

Big Bar Landslide

Southern Endowment Fund Science Workshop Summary



Prepared for:

Pacific Salmon Commission
600 – 1155 Robson Street
Vancouver, BC, V6E 1B5

Fisheries and Oceans Canada
200 – 401 Burrard Street
Vancouver, BC, V6C 3S4

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Prepared by:

Ecofish Research Ltd.



Fisheries and Oceans
Canada

Pêches et Océans
Canada



Foreword

On June 23, 2019, a significant landslide was discovered in a narrow section of the Fraser River. The rock slide created a five-meter waterfall that many of the Fraser River Chinook, sockeye, pink, coho salmon and steelhead populations needed to migrate past in order to reach their spawning grounds. Despite transport mitigation work throughout the summer months, the high water velocity at the slide created an insurmountable barrier for natural passage for many salmon, especially during the early part of the season when water discharge levels were higher. After the 2019 salmon season, considerable remediation work to improve natural fish passage migration conditions at the slide continued. In addition, alternative fish passage options were deployed for the 2020 season, including a concrete fishway and a flexible, pressurised fish transport tube. Despite the continuing mitigation efforts, the effects from the slide on the salmon populations may take years to completely dissipate.

For successful management of these stocks, it is crucial to gain a better understanding of the current and long-term impacts of the slide on the salmon populations. With the help of Pacific Salmon Commission Southern Endowment Funding, a two-day workshop was organised in Vancouver to bring together Canadian and U.S. experts to identify and prioritize research areas for future funding. During the workshop, a list of priority research areas was compiled. Given workshop time constraints, not all research priority areas were explored and discussed to the same extent during the workshop. Priority was given to those research areas for which access to subject experts was limited to the workshop meeting and where more clarification on proposed work was needed. For these research priorities, the workshop aimed to define potential research approaches and to identify ways this research would support mitigation or contingency monitoring activities. The workshop also aimed to identify the immediacy, study frequency and duration of the research, existing data sources, conditions for success/risk, potential project proponents, annual costs, and additional funding considerations.

While this report contains some scientific and technical information that contributed to the discussions during the workshop, this information should be considered preliminary and should only be referenced to support research and funding application, and not referenced within scientific or technical publications. We would like to encourage the readers of this report to contact experts directly if scientific or technical citable information is needed (BigBar@psc.org).

Overall, this report is meant to guide further research as well as support future funding applications. It is our sincere hope that, in doing so, this report will provide a valuable contribution to the continuous collaborative efforts by First Nations, Federal and Provincial governments to mitigate the impact of the rock slide on the salmon stocks within the Fraser River.

Catherine Michielsens and Fiona Martens
Pacific Salmon Commission

David Patterson and Mike Hawkshaw
Fisheries and Oceans Canada

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1. INTRODUCTION

In late fall 2018, a 125 m rock cliff sheared off into the Fraser River, creating a partial obstruction to upstream salmon migration in a remote canyon approximately 60 km northwest of Lillooet BC (Map 1). Many stocks of Chinook, Sockeye, Coho, Pink Salmon and steelhead need to navigate past this site to reach spawning grounds in the mid and upper Fraser River watershed. The Big Bar Landslide was first reported to authorities in June 2019 and a Unified Command that included all levels of government (First Nations, provincial and federal) assembled in Lillooet to lead the response operations. The team included scientists and engineers; First Nations fishing crews and archaeological monitors; field and support staff from the BC Wildfire Service; biologists; rock scalers and hydrologists; Canadian Coast Guard, and many other groups.

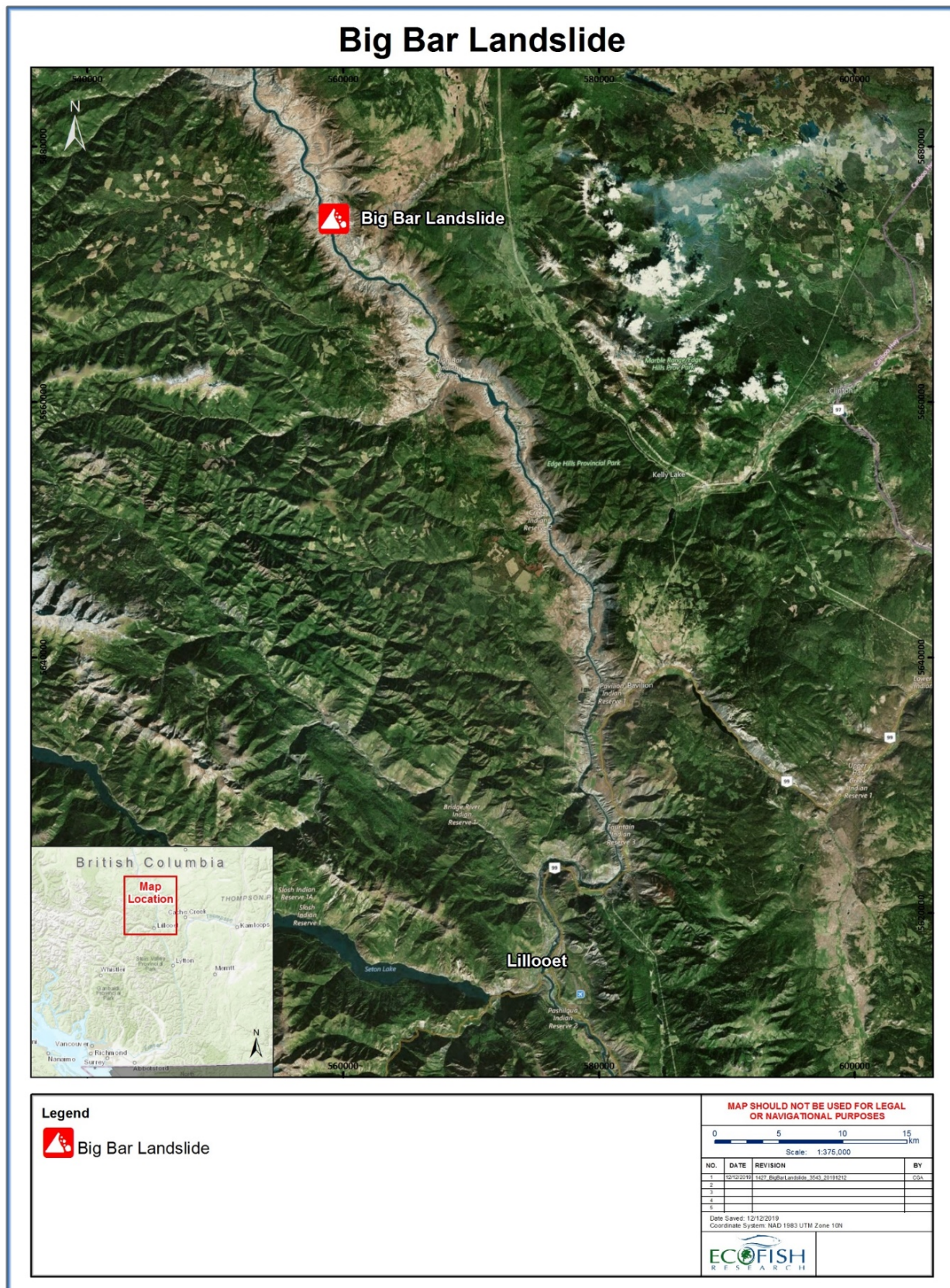
Between June and September 2019, a team of geologists, engineers, and scaling professionals performed controlled blasts and manipulated instream rocks and substrate below the slide on the West Bank of the Fraser to attempt to improve natural passage.

A trap and transport operation to actively move fish past the slide started on July 20th and ended on September 4th. During that period, over 60,000 salmon were captured by beach seine net and fish wheel and transported upstream of the slide by helicopter. A road was completed in early September to allow crews to transport fish past the slide by truck. The road and fish-trucking operation were tested but never fully implemented because natural passage was restored.

Since the end of September 2019, the Unified Command has been transitioning into a new Project Phase that involves efforts during winter to restore natural passage over the full range of river flows and to develop contingency plans in case fish passage is not fully restored. The Project team is guided by a Joint Executive Steering Committee, which is a collaboration between First Nations, federal, and provincial governments. Although mitigation efforts continue, effects from the slide may take years to completely rehabilitate. For effective management of stocks upstream of the slide it is crucial to understand the current and long-term impacts of the slide on migration success and survival rates under a variety of river conditions.

On March 3rd and 4th, 2020 a workshop was held in Vancouver to bring Canadian and U.S. experts together to seek advice, guidance, and ideas for future science research activities dealing with the impact and remediation of the Big Bar landslide. Participants to the meeting included academic scientists (UBC, SFU, Carleton University, University of California), governmental scientists (DFO, MFLNRORD, USGS), PSF, PSC, and BC Hydro (see Appendix A for participant list). **The goal of the workshop was to identify and prioritize research areas for future funding both within DFO as well as through external funding agencies; the workshop report is meant to guide and support external funding applications.** The workshop was facilitated by Ecofish Research Ltd and funded by the Pacific Salmon Commission Southern Endowment Fund (SEF).

Map 1. Overview map showing the location of the Big Bar Landslide.



2. SUMMARY OF SCIENCE ACTIVITY PRIORITIES

The first day and second day of the workshop included several presentations related to the Big Bar slide (summarized in Appendix B). Breakout sessions were held with participants divided into groups based on area of expertise to discuss three main questions regarding adult salmon, juvenile salmon, and populations and ecosystems:

1. What are the potential impacts of the slide on individual adult salmon migration and reproductive success?
2. What science activities are needed to better understand and or quantify the impact?
3. What science activities are needed to predict the impact?

For juveniles, question #1 was rephrased as: What are the potential impacts of the slide on the survival of individual juvenile salmon?

For populations and ecosystems, question #1 was rephrased as: What are the potential impacts of the slide on populations and ecosystems?

Below is a summary of the discussion that occurred in each of the three breakout sessions. A list of the potential science activities discussed in each of the breakout sessions is included in Appendix C.

2.1. Adult Salmon

Using the pathway of effects diagram for adult salmon (Figure 1), several potential impacts of the slide on individual adult salmon migration and reproductive success were discussed. The most broadly discussed impacts included: temperature and flow patterns related to migration success of individual fish, swimming ability of fish to navigate the slide area, latent effects of difficult migration, fish fecundity, mortality related to temperature and flow, gas bubble trauma, and straying of fish that cannot navigate the slide.

Participants discussed that mortality caused by the slide will likely be related to temperature and flow. These are conceptualized as “extrinsic co-factors” (Figure 1). There are historical data on temperature, discharge, mortality, and abundance that can be used for comparison to current conditions. High temperatures at the slide area could exacerbate pre-spawn mortality and delay migration of fish through the slide. It was noted that the temperature that fish are holding in is very important. If fish are delayed in high-temperature water, they may die or accumulate stress that results in negative effects as they continue to migrate upstream. Temperature and delay effects can be replicated in a lab. For example, some populations of fish die when held in temperatures of 21°C in three days. Flow also will impact the ability of fish to pass the slide area, with higher flows often impeding migration. Velocity thresholds for swimming ability vary across species. It was pointed out that the relationships between temperature/flow and passage likely will shift as the river erodes the blockage at the slide.

There was a discussion of tracking studies for adult fish that can pass the slide during upstream migration to spawning grounds. It was indicated that salmon populations throughout the Fraser River have been studied and that Chilko Sockeye Salmon and Chinook Salmon are the strongest swimmers

with the greatest success at passing through Hells Gate Canyon. It was noted that different populations within salmon species potentially have different swimming capacities but quantifying these differences has proven challenging as the temporal migration patterns of different populations covary with different flow conditions.

To determine if there are latent effects to fish from migration it was suggested that fecundity can be examined to see if fish have spawned (or not) on the spawning grounds. However, it was noted that effects on egg deposition would be difficult to determine because fish typically die before effects on eggs are seen. It was suggested that tagging studies could be used to see how long and where fish are holding upstream and downstream of the slide. Comparisons could be made in terms of rates of latent mortality across groups of fish that experience different flow conditions.

Gas bubble trauma could damage fish that are migrating through or holding below the turbulent slide area. It was noted that supersaturation issues occur downstream of dams where fish with gas bubble trauma symptoms are observed. It was suggested that dissolved gas concentrations be sampled downstream of the slide and potentially at other areas. It was noted that duration of exposure is important—the longer fish hold in the supersaturated areas below the slide, the higher the risk of gas bubble trauma.

Participants discussed the potential for fish to stray to spawning grounds downstream of the slide if navigation of the slide was too difficult. The slide creates one of three general consequences to fish migrating upstream: successful navigation of the slide and continuation of the spawning migration, unsuccessful navigation of the slide and subsequent dispersal to a non-natal downstream spawning location, or unsuccessful navigation of the slide and subsequent death. Genetic sampling could be done to determine straying and genetic impacts on downstream populations due to hybridization. Genetic and tagging studies could be used to study the reproductive fate of individual fish upstream and downstream of the slide.

Various science activities were discussed to quantify or predict the slide impacts to individual adult salmon migration and reproductive success. The most broadly discussed and evaluated were: expanding adult salmon tagging programs, expanding the Environmental Watch Program, genetic sampling, pathogen sampling, dissolved gas profile sampling downstream of the slide, biological sampling linked to telemetry studies, and quantifying burst swimming.

It was suggested that fine-scale telemetry is important to quantify passage success and rates. It was suggested that radio tracking with many receivers and potentially people hand tracking would provide fine-scale detail and could be performed in a noisy environment. A radio tag recovery program was recommended with tagging thousands of fish (between 1,500 and 4,500). Timing was discussed to focus on specific populations where run timing is known. Cost of a tagging program was discussed along with using a collaborative multi-agency approach. Compiling information on the various organizations tagging fish in the area was suggested to help build collaboration, potentially through conducting a tagging workshop. Location for adult fish tagging events was discussed (marine vs. freshwater). It was noted that marine tagging would give highly valuable information but would be

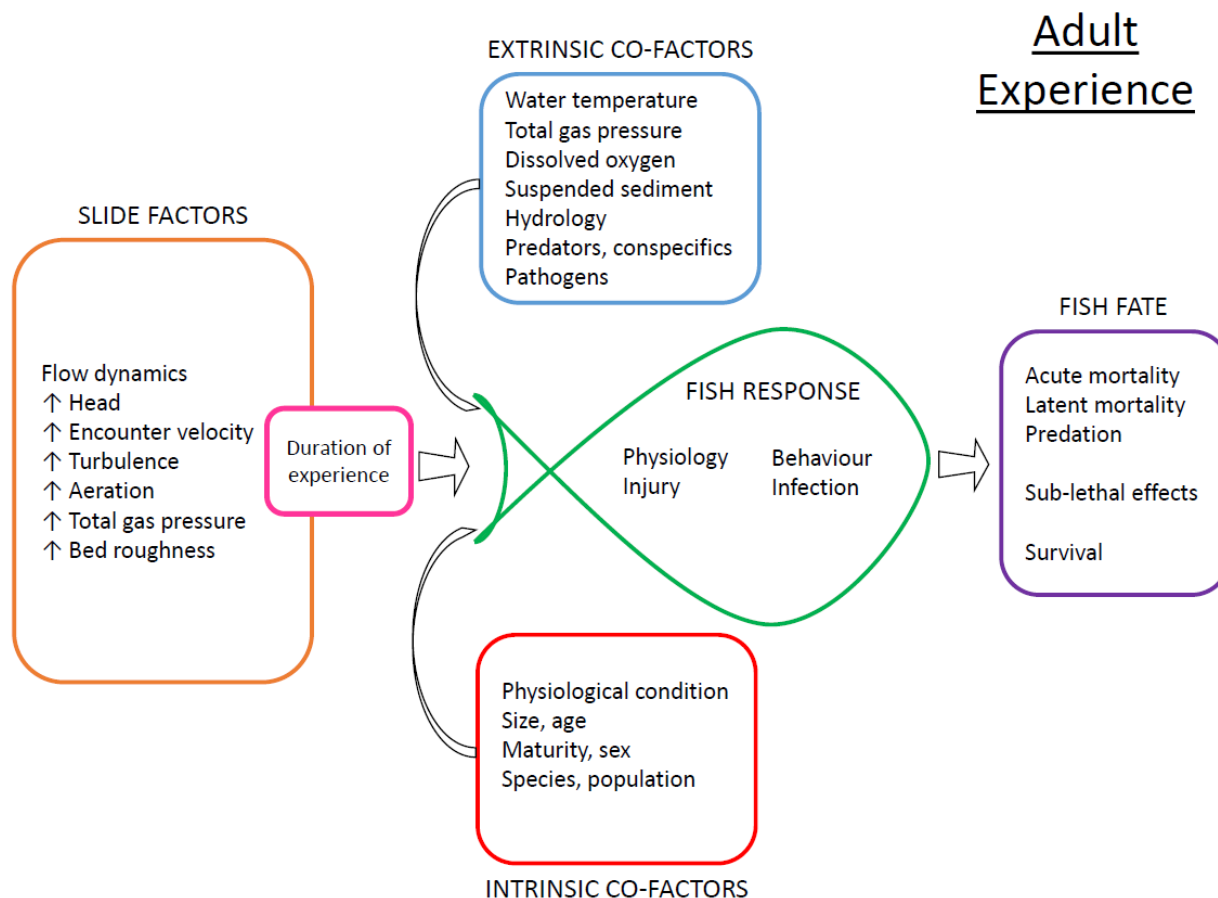
costly and would require a very large sample size to be successful. There was also a suggestion to use fish wheels for capturing fish in the lower river for tagging events. Lower water temperatures in the lower river would likely decrease the mortality associated with tagging in freshwater. It was suggested that different technologies for capturing, tagging, recording fish could be used over multiple years (5-10 years). An experimental approach was discussed where fish could be tagged at different flows during runs of different stocks. As mitigation blasting continues over the next two years, monitoring would continue to evaluate changes in fish migration success.

It is likely that the condition and traits of individual fish influence their ability to successfully pass the falls. These are described as “intrinsic cofactors” (Figure 1). Biological sampling of individual fish above and below the slide was discussed as a way of determining energy stores being used. It was suggested that this sampling be linked to telemetry studies. There was a suggestion to combine Peterson tags with biological sampling and to spread out biological sampling over the migration period to determine a gradation of migration effects. The Environmental Watch Program and Pacific Salmon Commission discussed collecting biological samples. Genetic sampling, fish condition, and morphology (lake vs. stream) of spawners could be added to biological sampling effort. It was suggested that energetics (correlated with distance fish need to travel to spawning grounds, as previously described) could be studied.

Participants discussed that additional genetic sampling would be important, including baselines for Chinook Salmon. It was suggested that genetic sampling could be paired with a pathogen study in 2020. It was noted that genetics from a random sample of transported fish should be collected because only radio tagged fish were sampled last year.

It was suggested that radio tags with tail beat frequency tags could be used to measure fish burst swimming below the blockage. The addition of this tag could be used to determine the costs of occupying different areas of the river, the point of failure when navigating upstream, and thereby potential cause of fish mortality. Telemetry is used to track the fish and tags do not need to be recovered to collect this information. It was suggested that a lab-based experiment could be done to determine burst recovery in long channels.

Figure 1. Conceptual pathway of effects diagram for adult salmon (modified from Patterson *et al.* 2017a).



2.2. Juvenile Salmon

Using the pathway of effects diagram for juvenile salmon, various science activities were discussed to better understand effects of the slide on individual juvenile salmon survival from downstream passage over the slide (Figure 2). Several topics were discussed; the most broadly discussed and evaluated were potential for expanding existing juvenile tagging studies, sampling juvenile fish for pathogens or immune suppression, potential for gas bubble trauma in juvenile fish, and the potential for juvenile mortality due to predation.

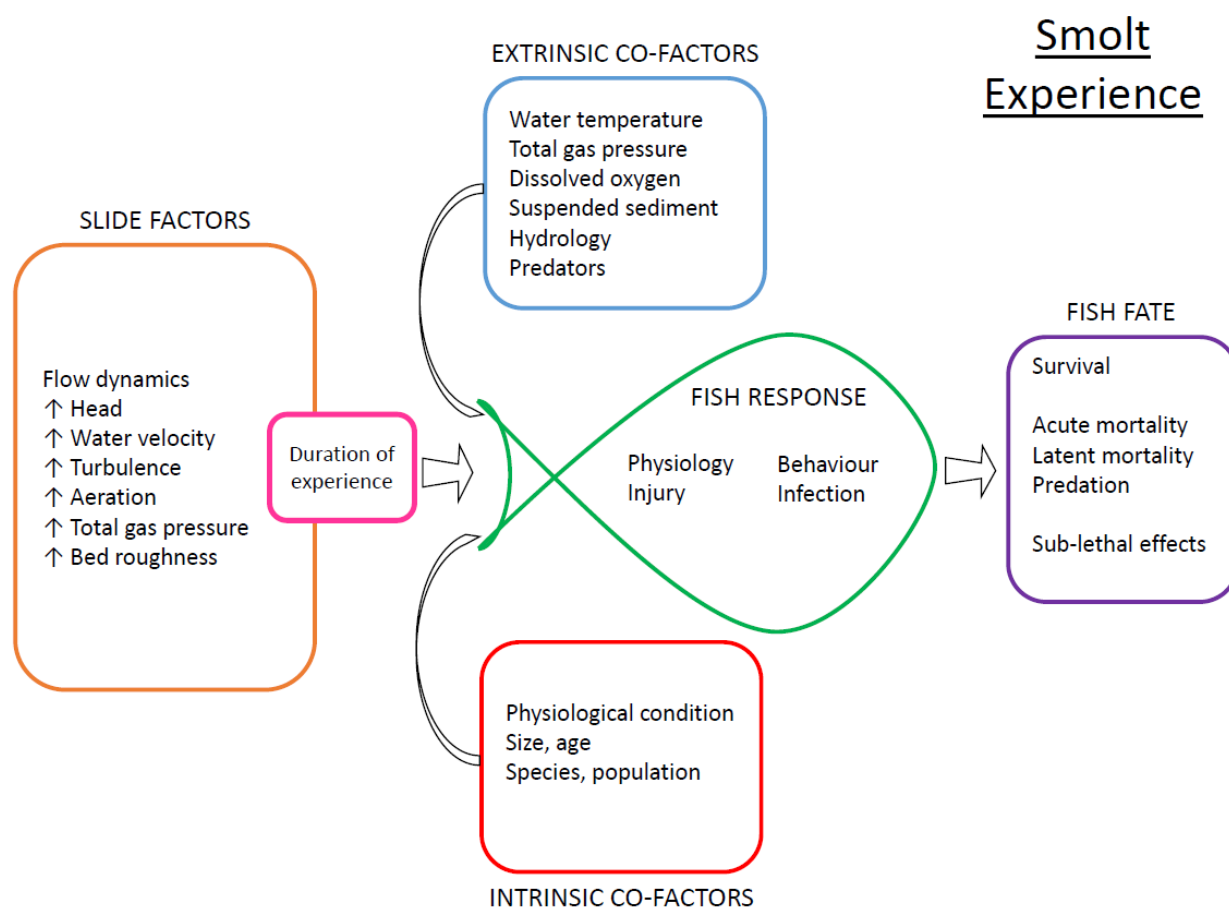
A juvenile salmon survival study was explored that would build on existing baseline acoustic tag studies for Chilko Sockeye Salmon smolts in the Fraser River. The previous study would provide a baseline comparison to additional years of tagging and survival estimates from post-slide data. Participants discussed adding additional receivers in key locations and increasing tagging effort relative to previous studies. There was discussion of tagging other species, specifically Chinook Salmon juveniles to collect survival and migration timing data.

Participants discussed potential for sampling juvenile fish at the Chilko Lake fish fence, near the slide location and downstream of the slide for pathogens or immunity suppression. Sampling closer to the slide could help pinpoint the slide as a potential problem but sampling juvenile fish may be challenging in some areas—various collection approaches were discussed such as incline plane traps.

There is potential for gas bubble trauma to affect juvenile fish and cause mortality. There was a discussion of dissolved gas sampling in the slide area at different flows and a discussion of the depth fish swim downstream during smolting. The potential for gas bubble trauma was expected to be lower for juveniles than for adults in light of the rapid transit of juvenile Sockeye Salmon through this region in comparison to adult exposure when migrating upstream.

The potential for predation of juvenile fish in the slide area was discussed. Predators include sturgeon, pikeminnow, trout, and avian predators. Participants suggested layering a study of predation and gas bubble trauma with a tagging study for juvenile fish.

Figure 2. Conceptual pathway of effects diagram for juvenile salmon (modified from Patterson *et al.* 2017a).



2.3. Populations and Ecosystems

Using the pathway of effects diagram for populations and ecosystems (Figure 3), several potential impacts and research priorities of the slide were discussed. The most broadly discussed were tagging, genetics and enumeration studies, stock assessment and marine survival work, habitat capacity estimation, and enhancement potential.

Participants discussed factors to systematically monitor Chinook Salmon populations including age structure, sex ratio, spawning success, and biological sampling using protocols already in place for monitoring Sockeye Salmon populations. It was suggested that the sampling of juvenile Chinook during the Mission juvenile Sockeye Salmon and Pink monitoring program should be expanded. A more intensive sampling monitoring program at Mission would provide potential to learn about distinct life histories and age structure of the progeny of successful Chinook spawners. There was a discussion about choosing index streams and how to scale tagging studies to the population level. Identifying areas to study genomic effects was discussed using baseline information from the 1980s as a starting point and then repeating sampling after slide mitigation to quantify potential genetic changes.

Participants discussed how to engage First Nations groups in studies. It was suggested that First Nations could help inform run timing and aid in collecting flow and temperature data.

Systematic monitoring of Early Stuart Sockeye Salmon was discussed to determine if there are changes in the location and spatial extent of spawning for that population.

The group discussed missing factors from the populations and ecosystem impacts in the conceptual diagram. Missing impacts noted from the population approach included fecundity and reproductive impairment (quality of offspring). Missing ecosystem impacts include groundwater impacts and hydrology in general.

Participants discussed genetic impacts and the need to establish genetic baselines for before and after the slide. The need to confirm the goal for genetic baseline collection was discussed. For instance, would the stocks be grouped to develop similar baselines for both Sockeye and Chinook Salmon in the Fraser River as a whole? The study would need to continue to use the same baselines to ensure consistency and determine if groupings have combined or if populations have shifted. There is a need to determine if straying is occurring because this straying could erode local adaptations and decrease population productivity. Given small returns of many populations above the slide in 2019, participants discussed whether it would be possible to obtain an adequate number of genetic samples from fish. Obtaining juvenile genetic samples during outmigration to assess success through this life stage was discussed. Adult genetic samples would be necessary to collect for genetic baselines.

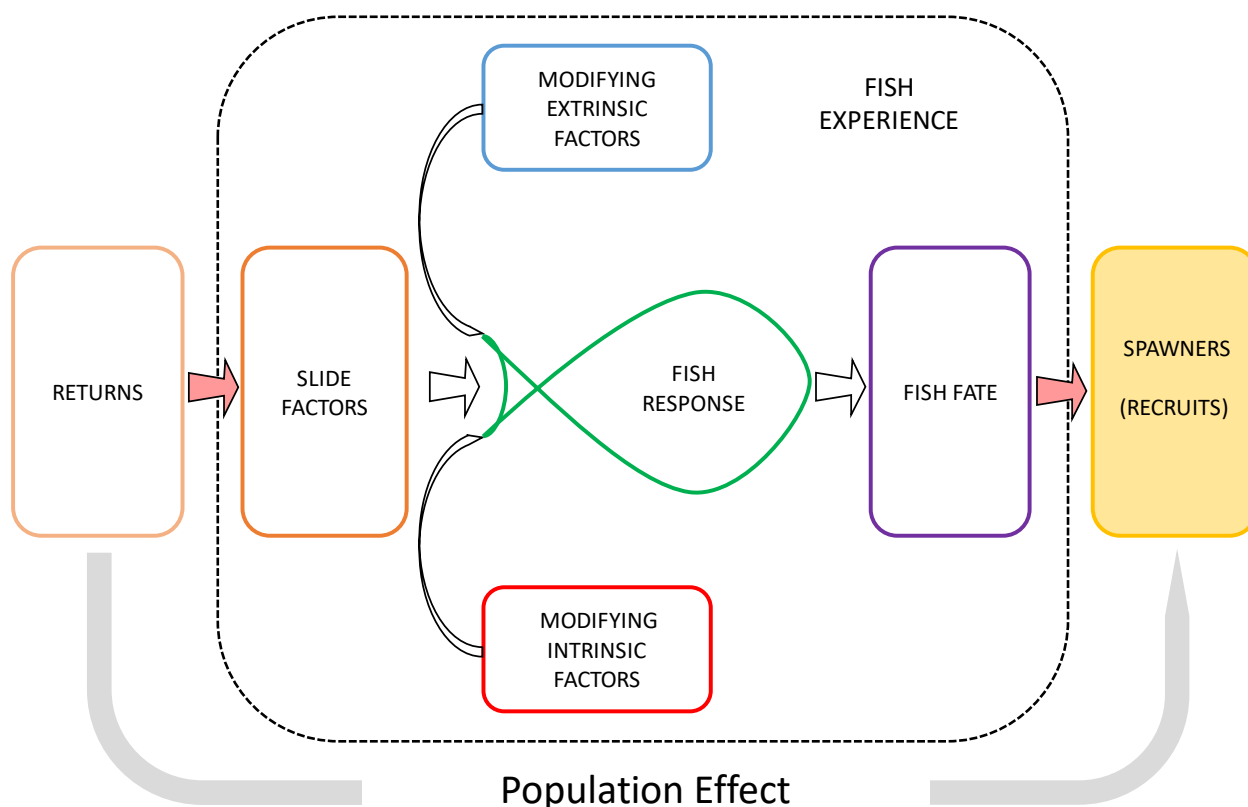
The group discussed the need for routine enumeration of fish and stock assessment work. It was suggested that enumeration at the lake scale could provide information on life cycles. There is currently a lack of information on cross species or full life cycle abundance. Dove tailing on current sampling would improve the amount of data collected but limitation of resources is an issue.

Participants discussed recent poor marine survival for Fraser River salmon and how poor ocean survival can intensify the effects of the slide to fish when they migrate in freshwater. A need to improve predictions of ocean survival for salmon was discussed. There was a suggestion to study lakes that support both anadromous Sockeye and Kokanee populations. There is potential to lose Sockeye Salmon populations due to poor marine survival or impeded migration success such as due to the slide. It was mentioned that there is potential for interfering with the adaptive process by trucking fish upstream of the slide; however, this risk contrasts with a situation of no fish successfully passing and population extirpation. The potential for enhancement to facilitate recovery was discussed. DFO's Stock Enhancement Program (SEP) is looking to enhance Sockeye production but obtaining sufficient broodstock is a problem, and so is broodstock survival.

Habitat capacity estimation was discussed as a potential science activity. It was noted that it was done once but is not static. For example, climate change is altering habitat capacity of sockeye rearing lakes. In addition, it is possible that decreases in salmon returns would decrease inputs of marine-derived nutrients and thereby alter habitat capacity. Lake productivity could be used as a metric to study fish capacity and stream capacity could be studied for Coho and Chinook Salmon. Different modelling studies were discussed to provide a framework for capacity studies.

There was discussion of Pink Salmon populations. Pink Salmon can access the upper Fraser River, although populations are still recovering from historic Hells Gate passage issues. It is thought that Pink Salmon stray more than other species and have less population structure.

Figure 3. Conceptual pathway of effects diagram for the population approach.



2.4. Shortlist of Activity Types from Day 1

A shortlist of priority science action topics was developed during Day 1 and several topics were identified for further discussion by breakout groups during Day 2. The following topics are thought to be well covered by existing information and were thus not discussed further during Day 2:

- Swim performance and energetic impacts of successful and unsuccessful fish passage; fine scale behaviour
- Additional tagging studies (PIT, acoustic, marine, radio, other, juvenile acoustic tagging)
- Bio sampling (fecundity, reproductive success, physical injury to juveniles)
- Slide risk and population resilience
- Fish habitat

Summaries of the breakout group discussions are provided below for the remaining topics:

- Total dissolved gas (TDG) (Section 3.6)
- Mortality modelling to inform management decisions (in season) (Section 3.7)
- Genetics studies and tools for mortality/dispersal/timing/stock ID/hybridization/selective pressures (Section 3.8)

- Physical parameters monitoring and characterization - temperature, hydraulics, flow, turbidity, etc. (Section 3.9)
- Productivity Modelling (density dependent effects, carrying capacity, nutrients, rearing habitat, ocean conditions, predation, competition from other species (non anadromous) (Section 3.10)
- Revise/update/change Stock Assessment framework and approach (Section 3.11)
- Study planning, data access and information sharing across agencies and institutions (Section 3.12)

3. PRIORITY SCIENCE ACTIONS FOR ACTIVITIES

The following section lists the various research areas identified during the workshop as priorities for further funding. Given workshop time constraints, not all research priority areas were explored and discussed to the same extent during the workshop. Priority was given to those research areas for which access to subject experts was limited to the workshop meeting. For these research priorities, the workshop aimed to define potential research approaches and to identify ways this research would support mitigation or contingency monitoring activities. The workshop also aimed to identify the immediacy, study frequency and duration of the research, existing data sources, conditions for success/risk, potential project proponents, annual costs, and additional funding considerations. The workshop did not further explore research priorities for which subject experts were already involved in Big Bar remediation efforts and for which expertise was readily available. These research priorities have been included in the list of research priorities but not further discussed.

3.1. Swim Performance and Energetic Impacts of Successful and Unsuccessful Fish Passage; Fine Scale Behaviour

Considered as high research priority but not further discussed at the workshop – for more information or direction please contact BigBar@psc.org.

3.2. Additional Tagging Studies (PIT, Acoustic, Marine, Radio, Other, Juvenile Acoustic Tagging)

Considered as high research priority but not further discussed at the workshop – for more information or direction please contact BigBar@psc.org.

3.3. Bio Sampling (Fecundity, Reproductive Success, Physical Injury to Juveniles)

Considered as high research priority but not further discussed at the workshop – for more information or direction please contact BigBar@psc.org.

3.4. Slide Risk and Population Resilience

Considered as high research priority but not further discussed at the workshop – for more information or direction please contact BigBar@psc.org.

3.5. Fish Habitat

Considered as high research priority but not further discussed at the workshop – for more information or direction please contact BigBar@psc.org.

3.6. Total Dissolved Gas (TDG)

3.6.1. Background

Total dissolved gas (TDG) supersaturation occurs when the total pressure of gases dissolved in water (i.e., total gas pressure; TGP) exceeds atmospheric pressure. Laboratory studies have shown that fish and other aquatic organisms are sensitive to air supersaturated waters (Fidler and Miller 1997a, Weitkamp and Katz 1980) when they are confined to shallow water, generally not exceeding 1 m deep. For example, gas bubble disease can occur whereby supersaturated gases come out of solution in blood or other body fluids, which can lead to impairment or death. A meta-analysis of studies (Fidler and Miller 1997b) found that cases of gas bubble disease occurred when TDG levels exceeded 110% saturation in shallow-water conditions, which led to the current provincial and federal water quality guideline for TDG in water.

Gas supersaturation is determined by several factors. There must be a pressure gradient between the gas and liquid, which forces gas to dissolve into a solution. Pressure gradients can occur in many different ways. The most common is when air bubbles are forced deep into the water column, where hydrostatic pressure causes air in the bubbles to dissolve into the surrounding water. The extent of supersaturation is influenced by the amount of air entrained, depth of the plunge pool, and the hydraulic dynamics within and downstream of the plunge pool. The longer hydraulic forces keep bubbles at depth, the more time there is for gas exchange to occur; hydraulic factors will also influence the plume of TDG downstream of the site. Many factors are involved in creating and maintaining TDG, so it is difficult to predict the potential for supersaturated water at a site without collecting empirical data.

There have been various literature reviews on total dissolved gas supersaturation and associated gas bubble disease (Weitkamp and Katz 1980, Colt 1986, Weitkamp 2008). Early studies were related to gas supersaturation concerns in the Columbia River system during the 1960s, which resulted in laboratory studies focused on physiological effects of supersaturation in various aquatic organisms (Weitkamp and Katz 1980, Colt 1986, Weitkamp 2008). Research indicates that when fish can reach compensatory depths or TDG is reduced, the capacity for recovery is increased and most reported mortalities are mainly attributed to a very high level of TDG (>130%) or areas where there are only shallow depths available to the organism (1 m or less). Population effects from TDG supersaturation have not been demonstrated.

3.6.2. Fisheries Management Needs and Required Modifications

The characteristics (magnitude, extent, timing, etc.) of TDG exposure and the exposure risk (duration and consequences of exposure) of adult and juvenile salmon at the Big Bar slide site are currently unknown. If TDG occurs at hazardous levels, it is expected that adults would be exposed when they

hold below the falls, and juveniles would be exposed when they pass over the falls as they migrate downstream.

Direct relevance to management: impacts to adults would reduce spawner abundance and viability and impacts to smolts would reduce recruitment.

Several science needs for determining potential TDG supersaturation and effects to adult and juvenile fish in the slide area arose from the Big Bar workshop discussions. Science needs focused on sampling environmental parameters (TDG, DO, and water temperature) upstream and downstream of the slide during both adult and juvenile fish migration periods, measuring the length of time that fish are exposed to supersaturation, and biological sampling of adult and juvenile fish for evidence of gas bubble trauma (GBT). Specific details of study needs, potential approaches and timing, and the rationale for study are summarized below.

- Study of hydraulic conditions in the slide area during freshet:
 - Approach:
 - Install cameras at slide area to systematically examine the surface flow patterns through the 2020 freshet (**Apr-Nov**)
 - Weekly drone surveys to examine surface velocity distribution in upstream backwater of the slide debris, at the hydraulic drop, downstream of the back eddy and through the exit of the canyon (**Apr-Jul**)
 - Measure TDG, potentially target high flows to characterize more extreme exposure scenarios (**Apr-Jun**), low flow measurements are also relevant for adult exposure (**May-Sep**); match with surface flow images
 - Reason:
 - Detailed characterization of the physical changes to the river and their effects on flow dynamics and encounter velocities, building on data collected in 2019 and comparing to data collected at the site prior to the landslide
 - Provide an understanding of why the slide occurred to facilitate preparations and potentially predictions for future landslide events
 - Contribute to an existing longer-term assessment of Fraser River bedrock canyons
 - Model entrainment likelihood of juveniles based on flow dynamics
 - Understand whether there is the potential for Gas Bubble Trauma disease to impact entrained juveniles or captured adults held at slide for transport
- Slide impacts on juvenile out-migration:
 - Approach:
 - Literature review on potential impacts of slide on outmigrating juvenile condition and survival, and expert opinion on magnitude of potential effect
 - Biological sampling – injury, GBT at or downstream of slide (**Apr-May**)

- Measure TDG during outmigration (**Apr-May**) and post-season modelling of entrainment
- Acoustic tagging of out-migrating Chilko smolts that must pass over the slide; compare reach-specific survival estimate to previous years (**Apr-May**)
- Consider additional juvenile sampling (other populations or species) if an issue with GBT is found
- Sensor fish sampler sent over the slide during outmigration window to assess transit time
- Sonar to examine fish movement and spatial location (TGP exposure risk) to investigate where in the Fraser River water column smolts of different species are migrating (edge, center, deep, shallow)
- Reason:
 - Determine whether this is a multi-year, multi-life stage impact, i.e. impact on downstream juveniles, as well as returning adults and potentially their offspring
- Assessment of adult fish transport mitigation effort
 - Approach:
 - Additional fine-scale (real-time) adult salmon radio-telemetry monitoring efforts at the slide area (**May-Sep**)
 - Measure TDG at holding locales for potential adult GBT (**May-Sep**)
 - Model transport efficacy by fish species, sex, size
 - Reason:
 - In-season information and post-season analysis of effectiveness of transport mitigation efforts
 - In-season integration with natural passage to ensure no additional harm policy
 - In-season information and post-season analysis of potential bias in mitigation efforts (e.g., condition, sex)

| Total Dissolved Gas (TDG) – Summary of Additional Discussion Topics | |
|--|--|
| Support mitigation/contingency monitoring activities | The risk of exposure to TDG is unknown for the Big Bar site. Empirical information would help characterize the site and lead to a better understanding of the cumulative risk associated with upstream and downstream passage past the slide. Understanding the TDG characteristics of the site may also influence mitigation planning for fish capture and transport or design of passage structures. |
| Immediacy, study frequency and duration | It is expected that characterizing TDG at the site could be mostly completed within one water year to get the full range of discharge levels; although some follow up studies may be required depending on the outcome of the initial work. |
| Existing data sources | We are not aware of existing TDG data for the Big Bar site. Literature is available to provide a risk assessment of duration and magnitude of exposure to TDG and resulting gas bubble trauma and mortality. |
| Conditions for success/risks | Water and land access to appropriate sampling locations at the site is likely the single biggest logistics challenge for the empirical work. If high quality data can be collected at appropriate times of year, the analysis and a write up that summarizes the results can be reasonably expected within six months. |
| Expertise, proponents, mandate to lead and/or contribute | It is expected that expertise for sampling, analysis and write up are available. Experts have been identified at UBC. |
| Annual cost | Cost for an initial study is expected to be low (\$<100k). |
| Funding considerations | Limited options, labour subsidy from UBC research? |

3.7. Mortality Modelling to Inform Management Decisions (in season)

3.7.1. Background

Big Bar can be used as an example of change to ecosystem and fisheries management systems during catastrophic events. There is a need to think about short term versus long term implication of fisheries management. Immediate scientific response is needed to address pressing issues such as fish accumulating at a migration barrier to determine if harvest should occur. Longer term, there is ongoing work to evaluate transitioning to more terminal fisheries. Additionally, an escapement target that considers Big Bar slide impacts could be included in the FRSSI process moving forward. It is expected that mortality modelling will impact escapement goals and will require major modifications to the existing framework. Many salmon populations are in conservation mode already so there is a need for accurate predictions to guide management and harvest.

3.7.2. Fisheries Management Needs and Required Modifications

Several data/information gaps were identified to improve fisheries management, including:

- Information on catch and release. Easier to get information on catch than on releases in fisheries.
- There is a lack of information on survival of fish at various life stages.
 - This could be examined for a few key stocks
 - Shorter term studies
 - The Fraser Sockeye Management Adjustment does not factor in considerations for the future (e.g., gamete viability).
- Distribution of Pink Salmon in the Fraser River
- Stock-recruit data are limited and potential to enrich existing data is limited. How will Big Bar impact be included in models with limited data?
 - Information on fish sex and age
- Potential for other factors that are limiting populations in addition to or instead of the Big Bar slide. Studying cumulative effects (e.g., effects from harvest, land use, water use and development pressures) could be important and the slide should not be examined in isolation.
 - Environmental effects- forest fires, marine etc.
- Examine historic effects of these types of locations (e.g., canyons, pinch points) on salmon populations to see if there has been an observed impact in the past.
 - Hells Gate is still a potential migration barrier in addition to Big Bar.
- Need models of en-route and pre-spawn mortality to determine a continuum of slide impacts.
 - Modelling mortality for CUs upstream of Big Bar has domestic value (i.e., important for more than just US-Canada allocations)
 - Scale up tagging data to add mortality estimates to models
 - The ability to change escapement targets considers the immediate effect but not if spawners are successful. This process may take a long time to implement.
- Obtain coded wire tag (CWT) information from the US in fisheries. This information comes in slowly.
- Examine slide issues through the lens of each species
 - Chinook - could use mortality models as an in-season domestic tool but no way to integrate this information yet
 - Chilko and lower Chilcotin Chinook adult programs are still in operation
 - Chinook is different than Sockeye in the way the message is delivered

- 10% of Coho migrate upstream of the slide including the weakest CU

The timeframe for modelling is a difficult task that needs to consider the needs and uncertainty of short-term predictions (e.g., 10 days in advance) versus annually. Model sensitivity should be examined going forward to see if the slide should be incorporated. Different types of models were discussed to inform management decisions including:

- Pseudo BACI design (Before and After Control Impact)
- Habitat modelling – spawning and rearing habitat (Carrie Holt, Steve Cox)
 - May not be one size fits all. Different stocks have different habitat needs.
 - Life-style model (French lab)- emergence, redd surveys, abundance estimates in the system and high seas. Have access to most of this data already.
- Life stage modelling
- Stock recruit modelling - right now there are spawner to spawner models. Need more data to predict recruits (e.g., fish sex, age). Can only predict escapement trajectory and spawner to spawner.
- Climate variability modelling - need to examine ecosystem structure using physical and biological models.
- Use Early Stuart stock as an indicator of slide related mortality since there is no harvest. Can see if improvements are working and make in-season management changes.
- Currently mortality is partitioned into freshwater and marine mortality. Survival could be looked at in terms of the entire life-cycle.

Fisheries management needs that were identified included:

- Modifying the current management system. For instance, if a spawning area is restricted due to forest fires, expectations should be adjusted. Traditional stock-recruitment relationships may no longer be useful due to climate change.
- Change data collection programs by doing more assessments when abundances are low instead of reducing the precision of assessments.
- Coordination of bio-sampling so there are consistent data being collected and shared.
 - Data collectors' workshop to coordinate and share data.
- Managing fish that are caught in international fisheries - need to negotiate data collection with the US (CWT, fishing mortality).
- Incorporation of identified bottlenecks for future scenarios. Bottlenecks decrease the productivity of the system; thus, models need to incorporate lags of spawner

abundance and reductions in productivity. It is tricky to tease out effects of the slide if other bottlenecks were already occurring in the Fraser River.

- Need to take a precautionary approach to management when there are mixed stock fisheries. Focus on conserving the upstream part of the portfolio for the future.
 - Restrict fishing in certain times and areas.
 - Change management away from harvest-driven practices.

Mortality Modelling – Summary of Additional Discussion Topics

| | |
|--|--|
| Support mitigation/contingency monitoring activities | <p>Fitness reduction could be calculated from the identification of bottlenecks to productivity.</p> <p>Consider a spawning escapement target that includes Big Bar slide impacts moving forward</p> <ul style="list-style-type: none"> • Differential value of fish above the slide |
| Immediacy, study frequency and duration | The needs of mortality modelling to inform management are immediate as well as long term. The learning process will take a long time. |
| Existing data sources | <p>Existing Fraser River data are limited - more data available for Sockeye, some data for Chinook, poor data for Coho and Pink Salmon. Data varied by stock.</p> <ul style="list-style-type: none"> • DFO • CWT data from the USA • Some data sources on fisheries are outside of the PSC purview but not with the stock resolution to the Fraser River. |
| Conditions for success/risks | Conditions for success revolve around the quality and completeness of data. Big Bar information from 2019 is not directly applicable to 2020 since conditions have changed. |
| Expertise, proponents, mandate to lead and/or contribute | <p>DFO for stock/fisheries information</p> <p>USA for CWT data</p> |
| Annual cost | Not Defined |
| Funding considerations | Not Defined |

3.8. Genetics Studies and Tools

3.8.1. Background

Genetic analyses play a critical role in modern day harvest management and conservation management. Genetic studies and genetic tools have the potential to provide answers to a lot of short-term and long-term information needs. Genetic studies are needed to support understanding of mortality differences among stocks; estimating effective dispersal (i.e., dispersal with subsequent reproduction); confirmation of run timing for different stocks; identification of stocks for in-river allocation and harvest management, and post-hoc analysis of management efficacy; estimation of hybridization rates associated with straying; and long-term understanding of straying and selective pressures.

3.8.2. Fisheries Management Needs and Required Modifications

Management needs for genetics information have been broken down into several categories.

Biomarkers – Ben Sutherland and Ruth Withler (genetic expertise)

Kristi Miller gene expression patterns can be used to see if fish have been experiencing severe environmental stressors, or have been exposed to different pathogens, as noted below:

- Panels for various stressors – thermal, hypoxia, salinity, bacterial versus viral infection, imminent mortality
- Biomarker sampling is different than DNA sampling
 - Biomarkers would provide a potential to predict fish fate based on fish condition during the migration. Matched with telemetry, biomarker samples can provide a better understanding of the intrinsic factors regulating passage success and survival to spawn (e.g., thermal markers - Houde *et al.* 2020).

Population Structure

Understanding population structure is important for a number of management and conservation efforts, as noted below:

- Chinook and Sockeye Salmon
 - Population structure baseline data (individual stock identification, relatedness among stocks, and estimates of gene flow among stocks) are required to identify fish that can be used as brood stock for enhancement of some runs.
 - Population structure baseline data are required to identify and differentiate upstream and downstream migration timing of different stocks.
 - Population structure baseline data are required to reconstruct run timing and magnitude from observations made on spawning grounds or at various interception points.
 - Population structure baseline data are required to understand stock composition of different fisheries, based on genetic samples from catches.

- Pink Salmon
 - Population structure baseline data are required to develop reliable escapement targets.
- Coho Salmon
 - Population structure baseline data are required to assign sampled individuals to Conservation Units (CUs).

Selection

- Nadina Sockeye Salmon
 - Currently, there is selection for the latter part of run due to interactions between the hydraulics at the slide and the annual hydrograph. There is interest in understanding the effects of this directional selection. Such a study may also indicate responses (e.g., genetic diversity, effective population size, change in run timing) in other stocks and species (e.g., Reed *et al.* 2011).
- Early Chinook and Sockeye
 - Persistence of the partial migration barrier could lead to phenotypic selection related to swim performance, such as size, age of maturity, anaerobic capacity, in turn this could lead to a change in population genetics (e.g., Hague *et al.* 2011).
 - Potential benefits of behavioural or physiological selection could be nullified through harvest or enhancement activities.
- Consequences of selection
 - Reduction in effective spawner population size to low numbers through selection can have an influence of genetic population structure and future productivity through Allele effects (genetic drift, bottlenecks).

Dispersal

There are a number of general information needs that would be supported by genetic studies at several temporal and spatial scales related to changes in fish distribution.

- Homogenization is potentially a major issue for stock identification that managers depend on for harvest allocations and assessing outcomes of harvest.
- Effects of straying, both past and present.
- Fitness of inter-stock hybrids relative to parental forms.
- Problems of genetic homogenization for enhancement, stock assignment and harvest allocation. Sampling of juveniles to understand genetic outcomes of hybridization.
- Geographic comparisons – upstream vs. downstream effects of straying and hybridization.
- Species comparisons – species differences in dispersal/straying and homogenization.

Consideration of Controls

There is a myriad of different and novel genetic studies that could be conducted in relation to selection gradients and mortality events associated with the impacts of the slide on wild populations. However, it was re-iterated that any large genetic study would need to carefully consider the appropriate control populations that are outside the influence of Big Bar.

Enhancement

Effective enhancement for the purposes of conservation and stock rebuilding will need to be informed by genetic information. There is potential to lose CUs in the upper watershed without some form of enhancement (hatchery augmentation), but there is also substantial concern about the effects of hatchery production on genetic diversity and fitness. Genetic tools will be required to identify and match specific individuals to the targeted population to support broodstock selection for a hatchery.

| Genetics Studies and Tools – Summary of Additional Discussion Topics | |
|--|---|
| Support mitigation/contingency monitoring activities | Stock differentiation can help with prioritization of transport efforts at the slide, potential enhancement/hatchery work, and monitoring of efficacy of these efforts. |
| Immediacy, study frequency and duration | both short term and long term |
| Existing data sources | not clear |
| Conditions for success/risks | not clear |
| Expertise, proponents, mandate to lead and/or contribute | Ruth Withler, Ben Sutherland |
| Annual cost | Annual costs for ongoing genetics work, including field sampling, laboratory analysis of samples, and reporting are expected to be high (\$>500k). |
| Funding considerations | Not Defined |

3.9. Physical Parameters Monitoring and Characterization - Temperature, Hydraulics, Flow, Turbidity, etc.

3.9.1. Background

Several environmental parameters may affect the design and implementation of biological studies. Monitoring of physical parameters includes:

- Flow
- Water temperature

- Habitat
- Chemistry
- Nutrients

Available supporting information on environmental conditions is mainly from previous work. There is a need to identify data gaps and assess how to request the relevant information from organizations leading previous work and conduct sampling to fill information gaps. Additionally, it would be helpful to have a broader study design to look at the physical parameter information in more comprehensive terms (outside of the lens of the slide) to gauge broader trends.

3.9.2. Fisheries Management Needs and Required Modifications

Important aspects to consider for management needs and modifications include:

- Access to data collected by different organizations
 - There is a need to make data publicly available and potentially have a broader consultation through a technical group to collate and interpret data from different sources.
 - Need buy-in to understand and interpret monitoring data from different organizations doing the work.
 - Need to know what has worked in the past and what has not to inform data use for future planning (e.g., other possible slides).
 - Need to have experts in the field work together and assess if the work done accomplished the goal.
- The natural environment is highly variable so there is a need for regular sampling plan/crew and equipment calibration.
 - Calibration after freshet.
- Need to factor sampling during high flows into study design. There is a safety risk and it is technically difficult. Fish will be migrating during high flow so information during that time is important.
- Need to collect information that would help understand the broader impacts of the slide on the Fraser River physical environment.
- Need to understand the geological time scale and decide if monitoring should be expanded to other areas.
- Need to decide the parameters to provide to managers and how to communicate effectively
 - Fisheries managers want to know if/which fish can navigate the slide area.
 - Providing raw data with the result is important.

- Need to communicate that data are needed to understand why/how fish are able to navigate the slide.

Data collection needs include:

- Missing data/information: suspended sediment, TGP, water temperature forecast, turbulence, velocity, sensor fish
 - Need to make a data request package
 - Determine timing of data needs (e.g., in-season)
- There is a lot of existing data but need the human resources to compile and analyze.
- Long-term monitoring of potential slide risk site geology (satellite, radar, citizen science activities, placer mining impacts assessment using texture analyses as an example)
 - To date there has not been a systematic approach to geoscience data collection.
 - Data are not readily available to parties outside of those who are collecting data.
 - There are opportunities to leverage data and share with broader scientific community.
 - Opportunity for research projects.
- Broader measurements of flow and velocity (upstream, downstream, and within-slide area).
 - Currently surface water hydrology is being measured.
 - Radar, cameras, or drones can be used where there are limitations to data collection.
 - Surface velocity measured upstream and downstream can be used to infer velocity at different depths (where fish swim) using two-dimensional riverbed topography in a three-dimensional model.
 - With fine-tuned velocity and swimming capability information, successful passage can be predicted.
 - Sensor (“robo fish”) should be investigated to collect data. Need to contact an experienced user.

| Physical Parameters Monitoring and Characterization – Summary of Additional Discussion Topics | |
|--|--|
| Support mitigation/contingency monitoring activities | <p>Monitoring of physical parameters upstream and downstream during high flow can be used to infer parameters nearer the slide during high flows.</p> <p>Monitoring the geology of potential slide areas can be done to predict a slide.</p> |
| Immediacy, study frequency and duration | There is a need for both short-term monitoring to determine immediate slide impacts as well as longer-term monitoring to determine long-term effects and potential for slides at other vulnerable sites. |
| Existing data sources | <p>Several potential existing data sources include:</p> <ul style="list-style-type: none"> • DFO - fish passage studies, environmental data, flow monitoring • Partners with network of lake data • Environment Canada - existing monitoring stations for pH and other water chemistry • NASA - satellite photos for long-term monitoring of 60 other potential slide sites. <ul style="list-style-type: none"> ○ Need to find people to look at images and may need to pay for the information. |
| Conditions for success/risks | There are site access and safety considerations for data collection in the Big Bar area especially during high flows. It is important to use the knowledge of engineers and carefully plan the study design in advance. |
| Expertise, proponents, mandate to lead and/or contribute | DFO, potentially form a technical committee of experts in the field |
| Annual cost | Not Defined |
| Funding considerations | Not Defined |

3.10. Productivity Modelling (density dependent effects, carrying capacity, nutrients, rearing habitat, ocean conditions, predation, competition from other species (non anadromous))

3.10.1. Background

- Productivity is an important metric to study. Sensitivity analyses on differences in productivity are being performed but we cannot currently forecast productivity.

- There is a need for a clear understanding of the productivity of salmon populations being impacted by the slide and to adjust harvest to preserve populations.
- This event sets up the opportunity to think about how catastrophes fundamentally shift and challenge fisheries management systems.
- We need modifications to the current way of modelling populations to achieve better understanding in the context of fisheries management.
 - Spawner recruit models are being used for Sockeye and to some extent for Chinook but not for Coho. Spawner recruit might not be the best approach.

3.10.2. Fisheries Management Needs and Required Modifications

Data/information gaps identified include:

- Need to understand which of the Fraser River salmon stocks are being caught internationally (US).
 - Data for Coho Salmon - fisheries are under-monitored, management is abundance-based instead of productivity-based.
 - Internationally, stocks are not managed at the CU level.
 - Getting CWT data from the US is slow. Genetic sampling could help but US would have to agree to take samples.
- Including sex and age into models.
- Include successful spawners into models - requires more work to make management adjustments for successful spawners. Can measure fish upriver but no certainty about spawning success. There is limited information on spawning success in season.
- A clear understanding of fisheries related incidental mortality (FRIM) to verify current data for Chinook if moving to mark selective fisheries.
- Including bottlenecks that reduce the fitness of fish into the recovery process.
 - Potentially lag fish productivity reduction - fewer fish, less productive.
 - Use studies on relative reproductive success of fish (e.g., hatchery vs. wild) to estimate fitness reduction.
 - The slide may be one of many bottleneck issues in the Fraser River for Chinook Salmon. Need to tease out the slide effects from other larger landscape effects (e.g., fire impacts).
 - Could examine cumulative effects.

Information/ models used/ that can be used for productivity include:

- Physical and biological information from streams – used to predict capacity for Columbia River Chinook re-introductions.
- Modelling for escapement changes using data that already exist (e.g., Sockeye data).
 - Many stocks are already well below escapement targets. In conservation mode.
- Use FRSSI model to help incorporate longer-term impacts on spawning escapement.
- Proxy measures of productivity if spawner/recruit information is not available.
 - Escapement trajectories
 - Spawner/spawner models
- Potentially use a pseudo-BACI design to try to tease apart slide impacts (McKinley time series).
- Models using control populations outside of the Big Bar area (e.g., Thompson River with and without fire).
- With current models limited may need to try new approaches
 - Life-cycle models - requires lots of data
 - Habitat models
- Models using predicted flow and temperature - have not yet been that successful. This will be a long-term process to see what the relationship is at different flows
 - Err on the side of conservation
- Need to determine how to better manage a mixed stock fishery
 - Change escapement goals (Sockeye)
- Decide what to manage (fisheries or conservation). May be adding to the problem trying to manage for both.

Productivity Modelling – Summary of Additional Discussion Topics

| | |
|--|--|
| Support mitigation/contingency monitoring activities | Need to adjust the timing of fisheries to preserve the salmon population portfolio upstream of the slide for the future. |
| Immediacy, study frequency and duration | Modelling for the short-term fisheries management and longer-term population management |
| Existing data sources | <p>DFO</p> <p>Existing data are limited - more data available for Sockeye, some Chinook, poor data for Coho and Pink Salmon. Data are varied by stock.</p> <p>Within the Fraser River there is good information on migration timing and working on better abundance indices. Funding is a concern.</p> <p>Conditions for success/risks</p> <p>Different models may be appropriate for different populations - Habitat models used for Chinook but did not work out for Sockeye</p> <p>Mixed stock fisheries need to be managed - local to international. Difficult to manage US fisheries that are catching Fraser River fish.</p> <p>May need a new management system because so many stocks are at conservation levels - Current methods would not change much (already managing for 5% escapement. If go to 3% it would not change how management decisions are made.</p> |
| Conditions for success/risks | |
| Expertise, proponents, mandate to lead and/or contribute | DFO science mandate (Spawning escapement, population modelling) |
| Annual cost | Not Defined |
| Funding considerations | Not Defined |

3.11. Revise/Update/Change Stock Assessment Framework and Approach

3.11.1. Background

Revising the stock assessment approach is tied to data needs for a management system.

- What specific information is needed and how does that tie into management needs?
- Immediate data needs to respond to stock assessments for 2020 and 2021 as well as data needs for events in the future.
- Information needs should be thought of in big picture terms - Big Bar and beyond.
- Develop new pathways to determine productivity and capacity instead of relying on spawner recruit models that are no longer valid but are the heart of fisheries management.

3.11.2. Fisheries Management Needs and Required Modifications

There is a need to examine what stock assessment can do and coordinate consistent bio-sampling to answer sampling questions.

There are budget issues for stock assessment work. The budgets are decreasing annually thus assessments have decreased. There are currently no Pink Salmon assessments, Coho assessments have decreased and while Sockeye assessments have been maintained they are inadequate.

Key data gaps that were identified for updating stock assessment included:

- Life stage survival - need to be able to partition life stage components to determine impacts
 - Egg to fry survival program - Previously there were programs to determine egg to fry survival that were discontinued (e.g., Gates outgoing fry migration program). The programs do not cost a lot and can be run for 5 years to get reasonable results.
 - Fry to smolt survival.
- Distribution of Pink Salmon spawning in the Fraser River.
- Freshwater effects on fry:
 - Nutrient effects.
 - Migration timing out of lake (early freshet).
- Climate Change effects - environmental variability but must define the environmental factors to measure.
 - The State of the Salmon Program is a good resource to look for important environmental variables to include for climate change.
- There is a need to examine precision of enumeration for stock assessments as populations decline.

- Precision (error and variability) in estimates decline with lower abundances – The marine assessment for early Stuart run was 27,000 but only 89 fish arrived at the spawning grounds.
- Can we detect slide impact based on current data? Not for Pink Salmon.
- Landscape drivers have different impacts that covary with abundance at the landscape level.
- The ability to detect change in spawner estimates would require increasing data collection. Sample size cannot increase when abundance is low.
- Look at indicator stocks covariance with environmental drivers to see if this suggests how stocks can recover.
 - Every stock may respond differently but occasionally patterns are similar.
 - Budget issues for this type of study. DFO does not have the capacity but another group might.

Several ideas for ways to fill data gaps include:

- Expansion of hydroacoustic programs.
- Increasing fly overs for abundance estimates of Fraser River salmon stocks. First Nations may be able to contribute to this work.
- Test fisheries - collect other species while looking at Sockeye (e.g., Chinook).
- Find a level of interest and partnership to seek additional resources.
- Coordinate and share bio-sampling data:
 - A lot of data collection is occurring throughout the Fraser River with consistent data being collected.
 - Hold a workshop to bring together parties collecting data to discuss what is being collected and where.

| Stock Assessment Framework – Summary of Additional Discussion Topics | |
|---|--|
| Support mitigation/contingency monitoring activities | It takes 15 to 20 years to make reasonable predictions with stock assessment and recruitment models. It may be reasonable to examine factors that predict change in abundance to determine allowable harvest or escapement. This would allow for a more immediate response. For example, if it is known that marine mortality increases in association with a heat wave than temperature can be considered when looking to set harvest/escapement goals. |
| Immediacy, study frequency and duration | Need to update stock assessment now and for the future |
| Existing data sources | Current stock assessment work mainly for Sockeye and some Chinook but not much enumeration work for other species. DFO |
| Conditions for success/risks | Declining populations harder to get accurate stock assessments. Need funding. |
| Expertise, proponents, mandate to lead and/or contribute | DFO has expertise. Other organizations to contribute (potential workshop for data collectors in the Fraser River system, include the USA). |
| Annual cost | Not Defined |
| Funding considerations | Stock assessment work is currently underfunded. There are funding opportunities outside of internal funding (PSC, DFO) that can be taken advantage of. Need to do a planning exercise to assess data needs for creating a new indicator stock (from a population that currently lacks funding). |

3.12. Study Planning, Data Access and Information Sharing across Agencies and Institutions

3.12.1. Background

Adequate planning for Big Bar studies, data access, and sharing information across a large and diverse group of experts requires thought about:

- Group structure - How to bring people together and who should be included (academia, agencies, DFO, etc.)
- What to manage?
- Broader engagement for longer term projects (for students)

- Keeping momentum
- Leadership and personnel capacity
- How to engage with outside partners
- Access to and storage of data, ownership of data (proprietary issues, roles and responsibilities)

3.12.2. Fisheries Management Needs and Required Modifications

There were several key factors to be considered for study planning, data access, and information sharing:

- Data management needs:
 - Where to store data so it is accessible to all (including the public). There is a need for infrastructure to deal with data storage and dissemination of information. Infrastructure examples exist and can be modelled (coordinated data set in Oregon, OTN)
 - Transparency of the data. Data ownership and sharing of data. Need to discuss with those funding data collection (e.g., BC Hydro)
 - Need to make the data openly available to the public
 - Different groups might have different strategies on data release (format, timing, extent of data released)
 - Prior to publishing papers data goes into the University library to be available to the public
 - Organization of metadata (Oregon, Ocean Tracking Network example)
 - Leverage existing infrastructure
 - Organization of data:
 - DFO data are scattered in different places and would require time to organize and centralize (biological data, NUSEDs, etc.).
 - Data can be publicly available but still difficult to access (NUSEDs). May not include metadata.
 - Data may not need to be organized. SharePoint could be used to centralize data to access information from different groups (the Chinook Technical Committee uses this).
 - May want to keep data spread out in case something happens to the centralized dataset.

- Common (web-based) documents to organize/share data information (similar to Google Docs)
- Development of science activities scope:
 - What is the format for groups/meetings if some activities get funded?
 - Need to keep people engaged to complete projects
 - Involvement of graduate students (e.g., Salish Sea Marine Survival group as a model)
 - A coordinating body with a long-term commitment is needed to link the different groups and facilitate data sharing. Potential people or groups to take this on include:
 - Full time position for master's level person with administrative experience
 - PSF or PSC person funded to take on the role
 - Fraser Basin council or other groups (e.g., First Nations)

| Study Planning, Data Access, and Information Sharing – Summary of Additional Discussion Topics | |
|--|--|
| Support mitigation/contingency monitoring activities | Not clear |
| Immediacy, study frequency and duration | Short-term and long-term study planning and data organization |
| Existing data sources | Data will come from a variety of sources and groups (DFO, working groups, academics etc.) |
| Conditions for success/risks | Keeping people engaged Successful funding |
| Expertise, proponents, mandate to lead and/or contribute | Many different groups needed with a broad range of expertise (government agencies, academics, private sector, etc.) Fraser Basin Council, First Nations groups in the upper Fraser watershed, Nicki Beauchamp (OTN) potentially available |
| Annual cost | Not Defined |
| Funding considerations | Create a report to be the catalyst for funding applications that could further inform SEF funding. Funding for an administrator to centralize and/or organize data. Will different groups (academics) need to bring their own funding? Need to establish a priority for funding (Federal and Provincial programs, SCF, PSF, SHRIF, NSERC, Trans-Mountain, Indigenous funding) |

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APPENDICES



APPENDIX A. BIG BAR SEF WORKSHOP PARTICIPANT LIST



Table 1. Workshop participant list.

| Participant | Affiliation | Contact email |
|-----------------|-----------------|---------------------------------------|
| Art Bass | UBC | artiebass@gmail.com |
| Rob Bison | Province-BC | Robert.Bison@gov.bc.ca |
| Doug Braun | DFO | Douglas.Braun@dfo-mpo.gc.ca |
| Nich Burnett | BC Hydro | nich.burnett@bchydro.com |
| Brendan Connors | DFO | Brendan.Connors@dfo-mpo.gc.ca |
| Steve Cooke | Carleton | steven.cooke@carleton.ca |
| Sean Cox | SFU | sean_cox@sfu.ca |
| Michael Crowe | DFO | Michael.Crowe@dfo-mpo.gc.ca |
| Erika Eliason | U of California | eliason@ucsb.edu |
| Mike Hawkshaw | DFO | Mike.Hawkshaw@dfo-mpo.gc.ca |
| Stephen Healy | DFO | Stephen.Healy@dfo-mpo.gc.ca |
| Scott Hinch | UBC | scott.hinch@ubc.ca |
| Ann-Marie Huang | DFO | ann-marie.huang@dfo-mpo.gc.ca |
| Les Jantz | DFO | Lester.Jantz@dfo-mpo.gc.ca |
| Krista Kraskura | U of California | kraskura@ucsb.edu |
| Leander McCabe | DFO | Leander.McCabe@dfo-engineer-mpo.gc.ca |
| Jonathan Moore | SFU | Jonathan.Moore@sfu.ca |
| Chuck Parken | DFO | Chuck.Parken@dfo-mpo.gc.ca |
| Naomi Pleizier | UBC | pleizier@zoology.ubc.ca |
| Lucas Pon | DFO | Lucas.Pon@dfo-mpo.gc.ca |
| John Reynolds | SFU | reynolds@sfu.ca |
| Andy Ritchie | USGS | aritchie@usgs.gov |
| Dan Selbie | DFO | daniel.selbie@dfo-mpo.gc.ca |
| Ben Sutherland | DFO | Ben.Sutherland@dfo-mpo.gc.ca |
| Joe Tadey | DFO | Joe.Tadey@dfo-mpo.gc.ca |
| Jeremy Venditti | SFU | jeremy_venditti@sfu.ca |
| Sam Wilson | SFU | swilson471@gmail.com |
| Ruth Withler | DFO | Ruth.Withler@dfo-mpo.gc.ca |

Table 2. Extension group participant list.

| Extension Groups | Affiliation | Contact email |
|-----------------------|-------------|-------------------------------|
| John Holmes | DFO | John.holmes@dfo-mpo.gc.ca |
| Jennifer Nener | DFO | Jennifer.Nener@dfo-mpo.gc.ca |
| Jason Hwang | PSF | jhwang@psf.ca |
| Fiona Martens | PSC | martens@psc.org |
| Catherine Michielsens | PSC | Michielsens@psc.org |
| Elan Park | DFO | elan.park@dfo-mpo.gc.ca |
| David Patterson | DFO | David.Patterson@dfo-mpo.gc.ca |
| Kendra Robinson | DFO | Kendra.Robinson@dfo-mpo.gc.ca |
| Yunbo Xie | PSC | xie@psc.org |
| Ian Murphy | Ecofish | imurphy@ecofishresearch.com |
| Todd Hatfield | Ecofish | thatfield@ecofishresearch.com |

**APPENDIX B. SUMMARY OF BIG BAR SEF SCIENCE WORKSHOP
PRESENTATIONS-DAY 1 AND 2**



1. DAY 1 PRESENTATIONS

1.1. Big Bar Rockslide Overview

David Patterson, DFO

David Patterson provided an overview on the Big Bar slide, what occurred, what it meant for salmon, what actions and mitigations have been implemented since last summer, and activities planned to date for 2020. The slide changed the physical environment. To date, two brood years have experienced the slide as either juveniles or adults and two more brood years will experience slide impacts in the next six months. Dave updated current assessment of salmon populations (Chinook, Coho, Sockeye, and Pink Salmon and steelhead) impacted by the slide.

In-river survival data for 2019 showed:

- Sockeye ~50% survival for late July to early September stocks (Nadina), ~80% survival for mid-August through September (late Stuart, Stellako, Quesnel, Chilko), <1% survival for July through early August stocks (Early Stuart, Bowron, Taseko)
- Chinook (age 5₂) ~50% survival for summer (July-August), ~10% survival for spring (May-July)
- Coho <20% of brood returned above the slide (Mckinley, Chilcotin), ~80% of the brood returned below the slide (Eagle, Dunn, Coldwater, Salmon).

These initial results indicate that survival varies by species and in-river conditions (discharge and river temperature). In 2019, discharge was relatively low and benign, and temperature was average. The forthcoming 2020 hydrograph is unknown but likely will be higher and more challenging due to the higher snowpack. Models of survival as a function of discharge and temperature can examine how potential environmental conditions could impact survival. Rock work is not expected to restore passage to pre-2018 levels. Previous landslides (e.g., Hell's Gate, Babine River, Fraser River at French Bar Canyon) can be examined for lessons learned. The take home message for Big Bar slide is that many populations are affected, it is a multi-year problem, and has the potential to be a multi-life stage problem.

1.2. Bedrock Canyons

Jeremy Venditti, SFU River Dynamics Lab

Jeremy Venditti provided an overview of his Fraser River Canyon research. He studies the physical processes of rivers—how they erode and create their physical forms. Jeremy and students from the SFU River Dynamics Lab have a field research program that performs on-the-ground measurements of the geomorphology of the Fraser Canyon. They surveyed the river from Quesnel to Chilliwack by boat to understand erosion in the canyon and have characterized the channel sections in the Fraser Canyon Atlas.

- Study observed 42 distinct canyons in the Fraser.
- Research identified 120 places along the Fraser as potential landslide areas; out of those, 60 were highlighted where failure and a slide of the canyon wall is likely to happen at some time.

The Big Bar Slide (French Bar Canyon) occurred at km 420 from the river head in a narrow, constricted canyon with fast moving flow. Sediment in the flow erodes and undercuts the canyon wall and destabilizes the upper slope. This creates a scenario for the wall to fail and fall into the channel. At Big Bar, the bedrock came down on the sill and into the plunging flows below creating a waterfall, which the river could not wash away. NASA satellite imaging identified the date of the slide as November 1, 2019 and images from one-month pre slide showed one-meter movement of rock in the area. There is currently no monitoring for potential slides. A geotechnical risk analysis, monitoring, and mitigation plan could be started for high risk areas. Most rockslides are not a problem if the river can erode the slide. The Big Bar slide highlights the need to understand more about the processes that undercut the rock walls. Current research includes examining the cause of plugging flows, examining why slides occur in rock canyons, and examining how old the Fraser canyon is and dating past major events by examining rock terraces. Because it is a multi-factor issue, it is difficult to link climate change to slides.

1.3. 2019 Adult Migration Results

Kendra Robinson, DFO

Kendra Robinson presented results from the 2019 Fraser River adult salmon migration monitoring. Radio tags were applied to 1,170 salmon (202 Chinook, 570 Sockeye, 224 Pink, and 174 Coho) and monitored at receivers throughout the watershed. Telemetry information at the Big Bar slide area was used to help guide when to trap and transport fish and to provide evidence of natural passage once improvements were made at the slide. Information on individual fish were collected (fish length, sex, stock ID, fat probe, condition, and photos). Helicopter transport of 60,000 salmon (8,500 Chinook, 51,000 Sockeye, 500 Pink) occurred July 23 through September 4, 2019 with salmon released 2.5 km upstream of the slide. Chinook (72) and Sockeye (92) were radio tagged to evaluate the success of transport. Approximately 50 to 60% of tagged fish resumed upstream migration after release and approximately 30 to 40% of tagged individuals fell back downstream of the slide. Potential reasons for fall back behaviour include capture and handling stress, water temperature, and fish condition. Milling and cycling behaviour was noted to at least 6 km below the slide producing inflated sonar counts. There are species-specific threshold values for passage at specific discharges and temperatures. Some fish did not pass when discharge dropped below the species threshold, while others did pass. Potential factors driving individual variability in passage include sex (males more successful), condition (maturation), capture bias, tag effects, water temperature, and dispersal behaviour. Most Coho Salmon (~70%) that left the Big Bar area moved downstream to disperse into the Bridge or Seton rivers. The tagging data are being reviewed to evaluate factors related to successful passage.

1.4. 2020 DFO Science Plans

Mike Hawkshaw, DFO

Mike Hawkshaw presented the current DFO science activities being implemented to better monitor, understand and/or predict the current and future impacts of the Big Bar rockslide on salmon. For juvenile salmon, 2020 slide-related activities and the related core activities include a literature review on gas bubble trauma and dispersal (Chilko smolt fence), juvenile monitoring for dispersal (Nautley RST smolt), environmental monitoring/TGP (Mission downstream), Chilko acoustic tagging (Chilko Chinook smolts). Adult salmon slide-related activities for 2020 included hydro-acoustics above and below the slide, expanding the radio telemetry receiver network to natal areas, and research and monitoring of migration biology. The related core activities for adult salmon in 2020 include a full census for Sockeye Salmon (EFS, fecundity, catch and return) and expanded spawner surveys (catch and reconstruction) for Chinook and Coho Salmon. There is scope to modify DFO science activities based on information requirements for key mitigation activities.

1.5. Pacific Salmon Swimming Capacity

Krista Kraskura, University of California

Krista Kraskura presented a review of Pacific salmon swim performance with an emphasis on anaerobic swimming (burst, sprint, anaerobic exercise and recovery). Current research is to review fish swimming meta data to determine how biotic factors (species, size, sex, condition, and behaviour) and abiotic factors (flow, temperature) influence anaerobic swim performance noting any effects of surgery or tags. The primary objective of the research is to identify key information gaps and provide direction for future work in 2020 related to adult burst swim performance. Sustained swimming is aerobic and can be maintained indefinitely and in an experimental setting is a speed that can be maintained for 200 minutes. Prolonged swimming is a mix of aerobic and anaerobic swimming and can be sustained for 30 seconds to 200 minutes. This type of swimming results in fatigue and requires recovery. Sprint or burst swimming is a short swim sprint performance between 15 and 30 seconds and requires recovery. There is a total of 52 previous studies on salmonid swim performance. Critical swim speed test (Ucrit) studies have been performed on a variety of salmonids but mostly on Sockeye Salmon (60%) and early work in the 1960s and 1970s focused on juvenile fish. The relationship between swim speed and oxygen consumption is similar between different size fish when swim speed is measured in body length per second (BL/s). However, swim capacity is a function of fish size when swim speed is measured in cm per second (cm/s). Smaller fish transition to anaerobic metabolism at lower velocities. Many studies report data in BL/s not cm/s and it is difficult to predict the conversion between the two measurements. Salmon can swim faster than we are capable of measuring in the lab. EMG tags are used in field studies to study swim speeds. Most studies on swim speeds in adult salmon are conducted over a narrow range of fish sizes, water temperatures, limited species, and most data are not sex specific. Factors related to a successful passage include burst swimming (frequency, top speed, total duration of swimming) and behaviour (energy reserves, sex, size, maturity, water temperature). Questions related to the metadata study include:

How frequently can/do adult salmon burst? What is adult salmon bursting capacity? How much bursting can be sustained and not lead to pre-spawning mortality? What is the absolute maximum swimming capacity of Pacific salmon? How much anaerobic swimming or bursting is bad? Bursting patterns differ between individuals, what are the behavioural drivers of these patterns? How often and how fast do salmon bursts lead to exhaustion and the inability to recover? What are the important factors related to successful passage?

1.6. Dispersal and Reproductive Success

Art Bass, UBC

Art Bass presented an overview of salmon dispersal and potential for reproductive success resulting from the Big Bar slide. Fish that are stressed, exhausted, injured, or unable to migrate upstream of the slide could migrate elsewhere (dispersal) to spawn in non-natal streams. There is historical precedent for this dispersal behaviour at Hell's Gate in 1913. A bulletin from the time described eddies downstream of the obstruction full of fish unable to pass. Eventually it was noted that these fish moved into available habitat downstream of Hell's Gate. There was evidence of multiple fish species spawning in the same habitat, redd superimposition, and sub-optimal habitat use. Egg viability was low in the few tests completed. Fish that disperse to unoccupied systems are mostly unsuccessful. Dispersal into occupied systems has the potential to change the demographic and genetic structure of recipient populations, particularly if the donor populations are large, straying is frequent, and the recipient population is small. Failure of the strays to successfully reproduce could be due to lack of local adaptation. Locally adapted fish tend to outperform non-locals. As the distance between the population comparisons increases, there are likely greater mismatches in local adaptations and lower survival. The biggest concern for fish dispersal from Big Bar slide is competition for spawning resources (redd superimposition) and possible genetic shifts in the local population (away from local adaptation) by spawning with dispersed fish. There is potential to extirpate the local population or establish a genetically "new" population. Possible actions to determine the impact of dispersal include testing GSI of emerging juveniles in the potential recipient populations and field observations/collections of strays during spawning seasons.

1.7. Gas Bubble Trauma Review

Naomi Pleizer, UBC

Naomi Pleizer presented on total dissolved gas supersaturation and depth effects on fish. Review of the literature indicated that most work on this subject was done in relation to dams. Gas bubbles form from mixing water creating supersaturation. Gas bubble trauma has several effects on fish and can lead to vulnerability to disease, pop eyes, bubbles in gill blood vessels, and swim bladder over-inflation. Extrinsic factors on gas bubble effects to fish include water temperature, depth of the fish in the water column, and the ratio of oxygen to nitrogen in the water. Intrinsic factors on gas bubble effects to fish include fish size and the severity of supersaturation. Models are based on extrinsic factors. Time to 50% mortality increases with the % of total dissolved gas (TDG). Dissolved gas downstream of Big Bar could be a problem for holding fish. There are no current field-based assessments or evidence of gas bubble trauma at natural waterfalls. All experiments are based on fish that are not experiencing a

lot of movement. Lab tests noted mortality at 12 to 14 hours. Exposure to supersaturation is not necessarily lethal to fish but there is a recovery time and re-exposure can be a problem. Field sampling in the Big Bar area should include depth of the plunge pool, TDG and water temperature monitoring downstream of the slide, and monitoring the depth in the water column that fish are migrating.

1.8. Sockeye Population Recovery Potential Modelling

Ann-Marie Huang, DFO

Ann-Marie Huang presented on the methodology used for Big Bar stocks in the Fraser Sockeye Recovery Potential Assessment. This modelling is part of the SARA process and uses stock-specific stock-recruit models with fixed mortality rates (0% to 90%) and future productivities (-50% to +30%). Spawner numbers from 2012 to 2018 were used to start the simulation. The simulation includes 99.5% mortality for Big Bar stocks (based on available information to mid-August 2019) and includes a 12-year projection. The Sockeye recovery process is a similar framework to the Chinook recovery process. The model looked at the reduction in productivity and is adjusted over multiple years with +30% increase in productivity being very optimistic. The challenge is that borrowing information from other stocks leads to model uncertainty. Recovery targets were used in the model, with target 1 approximating not endangered or threatened (not red) and target 2 approximating not at risk (green). Big Bar stocks base case is 99.5% mortality in 2019 then decrease in mortality from 2020 onwards. With a hypothetical fishway at Big Bar, en-route mortality in 2019 is 99.5%, 80% in 2020, 75% in 2021, and 2022 onwards the “base” 20% mortality. A sensitivity analysis is run for two to four years at 99.5% mortality. The model does include some stock-specific information (age-based rescue effects, stock-recruit dynamics, productivity assumptions and Big bar mortality, once estimates are available, and “background” en-route mortality applied at any intermediate level). The model does not include biological factors (intergenerational effects, impact on juvenile outmigration, changes to egg viability) or management factors (management unit level HCRs, overlap constraints, implementation error/outcome uncertainty). In the future, modelling will include the addition of tagging data, more stock-specific information, and understanding how baseline habitat is changing.

2. DAY 2 PRESENTATIONS

2.1. Fraser Sockeye Management Example

Fiona Martens, Catherine Michielsens, PSC

Fiona presented on the use of management adjustments (MAs) to account for the impacts of Big Bar in fisheries management. An in-season estimate of a total of 81% of the Fraser River Sockeye stocks were impacted by the Big Bar slide (100% of the Early Stuart run, 60% of the Early Summer run, 90% of the Summer run and 0% of the Late run). MAs are used to account for slide impacts by adding salmon to the spawning escapement targets (SET) for the purpose of increasing the likelihood of achieving the target. Prior to Big Bar, MA models related historical escapement differences to

environmental conditions within the Fraser River. Escapement differences compare the number of adults on the spawning grounds with the expected number based on escapement at Mission and en-route catches. MA estimates are produced both pre-season for planning purposes and in-season to inform fisheries management decisions. Prior to Big Bar, historical escapement differences for Early Stuart, early Summer and Summer Sockeye runs have correlated with high river temperatures and discharge at Hell's Gate. In 2019, there was no knowledge of the Big Bar slide and the in-season run sizes were too low to reach the SET; thus, the MA estimates were unnecessary for management decisions. The current MA approach is difficult to adjust to Big Bar. The expectation for 2020 is that 50% of the total Fraser River Sockeye runs will be impacted by Big Bar (100% of Early Stuart, 34% of Early Summer, and 63% of Summer run). For 2020, MA estimate could be adjusted to account for the additional mortality associated with the slide, but it would be challenging to predict pre-season and to update in-season. The forecast for 2022 using 2018 returns and management considerations predicts that 42% of the total Fraser Sockeye runs will be impacted by Big Bar (100% of Early Stuart, 21% of Early Summer, and 98% of Summer run). The conclusions of the presentation were:

- It is important to account for Big Bar impacts in fisheries management decisions for Fraser River Sockeye salmon.
- The easiest method would be to account for impacts within the current MA assessment and management approach, but it would require the development of methodology.
- Requires availability of pre-season expectations of successful migration to the spawning grounds.
- Preferable if pre-season expectation could be updated in-season with year-specific information.
- Traditional MA approach does not account for additional impacts such as reduced spawner success.
- There is no MA approach for Fraser River Pink Salmon.

2.2. Rockslide Mitigation Plans

Leander McCabe- Engineer RPSS, DFO

Leander presented and explained from an engineering perspective the response to the Big Bar landslide. The slide calved off rock (~125 m vertical height) and deposited debris in a radial pattern in a historically narrow and treacherous part of the canyon. The thalweg was previously on the west side of the river but has shifted to the east bank with the slide and the east toe blast. A barrier has been created by larger rock attenuating slide debris and impounding flow at the upstream section of the slide. The crest of the slide has 5 to 7 m of water on top of 10 m of slide debris on the original channel bed. At high flow the channel hydraulics are long and turbulent while at low flow there is a short, steep vertical drop. The hydraulics on the east bank are excessively fast and turbulent. Salmon prefer to migrate along the west bank. As flows reduce, the critical hydraulic section moves upstream. There

are localized hydraulic barriers to salmon migration. Hydraulic monitoring is a key focus to inform the next step of hydraulic modelling upstream and downstream of the slide. The velocity through the slide area marginally exceeds the swimming capabilities of Pacific salmon. The hydraulic effects (drop in headwater elevation) of the east toe removal are more substantial at higher flows. Higher flows will help to mobilize blast debris down river, decreasing the head level difference. The blasting has appeared to achieve the desired results. Winter flows have been slightly above average.

2.3. Response Spring Works

Mike Hawkshaw, DFO

Mike presented a briefing on the works at the Big Bar landslide from January to March 2020 and required work from March to May 2020. New river modeling information indicates a low probability of the ability of fish to migrate through the slide site at all flow conditions after Kiewit's construction work. Planning for alternative fish passage system and emergency conservation enhancement of priority salmon populations is underway. Timelines are tight and driven by the spring freshet. It is critical to complete plans and get necessary procurements completed in the coming weeks and months. There are seven areas of current work (razorback, west overland access road, skid trail/winch access, in channel access/debris, east toe, rockfall/protection mesh, highline). On January 14, 2020 Kiewit began work on rock removal to improve flow conditions to allow natural fish passage during salmon migration. There is no blasting on the west bank. Only manipulation of rock to create a bench and base for the fishway. Blasting for the west access road at the razorback is ongoing and the road is to be completed by February 28, 2020. The first blast of the east toe was on February 18 and the second blast was scheduled for March 9, 2020. In-river channel blasting to begin March 6-8, 2020.

The spring program decision-making process is structured with hydrological, engineering, and biological consultants advising and conducting data collection, analytical and design work. Internal DFO technical experts are working closely with consultants and information, planning, and design is discussed weekly with involved parties. External technical teams for alternative fish passage and conservation enhancement are reviewing and advising on work of DFO and consultants. New information from all sources is analyzed and evaluated quickly for incorporation into planning, design, and construction activities. The precautionary approach is required to manage project uncertainties and risks. NHC's modelling results based on ongoing bathymetric analysis of the slide area indicate that there is a low probability of fish migrating through the slide area at all flow conditions. The freshet is anticipated to occur at the end of March/early April raising the river levels and increasing velocities impeding migration of early arriving Chinook and Sockeye Salmon. It is necessary to have systems in place to move fish throughout the migration period with no single effective technology. All systems are unproven and subject to risks for operational difficulty. HDR Engineering developed an evaluation method and conducted analysis of passage options. The key technologies evaluated include:

- Assorted styles of engineered and natural fish ladders/fishways
- Trap and Truck - short haul and long haul

- Hydraulic fish pumps
- Pneumatic air fish pumps
- Archimedes Screws
- Brailers
- Mechanical fish lifts

Key evaluation factors to consider for each of the technologies included:

- Reliability – Expected to perform throughout the work period
- Efficiency and fish health - Minimize delay, injury, stress, and handling
- Effectiveness – Has a reasonable possibility of working in an untested location
- Availability - Presently available for use on site
- Procurement – Able to be acquired in time
- Adaptable and expandable – work in different flow conditions and able to pass small and large numbers of fish

A detailed evaluation of passage options was conducted by DFO and external consultants. Critical factors such as effectiveness, efficiency, impacts to fish health and feasibility were assessed for each system. It is necessary to have multiple systems able to work in different flow conditions, as well as have redundancies and backups. This requires multiple technologies and passage systems.

The first assisted passage component is to construct a highly roughened surface on the west bank to provide a natural-like fishway with eddies and jump steps made from rock removed from the river. The second component is a pneumatic fish pump as a backup for the fish ladder system and for flows over 4,000 cms. If the first two components are unsuccessful, access along the west side of the river will be used to truck and transport fish. Migration delays and handling induced stress occurs with this system and capture efficiency decreases. Most fishing effort will take place at the base of the slide, as this is where the fish are naturally congregating.

Planning for an emergency conservation hatchery enhancement program continues if ongoing blockages and migratory delays result in a risk to a second-year class of salmon. The approach will be based on response to success of winter work. The optimal plan will be to collect fish from natal streams to increase likelihood of genetic matching. However, poor, or total blockage passage conditions will likely necessitate collection at the slide site. There will need to be a balancing of biological risk. Short-term onsite adult holding capacity for Chinook will be required (constructed at French Bar) to give time for genetic testing and sorting. First Nations involvement will be high.

Fish monitoring will include use of radio tags and sonar units to determine salmon migration past the slide to inform real-time passage and enhancement decisions and actions. The risks and uncertainties

include the timing and magnitude of spring freshet, the quantity of rock to be removed, the extent of fish ladder infrastructure to be installed, and the operational success of the fish ladder and fish pump system once they are installed.



APPENDIX C. BIG BAR SEF WORKSHOP BREAKOUT SESSIONS POTENTIAL SCIENCE ACTIVITIES-DAY 1



1. ADULT SALMON

The Day 1 breakout group discussions that focused on adult salmon produced the following list of potential science activities needed to understand/ quantify or predict slide impacts.

- Field - adult radio telemetry below the slide
- Field - surface flow pattern changes with stage height
- Monitor downstream fish condition – baseline
- Characterize areas of geomorphology rockslide risk for canyon and match risk with fish distribution (need high velocity areas as well)
- Monitor high risk locations - geo tech
- General review of landslide risks; watershed size fish value
- Fine scale fish behaviour (telemetry)
- How common is cycling behaviour; canyon vs. alluvial locations
- Tagging program in a "control" area
- Replicate fish anaerobic behaviour and recovery from multiple events in the lab
- Role of temperature in burst swim performance and recovery
- Model post-passage temperature impacts (bioenergetic modelling); update PSC modelling approach
- Time to event analysis to estimate rate of fish passage
- Genomic sampling to look at migration timing biomarkers
- Genomic sampling of successful and unsuccessful fish to examine selection on specific genes or traits (e. g, timing)
- Fish condition factors (e.g. maturity, reproductive hormones) linked to variability in anaerobic behaviour in both lab and field
- Retrospective analysis if previous slide events match with current fish distribution, abundance, genetic structure, phenotypes, etc.
- Fine scale telemetry - lots of receivers, hand tracking, acoustic receivers maybe, scale will help with different objectives (just getting through vs where they drop back)
 - Hand tracking / recovery of tags on spawning grounds
 - Tagging three times the number of fish in previous studies

- Collection of basic information - fecundity, etc.
 - Focus on certain populations - Chilko is a good candidate
 - Piggyback on province radio receivers
 - Take experimental approach - tag at different flows, etc.
- Oxygen supersaturation- if it is there, how long is duration of exposure; need to sample upstream and downstream; are fish encountering this already?
- Destructive sampling above and below the slide
- Integration with test fisheries; PSC test fisheries; environmental watch program (DFO)
- Chinook genetic baselines (lab with existing data) and (field for unknown pops)
- Disease monitoring/health/condition assessments
- Genetic sampling from transported fish
- Classify burst swimming (Sigma 8 tailbeat tags)
- Lab based experiment to better assess recovery
- PIT array in any fishway or controlled passage structure
- Natal stream spawning sampling program to better understand reproductive success (parental based DNA), also potentially assessing existing Chinook samples from Chilco
- Assessment of in river fisheries effects by tagging released fish
- Larger scale PIT tagging study of a random sample and install readers in suitable infrastructure (spawning channels, etc.) upstream
- Marine tagging, or piggyback on other acoustic marine tagging programs
- Monitor other populations not affected by the slide
- Existing studies and overlap - what is everyone doing out there
- Flow controlled migration barriers and thresholds throughout the Fraser, beyond Big Bar
- Intrinsic factors affecting risk from landslides at other locations
- Temperature effects on fish fitness
- Risk assessment framework to set priorities for activities

2. JUVENILE SALMON

The Day 1 breakout group discussions that focused on juvenile salmon produced the following list of potential science activities needed to understand/ quantify or predict slide impacts.

- Field TGP measurement
- Field - Juvenile tagging including Chinook Salmon and acoustic tagging of Chinook smolts in the upper Fraser River
- Field - sampling for evidence of successful reproduction of fish that dispersed
- Predation assessment
- Genetic assessment of juveniles at Mission, lower Fraser River, Seton River, or Bridge River to understand any hybridization/dispersal
- Chilko tagging program, with additional tagging if this program is unsuccessful
- Chinook juvenile tagging program
- Slide tagging (balloon or robofish) to assess hydraulic effect on juveniles
- Investigate where in the Fraser water column that smolts of different species are migrating (edge, center, deep, shallow)
- Physiological assessments of smolt health in lower river (or upstream vs downstream experimental design)
- Literature stray rates
- Downstream telemetry (informed from 2019 results)
- Genetic analysis of parental vs juvenile
- Risk assessment of superimposition (is there overlap in timing)
- eDNA or field sampling
- General field health assessments (e.g. GBT)
- Field cage experiment
- Surface velocities and recirculation rates
- Sonar for looking at fish movement
- Residence studies of gas bubble trauma on Bull Trout
- Injury from passage itself into recirculation pool

3. POPULATIONS AND ECOSYSTEMS

The Day 1 breakout group discussions that focused on populations and ecosystems produced the following list of potential science activities needed to understand/ quantify or predict slide impacts.

- Lake fry surveys - Lakes Program (competitors)
- Lake limnology surveys (nutrients and prey)
- Changes in phenotypes of competitor (Kokanee)
- Bull trout and Rainbow Trout changes in large lakes
- Monitor long term trends in nutrients - look for analogs of population in the historic record
- Habitat alteration
- Look for good historic datasets (BACI design)
- Use fish as indicators of habitat quality
- Field - standard StAD activities
- Model - Sockeye recovery potential assessment modelling
- Systematic sampling design - look intensively and extensively across fair and poor populations
- Analysis to detect contracted spawning effect
- Middle Fraser River Coho Salmon study to better understand the stock
- Chinook juvenile outmigration program
- Consider greatest parameter uncertainties from the population models to drive priority science activities
- Population level tagging studies: how does the slide effect relate to the broader population
- Chinook spawning ground sampling
- Genomic analyses to better understand population level selective pressures
- Genetic baselines for Sockeye, Chinook, Coho, and Pink Salmon, steelhead
- Genetic basis for timing?
- Test fisheries
- More intensive monitoring of secondary physical/habitat parameters (flow, temp, turbidity, embeddedness, etc.)

- Chinook spawning ground samples for age structure and sex ratios
- Phenotype traits - need a database to get access
- Rockslide river dynamics - access to release physical data associated to the rock
- Detect trends in change fecundity at length
- Rethink the stock assessment framework to detect the effects of Big Bar slide for all species
- Total mortality quantification as per PST requirements
- Extended scenario analysis for a longer time frame
- Rethink the recovery goals in light these events

