SALISH SEA
MARINE SURVIVAL PROJECT

United States – Canada Science Retreat Report

2015

December 8-10
Vancouver Airport Marriott, Richmond, BC

Attendees

United States

Alan Chapman (Lummi Nation)
Austen Thomas (Smith-Root)
Barry Berejikian (NOAA)
Brian Beckman (NOAA)
Casey Ruff (SRSC)
Chris Harvey (NOAA)
Correigh Greene (NOAA)
Dave Beauchamp (UW/USGS)
Evelyn Brown (Lummi Nation)
Iris Kemp (LLTK)
Jacques White (LLTK)
Joe Anderson (WDFW)
Josh Chamberlin (NOAA)
Julie Keister (UW)
Kathryn Sobocinski (NOAA)
Ken Currens (NWIFC)
Ken Warheit (WDFW)
Lance Campbell (WDFW)
Madi Gamble (UW)
Mara Zimmerman (WDFW)
Megan Moore (NOAA)
Michael Schmidt (LLTK)
Mike Crewson (Tulalip Tribes)
Mike Mackay (Lummi Nation)
Neala Kendall (WDFW)
Parker MacCready (UW)
Paul Hershberger (USGS)
Scott Pearson (WDFW)
Steve Jeffries (WDFW)

Canada

Andrew Trites (UBC)
Ben Nelson (UBC)
Brian Riddell (PSF)
Bruce Bell (PSF)
Carl Walters (UBC)
Chrys Neville (DFO)
Cory Matheson (PSF)
David Welch (Kintama)
Dick Beamish (ret DFO)
Elise Olson (UBC)
Erin Rechisky (Kintama)
Francis Juanes (UVic)
Hassen Allegue (UBC)
Helen Gurney-Smith (VIU)
Ian Perry (DFO)
Isobel Pearsall (PSF)
Jennifer Boldt (DFO)
Jim Irvine (DFO)
Karia Kaukinen (DFO)
Ken Denman (UVic)
Kevin Pellet (BC Cons. Fnd.)
Kristi Miller (DFO)
Marc Trudel (DFO)
Maycira Costa (UVic)
Moira Galbraith (DFO)
Nathan Furey (UBC)
Nikki Wright (SeaChange Marine Cons. Soc.)
Stephanie King (Sea This Consulting)
Svetlana Esenkulova (PSF)
Terry Curran (ret DFO)
Tony Farell (UBC)
Villy Christensen (UBC – IOS)
Will Duguid (UVic)

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Summary

U.S. and Canadian scientists convened for their third Salish Sea Marine Survival Project Retreat in December 2015. The objectives of the meeting were to:

1. Present and discuss the status of current research, implementation issues, lessons learned, and preliminary results and implications from 2015 research studies and sampling programs.
2. Continue to work on research alignment between US (Puget Sound) and Canada (Strait of Georgia), and develop next steps to build out from proximate to ultimate causes of mortality.
3. Discuss comprehensive approaches to data synthesis, visualization, data aggregation needs, etc. Determine best methods of reporting to and receiving feedback from broader community at Project midpoint.

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. See the notes in body of this report for details. The early findings that were reported on are listed below:

Survival Trends and Outmigrant Survival Patterns

- The US-Canada Chinook Task Team found that hatchery chinook smolt survival trends grouped regionally (Southeast Alaska + BC Coast, Strait of Georgia, Puget Sound, WA/OR Coast + Strait of Juan de Fuca) with high inter-population variability. Differing temporal patterns in survival suggest that populations may be responding to more localized environmental factors more than to large-scale ocean forcing factors (e.g., PDO), supporting this Project's focus on factors affecting survival in Puget Sound and Strait of Georgia.
- The Strait of Georgia telemetry array was upgraded in 2015, now including dual frequency arrays in Johnson Strait and the Discovery Islands. These arrays successfully detected smaller acoustic tags. The smaller tags allow for migration and survival studies of salmon, such as Chinook, that outmigrate through the Strait of Georgia at a smaller size.
- Telemetry studies indicated a release location/migratory path effect. Juvenile steelhead that had to travel farther through Puget Sound died at higher rates. In a specific instance (not presented at the retreat), steelhead traveling south around Whidbey Island survived to the Strait of Juan de Fuca at half the rate of those that traveled the shorter route through Deception Pass (unpublished Connors – Seattle City Light). Similarly, Strait of Georgia steelhead outmigrating through Malaspina Strait (west of Taxeda Island) were twice as likely to survive to Queen Charlotte as those that took the eastern route.

Outmigrant Behavior and Growth

- Scale analyses indicate that returning adult Chinook from Washington Coast populations achieve a larger size by first ocean annulus than returning adults from Puget Sound populations. Furthermore, in the few years analyzed, Puget Sound Chinook smaller size by first ocean annulus is consistent with lower overall survival. This pattern was not seen with Washington Coast Chinook. Preliminary data also suggest regional differences in growth within Puget Sound sub-basins: South Puget Sound fish appear smaller at first ocean annulus.

- IGF-1 data and bioenergetics models suggest higher growth rates as Chinook move offshore in the Puget Sound environment, with growth increasing substantially in July. Results from 2014 are consistent with previous findings for offshore. 2015 not yet complete. Estuary-offshore movement related to growth and feeding may be population-specific.
- Coho IGF-1 was higher in northern Strait of Georgia in 2012 and 2014 compared to central and southern Strait of Georgia.
- Coho in 2015 trawl surveys were the largest and most abundant seen in the time series (1998-2015). Percentage of jacks was high.
- Microtroll data showed Chinook were caught deeper in 2015 than 2014 and suggested localized variation in depth selection and diet composition. It also showed larger Chinook, apparently faster growing in 2015 vs 2014. And, there was no obvious evidence of hatchery vs wild differences in diet or growth, and no evidence of a decline in hatchery abundance in sample areas over time.

Bottom-up Effects: Prey availability, changes to primary production and harmful algae

- Citizen Science vessels successfully sampled 10 sites around Strait of Georgia, recording CTD data, turbidity, pictures, and GPS locations. Collections of phytoplankton and zooplankton were also made. In 2016, ocean acidity measurements will be added.
- In Puget Sound, regional stratification is correlated with river flow. The datasets available did not show correlations between stratification and chlorophyll or downward radiation/light and chlorophyll on a monthly time step. Results were constrained by frequency of CTD data (monthly).
- The 2015 bloom in Strait of Georgia was earlier than normal. Moorings and MODIS satellite data found a localized “seeding” bloom in late February in Sentry Shoal followed by a spring bloom covering most of Strait of Georgia by March 7. Also SUNA nitrate sensor data suggest chlorophyll tends to peak with, or shortly after, high nutrient events. Periodic increases in nitrate through the summer occur with cold, salty events which indicate upwelling. MODIS satellite data also suggest the Strait of Georgia spring bloom covered Strait of Georgia in mid-April 2014, over a month later than 2015.
- Sampling at the Quadra Island field site in Northern Strait of Georgia suggest upwelling events are linked to phytoplankton blooms. 2015 conditions were favorable for diatom productivity. This did include mechanically harmful species; however, there was a mall presence of toxic species of plankton overall. Data also revealed times when potential for match-mismatch between food availability and the presence of outmigrating salmon could occur.
- Higher proportions of YOY herring were eaten by juvenile coho in northern Strait of Georgia regions, versus higher proportions of crab larvae in southern Strait of Georgia. And, higher proportions of YOY herring were eaten in 2012 and 2014 when IGF-1 in the juvenile coho was higher.
- Crab larvae dominated diets from seining and trawling for Cowichan Chinook in May-June. Typical diets from Ricker trawling for Cowichan Bay Chinook were dominated by crab larvae and hyperiid amphipods (July- summer) and YOY herring and euphausiids (October - late-summer/fall). Cowichan Bay chinook ate significantly less during phytoplankton blooms in 2014. The few non-empty fish ate high proportions of insects. Microtrolling data (sampling July through October) suggest decapod larvae and hyperiid amphipods dominated Cowichan Chinook diet.

- Crab larvae were dominant by weight in juvenile Chinook diets in the Puget Sound offshore, consistent with past findings. A comparison of Chinook diets and prey field suggest Chinook continue to feed on larval crab at a high rate as the availability of crab larvae declines. This may suggest a potential mismatch between the maximum supply of larval crab and demand by Chinook.
- The 2014 Puget Sound copepod community composition showed a seasonal cycle and regional specificity. The San Juans and Main Basin had the most different communities.
- Copepod community indices were developed through monthly zooplankton sampling at one Strait of Juan de Fuca site. A 3D ordination captured 88% of the community variance. Axis 1 was strongly correlated with sea surface temperature and showed a seasonal cycle and a decadal, PDO-like pattern. The two strongest species correlations with Axis 1 were with an inland-water species (positive correlation) and an oceanic species (negative correlation). Axis 2 correlated well with coho marine survival on a Puget Sound-wide scale and a sub-basin-specific scale. There was population-level variation in the strength of the correlation.
- In all seasons of 2015 (spring, summer, fall), 20-25 mm zooplankton dominated Strait of Georgia samples. Copepods (esp. Calanoid) dominated the samples in abundance and biomass throughout the collections. Crab larvae abundance peaked in April, euphausiids in March, and amphipods in June and August. For icthyoplankton, an abundance of larval clupeids and gadiformes peaked in March.
- Strait of Georgia age-0 herring biomass was related to age-3 recruit abundance (R^2 = 0.67). Age-0 biomass has varied interannually with higher biomass/abundances in even years, since 2004. Data suggest that age-0 herring condition may have improved since the 1990s. Northern Strait of Georgia chinook survival was positively related to age-0 herring catch weight (R^2 = 0.47).
- Detection algorithms have been developed to map kelp and eelgrass beds with satellite imagery and aerial photography + satellite imagery, respectively, to investigate changes in the spatial extent of these habitats since the 1980s.

Top-down Effects: Predators, disease and contamination

- A genome-wide association study on Puget Sound steelhead suggested survival/mortality was associated with a few specific loci. Smolts with certain alleles at those loci may be compromised by immunological response or fin development.
- Microbe richness varied by stock and region and peaked in fall. The majority of Strait of Georgia Chinook tested had at least one microbe known/suspected to cause disease. Fungal and protozoan parasites were more common than bacterial and viral pathogens. With fish health management primarily focused on in-hatchery performance, these microbes are generally not flagged as important because they result in chronic, sub-lethal impacts (reduced swim performance, predator avoidance, feeding, osmoregulation) versus acute impacts.
- The prevalence and intensity of the parasite, *Nanophyetus*, was very high in Central and South Puget Sound steelhead populations from the Green and Nisqually rivers. Tests for whether the parasite is leading to decreased swimming performance and increased mortality are planned for 2016.
- GPS-equipped seals typically foraged within 10 km of their home haul-out. Foraging behaviors in Strait of Georgia seals peaked at dusk with a secondary peak at midnight.

- At the peak of Big Qualicum coho outmigration, four Big Qualicum estuary seals ate 50 smolts per day, which satisfied about 50% of the seal's daily energetic requirement.
- Acoustic telemetry provided indirect evidence of seal-steelhead predation events in Puget Sound. Some steelhead tags were deposited near haul-outs, and some followed a tidal pattern of detections that mimicked seal behavior. No effect of acoustic noise on predation (aka dinner bell effect) could be detected in a telemetry analysis of Puget Sound steelhead.
- Modeled consumption estimates suggested harbor seals in the Strait of Georgia ate 40-67% of the outmigrating juvenile coho and 40-43% of the outmigrating chinook in 2012-2013. Mortality rates peaked at fish sizes 115-145 mm for both species. Mortality estimates were primarily based upon estuary-based harbor seal diets. Future work will include non-estuary based diets to better calibrate the results.
- (Not presented at retreat) Contaminants are entering Puget Sound Chinook and steelhead as they outmigrate, with levels increasing as they move offshore and significant exposures occurring in the lower parts of some rivers. Correlations with marine survival have been made in some instances (unpublished O'Neill, Washington Dept. of Fish and Wildlife).

US-Canada Alignment

Through a series of breakout sessions, scientists working together across the border or separately but on the same topic convened to discuss their approaches and progress, and discuss next steps in research. Per the alignment structure, the Project works toward aligning the Trend Analyses and Modeling, Bottom-up Sampling Program, and Data Management and Sharing while leaving individual bottom-up studies and top-down studies independent with cross-talk and collaboration occurring where it makes sense to do so.

Trend Analyses and Modeling

Trend analyses and modeling efforts are on-going in both US and Canada. Modeling and trend analyses specifics vary across the border, but outcomes should be broadly comparable. Researchers agree that developing a suite of models and trend analyses approaches is more informative than focusing on a single approach, and recommend increased cross-border communication during development and model scenario testing. Chinook, coho, and steelhead survival trend analyses all suggest some extent of Salish Sea decline, and all studies found a spatial component to smolt survival trends. Survival patterns vary by species and basin within the Salish Sea. Therefore, linking survival data to temporally- and spatially-explicit ecosystem and community data is of high relevance and importance for all species. Indicators development will begin Salish Sea-wide in 2016. End-to-end ecosystem model development will begin in Puget Sound in 2016. A data meeting will be held during the summer of 2016 to promote cross-border work.

Bottom-up Sampling Program and Studies (Salmon, Zooplankton, Physical)

There are some differences in space and time in salmon sampling, with a longer nearshore collection effort in Puget Sound because the fish tend to disperse more slowly there. Utilizing the Ricker vessel in the Strait of Georgia and Puget Sound in July and September for offshore salmon sampling remains a top priority. Participants recommended progressing work to compare Puget Sound and Strait of Georgia data. This includes cross-calibration of methods: purse seines and midwater trawls (size and species composition), scale and otolith, and diet analysis.

For zooplankton, vertical tows are being performed throughout the Salish Sea in a similar fashion. Sampling will continue in 2016. Oblique tows are being performed in Puget Sound; most of the issues experienced in 2014 were fixed in 2015. Participants recommended also conducting oblique tows in Strait of Georgia from March through September to sample salmon prey fields.

Physical monitoring approaches are more distributed, with sampling inconsistently disbursed in space and time, on both sides of the border, relying on a mix of moorings, CTD casts, and ferry-mounted monitors. However, the physical data collected are generally comparable, with circulation models helping to expand these data and describe physical characteristics Salish Sea wide.

Participants recommended integrating physical and biological data to identify the temporal (inter-annual vs long term) and spatial (large vs local) scales at which Salish Sea processes operate. Specifically, they suggest identifying areas of increased abundance and productivity (hotspots) and their relation to the rest of the ecosystem.

Participants also recommended developing a better understanding of the relationship between food supply, consumption, and fish behavior by: 1) Relating zooplankton communities to fish feeding, and identifying fish characteristics that indicate quality of feeding are priorities; 2) Monitoring fish feeding and survival over the first winter. Test functional feeding response to varied densities of prey; and 3) Determining factors driving fish movement from nearshore to offshore and the relative importance of feeding opportunity versus predation risk.

Finally the group re-emphasized the value of looking across salmon species for a better understanding of what is driving survival.

Top-Down Studies (Predators and fish condition)

The group acknowledged that steelhead—due to their limited residence period in the Salish Sea, high mortality rates, and ability to be tracked with acoustic telemetry— provide some advantages to assessing early marine mortality that other species don't . And, the group in general recommended that consideration be given to continue to pair acoustic tracking activities with other data (fish health via non-lethal tissue sampling, and environmental) to reap greatest benefit from technology.

For fish health studies, group recommended exploratory fish health work in Puget Sound similar to what Kristi M. has done in Strait of Georgia. This could be done cost effectively by providing existing samples (steelhead tissues in RNAlater) to Kristi's lab for analysis. Other recommendations included the need to affiliate signs of potentially compromised fish health (e.g., microbe presence and composition) with actual reductions in fish performance and increased predation. Contaminant and harmful algae studies are only occurring in Puget Sound and Strait of Georgia, respectively. The group recommends building upon each region's work if initiating on opposite sides of the border.

Additional work is needed to finalize estimates of harbor seal predation rates, including broader spatial coverage (sub-basins and estuary vs non-estuary) and up-to-date data on seal abundance and distribution. An assessment of potential management strategies may inform next steps for predation research and are listed in the notes section, below. Participants primarily recommended hatchery release manipulations (release numbers, timing, locations, variability) as an approach to test hypotheses regarding/effects of predation intensity, pulse prey abundance (prey switching, behavioral responses), buffering capacity (match-mismatch with buffer prey), and smolt foraging behavior (match-mismatch with juvenile salmon prey) on predation. Considerations discussed for hatchery release experiments are described in the notes section, below. Finally, from the bottom-up discussion, participants recommended considering impacts of artificial lighting and turbidity on the efficacy of visual predators.

Data Management and Sharing

The shared Project goal is to make ecosystem data assessed through this effort comparable across the Salish Sea and readily available and usable for a variety of analyses, with a life extending beyond this project. This is vital to project objectives such as establishing an ecosystem indicators program for salmon adult return forecasting. The shared approach for establishing long-term, useable data is to focus on back-end data needs, including data standardization to improve aggregation on a variety of platforms and automating data aggregation and quality control (QA/QC). LLTK continues to look to improve approaches to these back-end data needs. PSF continues to evolve the Strait of Georgia Date Centre as a central access point for Strait of Georgia data, and Puget Sound scientists continue to focus on established platforms such as NANOOS and NOAA's ecosystem indicators web site as data aggregators and access points for Puget Sound data.

In the near-term, the focus will be on data-sharing among Salish Sea Marine Survival Project participants (via Basecamp). The need for a Salish Sea data catalog was stressed at the 2015 retreat. This catalog should document datasets and associated metadata from both SSMSP studies and non-SSMSP studies. A dataset tracker/catalog will soon be accessible via the new "Datasets" project site on Basecamp. This site also serves as a data repository for those datasets shared internally among Project participants.

Critical Concerns, Project Gaps and Affiliated Considerations

Most participants recommend doing more with existing data in order to determine how the ecosystem shifted between the 1980s and today (and to distinguish processes controlling long-term trends versus inter-annual variability), and that the retrospective work should be more highly prioritized. Indicators and modeling exercises will help tell a more comprehensive story about the ecosystem and its effects on salmon, and evaluate current project hypotheses.

In the break-out sessions, the bottom-up group recommended more effort linking zooplankton to salmon in spatially- and temporally-explicit analyses. They also pointed to a lack of data on seasonal forage fish distribution and biomass, as well as a lack of data on abundance and diets of potential competitors and predators of juvenile salmon.

Throughout the meeting, there were several instances of an inter-annual seesaw pattern in abundance occurring in recent years (e.g., herring, pink, sockeye). Participants recommended focusing on this for clues regarding what is driving salmon survival.

Several participants were concerned over the lack of a comprehensive data catalog for the Salish Sea and the limitations that lack of data accessibility creates for modeling analyses. Some participants also recommended incorporating traditional ecological knowledge (TEK) and local ecological knowledge (LEK) into analyses. TEK and LEK were considered particularly useful for investigating ecosystem change across multiple decades.

Next Steps

- Participants should review this document in detail for recommendations relevant to their work.

- Participants recommended that next year's retreat be focused more on outcomes of integrating and comparing data among efforts, primarily between the Strait of Georgia and Puget Sound but also among the study focal areas. Thy include:
    - Comparing zooplankton data in space and time
    - Calibrating and comparing juvenile Chinook growth/diet/bioenergetics results
    - Integrating physical and/or biological data across collection mediums and up the food chain. For example, Strait of Georgia folks are discussing integrating phyto and zooplankton data from satellite and boat collections; chlorophyll data from satellite, citizen science, BC Ferries, etc; and phytoplankton/chlorophyll and fish migration data from satellite and acoustic telemetry, respectively. There was also discussion about the use of satellite measurements to derive turbidity data.
    - Comparing harbor seal diet data
    - Performing trend analyses among Salish Sea sub-basins, comparing salmon survival to fish characteristic and ecological data.

  Some of these concepts are described in greater detail in this report. We ask participants to begin working with one another as soon as possible, and then follow-up with LLTK and PSF on specifics for comparison work that could be completed in 2016 and presented in December.

- More work will be done throughout the year to better integrate efforts Salish Sea-wide. New Basecamp project sites are now established for general communications, publications and data management, and new indicators and modeling initiatives will work across borders. A data reference catalog (including datasets unaffiliated with the Project) is being developed as part of the Basecamp Datasets site and will in particular help propel indicators and modeling efforts now underway. A smaller US-Canada meeting will be hosted this summer focused on aggregating datasets relevant to indicators and modeling efforts.

- LLTK and PSF will consider approaches to improving how hypotheses are depicted, including categorizing hypothesis hierarchically, and using various methods to help prioritize them.

Tuesday, Dec. 8: Report on Current Findings

Trends Analyses

Salish Sea Chinook Survival Study Results (Casey Ruff)

A task team comprised of U.S. and Canadian researchers compiled a marine survival dataset for hatchery-reared Chinook salmon stocks within and outside of the Salish Sea. The dataset included 58 stocks with time series ranging from 7 to 36 years of data (overall, data covered the 1971-2008 time period). The task team focused on two questions: 1) are there regionally-specific trends in marine survival across time? and 2) at what spatial scale to marine survival trends co-vary among populations?

Using hierarchical agglomerative cluster analysis, distance-survival correlations, and multivariate autoregressive state space (MARSS) modeling, the team found some evidence for regional spatial/temporal patterns. The best-fit MARSS model suggested four regional groupings with a structural change in survival trends (a "regime shift" in survival): 1) Southeast Alaska and BC Coast, 2) Strait of Georgia, 3) Puget Sound, and 4) WA/OR Coast and Strait of Juan de Fuca. However, there was high inter-population variability. The cluster analysis did not indicate strong regional groupings over time, and the distance-survival correlations did not indicate strong coherence between neighboring populations over time. The team concluded that differences in survival patterns over time may indicate that hatchery chinook populations are more strongly influenced by localized environmental factors than large-scale forcing factors (e.g., PDO).

- Jim I. – were run timing and release strategy included in the analysis?
    - Yes, and there was little support for those groupings. Variable hatchery rearing practices were not controlled for.
- Ken W. notes that populations in close proximity are more related genetically – how can local conditions and genetic relationships be separated?
    - This is a confounding effect. Also, for Puget Sound fish, single genetic stocks (e.g., Soos Cr fall fingerlings) have been distributed to systems around the Sound.

Using Scales and Otoliths to Infer Chinook Growth (Lance Campbell)

Lance is using scales and otoliths from returning adult salmon and comparing with juvenile outmigrant data to identify successful life history and growth patterns for Salish Sea Chinook. Otoliths are being used to determine whether successful juvenile life histories vary geographically within Puget Sound and/or vary by stock. Scales are used to test the hypothesis that interannual variation in marine growth among populations affects survival to adulthood. The marine growth data provided by scales may also benefit forecasting models. Both Canadian and U.S. populations are included in the ongoing analysis (Cowichan, Nooksack, Skagit, Snohomish, Cedar, Green, Puyallup, Nisqually, Chehalis).

Otolith microchemistry is used to delineate freshwater residency and ocean residency periods, and fish size at ocean entry can be estimated based on otolith size at ocean entry. Trap data suggest a bimodal distribution of fry and parr/fingerling exiting river systems. Returning adults to the Nooksack and Cowichan were about 10-20% fry outmigrants and the rest were either parr outmigrants (Cowichan) or parr and yearling outmigrants (Nooksack). In contrast, no returning Cedar chinook were fry outmigrants. There is also some difference in outmigration timing by stock.

Scale morphometrics indicate that mean scale radius at first ocean annulus is larger for Washington coast fish than for Puget Sound fish – i.e., returning adults from coastal populations achieve a larger size by first ocean annulus than returning adults from Puget Sound. There may also be regional differences in growth within Puget Sound; South Puget Sound fish are smaller at first ocean annulus. However, there are potentially population-specific growth patterns that have not yet been accounted for.

- Madi G. – does the scale analysis include yearlings and subyearlings?
  - Only subyearlings.
- Marc T. – do otolith archives go back to the 1970s (i.e., can we look at how the proportion of fry and parr contributions to returns change over time)?
  - Otolith archives do not, but there are limited archival scale collections back to the 1950s or so.
  - The change in ocean conditions over the past couple years is exciting – what life history changes will result? Ongoing collections will address this.
- Evelyn B. – can scale metrics be related to otolith metrics in the first year? Do sample size needs for scales vs otoliths differ?
  - The goal is to have multiple years of analysis so fish can be tracked back to outmigration year and brood year. For otoliths, we need more samples. For scales, we have sample sizes needed to analyze by outmigration year, sex, and age.
- Michael S. – how many months at sea is encompassed in the first ocean year? Could this growth signal be confounded with Puget Sound/Strait of Georgia growth?
  - The growth could be confounded. The current results show substantial growth (10-20%) at early stage.

Bottom-up Studies

Factors Limiting Pacific Salmon Recruitment in Strait of Georgia (Marc Trudel, Chrys Neville)

Strait of Georgia researchers are estimating in-river survival calculated from mark-recaptures, completing cohort analysis on smolts collected from the hatchery and with beach seines, purse seines, and trawls, and comparing stocks that exhibit contrasting patterns of marine survival to test specific hypotheses.

Data from the first years of study suggest that:

1. Freshwater mortality for Cowichan chinook ranges between 11% (May release) to 20% (April release). PIT tags suggested 30% mortality from the hatchery. Wild chinook survived twice as well.
2. In Cowichan Bay, chum were the most dominant catch in purse seine surveys. Highest catch per unit effort was in May. The catch rate of juvenile chinook in Cowichan Bay increased to peak in early June. The timing in 2015 was similar to 2013/2014, but peak catch was higher in 2015. There was also a late catch of chinook in mid-August.
3. In Cowichan Bay, crab larvae were the dominant item in 2014-2015 summer chinook diets (over 80% of average diet in 2015), and crab and hyperiid amphipods were most common diet items. Fish from

sites just outside Cowichan Bay ate slightly less crab and more larval fish. The biggest changes from 2014 to 2015 was a decrease in larval fish contribution and the presence of *Oikopleura* in 2015. By September, diets were dominated (79%) by YOY herring and euphausiids, and hyperiid amphipods and euphausids were most common diet items.

4. In 2014, Cowichan Bay chinook had lower catch rates and ate significantly less during phytoplankton blooms. The few chinook that did eat during phytoplankton blooms ate high proportions of insects. There were no plankton blooms during 2015 sampling.
5. Coho from trawl surveys in 2015 were the largest and most abundant seen in the time series so far (1998-2015), and there was a higher percentage of Jacks.
6. Coho IGF-1 was greater in northern regions in 2012 and 2014. The diet composition also varied by region, with more YOY herring in the north and more crab larvae in the south.
7. Bite marks were noted on several fish this year. DFO is currently working to figure out what predator is leaving these marks; dogfish are a candidate. Lamprey wounds were also frequent.
8. Anchovy are not common in Strait of Georgia but were observed off the Fraser in 2014 and in Desolation Sound in 2015.
    - Mike C. – Chinook diets were 80% crab except during phytoplankton blooms when they were dominated by insects?
        - Most of the fish caught during the 2014 blooms were empty. The ones who were not empty had primarily ants and other flying insects in their stomachs.
        - Svetlana clarifies that there were no recorded blooms in 2015 in the Strait of Georgia. The 2014 blooms were phytoplankton blooms (there was also a toxic bloom in June 2014, but there were no fish samples taken during that time).

Chinook Distribution, Diet, Growth, and Survival in First Ocean Year (Will Duguid, Kevin Pellett)

PIT tags were used to investigate Cowichan chinook early survival. The further fish migrate through freshwater, the worse they survive in saltwater. No evidence for a critical smolt size for early marine survival based on mark-recapture studies. One limitation is that the detection efficiency of the PIT antenna is limited by noise and may have missed some proportion of returning tags.

Lab studies suggest that high growth and low growth can be differentiated with RNA:DNA ratio. Will D. is working with Brian B. to calibrate the RNA:DNA growth metric with IGF-1 growth metric.

Microtrolling, CTD casts, and phytoplankton samples were taken July-October at five Cowichan Bay sites with different physical dynamics on ebb and flood tides. Growth patterns differed between 2014 and 2015. A higher proportion of fish in 2015 were caught deeper than in 2014. Preliminary qualitative diet assessment suggests that crab larvae were important prey items at most sites; at one site diets had higher proportions of fish and lower crab. Hyperiid amphipods were also important. Catch per unit effort was higher at a more stratified site (Maple Bay), and the fish at that site appeared to select warmer depth strata perhaps to exploit zooplankton concentrated at the thermocline. Within one site (Sansum Narrows), flood tide (which introduced a plume of mixed water and potentially advected zooplankton into the bay) was associated with high CPUE.

- Dave B. – did you pump stomachs of larger chinook? Was there evidence of cannibalism?

  - Larger fish were from the BCCF survey, which did not do any gastric lavage. Anecdotally, about 1 in 20 fish had herring sticking out of their mouths.
- Evelyn B. – did you drag cameras through the site with microscale CPUE differences?
  - Will tested this and is thinking about using cameras to enumerate fish at depth. At that particular site, reasonable visuals can be obtained down to about 30m.
- Erin R. – what were the non-Cowichan fish, according to your GSI results?
  - Most of the fish caught were Cowichan. The bulk of the non-Cowichan fish were Puget Sound origin. There was also a small proportion of upper and lower Fraser stocks.
- Jacques W. – what are mechanisms by which marine survival might change as a result of feeding?
  - The first step is to understand what conditions fish prefer. There are many potential factors that may have changed over the past 40 years. Stratification may have changed. The behavioral use of tidal features for foraging probably has not changed. The use of certain hotspots could relate to predation. If fish are disproportionately concentrated in some areas, they may be more exposed to predators that focus on those areas. Climate change might increase temperatures such that fish are precluded from access to food.
- Mike C. – are changes in feeding location related to stratification and blooms?
  - There were more insects in 2014 diets, but it is unclear whether this difference was due to more blooms in 2014 or fish inhabiting shallower depths. Relating phytoplankton abundance to gut contents is a next step.
- Jim I. – why are hatchery fish dying in-river, and how much confidence do you have in the mark-recapture results?
  - Kevin tagged hundreds of fish and recaptured 25 wild and 46 hatchery fish. The fish moved quickly through the river: about two days to get to the estuary. This suggests that feeding is not an issue. They are entering very warm water and being exposed to predators (trout) in-river.
- Michael S. – do the deeper microtrolling catch depths in 2015 suggest that other net sampling was missing fish?
  - Marc T. says the purse seine may have missed fish but the Ricker would not have – it sampled deeper than the microtrolling. Chinook move deeper in the water column through the season and microtrolling sampling was not begun until July, whereas purse seine samples were taken starting in May.
- What is the hooking mortality for microtrolling?
  - Preliminary net pen assessment with 66 tagged chinook had one mortality and one tag loss over 24 hours. Also, one of the returned jacks in 2015 was a microtrolled tagged fish.
- Brian R. – we are trying to work out logistics for a televised derby program where experienced sport fishers microtroll and mark fish.

Critical Periods of Growth and Mortality in Puget Sound Chinook (Madi Gamble)

Offshore weights were always equal to or greater than weights in other habitats even during the same sampling season. IGF-1 samples from northern watersheds suggests growth rates are higher offshore. San Juan Island fish had highest IGF-1 levels. Diet data showed that insects were important in the estuary/nearshore and crab larvae were important to offshore growth. The peak crab larvae abundance in zooplankton samples occurred prior to fish moving offshore, suggesting a potential mismatch.

Bioenergetics models based on estuary-offshore movement scenarios and estimated growth suggested that, for Nisqually hatchery chinook, growth rates and feeding rates were highest offshore but there was no significant growth advantage associated with any particular habitat: fish that moved offshore later did just as well as fish that moved offshore early. For Skagit hatchery chinook, fish that moved offshore earlier had a growth advantage, but their feeding rates later in the season were lower than fish that moved offshore later.

- Chrys N.– does prey field zooplankton sampling measure crab abundance adequately, or would surface sampling gear like a neuston net be more appropriate?
    - Julie K. says the prey field sampling catches zoea well. Megalops are much more surface-oriented and a neuston net would perform better.
        - Madi says zoea and megalops were lumped for bioenergetics models but quantified separately in diet analysis. The intern doing diet analysis showed proportionally more megalops in the diet than in the water column samples.
- Marc T. – were literature values used for bioenergetics models?
    - Literature values were used for all energetic values, many with low confidence, and all were held constant through the summer.
- Lance C. – other studies showed decreased survival of hatchery fish soon after release. Does that bias your nearshore results?
    - The sampling scheme does not measure mortality directly.

Strait of Georgia Herring Assessment (Jennifer Boldt)

Recruitment is highly variable for age-3 Strait of Georgia herring. Age-0 herring biomass is related to age-3 recruit abundance. Since 2004, age-0 herring biomass varies interannually in a “sawtooth” pattern where abundances are higher in even years. Beginning around 2002, age-0 herring were heavier for a given length. This suggests better herring condition and possibly improved prey quality for salmon. Northern Strait of Georgia chinook survival is positively related to age-0 herring catch weight.

- Julie K. – coho survival in Puget Sound correlates with Juan de Fuca copepod community index and also has a sawtooth pattern. Are there other datasets showing this pattern?
    - Marc T. is looking into potential effects of pink salmon (which follow a 2-year cycle). YOY herring are more abundant in years with pink salmon; there may be a predation buffer effect. This does not explain patterns prior to 2002. Brian R. adds that pink abundance has increased through the 2000s.
- Francis J. – did herring surveys catch predators?
    - Sampling is conducted at night; catches are mostly small fishes and jellyfish.

- Francis J. – is there variation in the size structure of age-0 herring?
  - Yes. But there is no apparent trend over time and no see-saw pattern.
- Evelyn B. – the see-saw pattern may be a density-dependence issue; it could occur if a strong year-class prevents the next younger year-class from occupying optimal habitat.
- Dick B. – age-3 recruit abundance peaks around 2000 and then declines to a low in 2010. Over this period there is oscillating but always low abundance and over the same period, coho and chinook have low survival. The same factors may be affecting these fish, but it is not a simple relationship: the chinook population that survives best (S Thompson) enters in July and eats mostly amphipods.
- Ian P. – it looks like the change in condition happened in 1997-1998 (El Niño year) and then leveled out in 2010 (also El Niño year).

Puget Sound Zooplankton Update (Julie Keister)

The second field season of the Puget Sound zooplankton sampling program concluded in October 2015. This program consists of eight partnering organizations doing bi-weekly deep vertical tows and shallow oblique “prey field” tows over varying bottom depths at 14 sites in Puget Sound. Samplers learned from the initial 2014 field season and improved sampling consistency and sample quality dramatically in 2015.

Ordinations of the copepod community composition in 2014 show a seasonal cycle and regional specificity: San Juans and Main Basin of Puget Sound have the most different communities.

Monthly samples have been taken at the JEMS site in Strait of Juan de Fuca since 2003 (with some gaps). These data were not collected quantitatively until recently; the dataset consists of species proportions rather than abundances. A 3D ordination of the copepod community captures 88% of the variance. Axis 1 of the ordination captures nearly half the variance and is strongly correlated with sea surface temperature. Axis 1 shows a strong seasonal cycle and a pattern that looks similar to PDO. The strongest species correlations with axis 1 were a positive correlation with an inland waters species (*Corycaeus anglicus*, 0.83) and a negative correlation with an oceanic species (*Pseudocalanus mimus*, -0.71). Axis 2 captures a little over a quarter of the variance. The May-September average of this index correlates well with coho marine survival on a Puget Sound-wide scale and on a sub-basin-specific scale. Some coho populations correlate better than others, even from within the same region; there is variation within the general copepod community/survival relationship.

- Marc T. – is the copepod index correlated with chinook survival?
  - Julie does not yet have chinook survival data to do this analysis.
- Parker M. – what species are driving Axis 2?
  - It appears to be *Pseudocalanus* spp versus *Paracalanus* spp. But right now those are aggregates of several species, since juveniles are not speciated in analysis.
- Parker M. – were crab larvae included in the index?
  - Not yet.
- Jacques W. – does coho survival correlate with Axis 1 also?
  - The correlations are not strong. But Correigh Greene tested multivariate models of coho survival, and zooplankton indices based on both Axis 1 and Axis 2 were among the best

explanatory factors. Axis 1 is capturing environmental variability and likely relates to survival in that manner.

Strait of Georgia Zooplankton Update (Ian Perry)

Vertical tows were conducted every two weeks from February-October. Water temperatures in Strait of Georgia were much warmer in 2015 than normal. At the northern station, there was an early March bloom of small plankton. In early May, the traditional spring bloom of larger plankton occurred. The spring bloom in 2015 was the earliest since 2005. Size variability increased in late summer. Samples from the central station were similar, except there was no early bloom of small plankton observed. In all seasons, 20-25 mm plankton dominate. Ichthyoplankton observations showed a peak of clupeids and gadiformes in March. Crab larvae abundance peaked in April, euphausiids in March, and amphipods in June and August. Sample processing for 2015 is currently in progress and about halfway complete.

- Ken D. – has the decapod peak changed over time (potential match-mismatch with juvenile salmon)?
    - For some locations there are long-term samples, so those sites have potential for this analysis. However, crab larvae are patchy and difficult to pick up at any given time. Ian recommends caution relating *in situ* crab abundances to stomach samples because as crab larvae get older they 1) move deeper to settle and also 2) get patchier and harder to sample.
- Marc T. – Puget Sound fish appear to move offshore and feed on crab larvae. In Strait of Georgia, growth is higher when fish eat YOY herring. But, there were lots of crab larvae in Cowichan Bay guts.
- Dick B. – there is an interesting oscillation with high vs. low herring abundance that has been going on for a few years which is not reflected in growth.
    - We don't yet know if herring larvae show this pattern yet. Juvenile herring oscillate in abundance.
- Dick B. – can you compare these plankton samples to samples from the 1970s?
    - The samples are comparable where we have those data. Older samples are only available from a few locations.

Linking Primary Production to Stratification and Atmospheric Drivers (Parker MacCready)

Data on river flows, stratification, downward shortwave radiation, and phytoplankton blooms were included in this analysis. Stratification was somewhat correlated with river flow for all regions examined (Fraser, Deschutes, Puyallup, Dosewallips, Skagit Rivers; and associated marine sites). Stratification was not correlated with chlorophyll or light in any months at the location examined (Carr Inlet). The analysis was limited to a monthly frequency, since CTD casts were taken on a monthly basis. ORCA buoys provide sources of continuous data; however, the time series is not yet long enough to benefit this analysis.

- Ian P. – are winds included in this analysis?
    - Wind is not well-captured in the currently available data sources, but Parker is seeking others. He looked at SeaTac wind records, but no relationships were obvious. Site-specificity is likely important.

- Ian P. – Susan Allen (UBC) has a model that captures the spring bloom based on stratification, temperature, and other factors. Recommend discussing with her.
- Julie K. – how close are your modeling efforts to hindcasting Puget Sound conditions?
    - Within about 6 months the high-resolution Puget Sound model with biogeochemistry component will be hooked up to the daily forecast system. The pieces to complete a retrospective hindcast are there, but hindcasting the past 25 years is a big lift and funding is not yet available.

High-Resolution Monitoring of Surface Water Properties (Stephanie King)

Sensors were deployed in surface waters at three locations in Strait of Georgia (Sentry Shoal, Egmont, Halibut Bank) and take measurements every 30 minutes at 1 m water depth. In 2015, there was a very early localized spring bloom in late February at Sentry Shoal (north). There was a second, broadscale spring bloom in early March. There is a pattern where years with "seeding" blooms in inlets are years with earlier spring blooms. The 2015 bloom follows this pattern. Based on satellite data, the central Strait of Georgia spring bloom typically happens by mid/end-March and the north Strait of Georgia spring bloom happens a little earlier.

Strait of Georgia Citizen Science Update (Isobel Pearsall, Ryan Flagg)

Citizen science boats sampled in 10 locations around Strait of Georgia. All boats were outfitted with sampling gear and trained in sampling methods. The data collected includes CTD casts, secchi measurements (turbidity), phytoplankton, zooplankton (for some vessels only) and GPS locations. Metadata are transferred via a mobile app that provides near-real time data transfer and automatically associates data with time and GPS. Next year, ocean acidity will also be measured.

Chemical Oceanography with Biological Relevance (Helen Gurney-Smith)

Intensive sampling was conducted at a fieldsite off Quadra Island. Beginning in December 2014, sensors monitored sea surface temperature, salinity, pCO_2, and calculated pH and calcium carbonate saturation states every two seconds. Phytoplankton and zooplankton samples were collected twice a week from February until October (then once per week).

Preliminary results indicate that these data capture wind-driven upwelling events and the spring bloom. Aragonite saturation data showed extended corrosive conditions in fall and winter. Phytoplankton blooms were correlated with aragonite saturation. Zooplankton peaked 2-3 weeks following phytoplankton blooms.

Conditions in 2015 were favorable for diatoms, but there was little presence of toxic species in samples. Phytoplankton species composition did not vary between night and day tows, but zooplankton composition did: larval tunicates were only present in night samples.

Nearshore Habitat Studies (Nikki Wright, Maycira Costa)

The Seagrass Conservation Working Group is trying to remediate historical logging areas: how can eelgrass beds be effectively and reliably restored? Most sites (24) with transplanted eelgrass shoots held on or succeeded. Four sites failed, possibly because of sediment issues.

Detection algorithms are being developed to map bull kelp beds and eelgrass using satellite imagery. Kayak surveys were used to groundtruth satellite data. Satellite datasets go back to the 1980s; the goal is to understand the spatial distribution of kelp over time. The eelgrass dataset consists of aerial photos and archival data and will be used to understand intertidal eelgrass habitats in relation to shoreline development and land use change over time.

Top-Down Studies

Genome-wide Association Study of Outmigrating Puget Sound Steelhead (Ken Warheit)

This analysis tested for a correlation between a fish's genotype and phenotype: was a particular genotype associated with mortality/survival? DNA clips were taken from acoustically-tagged Skokomish, Green, and Nisqually steelhead. Four loci were significantly associated with survival outcomes, and two of those four were associated with genes coding for developmental and immunological traits. For the loci coding for morphogenesis, the heterozygote survived best. For the loci coding for immunology, one of the homozygotes survived best. Year, population, and release location were important factors; low sample sizes currently limit confidence to further analysis. The working hypothesis is that smolts with certain alleles may be compromised by immunological response or fin development.

- Kristi M. – is tagging-related mortality a concern?
    - Barry B. says the estimates of tag loss and tag mortality are very low. Their tag effect studies show nearly 100% survival and retention through the two-week outmigration period.
- Mike C. – why were those specific steelhead populations chosen, and why will 2016 analysis include only Green and Nisqually steelhead?
    - The three included populations had the highest sample sizes and the clearest mortality/survival pattern. The 2016 analyses will be limited to simplify the interpretation and to focus on increasing sample sizes to get robust results.

Strait of Georgia Genomics (Kristi Miller)

High-throughput monitoring assays to 45 salmon microbes known or suspected to cause disease and can be used to look at microbe distributions in wild, hatchery, and farmed salmon. Preliminary results for chinook salmon suggest that the majority of fish have one or more of these microbes. Fungal and protozoan parasites were more common than bacterial and viral pathogens. There were 24 microbes with a prevalence of >1%. The prevalence of individuals carrying at least one high-load microbe increased during ocean residence. High loads are more likely to be associated with disease; high load prevalence peaked in fall.

The distribution of microbes varied by stock and region. There were Salish Sea and outer coast differences, and some variation between yearlings and subyearlings. Seven microbes (all parasites) were more common in stocks of high conservation need.

Microbes commonly observed in Salish Sea chinook included *Paranucleospora*, which is transmitted through sea lice and causes proliferative gill disease; *Parvicapsula* spp., which have been associated with kidney disease, vision impairment, anorexia, and with increased predation risk by auklets on sockeye;

and *Loma* spp., which have been associated with inflammatory disease and reduced migratory survival in returning adult sockeye.

Nanophyetus *in Puget Sound Steelhead (Paul Hershberger)*

The parasite *Nanophyetus salmincola* was assessed in Puget Sound steelhead populations. Northern populations (Skagit, Snohomish/Skykomish) were negative, as was the Tahuya (Hood Canal) population. *Nanophyetus* was present in the Nisqually and Green/Duwamish systems. In the Green, prevalence increased over the migration route, with highest loads in the estuary. In the Nisqually, prevalence and loads were very high throughout the system. Next steps will test whether *Nanophyetus* is associated with decreased swimming performance and increased mortality.

- Lance C. – is downriver increase in *Nanophyetus* associated with an increase in the carrier *Jugo* populations? Flow might affect *Jugo* populations which might affect *Nanophyetus* infections.
    - *Jugo* biogeography is not well-documented. *Jugo* has been observed upriver in some areas. Paul would assume *Jugo* is mainly in the lower river though.
- *Jugo*/*Nanophyetus* is not necessarily associated with urbanization, but fish that are immunocompromised may be more easily infected.

New Array Deployments and Very Small (V4) Acoustic Tags (Erin Rechisky)

Two new dual-frequency sub-arrays were deployed at the southern end of the Discovery Islands and in Johnstone Strait in 2015. These sub-arrays use a new geometry designed by Kintama to increase the detection of 180 kHz tags compared to earlier sub-array designs. Kintama then tested the performance of a new 180 kHz transmitter (VEMCO V4) which is about the size and weight of a tic-tac. Test results found a 74% detection efficiency. Smolts as small as 100 mm, 10 g can be tagged with these tags.

- Chrys N. – will the new tag be in broad use soon?
    - Tags can be programmed to maximize battery life. Kintama is confident they will be able to get a satisfactory detection efficiency with good battery life. For the pilot study, battery life was 50 days. However, several sub-arrays (QCS, NSOG, JDF) do not operate at 180 kHz and therefore cannot detect 180 kHz tags.
- Megan M. – was there any effect of transport from hatchery on fish survival in tests?
    - The water temperature in the Strait of Georgia at time of transport was up to 18°C. Fish were released at night to avoid visual predators. They were clearly disoriented and flopping around at the surface. This method wasn't used in previous studies, so Erin & David W. aren't sure whether the behavior was normal for hatchery fish released into warm saltwater.

Movements of Steelhead and Sockeye Smolts in Strait of Georgia (Nathan Furey)

A meta-analysis of telemetry data suggested that migration route is important to steelhead survival. Steelhead outmigrating through Malaspina Strait (west of Taxeda Island) are twice as likely to survive to Queen Charlotte as those that take the eastern route. Circulation patterns may influence migration. Burrard Inlet appears to be a high mortality area: fish that were transported outside of Burrard Inlet survived better than fish that were released into the river feeding into the inlet. Survival was similar between the transport/non-transport group for other segments of migration.

Harbor Seal-Steelhead Interactions in Puget Sound (Barry Berejikian)

Steelhead outmigrate rapidly through Puget Sound (~2 week migration) and survive poorly (~20% survival). A reciprocal transplant study in 2014 showed no effect of translocation; fish that had to swim further through Puget Sound were less likely to survive regardless of population of origin. GPS/receiver packs on seals suggested that seals fed within 10 km of their home haul-out. Seals detected more steelhead tags than arrays did, and detected tags long after the outmigration period was over. Some tags were deposited near haul-outs. Some tags followed a tidal pattern of detections that mimicked seal behavior. A study of tags with delayed onset of pinging vs tags that continuously pinged did not find evidence of a dinner bell effect. Similar proportions of delayed and continuous tags survived, and similar proportions ended up at haul-outs.

- Erin R. – based on smolt release time and tag deposits near haul-outs, what is the evacuation rate of the tags?
    - Tags were deposited at haul-outs in about 3 days, which matches up with Vancouver Aquarium PIT tag results. But, evacuation may take longer: an aquarium test with V7s showed one tag was evacuated in 3 days. The others were not.
- Andrew T. – the sample sizes for the dinner bell effect study are very small. Do you trust results?
    - Sample sizes will be increased to get higher confidence in 2016, but currently nothing suggests a dinner bell effect. The 2014 study had the power to detect survival differences between delayed/continuous tags if those tags survived. The tag detections , detection patterns, and tag fate of delayed versus continuous tags were all similar.

Impacts of Harbor Seals on Early Marine Survival of Chinook and Coho (Ben Nelson)

Modeled consumption estimates suggest that in 2012 and 2013, harbor seals ate 40-67% of outmigrating coho smolts and about 40% of outmigrating chinook smolts. Highest mortality occurred early in the first ocean year. Mortality rates peaked at 115-145 mm, suggesting a size threshold.

- Steve J. – how do you address specialist seals (a few seals eating lots of smolts) versus generalist seals (lots of seals eating few smolts) from a management perspective?
    - Scat samples for coho show a bimodal distribution: lots of seals eating a low percentage of coho and a few seals eating much higher percentages.
    - The assumption that seals all act the same is not realistic. Seals have individualized behaviors and diets.
- Will D. – are scanners at haul-outs useful to find CWTs?
    - This was tested for PIT tags but detections were low.
- Jim I. – how many seals were examined? What is the confidence of the model?
    - Sample sizes were 20-30 per month per site for diet data. The model runs on a monthly time step.

- Austen T. – the frequency of occurrence of juvenile salmon in diets is higher in the San Juan Islands than the estuary data; the model data may underestimate non-estuary predation.

Harbor Seal Foraging after Big Qualicum Coho Release (Austen Thomas, Hassen Allegue)

Seals (N=20) were outfitted with a PIT tag detector beanie that activated during feeding intervals (defined by presence of head strikes). Beanies were on seals and active for 2-6 months. Big Qualicum coho were PIT-tagged (N=37k). On average, each seal performed 1k head strikes per day. Predation occurred mostly in evening/night hours. Predation peaked at dusk with a secondary peak around midnight. Seals mostly foraged near their home haul-outs.

Four seals detected PIT tags; in total, 31 PIT tags were detected. All were seals from Big Qualicum estuary, so expansions were limited to the estuary and corrected for the number of estuary seals. Based on this, most predation occurred in the first two weeks after smolt release. At the peak of outmigration, each seal ate 50 smolts per day, which met about 50% of the seal's daily energetic requirement. About 6% of the smolt release in the estuary was consumed by about 100 estuary seals.

- Barry B. – what percentage of seals that stay near the estuary ate tagged coho?
    - Preliminary movement data suggests that 20% spend all their time in the estuary and those are the seals that detected PIT tags. Another 20% used estuary and other areas but did not detect coho, and the rest didn't use the estuary.
- The peak in consumption of the average seal per day may be a functional response related to the availability of outmigrating smolts.
- Dave B. – does strike attempt equal success?
    - No; head strikes (foraging events) are not necessarily equivalent to prey capture.
- Evelyn B. – are foraging patterns related to sex or age?
    - All tagged seals were adults. Most (75%) were males; sex differences in foraging were not observed.
- David W. – based on this data, if there were no seals at all, survival would triple. Since the 1970s, the seal population has increased 9-fold and survival has decreased 10-fold. So this model suggests that seal predation accounts for about a third of the decline.
    - The mortality rates probably are not directly proportional to seal abundance; it is likely that multiple factors interact synergistically with seal abundance to affect smolt survival.
- Dick B. – this model relies on 2008 seal abundance estimates.
    - DFO did a 2014 seal census; the model will be updated to consider the new data.

Wednesday, Dec. 9: Breakout Sessions

Session Report: Bottom-up Sampling + Studies

Comparable data collection techniques and datasets are important. Zooplankton collection (vertical tow) is well-standardized cross-border; physical and fish data collection are not. Data from physical monitoring projects not affiliated with SSMSP should be linked to SSMSP efforts. There is a need to characterize the oceanography of the entire Salish Sea, as there are differences among basins. One recommendation was to map habitats (both offshore and nearshore) to assess nutrients and nutrient input to the Salish Sea. This is one way to include anthropogenic inputs in the hypothesis list.

Based on current knowledge and results, there are regional and stock-specific differences in habitat use and outmigration timing/patterns in both Strait of Georgia and Puget Sound stocks. There is minimal evidence for size-selective mortality in Puget Sound from hatchery/smolt trap through nearshore to offshore in July. In Cowichan, there is some indication of heavy mortality nearshore. Larval crab appear to be an important diet item offshore for Chinook. There are methodological needs to further compare Puget Sound and Strait of Georgia datasets: cross-calibration of purse seines and midwater trawls (size and species composition), cross-calibration of scale and otolith methods, cross-calibration of diet analysis methods, and common analyses for both datasets. Recommended activities to satisfy additional data needs included data on seasonal forage fish distribution and biomass over time, quantification of potential competitive effects (seasonal diets, abundance of potential competitors), and laboratory studies of functional feeding responses to variables like prey densities and water quality (light, turbidity).

Activities suggested for moving forward include:

- Develop a Salish Sea data catalog
- Distinguish temporal and spatial scales of Salish Sea processes integrating physical and biological data
    - Identify hotspots (areas of increased abundance and productivity) and how they relate to the rest of the ecosystem
    - Identify broad-scale vs local processes
    - Map habitats and nutrient levels/inputs across the entire Salish Sea. Assess differences (e.g., fewer point sources of wastewater in Strait of Georgia) and identify nutrient hotspots.
- Data archaeology and retrospective analyses: look further back into the past (1970s) instead of focusing on current interannual variability. Distinguish processes controlling interannual variability vs. long-term trends
- Coordinate and cross-calibrate (across border and among approaches) purse seines and midwater trawls (size and species composition), scale and otolith methods, diet analysis methods. Also, establish common analyses.
- Comparative experiments by species
- Ensure ocean acidification monitoring, but do not recommend directed experiments
- Do prey field sampling (oblique zooplankton tows) in Strait of Georgia, and do zooplankton sampling through September

  - Consider neuston net sampling at some sites (e.g., Cowichan Bay. Nathan suggested a station in the area of fish milling prior to moving through Johnstone Strait)
- Determine how to relate zooplankton to fish
  - What fish characteristics tell us whether they are feeding well?
    - A variety of different measures on different time/space scales are needed (e.g., IGF-1 for short-term spatially-explicit growth, summer juvenile weight which correlates with overall survival, fish condition)
  - What leads to seasonal conditions that promote salmon growth during the early/mid-summer period?
    - Herring are not a major diet component of Chinook in September, but they are in July. Coho eat YOY herring also. YOY herring eat copepods, but age-1+ herring have similar diets to coho and chinook. Salmon winter diet is mainly forage fish. Herring were larger in 2015 and may have exceeded threshold prey size for salmon.
  - How are zooplankton distributed relative to forage fish? What are forage fish feeding on seasonally? How has the biomass of forage fish changed?
- How strong are competitive effects? Overlaps were suggested with stickleback (Canada: freshwater, early marine), squid, pink salmon, dogfish (also feed on herring and crab; catches are increasing in Strait of Georgia)
  - Should there be a dogfish assessment?
  - What is the role of jellies? They feed primarily on copepods, fish eggs, and fish larvae
- Determine factors driving fish movement from nearshore to offshore: is it a “push” due to lack of nearshore refuge from predators, lack of prey, etc. or a “pull” due to tempting offshore food?
  - Determine why fish leave the Salish Sea and identify differences by stock
  - How does fish size dictate fish behavior?
  - Test fish functional feeding response to prey at various densities and turbidities
- Monitor fish feeding and survival over the first winter
- Chinook and coho sometimes eat juvenile salmon: at what rates does this occur?
- Link more closely to predation research: e.g., relationship of fish distribution to predation risk
  - Consider light and turbidity effects on efficacy of visual predators. Reducing predator efficacy may be a management strategy. Artificial light effects and nocturnal predation may be higher within Salish Sea than on the coast.

The group also recommends hierarchical categorization of the current hypothesis list. If these hypotheses will be used to drive next steps, a small group should sit down together and do this exercise.

- Chrys N. – fish length is not the same as fish condition. Need measurements of energy content so we can consistently look at actual condition and relate across stocks.

- Marc T. – understanding nearshore-offshore movement is interesting, but does it actually move us forward to understanding survival?
- Jacques W. – has there been a change in prey size over time? What is different in crab prey now than in the 1970s?
    - Dave B. – we don't know.
    - Julie K. – historical zooplankton analysis suggested a shift in crab larvae.
    - Evelyn B. – need to know what crab species are in diets. Lummi samplers saw one specific type in later-season 2015 samples.
    - Marc T. – there are other prey besides crab that may be important; be careful generalizing the 2014-2015 prey results.
- Correigh G. – acoustic telemetry could take advantage of varying turbidity levels to test visual feeding hypotheses (systems with big vs. small plumes).
    - Andrew T. – there is evidence that marine mammals can and do use light to feed. But there is also lots of evidence that they feed successfully without light. Marine mammals can track fish by changes in pressure as they move. Blind seals still find food. Light can affect predation (e.g., some marine mammals change foraging during moon phases), but it is not necessarily an important factor.
        - Dave B. – when they can use vision they do use vision. Presumably there is an advantage to visual feeding.
    - Evelyn B. – would ship lighting have an effect? Tankers look like lit-up cities.
        - Dave B. – reflective light (skyglow) extends tens of kilometers into offshore regions and there may be direct lighting in downstream corridors.
    - Jacques W. – higher night tides in Puget Sound are correlated with fish outmigration. Shoreline armoring prevents refuge in shallow water.
- Evelyn B. – humpback whales tune into salmon migration and have been increasing in abundance along with sea lions, seals, and harbor porpoises in the Salish Sea.
    - Andrew T. – there are records of humpbacks in Alaska waiting near release sites to eat salmon. There are no records of this in the Salish Sea. They likely eat herring and sandlance, but we do not have cetacean diet data to know for sure.

Other notes collected by Ian P. and Evelyn B.

Reviewed tasks for group and data collection methods

- Zooplankton: general agreement that collection techniques for zooplankton although slightly different are comparable via the metrics produced.
- Physics: not comparable in terms of what can be defined as drivers of zooplankton/prey dynamics; Canada has more extension collection and integration system via buoys, citizen science, remote sensing, etc.; US program is deficient and the ability to link physics-phytoplankton-zooplankton is missing (Julie)

- Gap Defined: **US is missing data collection on a finer scale to define regional/local dynamics that Can is able to do; this was considered a major issue**
    - Maycira and Mike have talked about expanding the Can remote sensing program to US but would require similar grid of validation stations for imagery
    - Key factor to define is definition of oceanographic regions sharing similar physical forcing parameters (e.g. Salish Sea/San Juans more oceanic and similar (?) to SOG than PS proper silled at Admiralty Inlet which Ian defines as more of a "fjord system"
    - Within these regimes, defining exchange rates is important
    - Differences will be observed in spring bloom timing because drivers will be different (e.g. oceanic transport vs buoyancy driven watershed input)
    - Mike C said control of phytoplankton/diatoms is more influenced by anthropogenic/human delivery which is not really addressed in hypthoses; the problem of increasing dinoflag.and jellyfish a severe problem in PS proper that is less of an issue in Salish Sea/San Juans; Mike sees this as a big disconnect in the program; linkages to programs like "eyes over PS" could help; Mike would like to see some focus of water quality and impacts on prey fields at salmon release sites
    - Julie said it is not so much nutrients as the Si/N ratios from stormwater/sewage outfall; current focus is on oceanic nutrient/transport impacts on plankton dynamics and not impacts from human delivery; agrees that nutrient/phytoplankton connections is a huge gap and US problem
    - Evelyn's comments are that defining a range of spatial and temporal scales related to a common set of ecological drivers is a key template for couching hypotheses and individual studies (e.g. 1) larger regions might be SOG- 3 regions (?), San Juans-N PS/Salish Sea part of southern SOG (?), PS proper south of sill; 2) medium regions at watersheds or groups of islands/inlets, and 3) small scale at the range of formation of ephemeral "hot spots", coves, salmon release sites, or other unique pockets of significant trophodynamic exchange for salmon); Evelyn will produce and share a graphic and a table to summarize the idea that may help in synthesis
    - Ian: stronger links and use of data defined and collected by other groups (e.g. PSP/PSEMP groups and linked programs; graduate students can help with chasing down and collating valuable data sets not currently collected by MSP projects or PIs IN ADDITION between a strong data sharing/exchange program between US and Can programs.

Hypothesis Review by ID# and recommendations of reorganizing by identifying "overarching" Hs vs sub-categories within those:

- 14: Julie says highly pertinent; importance of crab larvae as "quality metric" plus the hot spot idea is important to consider for this hypothesis; Evelyn's comment is evaluation of hypothesis depends on clear definitions of scale and defining "quality" which might be site/region specific (e.g. crab larvae in some areas, forage fish in others or both); this hypothesis might be an "overarching one" and combined /rephrased with 15

- 15. overarching and broad hypothesis with elements defined elsewhere; is is key but parts of hypothesis are not directly measured but rather, inferred (e.g. escapement rates from predators); contains important elements that can be rephrased and combined with 14.
- 17-21: good, clearly worded hypotheses that are important and could be a subelement of 14-15
- 36: lots of discussion on this one; issue of Si/N ratios came up again and noted differences in Can vs US programs;
    - although elements at the NOAA regional science center (i.e. Casey Rice) have organized an effort to deal with this, Mike worries the scale is inefficient to deal with local scales of concern by tribes and communities;
    - Ian and Maycira: it is at the local scale that specific anthropogenic factors can defined; much harder at larger scales where anthropogenic factors are combined and accumulated with natural factors and larger scale climate change impacts.
    - This hypothesis is really a synthesis product
    - **Ian and group consensus: key statement: It is critical to distinguish local vs regional/larger scales for tribes and communities because it is at the local scale that impacts on water, food and salmon can be defined in a way to define potential restoration/mitigation actions which CANNOT be defined at larger scales; couching local areas within a region can inform common or shared impacts on salmon survival within or between regions which provides clout and science-based background to affect change**
- 37 Lots of discussion on this and issue of ocean acidification in general:
    - Julie feels that we are completely unprepared to address impacts of ocean acidification on salmon prey which requires mechanistic studies;
    - Mike and Ian feel these studies are expensive and cannot be covered addressed within this program so we would need to rely on results from related studies (?);
    - Ian says the first need is to establish required monitoring (scale and cost) and connection to where monitoring is already occurring.
    - Ian and Julie said that ocean acidification is not currently a major driver in the system but if that changes, the signal will be detectable in the zooplankton as long as that monitoring continues
    - This is actually a component of hypothesis 40
- 39: Julie feels this Hypothesis is appropriate and addressable now with the current program and data; the process is well defined; it is a component of 40

- 38: Delete-don't need
- 40: overarching hypothesis; Mike called it a "big soup" question; Julie does not feel we have the data needed to fully address the components; ocean acidification is a subcomponent addressed in earlier comments
- 43: key and ONLY habitat hypothesis; Niki was a map of historic information to compare with what we had then, what we have now, and what can/be identified for restoration
    - Eelgrass restoration probably further along than in SOG;
    - A clearer definition of the links of habitat/eelgrass to salmon rearing, feeding and predator dynamics is needed; we know eelgrass can offset ocean acidity and some pollution issues, that eelgrass provides a habitat for salmon prey and may provide shelter from predators; collating results of previous on ongoing studies defining these connections will help
    - Evelyn says Lummi, Skagit and Nisqually have recent, ongoing or new projects that will help address this hypothesis with finding independent of MSP; although eelgrass is not specifically addressed, the changes in coverage/extent is noted and some areas have very detailed habitat maps that are updated every few years (e.g. LNR maps)
    - First step is to inventory and share current list of studies and results; the appropriate scale here is likely an individual watershed estuary (e.g. Nooksack or Skagit) or shoreline segment (e.g. Cherry Pt Aquatic and other PS DNR marine reserves)

Session Report: Top-Down Studies + Predator-Prey Dynamics

Items bolded and underlined are highest priority recommendations

General

The group acknowledged that steelhead provide some advantages to assessing mortality that other species don't: If you compare Beamish (coho) to Moore (steelhead), mortality is occurring in a much tighter timeframe for steelhead vs coho (and Chinook?): steelhead reside weeks vs (coho and Chinook) months in Salish Sea. This makes them good candidate for studying impacts. Also, you can acoustic tag them to assess mortality rates and locations. **The group in general recommended that consideration be given to continue to pair acoustic tracking activities with other data (fish health and environmental) to reap greatest benefit from technology**.

Fish Health

The group discussed the value of broadly assessing disease, including **exploratory fish health work in Puget Sound similar to what Kristi M. has done in Strait of Georgia**. The most cost effective approach is to provide some existing samples to Kristi's lab as starting point (e.g. Nisqually steelhead tissues in RNAlater AND/OR gill clips from 2016 fish). Skin swabs may also provide some idea of microbiome related to fish, although pre-infection.

The group discussed need to:

- Affiliate signs of potentially compromised fish health (e.g. microbe composition) with actual reductions in performance. Disease challenge studies were recommended, capturing juvenile wild coho or steelhead in the marine environment, assessing individual swim performance, osmoregulation, etc. and then comparing microbes, etc. among fish relative to their performance.
- Affiliate signs of potentially compromised fish health (e.g. microbe composition) with increased predation. Manipulative studies, such as the juvenile steelhead infected/non-infected (with *Nanophyetus*) telemetry study is occurring in Puget Sound in 2016. **Non-lethal tissue sampling of acoustic tagged fish (being done in Strait of Georgia) is another way, and there may be opportunity to expand on this**. Predator diets could be assessed; however, cross contamination is a concern as well as the need to also fully characterize the prevalence of diseases in the outmigrating fish population (to determine if predators were consuming larger relative proportions of diseased fish).
- Build back to underlying genomic factors that may be affiliated with disease prevalence and intensity (as is being done for Puget Sound steelhead).
- Other ongoing works includes contaminants in Puget Sound and algae bloom impacts in Strait of Georgia. If similar work begins on opposite sides of the border, the group recommends building upon each other.

Predation and proximate/ultimate dynamics

The group concluded that working backward from management options may inform next steps in research. Potential management strategies might be to change timing of prey availability/hatchery pulses, reduce hatchery production/biomass, restore the ecosystem (in particular, buffer prey), manipulate predator populations, or resolving underlying fish health issues if they exist. Predator manipulation might be predator disturbance within the outmigration time period and not necessarily culling. Control (undisturbed) and treatment (disturbed) groups are needed to test whether these manipulations are effective.

Hatchery release manipulations (release numbers, timing, locations, variability) might be useful to test effects of predation intensity, pulse prey abundance (prey switching, behavioral responses), buffering capacity (match-mismatch with buffer prey), and smolt foraging behavior (match-mismatch with juvenile salmon prey) on predation. Considerations for a hatchery release experiment include:

- Need control vs treatment. Consider replicates. Consider wild pop as control.
- Release groups (e.g. different release timing) themselves could address replication and control/treatment.
- Locations to consider include Burrard Inlet, Howe Sound and Cowichan. Puget Sound locations not discussed
- Track variable release timing around abundance/distribution of buffer prey
- Track variable release timing around abundance/distribution of predators
- Enumerate predators spatially and temporally and check diet before, during, after pulse abundance of prey (look at increase of impacted fish , eg. steelhead, during pulse abundance impact)
- If release timing, an overly protracted approach adds confounding factors.

- Compare mortality in staged vs pulse release. Compare predator behavior in staged vs pulse release
- Match-mismatch and but account for environment (food availability, physical environment)
- Look at behavior of predators in response to changes in release practices

Additional work is needed to finalize estimates of harbor seal predation.

- **Broader spatial coverage is needed, especially for basins that differ ecologically**. Random sampling by stratified habitat type and basin is a suggested approach. Capturing **predation rates outside of river estuaries (to compare to estuary data) is a significant data gap and may be the most feasible to address**. There are some data from the San Juan Islands that suggest predation rates on juvenile salmon may even be higher there than some estuary sites
- Seal abundance and distribution data must be as up-to-date as possible.
- Microsatellites can be a secondary metric for number of fish consumed. Confidence in coho, chinook, and steelhead outmigrant abundance estimates is necessary. Consider consumption on a stock-specific basis as well as broad scale; certain stocks may be more vulnerable/impacted.
- There is an opportunity to compare v4 and v7 mortality rates as another proxy for determining whether or not there is a dinner bell effect. Nathan Furey will be tagging steelhead with v4's and v7's in Strait of Georgia in 2016. In Puget Sound, tests for a dinner bell effect have been and continue to be done by comparing delayed to constant pinging v7's.

Session Report: Trend Analyses and Modeling

There are a variety of analysis and modeling techniques that would be useful to the SSMSP work, depending on goals. Each has strengths and weaknesses; the group agreed that developing a suite of models is more appropriate and informative than focusing on a single model.

Model	Status	Outcome	Strengths	Weaknesses
Statistical models	Ongoing	Quantify relationships between variables (survival~factor)	Simple, fast, cheap way to identify trends and break-points. Can feed into Bayesian belief networks.	Not mechanistic; can be misleading
Bayesian belief networks	Araujo et al. 2013 published for SOG coho; studies in other regions	Determine strongest interactions in a network of variables	Fast and fairly intuitive. Can make predictions based on quantitative and qualitative knowledge.	Subject to the same issues as correlation analyses
Environmental 3D explicit models	Ongoing (regionally)	Characterize the physical environment, water quality, and prey field that salmon experience	Work well in places with good data to test whether model represents reality, can feed other mechanistic models, spatially and temporally explicit, proposes mechanistic link between oceanic, atmospheric, and lower	Additional work needed to link to salmon survival, computationally intensive, model must be calibrated with recent data series (10-20 yrs)

			trophic level processes, datasets can be long-term	
Individual based models	Harbor seal ongoing	Spatio-temporal estimates of foraging, mort, survival, habitat use, growth, migration	Can tie environ models to salmon survival, can link to bioenergetics models and NPZ models, SSMSP team has expertise, new tech allows testing model, includes fish behavior	Generalizes across individual characteristics (life history, etc), need to understand behavior for each modeled species, data-hungry
Food web models	Complete for South & Central Puget Sound & Strait of Georgia	Generate hypotheses for field testing	Ability to test mgmt. strategies (harvest, habitat), can identify indirect relationships	Data-hungry, coarse-scale, “garbage-in = garbage-out”
End-to-end models	Atlantis model will initiate in 2016; projected completion mid-2017 (built and calibrated)	Historic reconstructions of ecosystem conditions, projections of future conditions and responses to mgmt. actions	Ability to test mgmt. strategies (harvest, hatchery releases, habitat restoration, eutrophication controls), spatially and temporally explicit, highly flexible for functional relationships, can identify indirect relationships	Data-hungry, computationally intensive, calibration is slow, coarse-scale
Life cycle models & life-stage specific models	Ongoing for some stocks			Do not have data to fully address this across the Salish Sea

The group discussed the status of addressing three hypotheses:

1. *Marine survival does a better job than freshwater survival in explaining productivity trends of chinook, coho, and steelhead in the Salish Sea.*

   Assessing relative importance of freshwater and saltwater survival to overall productivity trends is important, but does not get us closer to understanding what is happening in the marine environment (the primary objective of the Salish Sea Marine Survival Project). This hypothesis would be quickest and easiest to address for coho. The coho dataset has been developed already and preliminary assessment suggested that smolt survival explains productivity trends better than freshwater survival. For chinook, wild data would need to be aggregated and assessed. For steelhead, no data currently exist and life cycle modeling would be necessary.

2. *Ecosystem and community factors affect salmon and steelhead survival at different levels by area encountered, species, hatchery vs. wild, and within species by life history.*

   This hypothesis is of highest relevance and importance for all species. Retrospective survival analyses for coho, chinook, and steelhead found a spatial component to smolt survival trends for all three species. All Salish Sea survival trends decline to some extent, but patterns vary by species and basin. **A data catalog of available temporally- and spatially-explicit ecosystem and community data is needed**.

3. *Changes in circulation and water properties have altered phytoplankton and zooplankton production in ways that degraded salmon food webs in the Salish Sea.*

   This hypothesis could be addressed with mechanistic modeling, additional correlation analyses to evaluate importance of variables, and potentially an ecosystem model with an endpoint relevant to salmon (abundance, survival). Available data need to be documented. Parker's work in Puget Sound was unable to link stratification or atmospheric drivers to primary productivity. This may have been influenced by the sampling scale for water quality and chlorophyll (monthly WDOT samples have the longest time period, and don't go back further than 20 years). Associations between system productivity and zooplankton must be better quantified, and links to salmon need to be examined.

Thursday, Dec. 10: Synthesis, Visualization, Next Steps

Datasets Developed/Available

Strait of Georgia investigators are in the process of collating project reports and metadata, along with datasets. U.S. investigators have not yet aggregated datasets.

- Evelyn B. – include data limitations in metadata to prevent miscommunications/misuse when transferring data among different researchers.

Historic data are being compiled.

- Evelyn B. is fixing all Nooksack spawn, escapement, hatchery rack, and stock composition data.
- Lance C. has chinook age data back to 1970s and fishery data back to 1940s. He is also developing a growth dataset based on scale/otolith work.
- Terry C. has much of the Strait of Georgia data collated on the Strait of Georgia Data Centre site.
- Jim I. compiled all British Columbia sockeye, pink, and chum spawner and recruit data and posted the dataset on the publicly available government open data portal. He is currently working to update North Pacific salmon abundance estimates and Big Qualicum chum growth (40 years of data).

The CWT dataset housed on the RMPC website has been used to measure survival, but quality may be a concern.

- Carl W. says that survival rates in Canada are higher when calculated by smolts/escapement than when calculated by MRP for more recent years. Estimates based on the CWT dataset are limited by data quality.
    - Jim I. says the coho task team followed the MRP process and found reasonable estimates when aggregated to multiple release groups. There are no recent samples from fisheries in BC, but most of the coho caught are not captured there.
- Evelyn B. would estimate an 80% error rate for hatchery data in RMIS. The tribal commission has put in lots of effort to fix past data. Recovery of CWTs are so low that error bars are large, and this is not usually accounted for in expansions.

Data Analysis and Visualization Approaches

The MEOPAR Salish Sea Modeling Project (PI Susan Allen) is developing a coupled biological-chemical-physical model of the Strait of Georgia. This model will run a daily hindcast and forecast and results will be shared publicly. Currently, the physical model has been run daily since autumn 2014. Storm surge data are also available. Inclusion and validation of other datasets are in progress. Bloom prediction is one of the immediate next steps; preliminary results are encouraging. Model details and visualizations can be found here: http://salishsea.eos.ubc.ca/nemo/index.html.

- Kristi M. – are aragonite levels and carbonate chemistry included?
    - Not yet, but an incoming graduate student will be working on that.
- Julie K. – will Puget Sound be included?

  - Data from Puget Sound will be interesting to test accuracy throughout the domain, but the main focus area is mid-northern Strait of Georgia.

Villy Christensen is visualizing change in ecosystems via video graphics. The Lenfest Ocean Futures Project is one example where complex models were translated to a 3D multi-player decision support gaming environment and players could simulate ecosystem change based on their choice of scenarios (e.g., overfishing versus no fishing). The video visualization is easily accessible to non-scientists. It is essential to have a clear story before creating these videos. Two videos for PEW global shark campaign cost $25k total.

Carl Walters developed a individual-based model to illustrate potential distribution patterns of juvenile coho in Strait of Georgia to determine best placements for acoustic receivers. He has also used this to model haul-outs and foraging areas for seals; those data then feed into predation risk models for juvenile salmon.

- Erin R. – can this model simulate the growth of kelp/seagrass influencing predation risk for fish?
  - Different species can have different rules for behavior and habitat use. Also, no evidence that coho are seeking cover in kelp/seagrass habitat even when available. They are moving offshore.
- Chris H. – do the seals get saturated/satiated?
  - In the estuary they do, not in open water.
- Chris H. – can you release salmon from multiple sites?
  - So far sites have been manually chosen.
- This model does not account for spatial and temporal variation in seal diet. Carl says the main diet changes would be associated with herring spawners, which are present outside the simulation period (first 6 months of salmon ocean life). Spawners leave the system in May.
- Dave B. – foraging is reset each night?
  - Yes. If a fish has found prey along an ocean front, at night it loses this structure and by morning starts out fresh. Fish can find plenty of food – probably only spend 10% of the day foraging and the rest is spent hiding from predation.
- Jacques W. – if predators key in on fish feeding areas, the predation risk may increase at that feeding area. How does model account for that?
  - Fish prey are not included here; fish just move in expected foraging patterns. Minimizing predation risk is prioritized. According to the model, if seal foraging radius is reduced, predation risk decreases and salmon survival doubles.
- Kristi M. – if predation risk on salmon smolts is impacted by presence of microbes/disease, consider adding that data to the model to see whether microbe distribution patterns are controlled by predator risk or behavior.

Folks who asked to added to ecosystem indicator development distribution list: Evelyn Brown, Marc Trudel, Isobel Pearsall, Mike Crewson, Ian Perry, Julie Keister, David Welch, Chris Harvey, Neala Kendall, Joe Anderson.

Folks who asked to added to Atlantis Modeling distribution list: Julie Keister, Scott Pearson, Steve Jeffries.

Publications, Conferences, SSMSP Workshop

Publications will be tracked and numbered. Michael S. will shorten and distribute the recommended acknowledgement wording: "This is Publication Number **x** from the Salish Sea Marine Survival Project (SSMSP): ~~an international, collaborative research effort designed to determine the primary factors affecting the survival of juvenile salmon and steelhead survival in the combined waters of Puget Sound and Strait of Georgia~~ (marinesurvivalproject.com). Funding was provided by x." Text with strikethrough is now optional. Text is provided on

- LLTK will create a Publications Basecamp site to track and share publications, and to share technical reports.
- Julie K. – suggest automatic numbering system (or shareable spreadsheet in a pinch) rather than emailing for each publication number.
- Julie K. – publication numbers should not be assigned until after papers are actually accepted.

Upcoming conferences: Salmon Ocean Ecology Meeting (March 2016), WA-BC Chapter of the American Fisheries Society (March 2016), and Salish Sea Ecosystem Conference (April 2016). We have a session at SSEC.

Should we do a mid-point Fall 2016 workshop with the broader community? - Brian R. does not see value in doing this next year. At most, we may add a day to the 2016 winter retreat to update and receive feedback from a broader group, or a targeted critical group like donors.

Several participants agree that next year's theme should focus more on integrating and comparing data among efforts, primarily between the Strait of Georgia and Puget Sound.