMSP legacy programs (Citizen Science project, expanded zooplankton monitoring, review of forage fish assessments and mitigation, etc.), and further study of Fraser River sockeye salmon forecasting post-Salish Sea (acoustic tag arrays and estimation of sockeye abundances).
- PSF is working to begin consultations with forestry companies to discuss possible changes to log-boom placement and timing to allow for a reduction in seal "feeding platforms" during crucial salmon smolt outmigration and adult return periods. Similarly, the Puget Sound treaty tribes have recommended that Harbor seal predation and ways to mitigate the impact be assessed in their recent "bold actions" request to the Puget Sound Salmon Recovery Council.
- Discussion paper and meetings with Province of B.C. on: minimum waters flows in the Cowichan River during spring migration periods, investment in riparian management and restoration in local streams/rivers; review of PBDEs (fire retardant) use in BC and effects on Pacific salmon; and initiation of a BC Steelhead restoration program in southern B.C.
- Address federal and provincial systems with a proposal to establish a Salish Sea Institute to sustain efforts (both domestic and international) following from the SSMSP and learning from programs within each country, including support for the ecosystem modelling projects in both countries to track environmental changes over time and assess ecological impacts. In the United States, a Salish Sea Institute was recently established at Western Washington University to support increased, long-term collaboration between U.S. and Canada on shared issues and science needs.
- Very few smolts were observed on the southern shoreline of Cowichan Bay during the out-migration. As with many coastal towns, the foreshore has been completely altered; in this case, the village of Cowichan Bay was built on pilings, with docks extending out into the bay and numerous anchorages beyond. Sound and light pollution, sewage and grey water, cleaning agents, and garbage from boats further foul the water and affect marine organisms. Regrettably, this situation is common throughout the Salish Sea and destroys habitats of juvenile salmon. While these affects have been cumulative over time, they are now very substantial and likely merit a program to reduce impacts and restore habitats. Our information is providing increased focus on nearshore habitat restoration in the Strait of Georgia, as well as forage fish recovery in places like the San Juan Islands, where juvenile Chinook are consuming herring and Pacific sand lance at high rates. A potential legacy of the SSMSP could be a new initiative working with land owners and municipalities to strategically focus Community Salmon Programs to restore near-shore habitats surrounding the Salish Sea. This program could be built from ground up starting locally with community volunteers and building to federal programs to remove derelict vessels as recently announced under the federal OPP funding … the time and interest could be ideally situated to recommend this.

Appendix 1: Project Management in 2018

Seattle-based Long Live the Kings (LLTK) and Vancouver-based Pacific Salmon Foundation (PSF) are managing this international research effort: developing the project as a whole, coordinating research activities and administering funding[5], ensuring appropriate alignment throughout the Salish Sea, establishing and maintaining project outreach and communications, and working to create the necessary funding mechanisms for the length of the research effort.

The following is a compilation of the key activities, illustrated in 3 categories: project staffing, project development and coordination, and communications.

A1. Project Staffing

2018 project staff are listed below. Staff were directly supported via this grant (as indicated in the budget section), or peripherally via administrative overhead and match funding. This includes project management, communications, and research activity support where needed.

Canada

For project development and management, PSF staff working on this project include:

- Dr. Isobel Pearsall, PSF, Project coordinator
- Dr. Brian Riddell, CEO PSF, Science Lead.
- Tim Sucic, VP, Operations, PSF, for accounting, finance, audit, HR, reporting, corporate filing, governance.
- Michael Meneer, Vice President for Development, Marketing, Communications, PSF, for project fundraising and communications.
- Elayne Sun, Communications Coordinator, PSF, for communications and media.

To fill critical gaps in field support, PSF:

- supports two technicians: Colin Novak and Olivia McMillan, and a phytoplankton taxonomist, Svetlana Esenkulova. A short-term contract was provided to a VIU student who assisted with preparation of supplies for the citizen science field program.

For continued development of the Strait of Georgia Data Centre, PSF:

- supports a geospatial analyst, Terry Curran and one research assistants: Ianna Folkes
- supports a GIS analyst (part time contract): Ben Skinner

For analysis of the Citizen Science datasets, PSF:

- Supported a co-op student, Rhys Chappell at UBC.

United States

LLTK project development, management and field support staffing:

- Michael Schmidt, LLTK Program Director, continues as the Puget Sound coordinator.
- Iris Kemp, Research Ecologist. Supports co-ordination and helps fill critical research gaps.
- Jacques White, LLTK Executive Director, high-level coordination with U.S. project partners, and strategic positioning of the project within partner priorities.

[5] In Puget Sound, portions of some of the research activities are funded directly via other sources not administered by LLTK

- Lucas Hall, LLTK Project Manager and communications specialist, focused on reaching the general public about the project work, primarily through the interactive campaign LLTK developed called Survive the Sound (www.survivethesound.org).
- Mike Ewanciw and Allegra Carscallen, LLTK Finance Director and LLTK Finance Coordinator, manages project finances including direct expenses and sub-awards.
- Kathryn Sobocinski. LLTK hired a lead investigator on ecosystem indicators (under the guidance of a managing PI from NOAA). This position is stationed at NOAA Fisheries, but paid for directly by LLTK as term staff.
- Hem Morzaria. LLTK hired a lead investigator to develop a Puget Sound Atlantis model under the guidance of a managing PI from NOAA). This position is stationed at NOAA Fisheries, but paid for directly by LLTK as term staff. This position is funded by the Boeing Company. Raphael Girardin, who initially held this position, returned to France in fall 2017. Hem replaced him.
- Jennifer Eccles. LLTK hired an investigator to help assess geoduck growth increments as a metric for evaluating long-term productivity trends for Puget Sound. This position is funded by Vulcan Inc.

A2. Project Development and Coordination

The following are the project development and coordination activities that occurred in 2018. They include both joint and independent work.

United States (LLTK) and Canada (PSF)

- Maintained an up-to-date comprehensive website describing the project, background, purpose and details of research activities (www.marinesurvivalproject.com). This site will continue to be the primary mechanism for encapsulating critical details about the project and communicating with the interested public.
- Held frequent meetings between the US and Canadian project coordinators, Michael Schmidt and Isobel Pearsall.
- Held management meetings between key LLTK and PSF staff.
- Continued to maintain the project pages in the Basecamp web-based project management utility for key research activities. This site serves as an active project coordination utility. The utility allows for sharing calendars, resources, raw data, key findings and supports general communications among researchers.
- Completed the report from the 2017 US-Canada Retreat describing research status, findings, and project needs (available on the resources page of marinesurvivalproject.com.)
- Implemented the Transboundary Synthesis Committee and synthesis process with lead science reps from the US and Canada.

Canada - PSF

- Focus for Canadian SSMSP Activities for 2018 was on completion of field projects, sample processing and analyses, and on synthesis activities.
- The majority of field projects are now complete, and several final reports have been submitted. Other labs continue the process of sample analysis and data analysis (e.g. the Strait of Georgia Zooplankton and Juvenile Salmon Programs).
- Ongoing Canadian projects for 2018 included the following: PSF Citizen Science program, Dr. Maycira Costa's satellite imagery programs, Karyn Suchy's Synchronicity between phytoplankton and zooplankton

phenology program, EPIC 4, the Strategic Salmon Health Initiative (SSHI), PSF's Harmful Algal Bloom monitoring, Brian Hunt's project to examine the trophic structure of the Salish Sea plankton food web, the UBC Strait of Georgia Modeling program, the UBC Salish Sea Model, UBC Predation studies (seals and herons), and DFO-led Wild-Hatchery Interaction Studies (delayed release trials).

- For these projects, several graduate students are funded including David Costalago at UBC (salmon stable isotopes with Brian Hunt), Vijay Kumar at UBC (hydrographic Strait of Georgia modeling with Villy Christensen), Zachary Sherker at UBC (heron predation on salmon with Andrew Trites), Elise Olson at UBC (Salish Sea model with Susan Allen), Will Duguid at UVic (juvenile salmon studies with Francis Juanes), Karyn Suchy at UVic (bottom up processes with Maycira Costa), and Sarah Schroeder at Uvic (kelp studies with Maycira Costa). There are also a number of ongoing students working with DR. Kristi Miller on SSHI as well as several nearing completion in Scott Hinch's Lab at UBC.
- Modeling initiatives were ongoing in 2018, and Villy Christensen is working with his counterparts, Carl Walters and post docs to continue development of a full Strait of Georgia model. Progress continues at UBC and the food web modelling component will begin this fall.
- PSF have established focused workgroups for the following: Biological Oceanography & Environmental Parameters: zooplankton, ichthyoplankton & forage fish; Juvenile Salmon: predation, parasitism & pathogens; Nearshore Habitat and marine plants; and Analysis & Modeling. Workgroups continue to meet over 2018 to discuss progress with respect to the key SSMSP hypotheses: a Juvenile Salmon (Coho and Chinook focus) workgroup meeting was held at PBS in May 2018.
- PSF increased GIS capacity for analysis of our citizen science data, development of a data subsetting application for the Strait of Georgia (to allow downloads of subsets of data), as well as the creation of story boards to showcase the results of our projects. Here is an example for the citizen science project: (https://salmonwatersheds.maps.arcgis.com/apps/Cascade/index.html?appid=eeafc876ed814c4f8497f0789bd822e0). Another storyboard was created to showcase the Eelgrass and Kelp research and restoration projects done as part of SSMSP.
- Work continues with the Strait of Georgia Data Centre (SGDC) to collate datasets gathered under SSMSP, and time series for use by the modelers. Leaders of CRF funded projects with Cowichan Tribes, Seachange and Project Watershed are also in discussion with SGDC to house their data.
- SSMSP completed a final report for 2015-2017 Citizen Science Data program, and data are being made available to many SSMSP researchers.

United States - LLTK

- Facilitated Coordinating Committee, Technical Team, Workgroup and Task Team meetings.
- Executed sub-awards to support the research.
- Supported the execution of ongoing work.
- Began to develop tools for supporting next steps in research development.
- Participated as members of the Washington State Governor's Orca Recovery Task Force. Used findings of the marine survival project to influence over 20% of the Task Force recommendations, leading to substantial funding for SSMSP work in the Governor's budget.

A3. Communications- United States and Canada

The following are the communications activities that have been completed over the reporting period. They are reported jointly given the significant overlap and coordination.

- PSF Editorial:
    - 5 articles and a feature on SSMSP legacy projects in Salmon Steward winter edition on SSMSP initiatives
    - Dec.20, article in Business in Vancouver "Research finds bull trout, seals major salmon predators"
    - Dec. 18, article in the Province "UBC salmon tracking studies find mortality hotspots, migration bottlenecks"
    - Dec. 18, article in Vancouver Sun "UBC salmon tracking studies find mortality hotspots, migration bottlenecks"
      Dec. 10, article in the Province "Hungry great blue herons in Stanley Park eating young salmon"
    - Dec. 10, article in the Vancouver Sun "Hungry great blue herons in Stanley Park eating young salmon"
    - Nov.30, article in Coast Reporter "Marine survival project findings set for release"
    - Oct.26, article in Vancouver Sun "Conversations That Matter: Southern resident orcas are picky eaters"
    - Sep. 6, advertorial funded by YVR on support of Citizen Science Research
    - PSF provided an overview of SSMSP to the Canadian National Committee for SCOR (the Scientific Committee for Oceanic Research) newsletter.
    - News release "PRV VIRUS MAY CAUSE DISEASE IN CHINOOK SALMON" on finding from SSHI which resulted in coverage from Vancouver Sun, The Tyee, CTV News, Star Metro Vancouver, Hakai Magazine, Times Colonist and various blog sites
- LLTK editorial

In July, reporter Christopher Dunagan completed a comprehensive four-part series covering the work of the Salish Sea Marine Survival Project (https://www.eopugetsound.org/magazine/ssec2018/marine-survival). Other media results include the following:

11/1/2018	Harbors Magazine	Fighting For Survival in the Salish Sea	
11/14/2018	Global News Wire	Southern Resident Killer Whales to Benefit from More Than $700,000 in New Grants	http://www.globenewswire.com/news-release/2018/11/14/1651643/0/en/Southern-Resident-Killer-Whales-to-Benefit-from-More-Than-700-000-in-New-Grants.html
11/16/2018	King 5	Orca task force finalizes proposals to save Southern Resident killer whales	https://www.king5.com/article/tech/science/environment/orca-task-force-finalizes-proposals-to-save-southern-resident-killer-whales/281-615338923
12/14/2018	The Guardian	'Extinction is not an option': the $1bn push to save orcas in Washington	https://www.theguardian.com/us-news/2018/dec/14/orcas-washington-state-killer-whales
8/8/2018	Kiro 7	How to save the orcas? Task force meets Tuesday	https://www.kiro7.com/news/local/how-to-save-the-orcas-task-force-meets-tuesday/807674820
8/14/2018	Kitsap Sun	Task force looks for solutions as Southern Resident population declines	https://www.kitsapsun.com/story/news/local/2018/08/14/orca-task-force-southern-resident-population-decline/990795002/
9/4/2018	San Jan Journal	What will it take to save the Chinook?	http://www.sanjuanjournal.com/news/what-will-it-take-to-save-the-Chinook/
9/5/2018	Go Skagit	Orca task force seeks solutions, but some fear it's already too late	https://www.goskagit.com/anacortes/news/orca-task-force-seeks-solutions-but-some-fear-it-s/article_e86bc9e2-b09b-11e8-b487-93aee0ea4e89.html

9/5/2018	Bing.com	Salmon Migration in Full Swing	bing.com

- PSF Presentations:
    - September 27, Will Duguid presented findings at VIU Campus "Growing Pains: Trials of Chinook Salmon in their first year in the Salish Sea"
    - Fall PSF Major Donors Circle included a discussion with Andrew Trites and Brian Riddell on Orcas and Chinook which included research from SSMSP
    - Presentations from Cory Matheson at fundraising fishing derbies that benefit PSF throughout the summer
    - PSF presented the project at their various fundraising dinners throughout B.C., and at various boat and fishing tradeshows across BC where PSF attended.
    - Presentations from Brian Riddell at Three community dialogues: Victoria (March), Powell River and Pender Harbour (November); Five PSF community dinners (SSMSP only a portion of these brief presentations); Three lectures to service clubs (SSMSP major portion of these talks); Comox Probus Club (April), Pennask Lake Club (March), and Sport Fishing Institute's Policy Forum (November); Two presentations specifically concerning the Strategic Salmon Health Initiative (one major program within the SSMSP), one to Province of BC and one to the Kwakiutl First Nation.
    - Presentations by Isobel Pearsall at the Coho Festival West Van; the Island Marine Aquatic Working Group, Port Alberni; the 40th Annual WEM meeting, Vancouver; BC Salmon Farmers Association, Courtenay; etc.
    - Presentations by Terry Curran and Isobel Pearsall on the Strait of Georgia Data Centre at the Institute of Ocean Sciences, Sidney and at the Institute for the Oceans and Fisheries, UBC.
- PSF Social Media:
    - PSF provided blog coverage of various SSMP projects on the psf.ca blog with enhanced distribution via Twitter, Instagram and Facebook. This included information on harmful algal blooms and marine debris clean up.
    - PSF released video of discussion between Andrew Trites and Brian Riddell with over 18,000 views to date.
    - PSF and YVR co-released video on estuary restoration work through SSMSP in conjunction with year-end appeal fundraising efforts.
    - Ongoing sharing of news media and PSF editorial from SSMSP via PSF twitter, Instagram, LinkedIn and Facebook channels.
    - A Facebook page for the Harmful Algal Program: "Phytoplankton - Citizen Science Program" is regularly updated
- LLTK made numerous presentations to partners, stakeholders and the general public in 2018.
- We are now at a total of 26 accepted (25 published) manuscripts from the SSMSP. Here's the link to our publication tracker. There are also a number of technical reports and affiliated publications associated with SSMSP.
- SSMSP was allotted 4 full sessions in the Salish Sea Ecosystem conference; sessions were well attended and allowed for collaboration and networking by the SSMSP attendees. PSF and LLTK chaired the 4 sessions, and Isobel Pearsall served as part of the SSEC program committee.

- PSF and LLTK provided an overview of SSMSP results to the PSC Southern Panel (February 2018) and to the PSC Southern Fund (April 2018). PSF also provided overviews of SSMSP at the 40th Annual Watershed Enhancement Managers' meeting, the BC Salmon Farmers Research Priorities Workshop and the Annual meeting of the Avid Anglers.
- SSMSP results were also highlighted at the 2018 State of the Pacific Ocean meeting in Nanaimo, as well as the Salmon Ocean Ecology Conference in Newport Oregon.
- PSF and LLTK continue to moderate the various Basecamp sites, including a communications resources site for project participants to help them communicate about the project (includes stock presentations, photos, video, language/messaging resources, etc.).
- PSF and LLTK updated the project website, www.marinesurvivalproject.com
- LLTK again held their Survive the Sound interactive campaign: a new outreach and fundraising campaign grounded in an interactive web app where people can sponsor a juvenile steelhead and see if it survives its trek through Puget Sound (based upon acoustic telemetry data). This year, we had 2,000 individual sponsors, over 300 teams, and well over 500 classrooms engaged. Further, largely driven by our new partnership with Q13 news, but also via social media, newspaper and other providers, we reached over 5 million people through our stories about Survive the Sound, the marine survival project, and affiliated research.
- LLTK and PSF updated fundraising media, including flyers, appeals, and 2-page project descriptions.

Appendix 2: Status of SSMP Projects- US and Canadian

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
DFO (IOS)	Svein Vagle	Observation of temporal & spatial variability of water-column physical chemical & biological properties in Cowichan Bay	Oceanography	SOG	COMPLETE
Sea This Consulting	Stephanie King	High temporal resolution monitoring of surface chlorophyll in the Salish Sea	Oceanography	SOG	COMPLETE
Vancouver Island University	Helen Gurney-Smith	Coupling state-of-the-art chemical oceanography with biological relevance: examining phyto- & zooplankton populations in a dynamic coastal environment	Oceanography	SOG	COMPLETE
NOAA	Correigh Greene	Geoduck shells as a means to infer primary production patterns	Oceanography	PS	ONGOING
U of Strathclyde	Neil Banas	Assess links between physical forcing and copepod phenology	Oceanography	PS	ONGOING
UW	Parker MacCready	Explore relationships between physical forcing (wind, stratification, rivers) and phytoplankton bloom timing in Puget Sound	Oceanography	PS	ONGOING first part complete. Now, doing an update on long-term trends.
Multiple	Isobel Pearsall/ Colin Novak	Citizen Science Boats	Oceanography	SOG	ONGOING
ONC Innovation Centre	Ryan Flagg	Citizen Fishers (application); Initial Instrument Set-up & Data User Services, & Engineer Support	Oceanography	SOG	ONGOING
DFO (IOS)	Sophie Johanesson	Analysis of Sediment Trap Data from the Northern Strait of Georgia	Oceanography	SOG	Waiting for data from Chrys
University of Victoria	Maycira Costa	Spatial temporal analysis chlorophyll, turbidity & sea surface temperature of the Salish Sea: an integration of satellite imagery & data from vessels of opportunity	Oceanography	SOG	ONGOING

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
University of Victoria & DFO	Karyn Suchy (post doc), Ian Perry, Maycira Costa	Phytoplankton and zooplankton phenology in the Salish Sea by integrating satellite products with historical and present zooplankton data	Oceanography	SOG	ONGOING
SRSC/WDFW/DFO	Casey Ruff, Joe Anderson, Antiono Espenzo	Chinook marine survival trends	Juvenile Salmon	ALL	COMPLETE
WDFW/DFO	Mara Zimmerman, Jim Irvine, etc.	Coho marine survival trends	Juvenile Salmon	ALL	COMPLETE
NOAA	Barry Berejikian, Megan Moore	Steelhead reciprocal transplant experiment	Juvenile Salmon	PS	COMPLETE
NOAA	Megan Moore	Multi-population analysis of early marine survival of steelhead	Juvenile Salmon	PS	COMPLETE
NOAA/LLTK	Kathryn Sobocinski	Qualitative network analysis of factors affecting salmon growth and survival	Juvenile Salmon	PS	COMPLETE
Squaxin	Scott Steltzner	Assessing early marine mortality of Coho	Juvenile Salmon	PS	COMPLETE
WDFW	Neala Kendall	Steelhead marine survival trends	Juvenile Salmon	PS	COMPLETE
WDFW	Lance Campbell	Successful juvenile life history strategies in Chinook	Juvenile Salmon	PS	COMPLETE
WDFW	Lance Campbell	Age and growth of Chinook in Puget Sound and coastal watersheds	Juvenile Salmon	PS	COMPLETE
WDFW	Ken Warheit	GWAS to determine genetic associations with survival outcomes	Juvenile Salmon	PS	COMPLETE
Cowichan Tribes		Cowichan Chinook downstream survival	Juvenile Salmon	SOG	COMPLETE
J A Taylor & Associates		Cowichan Chinook downstream survival	Juvenile Salmon	SOG	COMPLETE
Key Mills Construction		Cowichan Chinook downstream survival	Juvenile Salmon	SOG	COMPLETE

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
Raincoast	Andy Rosenberg, Dave Scott, Misty McDuffee, Lia Califor	Characterizing juvenile salmon species abundance, growth and habitat use in the Fraser River estuary.	Juvenile Salmon	SOG	COMPLETE
NOAA	Josh Chamberlin	Growth and survival of resident Chinook	Juvenile Salmon	PS	ONGOING
NOAA	Megan Moore	Acoustic tagging and mobile tracking of steelhead	Juvenile Salmon	PS	ONGOING
Squaxin	Scott Steltzner	Barging juvenile Coho past mortality hotspots	Juvenile Salmon	PS	ONGOING
UW/USGS/NOAA	Dave Beauchamp, Josh Chamberlin	Size, growth, and size-selective mortality of subyearling Chinook	Juvenile Salmon	PS	ONGOING (PUBLICATIONS PENDING)
NOAA	Correigh Greene	Skagit Chinook life history modeling	Juvenile Salmon	PS	ONGOING?
BCCF	Kevin Pellet, Craig Wightman, James Craig	A PIT tag based method to investigate survival of Cowichan River Chinook throughout various stages in their first year of marine life	Juvenile Salmon	SOG	2020
University of British Columbia	Scott Hinch, Tony Farrell, Kristi Miller	Physiological & environmental factors affecting the migratory behaviour & survival of sockeye & steelhead salmon smolts	Juvenile Salmon	SOG	2017 data analysis ongoing
Kintama Research Services	Dave Welch, Erin Rechisky, UVic, DFO	Mortality, Movements, and Migration Timing of Age-0 Cowichan Chinook Salmon Tagged in the Southern Gulf Islands in Fall	Juvenile Salmon	SOG	2017 data analysis ongoing. Final report due Dec 2018
DFO	Marc Trudel, Chrys Neville, Kristi Miller	Understanding the factors limiting the recruitment of Pacific salmon in the Strait of Georgia – From patterns to processes	Juvenile Salmon	SOG	ONGOING
Kintama Research Services	Dave Welch, Erin Rechisky	Use of acoustic tagging methods to determine the behavior, migration routes, residency & survival of juvenile wild salmon migrating around salmon farms within the Discovery Island region	Juvenile Salmon	SOG	COMPLETE

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
University of Victoria	Francis Juanes, Will Duguid (PhD student)	Variation in juvenile Cowichan River Chinook salmon distribution, diet, & growth rate in relation to tidal mixing & water column stratification	Juvenile Salmon	SOG	ONGOING
NOAA/WDFW	Barry Berejikian, Steve Jeffries	Assess seal-steelhead interaction and dinner bell effect	Predation	PS	COMPLETE
WDFW	Scott Pearson	Determine potential juvenile steelhead predators	Predation	PS	COMPLETE
University of British Columbia	Hassen Allegue, Austen Thomas & Andrew Trites	Harbour Seal fine scale foraging behaviour during the out migration of salmon smolts from Big Q River	Predation	SOG	COMPLETE
University of British Columbia	Ben Nelson & Andrew Trites	Impacts of seals on salmon in Cowichan Bay during spring, summer & fall 2014	Predation	SOG	COMPLETE
WDFW/Smith-Root	Austen Thomas, Steve Jeffries, Scott Pearson, many others	Global compilation of harbor seal seal diet data from Salish Sea Marine Survival Project work: Puget Sound and Strait of Georgia (2012-2018)	Predation	ALL	ONGOING
LLTK	Ben Nelson	Estimating predation of Chinook and Coho by harbor seals	Predation	PS	ONGOING
NOAA/WDFW	Eric Ward, Barry Berejikian, Steve Jeffries, Austen Thomas, Scott Pearson	(Various activities via diet and telemetry) Estimating predation of steelhead by harbor seals	Predation	PS	ONGOING
USGS	Dave Beauchamp	Artificial light impacts and resident Chinook predation on juvenile Chinook	Predation	PS	ONGOING
UW	Gordon Holtgreive, Eric Ward	Assessing trophic changes in harbor seal diets over 100 years (affiliate project)	Predation	PS	ONGOING
UBC, DFO & BCCF	Andrew Trites et al.	Cowichan River Predation Study	Predation	SOG	ONGOING
University of British Columbia & DFO	Sheena Majewski, Andrew Trites	Juvenile salmon predation by harbour seals-study completion	Predation	SOG	ONGOING

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
Seachange	Nikki Wright	Eelgrass Restoration from 2013-2017	Nearshore Habitat	SOG	COMPLETE
Simon Fraser University, Comox Valley Project Watershed Society, Nile Creek Enhancement Society	Bill Heath, Sheryl Bisgrove, Braeden Schiltroth etc.	Restoration Research on Kelp Forest Habitats in the Salish Sea	Nearshore Habitat	SOG	COMPLETE
University of Victoria	Natasha Nahirnick & Maycira Costa	Spatial-temporal extent of eelgrass habitats & relationship with associated adjacency catchment area land use change: remote sensing approach using aerial phots & satellite imagery (1950-present)	Nearshore Habitat	SOG	COMPLETE
University of Victoria	Laura Kennedy	The effects of eelgrass density on prey availability for juvenile salmon	Nearshore Habitat	SOG	COMPLETE
University of Victoria	Josie Iacarella	Juvenile salmon association with eelgrass vs. non eelgrass habitat	Nearshore Habitat	SOG	COMPLETE
Nile Creek Enhancement Society & Cooper Beauchesne & Associates Ltd.	Andrew MacInnis, Diane Sampson	Eelgrass Mapping, Fish Monitoring, and Habitat Data Collection	Nearshore Habitat	SOG	COMPLETE- just waiting for data
Sea Watch Society	Ramona De Graaf	Beach Spawning Forage Fish of the Salish Sea	Nearshore Habitat	SOG	FINISHED but INCOMPLETE…
University of Victoria	Sarah Schroeder & Maycira Costa	Spatial temporal distribution of *Nereocystis luetkeana* (bull kelp) & use by juvenile salmonids in the Salish Sea	Nearshore Habitat	SOG	Almost COMPLETE
NOAA	Ben Nelson, Eric Ward	Changes to release timing of hatchery Chinook in Puget Sound and the Strait of Georgia (affiliate project)	Hatcheries	ALL	ONGOING
NOAA	Barry Berejikian, Megan Moore	Determine whether salmon hatchery releases / outmigration timing influence predator behavior on steelhead	Hatcheries	PS	ONGOING

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
WDFW/NOAA	Neala Kendall, Ben Nelson	Assessing density dependent effects of hatchery Chinook releases and competition with pink salmon (affiliate project)	Hatcheries	PS	ONGOING
SEP (DFO)	Dave Willis	Delayed hatchery release studies for Coho and Chinook	Hatcheries	SOG	ONGOING
Simon Fraser University	Willy Davidson	EPIC4 (Enhancing Production in Coho: Culture, Community, Catch) -Activity 3. To assess the ability of fish hatcheries to conserve Coho Salmon & enhance their numbers	Hatcheries	SOG	ONGOING
NOAA/LLTK	Kathryn Sobocinski	Ecosystem indicators for Coho and Chinook survival	Modeling & Analysis	PS	ONGOING
NOAA/LLTK	Hem Morzaria-Luna, Isaac Kaplan	Atlantis ecosystem modeling to assess multiple hypotheses	Modeling & Analysis	PS	ONGOING
UW	Julie Keister	Explore links between zooplankton community and salmon survival (JEMS)	Modeling & Analysis	PS	ONGOING
UW/NOAA	Jan Newton, Beth Curry, Julie Keister, Correigh Greene	Exploring bottom-up processes that affect juvenile salmon survival	Modeling & Analysis	PS	ONGOING
WDFW/NOAA/LLTK	Neala Kendall, Kathryn Sobocinski	Ecosystem indicators for steelhead survival	Modeling & Analysis	PS	ONGOING
UBC	Susan Allen & Elise Olson	Spatial and Temporal Variability of Primary and Secondary Production in the Salish Sea from a Coupled Model (SalishSeaCast with SMELT)	Modeling & Analysis	SOG	ONGOING
UBC	Villy Christensen	Environmental productivity of the Salish Sea: trends, impacts and projections	Modeling & Analysis	SOG	ONGOING
USGS	Paul Hershberger	Assess prevalence and intensity of *Nanophyetus* in Puget Sound steelhead	Disease, Contaminants, & Harmful Algae	PS	COMPLETE
USGS	Paul Hershberger	Develop qPCR tool to detect *Nanophyetus* in water samples	Disease, Contaminants,	PS	COMPLETE

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
			& Harmful Algae		
USGS	Paul Hershberger	Test treatments to eliminate *Nanophyetus* in hatcheries	Disease, Contaminants, & Harmful Algae	PS	COMPLETE
WDFW	Sandie O'Neill	Contaminant burdens in outmigrating juvenile Chinook from 4 populations	Disease, Contaminants, & Harmful Algae	PS	COMPLETE
WDFW	Sandie O'Neill	Contaminant burden in outmigrating juvenile steelhead	Disease, Contaminants, & Harmful Algae	PS	COMPLETE
USGS	Paul Hershberger	Determine whether *Nanophyetus* has sublethal or lethal effects during steelhead outmigration	Disease, Contaminants, & Harmful Algae	PS	ONGOING
USGS	Paul Hershberger	Profile Nanophyetus in Nisqually watershed to isolate hotspots	Disease, Contaminants, & Harmful Algae	PS	ONGOING
WDFW	Sandie O'Neill	Expanding contaminant body burden study to 17 populations	Disease, Contaminants, & Harmful Algae	PS	ONGOING
WDFW	Sandie O'Neill	Isolate contaminant sources in Snohomish River	Disease, Contaminants, & Harmful Algae	PS	ONGOING
WDFW	Sandie O'Neill	Isolate contaminant sources in Nisqually River	Disease, Contaminants, & Harmful Algae	PS	ONGOING
PSF	Svetlana Esenkulova	Salish Sea Harmful Algae Bloom Monitoring	Disease, Contaminants,	SOG	ONGOING (as PSF funded program)

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
			& Harmful Algae		
DFO, Genome BC, UVic et al.	Kristi Miller	Strategic Salmon Health Initiative	Disease, Contaminants, & Harmful Algae	SOG	ONGOING
UW/LLTK	Iris Kemp, Julie Keister	Assess historical qualitative zooplankton data	Zooplankton, Ichthyoplankton, & Forage Fish	PS	COMPLETE
DFO	Jennifer Boldt	Juvenile Herring Survey	Zooplankton, Ichthyoplankton, & Forage Fish	SOG	COMPLETE
DFO (IOS) & UVic	Stephane Gauthier	Forage Fish	Zooplankton, Ichthyoplankton, & Forage Fish	SOG	COMPLETE
UVic	J. Dower & Emma Pascoe, UVic	Spatiotemporal variability in lipid profiles of young-of-the-year herring from the Strait of Georgia	Zooplankton, Ichthyoplankton, & Forage Fish	SOG	COMPLETE
USGS	Dave Beauchamp	Energy content of specific salmon prey	Zooplankton, Ichthyoplankton, & Forage Fish	PS	ONGOING
UW	Julie Keister	Zooplankton prey quality	Zooplankton, Ichthyoplankton, & Forage Fish	PS	ONGOING
UW	Josh Chamberlin, Lorenz Hauser	Population-specific herring consumption by juvenile Chinook	Zooplankton, Ichthyoplankton, & Forage Fish	PS	ONGOING
UW/WDFW/Tulalip Tribes/many partners	Julie Keister	Puget Sound-wide Zooplankton Monitoring Program	Zooplankton, Ichthyoplankton, & Forage Fish	PS	ONGOING as a long-term monitoring program. (Reports/Publications pending)
DFO	Ian Perry	Zooplankton & ichthyoplankton status & trends in the northern Salish Sea	Zooplankton, Ichthyoplankton, & Forage Fish	SOG	ONGOING (now as DFO funded program)

Proponent	PIs	Title	Topic	Geographic Extent	Completion Dates
UBC	Brian Hunt & David Costalago	The trophic structure of the Salish Sea plankton food web: defining functional groups, energy pathways, and a mechanistic interface between bio-chemical and fish centric ecosystem models	Zooplankton, Ichthyoplankton, & Forage Fish	SOG	ONGOING

Appendix 3: PSF Program Synopsis

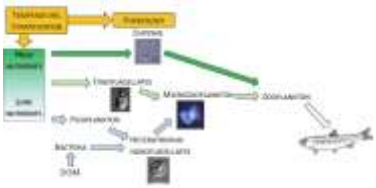
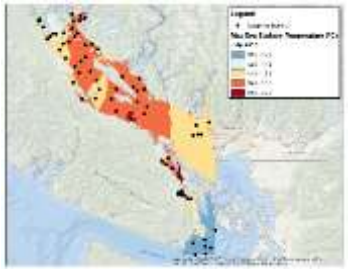
The following table provides a brief overview of key findings from the major PSF-led SSMSP programs. More detailed overviews are available at the following link:

https://www.dropbox.com/sh/kjc8wtycsact37b/AAAgwFHdBS4VuQIdmOouiudDa?dl=0

The table below includes information on relevant legacy programs that could be continued by PSF based on our findings to date.

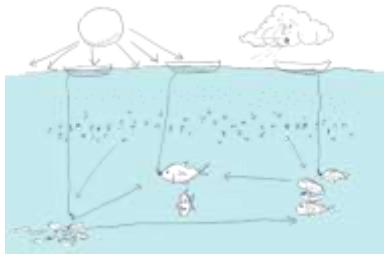
SYNOPSIS OF SSMSP PROJECTS AND RECOMMENDATIONS

In this table, we outline in blue any recommendations that would make up part of our SSMSP Legacy Programs.

Program	Description	Key Findings	Recommendations
Oceanography 	These studies look at spring bloom timing, and productivity in the Strait of Georgia. Studies also examine water quality – temperature, turbidity, oxygen levels, salinity, ocean acidity, nutrients and chlorophyll levels – and how variations affect marine life from phytoplankton up to fish.	Changing oceanographic conditions directly alter plankton community structure, abundance and distribution, and the changes to the phytoplankton community have direct effects on higher trophic levels with possible implications to overall salmon survival. In terms of productivity, it appears that 2017 was a bit less productive than 2016 and both were less productive than 2015. The relationship between bloom timing and the Strait of Georgia food web is under analysis.	**Continue the citizen science collections (strong spatial and temporal coverage).** Continue long term phytoplankton and zooplankton monitoring in the Strait. It appears that DFO is currently continuing an augmented DFO zooplankton sampling program (a critical development to assess annual variation).
Links between Phytoplankton-Zooplankton 	The overall goal of this research was to examine the level of synchrony between phytoplankton and zooplankton using long-term satellite-derived data.	This study has informed us on the drivers of spring bloom in the Strait of Georgia. These data are now being paired with zooplankton species and timing to determine how prey availability to salmon is influenced by early vs. late spring blooms.	Long-term spatial-temporal data for both phytoplankton and zooplankton is essential to accurately assess the impact of bottom-up factors on fish populations, particularly given the effects of increasing human pressures and a changing climate.
Citizen Science 	This involves volunteers using a "mosquito fleet" of their own fishing vessels to do oceanographic surveys in nine overlapping areas. That makes it possible to be "everywhere at once" collecting oceanographic data at spatial and temporal scales not previously realized.	Temperatures below 17◦C are best for juvenile salmon early rearing; given that surface waters were warmer than this in July and August for 2015-2017, it appeared that waters as deep as 10 m in the summer in most regions of the Strait were not good habitat for these fish. However, there were regional variations, with favourable water temperatures in highly mixed areas of the Strait (e.g. Campbell River and the Gulf Islands). Juvenile Chinook appear to have very defined rearing areas within the Strait, so current work relates these regional conditions to growth and survival of the various stocks caught in the DFO trawl surveys.	**The data from the Citizen Science program are being utilized for the UBC ecosystem modelling, and for many other projects in SSMSP.** **Ongoing citizen science monitoring is vital for understanding climate impacts in the Strait.** **This is recommended as a PSF legacy program.**
Zooplankton 	Zooplankton are the small invertebrates that are the main consumers of phytoplankton and also the main prey item for larval and juvenile fish. These studies look at how zooplankton levels vary and how that impacts salmon.	Overall zooplankton biomass in the central Strait has been trending up since 2005, with 2017 having higher than average biomass. This should be good for forage fish and salmon, although this also included increasing abundances of gelatinous zooplankton (not good fish food). However, in the Northern Salish Sea, the zooplankton data series from 2015-2017 suggests low levels of poor-quality food for Coho, Chinook and Sockeye and higher levels of quality prey items for Pink and Chum. Work is ongoing to link the trends and patterns in the zooplankton to potential environmental drivers and potential impacts to higher trophic levels, including juvenile salmon survival.	A consistent zooplankton monitoring program in the Salish Sea can assist with projections of future abundances of juvenile salmon. It appears that DFO is currently continuing an augmented DFO zooplankton sampling program (a critical development to assess annual variation).

Program	Description	Key Findings	Recommendations
Herring 	The Strait of Georgia juvenile (age-0) Pacific Herring survey was done to provide an index of the relative biomass of age-0 herring and relate it to the abundance of age-3 herring. This index may represent trends in potential prey availability to Coho and Chinook Salmon.	The relative biomass of age-0 herring in the Strait was lower and stable during 2013-2017, compared to the peaks within the time series. Age-0 herring were heavier for a given length in 2007-2017 compared to herring sampled prior to 2007. This may have implications for juvenile Chinook and Coho, which are piscivorous. The increase in body condition of Young-of-Year (YOY) herring since the 2000 has likely resulted in only the largest juvenile Chinook able to prey on YOY herring due to mouth gape limitations.	Understanding trends in the populations of small pelagic fish species and factors that affect their abundance and condition requires long-term monitoring of the nearshore pelagic ecosystem. We hope that DFO will continue this important time series.
Juvenile Salmon (in River) 	These studies assess and identify the range of potential factors that impact the survival of juvenile salmon in river. Work was carried out on Cowichan River to look at habitat preference, and in-river survival.	Mainstem and large side channel edge habitats with suitable velocities and intact over-stream and/or instream riparian vegetation cover were critically important for Chinook fry rearing. Freshwater survival is low during low flow years and survival rates of hatchery fish are much lower than for wild fish. The high level of in-river losses appear to be related to predation, and are particularly exacerbated during low flow years. The high level of predation by herons was an unexpected finding.	**We need to address the implications of using hatchery fish as indicators of marine survival in annual DFO assessments.** **We recommend an assessment of hatchery practices, release strategies & locations as a key component of the PSF Salish Sea Institute.** **Other recommendations include: flow manipulations and/or predator management on Cowichan River. in-stream restoration and riparian planting.**
Juvenile Salmon- Marine PIT tag studies 	This program was designed to determine the life history period which is the bottleneck to survival in juvenile Chinook Salmon, and to compare survival of wild and hatchery fish.	There appear to be two key survival periods- early after entry to sea, and then during the first winter. Hatchery fish appear to survive about 50-60% as well as wild fish, however, initial survival during the early marine period appears higher for hatchery fish.	**This project highlights the importance of the first winter in the ocean, a period that has been little studied. We recommend SSMSP Legacy programs focused on this period of Chinook life history. Information from the Citizen Science Adult Diet study would be a good first step.** **Given the efficacy and new information gathered during the Cowichan programs, expansion of these studies to other river systems would be beneficial. A SSMSP Legacy would be replication of the freshwater and marine PIT tagging study to a number of additional systems.**

Program	Description	Key Findings	Recommendations
Juvenile Salmon- Acoustic Tracking Studies 	These studies have been designed to determine migration survival of Pacific salmon through freshwater and segments of the Strait of Georgia, travel speeds and routes and the causes of mortality enroute. Studies have also examined the length of time that Pacific salmon spend around fish farms in the Discovery Island region.	Key findings include the following: -Survival rates vary geographically and are segment- and route-specific -Travel speeds vary among species -Pathogens and immune function were important to migration success, with higher predation on "sick" smolts in clear headwaters. -juvenile sockeye spent very little time around (unstocked) fish farms in Discovery Islands.	No further funding required.
Juvenile Salmon- DFO Trawl Surveys, Purse Seine and Beach Seines 	These studies examine the factors affecting salmon growth in the marine environment and relate information on ocean entry time, size, growth, diet, competitors, and origin (stock, hatchery or wild) to survival.	Chinook stocks appear to have defined distributions throughout the first summer until September. These juveniles will experience very different rearing conditions, with likely impacts to relative survival. Coho stocks appear more mixed in the Strait. Spatial analysis of stock distribution, growth and condition, and the relationships between primary productivity through to juvenile salmon growth and survival are underway. Growth of Coho and Chinook in the Strait was high during the warm conditions of 2014-2016: Coho are again resident in the Strait over the winter.	We should promote continuation of the DFO Trawl Surveys.
Predation-Seals 	Salmon have a number of predators and these studies have focussed on the role of predation, particularly from seals, on the survival of juvenile salmon. Key questions include: -How many Chinook and Coho smolts are consumed in the Strait of Georgia by Harbour seals? -What is the impact of seals on salmon recovery? -How can we mitigate the impact of seals?	-Seals may be taking up to 40% juvenile Coho and Chinook in the Strait, BUT we need to re-assess these estimates given studies that show lower rates of predation on salmon in non-estuary sites and significant year to year variability -Seal predation on smolts occurs primarily at dusk and midnight. -Seals show a variety of feeding strategies, and only some are specialised for feeding on smolts as they exit rivers and enter salt water.	DFO is continuing a harbor seal diet monitoring program in 2018 at index sites in Cowichan Bay (estuary) and 3 other non-estuary sites to extend the Strait of Georgia time-series. No further funding is required. **However, we suggest that an important role of the Salish Sea Institute will be to promote implementation of management actions such as changes to log bloom placement within estuaries, and changes to hatchery release strategies and size of smolts at release.**

Program	Description	Key Findings	Recommendations
Harmful Algae 	These studies have examined prevalence of harmful algae blooms and how they affect juvenile salmon.	-Phytoplankton community composition is strikingly different year to year and may have significant impacts on the resultant food web. -Harmful algal blooms (both toxic and mechanically harmful species) were common in the Strait and they impact wild juvenile salmon in the Strait, with similar impacts to those confirmed in BC salmon farms. Multi-year data on harmful algae species and their environmental preferences are currently being analyzed.	DFO has a strong interest in harmful algae research and it is hoped that they will continue this work.
Habitat Restoration and Research 	These studies look at salmon habitat – specifically eelgrass and kelp beds, how they have changed over time, and the progress of restoration efforts.	-Estuaries are vital for the smaller Chinook fry- rearing life history component. Eelgrass and kelp provide vital habitat for juvenile salmon, and are severely impacted by anchorages and marine debris. -Forage fish need specific habitat to lay their egg, and these shoreline habitats need to be protected as many are under threat.	**We recommend a PSF Legacy Program entitled "Estuary and Nearshore Habitat Restoration Programs". This could support studies to ameliorate habitat impacted by log booms, marine debris clean-up and protection of vital seagrass/kelp habitats (e.g. signs at anchorages, Navionics apps to show location of eelgrass beds), and create partnerships with the Stewardship Centre for BC for their Green Shores program.**
Ecosystem Modelling 	This project is to develop a coupled hydrographic and biogeochemical model of the Salish Sea, and link this to a spatial food web model to evaluate how the combination of changes in environmental productivity, food web structure and human impacts has changed in the Salish Sea over recent decades.	Project is in progress: The initial hydrodynamic (GETM) and biogeochemical (FABM) models were developed by Bolding & Bruggeman in 2017. Greig Oldford (PhD student) has started work on the food web model (spatial EwE) Sept 2018. An initial version of an individual based model (IBM) to explore smolt survival as a function of predator abundance (initially with seals) has been developed by Carl Walters. He is continuing to refine this.	This project has been funded for 5 years (2017-2021). No additional funds required.
Strategic Salmon Health Initiative 	This project is studying the microbes present in salmon in British Columbia that may be undermining the productivity of Pacific salmon, as well as the role of potential exchanges between wild and cultured salmon.	-8 novel salmon viruses have been found in aquaculture & wild individuals -Studies of HSMI - analysis of audit data suggests association between PRV and jaundice/anemia in Chinook salmon. If PRV transmission from farmed to wild salmon occurs, this poses a risk to wild Chinook salmon. -Their studies show linkages between infection status and risk of predation/mortality in sockeye salmon.	SSHI is currently preparing for challenge studies by attempting to culture viral and bacterial microbes, reaching out to experts on microbes likely to be highly ranked for follow up research, and working with VIU and UBC to set up challenge facilities. No further funds required.

Appendix 4: References

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[viii] Steve Baillie et al., unpublished, Pellett et al. unpublished.
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