SALISH SEA
MARINE SURVIVAL PROJECT

United States – Canada Science Retreat Report

2016

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Four Points Sheraton, Bellingham, WA

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Summary

U.S. and Canadian scientists convened for their fourth Salish Sea Marine Survival Project Retreat in December 2016. 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 12.

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

- A qualitative network model constructed of positive, negative, and neutral/unknown linkages among groups/factors relating to salmon metrics based on literature and expert opinion was created for Puget Sound. The model showed that anthropogenic impacts (hatcheries, habitat loss, contaminants, and disease) resulted in the strongest negative responses in survival and abundance. Also, feedbacks through the foodweb were strong, beginning with primary production (i.e., decreasing diatoms), suggesting that several foodweb variables may be important in mediating effects on salmon survival within the system. With this model, we were able to compare the relative influence of multiple drivers on salmon survival.
- Candidate indicators for Salish Sea salmon marine survival have been developed and dataset aggregation is in progress. Preliminary processing and standardization of datasets are underway. Monthly data and spatially discrete data are most valuable. Evaluation of candidate indicators for usefulness has begun. Data gaps include a lack of long time series, data from mid-trophic levels (zooplankton to piscivorous fish), and data characterizing anthropogenic impacts (habitat loss, artificial light, etc.).
- End-to-end ecosystem models are being developed for Puget Sound and Strait of Georgia. Regional comparisons and data sharing are encouraged, and modelers are working cross-border during model development.
    - An Atlantis model is under development for Puget Sound and currently in data acquisition phase. Model geography and depth layers were developed based on sub-basin structure and biological data. Hydrodynamic forcing is provided by Parker MacCready's ROMS model. Life history traits, species, and juvenile/adult life stages will be incorporated. Calibration of the model will extend through 2017, and simulations will begin in late-2017.
    - A model based on existing Ecopath with Ecosim, ROMS, and biogeochemical models will be developed for Strait of Georgia. The EwE model will be spatialized with a dynamic habitat model. Data gaps include long-term datasets (e.g., wind) to use as drivers for the physical model. The full ecosystem model is targeted for completion in 2019.

- Modelers and researchers discussed modeling scenarios (listed on page 36) to explore hypotheses related to early marine survival of chinook and coho. The group recommended multiple models, of varying complexity. Indirect interactions among variables (e.g., disease may moderate predation) should be considered. Spatial comparisons within the Salish Sea and with non-Salish Sea time series are important. A modeling workshop for scenario testing was recommended, as well as a workshop or task team to develop a process for hypothesis prioritization.

From physical conditions to plankton

- Both US and Canadian researchers are developing satellite-derived ecosystem metrics (water color, water clarity, algal biomass, etc.) across the Salish Sea at high spatial and temporal resolution. Researchers have discussed a cross-border *in situ* database tool for validation and atmospheric correction.
    - US processed data span Vancouver Island south to offshore Oregon, from 2002-2012 at a 300 m spatial resolution (MERIS satellite data). Monthly composites, seasonal composites, monthly climatologies, annual climatologies, and regional summary statistics are available. Contact Brandon Sackmann (bsackmann@integral-corp.com) for data access.
    - Maycira Costa et al. developed an autonomous data acquisition platform that has been installed on BC ferries to validate and calibrate long-term satellite imagery. Validated satellite data show seasonality and region-specific patterns in chlorophyll blooms within the Strait of Georgia.
- The SalishSeaCast, a high-resolution model including physical forcing (wind, river flow) and lower trophic levels (silicates, nitrates, ammonium and diatoms, cryptophytes, microzooplankton, and mesozooplankton), has been developed and is producing reasonable results. Simulations are depth-specific and daily "real-time"; the model can also produce hindcasts. Model results are available at http://salishsea.eos.ubc.ca/nemo.
- Preliminary comparisons of Strait of Georgia phytoplankton estimates derived from satellite imagery with zooplankton samples from the IOS database suggest that bloom initiation timing and bloom duration impact zooplankton abundance and biomass, with some amount of lag. Further analysis is needed to understand phytoplankton-zooplankton linkages over time and space.
- Harmful algae blooms in Strait of Georgia may be associated with negative impacts to juvenile salmon. In 2014, juvenile salmon appeared lethargic when caught and post-tagging mortality was high; in 2014-2016 chinook salmon had lower catch rates and a greater proportion of empty stomachs during blooms. In 2015, gill condition of salmon was poor following mechanically harmful non-toxic diatom blooms. In 2016, fish caught in sublethal toxic blooms had edema in the gills and signs of liver degeneration. Coho were more affected than chinook.
- Zooplankton sampling programs have been developed and are ongoing for Puget Sound and Strait of Georgia; researchers have begun collaborating cross-border on data analysis. In general, regional and seasonal patterns in species composition are present throughout the Salish Sea.
    - In Strait of Georgia, zooplankton abundances are dominated by copepods and biomass is dominated by "fish food" (euphausiids, amphipods, decapods). Time series anomalies (1990-2010) were created for fish food taxa in Central Strait of Georgia and correlated significantly with residuals of the linear trend in coho marine survival declines. This relationship indicates that interannual variation in survival can be related to the zooplankton community. The NPGO also appears related to fish food taxa.

  - In Puget Sound, fish food taxa contributions to overall zooplankton biomass are observable, but they do not dominate like in Strait of Georgia – zooplankton community abundance and biomass are both dominated by copepods. There was a shift in species composition from 2014 to 2015, overall and within each region. Abundances of almost all taxa increased from 2014 to 2015. A copepod index developed from the JEMS time series (sampled 2003-present) correlates strongly with coho marine survival. Coho survival residuals show a zig-zag pattern which matches the copepod index: even-year peaks from 2003-2010. Preliminary assessment of chinook data suggest that yearling chinook marine survival is correlated with the copepod index but subyearling chinook marine survival is not.

Forage fish and salmon growth and survival

- Age-0 herring comprise up to 30% of chinook diets in Strait of Georgia offshore surveys, and survival of some chinook stocks is correlated with age-0 survey catches. Modeled age-0 herring abundance increased with spawning biomass, increasing predators, and increasing competitors. These results suggest that favorable conditions for herring may also favor coho and chinook. Modeled age-0 condition decreased with increased spawn biomass, higher temperature, and peaked at a given predator abundance and zooplankton density. These results indicate that condition may be density-dependent and that chinook and coho may influence herring condition.
- Puget Sound has three genetically distinct herring stocks: Cherry Point, Squaxin, and other (a group composed of 18-21 stocklets defined by spawn site location and spawn timing). Spawn biomass of Cherry Pt declined over the 1970s and has remained low; spawn biomass for all other stocklets varies interannually. Cherry Pt is anomalously late-spawning (April-June); others typically spawn January-March. Over a one-year intensive midwater sampling program, herring catches were highest in April and September, and about 70% of the fish were age-2 or younger. Chinook survival showed weak positive or stronger negative relationships with herring abundance from the same sub-basin, depending upon the Chinook and herring populations/sub-basins assessed. The relationship between herring abundance and steelhead survival Puget Sound wide was insignificant.
- Through assessing 8 specific years of high/low marine survival across 3 decades, Puget Sound Chinook first year growth is positively related to marine survival, whereas first year growth of Washington coast populations does not correlate with marine survival. Early marine growth may provide a good indicator for forecasting.
- Summer weight and fall weight correlated positively with overall marine survival of coded-wire-tag (CWT) release groups but the strength of these relationships varied by time and region. In 1997-2001 and 2007-2008, summer weight was positively correlated with survival. From 2002-2006 and in 2011, fall weight was positively correlated with survival. Generalized linear models (GLMs) based on CWT release groups indicated that the best predictors of survival for US stocks were summer and fall weights and release date. Preliminary models based on individual fish characteristics suggest Puget Sound growth (weight change with relation to time spent in Puget Sound waters) affects overall marine survival.
- Otolith microchemistry results indicated that, for North Puget Sound and Cowichan chinook stocks, fry outmigrants contribute up to a third of returning adults. Fry outmigrants contribute much less to Central and South Puget Sound populations. Amount of estuary development may be negatively related to fry contribution.

- South Thompson chinook escapement has increased while other stocks have declined. Their ocean entry timing is later than most other stocks, but may be changing in recent years. Most are caught in Malaspina Strait and South Strait of Georgia. They tend to eat more amphipods and fewer euphausiids than other stocks.
- In general, Strait of Georgia chinook offshore diet composition varies regionally with herring more important in South Strait of Georgia. Diet varies seasonally and with fish size. Non-herring larval fish are becoming more common in diets. Stable isotope data suggest stock-specific diet variation; this may be due to stock-specific sizes, differential use of prey resources, or stock distribution and regional food availability.
- Juvenile chinook micro-trolling results indicated fine-scale spatial and seasonal variability in distribution, size, and diet. Evidence suggests that fish outmigrate in a pulse, may aggregate in areas of tidal mixing, and may remain fairly resident in a small area for a period of time. Growth appeared to be higher in 2015-2016 than 2014. About a third of all diet items by weight were herring, but only a few fish ate herring. The fish that did eat herring ate large herring (almost half their length) and had wider circulus spacing indicating higher growth. Zooplankton abundances declined from July-October, coincident with an increase of fish in chinook diets. Key point here is that the YOY herring are at or above prey length threshold for most Chinook. Chinook too small to feed on herring would be faced with declining zooplankton abundances, with likely further detrimental impacts on growth.
- Scale analyses of early growth (from release until July) within Puget Sound watersheds in 2014 showed little to no evidence for size-selective mortality. Growth rates appeared highest for fish transitioning from nearshore to offshore and generally higher offshore than nearshore. Nearshore diets included high proportions of insects and offshore crab larvae. Modeled feeding rates did not differ among habitats. Temperatures observed in warmer nearshore and cooler offshore habitats may impact growth.
- IGF-1 concentrations for Skagit, Nooksack, and San Juan Islands samples were higher in offshore regions than nearshore regions. San Juan Islands samples had elevated growth rates in both nearshore and offshore habitats relative to other regions. Growth rates did not vary highly between 2014 and 2015. Length may be a confounding factor; there was a significant relationship between fork length and IGF-1. Regional IGF-1 differences may reflect regional diet variation: there is a significant increase in IGF-1 when fish are incorporated into the diet, and San Juan Islands diets were more fish-dominated.

Salmon behavior, survival, and interactions with the surrounding environment

- Juvenile Cowichan Chinook survival in freshwater was found to be strongly correlated to migration distance (i.e. tagging site) for both wild and hatchery groups based on PIT tag detections. For groups released furthest upriver, survival during the 47 km migration to the estuary was estimated at 14% for wild fish and 12% for hatchery. Migrants from the mid-river (26 km) fared better at 59% for wild fish and 53% for hatchery. Significantly lower marine recapture rates for upper river groups supported in-river survival estimates.
- Over 100 Cowichan Chinook PIT tag detections were recorded in a lower river side channel from mainstem release groups. Further investigation revealed groups of tags migrating upstream synchronously. Trail cameras were deployed and raccoon activity was high; behavior suggested any tags inside the animals could have interacted with the detection field of the antennas. Assuming

upstream migrating tags were attributed to raccoons, losses for just the late hatchery release (12 of the 100 tags) were estimated at 14% of the total available or approximately 4800 fish.

- There was no evidence to suggest larger Cowichan Chinook migrants survived the downstream migration at a higher rate than smaller. Larger fish tagged in the marine environment during 2015 were found to return at a higher rate in fall 2016 as age 2.
- Acoustic-tagged hatchery-reared Chilko River Chinook smolts (N = 100) had in-river survival rates of 48%, which is similar to Chilko Lake sockeye and Chinook from other regions that migrate similar distances (~650 km). Only one tagged fish was detected in the marine environment. These fish were tagged with 180 kHz (V5) tags, which cannot be detected by the Juan de Fuca acoustic sub-array. Because fish were not detected leaving the Salish Sea via the northern route, either mortality upon saltwater entry was high, fish resided in the Strait of Georgia, or fish outmigrated south through the Strait of Juan de Fuca.
- Migration path influenced survival of acoustic-tagged Seymour steelhead: migrating through the Discovery Islands was associated with higher survival. Fish released in-river (south of Burrard Inlet) survived to Queen Charlotte Strait at a rate of 9% while fish released north of Burrard Inlet survived at a rate of 27%. Burrard Inlet appears to be a mortality hotspot.
- Acoustic-tagged age-1 Chilko Lake sockeye had higher survival to Johnstone Strait (16%) than age-2 Chilko sockeye (2%), with the biggest survival difference occurring in the first 14 km of outmigration in the Chilko River. This may be influenced by size-selective predation (by, e.g., bull trout), tag burden, and potential differences in physical condition, microbe load, or feeding behavior. Median residence time of age-1 fish in the Strait of Georgia was 20.5 days.
- A 2016 replication of the 2014 study found no evidence that harbor seals' ability to hear the acoustic tags implanted in Puget Sound steelhead bias estimates of the rate and locations of steelhead early marine mortality (aka. dinner bell effect): there was no significant difference between survival of continuous-tag fish and delayed-tag fish.
- Previous acoustic tag studies (2006-2009, 2014-2015) on steelhead found survival rates of less than 20% through a 2-week outmigration through Puget Sound. In 2016, survival was surprisingly high – almost 40%. Travel times were not different from previous years. In-river survival was lower than typical. Earlier outmigrants survived better in-river. Outmigration timing did not affect marine migration segments. All stationary tags (presumed mortalities) were found within 5 km of saltwater entry. Some tags exhibited abnormal behavior consistent with predation.
- Acoustic-tagged coho had higher survival within Puget Sound in 2016 than estimates from previous years. Coho appeared to remain in Puget Sound through most of the summer.
- Seal packs were deployed on 16 harbor seals in South Puget Sound, Central Puget Sound and Admiralty Inlet in 2016 to assess seal foraging behavior and increase spatial coverage of tag detections. About 60% of tagged steelhead and coho were detected by seals, and coverage of haul-outs and nearby areas was very good.

Predation, disease, and contaminants

- Seal scat collections suggest that some seals eat juvenile chinook, coho, and sockeye, and appear to select them over juvenile chum. A small number of seals may be specialists (smolt-eaters). Consumption models suggest that seals have the capacity to consume a large proportion of the smolt population. Model estimates for Strait of Georgia indicate up to 55% of coho smolts and 44%

of chinook smolts may be eaten by seals. Modeled consumption for inland Washington waters suggest that seal consumption increased from 1 million chinook smolts in 1970 to 7.8 million chinook smolts in 2015. Male seals appear to eat more salmon (particularly coho) than female seals. Scat collections are ongoing to improve diet proportion data.

- Seal behavior studies indicate three foraging ecotypes: non-estuary, intermediate, and estuary. In Big Qualicum estuary, 96 seals ate almost 24k smolts. These estuary specialists are a small component of total seal predation. Estuary predation occurs mostly in the evening/night, possibly because more fish outmigrate then. Additional data are needed to characterize non-estuary and intermediate feeding.
- Researchers developed a molecular test that can detect diseased individuals before mortality and has the potential to detect pre-symptomatic individuals. The tool is applicable across salmon species and tissue types, and works for all RNA viruses tested so far. Additional tests are ongoing.
- A genome-wide association study found strong group structure among steelhead loci associated with parental life history (two anadromous (vs. resident) parents vs. one vs. zero) in the Green and Nisqually watersheds. After removing group structure, loci associated with parental life history remained significantly related to survival for Green River steelhead. No loci were significantly associated with survival for Nisqually steelhead.
- Comparison studies between release groups and laboratory groups of *Nanophyetus*-exposed and unexposed steelhead were conducted. Results suggested that exposed fish had slightly lower survival through Puget Sound, swam slightly poorer, and had slightly higher mortality on saltwater transition. Differences were not significant among groups. Parasite loads attained in these studies were much lower than parasite loads observed in the wild (mean 232 in lab vs. 2546 in wild). Laboratory studies will be repeated with higher parasite loads in 2017.
- Researchers developed a qPCR tool to quantify *Nanophyetus* presence. The tool can detect *Nanophyetus* in fish samples, snail samples, and water samples and is currently being used to quantify seasonality of *Nanophyetus* presence in Soos Creek.
- Treatment options for *Nanophyetus*-impacted facilities/watersheds were tested. Formalin and salinity treatments both achieved 100% mortality over short periods of time.
- Chemicals of emerging concern (CECs) were present in Skagit, Snohomish, Green, Puyallup, and Nisqually chinook samples. CECs were detected in both urban and non-urban watersheds, with slightly more urban detections. Antibiotics were most frequently detected; all samples contained at least one type of antibiotic. Antidepressants were also commonly detected: antidepressants were present in all Puyallup samples and 2/3 of Green, Snohomish, and Skagit samples. No antidepressants were detected in Nisqually samples. Previously reported results indicated that a third of these samples contained contaminants of known concern (PCBs, PBDEs, DDTs, PAHs, lead) at concentrations associated with adverse effects likely affecting marine survival. Increasing temperatures may worsen contaminant effects.

Critical Concerns, Project Gaps and Affiliated Considerations

The group strongly recommended development of a list or catalog of in-hand datasets that would be made available to all SSMSP researchers. A centralized repository for data would be beneficial; currently the Strait of Georgia Data Centre and Basecamp websites are serving data-sharing roles. The group also recommended continued cross-border and cross-discipline communication in the form of task teams and workshops, more focus on years of high variability, time series which span a period of ecosystem change (or "regime shift"), and regions/populations with contrasting patterns.

Data gaps reported by researchers included disconnects between scales of data collection, a lack of productivity rate measurements, limited information on non-salmonid fish species which may impact salmon or indicate ecosystem change, and a continued lack of experimental studies.

Modelers should be working cross-border as much as possible through model development. There are some concerns about cross-border data comparisons; for example, herring are aged differently in Canada than in the US. Modelers should keep communication lines open with all researchers providing data and all cross-border working groups. Multiple models of varying complexity should be incorporated in ecosystem indicators and ecosystem modeling work, and models should consider both direct and indirect interactions among variables. For example, disease may indirectly affect salmon survival by influencing their susceptibility to predation. Some variables may have direct and indirect influence: at high concentrations, *Noctiluca* and gelatinous zooplankton abundance can directly impact salmon – but they are more likely an indicator of another variable or ecosystem shift. Currently planned models do not address individual variation in survival probability (i.e., genetics of an individual is not detailed in current models). Stock-specific analyses may be incorporated to address genetic variation of stocks; disentangling stock-specific variation from watershed variation is difficult.

Next Steps

- Both US and Canadian researchers have prioritized ecosystem modeling efforts, linking fish performance and behavior to oceanography and lower trophic levels, determining how to scale focused studies to the larger ecosystem, and continuing and developing workgroups to address cross-border and cross-project needs. Specific project activities under consideration are listed on page 38.

- Given the ongoing US and Canadian ecosystem modeling efforts, hold a series of ecosystem modeling workshops at strategic points over the course of Puget Sound and Strait of Georgia model development. LLTK and PSF will work with the modelers on this concept. This includes workshops to review model parameterization/data gaps, finalize the suite of hypotheses/scenarios to test, and review model outputs.

- Create a US-Canada synthesis/results task team. Based upon discussions after the retreat, this task team would begin to convene in 2017 to help prioritize hypotheses for model/indicator analysis, review the timeline of when results will be available and determine what the key synthesis/results papers should be for the project that identify the key limiting factors and explain remaining data gaps. Initially, we could envision a limiting factors manuscript accompanied by a white paper suggesting management actions. LLTK and PSF will guide this effort.

- Continue to work on cross-border dataset comparisons. Current efforts underway or planned include zooplankton abundance and composition, harbor seal diets, chinook population distribution and survival, and chinook diets and level of piscivory. Also being considered are success of chinook outmigrant strategies based on adult otolith collections, and satellite data (bloom timing, turbidity, etc.). Integration of physical > plankton > fish data and integration of satellite data with in situ observations are being explored. Coho and chinook survival time series are being updated, including improving the wild coho survival dataset for British Columbia, and scientists from US and Canada are comparing freshwater to marine survival for certain Salish Sea wild coho populations.

- Create a list or catalog of in-hand datasets available for all SSMSP participants.

Thursday, Dec. 1: Report and Discuss Current Results

Primer: Ecosystem Modeling and Indicators with Focus on Data Gaps

Exploring drivers in declining marine survival in Pacific Salmon using qualitative network models (Kathryn Sobocinski)

Qualitative network analysis is a tool to determine relative influence of different factors on variables of interest, allowing us to explore the relative impact of a suite of drivers on salmon survival and abundance. This type of analysis can incorporate variables which are not standardized to each other and variables with little data, and can be used as a planning tool.

The model consists of nodes (variables of interest, e.g., diatoms, salmon survival, disease, upwelling) and linkages (relationships between nodes; can be positive, negative or neutral/unknown). A pool of stable models is developed via simulation analysis where random weights are assigned to linkages. Perturbations to individual nodes or to groups of nodes can then be introduced to assess how salmon-related nodes respond.

The major groups of drivers included in these models were environmental (climate, physical), primary productivity, food web, and anthropogenic. Salmon population abundance and survival and individual fitness, size, and residence time were assessed in response to perturbations to drivers. The focal species for this exercise were chinook, coho, and steelhead.

Sensitivity analyses suggested that weighting scheme was not highly influential, some mid-trophic level linkages were highly sensitive, and nodal distance did not strongly influence results (i.e., both direct and indirect factors impacted salmon survival).

The strongest impacts to salmon metrics were from a suite of anthropogenic factors (hatcheries, habitat loss, contaminants, disease), which had negative effects on survival, abundance, and fitness. Impacts from other groups of drivers on focal salmon species were mixed. Decreasing diatoms produced strong negative effects on survival and abundance, and decreasing zooplankton produced strong negative effects on fitness and size. Increasing CO_2 had strong positive effects for survival and abundance, likely because it increased diatoms. Food web responses to perturbations, although indirect, were relatively strong.

Q&A

- Ken Warheit – hatcheries can have species-specific impacts. Is this incorporated? How much of the anthropogenic group impact is driven by hatcheries?
    - This model does not support that specificity; it does not have the power to discern details like multiple life history strategies, etc. Hatcheries created negative impacts via the food web by adding more fish into the system. Conversely, harvest had a positive impact on survival because abundance decreases reduced competitive aspects of the food web.
- Ken Denman – can this model be used in a predictive mode? For example, could you include temperatures predicted 20 years from now?

   - Kathryn incorporated literature and trends as much as possible. Uncertainty could be added, but it would introduce additional complexity to a model already more complex than most other qualitative network analyses.

- Ian Perry – in Bayesian models, there is a "wash-out" effect with more, longer linkages. Is this model susceptible to that effect?
   - Kathryn will follow up on this; whether/how number of drivers affects model results and varying levels of perturbations on certain nodes are to-do items for this analysis that are not yet complete.

Salish Sea ecosystem indicators: data aggregation progress and gaps (Kathryn Sobocinski)

The objectives of this project are to develop candidate indicators of salmon marine survival and aggregate datasets, evaluate candidate indicators, and include useful indicators within retrospective and predictive modeling frameworks. Useful indicators should be theoretically sound, respond predictively to ecosystem change, be integrative, and be relevant to management concerns. Response variables for this study are marine survival of chinook, coho, and steelhead. Abundance will also be included as a response variable. The longest marine survival datasets have 40 years of data; this varies widely by species and population.

Candidate indicators have been developed and include variables reflecting boundary conditions (e.g., spring river discharge, upwelling index, ENSO), Salish Sea conditions, salmon characteristics (e.g., abundance of outmigrants, outmigration timing, growth), food web, and anthropogenic impacts. Dataset aggregation is in progress. Many datasets are in hand and undergoing preliminary processing and standardization. Monthly and annual datasets are most valuable, and spatially discrete data are desired at the sub-basin scale. Evaluation of candidate indicators for usefulness is just beginning.

Data gaps include

1) lack of long time series. There are few datasets from the 1970s, when survival was good. Where break points have been defined in survival time series, good data on either side of the break for candidate indicators is needed.
2) data from mid-trophic levels. There are few long-term datasets characterizing the middle of the food web (zooplankton to piscivorous fish).
3) data characterizing anthropogenic impacts. Habitat loss, artificial light, etc. have not always had systematic surveys.

Q&A

- Villy Christensen – caution against selecting useful indicators based on correlation.
   - Kathryn will incorporate other statistical analyses (GLMs, GAMs, multivariate analysis, DFA) in addition to correlative studies to assess candidate indicator usefulness.
- Brian Riddell, Julie Keister, and Ken Denman recommend shared database access.
   - A centralized repository is important; people are generally more willing to provide data when access is not totally public. Currently, SOG Data Centre and Basecamp sites are used.
   - Strong recommendation from the group to develop a list/catalog of datasets in-hand for distribution to all US-Canada folks.

Puget Sound Atlantis ecosystem modeling: progress and gaps in testing hypotheses related to salmon early marine survival (Raphael Girardin)

An Atlantis ecosystem model is under development for Puget Sound. Atlantis is a good tool for investigating hypotheses around early marine survival, understanding trophic interactions and cumulative impacts, and evaluating management scenarios. The model is not intended for tactical management (e.g., developing quotas), stock assessments, or parameter estimation.

Atlantis is a dynamical biogeochemical end-to-end model which follows fluxes of nitrogen through a system. Hydrodynamic forcing is from the ROMS model developed by Parker MacCready. Geography for the model was developed based on sub-basin structure and data sources like forage fish and groundfish surveys and salmon recovery areas. A circulation model controls passive fluxes (water, heat, salinity) through the sub-basins on 12-hr time scales.

The model incorporates life history traits, species, and juvenile/adult stages. Functional groups were designed based on the Atlantis model for the California Current, Puget Sound Ecopath with Ecosim models, and expert advice. Salmon groups in the model are defined by species, sub-basin, wild/hatchery, and run types. Each group includes a juvenile and adult component.

This project is currently in the data acquisition phase. Calibration of the model will begin in March 2017 and extend through 2017. Model simulations will begin in late 2017.

Q&A

- Sandie O'Neill – do you have WDFW bottom trawl data collected by Wayne Paulsen?
    - Dayv Lowry is aggregating WDFW data to send to Raphael and Isaac.

How has the environmental productivity of the Salish Sea changed in the last 50 years, and what impact has this had on salmon? (Villy Christensen)

This modeling effort couples food web models (EwE) with physical (Salish Sea ROMS) and biogeochemical models to produce an end-to-end model for the Strait of Georgia. The EwE model will be spatialized with a dynamic habitat model. The ROMS model will be extended as far back in time as possible (1980?), and the biogeochemical model will be adapted to the same time period. Maycira Costa's primary production maps from satellite imagery will be used for validation. The full model is targeted for completion in 2019. One key data issue right now is drivers for the physical model. The model uses wind data, but not all 21 wind stations have long time-series.

Q&A

- Dick Beamish – how do these models deal with the abrupt change in phytoplankton anomaly 1989-1990? Most people accept that 1977 and 1989 were years of regime shifts. Also we started seeing the warming effect of climate change in the 1970s. What changed between mid-1980s and early-1990s? Abrupt shifts likely only affect a small number of parameters then propagate throughout the system.
    - Isaac Kaplan – we do not have long time series of winds or physical forcing in Puget Sound. The Atlantis model is based on the ROMS model (2 years). We hope to coordinate with Villy and share ocean forcing to the extent possible. Model components (e.g. phytoplankton) can be manually forced if needed.

- Parker MacCready – long time series are clearly essential for model scenarios. We have good data for rivers. Weather products are not as long-term, and they tend to improve in quality over the time series. Open ocean (boundary) conditions will likely be important.
- Villy Christensen – data availability is definitely an issue: some critical data starts 1990s or later. Modeling efforts for other regions have used average conditions to substitute for missing data, which may be an option here. Model hindcasts for boundary conditions can be used. The hope is that signals would be so strong that they will be obvious.
- Chris Harvey – regime shifts can be used to validate model calibration.

- Evelyn Brown – the U.S. is moving towards ecosystem-based fisheries management. How can stochastic fish models be paired with EwE models?
  - Villy Christensen – for EwE it is standard procedure to incorporate uncertainty.
  - Isaac Kaplan – the PFMC has put lots of effort into integrating EBFM with day-to-day management. Ecosystem modeling is incorporated into groundfish impact documentation. Definitely considering this as we move forward.

From Physical Conditions to Plankton

Surface water conditions in the Salish Sea: satellite and in situ *(Brandon Sackmann)*

The objective of this work is to provide satellite-derived ecosystem indicators across large spatial areas at high spatial/temporal resolution. Water quality indicators (color, clarity, algal biomass, freshwater influence, and SST) can be measured from satellite images by combining traditional ocean color sensors and terrestrial platforms. Satellite data span 1984-present (1-8 day revisit) at 30-500 m spatial resolution. 2002-2012 (3-day revisit) MERIS data was chosen as a starting point as it provides increased temporal resolution, important for cloudy regions. Brandon has transformed raw data into geophysical metrics (e.g., chlorophyll, diffuse attenuation coefficient, turbidity), as well as other indicators (fluorescent line height, etc.). Data span Vancouver Island south to offshore Oregon. Monthly composites, seasonal composites, monthly climatologies, and annual climatologies are all available and produced graphically. Regional summary statistics over the time series are available. Time series data can be paired with DOE and KC long-term monitoring data to groundtruth. Future work will include groundtruthing, long-term trend analyses and region-specific anomalies, comparing MERIS and UVic MODIS time series, extending MERIS time series with Sentinel 3 data, and hi-res and SST product development.

To get data, email bsackmann@integral-corp.com and provide Brandon with an external hard drive (each L1/L2 product compresses to about 5 TB). MATLAB access is required to use existing scripts.

Q&A

- Parker MacCready – can you comment on clouds and subsurface chlorophyll maximum?
  - Clouds will always be an issue. Typically monthly compositing looks okay, but finer-scale is not always so good. Subsurface chlorophyll maximum depends on where you are offshore. In Puget Sound, light attenuates too quickly – use discrete CTD measurements instead.
- Julie Keister – monthly composites are too long for zooplankton lifecycles. Weekly or daily composites are needed.

Spatial-temporal dynamic of productivity in the Salish Sea (Maycira Costa, Karyn Suchy)

This study validates long-term satellite imagery with autonomous data acquisition from ferries. Sensors installed on ferries continuously measure light, sun position, and ferry position. These data are used to calibrate satellite data. Composites (8-day) were produced from 2002-2016 for North, Central, and South Strait of Georgia.

Data show seasonality and region-specific patterns in chlorophyll. Central Strait of Georgia bloom timing from 2014-2016 was April 2, Feb. 21, and March 8 (respectively), and North Strait of Georgia bloom timing in the same years was April 10, Feb. 21, and March 16. EOF analysis is being used to recover missing data due to cloud coverage. Currently, Maycira et al. are identifying spatial-temporal hotspots of productivity and determining whether zooplankton and fish patterns align. The next phase is to split data into smaller regions. Also, link with Sentinel 3 (2016-onwards) to allow for very high spatial resolution.

Pairing phytoplankton estimates (derived from satellite imagery) with zooplankton samples (IOS database) for northern and central Strait of Georgia 2002-2016 may be difficult because data are collected on different time scales. Data suggest there may be a time lag between phytoplankton and zooplankton. Generally crustacean abundance is dominated by small zooplankton (small copepods, etc.) while biomass is dominated by medium zooplankton (medium copepods, etc.). Abundance and biomass anomalies were very different in 2010 & 2011, when chlorophyll data showed a late bloom initiation and short bloom duration.

Q&A

- Isaac Kaplan – can these sensors be added to Puget Sound ferries? Can groundtruthing be generalized to Puget Sound?
    - The main use of the ferry data is for atmospheric correction. There is an assumption that the data collected along the Horseshoe Bay-Departure Bay-Tsawwassen-Swartz Bay routes are spatially representative of the Salish Sea. Brandon and Maycira have discussed a cross-border *in situ* database tool.
    - Installing and maintaining sensors and developing autonomous data acquisition algorithms is time-intensive and expensive. Brandon says the Victoria Clipper has optical sensors and some WA state ferries have ADCPs.
- Jim Irvine – encourage quantitative retrospective analysis where possible. Calibrate data during periods of change. Chrys Neville suggests recent years of high variability: 2005, 2007.
- Dave Beauchamp – are ferry measurements taken through the night as well?
    - Data become unusable when sun is below 30°. No data November-February for ferries or satellite data, and no nighttime data.

SalishSeaCast: a real-time, coupled bio-physical model of the Salish Sea (Elise Olson)

The SalishSeaCast is a high-resolution model based on NEMO (European ocean model) which includes physical forcing (Environment Canada wind data, Fraser River flow) and lower trophic levels (silicates, nitrates, ammonium and diatoms, cryptophytes (flagellates), microzooplankton, mesozooplankton). The model is currently running and producing reasonable results. Simulations are depth-specific and are daily “real-time” since December 2015. The model can also produce hindcasts. Improvements to the model that are currently underway include improving parameterization for light attenuation including river discharge effects and tuning based on sensitivity analyses. Model results are available at a 1-hour resolution via website (salishsea.eos.ubc.ca/nemo) and ERDDAP server.

Q&A

- Parker MacCready – how did you decide on a 500m resolution?
    - The 500m resolution is a balance between the highest-desirable resolution and what is computationally feasible.
- Marc Trudel – suggest groundtruthing model by testing whether it can generate images that match Maycira's satellite imagery.

Phytoplankton and harmful algal blooms in the Strait of Georgia (Svetlana Esenkulova)

Phytoplankton community groups include diatoms, dinoflagellates, silicoflagellates, and raphydophytes. These groups are all very different; for example, diatom cells are made of silica and they are autotrophs with rapid growth rates, whereas dinoflagellate cells are made of organic compounds and they are autotrophs/mixotrophs/heterotrophs with slow growth rates and swimming capabilities. Phytoplankton dynamics in Strait of Georgia are controlled mainly by Fraser River discharge and stratification/mixing depths (winds).

The SOG Citizen Science program sampled physical data, nutrients, phytoplankton, and zooplankton every 2 weeks February-October 2015-2016 at about 80 locations. In 2015, the spring bloom was very early with *Skeletonema costatum* as the dominant diatom species. Dinoflagellate contribution was unusually low and silicoflagellates and raphidophytes were almost absent. The early bloom was associated with warmer water temperatures and earlier snowmelt than average, and low summer biomass and high diatom dominance were associated with low river discharges and low summer rainfall.

No *Heterosigma* blooms were recorded in 2015; however, there were moderate to high levels of mechanically harmful diatoms (*Chaetoceros* spp) in several locations during late-May/early-June. Gill condition of juvenile salmon was poor following these blooms.

In 2016, the spring bloom was several weeks later and longer duration than in 2015, with higher biomass throughout the summer. The species composition was more normal, with contributions of dinoflagellates, silicoflagellates, and raphidophytes as well as diatoms. There were moderate blooms of mechanically harmful coccolithophores in summer, and elevated levels of toxic phytoplankton in some areas after heavy rains.

Histological analysis was performed on juvenile salmon for a control group, a group caught during a toxic bloom, and a group caught in a nontoxic coccolithophore bloom. Preliminary results suggest edema in gills of fish caught in toxic bloom. There were also signs of liver degeneration: glycogen vacuoles (sign of starving), swelling of hepatocytes, and nuclear apoptosis. Toxic bloom concentrations were sublethal. Coho were more affected than chinook.

Q&A

- Paul Hershberger – was there wild fish mortality during the *Heterosigma* event?
    - During the bloom, high mortalities occurred during PIT tagging, which usually has a very low mortality rate. Lethargic behavior was observed in seines. Chum looked least affected;

however this may be an artifact of to the depths the fish occupied before being brought to the surface by the trawl.

- Ken Denman – satellite images showed a huge plume off the mouth of the Fraser in 2016. Was that a coccolithophore bloom, as seen in other regions? Maycira – there was a dramatic change in water color in Central Strait of Georgia during the two weeks of that bloom timing.
    - Svetlana – one of the limitations of *in situ* data is that our preservation methods are destructive to coccolithophores.
- David Welch – how can we test the link between these observations: effects on gills and effects on survival?
    - These are the first observations on wild fish of how phytoplankton may directly affect survival. The liver effects are the first case of wild fish in documented bloom with a health issue.
    - Kristi Miller – suggest teaming up with aquaculture industry to understand links. Sample cultured fish when there is a bloom event: bloom metrics, fish gills, liver, mortality rate. We need a baseline set of information that does not yet exist and would not be feasible to get from wild fish. The industry doesn't like to sample fish during blooms, since they don't want to handle them. So that would be an issue to overcome.
    - Paul Hershberger – Jack Rensel did holding studies with *Chaetoceros* and showed similar levels producing mortality.

Zooplankton status and trends in the Strait of Georgia, Canada: 2015 in context and relationships with coho (Ian Perry)

In 2015, spring genus-level composition of Central and North Strait of Georgia overlapped; nearshore regions were different from all others. In the summer, NMDS plots indicated a gradation in composition from northern to central to southern Strait of Georgia. Abundances were dominated by copepods; biomass was mostly euphausiids, amphipods, and decapods ("fish food"). Fish food taxa peaked in abundance in early spring (euphausiids and decapods) and late spring through summer (amphipods). The largest biomass of fish food taxa occurred in late fall. There was a pulse of high ichthyoplankton abundance in March, and a biomass pulse in June (smelts). Spatial distributions showed highest arthropod biomass in northern areas, and there were high abundances near Texada Island.

Time series anomalies (seasonal, averaged to annual) were created for fish food taxa in Central Strait of Georgia for 1990-2010. There is a significant correlation (although low explanatory power) between fish food anomalies and residuals of the linear trend in coho marine survival declines. This relationship doesn't address long-term declines, just interannual variation (the trend is removed for analysis). NPGO also appears related to fish food taxa; a relationship with PDO is less clear.

Q&A

- Kathryn Sobocinski – estimating production vs. standing stock abundance. Are you accounting for fish abundances, movement? Marc Trudel – adding to this question, salmon are small players in the pelagic community. Accounting for other groups (e.g., herring) is necessary and probably best done through an ecosystem model.
    - Ian's group is working to get zooplankton production measurements directly, and looking at fish guts for insight.
- Ken Denman – if you estimated salmon consumption needs, would they dovetail with zooplankton abundance? There aren't many cases of phytoplankton/zooplankton where we conclude top-down

harvest control – does that mean that food is not limiting, or does it mean our interpretation is flawed?

- Chrys Neville – fish are size-selective. Are you looking at zooplankton sizes?
    - Ian's group is working on looking at size. They have point estimates but no time series yet. Crustaceans have discrete sizes, non-linear growth.

Southern Salish Sea zooplankton (Julie Keister)

The Puget Sound sampling program uses a distributed sampling approach where 10 sampling groups collaborate to sample 15 stations every two weeks from March-October. One additional station (JEMS) in Strait of Juan de Fuca has been sampled monthly since 2003. The JEMS station is sampled with vertical tows. The other 15 stations are sampled with both vertical tows over the full water column and oblique tows designed to capture the salmon prey field in the upper 30 m of the water column. Over the first three years of the program (2014-2016), sample quality improved from a 15% error rate to 5% error rate for oblique tows, and from a 13% to a 0% error rate for vertical tows.

The warm blob intruded into Puget Sound late 2014, and 2015 was off-the-chart hot throughout the spring, summer, and fall. Blob effects varied by region.

Zooplankton composition in vertical samples varied by region, generally in a north-south gradient pattern, where more northern stations had more oceanic taxa and more southern stations had more Puget Sound taxa. There was also a shift (in each region and overall) in composition from 2014-2015. Abundances of almost all taxa increased from 2014 to 2015.

Abundances in vertical tows were dominated by copepod species. Biomass was also dominated by copepods. Amphipod, euphausiid, and decapod contributions were observable, but did not dominate biomass like in Strait of Georgia. In May-June 2015, decapod contribution was larger than all other months in 2015 and 2014.

Abundances in oblique tows were dominated by copepods. Biomass was mainly copepods and (in 2015) decapods. The oblique tows with larger net mesh catch larger zooplankton better than vertical tows with smaller net mesh.

A copepod index developed from the long-term JEMS time series correlates very strongly with Puget Sound coho marine survival. Residuals from 3-year running mean coho survival show a zigzag pattern with odd year peak survival from approximately 1989-2003 and then a shift to even year peak survival until 2010. The copepod index also shows the zigzag pattern with even year peaks from 2003-2010. The copepod index pattern shifts from 2010-2011 to odd year peaks. Additional years of coho data are needed to see whether the coho zigzag pattern also shifts. Preliminary assessment of chinook data show that yearling chinook marine survival correlates well with the copepod index but subyearlings do not, suggesting that size/timing at marine entry may affect the mechanisms driving the relationship.

The copepod composition differs between even and odd years, but does not appear to reflect an oceanic/Puget Sound signal. There may be some evidence of a size-based signal (proportionally more large-body species in odd years), which might reflect size-selective predation.

Q&A

- Evelyn Brown – can oblique tow data be scaled to vertical tow data?
    - Scaling could be possible eventually, with a long-term data series. Developing relationships between Strait of Georgia and Puget Sound is high-priority.

- Marc Trudel – with predator-prey relationships, both predators and prey can co-vary and then crash of one leads to reversal of the pattern. This kind of dynamic could be associated with the zigzag pattern.
- Dick Beamish – the zigzag pattern occurs too frequently in the Salish Sea to be random. There is something fundamental here that must be understood.
- Young-of-year herring also has a zigzag pattern, but the pattern doesn't reverse at the same times in the same years.

About Forage Fish, and Salmon Growth and Survival

Juvenile Pacific herring trophic linkages in the Strait of Georgia (Jennifer Boldt)

Temperature affects timing of herring recruitment to each lifestage. There is an odd-even year zigzag pattern in age-0 abundances (mostly peaks in even years). From 1997-2014, age-0 condition increased (i.e., heavier fish for a given length). In 2005 and 2007, there were virtually no herring in Strait of Georgia, but the few that were caught were in good condition.

Processing for 2016 samples is in progress, but preliminary abundance estimates are similar to 2015 abundances. Anchovies were caught along the Sunshine Coast and south of Dodd Narrows.

North Strait of Georgia and South Strait of Georgia chinook survival is correlated with age-0 herring survey catches. Fraser/Cowichan chinook survival is not. Age-0 herring comprise up to 30% of chinook diets in Strait of Georgia midwater trawl surveys. Juvenile pink, chum, sockeye, and herring eat the same taxa and may compete. Herring size in Puget Sound is associated positively with summer temperature and negatively with fall abundance. There is evidence that avian predators target poor condition fish.

Based on these observations, hypotheses include 1) juvenile herring abundance is higher when there are fewer predators (chinook, coho), fewer competitors (pink, chum, sockeye), more prey (zooplankton), more herring spawn, and hatching aligns with spring bloom, and 2) juvenile herring condition is better when there are more predators, fewer competitors, more prey, warmer temperatures (metabolism, food conditions), and hatching aligns with spring bloom. GAMs were used to test these hypotheses.

GAM results suggested that age-0 herring abundance increased with spawning biomass, peaked when herring spawn was 20 days prior to spring bloom, increased with increasing predators, and increased to an asymptote with increasing competitors. These results don't support the hypothesis that predators (coho, chinook) are limiting herring abundance. Favorable conditions for herring may also be favorable for predators. Age-0 herring condition decreased with increased spawn biomass (potentially indicative of density dependence), increased when spawn timing was closer to spring bloom, increased with higher temperatures, increased to a peak of predator abundance then decreased (predator avoidance behavior might affect foraging at high predator abundance), and increased to a peak of zooplankton density then decreased. Preliminary conclusions are that bottom-up factors appear to affect age-0 herring: density dependence may influence herring condition, spawn date affects abundance and condition, salmon predators may not affect abundance but may influence condition, and salmon competitors may not negatively impact age-0 herring.

Q&A

- Evelyn Brown – are other year-classes of herring present in Strait of Georgia while age-0s are metamorphosing? Could zigzag pattern be a product of effects from older year-classes?

    - Most older herring are not present in Strait of Georgia during that time. Age-0 herring were included in models as competitors, and spawning biomass was included in models.
- Dick Beamish – is there a relationship between age-0 and age-3 recruits?
    - There is a significant relationship, but it is driven by two years (2005, 2007) where there were virtually no herring in Strait of Georgia.
- Francis Juanes – fish predators select based on length, not condition.
    - Condition was used in models because from the herring perspective, the fish has to hit a certain point before overwintering. Jennifer tried modeling using herring lengths, but did not find compelling results.

Trends in spawn and biomass of Pacific herring in Puget Sound (Todd Sandell)

Commercial fisheries for herring in Puget Sound were active since the late 1800s, with annual landings ranging from <50 to 6500 metric tons. The only active commercial fishery since 1996 has been the sport bait fishery, which lands 3-5% of cumulative spawning biomass annually (maximum harvest guideline is 10%) and targets juvenile fish from mixed stocks in Central Puget Sound. The Cherry Point stock harvest was closed entirely due to its decline since the 1970s. There are three genetically distinct groups of stocks: Cherry Point, Squaxin, and all others (18-21 stocklets defined by spawn site location and spawn timing).

There is high interannual variation in estimated spawn biomass of stocklets (aside from Cherry Pt, which has been consistently low since the decline). Qualitatively, based on old 1930s-1950s comments on fishery landings, Cherry Pt may have a decadal boom/bust pattern. The Cherry Pt stock is currently at an all-time low. Over the past couple years, Semiahmoo stocklet peaked then decreased again, and Quilcene stocklet had a dramatic increase – it now produces half the herring biomass in Puget Sound.

Spawn timing in Puget Sound is generally January-March, with a slight trend of earlier in southern stocklets. Cherry Pt is anomalously late-spawning, April-June. A new stocklet appeared recently in Elliot Bay which is also late-spawning (April) but not apparently related to Cherry Pt.

Generally relationships between herring biomass and juvenile chinook survival are positive (but with low explanatory power). A few exceptions are negative (Skykomish, UW). Steelhead and herring biomass relationships are all slightly positive. Big Beef Creek coho jacks are negatively related to Hood Canal herring.

In 2016, the WA state legislature funded a one-year intensive acoustic-midwater trawl survey targeting forage fish. Most of the Puget Sound catches are herring, in April and September. Jellyfish catches increased in summer. About 70% of the herring in the catch are age-2 or younger.

Q&A

- Evelyn Brown – there was an explosion of anchovy in 2016 off Grays Harbor and Squaxin, more than the locals had ever seen. Not just little ones, mixed-age.
    - The midwater trawls didn't catch many anchovy, maybe because they were trawling further offshore. They did catch some off Nisqually.
- Ken Warheit – initial genomic sequencing analyses with Eleni Petrou show Quilcene Bay as a distinct stock, closely related to Port Gamble.
- Francis Juanes – are Cherry Pt herring smallest in the summer because of their later spawn timing?

- Todd would assume yes, within a given year. They did some variable gillnet sampling at Cherry Pt for age structure, and caught 7 and 8-year-olds which was unusual – nobody sees those older fish in Puget Sound anymore.
- Dick Beamish – if January is the first birthday for U.S. herring, they are aged differently than in Canada. Modelers, take note!
    - Todd – yes. Also, we assume our fish to spawn at age-2, not age-3.
    - Andrew Claiborne – aging protocols differ between the U.S. and Canada. We are working to standardize.

Correspondence between scale growth and survival of adult Chinook salmon returning to Puget Sound and coastal Washington: implications for forecasting (Andrew Claiborne)

This study used scale metrics to assess whether there is a relationship between early marine growth and survival for Puget Sound chinook, and whether marine growth differs between coastal Washington and Puget Sound chinook stocks. Eight outmigration years of relatively poor vs good survival for Puget Sound vs. coast were selected (1976, 1985, 1992, 1998, 2002, 2005, 2008). Equal numbers of male vs. female unmarked fish were chosen for analysis from returns to the Skagit, Nooksack, Green, Puyallup, Quillayute, Willapa, and Grays Harbor. Scales were measured for size at ocean entry and growth over first and second marine year.

Results showed regional differences in size at ocean entry. Generally fish from coastal populations were 14% larger at ocean entry. Puyallup fish had low first-year growth, but fish from other Puget Sound and coastal populations appeared to grow similarly. Second-year growth appeared similar among all regions. Annual first-year growth anomalies generally seem to covary in Puget Sound populations, and are positively related to survival. Growth covaries for coastal populations, but overall varies less than Puget Sound. There was no relationship between growth and survival for coastal populations, and annual coastal growth was not related to Puget Sound growth. The use of age-specific marine growth to predict survival of an entire cohort has potential based on this analysis for Skagit, Nooksack, and Green/Duwamish fish. There was no significant relationship for Puyallup fish.

Q&A

- Francis Juanes – do you have otoliths for these fish to calculate freshwater growth rates also?
    - Otoliths are available for the most recent years included in this study.
- Dave Beauchamp – did you measure to the annulus or look at circuli (growth within a year)?
    - This study measured to annulus, but circulus level could be achieved with the scale images.
- Evelyn Brown – were there correlations between size at ocean entry and size at year 1?
    - No consistent relationships.
- Sandie O'Neill – South Puget Sound fish are more likely to become resident. Also the Puyallup is a glacier-fed system, whereas the others aren't.

Relating outmigrant characteristics to survival of coded-wire tagged Chinook (Iris Kemp)

Release data (size, timing, release region) and 10 years of midwater trawl catch data (catch size, catch timing, catch region) were used to model relationships between CWT chinook survival and juvenile characteristics. Summer catches of CWTs were largest in north Admiralty Inlet and south Central Puget

Sound, while fall catches of CWTs were largest in south Admiralty Inlet and south Central Puget Sound. Stock compositions were predominantly South and Central Puget Sound fish in both summer and fall, although catches of North Puget Sound and Hood Canal fish were more common in fall.

Average summer weight of a given release group correlated positively with survival, as did average fall weight of a given release group. This relationship varied by time and region. From 1997-2001 and 2007-2008, summer weight correlated more strongly with survival. From 2002-2006 and 2011, fall weight correlated more strongly with survival. Stocks from South and Central Puget Sound tended to have stronger relationships than stocks from North Puget Sound and Hood Canal. GLMs were used to assess survival given juvenile characteristics of a given release group. For U.S. stocks, the best-fit model included summer weight (positive), fall weight (positive), and release date (negative) as predictive variables. For Canadian stocks, the best-fit model included release region and release weight. Models based on individual fish characteristics rather than release group characteristics are in progress. Spatial and temporal autocorrelation are issues. Preliminary results suggest a positive relationship between individual growth rate (weight at catch – weight at release/days from release to catch) and survival for some regions, strongest for Central Puget Sound stocks. Within a given cohort, growth rates can be highly variable. Over all regions, growth rates in 2005 fall were anomalously high, and 2009 summer were low. From 2006-2009, some individuals appeared to lose weight between release to summer catch, which may be due to the use of an average release weight for each tag group (i.e., those individuals may have been smaller at release than reported).

Q&A

- Chrys Neville – 2005 fall growth was good in Strait of Georgia also.
    - Julie Keister – 2005 had strong upwelling in fall.
- Ken Warheit – if all hatcheries in your model are genetically distinct, there may be population differences in growth.
- Lance Campbell – weight loss is most likely a hatchery artifact. Suggest contacting hatchery managers for input.

Juvenile life history strategies of Salish Sea Chinook salmon, as inferred from otolith microchemistry (Lance Campbell)

Otolith microchemistry was used to determine successful life history strategies and regional differences in life history expression. Chinook salmon outmigration timing is bimodal, with a fry component (< 45 mm) early in the year (Feb-March) and parr component (> 60 mm) in the summer. This analysis looked at Nooksack, Skagit, Cedar, Green, and Puyallup subyearling outmigrants caught in traps in relation to otoliths of returning adults (i.e., what size outmigrants successfully returned). North Puget Sound populations differed from Central and South populations: both Skagit and Nooksack had higher proportions of fry outmigrants (20-30%) in their returning adults. The Cowichan also has successful fry outmigrants. Based on a qualitative assessment, the systems where fry contribute to adult returns have less developed estuaries.

Q&A

- Ken Warheit – Puyallup, Green, and Cedar are also closely related and dominated by hatchery fish.
    - Differential effects of survival with size may not be due just to estuary habitat. Those systems are also highly contaminated. Could be several factors.
- Evelyn Brown – are all fish in this study natural-origin?

    - That is the intent. Some places are easier to split natural-origin from unmarked hatchery-origin fish. In some portions of the Green, we can identify unmarked hatchery-fish by otolith chemistry.
- Jim Irvine – are there seine or trawl data indicating proportion of fry vs parr migrants for these systems?
    - Trap data measures outmigrant strategies. There are also beach seine surveys; it would be interesting to compare with data from those, especially across seasons.
- Ken Warheit – for some rivers, isn't the proportion going out as fry density dependent? Joe Anderson – parr production is density dependent. Fry go rear elsewhere.
- Eric – suggest more quantitative estuary metrics (extent, etc.). Otolith microchemistry bifurcates freshwater and ocean but fish might move back and forth in the river and estuary.

Strait of Georgia juvenile salmon early marine research (Chrys Neville)

South Thompson chinook escapement has increased over the period of Salish Sea survival declines, with the highest returns on record in recent years. What makes this stock more successful than others?

Key stocks included in Strait of Georgia sampling are Cowichan (primary study site, and chinook remain in the area over an extended period), East Coast Vancouver Island (Quinsam, Puntledge, Big Qualicum; large numbers recovered in trawl surveys), and South Thompson (increasing returns).

Cowichan chinook are sampled in-river (trap), in the estuary (beach seines), and in the marine environment (purse seines, midwater trawls). In 2016, the purse seine catches had higher proportion of CWTs than beach seines. Virtually all Cowichan hatchery fish are CWT fish. This may suggest that the hatchery fish move through the nearshore habitat rapidly or do not use it at all. Almost all fish caught near Cowichan are Cowichan-origin, and largest catches are always within the bay, suggesting the fish are mostly resident there through the summer. Stickleback, chum, chinook, herring, pink, and squid comprise 98% of the purse seine catches.

Fish size increased throughout the season. There was no significant difference in size among regions nor between hatchery/wild fish. There was little variation in CPUE by depth. There were no trends in empty stomachs or in % fullness over 2016 sampling. Diet was similar to previous years. Larval herring were the largest component of the early May diet in Area 1 (Cowichan Bay), and crab and larval fish were the largest components in Area 2 (exiting Cowichan Bay). By late May, crab larvae dominated diets in all areas (~80%) with small percentages of hyperiid amphipods and insects in some areas. Ratios of crab zoeae to megalopae varied by region and time.

There has been an increase in South Thompson chinook catches in recent years of midwater trawl surveys. Most are caught in Malaspina Strait and South Strait of Georgia. In general, there is regional variability among chinook diets from all stocks. Diet compositions include the same taxa, but herring is more important in South Strait of Georgia. South Thompson fish typically have more amphipods and fewer euphausiids in their diets than other chinook. This may be due to size differences of the fish, or differences in food availability across regions. Stable isotope data for 2015 trawl surveys suggest stock-specific diet variation which may represent regional feeding differences or differential use of prey resources by stocks. Analysis is ongoing.

Other thoughts on patterns seen in trawls: development of YOY herring is earlier nowadays (mismatch with chinook demand?) and non-herring larval fish are becoming more common in diets. Dogfish distribution has shifted; small dogfish especially are more broadly distributed in Strait of Georgia. Anchovy were caught in 2015-2016 trawls and had not been previously. Trawl surveys have been conducted since 1997. YOY pollock have increased in Strait of Georgia and are now seen in coho and chinook diets. There is an increasing number of observed predator wounds that look like small dogfish bites. Catches of lamprey throughout Strait of Georgia have been high.

Q&A

- Barry Berejikian – how are South Thompson coho and steelhead stocks doing?
    - Kevin Pellett – this year was the lowest return ever for steelhead, and think that interior coho are declining also.
    - Chrys – Harrison sockeye have a later entry (like South Thompson chinook) and they are doing okay. Also, there is an increase in larval fish biomass and zooplankton in August.

Fine-scale spatiotemporal patterns in late summer distribution, diet and growth of juvenile Cowichan Chinook salmon (Will Duguid)

This was the second year of fine-scale microtrolling and PIT tagging to look at variability within a scale of 100s-1000s m. Based on 2015 results, sampling focused on two sites: Sansum Narrows and Maple Bay. August-October fish sampling (28 days total), two days of sub-hourly zooplankton sampling, and three days of hydroacoustic/ADCP transects were conducted through the tidal cycle. Scats (n = 31) were collected and scanned for PIT tags at nearby seal haul-outs. Sport fishermen reported high catches of juvenile chinook in Juan de Fuca in October, so a couple microtrolling trips were made there also.

Over 2000 chinook were caught in 2016, with very low bycatch. PIT tags were detected on haul-outs: 4 from 2015 and 4 from 2016. Of those 8 fish, 3 had been caught during microtrolling. Fish caught in 2015, 2016 were larger and appeared to grow faster than 2014 fish. CPUE results suggest that fish outmigrate in a pulse.

Size varied by site. In 2015 and 2016, Sansum Narrows had the highest proportion of fish, and those fish were also larger. Based on PIT tag recoveries, fish remain fairly resident within a small area. At Sansum Narrows, high CPUE occurred on the flood tide. Acoustic transects showed high amounts of fish targets in areas of tidal mixing. There may also be concentrations of plankton on the flood tide.

Diets differed from 2015 to 2016. The frequency of occurrence of hyperiid amphipods decreased, as did juvenile octopus. *Themisto pacifica*, calanoid copepods, and pteropods presence increased. About 30% of all diet items by weight were herring, but only about 5% of the fish contained herring. These fish were eating large herring (~45% of the chinook length). Fish that ate fish had wider circulus spacing, suggesting higher growth, than fish eating zooplankton for both 2015 and 2016. Zooplankton abundances declined from July-October, coincident with an increase in fish in the diets.

Q&A

- Chrys Neville – do you have DNA samples for Juan de Fuca or Sooke fish? When we have processed fish caught in Juan de Fuca, we have found mostly Puget Sound fish. Marc Trudel doesn’t catch Cowichan fish on WCVI until February.
    - Will took DNA samples, but they don’t currently have funding to process.
- Marc Trudel – fishing locations are a limitation. To infer movement out of an area, need to sample outside the area. Residency can’t be generalized beyond the few recaptured fish.
    - Chrys Neville – we don’t pick up Cowichan tags often in standard Strait of Georgia surveys. Based on where we see them, they do seem pretty localized.

- Marc Trudel – South Thompson chinook diets suggest they are feeding on hyperiid amphipods. For some stocks, eating herring appears to be important but the stock that is currently doing best doesn't eat much fish.
    - Chrys Neville – in 2016, South Thompson diets had lots of larval fish (likely anchovy).
    - Alternative fish prey field is important to consider. Salish Sea is a herring-dominated system whereas (for example) California Current fish eat rockfish, anchovy. The presence of anchovy in the Salish Sea might change feeding dynamics.
- Austen Thomas – how large were PIT tagged fish when they were consumed by seals?
    - At date of tagging, one fish was 330 mm, others were a variety of sizes. No way to tell when they were eaten, and sample size is very small.

Critical growth periods and marine survival of Chinook salmon in Puget Sound (Dave Beauchamp, Josh Chamberlin)

Fish from Nooksack, Skagit, Snohomish, and Nisqually were sampled in-river (trap), in estuary/nearshore marine (beach seine), and offshore (purse seine) through July. Scale analysis for 9 stocks (7 hatchery-origin, 2 natural-origin) showed little to no evidence for size-selective mortality. Growth rates appeared to be higher offshore and highest for fish transitioning from nearshore to offshore. Generally nearshore diets included high proportions of insects and offshore included high proportions of crab larvae. Bioenergetics simulations showed fairly low and highly variable feeding rates but no significant differences among habitats. Temperature measurements were taken at the surface. Nearshore habitats were warmer than offshore habitats and, at observed feeding rates, warmer nearshore temperatures may reduce growth by 43% from optimal temperature conditions while cooler offshore temperatures may reduce growth by 16% from optimum.

IGF-1 concentrations were compared among fish caught in nearshore and offshore habitats of the Skagit, Nooksack, and San Juan Islands for 2014-2015. Growth rates among regions and between years were relatively stable. Generally IGF-1 concentrations were higher offshore than nearshore, indicating higher growth rates. San Juan Islands had elevated growth rates in both nearshore and offshore habitats. Length may be a confounding factor in comparisons: there was a significant relationship between fork length and IGF-1 (larger fish have higher growth rates). Length was the highest source of variation in IGF-1; region was the second highest. Regional IGF-1 differences may reflect regional variation in diet items. Of the 26 prey items observed in diets, 6 explained 96% of the observed variation: fish, crab zoeae and megalopae, euphausiids, insects, and other crustaceans. San Juan Islands diets are more fish dominated. Smaller fish eat more insects and crab larvae. There is a significant increase in IGF-1 when fish are incorporated into the diet.

Q&A

- Isaac Kaplan – if the offshore habitat is more beneficial to fish growth based on bioenergetics modeling, what keeps some fish nearshore longer?
    - Factors like predation risk, acclimation to salinity, etc. may influence the nearshore-offshore transition.

Friday, Dec. 2: Current Results, Data Gaps, 2017-18 Plan

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

A PIT tag based method to investigate survival of Cowichan River Chinook throughout various stages in their first year of marine life (Kevin Pellett)

An array of 12 PIT tag antennae was installed in the Cowichan to detect outmigrating smolts and returning adults. The array detected about 50% of juvenile tags deployed in 2016. Wild and hatchery fish appeared to migrate at different times but survived similarly, suggesting that mortality happens during migration and not in-river holding. Some mainstem releases were detected in groups moving upstream into a side channel, indicating potential predation. After deploying trail cams, a family of raccoons was identified in the channel interacting with the detection field of the array. This year was a low flow year with isolated pools; it's difficult to know whether this was predation or scavenging. For groups released furthest upriver, survival during the 47 km migration to the estuary was estimated at 14% for wild fish and 12% for hatchery.

The array had 93% detection efficiency for returning adults in 2016 – a big improvement from the 14% efficiency in 2015; in total, 159 tags were detected and 133 were confirmed to have moved past the site. A secondary detection site 26 km upstream produced 13 tag detections, 12 of which were previously detected downstream. Also noted one coho from 2015 Big Qualicum study and one microtroll chinook tagged during a TV segment in 2015. Larger fish tagged on the purse seiner in 2015 were over-represented in the 2016 returns, suggesting that age at return may be influenced by early growth. There was no evidence to suggest the size of fish at release in-river influenced downstream survival.

Q&A

- David Welch – what is survival from hatchery release to adult return? You saw low survival down the river, but what about the rest of the lifecycle? Suggest taking release to return survival rates and accounting for in-river rates to determine marine survival.
- Marc Trudel – if consumption calculations for predators are expanded to population of smolts being released, how many smolts would be consumed by predators?
    - Based on back-of-the-envelope calculations, about 4800 fish from the late hatchery release would be consumed (12 tags x 1 in 365 fish were tagged) representing about 14% of what was available after upper river losses. Estimates for wild tags suggest 1-8% of the fish in the lower river were consumed (wild population unknown). That seems high, but unless raccoons specifically target tagged fish, then that's the amount of predation 2016 observations suggest.
- Jim Irvine – 80% mortality in-river seems high. Is there tag mortality?
    - Hatchery fish are held for a month post-tagging. They are fully healed and healthy at release.
- Francis Juanes – do you collect scales and otoliths from returning adults?
    - This study is based only on detection at arrays, not handling fish. Other adult sampling groups may take these samples.

Use of telemetry to investigate residence time and survival of juvenile Fraser River Chinook salmon in the Strait of Georgia (Erin Rechisky)

This study builds on the 2015 proof-of-concept for small 180 kHz acoustic tags by using V5 tags to measure freshwater and early marine survival of Fraser River Chinook. The smaller tags have a limited battery life and the residence time of Chinook in the Strait of Georgia is unknown therefore hatchery-reared Chilko River fish were tagged with "early" tags (on in the river, N = 50) and "late" tags (off for the first 106 days then turned on from mid-July to mid-Sept, N = 50). 180 kHz tags could be detected in the river and only the northern detection arrays (Northern Strait of Georgia, Discovery Islands and Johnstone Strait).

Results showed that in-river migration was variable, but took approximately one month. Survival to the estuary from the release location in the Chilko River was 48% over about 650 km travel distance. This survival estimate is similar to Chilko sockeye and to Chinook from other regions that migrate over similar distances. Thus, for Chilko Chinook, 1 in 2 fish survive the river, but only 1 in 50 fish survive the ocean to return as adults.

In the marine environment, only one fish was detected. This fish was detected on the northern Strait of Georgia sub-array, and it wasn't detected again. There is a low probability that fish migrated north via the Discovery Islands and Johnstone Strait without being detected, so either fish died very soon after entering saltwater, they resided in the central and southern Strait of Georgia, or they migrated south through Strait of Juan de Fuca where they could not be detected.

Q&A

- Raphael Girardin – what is the effect of tags on growth rate?
    - When tags are first implanted, growth rates may be depressed for about a week. As you follow tagged and untagged cohorts through time, no evidence for long-term difference.
- David Welch – we are measuring survival across all the fine-scale patterns seen in satellite data, etc. We should integrate those data to understand what fish encounter through their outmigration that may affect survival in a given segment.

Physiological and environmental factors affecting the migratory behavior and survival of sockeye and steelhead salmon smolts (Nathan Furey)

Seymour hatchery steelhead (N = 273) were gill biopsied and tagged in 2015 to measure migration-segment-specific survival and link survival outcomes with genomics. Fish were released from south and north of Burrard Inlet to test whether it was a mortality hotspot.

Two of the river released fish went south; all others went north. Some fish appeared to move back upstream and some hung out for a while, potentially a sign of predation. Higher use of the Discovery Islands migration path was associated with higher survival. There was poor survival in Burrard Inlet, and in-river (over about 2.5 km). Cumulative survival to Queen Charlotte Strait was 9% for river release and 27% for marine release.

Chilko wild sockeye (N = 200 age-1 with V4 tags, 99 age-2 with V7 tags) were gill biopsied and tagged in 2016. Fish migrated through river in about a week. Only two age-2 fish were detected at Queen Charlotte Strait. Tagging efforts on age-2 sockeye from 2010-2014 suggested 21-48% in-river survival and 3-10% survival to Queen Charlotte Strait. In 2016, age-2 sockeye had 28% in-river survival and 2% survival to Queen Charlotte Strait. Age-1 sockeye had 56% in-river survival and 16% to Queen Charlotte Strait.

Factors that may explain why age-2s had lower survival than age-1s in 2016 include predation (Furey 2016 found that bull trout feed disproportionately on age-2 smolts), tag burden (slightly higher for age-2s), and potential differences in microbes or physical condition. Next steps include relating genomics results to migration fate. Very preliminary results for Seymour steelhead suggest biomarkers for stress, growth potential, osmoregulation, and immune system.

Q&A

- Michael Schmidt – was there a difference in survival at Texada Island?
    - Based on a meta-analysis of previous years, fish that used Malaspina Strait had better survival. But that pattern was not apparent in 2015.
- The biggest difference in survival between age-1s versus age-2s was within the first 14 km. However, it is difficult to assess beyond that given the very low survival and resultant small sample size of age-2s.
- Jim Irvine – age-2 fish may be more susceptible to predation. Consider also that they are the slower-growing fish (the "runts of the litter") and may be less aggressive feeders, less efficient, genetically slower growers.
    - Over a short distance, feeding may not be a big issue, but behavior definitely could contribute to differences in survival.
- Megan Moore – do you have insight into why estuary and Burrard Inlet survival is low for Seymour steelhead?
    - There are lots of avian predators in Burrard Inlet, but that is a guess – no hard evidence.
- Francis Juanes – suggest using small tags on large fish.
    - That is the plan for 2017 tagging.
- Sandie O'Neill – both steelhead and sockeye have short estuary residence times. Are there plans for tagging migrants like subyearling chinook that have prolonged estuary residence?
    - There are limitations for using this technology on fish that reside in the lower river and estuary. We are limited by fish size and where we can put arrays. There is a larger tagging risk for species with non-directed migrations – if the fish don't go where receivers are, then we get no data.

Harbor seal-steelhead interactions under variable survival conditions in Puget Sound (Megan Moore, Barry Berejikian, Steve Jeffries)

Several years of acoustic telemetry studies of Puget Sound steelhead indicated rapid (~ 2 weeks) outmigration, low survival rates (~20%) within Puget Sound, and spatial patterns of mortality, with higher mortality in main basin of Puget Sound and at Hood Canal Bridge than other areas. These observations suggested predation was a source of mortality and Pearson et al. 2015 determined that the most likely predators of Puget Sound steelhead included harbor seals, harbor porpoises, double-crested and Brandt's cormorants, Caspian terns, and common murres. Harbor seals were chosen for investigation based on several reasons: 1) their abundance has increased concomitantly with declining steelhead survival/abundance, 2) they are opportunistic feeders, 3) their preferred prey species (pollock, cod, hake, rockfish, herring) have declined in Puget Sound, and 4) they have been observed feeding on steelhead smolts in other systems (Lower Columbia, San Lorenzo River, Puntledge River, Strait of Georgia).

In 2014, tagged steelhead smolts were released from two systems in central and south Puget Sound. Harbor seals from central Puget Sound and Admiralty Inlet were outfitted with radio tags, GPS, and telemetry receivers. Stationary tags (i.e., probable mortalities) were detected repeatedly at harbor seal haul outs. Higher proportions of stationary tags and tags detected by seals were observed in central Puget Sound, where mortality was most acute. Tag detection patterns near seal haul outs were consistent with harbor seal movements, and some tags were observed to move back and forth with tidal height in estuaries – a behavior that harbor seals exhibit.

The 2016 research plan increased sample sizes, spatial coverage, and added mobile tracking capabilities to pinpoint stationary tag locations. A proportion of the tags were delayed in order to perform a second test of the dinner bell hypothesis. Predation rate will be estimated based on tag deposition, deposition probability, harbor seal spatial distribution and abundance, and steelhead smolt abundance, and spatial models to assess predation risk will be constructed.

Preliminary survival results for 2016 suggest that release date impacted survival of the first (in-river) migration segment: earlier migrants survived better in-river. Overall, survival in 2016 was surprisingly high. Freshwater survival was lower than typical, but survival from the Nisqually river mouth through main basin of Puget Sound was very high (almost 40%) in comparison to 2014, and survival from the Admiralty line through Strait of Juan de Fuca was very high compared to 2014-2015. Travel time through the system was almost identical in 2014 and 2016. Almost all stationary tags were found in the Nisqually estuary; all stationary tags were within 5 km of saltwater estuary. Back and forth tidal behavior was observed in the Nisqually estuary, and all tags that exhibited that pattern became stationary and/or were not detected at later receiver lines (i.e., apparent mortality). All stationary tags in the estuary and nearshore showed the back and forth pattern before becoming stationary. In one case, 4 tags showed identical patterns and were then all deposited in one marine location, suggesting they had all been in the belly of a single predator.

Using harbor seals as mobile receivers to increase spatial coverage of tag detections has been successful. In 2014, 33% of tagged Nisqually steelhead were detected. In 2016, with more seals and additional haul-outs, 60% of tagged steelhead and 60% of tagged coho were detected, and we had good coverage of Orchard Rocks, Pt Defiance, Nisqually estuary, and Gertrude/Eagle Island.

There was no evidence of a dinner bell effect in 2016, which agrees with the 2014 results.

Q&A

- Ken Denman – do steelhead swim faster when temperatures are higher? Outmigration was faster in 2015 than 2014, 2016.
    - Steelhead are swimming at close to maximum speed, traveling about 2 body lengths/second. Rapid outmigration is consistent across years.
- Evelyn Brown – can seals be captured with tranquilizer guns?
    - They spook easily and it is difficult to get close enough.
- Austen Thomas – speculation on why survival in 2016 was so much higher?
    - In 2014 there were lots of stationary tags in Central Sound and survival was low; in 2016 stationary tag locations were all in South Sound and survival was high. Harbor seals are not the only predators in Puget Sound, but likely contribute to some amount of steelhead mortality. Speculation: maybe harbor seal behavior changed (e.g., due to transient killer whale presence, changes in buffer prey).
    - Also note that tagged coho survived really well – much better than reported in the past. These coho appear to stay in Puget Sound through most of the summer, which suggests that conditions within Puget Sound were good. Blackmouth fishermen report that the past

couple years have been good. The observed improvement in steelhead survival may be part of a larger shift in Puget Sound.

- Erik Neatherlin – seems odd that big marine survival increase was concurrent with big freshwater survival decrease.
    - This may support the predator behavior speculation: seals may have spent more time in the estuary/river mouth in 2016. If transient killer whales were present and preying on harbor seals, the seals would escape into shallow water, estuaries. Harbor porpoises also might respond to transients by leaving the area.

Predation, Disease, and Contaminants

Lessons learned from 6 years of harbor seal predation studies (Austen Thomas)

There is an apparent inverse relationship between seal population abundance and smolt survival, with seals increasing significantly over the same period of coho and chinook declines. Seals are more highly concentrated in Strait of Georgia than on the coast. Scat collections from 2012-2013 Comox, Fraser, Cowichan estuaries and Belle Chain (non-estuary), suggest that seals eating juvenile salmon favor juvenile chinook, coho, and sockeye. However, midwater trawls predominantly catch juvenile chum, suggesting that seals selectively forage on certain salmon species.

Even if smolts contribute small fractions to the overall seal diet composition, seal energetic needs and the abundance of the seal population could represent consumption of a large proportion of the smolt population. Modeled consumption estimates based on observed diet fractions and smolt sizes suggest that, on average, a seal eats 5 coho smolts/day. Using abundances from 1999-2007 (seals at carrying capacity), Ben Nelson's consumption models estimated 55% of coho smolts and 44% of chinook smolts consumed by seals in Strait of Georgia. In WA inland waters, Brandon Chasco's consumption models suggested an increase in seal consumption from 1 million chinook smolts in 1970 to 7.8 million chinook smolts in 2015. Estimated pinniped consumption of chinook in 2015 was double that of resident killer whales and 6x greater than combined commercial and recreational catches.

Smolt consumption may be a sex-dependent activity: Spitzer et al. at WWU found male seals ate more salmon than females, and juvenile coho were predated almost exclusively by males. Scat samples also suggest specialists vs. non-specialists: a small number of seals specialize on smolts.

Studies on foraging behavior indicate that estuary predation occurs mostly in evening/night, possibly because fish outmigrate more at night. Hassan Allegue's research defined three foraging ecotypes: non-estuary, intermediate, and estuary foragers. Estuary specialists are a small component of total predation. In Big Qualicum estuary, 96 seals ate ~23,800 smolts (6% of total population mortality). Overall, there are about 40k seals in Strait of Georgia.

Q&A

- Barry Berejikian – the size of chinook and chum smolts are very different. Could seals be eating more chum than chinook but chum are smaller? Are diet proportions sensitive to size of fish?
    - Typical smolt size depends on the timing of when predation occurs. The majority of scat samples collected are from late April and May. A chum growth model was not incorporated in consumption estimates.
- Dave Beauchamp – does predation occur more in evening/night outside of the estuary?
    - No PIT tag detections occurred outside of estuary. Open question.

- Dick Beamish – coho survival has doubled in the last 5-10 years. Does that mean seals are eating fewer coho? Seals haven't decreased in abundance, and you didn't report changes in diet.
    - Diet data are a point estimate. If study were repeated now, diet proportions might be different. Consumption models are sensitive to diet proportion; collections are ongoing to improve diet data.
- Francis Juanes – are seals size-selective?
    - Limited data suggest that sizes of consumed fish (based on otoliths) were not significantly different from sizes of fish caught in trawls. However, sample sizes are low as very few otoliths were undigested enough to measure.
    - Chrys Neville – by June, chinook and chum are similar sizes in trawls. We also almost always see a mixture of species: in purse seines, we never get just chum or just chinook. No observed difference in distribution. However, smolts have appeared to grow faster in the past couple of years.
    - Strahan Tucker's work showed that smaller, weaker fish were predated more by birds. Are seals eating dead fish swimming?

Molecular indices of viral disease development in wild migrating salmon (Kristi Miller)

The SSHI Project (Miller et al.) developed an infectious agent monitoring tool. Samples were collected looking at contrasting shifts over time, space, stock differences, variations in survival, hatchery/wild, life-history types, species, and aquaculture samples. Most samples will be run by 2017.

Truncated load distributions – where infectious agent becomes abundant, high load, then drops off (i.e., potential mortalities) – can identify which agents actually impact smolt survival. With the new monitoring tool, 8 microbes with powerful truncated loads were found. These microbes were seasonal, summer to fall and fall to winter.

Linking pathogens to disease outcomes in migratory fish is difficult. Sub-lethal effects of infection – altered swim performance, feeding, ion homeostasis, migration timing, migration speed – may be more detrimental in wild than cultured fish. Developing molecular methods to recognize early developing disease states can address this question. Miller et al. developed a panel that can differentiate IHN-diseased sockeye, chum, and Atlantic salmon, and jaundice in chinook. It can detect these individuals before mortality, and has the potential to detect pre-symptomatic individuals. This tool was tested on wild Chilko sockeye gill clip samples, and there was a group of individuals positive for IHNV. Current results suggest that the tool works across salmon species and tissues for systemic infections, and can identify diseased wild salmon. It can detect all tested RNA viruses so far; tests are ongoing for additional diseases. Additional work towards identifying bacterial, microsporidian, and myxozoan diseases is also underway.

Q&A

- Todd Sandell – does this study include multiple outmigration groups?
    - Yes. There are about 900 samples in analysis. Hoping to transfer tool across groups and species. Looking for 11 most robust biomarkers, 5 of which overlap with previous human work.
- Paul Hershberger – concern about using gill tissue as gills are first line of defense for a fish. A positive pathogen on gill indicates exposure but not necessarily disease. How long were challenge

studies? Are you detecting any recoveries? We have seen immune response and recoveries around 18 days.

- Kristi et al. validated across different tissues. Despite the fact that gill is not a primary infective tissue, the signal can still be picked up. For chum, if there is infection of kidney, you see upregulation of genes from both gill and kidney samples. Infection challenge periods were 18 days, which may not detect recovering fish. But farm studies on longer timescales (11 months or so) using natural infections have been done to test that.

Genome-wide association study using 1) survival in acoustically tagged and 2) Nanophyetus salmincola *infected steelhead smolts in south/central Puget Sound (Ken Warheit)*

In 2014, a preliminary study was done to assess genotype with phenotype (survived/died) of acoustically-tagged steelhead smolts. That study found two groups of genes associated with survival: immunological and developmental. Limitations were low sample sizes, lack of independence between year and source/release locations, and model design. Further research to address these limitations was conducted in 2016 on 2014-2015 samples (N = 500) from the Green and Nisqually rivers.

Fate was included as a quasi-continuous variable:

0 – no evidence of leaving freshwater
0.25 – evidence of leaving freshwater, but no other detections
0.5 – detection at Tacoma Narrows or Central Puget Sound lines
0.75 – detection at Admiralty line
1 – detection at Juan de Fuca line

More than half of the loci included (10.8k total) have been mapped. PCA of Nisqually 2014-2015 samples indicates three distinct groupings along Axis 1, driven by 174 loci with $r^2 > 0.9$. Of these, at least 80% are from chromosome 5, which is known for tight genetic linkage and associated with life history differentiation (anadromous vs. resident). PCA of Green 2014 samples shows the same pattern, with three distinct groupings along both Axis 1 and 2.

No loci were significantly associated with survival for Nisqually steelhead. However, about 20 loci were highly significantly associated with survival for Green steelhead. All but one (unmapped) were on chromosome 5. Results remained highly significant after removing group structure. This may indicate that parent life history matters (e.g., a fish with two anadromous parents may survive better than a fish with one anadromous parent and one resident parent). We may not see this in Nisqually due to the overall poor survival of that population (e.g., no matter who your parents are, you die).

Q&A

- Lance Campbell – we did some previous research on juvenile steelhead produced by anadromous versus resident mothers and found about 10% of mothers were residents. No data on fathers.
    - Ken would love to see those data. That estimate (10%) aligns with the number of fish in groupings. This study would also suggest high anadromous/resident interbreeding.
- Barry Berejikian – survival may be linked to traits like growth that regulate residency/anadromy. Green fish may have less plasticity than Nisqually fish. And there may be different interactions between residency/anadromy by rivers.
    - Ken agrees. This implies that each basin would be different in terms of survival.

- Kristi Miller – we are currently validating a tool to look at level of osmoregulatory preparedness; would be interesting to evaluate for these samples, link to gene expression.

2016 update: Nanophyetus salmincola *studies (Paul Hershberger)*

Nanophyetus salmincola, a salmon parasite, was found at high prevalence and loads in Green/Duwamish and Nisqually river systems. Loads increase as fish move downstream. Comparisons between groups of infected and uninfected steelhead were conducted in 2016 to determine whether *Nanophyetus* infection status was correlated with survival. Infected and uninfected fish were either 1) acoustically tagged and released, 2) held in lab tanks, or 3) subjected to swim challenges in the lab. Tags were inserted May 11-13, and exposures began on May 16 for 7 days. Fish were released or transitioned to saltwater at the end of May. Each swim challenge fish was tested twice, with a month lag between swims.

One issue for this study was that little is known about the conditions that stimulate the parasite's intermediate host (the *Juga* snail) to shed the parasite's cercaria life stage into the water where it can infect fish. Parasite loads achieved in laboratory fish (mean 232) were much lower than observed in wild fish (mean 2546, Nisqually 2014). Laboratory components of these studies should be redone in 2017 with higher loads.

Overall, acoustically-tagged *Nano*-exposed fish had slightly but not significantly lower survival than tagged fish that were not exposed. When laboratory fish were transitioned to saltwater, *Nano*-exposed fish had slightly more mortality than control fish. Uninfected fish swam slightly but not significantly better than infected fish for both swim trials. Parasite load was not strongly related to swim speed, but the fish with the highest load (just under 800) died about 2 hours after its first swim.

Treatment options for facilities/watersheds with *Nanophyetus* were considered. Interrupting the parasite's life cycle is the best method to prevent fish infections. However, the locations and times of exposure are not well-understood. Paul et al. developed a qPCR tool that can detect *Nanophyetus* in fish samples, snail samples, and water samples. There is a tight regression between cercaria count and qPCR copy, meaning that this tool can quantify *Nano* presence in a watershed. Currently, daily water samples are being tested from Soos Creek for one year to determine seasonality of *Nano* presence. Prophylactic water treatments tested included formalin, hydrogen peroxide, and salinity. Formalin concentrations in the FDA approved range for aquaculture were effective: 167 ppm (highest end of approved range) caused 100% mortality in 30 minutes. Hydrogen peroxide was less effective. Salinity was effective: at half-strength seawater, 80% mortality occurred almost immediately; full-strength seawater produced 100% mortality.

Next steps include redoing laboratory studies, identifying temporal and spatial *Nano* hotspots in watersheds, and comparing marine survival of infected and uninfected hatchery groups on a larger-scale using coded-wire-tags. Potential mitigation strategies include water treatment/filtration, adjusting hatchery release dates, relocating rearing locations, snail control, and transporting fish around *Nano* hotspots.

Q&A

- Michael Schmidt – could *Nano* prevalence peaks be stimulated by river flow?
    - It's possible. There is a USGS stream gauge in Soos Cr, so that will be investigated. There is also a risk that the qPCR tool may undermeasure in high flows.

- Scott Hinch – we performed a similar swim challenge study with adults migrating into the estuary and compared pre-estuary (controls) and post-estuary (infecteds). Looking at individual data rather than averages showed that control individuals did better on their second trial whereas infected individuals did worse on their second trial. Also, consider less time in between individual trials (< 1 month between trials 1 and 2).
    - Paul et al. began individual comparisons between trials, but realized that all fish swam poorly immediately after saltwater entry. When this study is repeated, first trial will be delayed a few days longer after seawater transition. The time between trials in 2016 was limited by swim chamber size; Paul et al. are building a flume that should allow more trials per day in 2017.

Assessing the threat of toxic contamination to early marine survival of Chinook salmon in the Salish Sea (Sandie O'Neill)

Contaminants were surveyed through 5 populations of chinook salmon in 2013: Skagit, Snohomish, Green/Duwamish, Hylebos/Puyallup, and Nisqually. Previously reported results indicated that contaminants of known concern (PCBs, PBDEs, DDTs, PAHs, lead) were elevated in fish from urban estuary and nearshore habitats, fish continued to accumulate contaminants in the offshore habitats of all marine basins, and a third of all samples had contaminant concentrations associated with adverse effects likely affecting marine survival. About a third of the Snohomish fish had PBDE levels associated with altered thyroid hormones and disease susceptibility, and most (79%) Green/Duwamish and Hylebos/Puyallup fish had PCB + PBDE levels high enough to cause effects like mortality, impaired growth and reproduction, increased disease susceptibility, etc. A little over half of all fish caught offshore had PCB levels above the adverse effects threshold. Other research (Meador 2014) found that Puget Sound hatchery Chinook migrating from contaminated rivers had 45% lower marine survival than those from uncontaminated rivers.

In 2016, the 2013 samples were reanalyzed for chemicals of emerging concern (CECs), which include pharmaceuticals, personal care products, industrial compounds, and caffeine. Overall, 194 chemicals were tested for and 48 were detected. CECs were detected in both urban and non-urban habitats, with slightly more detections in urban habitats. Antibiotics (15 types) were the most frequently detected; all samples contained at least one type of antibiotic, and on average 5-6 antibiotics were present in each sample. All samples had penicillin, most (93%) had ACTC, half had oxolinic acid, and a third had erythromycin-H20 and sulfadiazine. Five antidepressants were detected: citalopram (40%), Zoloft (27%), Prozac (20%), Prozac metabolite (7%), and amitriptyline (7%). At least one type of antidepressant was detected in all Puyallup samples and 2/3 of Duwamish, Snohomish, and Skagit samples. Generally samples had 3 types of antidepressant. No antidepressants were detected in Nisqually samples.

Over the period of salmon decline, PCBs have declined and PBDEs increased then declined, but both remain at concentrations that cause adverse effects. Declining PCB concentrations have been observed for chinook, herring, and harbor seal samples. PBDEs increased in the 1990s based on harbor seal samples and declined in the 2000s based on herring samples. CEC trends are not well understood, but they are likely increasing, especially in developed habitats: areas with high population density and percent impervious cover. All five watersheds included in this study have increasing population densities and impervious cover. Contaminant effects on juvenile chinook likely worsen with increasing temperatures.

Ongoing work expands these analyses across all ESA-listed populations and includes testing for more types of CECs, more health endpoints (e.g., altered microbiome, hormones), and modeling effects of contaminant mixtures rather than individual contaminants.

Q&A:

- Marc Trudel – how much of a temperature increase is necessary to see measureable impacts on adverse effects?
    - Hard to say: temperature impacts likely vary with different types of chemicals. There may be compounding effects of contaminant mixtures which are not well-understood. A temperature change of 5°C would likely impact.
- Ken Warheit – many of the antibiotics you detected are used in hatcheries to treat fish. For example, tetracycline and erythromycin are standard for treating BKD. Sensitivity testing very important.
    - Antibiotic resistance is also a concern – these antibiotics are in the water, not just the fish, and the bacterial community may be changing in response. We could compare the hatchery vs. wild samples we analyzed. Most likely it's a concern for both: Nisqually fish were mostly hatchery and Skagit fish were mostly wild, but both populations had antibiotics.

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

Discussion: modeling scenarios to explore hypotheses related to early marine survival of Chinook and Coho (Isaac Kaplan)

Modelers can compare actual observations from 1970-2015 to model scenarios for 1970-2015 to investigate hypotheses around early marine survival. A preliminary list for discussion:

Scenario	**Hypothesis addressed**
No pink salmon	Competition between pink/salmon or pink/herring
Higher herring abundance	Abundance & timing of herring prey availability (appropriate sizes of YOYs)
Lower pinniped abundance	Predation mortality drives declining abundance
PDO, climate change effects	Climate "shift" and satellite data (temperature, primary productivity)
Increasing *Noctiluca*, jellies	Energy flow towards *Noctiluca* and gelatinous zooplankton reduces salmon prey
Improved salmon growth	Faster growth may allow salmon to escape predators and access more prey
Fewer hatchery fish	Competition between hatchery/wild conspecifics
Higher gadoid abundance	Pinniped predation has increased due to lack of non-salmonid prey resources
Stormwater	Health, survival, growth has declined for specific stocks in stormwater locations
Disease	Potential effects on mortality and growth
Altered crab spawn timing	Match/mismatch of crab larvae availability and salmon consumption needs

Group feedback:

- Parker MacCready – it's easy to imagine these scenarios individually, but in reality there are likely multiple factors impacting salmon survival at any given time, and relationships are probably not all linear. Interactions are likely complex and vary with time. Even simple, dynamical systems have an adjustment time such that linear correlation is not very useful. Consider models that are more complex than linear regression but less complex than the full-fledged Atlantis model. Consider testing multiple effects at once.

  - Modelers should think about models of intermediate complexity to refine hypothesis testing scenarios.
- Ken Warheit – all individuals are not equal from a genetics standpoint; they have unequal probabilities of dying. Can models incorporate individual variation in survival probabilities? Add individual stock variation to hypothesis/scenario list.
  - Typically models can detect differences among stocks and regions, but are not detailed to individuals.
- Evelyn Brown – include interactions among variables and indirectly affect mortality. For example, disease might moderate predation.
- Julie Keister – if the model is perturbed in one of these scenarios and effects are not seen, that's informative but it doesn't mean the hypothesis can be ruled out. For example, at high concentrations, *Noctiluca* and gelatinous zooplankton abundance and crab spawn timing can directly impact salmon. However, they are more likely an indicator of another variable or ecosystem shift.
- Francis Juanes – an ideal scenario would be if researchers could run the model themselves to test their hypotheses. Will Atlantis model be available once developed?
  - Isaac Kaplan – Atlantis is too complex and slow to have that capability. Other modeling frameworks could be used. It will be essential to keep open communication lines between modelers and non-modelers.
  - Michael Schmidt – others are considering how to incorporate the tech community to give more direct access to modeling capabilities.
  - Villy Christensen – suggest a modeling workshop to host scenarios in real-time.
- Brian Riddell – the only way to get buy-in is to develop the model and show that it works. I won't put faith in results until I understand the model. Suggest an active workgroup for modelers to begin demonstrating model capabilities. Susan Allen's MEOPAR model took 5 years to build and validate. We are getting ahead of ourselves with Atlantis; the model is not yet developed and there is no guarantee it can reproduce Salish Sea patterns. Endorse multiple models approach.
  - Isaac Kaplan – Atlantis and Ecopath with Ecosim have been demonstrably useful in other systems for policy and decision-making. These scenarios are not final decisions; brainstorming hypotheses to address aids in model construction (what species to include, what needs most validation, etc.). Models are planned to be multi-year efforts.
- Neala Kendall – recommend adding steelhead to Atlantis model, or at least to intermediate models. There is not much Canadian data, but steelhead are important in the US.
- Neala Kendall – consider changes in structure for refuge habitat (kelp, eelgrass).
  - Austen Thomas – this hypothesis is based on foraging arena theory and depends on a spatially explicit model.
  - Isaac Kaplan – refuge habitat could be included in models, and may be useful to add in context of habitat restoration.
- Dave Beauchamp – suggest incorporating artificial light pollution and how that has affected refuge space in pelagic habitats. Change in transparency associated with *Noctiluca* blooms can impact predator efficacy. Also incorporate resident chinook as predators on juvenile chinook.
- Jim Irvine – there is value in looking at time series outside the Salish Sea as "controls" to compare/contrast patterns. Some hypotheses are only relevant to the Salish Sea; use spatial variability to evaluate.
  - Isaac Kaplan – point taken. Spatial differences within Salish Sea are also important and are a priority for modelers.

- Erik Neatherlin – it will be easier to generate additional hypotheses than to narrow the existing ones down. Challenge to the group: start thinking in phases and prioritization. How will you make sure that data formats, etc. can be input and tested? Recommend regular modeling workshops.
  - Isaac Kaplan – from the modeling perspective, the triage of most important questions is really important. On the west coast, we have a sardine working group that is really focused on sardine patterns and model validation. Hopefully we can develop a similar process for hypothesis prioritization here.
  - Michael Schmidt – hypotheses can be aggregated around core issues as a means of organization.
  - Brian Riddell – we will allocate funds to support several workshops if you get a group organized.
- Michael Schmidt – consider including eulachon: there was a significant decline in Fraser eulachon coincident with salmon decline.
  - Todd Sandell – if anyone catches eulachon, please send them to us.
- Parker MacCready – Puget Sound would benefit from a study similar to Olivier Riche's work in Strait of Georgia: aggregating long time series and compiling patterns in one summary.
  - Isaac Kaplan – dealing with multi-decadal changes in productivity is critical for Atlantis.
- Brian Beckman – what data do we need to be collecting to parameterize the Atlantis model?
  - Isaac Kaplan – for now, wherever data gaps exist are most important. Later, developed model can be used to optimize monitoring.
- Michael Schmidt – suggest testing why pink and chum are doing better than coho, chinook. Also, what scenarios affect Hood Canal less than Puget Sound?

Moving forward: proposed and planned work through 2018 (Michael Schmidt, Isobel Pearsall)

In addition to ongoing work, US activities proposed for 2017-2018 are:

- Explore bottom-up processes that control juvenile salmon growth and survival: comparative analysis of regional datasets (2011, 2014-2016)
- Explore JEMS zooplankton time series (2003-present) to better understand and refine its value for salmon forecasts
- Infer long-term primary production patterns based on geoduck growth
- Measure seasonal availability and energy content of key prey for chinook
- Quantify juvenile salmon prey quality and explore trophic linkages in Puget Sound
- Investigate population-specific consumption of Pacific herring by juvenile and sub-adult chinook salmon in Puget Sound
- Explore predation impacts of resident chinook and impacts of artificial light in Puget Sound
- Spatial analysis of contaminant exposure in juvenile chinook along their outmigrant pathway through the Snohomish River and spatial analysis of PBDEs associated with steelhead contaminant levels in the Nisqually River
- Ongoing steelhead studies (forthcoming/funding dependent)

Canadian activities under consideration include:

- Citizen science program- final year
- Spatial temporal analysis chlorophyll, turbidity and sea surface temperature of the Salish Sea- final year - Maycira Costa

- Availability of food in the Strait of Georgia as an indicator of the health of juvenile salmon – wrap up - Sophie Johannesson
- High temporal resolution monitoring of surface water properties in the Salish Sea - final year- Steph King
- Coupling state-of-the-art chemical oceanography with biological relevance -final year- Helen Gurney-Smith
- Zooplankton and ichthyoplankton status and trends in the northern Salish Sea – final year- DFO
- Investigating the level of synchronicity between phytoplankton and zooplankton phenology in the Salish Sea – Karyn Suchy
- Plankton food web pathways to juvenile salmon – Brian Hunt (post doc)
- Juvenile Herring Survey – final year- DFO
- Spatial-temporal environmental data database (2002-2016) organization to support zooplankton-phytoplankton synchronicity and modeling analysis – John Dower
- Examination of the production of the prey and predators of juvenile salmon, and their links to the juvenile salmon survival in the Strait of Georgia – using hydroacoustics – final year- Lu Guan
- Cowichan Predation Study - Kevin Pellett et al.
- Understanding the factors limiting the recruitment of Pacific salmon in the Strait of Georgia – From patterns to processes – final year- DFO
- Variation in juvenile Cowichan River Chinook salmon distribution, diet, and growth rate in relation to tidal mixing and water column stratification - analysis and write up - Will Duguid
- Physiological and environmental factors affecting the migratory behaviour and survival of sockeye and steelhead salmon smolts – final year - UBC
- Strategic Salmon Health Initiative – Kristi Miller et al.
- Spatial Temporal Extent of Kelp Canopy Area – final year - Maycira Costa
- Estuarine and Coastal Restoration – final year – Seachange
- Restoration Research on Kelp Forest Habitats in the Salish Sea – final year- Sherryl Bisgrove and Bill Heath
- Eelgrass Mapping, Fish Monitoring, and Habitat Data Collection – final year- Nile Creek Enhancement Society
- Remote Sensing for Eeelgrass Distribution – final year- Maycira Costa
- Hatchery Delayed Release studies – final year - DFO
- Modeling: Angelica Pena, Villy Christensen, Susan Allen
- Database development: Spatial-temporal environmental data database (2002-2016) organization to support zooplankton-phytoplankton synchronicity and modeling analysis – Maycira Costa
- Strait of Georgia Data Centre development – Isobel Pearsall and Terry Curran

Participant suggestions from the Canadian 2016 Year End Retreat included the following:

- Compare current studies of microbe load to pathogen DNA in archived samples
- Compare current citizen science data with historical oceanographic data
- Collate hydrometric data to look at their association with blooms (over and above Fraser River discharge)
- Relate results from acoustic tracking to zooplankton, MEOPAR model, citizen science oceanographic data
- Consider installing Central Strait of Georgia sediment trap

- DNA analysis of juvenile salmon stomach contents
- Extend time series of satellite data and phytoplankton estimates
- Continue kelp restoration studies
- Analyze time series of kelp and eelgrass changes in Salish Sea
- Collaborate with Hakai to link to northern studies
- Investigate why chum populations are doing well
- Consider ecosystem focus and species that interact with juvenile salmon

Perspectives on US-Canada synthesis and assimilation work (Schmidt and Pearsall)

Spring-summer 2016 meetings and ongoing work depends on cross-border communication and data aggregation. Kathryn Sobocinski is working with Isobel Pearsall to conduct cross-border trend analyses among Salish Sea sub-basins. Villy Christensen, Isaac Kaplan, Raphael Girardin, and others are calibrating ecosystem modeling efforts between Puget Sound and Strait of Georgia. Datasets are shared across modeling and indicators efforts.

Cross-border dataset comparisons are underway or planned for zooplankton abundances, harbor seal diets, chinook population distribution and survival, chinook diets and level of piscivory, success of chinook outmigrant strategies based on adult otolith collections, and satellite data (bloom timing, turbidity, etc.). Integration of physical > plankton > fish data and integration of satellite data with in situ observations are being explored. Coho and chinook survival time series are being updated, including improving the wild coho survival dataset for British Columbia, and scientists from US and Canada are comparing freshwater to marine survival for certain Salish Sea wild coho populations.

Pacific Salmon Foundation hosted a workshop to summarize Canadian progress to date and assess inter-project and cross-border collaboration. Overall, there are lots of good datasets and a data portal through the Strait of Georgia Data Centre, but big-picture synthesis is needed. Data gaps reported by researchers included

- disconnects between scales of data collection,
- no productivity rate measurements,
- few studies in Fraser, Juan de Fuca, and inlets (e.g., Howe Sound, Burrard),
- more focus on chinook over coho,
- limited focus on carrying capacity,
- too little focus on non-salmonid fish species, particularly abundant species like *Leuroglossus*,
- limited information on forage fish abundance and diets, in particular beyond herring
- no contaminant studies on the Canadian side, and
- lack of experimental studies.

Moving forward, Canadian researchers prioritized linking fish performance and behavior to oceanography and lower trophic levels, determining how to scale up focused studies into a larger-picture, adding personnel for sample processing, data analysis, and GIS needs, and developing focused workgroups to address cross-border and cross-project needs.

Other feedback on project process, progress, and next steps

- Francis Juanes – indirectly funded work may also be of interest to incorporate. For example, microplastics ingestion studies through the Juanes lab, or shellfish aquaculture which has effects on juvenile salmon.
    - Brian Riddell – in Canada, much of the kelp and eelgrass restoration effort has to do with intensive shellfish aquaculture areas.