SALISH SEA
MARINE SURVIVAL PROJECT

United States – Canada Science Retreat Report

2017

December 6-7
Vancouver Airport Marriott, Richmond, BC

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Summary

U.S. and Canadian scientists convened for their fourth Salish Sea Marine Survival Project Retreat in December 2017. The objectives of the meeting were to:

1. Present and discuss project results, implications, and how data products and results are being used. When applicable, discuss results in the context of previous years.
2. Discuss data gaps, ongoing needs, and next steps for the Salish Sea Marine Survival Project.

Report of Initial Findings

Participating scientists presented on the status, implementation issues, lessons learned, and preliminary results of research activities associated with the Salish Sea Marine Survival Project. A summary of progress and results for each project component is included here. For additional details and discussion around research activities, see notes beginning on page 8.

Ecosystem modeling and indicators: dataset aggregation, data gaps, and modeling scenarios

- Evaluation of suites of candidate ecosystem indicators suggested that hatchery release abundance of subyearling chinook and timing and harbor seal abundance had the strongest explanatory power for steelhead smolt survival. The lack of forage fish data hinders evaluation of some hypotheses (e.g., buffer prey).

- The Puget Sound Atlantis ecosystem modeling effort is in the data assimilation phase, with a working model targeted in late summer/early fall 2018. Retreat participants provided input on prioritizing model simulations for hypothesis testing. A parallel ecosystem modeling effort is underway in Strait of Georgia.

From physical conditions to plankton

- Salish Sea Model hindcasts have been run from 2014-2017 to simulate lower trophic level dynamics over this time period. Model results, plots, and movies can be found at salishsea.eos.ubc.ca/erddap. Turbidity parameterization testing is underway.

- Satellite-derived Strait of Georgia chlorophyll data was correlated with Fraser River flow, wind speed, sea surface temperature, and PAR. Relationships varied regionally.

- Human-derived nitrogen inputs to Puget Sound have increased over the past 20 years, and Si:DIN (a eutrophication indicator) has declined. Changes in the nutrient balance can alter the base of the food web, potentially favoring undesirable trophic dead-end species (*Noctiluca*, jellyfish). Seasonality is important to consider; for example, wastewater DIN input is highest in summer, so sluggish summer water exchange can further exacerbate nutrient issues.

- Relative contributions of fatty acids from diatoms versus dinoflagellates and bacteria can impact juvenile salmon condition. Preliminary surveys suggest regionally unique food web structures within the Strait of Georgia.

- Phytoplankton are spatially, seasonally, and interannually variable. Microplastics were identified in Cowichan Bay, Baynes Sound, and Steveston samples from the Strait of Georgia citizen science sampling program.

- Geoduck were investigated for use as a proxy of primary productivity. However, stable isotope data suggest that geoduck do not exclusively feed on phytoplankton, weakening potential chlorophyll-related growth signals. However, geoduck indices and coho and chinook salmon survival were correlated in some locations.

- Data from both Puget Sound and Strait of Georgia sampling programs show zooplankton are seasonally, regionally, and interannually variable. Zooplankton communities appear to be responding to environmental drivers (e.g., the recent warm blob anomaly). Strait of Georgia coho abundance data outside of the mid-1990s (period of decline) are related to class Malacostraca biomass anomalies, suggesting that food metrics relate to abundance but prey is not always a primary driver.

Forage fish and salmon growth and survival

- Age-0 herring biomass in Strait of Georgia is related to the amount and timing of adult herring spawning relative to spring bloom date and presumed zooplankton prey availability. Higher age-0 herring condition was related to warmer temperatures and mid-levels of zooplankton and predator abundances.

- Anchovy have been observed in catches in both Strait of Georgia and Puget Sound over the past few years. Anchovy presence/abundance in the Salish Sea may be related to ocean conditions and/or coastal anchovy populations. We do not have enough data to quantify the impact of anchovy on salmon, but they represent a potential new prey source for salmon and salmon predators.

- Otolith chemistry has the potential to identify wild-origin versus hatchery-origin salmon. Initial data suggest 25% of unmarked adult returns to some Puget Sound rivers had chemistry consistent with hatchery-origin fish.

- Genetic data from June and September Strait of Georgia midwater trawl surveys show that stocks are caught in different seasonal proportions and suggest mortality of some stocks within Strait of Georgia waters during the first marine summer. There is evidence of stock-specific distribution, behavior, and diet composition.

- Laboratory experiments suggest that starvation has impacts on salmon growth that extend beyond the period of starvation.

- Early chinook growth is correlated with survival to adulthood, but no size-selective mortality has been observed in Puget Sound prior to August. Highest feeding and growth occurs in offshore environments of Puget Sound, where chinook predominantly eat crab larvae (megalopae and late-stage zoeae). Thermal sensitivity in growth varies by habitat. Competition may impact feeding and growth. Changes in the visual environment over time due to increased anthropogenic light may exacerbate the impact of visual predators on salmon populations.

Salmon behavior, survival, and interactions with the surrounding environment

- A decay curve based on PIT tag data shows large loss (-95%) between micro troll (first ocean year) and age-2 life stages. According to this theoretical model, hatchery fish may survive better to the micro troll stage than wild fish, but have higher mortality from micro troll to age-2.

- Acoustic tag data for Chilko Lake sockeye and Seymour River steelhead suggest that choice of migration route impacts mortality. Pathogen loads correlate to mortality in Chilko Lake; Chilko bull trout select smolts with high virus loads and compromised immune function. Predator swamping may reduce predation risk.

- While 70% of tagged Chilko sockeye were exposed to Atlantic salmon farms during their migration, their near-field exposure time was only about 5 minutes at individual farms.

- Tagged Cowichan chinook displayed some degree of site fidelity and site-specific behaviors on a localized scale.

- Tag data from Puget Sound steelhead and seals suggests a shift in seal feeding behavior between 2014 and 2016. Although behavior of tagged steelhead remained the same, survival rates doubled from 2014 to 2016 and tidal movement behavior (a seal behavior) in the estuary increased, while fewer tags were found at seal haul-outs. Hypotheses about altered seal behavior include 1) recent increases in anchovy abundance may have provided a prey buffer and 2) seal-eating transient killer whale presence may have influenced seals to shift into shallower estuary waters to forage.

Predation, disease, and contaminants

- South Puget Sound seal scat analysis indicates seals have a generalist diet. Juvenile steelhead DNA was observed in three scats; juvenile chinook and coho were also identified in small proportions. A comparison of spring 1997 and spring 2016 diets showed that seal diets included more juvenile salmonids and flatfish in 1997 versus more gadids, clupeids, and anchovy in 2016.
- Strait of Georgia data suggest seals may be size-selective for larger fish. Seal predation is higher at night and more salmon are eaten by seals that predominantly forage in estuaries.
- Bacterial diseases are more common in hatchery-origin fish than wild-origin fish, but wild fish tend to have more parasites than hatchery fish.
- The parasite *Nanophyetus salmincola* may impact steelhead health, swimming performance, and survival in central and southern Puget Sound watersheds. There are seasonal patterns in parasite intensity and fish infection. Surveys to map parasite hotspots are underway and prophylactic treatments have been tested for hatchery fish.
- Contaminant fingerprints in fish tissues can be used to quantify chinook residency in Puget Sound and to track movements and rearing/feeding locations of salmon.

Next Steps

- Creating a framework for synthesis across the project is a high priority moving forwards. Several Strait of Georgia workgroups were formed to bring data and information together across projects. Formation of a project-wide SSMSP Synthesis Committee to guide synthesis efforts and products is underway.

Wednesday, Dec. 6: Research Updates

Ecosystem Modeling and Indicators Updates

Ecosystem indicator development (Kathryn Sobocinski)

The goal of this indicator development exercise was to evaluate hypothesis-driven potential indicators and eliminate metrics that 1) are not changing over time and/or 2) do not have a full timeseries. Steelhead was a starting point; they are simpler due to their short residence time in Puget Sound.

Qualitative network analysis guided hypotheses and candidate indicator lists. Five hypotheses were tested: 1) predation – increases in marine mammals increase early marine mortality, 2) buffering – forage fish provide a predation buffer, 3) competition – other salmon (including hatchery fish) compete for resources, 4) rearing conditions – adverse stream flow and water quality at marine entry, and 5) unfavorable ocean conditions.

Kathryn used generalized additive models (GAMMS) to evaluate suites of potential indicators within a hypothesis and select those with most explanatory power for smolt survival. Results suggested that hatchery release abundance and timing and harbor seal abundance had the strongest explanatory power. Ocean conditions were not strong predictors, but did add explanatory power. Sea surface temperature was the only Salish Sea water quality parameter with any explanatory power. Flow conditions were generally poor predictors. Better forage fish data are needed to evaluate related hypotheses.

Q&A:

- Megan Moore – can you quantify the weight of each variable to determine the magnitude of effect?
    - Kathryn – yes, but have not explored that much. We looked at AIC-drop-one to determine predictive power.
- Evelyn Brown – consider including bycatch data from high seas trawl studies – available in reports.
- The GAMM captures the downtick in SAR at the beginning of the timeseries, but not the uptick at the end. Kathryn says missing data (e.g., forage fish, anchovies) are a hindrance.
    - Barry Berejikian – could that be related to differences in which populations are used over the timeseries? For example, adding newly monitored populations to later years?
        - Kathryn – possible. More work to be done.
    - Sandie O'Neill – uptick may be related to residency.
- Mike Crewson – Snohomish steelhead have increased a lot over the past few years. Anchovies, sardines as potential buffer prey.
- Michael Schmidt – how were hatchery releases included in the model?
    - Kathryn – release abundance was calculated as an annual March-July average.

Puget Sound Atlantis ecosystem modeling: progress and gaps (Hem Morzaria)

Atlantis is a biochemical end-to-end model that follows nitrogen fluxes and runs on a daily/12-hour time step. It can help understand big-picture questions and hypotheses around competition, predation, pollution, and food supply; it cannot consider small-scale perturbations.

Hydrodynamic forcing will come from the UW ROMS model which includes river data, atmospheric data, and ocean circulation data. The model is built on a 3D polygon structure. Seafloor habitat type and seagrass habitat will be included. Salmonid functional groups include chinook, coho, chum, pink, and Canadian salmon (coarse grouping to investigate competition and/or predation effects on US salmon). The species are split to wild vs. hatchery and yearling vs. subyearling. Hem et al. are deriving spatial distributions and abundances for other species from available survey data. Landing trends through time for each functional group were collected through commercial and recreational fishery data. Diet data is currently a gap – please contact Hem with any dataset leads.

The model will consider hypotheses associated with short- and long-term changes in circulation, water chemistry, and primary productivity and how those changes may impact prey availability, the sensitivity of the system to human activities such as nutrient/contaminant inputs, and effects of competition and predation within the Puget Sound food web on juvenile salmon survival.

Currently, this project is in the data assimilation phase and targeting a working model in late summer/early fall 2018.

Q&A:

- The model does not include wetlands or delta areas, so degradation of nearshore habitat is not well-captured.
- Evelyn Brown – there is a difference between natural predation and fisheries-modified predation. There are higher mortality rates associated with catch-and-release fishing due to marine mammals following the boats.

Evaluating relative impact of long-term environmental, food web, and human impact on salmon productivity in the Salish Sea (Villy Christensen)

Variation in environmental productivity can be amplified through the food web. Christensen et al. hypothesize that low marine survival is due to a combination of low productivity and high predation pressure. Fisheries pressure is an unlikely driver, since there have been drastic reductions in fishing effort for chinook and coho with no improvement in survival.

This end-to-end modeling activity parallels the US Atlantis model. The model is based off a 3D hydrodynamic model (Salish Sea General Estuarine Transport Model (GETM)) and Framework for Aquatic Biogeochemical Models (FABM) model coupling. There are several potential biogeochemical models; models will be evaluated based on comparisons of model-generated primary productivity to MEOPAR and Costa observations. It will also incorporate Brian Hunt's plankton model, a spatially-explicit Ecopath with Ecosim food web model, and an individual-based model for smolt predation risk. The food web model will focus on salmon and will include spatial distributions based on environmental preference functions (species presence influenced by environmental conditions).

The key data gap is consistent wind data for the hydrodynamic model. Christensen et al. are using ERA5 climate reanalysis for data, run retroactively. This will allow simulations 1950-present for all models after the Q1 2019 ERA5 release.

Q&A:

- Parker MacCready – what data source will be used for open ocean/boundary conditions? Does ocean state matter?
    - Villy – likely the same source as Susan Allen, but it hasn't been incorporated yet. Yes, ocean state probably matters.

- Dick Beamish – several of the major Strait of Georgia fish species are basically unstudied (*Leuroglossus*, ratfish, juvenile hake and pollock, etc.).
- Carl Walters – we did an ecosystem model fitting exercise 10 years ago using every long time series we could find. We varied primary production and found co-varying declines in many of the other datasets, including hake. Fitting the data for larger organisms indicated a decline of 50% in effective primary production. The only correlation was airport wind data – a correlation that has broken down in recent years.

From Physical Conditions to Plankton

Modelling 2014-2017 lower trophic level ecosystem dynamics in the Salish Sea: challenges and successes (Susan Allen)

Model results, plots, and movies can be found at salishsea.eos.ubc.ca/erddap. SalishSea Model hindcasts have been run from 2014-2017. The SMELT biological model produces high-resolution estimates for near-surface phytoplankton, including 3 groups that photosynthesize, 2 grazer groups, and mesozooplankton to close the system. The model is forced with winds, rivers, tides, sea surface height, temperature, salinity, and nutrients.

Model outputs were compared to PSF citizen science observations, Ocean Network Canada nodes, and satellite data. Modeled salinity, temperature, nitrate, and silicate match citizen science observations fairly well. The model tracks salinity well at deep stations but less well at shallower deep water stations. The modeled Fraser River plume is approximately the right shape, but is positioned too far north. In the model, diatoms dominate throughout the year, with strong spatial variation. On average, modeled Juan de Fuca productivity is higher than it should be. However, based on the three nutrient data stations at Friday Harbor, the model is able to pick up real differences in spring bloom timing. Model evaluation is ongoing.

Q&A:

- Ken Currens – do you have a silica cycle in model?
    - Susan – yes. Strait of Georgia is not generally silica-limited though.

Recent physical conditions and implication for water quality and biological conditions in Puget Sound (Christopher Krembs)

Water temperatures were high in 2017, and Puget Sound was extremely fresh year-round. This was unexpected, since we had a dry summer and normal upwelling. Oxygen levels in Central and South Puget Sound were not as low as in 2016.

Conceptually, the timing of processes (river flow, upwelling, water residence time, etc.) will be affected by future climate. Early snowmelt and summer droughts will increase the human burden on water quality. In summer months, less upwelled water will enter Puget Sound, increasing the residence time of water within Puget Sound. Increased residence time means that the water will get warmer and receive less ocean nitrogen, which may shift Puget Sound from an upwelling-influenced system to a regenerative system. Longer water residence will also increase the pollution burden. Considering seasonality matters: for example, wastewater treatment plant contribution to DIN is highest in the summer – sluggish summer water exchange could further increase pollutants.

Most nitrogen input into Puget Sound is from the ocean; when ocean nitrogen patterns are accounted for, there appears to be in increase in human-derived nitrogen inputs to Puget Sound over the past 20 years and a consistent decline of Si:DIN. This ratio is a eutrophication indicator, and changes in the nutrient balance can alter the base of the food web. Flagellates may benefit under a eutrophic Puget Sound scenario, and Eyes Over Puget Sound aerial surveys have observed flagellate blooms and other nuisance species over the past several years: lots of *Noctiluca* in 2012-2014, lots of jellies during 2015-2016, and lots of macro-algae in 2017. Quantitative data are not consistently collected on these species. Depth-integrated phytoplankton biomass has decreased since the beginning of the time series in 1999. Chlorophyll decreases at the surface mean that less chlorophyll can make it to depth (changed organic particle export).

Q&A:

- Dick Beamish – bottom-up control for survival of juvenile chinook salmon (at least in recent years) may explain what's going on. Suggest that bottom-up control is preventing juvenile chinook from growing faster quicker. That is key to their survival under the critical size/critical period hypothesis.
- Sophie Johannessen – you said that WWTP contribute nitrogen in summer but also that ocean is still the highest nitrogen contributor. Over the full year, what is the total WWTP contribution?
    - Christopher – the ocean is 60-90% of nitrogen load. The rest is divided among WWTP and rivers. Total load is not necessarily the critical concern here: it's the relative contribution of each source. If you shift from diatom-based food web to a microbial food web, you change energy channeled to upper trophic levels. Most of the material cycles thru base of food web, where we have very little data.
- Evelyn – how does wind impact phytoplankton blooms (forcing mixing, etc.)? There was some relation in the Strait of Georgia.
    - Christopher – Uncertain. Puget Sound is spatially more discrete and harder to model than Strait of Georgia. For example, Hood Canal blooms are observed as early as February while Main Basin blooms are generally in May. Basin topography and stratification can influence blooms. In Puget Sound, terrestrial sources contribute a large fraction (~30% based on literature) of input into system.
- Dave Beauchamp – understanding nutrient input sources is important. Is the net decrease in springtime silica inputs a function of a change in hydrology?
    - Christopher – Ecology's freshwater unit is currently looking at silicate inputs, but we have little historical data. Damming impacts silica budget, and most Puget Sound rivers are dammed.
- Are decreases in chlorophyll linear over time? River flows are cyclical.
    - Christopher – there is a Hood Canal study that suggests that microzooplankton grazing can clear 100-120% productivity per day. Small differences in the microzooplankton community can potentially have large impacts on chlorophyll patterns. We want to extend that concept from Hood Canal to a larger scale and focus on dynamics at base of food web.
- Sophie Johannessen – would chlorophyll:silica relationship change interannually?
    - Christopher – we don't know because we don't measure productivity: big data gap.

Flash update: new study to explore bottom-up processes related to salmon growth and survival (Beth Curry)

Long-term indicators of bottom-up processes in Puget Sound are lacking, so it is difficult to test how bottom-up processes have influenced historical declines. This project will explore relationships among oceanography, lower trophic levels, and salmon growth and survival. Datasets included are coho and chinook marine survival time series, size and growth data from multiple monitoring efforts, abiotic data (temperature, DO, pH), chlorophyll and harmful algal bloom data, and plankton data. Years where data collection was most comprehensive were 2011, 2014, and 2015. There are a few select longer time series available.

This project will test whether variation in ocean circulation and water properties alter plankton production and salmon survival, and whether there is insufficient food supply to meet chinook and coho demand. If water column properties impact plankton production and salmon survival, we would expect 1) salmon growth decreases when water temperature is outside the peak window for metabolism, 2) fish that do not reach a critical size prior to winter do not survive, 3) mortality increases as prevalence and intensity of harmful algal blooms increase, and 4) carbon inputs and climate change have reduced Salish Sea productivity. If there is insufficient food supply for chinook and coho, we would expect 1) timing, abundance, and spatial extent of prey influences salmon consumption rates and growth, 2) smolts entering during optimum food supply conditions have higher survival rates, and 3) survival and growth increase with availability of fat/nutritious prey.

Environmental drivers and spatiotemporal patterns of satellite-derived chlorophyll-a in the Strait of Georgia from 2003-2016 (Karyn Suchy & Maycira Costa)

Suchy, Costa and others are integrating satellite products with historical and current zooplankton data to identify seasonal and interannual patterns of phytoplankton and zooplankton phenology. The focus is on Central and Northern Strait of Georgia. The spatial data products can then be used to understand relationships among environmental drivers and lower trophic levels. The environmental drivers considered in this project are satellite-derived sea surface temperature and photosynthetically-active radiation, wind, and river input.

Because of high cloud cover in the Salish Sea region, satellite-derived products have issues with missing data. Costa et al. are using empirical orthogonal functions (EOF) to interpolate missing data. The algorithm learns over space-time and performs well compared to observed data.

Chlorophyll results suggest high spatial and temporal variability within the Strait of Georgia. In general, median chlorophyll was slightly higher in central regions than northern regions. The average start date of the spring bloom was end of March, with early blooms occurring in 2004, 2005, and 2015 and late blooms in 2007 and 2008. In anomaly space, the strongest positive anomalies were spring 2005, spring 2015, and fall 2008, while strongest negative anomalies were spring 2011 and spring 2007.

Chlorophyll in Central Strait of Georgia was correlated most strongly with Fraser River flow and also with wind speed, sea surface temperature, and PAR. Chlorophyll in Northern Strait of Georgia was correlated most strongly with sea surface temperature and PAR, and also with Fraser River flow.

Q&A:

- Hem Morzaria – is the whole time series Aquamodis? I have heard cautions about using MODIS data after 2014.
  - Maycira – yes. We are upgrading to Sentinel 3 products. We are aware of the MODIS issues and we validate all the products we use.
- Ken Currens – have you validated your EOF models by testing locations where you have data?
  - Maycira - I showed a plot of that. It works quite well.
- Villy – have you integrated for each year – summing the entire year? How much variation is between years? What's the capability of going further back in time?
  - Maycira – summing over the entire year would be an interesting idea to try. We do not have data acquisition on a consistent temporal scale, though we are trying to recover data from 1980s to now.
  - Karyn – there is both interannual and intra-annual variability in biomass. We are considering seasons and sub-regions. For example, in 2005 and 2015, we saw stronger peaks in spring. We generally see more dominant fall blooms in Central Strait of Georgia than Northern Strait of Georgia.

Structure and function of the plankton food webs supporting juvenile salmon in the Salish Sea (Brian Hunt)

This is a new project, initiated based on 2016 SSMSP retreat discussions, intending to develop a mechanistic understanding of how salmon productivity is impacted by the influence of environmental conditions on plankton prey. Food web pathways impact the energy available to juvenile salmon; the length of a food chain is inversely related to transfer efficiency. Food web pathways are influenced by temperature, stratification, and physiology, and, in turn, influence the quantity and quality of prey available. For example, diatoms produce EPA and dinoflagellates produce DHA. These essential fatty acids contribute to juvenile salmon growth.

The goals of this project are to use stable isotopes and fatty acids to identify sources and transfer of source materials through the food web and to measure prey quality and track specific prey groups. The plankton community will be size fractionated for simplicity. Bayesian mixing models will be used to trace linkages.

Initial data were collected 2015-2017 and focused on sockeye salmon. Preliminary results show that the spring phytoplankton bloom was 6 weeks earlier in 2015 than 2016-2017 and there was a massive fall nanoplankton bloom in 2016. Phytoplankton size classes varied intra- and inter-annually. Sockeye condition was higher in 2015 than 2016, but total fatty acids were higher in 2016. Fatty acids increased May to July in both years. Dietary ratios of DHA:EPA > 2 are considered optimal and while total fatty acids were higher in 2016, DHA:EPA ratios were higher in 2015. This suggests that relative contributions of fatty acids may affect fish condition. Diatoms were higher in Northern Strait of Georgia; dinoflagellates and bacterial fatty acids were higher in the south, indicating different food web structures within Strait of Georgia.

Q&A:

- Will Duguid – are you looking at fatty acid composition at a species-specific level for zooplankton?
  - Brian – we have a size fractionation process that gives us fractions ranging from very small to 4 mm (salmon prey: krill, decapods, etc.). We target all 4 mm size class individuals for species-specific measurements.

- Brian Beckman – a word of caution: zooplankton people have a history of not talking to salmon people about what salmon actually eat.
    - Brian – we are also analyzing salmon diet data; not just guessing about what salmon eat.

Modelling the impact of riverine turbidity on phytoplankton growth in the Strait of Georgia (Elise Olson)

In developing the Salish Model Ecosystem – Lower Trophic (SMELT) biological model, one issue is resolving the impact of the Fraser River plume and plume turbidity on light attenuation. It's a challenge to correctly represent suspended sediment in the model; sediment sinks over time, so the model must include a removal process. Incorporating a single constant sinking rate did not satisfactorily represent observed data, possibly due to seasonal and/or spatial variation in sinking rates. Incorrect turbidity parametrization could impact bloom/diatom results. Alternative sinking parameterizations (concentration-dependent sinking rate, salinity-dependent flocculation) are being tested and show promise.

Q&A:

- Chris Harvey – can you comment on the biological significance of chlorophyll change in model with vs. without turbidity?
    - Elise – without turbidity included, modeled chlorophyll exceeds observed chlorophyll in Central Strait of Georgia in summer.

Phytoplankton dynamics and temporal/spatial harmful algae distribution in the Strait of Georgia 2015-2017 (Svetlana Esenkulova)

The Citizen Science program targets 10 areas in Strait of Georgia and includes 80 stations, sampled twice per month from February to October. Among other data, collections include discrete water samples at surface and select depths at select stations that are processed for phytoplankton. From 2015-2017, almost 6000 samples have been collected and 80% of them have been analyzed to date.

Phytoplankton are spatially and temporally variable, and there is high interannual variability. Overall, there was seasonal synchrony, but clear regional differences. Most samples were dominated by diatoms. Only a few samples had very high cell counts; all those samples were dominated by *Skeletonema costatum*. The diatom bloom was very high and early in 2015, and the summer community structure was different in 2015 than in 2016-2017. Harmful algal bloom levels also differed among years. *Chaetoceros* spp. (mechanically harmful) levels were high in 2015, whereas *Dictyocha* spp. (toxic) levels were moderate in 2016.

Cowichan Bay had the most microplastics of all study areas, followed by Baynes Sound and Steveston. In June 2017, strange coagulated organic strands – as yet unidentified, but not phytoplankton or zooplankton – began appearing in Cowichan samples.

*Reconstructing historical patterns of primary production in Puget Sound using growth increment data from shells of long-lived geoducks (*Panopea generosa*) (Jenny Eccles)*

Puget Sound does not have long-term records of primary production. This project aims to use geoduck growth as a metric of historical primary production in basins of Puget Sound. Geoducks are long-lived; the oldest on record was aged at 174 years. They lay annual shell increments down throughout their lifetime, with most growth occurring early in life. They filter-feed and are assumed to feed on phytoplankton. Therefore, in theory, geoduck growth rings can be linked to location-specific temperature and primary production.

This project examined geoducks from 5 sites throughout Puget Sound basins. A growth index (population-scale metric) was calculated for each site. The index varies across sites, since each site experiences a unique microclimate. The growth index and temperature correlate until the 1980s, when the correlation appears to break down. The strength of this relationship varies across sites and time periods. Geoduck are thought to grow during the March-October season, but data suggest the optimal growth window may be smaller.

Monthly chlorophyll data were obtained from DOE water quality monitoring stations. The data are noisy and relationships between chlorophyll and growth are weak. Stable isotope data suggest that geoducks may eat things other than phytoplankton, which may weaken a potential chlorophyll-related growth signal. Although geoduck may not be a good proxy for primary productivity, they may still serve as an indicator for salmon survival. Preliminary analyses suggest that geoduck indices are correlated with coho and chinook salmon survival in some locations.

Q&A:

- Todd Sandell – juvenile salmon feed at surface, but presumably geoduck feed at depth. Does that present an issue?
    - Jenny – the depth at which geoduck were collected was a pretty narrow band. We used local conditions and averaged over the top 30 m of the water column. We are making some assumptions about what geoduck can access.
- Christopher Krembs – what is the variability among individuals?
    - Jenny – we’re looking at population metrics; individual numbers don't mean anything.

Zooplankton status and trends in the Southern Salish Sea (Iris Kemp, on behalf of Julie Keister)

The Puget Sound-wide Zooplankton Monitoring Program has been ongoing since 2014. Ten regional entities sample 15 sites throughout Puget Sound, conducting vertical tows over the full water column and oblique tows over the upper 30 m monthly November-January and biweekly (twice per month) February-October. The vertical tows are done with a 200-µm mesh single-ring net to capture detailed species information on small zooplankton. These data are being used to develop indicators of environmental variability. The oblique tows are done with a 335-µm mesh bongo net and are intended to capture larger organisms representing the juvenile salmon prey field.

The program initiated with one vertical tow and three oblique tows at each site; after the first two years, oblique sampling tows were optimized based on the collected data and reduced. Sample quality is high, with 100% of vertical samples and >90% of oblique samples considered good-quality in 2017. More stringent QA standards were implemented in 2016 and routine flow meter testing was implemented in 2017; oblique tow sample quality is expected to further improve.

The data collected through this program show region-specific seasonal patterns in zooplankton abundance. Copepods are the most abundant taxa; larvaceans also have high abundance peaks in spring and some summers. The tow data suggest that cumulative abundances of zooplankton were higher and the productivity cycle may have initiated earlier in 2015-2016 than in 2014. Community composition also shifted annually. Community structure showed lower seasonal variability in 2015-2016 compared to 2014.

Zooplankton status and trends in the Strait of Georgia, Canada: responding to SSMSP hypotheses (Ian Perry)

Plankton sampling in Strait of Georgia has a three-tiered approach: DFO surveys provide data from core stations, smaller charter vessels fill in times between DFO surveys, and citizen science vessels sample select locations at a weekly frequency.

Preliminary data show regional differences in monthly zooplankton biomass by region. One area of interest is sampling plankton across salmon migration paths around Texada Island. “Fish food” plankton (crab, krill, amphipods) are generally at lower biomass overall but higher proportions in the middle of the Strait. This pattern varies seasonally. Juvenile salmon may have best foraging opportunities in Malaspina Strait in May and the west side of Texada Island in June/July. Biomass of fish eggs and larvae were abundant in Baynes Sound in March, due to a large amount of herring larvae.

Over the available time series of data (1990-2016), “fish food” plankton biomass was low in 1996, 2005, and 2007 but high in 2008. If data from the mid-1990s (period of coho decline) are removed from the time series, the remaining data shows a relationship between class Malacostraca biomass anomalies and coho abundance. This may indicate that food metrics are related to coho abundance but prey is not always a primary driver.

Q&A:

- Evelyn Brown – how difficult would it be to relate US and Canadian datasets? Could we infer backwards in time in Puget Sound based on Strait of Georgia data?
    - Ian – we’ve discussed this with Julie. A starting point is comparing patterns in the US JEMS data to Strait of Georgia. We are also looking at spatial decorrelation scales with more intensive sampling in recent years to determine whether we can reduce sampling stations.
- Dick Beamish – how were regions defined?
    - Ian – we used a qualitative expert-based approach, considering general water circulation and zooplankton differences.
- Dick Beamish – the decline in marine survival of coho occurred in the 1980s; survival was already consistently low by the 1990s. The major change in coho survival occurred before the beginning of your time series.
    - Ian – our data are best from 1989 onwards, though we do have some data from the early 1980s. But yes, right now we are looking at interannual data within an overall low-survival regime.

Forage Fish

*Juvenile Pacific herring (*Clupea pallasi*) in the Strait of Georgia, British Columbia (Chrys Neville, on behalf of Jennifer Boldt)*

Based on midwater trawl diet data, juvenile chinook eat herring and unidentified fish in summer and fall in Strait of Georgia. This project examined age-0 herring abundance to understand patterns in salmon prey availability. Nighttime herring purse seine surveys were conducted September-October 1992-2016. Fish and plankton data were collected across 10 transects. These data were used to develop an age-0 herring biomass index.

Age-0 herring biomass varies interannually, in a zig-zag pattern with peaks every 2-3 years. The last few years have been relatively stable but lower than previous years. Condition (length-weight residuals) has increased from 1992-2016. Based on general additive model results, age-0 herring biomass was affected by the amount and timing of adult herring spawning relative to spring bloom date and presumed zooplankton prey availability. Age-0 herring condition was better at warmer temperatures and mid-levels of zooplankton and predator abundances.

In 2017, anchovies were also caught in the herring survey.

Q&A:

- Francis Juanes – are you doing size-structure work on herring to determine whether they are optimal sizes for salmon predation?
    - Chrys – we haven't done detailed analysis but observationally juvenile herring have been silvered up by May in recent years; historically they would still be primarily larvae in May.
- Dick Beamish – is interannual variation related to spawning stock biomass? Coho survival is related to pink juveniles in Strait of Georgia.
    - Chrys – pinks are high in the same years that the herring index is high; pink salmon don't eat herring.
        - Villy Christensen – maybe pink salmon scare herring away from the surface.
            - Chrys – we catch young-of-the-year herring throughout the depth distribution of our daytime trawls. At nighttime, they're at the surface.
- Mike Crewson – until recent years, we also saw a zig-zag odd/even pattern in Puget Sound zooplankton index. Coho outmigrants do poorly in the years with abundant pink outmigrants. Could that actually be a top-down competition effect?
    - Chrys – we see these seesaw patterns in a number of species, but haven't figured out what it means yet.
    - Evelyn Brown – we discuss this every year. Doesn't the fact that the pattern is there when population is normal and disappears when the population is low mean something?
    - Michael Schmidt – have pinks crashed in Strait of Georgia like they did in Puget Sound?
        - Sue Grant – this year's pink return was very low.

A snapshot of the pelagic fish community of Puget Sound: results from the 2016-17 acoustic midwater trawl survey (Todd Sandell)

Todd et al. conducted one year of bi-monthly acoustic-trawl surveys near herring spawning areas. Most tows were taken during the daytime, targeting forage fish aggregations at depths > 15 m. Herring were most abundant in the catch; they also observed hake, jellies, dogfish, ratfish, anchovies, and other fish. There were several large hake catches in Whidbey Basin and Main Basin, and anchovy catches in Whidbey and South Sound. Species that were > 5% of the catch were considered acoustically relevant.

Overall, pelagic community diversity in Puget Sound measured by this survey was low, with an effective number of species (Hill's number) at 2-4 across basins.

Elastomer tag studies on surf smelt were also conducted. Results suggest that larvae initially mix but localize upon settling. Tag recovery was low, so population estimates are not possible at this point.

Q&A:

- Chrys Neville – how do you identify dogfish in acoustic signal?
    - Todd – Mike Berger does all our acoustics. He seems to think he can pick them out. Will get back to you on methodology.
- Paul Hershberger – why are north Hood Canal herring patterns so different from other stocks? Are they going somewhere unique? We have seen an unusually high prevalence of *Ichthyophonus* in north Hood Canal for the past 5-6 years.
    - Todd – they're doing great but we don't know why. They may be a little more migratory than other stocks; there is some hint that they may go out to the ocean. We are limited to where we can catch them with this trawl, and we don't have good data from south Hood Canal.
- Scott Pearson – what time of year did you catch anchovy in South Puget Sound?
    - Todd – they're present in South Puget Sound year-round. Our trawl doesn't go nearshore enough to really catch them. We gillnetted some during the winter and we got reports of fish kills when they got caught by the tide.

Northern anchovy in the Salish Sea (Will Duguid)

The forage fish community in the Salish Sea is dominated by herring. Anchovy are present, but rarely considered an important component of the ecosystem. In 2015-2016, anchovy abundance spiked and Will et al. started seeing post-larval anchovy in chinook guts.

A literature search on the history of anchovy in the Salish Sea and collated survey data suggest that anchovy presence is spatially and temporally variable. Anchovy appear to have been present in high abundances in the past; anchovy were the third most abundant fish in First Nations middens up to 3000 years old and were present in 37% of 94 First Nations archaeological sites in the Salish Sea. Literature accounts from the 1800s describe "enormous quantities" of anchovies during autumn in the Salish Sea.

Eggs and larvae are present in the Salish Sea and there appears to be a peak mid-summer in reproductive activity. Size distribution from surveys in 2016 show mature and larger anchovies are present throughout the year, with age-0 fish appearing in August. This indicates that recruitment is occurring within the Salish Sea; it's unlikely that juveniles migrate in through Juan de Fuca every year.

Will et al. ranked abundance of anchovy from 1938-2016. Abundance metrics differ by sampling group, since each program reports catch differently; generally, frequency of occurrence by sampling event was used. There appears to be some coherence among datasets. Salish Sea abundance may be related to coastal populations, but data are lacking. Some periods of elevated abundance may be related to warm ocean conditions.

An influx of abundant anchovies represents a new prey resource for juvenile salmon, which may be important if larger herring sizes and/or earlier herring maturation is becoming an issue for salmon consumption. Anchovy are asynchronous batch spawners, so they have the potential to provide a more accessible, longer-duration food resource for salmon and other species. There have been recent reports of humpback whales eating anchovy. Anchovy appear to feed at the surface during the day, which may lead to competitive interactions with juvenile salmon. We do not have enough data to understand impacts of anchovy presence in the Salish Sea. Data on population genetics and abundance monitoring would be valuable.

Q&A:

- Chris Harvey – in 2015-2017, Ric Brodeur et al. found adult anchovy, eggs, and larvae off the Oregon coast which syncs up to your data better than the Columbia River plume survey data.
    - Will – there was also an unusual anchovy abundance event in the Columbia River estuary in 2016 for unknown reasons.
- Megan Moore – are there plans to continue anchovy data aggregation efforts?
    - Will – no plans that I'm aware of.
- Dave Beauchamp – what month or size do young-of-year anchovy become fully pigmented?
    - Will – not sure. Month doesn't really apply, because they appear in batches. From personal observation, we were seeing 30-40mm SL unpigmented anchovy in chinook stomachs while concurrently we saw pigmented 60mm SL anchovy schooling around our boat.
- Ken Currens – about 15 years ago, there was lots of work on asynchronous sardine/anchovy cycles on the scale of about 50 years. These were global patterns, leading to the idea that they reflected large-scale forcing.
    - Will – according to presentations at the small pelagics meeting last year, current thought has shifted away from those ideas. Some of those time series have been extended and revised and the asynchrony breaks down. In California Current, there is a link between cooler regimes and higher anchovy abundances. The Salish Sea appears to have the opposite pattern, perhaps due to temperature limitations. We are not currently experiencing spillover from California, since currently that southern population is at the point of collapse. Historically, spillover events may have occurred. Literature suggests anchovy arrived as a run, which may indicate that they weren't spawning within the Salish Sea back then.
- Evelyn Brown – the bottom line is we don't have good information on anchovy: there are no regular stock assessments and lots of disagreement about the state of collapse. Fish are patchy and surveys are patchy. We need to push to get US and Canadian governments cooperating on this issue. Suggest implementation of a test fishery.

Salmon Growth and Survival

Update: juvenile life history strategies in returning adult Chinook salmon from the Salish Sea basin (Lance Campbell)

This project uses otolith chemistry data to determine successful life history strategies in Salish Sea chinook. Results show that fry outmigrants do not survive to return as adults in some populations (Green, Puyallup, Cedar), but contribute about 30% of adult returns in other populations (Skagit, Nooksack, Cowichan).

There is potential to identify hatchery fish by otolith chemistry. Based on initial tests comparing chemistry data with CWT data, chemistry assignment is accurate in > 90% cases. Chemistry assignments in the Green River suggested that not all unmarked adult returns are wild-origin; of the unmarked fish on the spawning grounds, about 25% had otolith chemistry consistent with hatchery-origin fish.

Q&A:

- Michael Schmidt – how do unmarked hatchery fish influence the fry/parr distribution?
  - Lance – we haven't done that analysis yet.
- James Losee – your chemical assignment suggested that 30% of the unmarked fish were hatchery-origin. That number doesn't match our mis-clip estimates – are mis-clip estimates off?
  - Lance – we feel confident in our assignments. Tag mis-clip estimates are obtained by holding fish for a month. Returning adults have been out in the ocean for much longer than that – could the adipose fin regrow in some fish? We also don't have a good count of how many fish escape; systems could be leakier than we think.
- Mike Crewson – we have done paired studies and see low rates of pAD fish but we don't think mis-clips are high. How do you tell chemically that a fish is hatchery-origin?
  - Lance – the chemical composition of hatchery fish is different than wild fish, though we're not really sure why. We link elemental composition of otoliths to stream water all the time and strontium has very strong correlations. But we know very little about effects on other elements.
- Dick Beamish – what is considered a fry?
  - Lance – we define fry as fish that enter estuary/ocean residence in the 35-60mm size range.

The journey of a juvenile salmon over their first marine summer – what can they tell us? (Chrys Neville)

Midwater trawl surveys have been conducted annually in late June/July and September/October since 1998 in Strait of Georgia. The net is set at 15 m intervals from surface to 60 m depth. Purse seine surveys were also conducted 2014-2017 in Cowichan and Big Qualicum estuaries and the Discovery Islands.

Catches vary seasonally and interannually. In 2017, coho catches were low and September catches of chum were the lowest ever observed in this survey. Chinook are caught in 80-85% of sets; they seem to be everywhere regardless of sea surface temperature. Certain areas are hotspots for catch.

Different stocks are caught in June surveys than September surveys; each survey represents different populations. Chinook distribution in the Strait appears fairly cohesive with river of origin. September catches are predominantly South Thompson fish (which make up a very small proportion of the June catches), and there is no evidence of large migrations out of Strait of Georgia for other stocks based on acoustic tagging and WCVI/QCS surveys. This may indicate that chinook are dying within the Strait of Georgia prior to September. South Thompson chinook enter Strait of Georgia later than other stocks, and they have had better returns in recent years.

Purse seines in the Gulf Islands had high catches of Cowichan chinook throughout May-August. Some Cowichan chinook were also captured offshore in Strait of Georgia (about 3% of the total chinook catch). The fish that left the Gulf Islands and were captured in North Strait of Georgia were the fastest-growing fish with high condition factors, almost all wild-origin, and had different diet compositions: Gulf Island fish diets were dominated by crab larvae, whereas North Strait of Georgia captures ate high proportions of euphausiids. There is some evidence of stock-specific diet composition from Malaspina Strait catches where the data were corrected for fish size. South Thompson fish ate crab larvae, fish larvae, and amphipods while other stocks ate crab larvae, fish larvae, and euphausiids. Preliminary DHA:EPA ratio (a metric of growth/condition) appeared higher in 2016 than 2015 for Big Qualicum/Puntledge fish. The ratio decreased from May-September both years.

Other observations from surveys: lamprey wounds can be massive and deep (even to the bone). In 2014, bite marks began to appear on fish bellies. The predator is unknown: the bite pattern matches a dogfish, but dogfish experts say that dogfish of that size don’t eat fish. However, juvenile dogfish catches have increased. Chrys et al. are doing gel impressions of predator mouths to match the bite marks. Larval anchovy have appeared in juvenile salmon diets over the past few years, and adults are also being caught in trawls.

Q&A:

- Michael Schmidt – dogfish may bite salmon without eating them.
    - Chrys – there do seem to be more dogfish these days since we’ve stopped fishing them.
- Sandie O’Neill – dogfish may just bite at anything in the net when you pull it up.
    - Chrys – if that were the case I'd expect the bite marks to be random (like heads gone etc.) but it's always the belly – that suggests a predator coming up from below the fish.
- Sandie O’Neill – do you pick up Harrison/Chilliwack fish on WCVI?
    - Chrys – they aren’t caught in summer juvenile surveys. They’re caught in Oct/Nov surveys, but not in the proportion we'd expect to see.
- Sandie O’Neill – I don't have juvenile data from Chilliwack but we do have adult returns caught in Albion test fishery. Their contaminant fingerprint looks just like a Puget Sound fish, suggesting that they're going wherever Puget Sound fish go. That fingerprint is very different from South Thompson, etc. stocks.
- Christopher Krembs – the ratio of DHA:EPA was high in 2016, and weren’t dinoflagellates present in 2016 but not 2015? Could be a connection to explore.
    - Nina Nemcek – wouldn’t that be the opposite of what you’d expect?
    - Ian Forster – we’re still analyzing data and diets. We don’t think the relationship is straightforward, and we don’t have firm rationale behind our findings yet.
    - Brian Hunt – we did notice that the ratio increased in 2015 fall, which corresponded with the fall dinoflagellate bloom.
- Michael Schmidt – do South Thompson chinook migrate up Malaspina Strait?
    - Chrys – we don’t know yet. Marc Trudel's survey caught South Thompson fish on WCVI, so we need to do more work to understand where they're going.
- Will Duguid – are genetics samples run spatially stratified or single-batch?

    - Chrys – they are run as survey groups. We use 60% probability as our cut-off and lump together stocks with low separation.
- Will Duguid – would be interested to run Gulf Islands fish separately to confirm the Cowichan fish outside of Gulf Islands.
    - Chrys – otolith data will help verify.

The Hakai Juvenile Salmon Observing Program: 2015-2017 (Brian Hunt)

The Hakai Juvenile Salmon Observing Program is a collaboration among several Canadian groups intended to complement SSMSP with a focus on pink, sockeye, and chum. Their objectives are to resolve migration timing, rates, pathways, and mortality estimates; map migration habitat; understand spatial and temporal dynamics of food resources and juvenile salmon foraging dynamics and growth; and determine the impact of parasite and pathogen infections on salmon growth and health.

The program has been conducting surveys in North Strait of Georgia since 2015, focusing on the Discovery Islands and Johnstone Strait. They collect data on ocean conditions, plankton, and salmon. Data are reported on a weekly basis during the outmigration season and are available at data.hakai.org or github.com/HakaiInstitute/juvenile-salmon.

The zooplankton bloom was one month earlier in 2015 than in 2016-2017 and corresponded with phytoplankton data. There was a massive fall nanoplankton bloom in 2016, and a massive fall zooplankton bloom in 2015. Hierarchical cluster analysis suggests that regions (Discovery Islands, Johnstone Strait, North Strait of Georgia) cluster distinctly based on zooplankton species composition. Sockeye diet composition and foraging success (measured as mean % stomach of body weight) also vary regionally.

Sockeye migration time was progressively one week later each year from 2015 to 2017 in the Discovery Islands. A similar pattern with more variability was observed in Johnstone Strait. Sockeye condition was highest in 2015; 2016-2017 conditions were about equal.

Laboratory experiments show that starved sockeye show growth impacts that extend beyond the period of starvation. Starved fish growth (measured by increase in fork length) was slightly but not significantly reduced relative to control (fed) fish during the starvation period, but was much lower than controls up to 2 weeks after normal feeding resumed.

Q&A:

- Chrys Neville – do you really think there's been a change of feeding dynamics in Johnstone Strait? It’s an area of lots of mixing. In our surveys, we see lower feeding and quick movement through the area. In Cowichan Bay, there was a non-toxic phytoplankton bloom during which salmon feeding rates dropped dramatically. Lowered feeding due to phytoplankton could really impact early marine growth overall.
    - Brian – we’re not suggesting long-term changes in Johnstone Strait, just spatial variation along migration routes. We will be looking into changes in conditions back to 1930. There is a persistent density front in Johnstone Strait down towards Discovery Passage that has been there for decades; that is likely relevant biologically.
- Sue Grant – we see stock-specific population dynamics – Fraser sockeye, for example.
    - Brian – we measure stock composition also.
- Christopher Krembs – in your starvation experiment, were the starved fish that did not add much length when re-fed just restocking lipid reserves?

  - Brian – maybe; we haven't analyzed that yet.
- Francis Juanes – what temperatures were used during starvation experiments? We did similar experiments and temperature was critical.
  - Brian – not sure off the top of my head, but we measured it so we can check.

An overview of processes affecting critical growth and marine survival of Puget Sound Chinook (Dave Beauchamp)

Early growth is positively correlated with survival for Puget Sound chinook. Two years of intensive study (2014-2015) found no evidence of size-selective mortality prior to early August. Generally, feeding and growth were low in nearshore habitats where fish ate insects and epibenthic prey. During the nearshore-offshore transition and in offshore habitats, feeding and growth were high and the dominant prey was crab larvae. The thermal sensitivity of growth potential varies among habitats, seasons, and years. In nearshore habitats, fish were exposed to warmer temperatures and lower-growth scenarios.

The default assumption in bioenergetics models is that as fish grow, energy density increases. An alternate hypothesis is that if size-selective mortality is a driver, the fish should allocate more energy into early somatic growth. The data collected for this study showed little difference in energy allocation across estuary, nearshore, and offshore habitats, but there was seasonal variation across March-October. Fish in nearshore habitats in September fell below the literature value of a theoretical lethal threshold (4000 j/g wet mass).

There may be competition impacts to juvenile chinook while in Puget Sound as crab larvae are a common prey source for other salmon and herring, and herring far outnumber salmon. Predation by resident chinook may also impact juvenile chinook. Initial simulations suggest that the resident chinook population may be able to eat up to 50% of outmigrating smolts. Data on resident chinook diets will be collected in 2018 to improve these simulations.

Changes to the visual environment may have increased predation risk over time. Light pollution increases over the past several decades have been more rapid and widespread within the Salish Sea than on the coast, making our current night more like a perpetual twilight. Data from Lake Washington suggests that in the 1980s, predation events occurred mainly during dawn/dusk hours, whereas in 2005 predation events occurred throughout the night. Turbidity may also have changed over time; declining chlorophyll could lead to increased water transparency, benefitting visual predators.

Q&A:

- Maycira – what wavelengths do salmon see underwater? Are they sensitive to thermo-infrared?
  - Dave – they see through blues to yellows and greens. Vision starts dropping off toward reds. They are not sensitive to infrared or thermo-infrared. In the US, we have switched to LED street lighting, which is blue-based and high-intensity and can penetrate deeper into the water.
- Chrys Neville – have you measured the size of prey in fish diets? We observe fish selecting for the biggest individuals of any given species.
  - Dave – for a lot of the larval crab species, chinook feed mainly on late-stage zoeae and megalopae, and on slightly smaller larvae than what is available in the water column. Dungeness crab larvae are too large for chinook.
- Christopher Krembs – how does bioluminescence play into the nighttime foraging environment? And how does body length and swim speed relate to energy density? Would fish compromise energy density for length and speed?

- Dave – we measure energy density in j/g body weight. The longer the fish the faster they can swim. In terms of evasion they don't have to do much - a couple tail strokes – so stamina is not a real problem. Acceleration is more important.

Thursday, Dec. 7: Research Updates, Synthesis

PIT Tagging and Acoustic Telemetry to Assess Salmon Behavior, Survival, and Interactions with the Surrounding Environment

Survival of juvenile Cowichan River Chinook throughout their first year of life – a summary of PIT tag returns through fall 2017 (Kevin Pellett)

This study has deployed just over 56k tags over 2014-2017 through in-river catches, beach seines, purse seines, and micro trolling and has recovered nearly 400 tags. Initial results suggest that wild fish survive at a much higher rate than hatchery fish at all life stages and that survival increases across life stages for both hatchery and wild fish. A decay curve based on tag data shows large loss (-95%) between micro troll (first ocean year) and age-2 life stages. According to this theoretical model, hatchery fish may survive better to the micro troll stage that wild fish, but have higher mortality from micro troll to age-2. Adult returns represented the full size spectrum of outmigrants, but there was some suggestion that bigger fish might survive better.

Q&A:

- Evelyn Brown – what are your tag numbers, and have you considered using acoustic tags?
    - Kevin – we proposed 2500 tags per stage in our design. There were low catches of hatchery fish in beach seines (likely an artifact of size), but we are confident in our river and purse seine catches as well as in micro trolling. We did best in 2016 so that will be our year of focus.
- Brian Beckman – have recent good returns been isolated to Cowichan fish?
    - Kevin – no, the pattern is broader than Cowichan. Puntledge returns were twice their 4-year average in 2017, and Big Qualicum has increased too. Cowichan stands out as a stronger responder than the other systems. Other rivers are driven by hatchery production while Cowichan hatchery contribution is only ~7-10%.
        - Chrys Neville – Fraser River stocks, including South Thompson, were low in 2017.
            - Dick Beamish – South Thompson fish enter later than other stocks. So whatever was going on early in Strait of Georgia was beneficial to early ocean entry timing and later fish didn't do as well.
    - Barry Berejikian – what do Puget Sound returns look like for 2017?
        - Mike Crewson – chinook are the best returns in a long time.
        - Michael Schmidt – and coho were high last year.
- Chrys Neville – coho have been larger in surveys since 2015. In 2017, fish were huge in July survey but numbers were low in September.

Survival and behavior of acoustic tagged sockeye and steelhead smolts in coastal BC (Scott Hinch)

Chilko Lake sockeye juveniles (age-1 and age-2) were acoustically tagged for the past 3 years. Gill biopsies were also taken to do genomic assessments of gene expression and pathogen loads. The fish had high mortality in the first 14 km of the river. Age-2 fish had poorer survival throughout the migration, which may be influenced by tag burden. Travel rates were slow; fish only migrated at night. They picked up speed as they went down-river, then slowed in the marine environment. Travel rates increased in Discovery Islands. There was no age difference in migration rates. Very preliminary results on migration routes through the Discovery Islands suggested that fish migrating through Discovery Passage and Desolation Sound may have survived better than fish migrating through Sutil Channel.

Seymour River steelhead were also tagged and released at either an in-river location or a marine location. Fish released into the marine environment beyond Burrard Inlet survived better; Burrard Inlet may be a hotspot for mortality. Fish that migrated through Discovery Passage had higher survival than fish that migrated through Sutil Channel. Travel rates increased in Discovery Islands similarly to sockeye results.

Previous studies showed pathogen loads correlated to mortality, and high levels of bull trout predation in Chilko Lake. Bull trout selected smaller fish and smolts with higher virus loads and compromised immune function. Gene expression profiles of the biopsied fish were predictive of survival/mortality fate.

Predator swamping may reduce predation risk. The probability of tagged fish survival increased when outmigration density was high. This pattern has been consistent 2010-2016, with annual variability in the strength of the relationship.

Q&A:

- Kathryn Sobocinski – are you going to do flume work with compromised juveniles?
    - Scott – we have thought about it but haven’t been able to do it yet. It’s logistically complicated since it would likely have to be done on site.
- Sue Grant – by the time you get to the marine environment there isn’t much mortality left, based on the high river mortality you’re seeing. When you release downstream of the weir, you aren’t always releasing in aggregation. How would predator swamping effects differentially impact released, tagged fish?
    - Scott – our absolute estimates are probably low for the reasons you mentioned and the assumptions we make about detection efficiency of our last line. However, we believe the relative patterns are solid.
    - Nathan Furey – we are creating density-dependence curves to refine our telemetry survival estimates, using fence data for actual population estimates.
- Lance Campbell – is initial mortality associated with tag implantation?
    - Scott – we've done holding studies and are confident that our handling and holding protocols are good. Holding studies have had near-perfect survivorship for up to 2-3 weeks. Tag burden is the only issue we have to confront. Tag burden varies based on size of fish and we can correct for that in model.
- Dick Beamish – did you change methodology for detecting IHN across years?
    - Scott – no.
- Francis Juanes – are size and infection rate related within a year-class?
    - Nathan Furey – for the 2014 fish, there was no correlation between size and IHN.

- Dave Beauchamp – especially at night, predation events happen on the order of milliseconds. So very subtle differences in infected fish behavior could result in higher predation success of bull trout.

Exposure time of juvenile sockeye salmon to Discovery Islands fish farms (Erin Rechisky)

BC salmon farms are controversial, but they represent $1.14 billion (and BC's #1 agricultural export) and generate 5k jobs. There are 109 salmon farm sites in BC with 60-70 active farms at any given time. This study aims to quantify impacts of farm exposure during outmigration of acoustically-tagged Chilko Lake sockeye. 70% of the tagged fish were exposed to fish farms, based on their choice of migration route through the Discovery Islands. Exposure times through channels with fish farms were generally low. Near-field exposure times were about 5 minutes near individual farms. During the study period, the farms were fallow; this study will be repeated in 2018 when farms are stocked with Atlantic salmon and parasites and diseases will be investigated more intensively.

Migration maps can be viewed here: http://kintama.com/animator/dep/Chilko2017_sockeye/

Q&A:

- Brian Riddell – how do you calculate exposure times?
    - Erin – the smaller transmitters only have a range of about 100m. We looked at the duration of time a fish was detected – so for example if the fish moved in and out of range, we would add that up to a total exposure. The exposure time represents the cumulative time a fish spent in the area. Exposure times are generally short because fish outmigrate quickly through the Discovery Islands (consistent migration pattern across years).
        - Chrys Neville – our purse seine data also suggest that fish move through Discovery Islands very quickly. Did you see more fish on either side of Okisollo Channel?
            - Erin – we haven't looked at that detail yet
- Chrys Neville – 2018 is a low cycle year for Fraser River sockeye. In 2014, the last low year, we caught very few sockeye. You will be swamped by pink and chum in Souk Channel next year, but sockeye abundance will be very low.
- Dick Beamish – in volume 3 page 9 of the Cohen Commission report, the judge said "highly anomalous ocean and climate conditions" was the reason for poor returns. By law in British Columbia, salmon farming is a fishery. The value of that fishery exceeds the value of all other east and west coast Canadian fisheries combined (minus east coast lobster).
    - Erin – there were about a dozen Cohen Commission recommendations on salmon farms. The $1.1M is an uptick; 2017 was the best year BC salmon farmers have had.
- Todd Sandell – the wild salmon is a self-replicating resource in that equation. But also, we saw that salmon stick around farms in other areas.
- Brian Hunt – pathogens aren't just in farms, they are in the water column. Pathogen footprint is actually quite large based on modeled impacts.
    - Erin – we are considering that work as we move forward with future tagging studies.

Mortality, movements, and migration timing of age-0 Cowichan Chinook salmon tagged in the southern Gulf Islands in fall (Will Duguid)

This study looks at fine-scale patterns of habitat use for Cowichan chinook relative to survival and disease. Fish were captured via micro trolling, acoustically tagged, and released in Sansum Narrows and Maple Bay: sites about 4 km apart, where site-specific growth and diet compositions have been observed.

Preliminary results indicated a high detection rate (85%) via mobile tracking and detection of 15 stationary tags (19% of total tagged fish); passive receiver data were not available at the time of this presentation. Half of the stationary-tag fish died within a day or two of tagging. About 20 live fish were detected two weeks after tagging, and some fish were detected two months after tagging.

Distribution patterns of the fish caught at the two tagging sites differed; tagged fish tended to be detected near where they were tagged (site localization). There is a seal haul-out in Sansum Narrows, so it is possible that those fish experience higher predation risk. When passive receiver data are available, it will be examined for potential predator behavior patterns.

Q&A:

- Michael Schmidt – is the tag burden higher using both PIT tags and acoustic tags?
    - Will – PIT tags are very small for fish of this size.
    - Erin Rechisky – we assessed and found negligible tag burden.
- Neala Kendall – how do these findings relate to seal predation work in Strait of Georgia?
    - Will – with our small sample size, we are unlikely to get good data on seal predation, although we hope to assess tag behavior for possible predator patterns. We don't have any information on winter seal predation.
- Ben Nelson – the decay curves you showed are very valuable in corroborating our modeling studies. Our model curves are similar.
- Dave Beauchamp – it seems like temperature-sensitive tags are the best method of addressing uncertainty over when/where predation has occurred.
    - Will – the issue with temperature-sensitive tags and predator tags are size (higher tag burden) and low detection range. We considered acid-sensitive tags.
- Chrys Neville – what was smallest fish you tagged?
    - Will – size range was 143mm to 230mm. We were hoping to get as many Cowichan fish as possible, so the only fish we excluded were fish that were adipose-clipped with no CWT (those fish are usually Puget Sound origin).

Inter-annual variation in early marine survival patterns of Puget Sound steelhead smolts indicates shifting predation pressures (Barry Berejikian)

A meta-analysis of acoustic tag data for Puget Sound steelhead showed that all tracked populations were exhibiting low early marine survival, which appeared to worsen from 2006-2009. When we tracked Nisqually and Green steelhead and tagged seals as part of SSMSP in 2014, we observed low survival (17% Green, 6% Nisqually) and found stationary tags at harbor seal haul-outs. In 2016, we repeated this study but results were very different. Steelhead travel times were nearly identical between years and migration routes were generally similar. However, steelhead survival was high (nearly 40% Nisqually) and no tags were found at haul-outs. However, tidal movement behavior in the estuary increased and tags that exhibited that behavior all became stationary. Seals exhibit that behavior; it's likely that those tags were in seals. These data suggest a shift in seal predation/behavior between 2014 and 2016, but the reason is unclear. Hypotheses include 1) recent increases in anchovy abundance may have provided a prey buffer and 2) seal-eating transient killer whale presence may have influenced seals to shift into shallower estuary waters to forage.

Q&A:

- Jenny Eccles – can seal tag data be paired with population-wide seal surveys?
    - Steve Jeffries – yes, we have those data.
- Steve Jeffries – the 4 tags exhibiting identical back and forth tidal behavior are likely all in one seal, indicating that individual seals may specialize on smolts. If smolt predation is not a population-level behavior, it could change modeled predation rates.
- Will Duguid – what was the longest duration a tag exhibited back and forth tidal behavior?
    - Barry – an awfully long time. The typical gut passage time for a tag is 3-4 days, but apparently harbor seals can aggregate hard parts in guts and then pass as a bolus which may take much longer.

Predation, Disease, and Contaminants

Seal diets in southern Puget Sound as derived from DNA and hardparts from feces (Scott Pearson)

Scats were collected from six harbor seal haul-out sites in South Puget Sound: every other week through the 2016 outmigration season. These collections represent a very small percentage of the potential scats produced by seals on these haul-outs, and we have no way of knowing whether these samples are representative of the full population. Scats were processed with DNA metabarcoding and hard parts analysis. A single scat represents prey from previous foraging, with one "meal" being passed in ~4 scats over 24-48 hours post-meal. Primary prey cannot be separated from secondary prey (i.e., if a bull trout ate a salmon and the seal ate the bull trout, diet analysis would show both trout and salmon as seal prey items).

South Puget Sound seals have a catholic diet comprised of fish, crustaceans, and cephalopods. It is not uncommon to see > 35 species of prey in a scat. In total, 57 different prey species were observed: 53 species of fish (including chinook, chum, coho, cutthroat trout, and steelhead), 1 unknown crustacean, and 3 species of cephalopods. Only 3-15 species are typically common (defined as ≥5% of diet); other species are eaten opportunistically. There was generally good agreement between DNA metabarcoding and hard parts analysis; generally, high sample sizes are required for this comparison to be robust.

Juvenile steelhead DNA was observed in three scats in May-June (total N = 149). One of the scats was 100% steelhead, another was 43% steelhead, and the third was 2.5% steelhead. Juvenile chinook and coho DNA were observed March-June in small proportions (<1.5%). Juvenile salmon (not speciated) were observed in higher proportions in July-August hard parts analysis.

Spring 2016 hard parts data were compared with spring 1997 hard parts data. Seal diets included more juvenile salmonids and flatfish in 1997 versus more gadids and clupeids in 2016 and more anchovy in 2016. More hatchery salmon were produced in 1997 than in 2016, which may explain this difference.

Q&A:

- Jenny Eccles – even a small percentage of seal diets being salmon equates to a lot of fish. How to quantify on a population level?
    - Scott – Chasco et al. modeled population consumption. However, it's not appropriate to assume that seal behavior is the same across locations, so scaling up spatially is problematic. South Puget Sound consumption is likely different from San Juan Islands consumption is different from Cowichan consumption.
- Kathryn Sobocinski – have you looked at regressions of vertebrae size and fish length?
    - Scott – we're working on obtaining enough samples to do that.
- Evelyn Brown – we do not have enough population data on anchovies or herring. The official anchovy assessment said they are low abundance, even though they boomed in Puget Sound in 2016-2017.
- Megan Moore – you had a single sample that was 100% steelhead – was that adult or juvenile steelhead?
    - Scott – that sample was 100% steelhead DNA but contained hard parts from several different species. There's a high likelihood it was juvenile steelhead, but not sure about how many. A single sample is not very informative. DNA and soft tissue can pass at different rates than hard parts, and anything that is detected at <1% in DNA is thrown out (so the species detected in hard parts analysis may have been detected in DNA also but discarded according to DNA methodology).
- Todd Sandell – are seals disproportionately eating sick fish?
    - Michael Schmidt – Paul Hershberger is looking into that.

Update on Strait of Georgia seal predation studies (Ben Nelson)

Thomas et al. 2016 found that Strait of Georgia seals ate chinook, coho, and sockeye smolts in higher percentages than they did pink and chum smolts; for adults, the pattern is reversed. Allegue et al. tagged 17 seals and found that feeding patterns coincided well with hatchery coho release (May 4th, 350k coho) but less well with hatchery chinook release (May 14th, 3 million chinook). This agrees with Nelson et al.'s work suggesting that predation rates on coho smolts are high at saltwater entry while predation rates on chinook smolts are lower at saltwater entry and increase as fish go. Seals may be size-selective for the larger fish.

Seal predation was higher at night, likely because fish are more active at night. Non-estuary seals, seals that used both estuary and non-estuary habitats ("intermediate" group), and estuary seals showed differing foraging patterns. Surface feeding events were constricted to eating. In intermediate and estuary groups, seals engaged in intense daytime foraging events around 100m. These seals may have been feeding on adult salmon and gadids at depth.

Diets of estuary and non-estuary seals in 1980s vs. 2016 were compared. Gadids and herring dominate the diet in both time periods. Salmon predation is higher in estuaries than non-estuaries: in spring, estuary seal diets were 3% salmon (mostly juvenile chinook) versus 2.5% in non-estuary seals and in fall, estuary seal diets were 35% salmon (mostly adult chum) versus 10% in non-estuary seals.

Q&A:

- Chrys Neville – why don't seals eat juvenile chum? They eat adult chum, the abundance in our trawl catches for juvenile chum is 10-20 times greater than juvenile chinook catch, and juvenile chinook and chum overlap in size. Are seals selectively targeting naïve hatchery chinook?

- Ben – it's possible they target hatchery chinook. Predation on chinook smolts by seals is maximized later in July, when chinook are over 10 cm.
  - Chrys Neville – we see 26x more chum in July/August than chinook and size overlap is very high in that time period – 10-20 cm fish in Cowichan Bay.
    - Ben – honestly don't know. Maybe schooling behavior varies between chum and chinook?
  - Barry Berejikian – hatchery rearing influence on late summer predation is unlikely since the fish have been in the environment for a while and should no longer be naïve. The hatchery hypothesis makes more sense if predation happens at ocean entry.

Infectious profiles of Chinook salmon: life-history variation, novel viruses, and disease potential (Emiliano DiCicco)

The Genome BC Strategic BC Salmon Health Initiative led by PSF and DFO is currently about halfway through Phase 2: examining Phase 1 collections to determine when and where potential pathogens are present. They are screening 26k BC salmon to identify novel viruses, explore microbe evolution, assess potential linkages with disease, and evaluate potential for disease exchange. Salmon surveillance programs suggest that bacteria *Piscrickettsia, Renibacterium*, and *Vibrio anguillarum*, and rheovirus (PRV) are rare in wild smolts. Wild fish tend to have more parasites than hatchery fish.

Data from published microarray studies were used to train a model to detect viral disease state. The model appears to perform well, based on proof of efficacy tests with chinook diagnosed with viral diseases versus bacterial and parasitic diseases. Three novel chinook viruses were identified.

PRV and jaundice/anemia in farmed chinook salmon is an issue. Wild chinook show similar viral tissue patterns to farmed chinook, including viral inflammation in heart tissue. Farmed chinook may serve as a model as well as a sentinel for the diseases that impact wild salmon.

Q&A:

- Paul Hershberger – do you have another probe for BEN or IPEs?
  - Emiliano – we don't yet but are planning to get one. Apparently we should use the same probe as PRV?

A seasonal profile of Nanophyetus *exposures within an endemic watershed (Paul Hershberger)*

Higher steelhead mortality occurs in South Puget Sound watersheds than in north Puget Sound. Mortality occurs shortly after smolts enter seawater. The cause(s) of mortality operate on both hatchery and wild steelhead, but the relative effect is greater in hatchery fish. A trematode parasite *Nanophyetus salmincola* affects steelhead and coho, and fits the steelhead mortality patterns in Puget Sound. A snail (*Juga* spp.) is the intermediate host; *Juga* populations can be very concentrated in central and south Puget Sound watersheds. The snail host is not present in northern watersheds due to temperature limitations.

The parasite infects all internal tissues, with a particular preference for the posterior kidney. At high exposure levels, parasite infection can cause direct mortality. At sublethal exposures, it may impact swimming speed and fish health.

To mitigate the impacts of *Nanophyetus*, the basic epidemiology – fish exposure and infection – must be understood. Paul et al. developed and validated a qPCR tool able to detect *Nano* in fish tissue, snail tissue, and water samples, and monitored a Soos Creek index site at a hatchery intake pump for one full year. They identified seasonal patterns in parasite shedding (when the snail host releases the free-swimming form of the parasite into the water column), with a peak (up to 7 parasites per liter of water) in October/November followed by very little if any shedding February-April and moderate shedding in spring-summer. Parasite loads measured in hatchery sentinel fish corresponded well with water samples: parasite loads peaked in fall at 800 metacercaria per kidney. Exposures to wild fish in-river are likely a reflection of waterborne *Nano* concentrations and stream flows.

Surveys in Green and Nisqually watersheds are underway to identify *Nano* hotspots. Potential mitigation/treatment techniques are prophylactic water treatment or filtration for hatcheries, modifying hatchery release dates to avoid *Nano* peaks, relocating rearing locations, snail control (e.g., with Puget Sound crayfish), transporting fish around *Nano* hotspots, and preventing carcass transport to reduce the chances of seeding watersheds with the parasite.

Q&A:

- Todd Sandell – what was the load comparison between wild and hatchery fish?
    - Paul – loads were similar in Green/Duwamish. Nisqually steelhead are all wild, and their loads were 10x higher than the Green/Duwamish fish.
- Mike Crewson – your peak loads were in fall. Does that impact adults and juveniles?
    - Paul – both: adults get exposed when they return. There are concerns in Willamette and lower Columbia River that parasites impact adult return.

Contaminant fingerprints reveal marine distribution patterns of Salish Sea salmon populations (Sandie O'Neill)

Persistent Organic Pollutants (POPs) are a class of toxic man-made chemicals. They are lipophilic and dissolve easily in animal fat but are not easily metabolized so they accumulate with age and bio-magnify up the food web. These characteristics result in animals having contaminant "fingerprints": distinct patterns of POPs based on foraging and environmental attributes. For example, Puget Sound has high levels of PCBs whereas the California Current has high levels of DDT: fish that have spent time in either system reflect the system's contaminant patterns.

Pacific herring populations have distinct contaminant fingerprints, as do chinook salmon. Herring and chinook fingerprints overlap, indicating similar marine distribution and foraging habitat. Chilliwack chinook fingerprints look very similar to Puget Sound chinook; some Chilliwack fish actually reside in Puget Sound. Puget Sound resident chinook fingerprints overlap with Puget Sound herring populations; Puget Sound non-resident chinook overlap with fingerprints of multiple Salish Sea herring populations, suggesting that they feed in similar areas. Southern Resident Killer Whale pods have different fingerprints that overlap with fingerprints of different chinook populations, which could help determine where/on what fish they are feeding.

In 2016, Sandie et al. conducted a resident Puget Sound chinook survey with samples from sport fisheries and commercial test fisheries. PCB levels were high, above DOH screening levels. DDT levels were low and had low variability among areas. Fish caught in areas 6 and 7 (San Juans, JDF) generally had lower contaminant levels. Contaminant patterns were consistent with fish movement patterns observed in prior tagging studies.

Q&A:

- Christopher Krembs – are you sampling outmigrating salmon to see when they pick up signal?
    - Sandie – we have contaminant concentration data for juveniles; we could do fingerprints also. We know where juvenile hotspots are generally.

Revisiting Data Needs for Modeling and Indicators…and Discuss Next Steps

Discussion: ecosystem modeling hypotheses and priority scenarios revisited (Chris Harvey, Hem Morzaria)

The Atlantis model can test hypotheses via scenario comparisons, but it is time- and funding-intensive to run all potential scenarios. SSMSP participants can help by prioritizing the most important hypotheses to test. A list of hypotheses was presented to all participants, who ranked them online. Initial (real-time) survey responses suggested a variety of opinions: no single hypothesis had extremely strong support.

Francis Juanes suggested working towards consensus by using the Delphi method (repeated sequential discussions and anonymous voting).

The hypothesis list presented was as follows:

Hypothesis	Compared to null model, what would have happened if…
Reduction in edible phytoplankton has decreased food availability for early marine Chinook and coho.	…diatom production had remained stable, at levels derived from sediment cores?
Decline in forage base reduces early marine survival of Chinook and coho.	…abundance of spawning adult herring, particularly Cherry Point herring, had remained stable?
Change in growth of forage fish reduces food availability for Chinook and coho.	…growth rate of juvenile herring during Chinook and coho outmigration remained low enough for predation?
Shifts in energy flow toward *Noctiluca* and gelatinous zooplankton decrease production of plankton that support juvenile salmon.	…abundance of *Noctiluca* and gelatinous zooplankton were maintained at low levels?
Change in the timing of larval crab production has reduced prey base for salmon.	…availability of larval crab were maintained at high levels?
Juvenile pink salmon compete with Chinook and coho prey base for zooplankton.	…pink salmon biomass had not increased over time?
Competition for food between wild and hatchery salmon may limit wild juvenile growth and survival.	…stocking rates of hatchery Chinook and coho were maintained at low (~1975) levels?

Competition with other pelagic fishes for key prey (e.g., crab larvae) reduces juvenile salmon growth during critical periods.	…larval crab were not available to forage fish (e.g., herring) before/during critical growth periods for juvenile salmon?
Recovering pinniped populations have increased predation pressure on early marine Chinook and coho.	…harbor seal abundance had not increased?
Harbor porpoises are important predators on early marine Chinook and coho.	…harbor porpoise abundance had not increased?
Seabirds are important predators that affect fish community composition.	…seabird populations had not changed since the 1970s?
Older age classes of salmonids are important predators on early marine Chinook and coho.	…we reduced availability of early marine salmon as prey to older, resident salmon?
Hatchery Chinook outmigration timing is driving a pulse response from predators.	…hatchery Chinook were not released in one pulse?
Increases in urban light have exposed juvenile salmon to greater predation pressure.	…juvenile salmon were less available to visual predators?
Development, survival, and/or growth have declined in stocks that spend time in highly contaminated areas.	…contaminant effects were not present at all in Elliot Bay, Sinclair Inlet, and Commencement Bay?
The pathway by which organic pollutants enter the food web affects their concentration in juvenile salmon tissues.	…organic contaminants entered the food web primarily through pelagic pathways? …or, through benthic pathways?
Entry of contaminants through stormwater reduces juvenile salmon survival.	…stormwater inputs did not contribute any contaminants?
Turbidity from stormwater reduces light availability for phytoplankton, and thus lowers overall food availability.	…stormwater inputs did not reduce light availability, which is one of the drivers of diatom production?
Reductions in early marine survival are some combination of impacts, and recovery will require multiple management actions.	…we released different combinations of pressures on early marine survival? (Are effects additive, synergistic, or antagonistic? Are the most significant sources ones that we can manage, or merely mitigate?)

Moving forward: Strait of Georgia workgroup assimilation plans

Canadian workgroups were formed to begin syntheses among projects. These workgroups included:

- Environmental Parameters & Biological Oceanography (led by Ian Perry);
- Zooplankton, Ichthyoplankton, & Forage Fish (Ian Perry);
- Juvenile Salmon (Dick Beamish & Brian Riddell);

- Nearshore Habitat (Nikki Wright & Bill Heath);
- Predation & Disease (Andrew Trites);
- Analysis & Modelling (Villy Christensen).

The bottom-up groups led by Ian Perry have met twice so far to identify key questions and develop data integration plans, as follows.

- Are coho and chinook survivals related most strongly to water properties within the Strait of Georgia? How do oceanographic conditions differ among basins within the Strait of Georgia and how do they affect the marine survival of juvenile coho and chinook salmon?
    - Karyn Suchy is leading a project to define regional properties (physical, biological).
    - Brian Hunt is leading a structured comparison of whole-water-column vertical zooplankton tows vs. upper-layer-only vertical tows, and physical determinants.
- Are reductions in survival and/or productivity of coho and chinook related to changes in water quality within the Strait of Georgia? Were there significant changes in water quality during the 80s/90s?
    - Sophie Johannessen is leading assembly of time series of physical and chemical properties in the Canadian Salish Sea.
    - Alex Hare is leading a study to predict CO_2 concentrations from common oceanographic measurements.
- Are reductions in survival and/or productivity of coho and chinook related to prevalence of *Heterosigma* and other harmful algae? Is there any evidence that prevalence of harmful algae increased during the 80s/90s?
    - Discussions are ongoing among workgroup members.
    - Tamara Brown – Microthalassia has phytoplankton time series since 1999 that includes known HABs. In general, there has been an increase in the length of HAB blooms and increased spatial distribution.
- Does there appear to be evidence that outmigration timing influences the magnitude of competition, predation, and environmental variation on survival in the Strait of Georgia?
- Is food availability and/or quality paramount to the marine survival of coho and chinook in the Strait of Georgia?
    - Jennifer Boldt is leading work on this question.
- **General recommendations:** 1) the SSMSP should develop a consistent time series of coho and chinook abundances (escapement) and, where possible, marine survival, likely by hatchery/stock complex; 2) the SSMSP should support detailed multivariate statistical analyses of these fish time series with as many of the potential independent variables influencing salmon as possible; and 3) data for the specific physiological requirements/thresholds for all salmon species should be amassed for both juvenile and adult stages.
    - Will Duguid – SAR data for recent years (2014+) are not available, so the question is what can we use in those years as a proxy for survival?
    - Mike Crewson – there is a lag for availability of marine survival data, but escapement data are available on a faster time scale. There is value in looking at escapement patterns across species to potentially identify common drivers. For example, steelhead and coho escapements crashed in 2009 – was there a significant environmental change across all those stocks at that time?

- Dick Beamish – the Strait of Georgia coho story that is often overlooked is the behavioral shift in the 1990s. We initially had a coho fishery in Strait of Georgia that was almost unregulated. In the late 1980s, we thought overfishing and habitat damage was the cause of declines; in the early 1990s, we realized marine survival declines due to ocean and climate change were the issue but that idea wasn't accepted until the late 1990s when catches were reduced. In 1994, there was a major change in coho behavior that lasted until 2013. How does that story fit with these hypotheses?

The Nearshore Habitat Workgroup is addressing these questions:

- Is there a historical connection between loss of habitat and decline of salmon?
- What research is there on habitat loss?
    - Pilot studies on eelgrass extent in spatially localized areas suggest a general decline of about 40% from 1930s to present-day. Similar projects are beginning to assess kelp loss.
- What recommendations around nearshore habitat should be given to managers?
    - Combine spatial extent of habitat with fish distribution data.
    - Institute nearshore habitat monitoring for area and habitat fragmentation. Map nearshore habitats every 5 years.
    - Initiate restoration programs for eelgrass and kelp. Use fixed cameras to gather data on salmonid habitat use.
    - Simplify monitoring procedures to facilitate community involvement.
    - Bridge the gap between the scientific and management communities.

The predation and juvenile salmon workshops have initiated meetings to work on specific hypotheses and recommendations.

The analysis and modeling workgroup is in the data collation phase.

Synthesis committee and strategy update (Michael Schmidt)

The SSMSP Synthesis Committee, composed of Strait of Georgia Science Team and Puget Sound Technical Team representatives, will be gearing up over 2018 and into 2019. The committee will provide guidance and contribute (where practicable) to the development of key results and publications, potentially including a manuscript describing our current state of knowledge and remaining data gaps and a white paper suggesting management actions and next steps. Preliminary concepts include cross-border synthesis of zooplankton data, fish data, harbor seal data, and ecosystem models.

Group comments:

- Evelyn Brown – begin by looking for spatial coherence in salmon population patterns as a framework for guiding selection of participants/participation. Include run timing.
    - Kathryn Sobocinski – the ecosystem indicators work is currently looking across chinook, coho, and steelhead for patterns which are coherent across species and/or across regions. All data that were aggregated in survival time series work is included.

General feedback on project process, progress, and next steps

- Mike Crewson – we need to understand the see-saw pattern. It appears in several various datasets; we should discuss it as a subject of primary importance.
- Villy Christensen – we need to determine the impact of hatcheries. Potential impacts are often ignored.
  - Michael Schmidt – based on Dave Beauchamp's arguments, competition with non-salmonids outweighs hatchery/wild competition effects.
  - Kathryn Sobocinski – my models do suggest that hatcheries may have an impact.
  - Evelyn Brown – a framework for information synthesis is the most important. We cannot think in simplistic terms. Competition is difficult to document; mechanistic modeling approaches are a good way to get at the question. Also consider potential predator swamping effects.