Fraser River Sockeye – Proposed Research Framework
Request for Projects
Due: COB, Friday, August 6, 2010

Outcome: To identify a combination of monitoring and research work that will partition sources and/or locations of mortality to better understand the effects of anthropogenic activities on future production of Fraser River sockeye salmon.

For each element, contributors were asked to provide brief sketches of the type of monitoring and/or research that would be recommended at 3 levels: "low cost" (bare minimum), "moderate cost" and "full cost" (all-inclusive), along with a very rough estimate of the cost at each level. For each of the three sketches, provide a brief description and rationale along with approximate cost and timeline (defined as either ongoing monitoring or targeted research).

1. Lake monitoring (abundance, acoustic) [Dan Selbie & Jeremy Hume]

[Selbie]

Principal Investigators: Daniel Selbie, Jeremy Hume, Lucas Pon, Erland MacIsaac, Jim Irvine (remote sensing project)

Objectives: Develop and implement a rotational monitoring and research framework to ensure adequate assessment of juvenile Fraser sockeye salmon freshwater abundance, survival, and habitat.

Organizational Requirements: The majority of sockeye salmon mortality occurs during freshwater residence, requiring critical and recurring assessment of factors that limit sockeye salmon productivity in freshwater. Strategies 1 and 2 of the Wild Salmon Policy outline the need for *standardized monitoring of wild salmon status* and *assessment of habitat status* respectively. Recent sockeye salmon population trends within the Fraser drainage have highlighted the necessity for an enhancement of systematic monitoring and research to detect freshwater versus marine inter- and intra-stock survival trends and determine the factors influencing population variability. DFO's Lakes Research Program (LRP) currently provides core systematic habitat (limnology) and stock status assessments (pelagic juvenile surveys) and research on only a few selected Fraser watershed nursery lakes. We propose the development and implementation of a systematic rotational freshwater monitoring framework within the Fraser drainage (similar to the ongoing LRP rotational surveys on the North and Central coasts), with targeted ecological studies (i.e. plankton community compositions and trophic energy transfers) and the development of new monitoring techniques (i.e. satellite-derived water quality-salmon survival relationships). Collectively, the proposed monitoring and targeted research would substantially improve our knowledge of sockeye ecology and survival; establish population benchmarks and routinely evaluate juvenile stock status; maintain datasets that directly monitor identified WSP lake habitat indicators (among many others); and contribute substantially to informed salmon conservation and management.

Basic Option

Monitoring Components:

- Continuation of reactionary monitoring to notable changes in major production systems in Fraser River drainage (i.e. Quesnel, Shuswap, Chilko) and long-term monitoring of Quesnel, Chilliwack and Cultus lakes.

Research Components:

- Ecosystem survey studies exploring biological communities responsible for variable trophic energy transfers and efficiencies in the production of sockeye salmon.

Financial and Personnel Requirements
- Est. O&M $250K/yr ($175K monitoring & core maintenance; $75K research); $15K to support DFO's low-level nutrient chemistry lab); plus 2 additional FTE's.

Moderate Cost Option (Basic Plus…)
Monitoring Components:
- 8-year rotational framework for juvenile stock status and annually-resolved rearing habitat assessments (i.e. productive capacity, limiting factors) focusing on the approximately 20 major stocks in the Fraser River watershed.
- Rapid-response monitoring and assessment capacity for arising freshwater issues (i.e. recent changes in Chilko juvenile production).

Research Components:
- Experimental and ecosystem-scale studies to link chemical, physical and biological limnology to trophic energy transfers and efficiencies for the production of sockeye salmon and to anthropogenic influences (both terrestrial and aquatic).
- Refinement of nursery habitat productive capacity modeling and predictions for management

Financial and Personnel Requirements
- Est. O&M $400K/yr ($275K monitoring & maintenance; $100K research; $25K to support DFO's low-level nutrient chemistry lab); plus 2 additional FTE's and two 6-month term technicians/yr or Graduate student support.

Full Cost Option (Moderate Plus…)
Monitoring Components:
- 4-year rotational framework for juvenile stock status and annually-resolved rearing habitat (i.e. productive capacity, limiting factors) assessments focusing on 20 major stocks in the Fraser River watershed.
- Inaugural rearing habitat and stock status assessments of previously unstudied, less productive stocks in the Fraser River watershed (targeted Wild Salmon Policy objective).
- Rapid-response monitoring and assessment capacity for arising freshwater issues (i.e. recent changes in Chilko juvenile production).

Research Components:
- Exploratory development of water quality indices (i.e. lake primary production) from satellite image data for large, productive nursery lakes in the Fraser River drainage (i.e. Chilko, Quesnel, Shuswap, Stuart-Takla system lakes) with the possibility of broader application throughout the Pacific Region.
- Experimental and ecosystem-scale studies to link chemical, physical and biological limnology to trophic energy transfers and efficiencies for the production of sockeye salmon and to anthropogenic influences (both terrestrial and aquatic).
- Refinement of nursery habitat productive capacity modeling and predictions for management

Financial and Personnel Requirements
- Est. O&M $575K/yr ($375K monitoring & maintenance; $150K research; $50K to support DFO's low-level nutrient chemistry lab); plus 4 additional FTE's & two 6-month term technicians/yr or Graduate student support.

[Hume]

Principal Investigators: Erland MacIsaac, Timber Whitehouse, Herb Herunter, David Patterson, Jeremy Hume

Objectives: To develop a long-term monitoring and targeted research program on sockeye spawning streams to evaluate the relationship between sockeye fry production and variations in spawning bed conditions driven by climate changes and anthropogenic disturbances.

Organizational Requirements: The production of sockeye fry recruiting to their rearing habitats depends on egg-to-fry survival rates that are largely determined by the physical, chemical, thermal and hydrologic incubation conditions in the spawning beds. Annual variations in egg-to-fry survivals contribute an unknown portion of the variability in stock-recruit relationships between effective female spawners and summer fry abundance for acoustically enumerated Fraser River sockeye populations. Spawning bed incubation conditions are not static but are affected by seasonal and annual variations in local weather, sediment and streambed dynamics, stream hydrology, and incubation water quality which affect the development and survival of incubating eggs and the timing of fry emergence and emigration to rearing areas. Anthropogenic climate change, forest pest infestations, and land-use activities in the watersheds alter the hydrologic conditions and sediment dynamics of spawning beds (e.g. increased peak flows and streambed scouring, winter low flows and red stranding, changes in groundwater and intergravel flows, fine sediment generation) but the overall long-term effects on fry recruitment are difficult to predict. Assessments of egg-to-fry survivals and fry emigration timing coupled with targeted research into spawning and incubation bed conditions have only been completed for some of the Early Stuart Fraser River sockeye spawning streams for a short period of time so our understanding of how changes in spawning bed conditions affect juvenile recruitment and sockeye productivity is still poor. Developing a spawning bed and fry monitoring program coupled with targeted research to link changes in fry production rates to natural variations and man-induced changes in stream hydrology, water quality and sediment dynamics is required to assess past and predict future changes in the productivity of spawning bed habitats. Sockeye spawning beds are also a key critical habitat for Wild Salmon Policy habitat status reporting that is currently not being directly addressed.

Basic Option

Monitoring Components:

- No long term monitoring

Research Components:

- Spawning bed surveys to relate physical conditions in a broad range of spawning habitats to variations in natural and anthropogenic watershed influences on stream hydrology and sediment dynamics. Modeling used to infer potential effects on fry production.

Financial and Personnel Requirements

- Est. $75K/yr directed research plus 1 additional FTE.

Moderate Cost Option (Basic Plus…)

Monitoring Components:

- Fry assessments focusing on 2 key index stocks and spawning streams in the Fraser River watershed where spawner escapement, potential egg deposition and spring fry enumerations can be successfully completed annually.
- Automated monitoring of stream and spawning bed temperatures, surface and intergravel water flows and water quality, and meteorological conditions in 2 study streams.

Research Components:

- Artificial egg incubation studies to define egg-to-fry survival rates under controlled and selected field conditions to relate rates to variations in spawning bed conditions.
- Spawning bed surveys to relate physical conditions in a broad range of spawning habitats to variations in natural and anthropogenic watershed influences on stream hydrology and sediment dynamics.

Financial and Personnel Requirements

- Est. $250K/yr ($100K sockeye escapement & fry monitoring; $25K automated data collection stations and maintenance plus $25K capital instrumentation; $100K directed research); plus 1 additional FTE.

Full Cost Option (Moderate plus…)

Monitoring Components:

- Fry assessments focusing on 4 key index sockeye stocks and spawning streams in the Fraser River watershed where escapement, potential egg deposition and spring fry enumerations can be successfully completed annually.
- Automated monitoring of stream and spawning bed temperatures, surface and intergravel water flows and water quality, and meteorological conditions in 4 study streams.

Research Components:

- Artificial egg incubation studies to define egg-to-fry survival rates under controlled and selected field conditions to relate rates to variations in spawning bed conditions.
- Digitizing of existing historical spawning ground maps (circa 1940 and later) to enable GIS analysis of changes in spawning ground location and utilization over a 70 yr time span.
- Spawning bed surveys to relate physical conditions in a broad range of spawning habitats to variations in natural and anthropogenic watershed influences on stream hydrology and sediment dynamics.

Financial and Personnel Requirements

- Est. $400K/yr ($175K sockeye escapement & fry monitoring; $50K automated data collection stations and maintenance plus $50K capital instrumentation; $125K directed research); plus 2 additional FTE's.

2. Habitat status monitoring (WSP pressure/state indicators) [Kim Hyatt]

Targeted Research on Fraser and non-Fraser Sockeye Indicator Stocks: Hyatt et al. (2010) have recently assembled and discussed the origins of time-series data that permit partitioning of freshwater and marine survival events or trends exhibited by several sockeye "indicator stocks" originating from freshwater systems, representing both Fraser and non-Fraser sockeye, in southern B.C. Analysis of these data has led to an exciting new discovery that ENSO variations induce harmonic oscillations in marine survivals (**HOMS**) of both Fraser and non-Fraser sockeye populations from the central to south coast of B.C. This constitutes the latest demonstration that <u>dependent-variable</u> observations of salmon survival partitioned into freshwater and marine components are highly valuable in determining the location (freshwater or marine, inside marine waters versus outside marine waters), time (single year to multi-year events) and potential identity (e.g. physical variables, predators, pathogens, parasites, competitors etc…) of causal agents or mechanisms involved as <u>independent variables</u> in controlling sockeye survival. Thus, expenditures on new research on a wide range of biophysical factors (parasites, disease, predators, competitors, climate indices) serving as independent or explanatory variables should not be initiated in the absence of careful consideration of the extent to which proposed independent variable information may be linked to explicit <u>survival events</u> or <u>survival trends</u> exhibited by an existing suite of sockeye indicator stocks. Here we propose a program of targeted research to first improve documentation and accessibility of sockeye indicator stock survival observations and then to conduct retrospective analyses to examine associations between time-series data sets on independent variables and specific marine survival events or trends that are shared among Fraser and non-Fraser, sockeye indicator stocks.

Option A. - Low Cost Proposal: The source methods, data and metadata supporting existing, sockeye, smolt-to-adult return (SAR) series are incompletely documented and have been subjected to variable levels of quality control over decades of time (Hyatt et al. 2010). We propose that DFO increase support to complete data and metadata assembly, review, analysis and documentation so that valuable time series of partitioned survival observations for salmon indicator stocks are authoritative, peer reviewed and managed in secure regional databases. Similar methodological and data issues noted here are dealt with for Chinook and coho salmon by Pacific Salmon Treaty technical committees. We propose DFO consider creation of a region-wide, sockeye technical committee (STC) to promote greater standardization of indicator stock assessments in Canadian and U.S. waters to improve the availability and quality of survival series data sets and explanatory information for agencies in both countries. Incremental costs to support 1-2 annual meetings of STC members drawn from DFO Area and core stock assessment personnel estimated at $15K for travel and meeting support (less if integrated with PSC meetings but at the risk of losing focus). An additional $15K for term or casual salary is required to support data management and report production by our unit within the Salmon Assessment Section at PBS.

Net Incremental Cost of Option A to DFO Pacific Science: $30K per annum (ongoing)

Option B. - Medium Cost Proposal: Option-A is restricted to stock monitoring and data evaluation activities devoid of targeted research that Science Sector personnel consider to be part of their core mandate. The recent discovery by Hyatt et al. (2010) that ENSO variations induce HOMS in both Fraser and non-Fraser sockeye populations from the central to south coast of BC raises several questions for which targeted research may provide answers. A question of immediate interest is "What associations exist with respect to seasonal to annual variations in biological traits of juvenile and/or adult sockeye (*e.g*. growth rates, size, condition, migratory timing for particular freshwater or marine life history stages) and subsequent survivals during high survival La Niña versus low survival El Niño phases of HOMS for sockeye indicator stocks?" This question may be addressed through retrospective analyses of existing time series observations using software tools such as RASTAR (rapid screening through analysis and regression, Borstad and Thomson) to identify associations among: indicator stock survival (freshwater and marine), biological traits (e.g. fry and smolt size and age, smolt migratory timing variations) or ocean conditions (time of spring transition, annual to seasonal chlorophyll variations etc…). Our program has unique, sample inventories (of adult scales, otoliths, fry, smolts) and independent variable observations (migratory timing, size at age etc…) sets to support analyses on several of the subject sockeye indicator stocks. If combined with reconstructed, historic variable data sets on ocean (and freshwater?) conditions developed by Borstad et al., retrospective analyses will generate new insights into factors controlling indicator stock survival and production variations. Execution of an initial round of this research could be completed given salary and program support (space, travel and O&M support) for a Postdoctoral Fellow in our lab at a cost of $75K per year for three years.

Net Incremental Cost of Option B to DFO Pacific Science: $75K per annum (3 years)

Option C. - Full-cost Proposal: Options A and B above are low to moderate cost approaches that provide incremental improvements to sockeye indicator stock maintenance and targeted research activities. Our full-cost proposal consists first of funding for Options A and B above (i.e. $100K of new funding per year). However, two questions not addressed above, but raised here are: (1) How persistent are the ENSO-HOMS patterns over much longer time intervals than the Hyatt et al.(2010) SAR series? (2) How geographically widespread are ENSO induced HOMS patterns in the eastern Pacific among Fraser and non-Fraser sockeye stocks? Targeted research to address these questions could help identify drivers of salmon production variations in freshwater and marine ecosystems and improve the basis for salmon forecasting. To address these questions we propose additional collaborative research (with D. Selbie at Cultus L.) involving acquisition and analysis of sediment cores from lakes. Results would be used to first verify associations between contemporary indices of ecosystem state change (i.e. productivity, fish abundance) and paleo-indicators of these same ecosystem state changes. Next we would use paleo-indicators to reconstruct historic (100 year) and prehistoric (hundreds to thousands of years before present) conditions including major abundance variations in adult and juvenile salmon returning to or rearing in freshwater. We suggest an initial 3 year collaborative project between Hyatt and Selbie focused on key sockeye indicator stocks and lakes (e.g. Chilko, GC-Sproat, Osoyoos) would test the utility of paleo-data to resolve the above questions in locations for which we already have a rich set of historic observations. Dr. Peter Leavitt (University of Regina) has indicated an interest in participating in this work as well. Cost for an initial 3 year research initiative is suggested to be roughly $75K per year.

Net Incremental Cost of Option C to DFO Pacific Science: $180K per annum

3. Smolt monitoring/tagging(POST/archival/other) in Fraser River (including lower river and estuary index/indicator) [Timber Whitehouse & Bev Bravender]

[Whitehouse]

Freshwater monitoring – juvenile sockeye: smolts from nursery lake exit to sea entry

Principle Investigators: Keri Benner, Timber Whitehouse, David Patterson, Kristi Miller.

In order to understand where, and with what consistency, during their life history mortality is occurring for Fraser River sockeye salmon, it is essential that stanza-specific survival estimates be systematically collected. Recruitment, for the majority of the currently estimated production relationships for these populations relies on mortality (survival) estimates integrated across total freshwater and marine life history because production relates total returns to previous spawner abundance levels. As populations respond to survival events in both freshwater and marine environments, both unique one-time, one-place events or larger scale systematic shifts, it is extremely difficult to identify where mortality anomalies occur, let alone identify factors that may have been responsible, when mortality (survival) is integrated over the entire life history. A stratified approach to collecting stanza-specific survival information, one that breaks life history into discrete periods which include important life history “events”, is required to enable researchers and managers to better understand where and under what circumstances particular mortality patterns may be expected. Over time, given a commitment to long-term monitoring, this approach can lead to improved production forecasting capability, and a much improved understanding of population dynamics for Fraser sockeye populations.

Knowledge related to the factors responsible for stock-specific and inter-annual patterns in smolt production from Fraser sockeye systems is extremely limited. Smolt production patterns can only be described for two populations, Cultus and Chilko, while for the remaining spawning populations even basic information like out-migration timing, sea-entry timing and annual smolt abundance and size variation is not yet described. Work to describe factors responsible for the survival patterns observed has been opportunistic as opposed to structured and systematic, and as progress is made in this area it is apparent that the information gaps that exist within the production data are large and will limit the ability to ultimately describe with certainty the factors responsible for sockeye production variability under changing production regimes (freshwater or marine). One solution to address these information gaps is to invest in a systematic monitoring approach to evaluate survival across a representative suite of spawning/rearing populations on a time-step that is meaningful to (and brackets) major life-history events. This proposal deals with monitoring sockeye smolt output from Fraser sockeye nurseries through to the time of sea-entry.

Base Project (Low cost)
Description: Work would entail: 1) monitoring sockeye nursery lakes at their outlet to characterize the timing of salmon outmigration from their nursery as smolts, characterize their size and age composition on lake exit, and in the case of multi-CU complexes determine relative contribution of major components to the outmigration. This is new work which would require development of appropriate sampling protocol, trapping or acoustic plus trapping, to collect relevant data in appropriate systems annually. 2) Monitoring sockeye smolt passage through the lower Fraser River just prior to sea-entry to identify migration timing between the nursery and the lower river, population composition for major contributing components, size and age composition. This component would build on the existing Mission downstream program which operates in even numbered years only, with an enhanced sampling protocol (surface trawling) to capture smolt-sized migrants.

Rationale: With the exception of Cultus and Chilko, very little is known about smolt outmigration timing from Fraser sockeye nurseries. Very little work has been done to characterize timing of sea-entry for Fraser sockeye populations. Coupling lake emigration sampling with downstream passage monitoring in the lower Fraser, this project would develop data on migration and passage timing for selected populations to understand when smolts leave their nurseries, their size and age composition at that time, the rate at which they migrate sea-ward, and their period of ocean entry and the size and age composition here as well.

Linkages: This program would form the infrastructure required for detailed smolt sampling to evaluate hypotheses related to causal or explanatory factors related to smolt output from Fraser sockeye nurseries and in-river migration conditions. The project would support evaluation of biological indicators of population health by providing sampling platforms to obtain representative samples of sockeye at lake out-migration and immediately prior to sea-entry.

Timeline: Ongoing project operating in even numbered years: nursery outmigration monitoring needs to occur between 15MAR and 15JUL. Monitoring in the lower Fraser is required between 01APR and 15AUG.

Cost Estimates – Base Project (even years only):

Item	Source	Est. Cost
Vessel replacement: 8m workboat with trawl capacity (start-up)	Capital	$250K
Equipment: surface trawl, RST traps (x2) (start-up)	Capital	$60K
Nursery outmigration sampling: (3 systems / year)	O&M	$75K
Lower Fraser smolt trawling: operating April – August	O&M	$60K
Sample processing (SID, Ageing)	O&M	$25K
Staffing	S&W	

Enhanced-Base Project (Increments beyond Base level)
Description: Ramping sampling effort up to annual assessments from even years only.

Rationale: Same as Base level.

Linkages: Same as Base level.

Timeline: Same as Base level but with annual sampling.

Cost Estimates – Enhanced Base Project (Annual cost increment to Base):

Item	Source	Est. Cost
Nursery out-migration sampling: (3 systems / year)	O&M	$75K
Lower Fraser smolt trawling: operating April – August	O&M	$60K
Sample processing (SID, Ageing)	O&M	$25K
Staffing – 1 FTE (Technician)	S&W	$65K

Comprehensive Project (increment beyond Enhanced- Base Project)

Description: In addition to the sampling undertaken in the Enhanced-Base project above, this component adds evaluation of in-river Fraser sockeye smolt migratory success to the monitoring design. There is no information available at this time that provides any understanding of the importance of the down-stream migratory corridor used by sockeye smolts as a location of variable survival within, or among Fraser stocks, or across years. Acoustic tag application at time of lake outmigration is required, along with installation and maintenance of an acoustic receiver array between the lake outlet and the Fraser River near Mission to address this information gap. An acoustic tagging strategy which systematically evaluates migratory success for populations with variable emigration and sea-entry timing will help to identify if and where mortality is occurring in-river, and where common or diverging survival trends exist among populations.

Partnerships are critical to this component and may extend the benefit of the tagging well beyond the river environment. Tracking arrays at Fraser River mouth (UBC) and in marine areas (UBC, POST, OTN) are needed for extended information collection success and to provide for additional tracking/survival detail beyond Fraser River. In-river monitoring would need to be managed and funded by DFO in the long term.

Rationale: Project component adds the ability to monitor reach-specific survival for Fraser sockeye to determine, over time, if there are specific or broad temporal-spatial survival patterns in sockeye smolt output from Fraser sockeye nurseries.

Linkages: Same as Enhanced Base project, with additional critical linkages to UBC and potentially POST and OTN.

Timeline: Annual monitoring project with same timelines as Enhanced Base level but with acoustic tagging and monitoring added to project protocol annually.

Cost Estimates – Comprehensive Project (Annual cost increment to Enhanced base):

Item	Source	Est. Cost
Acoustic Receivers (start-up)	Capital	$35K
Support costs (vehicle, IT) (start-up)	Capital	$40K
Acoustic tags (200/system – 3 systems annually)	O&M	$90K
Operations (receiver deployment, retrieval and tagging)	O&M	$75K
Staffing – 1 FTE (Biologist)	S&W	$75K

[Bravender & Whitehouse]

Freshwater monitoring – juvenile sockeye: immediate fry migrants from nursery lake exit to sea entry (Harrison Sockeye)

Principle Investigators: Keri Benner, Bev Bravender, Timber Whitehouse.

Ocean-type sockeye, those migrating to the ocean in the same year as their emergence, from the Harrison River have displayed a recruitment pattern in recent years that is directly opposite to the majority of Fraser River sockeye stocks which are lake-type (i.e. spend one or more years in freshwater prior to migrating to sea as smolts). While the predominant lake-type Fraser sockeye populations have exhibited declining recruitment patterns since the early 1990's, the Harrison population has exhibited consistent positive growth during the same period. Harrison sockeye have gone from a relatively minor contributor to total Fraser sockeye abundance prior to 2000, to representing a major population on a yearly basis since then.

In order to understand details of this unique life-history type in the Fraser and to identify factors that may account for its high productivity in the face of across-the-board declines elsewhere in Fraser sockeye populations, it is important to understand how habitat utilization and species interactions differ between ocean-type and lake-rearing life-history types. This will require development of knowledge related to the importance of tidal sloughs in the lower Fraser River and the Fraser River estuary related to the rearing and staging of juvenile sockeye prior to seaward movement. This proposal deals with monitoring juvenile salmon presence and use of lower Fraser River tidal habitats between April and August annually.

Base Project (Low cost)
Description: Work would entail conducting regular assessment of fish community composition in tidal sloughs and estuarine habitat within the lower Fraser River, coupled with measurement of physical habitat parameters. Monitoring of sockeye utilization within the lower river will identify timing, size and spatial distribution of sockeye within the lower river nursery areas, and provide indication of on-set of seaward migration timing. This work will extend surveys conducted in the 1980s and provide data for comparison to past patterns. This work compliments the assessment of in-river smolt assessment which is covered in another proposal.

Rationale: Very little work has been done to characterize timing of sea-entry for Fraser sockeye populations. Coupling natal river emigration sampling with downstream passage monitoring in the lower Fraser, this project would develop data on migration and passage timing for ocean-type populations: defining when fry leave their spawning grounds, their in-river migration rates, their size and age composition at that time, the distribution and residency in the lower river, and the timing of their ocean entry. If delayed rearing in the lower river accounts for later ocean entry timing this may affect subsequent survival rates on ocean entry, and may help to explain the different production pattern exhibited by this life-history type.

Linkages: This program would form the infrastructure required for detailed sockeye sampling to evaluate hypotheses related to causal or explanatory factors related to variability in smolt output from Fraser sockeye nurseries. The project would support evaluation of biological indicators of population health by providing a sampling platform to obtain representative samples of sockeye within the lower Fraser prior to sea-entry.

Timeline: Ongoing project operating annually between 01APRand 30SEP.

Cost Estimates – Base Project (even years only):

Item	Source	Est. Cost
Vessel support: 6m workboat with seine capacity (start-up)	Capital	$50K
Equipment: beach seine nets, sampling gear; CTD	Capital	$25K
Field sampling:	O&M	$70K
Sample processing	O&M	$10K

Enhanced-Base Project (Increments beyond Base level)
Description: In addition to fish community sampling, this component adds invertebrate sampling (epibenthos and surface plankton) to describe food resources available to salmon and incorporates diet analyses to evaluate resources used by juvenile salmon across lower Fraser habitats sampled.

Rationale: Same as Base level, but with addition of trophic resource availability and utilization.

Linkages: Same as Base level.

Timeline: Same as Base level.

Cost Estimates – Enhanced Base Project (Annual cost increment to Base):

Item	Source	Est. Cost
Sampling equipment (start-up cost)	O&M	$5K
Invertebrate sampling	O&M	$35K
Invertebrate sample processing	O&M	$30K
Staffing – 1 FTE (Technician)	S&W	$65K

Comprehensive Project (increment beyond Enhanced- Base Project)
Description: Same as above with the addition of more sites, including assessment of lower Pitt River ocean-type population.

Rationale: Understanding variability within ocean-type sockeye populations using lower Fraser River.

Linkages: As above.

Timeline: As above.

Cost Estimates – Comprehensive Project (Annual cost increment to Enhanced base):

Item	Source	Est. Cost
Field sampling – fish communities	O&M	$30K
Field Sampling – invertebrate communities	O&M	$30K
Staff – 1 FTE Biologist	S&W	$75K

4. Strait of Georgia (trawl/seine/oceanography/nekton & pelagic surveys) [Dick Beamish, Marc Trudel, Ken Cooke/George Cronkite, Dave Mackas/Rick Thomson/Bill Crawford/Angelica Pena, and Jim Irvine]

This proposal identifies the physical and biological research needed to identify the factors affecting the early marine survival of juvenile sockeye salmon in the Strait of Georgia. As part of this research, it is necessary to continue and expand the surveys for juvenile Fraser River sockeye salmon in Queen Charlotte Strait, Queen Charlotte Sound and Hecate Strait.

Trawl surveys

The trawls used to sample juvenile sockeye salmon are an effective method of studying the population. Purse seine catches are useful but limit the ability to survey all areas in all types of weather. In the Strait of Georgia, a 10-day survey is needed in early June and early July. If the study of Harrison River sockeye salmon is important, an additional survey is required in mid-September. The surveys in Queen Charlotte Sound and Hecate Strait are important and need to be expanded. Initially, we propose that there be a 7-day survey in Hecate Strait in the third week of June and a 7-day survey in Queen Charlotte Sound in the last week of June.

All trawl surveys would sample juvenile sockeye salmon for length and DNA. Other samples would be collected as determined by the investigator and by the funds available. Other measurements, such as the use of hydro-acoustics, could be considered.

Plankton sampling, including toxic algae

It is essential that there is a routine monitoring of plankton production in the Strait of Georgia. The resulting time series will become as important as the existing temperature time series. Dave Mackas provided the Pacific Salmon Foundation with an appropriate monitoring study at a cost of $250,000 a year, plus ship time (appended at back of full document). The plankton program needs to be linked to the nekton that are the main diet items of juvenile sockeye salmon. Diet items will be determined from the trawl surveys, but the diets of these prey items (such as crab megalops) need to be determined by the plankton program.

<u>Nutrient monitoring in the Strait of Georgia</u>

Low cost

- Seasonal nutrient, chlorophyll and pigment sampling during SoG "regular" oceanographic surveys (5 days cruise, 4 times per year)
- Instrument one weather buoy with a CTD/fluorometer and PAR (Photosynthetically Available Radiation) sensor for continuous measurements at one depth in one location.

Moderate cost:

- Seasonal nutrient, chlorophyll and pigment sampling during SoG "regular" oceanographic surveys (5 days cruise, 4 time per year)
- Equip the two weather buoys (Halibut Bank, 49°20. 4' N 123°43.6' W, and Sentry Shoal, 49°54.4' N 124°59.1' W) with proper equi pment to measure continuously both at 1m and 10 m depth the following: temperature, salinity, nitrate concentration and fluorescence. In addition, a surface PAR (Photosynthetically Available Radiation) sensor would be installed on the buoy. The instruments would be regularly serviced in order to retrieve the data and assure proper functioning (similar to proposed monitoring sent to Pacific Salmon Foundation)

Full cost:

- Seasonal nutrient, chlorophyll and pigment sampling during SoG "regular" oceanographic surveys (5 days cruise, 4 time per year)
- Equip the two weather buoys (Halibut Bank, 49°20. 4' N 123°43.6' W, and Sentry Shoal, 49°54.4' N 124°59.1' W) with proper equi pment to measure continuously both at 1m and 10 m depth the following: temperature, salinity, nitrate concentration and fluorescence. In addition, a surface PAR (Photosynthetically Available Radiation) sensor would be installed on the buoy. The instruments would be regularly serviced in order to retrieve the data and assure proper functioning (similar to proposed monitoring sent to Pacific Salmon Foundation)
- Deploy an ocean glider with optical fluorometer/scattering sensors during spring/summer season to obtain frequently-repeated measurements extensive in space (horizontal and vertical) of a variety of physical and biological parameters.

Physical oceanography of the Strait of Georgia

There are trends in the production of Fraser River sockeye salmon that indicate that the impact of climate and ocean conditions is not random. There also are responses that are synchronous with changes in the dynamics of other species such as occurred in 2005 and 2007.

Re-establish oceanic monitoring at deep (250 m) mid-channel site SG02 or SG03 in the south-central Strait of Georgia to characterize changes in temperature, salinity, dissolved oxygen, pH, mixed layer depth, currents (including deep-water intrusions) and other parameters from the seafloor to near-surface.

Deploy and maintain a long-term mooring in the Northern Strait of Georgia to monitor changes in water temperature, salinity, dissolved oxygen, pH and flow velocity associated with the exchange of water between Johnstone Strait/Discovery Passage and the strait. The importance of the exchange of water between the northern strait and the northern channels is unknown. All previous work has focused on the southern channels.

Use the diagnostic model developed for the northeast Pacific by Thomson and Fine (2009) to generate time series of mixed layer depth for the Strait of Georgia. This model uses a simplified heat balance equation and remotely sensed (satellite) surface data to determine the depth of the mixed layer. Because the buoyancy flux to the upper ocean is primarily through the ocean surface, daily time series of mixed layer depth from early spring to late fall can be closely approximated using only records of the sea surface temperature and surface heat flux. A test of the diagnostic model using the 55-year series of oceanographic and meteorological data from Ocean Station “P” (50º N, 145º W) and recent data from Argo drifters for the northeast Pacific shows that the model provides more accurate estimates of mixed layer depth and is simpler to apply than established models.

Use existing datasets from the Nanoose Bay test range, NOAA satellites (temperature, chlorophyll and wind velocity), coastal lighthouses, and past research programs, and ongoing VENUS program to examine linkages between the marine survival of Fraser River salmon and the marine environment. This falls into the "analysis of existing data" category requiring relatively long time series of ocean data.

Budget

Trawl surveys

• *W.E. Ricker* @ 15K / day for 34 days	510 K
Or commercial charter @ 10K / day for 34 days	340 K
• DNA analysis – 1,200 samples	24 K
• Stomach analysis	20 K
• Technical support, sampling, analysis, reporting	42 K
• Harrison sockeye survey in September is extra	
Annual Total	426-596 K

Plankton surveys

• Not including ship time	
• Dave Mackas provided details of his budget for Pacific Salmon Foundation proposal (appended at back)	250 K
• Nekton diets	20 K
• Toxic algae [Irvine]	
o Low cost	17 K
o Moderate cost	29 K
o Full cost	188 K
• Seasonal nutrient studies [Peña]	
o Low cost	50 K
o Moderate cost	200 K
o Full cost	400 K
Annual Total	337-858 K

Physical Oceanography

(Item 1 = bare minimum; items 1+2 = moderate costs; items 1+2+3 = full cost)

- Item 1: Purchase 1 SeaBird CTD and nutrient, transmissivity, pH and chlorophyll sensors [Crawford] 85 K
- Item 2: Modify *Ricker* to allow operation of 6-bottle rosette system [Crawford] 400 K
- Item 2: Purchase of one SeaBird 6-bottle rosette systems plus bottles, CTD & sensors (nutrient, transmissivity, pH, chlorophyll) [Crawford] 125 K
- Item 2: Teledyne 75 kHz ADCP X 1 mooring south-central Strait of Georgia; currents throughout the water column [Thomson] 60 K
- Item 2: Teldyne 150 kHz ADCP X 1 mooring northern Strait of Georgia; currents throughout the water column [Thomson] 60 K
- Item 2: Seabird Microcat X 8 high resolution temperature and salinity at fixed depths [Thomson] 56 K
- Item 3: Purchase extra SeaBird 6-bottle rosette system with CTD & sensors [Crawford] 125 K
- Item 3: DO / pH sensors X 4 high resolution dissolved oxygen and pH at fixed depths [Thomson] 10 K

One-time cost 85-921 K

- Item 1: contractor (annual) X 2 - process / analyze time series (including VENUS data); assist in field program; model mixed layer depth [Thomson] 60 K
- Item 1: Personnel, expense, supplies, analysis [Crawford] 110 K
- Item 2: mooring costs (annual) X 2 - mooring expendables and preparation; field contractor support [Thomson] 20 K
- Item 2: Incremental costs for rosette system on Ricker [Crawford] 90 K
- Item 3: Incremental costs for additional rosette system on Ricker [Crawford] 200 K

Annual cost 170-480 K

[Cooke]

Any directed acoustic work to support this survey effort would require minimum 2 FTEs (acoustic experts) for the duration of the effort. Our experience with ship-mounted transducers is that salmon make for poor acoustic targets because they are largely surface oriented. The top 20-30m of the water column is not adequately survey with our current ship-mounted transducers on the Ricker. This suggests that any acoustic effort would therefore require development of new tools or use of other smaller vessels which are not currently available. My best guess:

- "low cost" approach is use of a single frequency, upward looking towed system for use with the Ricker (capital investment of ~100-200K)
- "moderate cost" is multi-frequency, upward and downward looking towed system for use with the Ricker (capital investment of ~300-500K)
- "full cost" is use of multi-frequency towed system (capital investment of ~300-500K) and installation of high quality, data-recording scanning sonars which would be retrofitted to the Ricker (capital investment of ~800-1000K; this system is proposed for the OFSV Ricker replacement vessel but may not be funded).

Note: These options have not previously been attempted in our region but both have proven success elsewhere in the world to monitor migration of near-surface fishes and to estimate abundance. ***This work would require minimum 3yr of development of methodologies and ground-truthing the technology, 2 dedicated acoustic FTEs (total salary ~150K/yr) and annual O&M of ~25-50K/year regardless of the level chosen. The capital investment is a prerequisite.***

[Gower]

Phytoplankton concentrations are though to have significance for local fish stocks, including the Fraser River Sockeye. Understanding the phytoplankton is fundamental to producing successful models and estimates of the food web in the Strait of Georgia system. Previous studies of the phytoplankton concentrations using shipboard measurements do not have the appropriate temporal resolution; sustained observations over a range of spatial scales are required to attain a detailed understanding of the phytoplankton dynamics in the Strait of Georgia.

Past research using satellite imagery, moored fluorometers, research vessels, BC Ferry flow-through systems, and ocean gliders have produced high quality, fine resolution data regarding the spring phytoplankton bloom in the Strait of Georgia system. These monitoring tools have been developed to observe phytoplankton on a range of temporal and spatial scales, each of which enhances the observations of the other. The systems require equipment, monitoring, and personnel to operate efficiently.

This proposal complements a proposal by Angelica Peña for phytoplankton observations from DFO research vessels and gliders

Minimum Cost

Description: Investigation of the Strait of Georgia using satellite sensors to investigate spatial variations, as well as a deployed fluorometer to investigate temporal variations.
Timeline: 1-year

Cost: 11 K

FLH monitoring	- $10K
Fluorometer Deployment	- $1K

Moderate Cost

Description: Investigation of the spring bloom using a range of monitoring tools able to provide data on a range of temporal and spatial scales.
Timeline: 2 years

Cost: 47 K

FLH monitoring	- $20K
Ferry flow through system	- $5K
2 Fluorometers at $10K each	- $20K
Fluorometer Deployment	- $2K

All Inclusive

Description: A comprehensive in situ investigation of phytoplankton using a range of monitoring tools able to provide data on a range of temporal and spatial scales.
Timeline: Ongoing monitoring

Cost: 72 K

Satellite monitoring of chlorophyll fluorescence	- $20K
Ferry flow through system	- $10K
4 Fluorometers at $10K each	- $40K
Fluorometer Deployment	- $2K

5. Johnstone Strait – abundance index (hydroacoustics/seining) [Ken Cooke & George Cronkite]

[Cooke]

It may be possible to monitor migration of smolts-out and adults-in to the Strait of Georgia along key migratory corridors using fixed aspect side looking or mobile platforms. Both cases would need calibrated sounders (such as SIMRAD EK60) or imaging sonar (such as DIDSON) and major dedicated research and development programs conducted over a number of years to prove viability. The areas to be considered for such work are not currently known but might be along the Sechelt Coast and in various locations in Johnstone Strait. *All acoustic effort must be considered as research and development as there are no previous studies of this kind in the region with proven success. Development of an acoustic monitoring and enumeration program should be conducted in phases.*

Phase I "low cost"

~350K annual operating budget; ~100K capital investment; 1.2M for contract support

Initially conduct seining/acoustic tracking study of adult sockeye salmon for minimum 2yr to identify the migratory corridors of adult sockeye salmon and seining study to verify juvenile salmon migration routes first reported in 1980s (Groot, Quinn, Cooke et al). Requirement for contract fishing support for 3-6months (juvenile and adult seining operations, adult tagging, release and recapture; contract costs ~8K/day for 150days = 1.2M, annual O&M ~100K), minimum 3-4 FTEs (acoustic experts and support field staff; total annual salary ~300K), and capital investment (tagging gear, DFO retrofit of existing vessel for tracking platform ~100K)

Phase II "moderate cost"

~450K annual operating budget; 300-500K capital investment; 1.2M for contract support

Follow-up on successes of Phase I (requires that Phase I is completed); R&D on use of fixed aspect acoustic observation sites or use of mobile acoustic observation platforms using side-looking acoustics (DIDSON or multi-frequency acoustics) to monitor migration timing and behaviour and to estimate abundance. The acoustic data would require physical sampling with fishing gear to identify targets and verify the acoustic signals (contract fishing support for 3-6months includes juvenile and adult fishing operations ~8K/day for 150days =1.2M$). This work would require minimum 3yr of development of methodologies and ground-truthing the technology, 3 dedicated acoustic FTEs (total salary ~300K/yr) and annual O&M of ~100K/year and capital investment of ~300-500K (1 multi-frequency sounder or multiple DIDSON installations).

Phase III "full cost"

~700K annual operating budget; 500-800K capital investment; 1.2M for contract support

Phase III assumes success with Phase I and II and expands on Phase II program to develop more fixed-aspect acoustic observation sites or expanded coverage of mobile survey operations. The acoustic data would require physical sampling with fishing gear to identify targets and verify the acoustic signals (contract fishing support for 3-6months includes juvenile and adult fishing operations ~8K/day for 150days =1.2M$). This work would be conducted at multiple locations during the duration of the smolt and adult migration periods. Minimum requirement for 6 dedicated acoustic and field support staff FTEs (total salary ~600K/yr) and annual O&M of ~100K/year and capital investment of ~500-800K (minimum of 2 multi-frequency sounders or multiple DIDSON units).

[Cronkite]

I have been asked to comment on the study titled "A study to determine the feasibility of hydroacoustic monitoring of migrating sockeye and pink salmon in the marine area" completed in 2007. I think that the study was worthwhile and provided interesting results. The results did show some correlation with the salmon counts at Mission BC, and possibly spatial separation between sockeye and pink salmon migrations in Johnstone Strait. However, I may be more pessimistic than some as to the viability of this method for ongoing determination of salmon abundance returning to the Fraser River. I think the main problem is the identification of the acoustic targets as to species and even as to whether targets are fish targets or noise targets. There is a large amount of acoustic noise in the area due to tidal flows, weather events, marine traffic etc. Also, there are many species that inhabit Johnstone Strait including salmon (multiple stocks and species) as well as potentially large populations of pelagic species. These factors lead to difficulty in interpreting the data. I don't see how we can effectively determine the composition (target type and species) of the recorded targets. This is the single most confounding problem with our in-river acoustic monitoring sites even though the estimates are derived from a relatively confined area with limited species composition, often with the species of interest being predominant. There is also the issue that for acoustic monitoring in Johnstone Strait to be effective then the northern/southern diversion rate needs to be known accurately, as the Johnstone Strait acoustic site will only detect salmon that use the northern route. The proportion of fish using the northern route can vary considerably among years.

Another issue I would like to mention is with marine mammals. There is only anecdotal information and whether perceived or otherwise, the issue of the affects of these acoustic systems on marine mammals in the area, particularly the Orca population, is an issue that would need to be addressed if these acoustic operations were ongoing.

6. Offshore/high seas (trawl/oceanography/samples from US/tagging) [Marc Trudel, Dave Mackas, Rick Thomson, Bill Crawford, Angelica Pena]

Prey Quality *(Potential PIs: D. Mackas, M. Trudel, S. Tucker, R. El-Sabaawi, I. Forster, A. Mazumder, J. Dower)*

In the Strait of Georgia, zooplankton biomass, composition, and quality has changed substantially during the last two decades (D. Mackas, upublished data). In particular, the abundance of *Neocalanus plumchrus*, has declined precipitously in the Strait of Georgia between 2001 and 2006 (El-Sabaawi et al. 2009). This decline appears to be linked to changes in the phytoplankton species community and to the fatty acids produced by these algae (El-Sabaawi et al. 2009). Interestingly, the marine survival of wild and hatchery Strait of Georgia coho salmon is correlated to the fatty acid composition of *N. plumchrus* (M. Trudel, unpublished data), suggesting a potential link between salmon survival and prey quality at the base of the food web (Mackas et al. 2007).

We propose to measure fatty acids in marine zooplankton and juvenile sockeye salmon in areas utilized by Fraser River sockeye during their early marine life (i.e. Strait of Georgia, Queen Charlotte Strait, Queen Charlotte Sound, and Hecate Strait). Since we cannot derive a relationship between growth, marine survival, and prey quality with only one year of observation, several years of observations will be needed to understand the mechanisms regulating Fraser River sockeye. Alternatively, we can take advantage of large differences observed among ecosystems, such as the Strait of Georgia and west coast of Vancouver Island, as a series of natural experiments to contrast the performance of juvenile sockeye salmon in marine ecosystems that differ in prey quality. Ideally, this project should target the prey consumed by juvenile sockeye salmon (i.e. Amphipods, Euphausiids, Crab Megalope, Copepods). However, it may be possible to focus this project on *N. plumchrus*, as there is already a six-year time series of fatty acids profiles for this species in the Strait of Georgia.

<u>Low cost:</u> Fatty acids in *N. plumchrus* and juvenile sockeye salmon in the Strait of Georgia
150 samples @ $50/sample: $7,500 per year

<u>Medium cost-A:</u> Fatty acids in *N. plumchrus*, Amphipods, Euphausids, Crab Megalope, and juvenile sockeye salmon in the Strait of Georgia
300 samples @ $50/sample: $15,000 per year

<u>Medium cost-B:</u> Fatty acids in *N. plumchrus* and juvenile sockeye salmon in the Strait of Georgia, Queen Charlotte Sound, Queen Charlotte Strait, Hecate Strait and West Coast of Vancouver Island
500 samples @ $50/sample: $25,000 per year

High cost: Fatty acids in *N. plumchrus*, Amphipods, Euphausids, Crab Megalop, and juvenile sockeye salmon in the Strait of Georgia, Queen Charlotte Sound, Queen Charlotte Strait, Hecate Strait and West Coast of Vancouver Island
2,500 samples @ $50/sample: $125,000 per year

Notes: These costs do not include the ship time and technical support required to collect the samples. It is assumed that, at the minimum, current sampling effort will be maintained.

Early Marine Growth *(Potential PIs: R. Beamish, R. Sweeting, M. Trudel, A. Mazumder, J. Dower, L.Godbout)*
The marine survival of Pacific salmon is highly variable and currently difficult to predict, which presents challenging difficulties to DFO for the sustainable management of ocean and terminal salmon fisheries. Although a diversity of hypotheses and mechanisms has been proposed to explain this variability, they generally predict that marine survival of salmon depend primarily on growth during their first year at sea.
The estimation of juvenile salmon growth rate is, in principle, straightforward, as growth is simply defined as the change in size over time. However, smolt size and ocean entry time are generally difficult to determine for juvenile salmon, as stocks that originate from different systems mix in the ocean. This complicates the estimation of growth when only the size at capture is available. Calcified-structure, such as scales and otoliths, provide an alternative approach for estimating juvenile salmon growth (Zhang and Beamish 2000). In addition, calcified-structures can be used to reconstruct the growth history of juvenile salmon during their entire marine life. This approach could be used to estimate recent short-term growth (i.e. last 1-2 weeks), and evaluate how salmon respond to local conditions, which represent the scale at which fish and oceanographic are usually collected
We propose to reconstruct the early marine growth of juvenile Fraser River sockeye using archived otoliths obtained from research surveys conducted by DFO since 1998, and to examine the relationship between their marine survival and early marine growth, as well as to ocean conditions measured by DFO during these surveys. Beamish and Trudel have preserved otoliths from juvenile sockeye in the Strait of Georgia, Queen Charlotte Sound, Hecate Strait, and the west coast of Vancouver Island since the late 90s. DNA analyses have been performed on all the juvenile sockeye salmon collected in the High Seas Salmon surveys between 1998 and 2009, making it possible to determine the early marine growth of Fraser River sockeye salmon (most juvenile sockeye caught in the Strait of Georgia during summer are likely from the Fraser River). We can also take advantage of large differences observed among ecosystems, such as the Strait of Georgia and west coast of Vancouver Island, as a series of natural experiments to contrast the performance of juvenile sockeye salmon in marine ecosystems that differ in ocean productivity, and thereby, increasing the range of early marine growth.

Low cost: Reconstruction of the growth history of juvenile Fraser River sockeye salmon collected in the Strait of Georgia, Queen Charlotte Sound, and Hecate Strait.
Technician: 0.5 FTE or $25,000

High cost: Reconstruction of the growth history of juvenile Fraser River and Barkley Sound sockeye salmon collected in the Strait of Georgia, Queen Charlotte Sound, Hecate Strait, and west coast of Vancouver Island.
Technician: 1 FTE or $50,000

Notes: All the samples required for this project have already been collected using standardized protocols that are in accordance with DFO's regulations. If significant relationships are derived between the marine survival and early marine growth with these archived samples, we propose to continue collecting and processing juvenile sockeye salmon otoliths in future years as a tool to forecast the annual returns of sockeye salmon to the Fraser River and other systems.

Migration *(Potential PIs: R. Beamish, C. Neville, T. Beacham, D. Welch, S. Hinch, M. Trudel)*
In order to understand the effects of ocean conditions on salmon survival, we must know the areas where salmon live in and migrate through, how much time they spend in various areas, and the physical and biological conditions they encounter at these locations. Research conducted to date suggests that juvenile Fraser River sockeye migrate out of the Strait of Georgia in the spring and summer primarily through Johnstone Strait, except juvenile Harrison River sockeye which appear to remain longer in the Strait of Georgia and leave via Juan de Fuca Strait in late fall/early winter (Tucker et al. 2009; Welch et al. 2009). Hence, the unique life history of Harrison sockeye, including their migratory behaviour, might be expected to result in differences in their productivity relative to many other Fraser River sockeye stocks. However, direct evidence of the migration route actually taken by Harrison River sockeye is lacking, as their migration behaviour has been inferred from DNA analyses performed on juvenile sockeye caught over a limited time of the year (June-July, October-November, February-March).
We propose to implant Fraser River sockeye salmon with acoustic tags and track their migration in and out of the Strait of Georgia. Because Harrison River sockeye smolts are too small to be tagged and appear to remain in the Strait of Georgia until September (R. Beamish, unpublished data), we propose to tag juvenile sockeye salmon collected in the Strait of Georgia with a purse seine in September, when Harrison River sockeye salmon are sufficiently large to be tagged with acoustic tags.

<u>Low cost:</u> Collection and tagging of Harrison River sockeye salmon.
Charter vessel (purse seine): $15,000 (6 days @ $2,500/day)
Tags: $40,000 (100 tags @ $400/tag)

<u>Medium cost:</u> Collection and tagging of Chilko Lake and Harrison River sockeye salmon
Charter vessel (purse seine): $15,000 (6 days @ $2,500/day)
Smolt trapping: $2,500 (travel cost and accommodations for 2 technicians)
Tags: $80,000 (200 tags @ $400/tag)

<u>High cost:</u> Collection and tagging of Chilko Lake, Cultus Lake and Harrison River sockeye salmon
Charter vessel (purse seine): $15,000 (6 days @ $2,500/day)
Smolt trapping: $5,000 (travel cost and accommodations for 2 technicians)
Tags: $120,000 (300 tags @ $400/tag)

Distribution and Abundance of Canadian Sockeye Salmon in the North Pacific Ocean
(Potential PIs: T. Beacham, R. Beamish, M. Trudel, S. Tucker)
Current management strategies of Fraser River sockeye by DFO include both a forecast based on stock-recruitment models and an in-season adjustment based on actual returns assessed from test fisheries conducted in Johnston Strait and Juan de Fuca Strait. The stock-recruitment models currently used by DFO often fail to predict the actual returns of Fraser River sockeye salmon, whereas the test fishery occurs too late in the year to let the fishing industry to adequately plan their harvest strategies. Hence, a more accurate pre-season forecast is required.
Fraser River sockeye salmon undertake a northwest migration along the continental shelf that brings them eventually in the North Pacific Ocean before returning to the Fraser River either through Johnston Strait or Juan de Fuca Strait (Tucker et al. 2009). As brood year strength is expected to be determined early during their marine life (Beamish and Mahnken 2001), catch-per-unit-effort (CPUE) data of Fraser River sockeye salmon in the North Pacific Ocean may be used as an index of their abundance, and therefore, may provide an accurate pre-season forecast to DFO and the fishing industry.
We propose to develop an index of Fraser River sockeye salmon abundance in the North Pacific Ocean using stock-specific CPUE data determined in standardized gillnet surveys conducted by Japan along north-south transects at 145°W from 1972 to 2001 and at 165°W,

and 180° from 1972 to present. Biological characteristics and scales samples have been collected for a maximum of 30 sockeye salmon per set. The origin of these fish will be determined on archived scales using DNA analyses (Beacham et al. 2005). Estimates of Fraser River sockeye CPUE will be correlated to actual return data to provide a pre-season forecast for Fraser River sockeye. Sampling at 145°W may be necessary in the future if strong correlations are observed between Fraser River sockeye returns and CPUE.

Low cost: As the abundance of Fraser River sockeye salmon in the North Pacific Ocean is expected from east to west, we suggest prioritizing DNA analysis on sockeye collected at 145°W, with 5 years of low returns and 5 years of high return.
DNA analyses: $30,000 (150 samples/year x 10 years @ $20/sample)
Travel cost to recover archived scales in Japan: $10,000

Medium cost: As the abundance of Fraser River sockeye salmon in the North Pacific Ocean is expected from east to west, we suggest prioritizing DNA analysis on sockeye collected at 145°W for all the years.
DNA analyses: $90,000 (150 samples/year x 30 years @ $20/sample)
Travel cost to recover archived scales in Japan: $15,000

High cost: DNA analyses on all the sockeye salmon collected by Japan at 145°W, 165°W, and 180° between 1972 and 2001.
DNA analyses: $270,000 (450 samples/year x 30 years @ $20/sample)
Travel cost to recover archived scales in Japan: $20,000

Notes: The number of fish available for DNA analyses may be lower. Thus the estimated cost for these analyses likely represents an upper limit. A 20-30 day research survey in the Gulf of Alaska during July may be necessary in future years to provide accurate pre-season forecast if this project is successful at developing reliable indices of Fraser River sockeye abundance. The estimated cost for this survey is $300K-$450K (assuming a daily rate of $15K). This approach can be easily extended to other stocks of interest such as the Nass/Skeena and Barkley Sound sockeye, as DNA analyses will identify these stocks as well.

[Thomson]

The limited current/water property moorings DFO is maintaining at west coast Vancouver Island sites A1 on the continental slope and E1 on the inner continental shelf are insufficient to monitor changes in water temperatures, salinity, dissolved oxygen, flow velocity, mixed layer depth, and other needed oceanic parameters in the offshore region. We are proposing a multi-pronged approach consisting of enhanced oceanic monitoring for the west coast of Vancouver Island combined with new funding to support the analysis, interpretation, and modeling of time series data to be better understand and predict the migration timing and survival of Fraser River sockeye.

1. Maintain oceanic monitoring at the long-term mooring sites A1 (continental slope, SW Vancouver Island) and E01 (inner continental shelf, Estevan Point) to characterize the wind-forced, seasonally reversing Shelf-break current, California Undercurrent, and persistently poleward Vancouver Island Coastal Current off southwest Vancouver Island. Upgrade the mooring to incorporate bottom-mounted acoustic Doppler current meters and a string of high resolution Seabird Microcat sensors to define temperature, salinity, dissolved oxygen, and pH through the water column. Understanding the intensity and temporal variations of these three-major currents is critical to our understanding of how ocean conditions affect the marine ecosystem and fisheries off the west coast.

2. Re-establish current and water property monitoring sites BP1/BP2 off Brooks Peninsula and at E03 on the continental slope seaward of Estevan Point. Moorings A1 and E01 discussed in (1) provide fundamental information on temporal conditions off southwest

Vancouver Island but no information on the along-island extend and cross-shore spatial structure of the dominant currents and water property structure off Vancouver Island. Support to re-occupy previous monitoring sites BP1 and BP2 immediately seaward of Brooks Peninsula and site E03 on the continental slope off Estevan Point will provide much needed information on changing water properties (T, S, DO, pH) and the spatial extent of the poleward flowing California Undercurrent and Vancouver Island Coastal Current, and seasonally varying Shelf-break Current along the entire length of Vancouver Island.

3. Use the diagnostic model developed for the northeast Pacific by Thomson and Fine (2009) to generate time series of mixed layer depth for the west coast of Vancouver Island and the Queen Charlotte Islands.

4. Use existing datasets from DFO, NOAA, NASA, coastal lighthouses, past research programs, and NEPTUNE Canada to examine linkages between the marine survival of Fraser River salmon and the marine environment. This falls into the "analysis of existing data" category requiring relatively long time series of ocean data.

West Coast of Vancouver Island costs
(Item 1 = bare minimum; items 1+2 = moderate costs; items 1+2+3 = full cost)

Item	Type	No.	Unit cost	Total cost	Comment
1	Contractor (annual)	2	30,000	60,000	Process/analyze data (including NEPTUNE data); assist in field programs; model mixed layer depth
2	Mooring costs (annual)	5	10,000	50,000	Mooring expendables and prep; field support
	Annual cost			***110,000***	
2	Teledyne 75 kHz ADCP	2	60,000	120,000	Moorings A1 and E03, 400 m depth, southern VI
3	Teledyne 300 kHz ADCP	2	40,000	80,000	Moorings E01/BP1 at 100 m depth; VI shelf; currents
2	Seabird Microcat	10	7,000	70,000	High resolution temperature and salinity at fixed depths
3	DO/pH sensors	4	2,500	10,000	High resolution dissolved oxygen+pH at fixed depths
	One-time cost			***280,000***	

[Crawford]

MODERATE AND LOW COST PROPOSALS

Without expensive changes to the *CCGS Tully*, none of this work can be done, so even the Low Cost proposal will be close in costs to the Full Cost Proposal.

FULL COST PROPOSAL

Modify *CCGS Tully* to allow operation of fishing net to trawl for salmon at Ocean Station Papa (50N, 145W) and surrounding waters in winter. This will possibly fill a gap in our knowledge of sockeye salmon after they depart Canadian Coastal waters and before they return to the Canadian coast one to three years later. The existing June, August and/or February *CCGS Tully* research cruises could be extended four days each to allow this research fishery. Additional ocean measurements would be made during fishing operations. Combining fishing and oceanography plus zooplankton and phytoplankton measurements will allow complete food chain measurements in one location and time. Extra staff will be located at IOS due to shortage of space at PBS and to collaborate with oceanographers at IOS

Initial, one-time costs

Modify *CCGS Tully* to allow research fisheries	est.	$2000K
Modify *CCGS Tully* to provide cabin space for 4 extra scientists	est	$1000K
Purchase of fishing nets	est	$ 300K
Total one-time cost		**$3300K**

Annual costs	
Extra Coast Guard seaman on *Tully* for 8 weeks at sea	$ 20K
Research scientist at IOS	$ 80K
Ocean technician at IOS	$ 70K
Office space, IT and travel costs for two staff at IOS	$ 40K
Sea going costs and overtime for research scientist and technician	$ 40K
Supplies, analysis, calibrations, repairs to nets	$ 50K
Total annual costs	**$300K**

7. Returning to zone – test fisheries sampling (health/genomics), environmental sampling in river is key), tagging [Dave Patterson & Merran Hague with input from Timber Whitehouse and Kristi Miller]

[Patterson]

Over the past 16 years en route loss estimates, ranging annually from 137K to 4.8 million have decreased spawner abundance in all Fraser stocks. This caused a mean annual spawner loss of 28% for all Fraser stocks with annual stock-specific losses exceeding 90% during the same decline period. Although the en-route loss associated with adverse migration conditions has been documented through field observations, lab and field experiments, there is still considerable uncertainty in applying this knowledge to overall productivity declines in Fraser sockeye on a stock-specific basis. Therefore, an improved understanding and better quantification of declines associated with return spawning migration are critical to **A)** generate more accurate and defensible estimates of juvenile freshwater and/or marine productivity (i.e. R/EFS or SAR) **B)** partition the sources and locations of mortality during spawning migration on stock basis and **C)** to model the potential intergenerational consequences to declining populations.

A) – Accurate post season recruitment estimates for stock-specific productivity
Concern: Escapement discrepancies, that are synonymous with en route loss, are applied to post-season estimates of total recruits/returns. However, this application is inconsistent and without a rigorous protocol. More disconcerting is the fact that all research groups using R/EFS or SAR are vulnerable to potentially large biases/errors in estimates of recruitment and/or inconsistency in the calculation of recruitment throughout the pre-decline and decline period (pre-1992 different method), especially when testing their hypotheses on a stock-specific basis.
Objective: Partition post-season escapement discrepancies into component sources, improve estimates of stock-specific discrepancies and develop a defensible and transparent process for calculating post-season estimates of recruitment based on realistic estimates of en route mortality.

B) – Sources and locations of mortality during spawning migration
Concern: The mortality of adult Fraser sockeye is an interaction of a fish's biological condition (stock origin, energetic state, reproductive state, disease, and genomic signatures) and environmental exposure (temperature, flow, location, and fishery encounters). However, more work needs to done in order to understand the interaction amongst these factors and their cumulative impact on migration mortality at a stock-specific level.

Objective: Quantify the contribution en route loss to population-specific declines through the improvement estimates of en route mortality associated with different biotic and abiotic factors.

C) – Importance of intergenerational effects to sockeye productivity

Concern: Parental life history experience, such as exposure to extreme migration conditions, can result in changes in phenotypic traits to both parents and offspring, such as fish size, age at maturity, egg number, egg size, egg retention, gender ratios, fertility, and offspring quality. These traits will have population level intergenerational effects that will influence productivity estimates (e.g. R/EFS) and population dynamics (e.g. decline rates). Currently these impacts on recent declines and future population dynamics are not incorporated or well understood.
Objective: Improve understanding of intergenerational effects and evaluate impact of these effects on short and long-range forecasts of productivity and abundance.

Basic Cost Option**:** (all costs are per annum)
A) Recruitment Estimates:

- Collaborate with the PSC, Resource Management, and STAD to develop stock-specific en route loss models using existing data (e.g. acoustic/radio tagging, DBE's, experiments, environmental data, genomics) for improved post-season production estimates ($50K + 0.5 FTE; Research – 2 years)

B) Migration Mortality:

- Match population specific declines to differences in stock-specific biology (e.g. thermal tolerance), trends in environmental exposure and vulnerability to exposure (e.g tagging data, thermal refugia) ($60K + 1FTE; Research – 2 years)
- Increase biological monitoring (e.g. condition, genomics) of returning fish during migration ($40K 1FTE; Monitoring)

C) Intergenerational Effects:

- Evaluate existing historic data of phenotypic traits that have intergenerational effects on population dynamics (eg. R/EFS), such as fish size, age of maturity, egg number, gender bias, egg retention, and fertility ($35K +0.5FTE; Research – 2 years)

Moderate Cost Option*:*
A) Recruitment Estimates:

- Partition escapement discrepancies using existing information to estimate escapement bias, unreported catch and incidental mortality. Develop a Bayesian framework for post-season estimate of true in-river mortality including quantifying uncertainty in other sources of discrepancy ($70K + 1FTE (post-doc); Research – 3 years)

B) Migration Mortality:

- Strategic biotelemetry experiments focussed on key stocks (Chilko, Quesnel, E&L Shuswap, E&L Stuart) and apply genomic tools at different river stages and populations to test vulnerability of these stocks at specific locations ($250K + 2FTE; Research – 4 years)
- Increase environmental and biological monitoring of key migration bottlenecks (S.o.G, Lower River, Canyons, Spawning Gd.) to remove current uncertainty in estimating environmental exposure and stock specific fish condition by location ($135K + 1FTE; Monitoring)

C) Intergenerational Effects:

- Match inter-annual variability in the phenotypic traits with exposure to adverse environmental conditions. Sensitivity analysis of trait variation with productivity analysis ($50K + 1 FTE (grad student); Research – 2 years)

Full Cost Option
A) Recruitment Estimates:

- Integrate future work on sources and location of mortality and intergenerational effects into past and future estimates of productivity. Evaluate the influence of including in-river mortality in recruitment estimation and impact of uncertainty of these estimates on stock-recruit relationships. Develop a transparent framework for calculating post-season recruitments for each major stock complex or CU ($100K + 1 FTE; Research - 3 years)

B) Migration Mortality:

- Integrated a system wide tagging program matched with environmental monitoring and biological assessments (disease, physiology, genomics) to monitor and predict fate, and assess spatial and temporal vulnerability for major populations migration from marine approach to spawning grounds ($500K + 3FTE's; Monitoring)
- Extend temperature monitoring of migration corridors (e.g. all major lakes) to assess all major sockeye populations and generate forecast predictions for all major tributaries ($80K + FTE; Monitoring)
- Assess future vulnerability due to climate change (i.e. thermal refugia limitations) ($100K + 1FTE; Research – 3 years)

C) Intergenerational Effects:

- Experiments on assessing the impact of parental exposure of offspring fitness traits (e.g. vertical transmission of diseases, temperature). Development of life history models used to conduct a population viability analysis of sockeye stocks under the influence of en route loss, intergenerational effects and climate change. ($120K + 2FTE (post-doc 3 years) ; Research – 3 years)
- Monitor offspring fitness (biomarkers, health, viability) for major stocks ($90K + 1FTE; Monitoring)

<u>Notes:</u>
This proposal is predicated on the assumption that core funding for the Ewatch program that is a combination of research and monitoring work that does seek to partition sources/location of mortality will continue - ~144 K O&M and 2PY's. In addition, it also assumes the costs associated with other supporting programs will continue (e.g. stock assessment). A separate proposal or request to formalise the support for the work could be initiated, but would require more time at present.
Partners: All of the above work would require partnerships both within the division and outside and benefit from collaboration with other project, such as Genomics, Stock Assessment, SoG, High Seas, Lakes, Resource Management, Fish Health, Pacific Salmon Commission, SFU, UBC, other academics.

[Whitehouse]

Freshwater monitoring – Adult sockeye catch accounting and spawning grounds enumeration

Principle Investigators: Keri Benner, Jamie Scroggie, Les Jantz, Timber Whitehouse.

Production relationships used to forecast future abundance of Fraser River sockeye populations are based on the relationship between total adult sockeye returns relative to measures of productive potential, i.e. spawning abundance, effective female spawners, fry or smolts produced from a particular spawning event. Critical to these assessments is the assumption that the total adult sockeye return from any relative starting point is known with acceptable precision and accuracy. Satisfying this requirement with continued downward pressure on the financial resources needed to undertake the necessary assessment work is becoming more and more difficult and is undoubtedly introducing higher levels of process driven variability into Fraser sockeye datasets.

The majority of production relationships used to predict future Fraser River sockeye abundance rely on the relationship between total adult returns and effective female spawning abundance. Total return is comprised of many components, but most fundamentally it includes estimates of catch and spawning escapement. Since 2002, as a result of funding shortfalls, several major sockeye spawning populations have not been directly estimated (as required by agreement under the Pacific Salmon Treaty). These gaps require infilling to provide proxy escapement estimates and this infilling introduces process variability into the data time-series and subsequent recruitment relationships. During periods when Fraser sockeye stocks are exhibiting marked production shifts increased variance related to estimation process serves only to further confound identification and resolution of underlying mechanisms. Similarly, in-river catch monitoring efforts have been subject to large variation in effort and resultant data quality recently as a result of funding pressures. Assessment of precision and accuracy for this element has been limited, but suggests the potential for large inter-annual variation in catch accounting data. Like process-related error in escapement estimation, unquantified and unpredictable variability in catch accounting data will confound recruitment relationships making determination of “true” productivity trends more difficult to separate from process-generated noise.

This proposal addresses gaps in in-river catch and escapement monitoring coverage for Fraser sockeye assessments that occur on an annual basis to ensure that the data sources which are fundamental to production and conservation assessments are available into the future.

Base Project (Low cost)
Description: Work entails: 1) delivery of spawning grounds assessment for Fraser River sockeye populations that ensures consistency with historic time series and commitments under the Pacific Salmon Treay. Most of the pressure is related to cost of expensive-to-implement high precision estimates – mark-recapture experiments or acoustic counts for populations >75,000 spawners annually. Populations for which funding pressures are persistent include Adams, Little, Lower Shuswap, Harrison, Mitchell and Upper Pitt rivers. 2) regularizing funding available to conduct FN catch monitoring on the Fraser River. Catch monitoring coverage has been variable annually depending on availability of funding, leaving gaps or inconsistent coverage in some years. 3) development of variance estimation procedures for catch estimation surveys conducted to assess in-river Fraser Sockeye harvest.

Rationale: these data sources form the fundamental basis on which all remaining production assessments are dependant. Failure to address these gaps will introduce increasingly larger process related error into the data time-series and will confound true production trends.

Linkages: these projects, in conjunction with existing catch and escapement programs, form the basic data series on which all subsequent evaluations of production related assessment are dependant. Evaluating hypotheses related to causal or explanatory factors rely on consistently implemented production accounting processes to generate representative data for trend and explanatory analyses.

Timeline: ongoing project operating annually.

Cost Estimates – Base Project:

Item	Source	Est. Cost
Fraser sockeye spawning escapement funding gaps	O&M	$600K
In-river catch monitoring funding gaps	O&M	$300K
Development of catch variance estimation procedures	O&M	$30K

8. Contaminants (including lake, river, Strait of Georgia, coastal and high seas components) [Peter Ross/Robie Macdonald]

Contaminants have played a direct role in the decline of several salmon populations around the world, and may represent a population-level risk to sockeye in BC. The abundance of chemicals used in Canada together with inadequate records of use and incomplete understanding of environmental toxicology presently limit our ability to eliminate compounds from consideration or identify compounds that have a high potential to play a role in sockeye declines. These circumstances suggest that two strategies are required to narrow our focus on the issue: 1) Collation of information and 2) Research.

1) Information needs ($15,000 to $50,000)

- information gathering on *forestry and agricultural pesticide use* (BC) in lake and river watersheds, including Chilco Lake and Lower Fraser Valley (pesticide types, quantities, application areas);
- information gathering from HC-Pest Management Regulatory Agency (PMRA) on *adjuvants/dispersants* used for the different pesticide formulations applied in BC salmon habitat;
- audit of point source releases of contaminants in sockeye habitat (lake and river), notably in the Lower Fraser Valley (pulp mills, petrochemical, mines and WWTP);
- characterization of non-point source releases of contaminants in sockeye habitat;
- critical update of two priority lists (Johannessen et al 2002; Verrin et al 2004) for contaminants of concern in salmon habitat;

2) Research needs

- Habitat-based characterization of persistent and non-persistent contaminants in sockeye salmon habitat (e.g. sediment cores for history of persistent contaminants; glacial melt-related release of archived contaminants from the past; seasonal changes in water-soluble mixtures of pesticides) ($ 20,000 - $ 75,000 per year for 3-4 years);
- Field-based studies of salmon health using in situ/caged exposures (real world, complex mixtures) in habitat areas of concern and new toxicological approaches (genomics, endocrine measurements) ($40,000 - $ 60,000 per year for 3-4 years);
- Lab-based studies of single chemical vs complex mixture effects on sockeye salmon ($ 25,000 – $ 50,000 per year for 3-4 years);
- Screening and monitoring of persistent and non-persistent contaminants in outmigrating vs returning sockeye salmon ($ 50,000 - $ $75,000 per year for 3-4 years).

9. Marine Mammals (including Strait of Georgia, coastal and high seas components) [Peter Olesiuk/John Ford]

[Ford]

Of the few cetacean species that are known to prey on sockeye salmon, the Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) has the greatest potential to prey on significant quantities of sockeye salmon. Preliminary studies of this dolphin's diet indicate includes various species of salmon, including sockeye, up to 60 cm in length. Pacific white-sided dolphins typically travel in groups of 200 to 1000 or more, with a minimum abundance of more than 20,000 along the BC coast. These animals may well target outmigrating sockeye smolts or returning adults in areas and at times where sockeye occur in high densities.

In order to assess the relative impact of Pacific white-sided dolphins on sockeye salmon, field studies focused on determining foraging strategies and diet are needed. We propose to undertake such studies using a variety of field sampling techniques, especially prey fragment and scat sampling during feeding bouts. Identity of prey species will be determined from these samples using scale or DNA analysis. Information on diet composition will be incorporated into bioenergetics models to estimate total biomass of key prey species consumed over various time periods with special focus on sockeye salmon.

Preliminary Cost Estimates:
Minimal research program (one year)
Field work using small vessel, northern Georgia Strait, Johnstone Strait, Queen Charlotte Strait; 2 science personnel, 90 field days, May-August, inclusive of salary, provisions, DNA analysis, misc expenses. Total: $70k

Intensive research program (two year)
Expanded field work using small vessel and CCG ships, northern Georgia Strait, Johnstone Strait, Queen Charlotte Strait, central coast, Queen Charlotte Sound; 2 science personnel, 90 field days/year, expenses as above. Total: $150k over two years.

[Olesiuk]

Harbour Seals: Previous studies indicated that harbour seals in the Strait of Georgia preyed mainly on hake and herring. Salmon comprised 4% of the overall diet, and seals took mainly pre-spawning adult salmon as they concentrated in estuaries and rivers. Except in special circumstances (seals foraging on outmigrating smolts using bridge lights in the Puntledge River), juvenile salmon were rarely consumed. The diet studies were conducted during 1982-88 when the seal population was still recovering and increasing exponentially. Recent surveys indicate that the seal population has since stabilized at historic levels, suggesting it is now at carrying capacity and probably food limited. Bioenergetic models indicate that seal predation levels on hake and herring stocks have increased since the 1980s. Telemetry studies currently underway indicate that foraging behaviour has also changed in recent years, with seals spending a greater proportion of time diving and utilizing larger areas than they did in the early 1990s. It might be expected that the diet of seals has become more diversified as competition for prey resources increased, but there are no recent diet data to assess this hypothesis.

Minimum Research Effort: A narrowly focused study could be conducted specifically to address whether seals in the Strait of Georgia are preying on Fraser River sockeye. Scat collections would be made at select haulout sites where and when seals have greatest access to sockeye during the smolt outmigration (as determined from the Beamish et al. surveys) and returning pre-spawning adults (Fraser River estuary during peak sockeye returns). The study would require a modest budget for small boat fieldwork, and 4 months of salary for a technician and student assistant to collect and process scat samples. Several hundred scat samples would be collected, and undigested bone fragments analyzed to determine prey species ($40 per sample) and genetics analysis conducted on a subsample to determine salmon species (single prey, $24 per sample). Approximate cost: $70K for a one-year study (optionally could be repeated a second year to contrast years of high and low sockeye abundance).

Moderate Research Effort: The above study could be expanded to include seals in the Fraser River. Seals have never been systematically surveyed in the Fraser River, and existing survey methods (low-tide surveys at tidal haulout sites) are not applicable in a riverine habitat. Anecdotal reports and historic records indicate that seals occur, albeit in relatively small numbers, as far up as Harrison, Hatzic and Pitt Lakes and probably range as far as the major rapids at Alexandria on the Fraser River. A pair of students would be hired to interview fishers, boaters, marina and lodge operators and shoreline residents and industries to compile local knowledge on seal behaviour and sightings, and to conduct shore-based observations to validate seal reports. A series of aerial reconnaissance flights would be conducted to count swimming animals and search for haulout sites. Scat samples would be collected opportunistically from any significant haulout sites discovered. Approximate cost: this would add approximately $50K per year to the cost of the minimum research effort, for a total of $120K per year.

Major Research Effort: The broad-based scat studies conducted in the 1980s could be repeated to provide updated information on the overall diet of harbour seals in the Strait of Georgia, and test the hypothesis that the overall diet has become more diversified in recent years as seal populations have attained carrying capacity. The harbour seal is a predominant apex predator in the Strait of Georgia, and a broad-based study would facilitate ecosystem modeling as well as impact assessments on a wide array of prey including salmonids, herring, rockfish and lingcod. The study would require a 3-year effort involving year-round scat collections throughout the Strait of Georgia. A technician or biologist would need to be staffed to oversee the program, and a series of students hired to assist with field work and processing samples. Several thousand scat samples would be collected and bone fragments analyzed ($40 per sample), and genetic analysis conducted on a subsample to refine prey identifications and assess potential biases (multiple prey, $55 per sample). Approximate cost: roughly $500K over a 3-year period.

Steller sea lions: Steller sea lion populations in BC were reduced by predator control programs between 1912-68. As local populations were depleted, the species established a new rookery 20 nm north of the Alaska border that has grown into the largest breeding site for the species, making it difficult to separate populations in BC and SE Alaska. Abundance of Steller sea lions in BC and SE Alaska has been gradually increasing since the last major kills in the mid-1960s. Abundance has now surpassed known peak historic levels that occurred in the early 1900s prior to any major kills, but the population continues to increase. The breeding population of Steller sea lions on the west coast has also shifted northward and is now centered off central BC, and the species has recently established several new breeding sites in BC and SE Alaska. The reasons for the continued growth and redistribution of Steller sea lions are not understood, but they are now the predominant pinniped predator in BC, consuming about twice as much prey annually as harbour seals.

In 2008, a study was initiated to estimate the prey requirements and assess the importance of salmon in the diet of Steller sea lions. PSC provided funding to initiate the study, which was expanded with supplementary funding from SARA, A-Base and Parks Canada. Surveys were conducted throughout the year to determine abundance and seasonal distribution, a bioenergetics model was developed based on captive studies and telemetry data to estimate prey requirements, and scat samples collected to determine diet. Researchers from NMFS, WDF&W, ODF&W and UBC have collaborated on the study and provided access to scat samples that had previously been collected but never published, allowing the PSC funding to be directed to filling seasonal and geographic gaps in sample coverage. Preliminary results indicate that salmon is a fairly important prey of Steller sea lions, occurring in about 24% of scat samples. The amount of salmon taken by Steller sea lions in BC may now be of the same order of magnitude as landed in commercial fisheries. The study is scheduled to be peer-reviewed at the next National Marine Mammal Review Committee Meeting in November, 2010, with a final report available by the end of 2010.

Minimal Research Effort: The original goal of the PSC study was to collect about 60 scat samples from 8-10 sites in each of 4 seasons (i.e. 480-600 samples per season or 1,920-2,400 samples in total) for diet analysis. With the contributions of data from other agencies, 6,413 scat samples have been compiled, or about 3 times the original target. This will allow for a more comprehensive assessment of sea lion predation on salmonids. However, the species of salmon can rarely be determined from visual examination of undigested bone fragments recovered in scats. Recently, specialized genetic techniques have been developed at the PBS Molecular Genetics Laboratory to extract DNA from bone fragments, allowing species of salmon to be identified. The remaining PSC funding is sufficient to analyze about one-third of the scat samples with salmon, and additional funding is required to complete the analysis. Doing so will allow us to partition salmon consumption by species, and identify where and when sea lions are feeding on each species of salmon. Approximate cost: $22K is required to cover technician salary and laboratory supplies, and samples would need to be analyzed by early October 2010.

Moderate and Major Research Efforts: It is recommended that plans for further research initiatives on the feeding habits of Steller sea lions and impact on salmon stocks be deferred until the results of the PSC study are available. The PSC study will provide estimates of the total prey requirements of Steller sea lions in BC and adjacent waters, and assess the importance of salmon in the diet in the Southern Endowment Area (Cape Caution to the Columbia River). The study will also identify when and where salmonids are being consumed by sea lions, and attempt to quantify sources of uncertainty in the salmon consumption estimates. These results will be useful for evaluating the need for and planning future research.

10. Unreported catch outside the PST area [Terry Beacham]

This project would ideally center on evaluation of stock composition and catch of sockeye salmon in Aleutian Islands fisheries, specifically Area M of the Aleutian Islands. Samples of catch from this region have been collected during the last few years under the WASSIP (Western Alaska Salmon Stock Identification Program) program of ADF&G. While fisheries target maturing individuals, immature sockeye salmon are also intercepted in fisheries along the Aleutian Island passes into the Bering Sea. As immature Canadian-origin sockeye have been observed in the Bering Sea during summer, they can potentially be intercepted in this fishery as they pass by the Aleutian Islands into the Bering Sea, but not be counted or sampled in the catch of maturing fish. Samples of maturing sockeye salmon are available, but it is unlikely that samples of immature fish have been collected. Although samples are available from the Area M fishery, ADF&G is unwilling to provide samples to DFO for analysis, so a concerted effort will be required to obtain these samples and have these samples analyzed by DFO staff.
Under the present structure of funding for the MGL, staff salaries are charged to a variety of SPA accounts. If this funding structure is maintained, a charge of $17 per fish would be applicable for this project. Costs for the project would be:

Low level – 1,000 fish analyzed, project cost $17,000
Mid level – 5,000 fish analyzed, project cost $85,000
High level – 10,000 fish analyzed, project cost $170,000

11. Disease (including lake, river, Strait of Georgia, coastal and high seas, as well as all life history types) [Kyle Garver/Kristi Miller/Stewart Johnson]

[Johnson]
With respect to pathogens of Fraser River sockeye we have scattered information from approximately 157 diagnostic cases that have been submitted to the Aquatic Animal Health (AAH) Group since 1975. Unfortunately these data do not allow us to draw many conclusions about the prevalence of pathogens or the role they play in sockeye salmon population dynamics.

We are proposing a combined field and laboratory-based program to examine what roles pathogens and/or disease play in the population dynamics of Fraser River sockeye. Such a program would examine for a limited number of stocks:

1. what pathogen(s) are present and how their prevalence(s) change throughout the life cycle,
2. how much variability there is between years in the prevalence of pathogens in the various life history stages,
3. the relationships between abiotic and biotic environmental factors, host factors and the prevalence of pathogens or disease,
4. the mechanism/s by which pathogens affect the ecological performance of sockeye salmon, and
5. the role/s of host and environmental factors in disease development.

The following pathogens will be surveyed for:

1. VHSV (causative agent of Viral Hemorrhagic Septicemia)
2. IHNV (causative agent of Infectious Haematopoietic Necrosis)
3. ISAV (causative agent of Infectious Salmon Anemia) not known to be in BC but of concern to environmental groups
4. Salmon Herpes Virus
5. *Aeromonas salmonicida* (causative agent of frunculosis)
6. *Rennibacterium salmoninarum* (causative agent of bacterial kidney disease)
7. *Myxobolus arcticus (myxosporean)*
8. Parvicapsula sp. (myxozoan parasite)
9. Sea lice (*Caligus* and *Lepeophtheirus* species)

Minimum Program

This program would investigate pathogens and disease in smolts during the out migration and early sea water residency in the Strait of Georgia for 4 consecutive years. Samples of out migrating smolts within the river will be obtained at their source and from lower reaches prior to seawater entry. Smolts will be sampled at 3 time points from various sites within the Strait of Georgia. Samples will be obtained for histology, virus screening (cell culture and molecular), bacteriology (molecular), and stock identification (when necessary). We will focus our efforts on stocks that are accessible and abundant enough to obtain sufficient samples for analysis.

Due to the severity and potential impact of IHN and the presence IHNV in most stocks of sockeye salmon, laboratory studies will focus on this disease. We will determine: 1) the susceptibility and minimum infectious dose for sockeye salmon 2) how IHNV is perpetuated in sockeye populations, and 3) factors which control the switch from IHNV carrier status to disease. Gene transcription studies and in-situ hybridization will be used to compare carrier and non-carrier hosts.

Studies to examine the susceptibility of sockeye salmon to infection with *L. salmonis* have been funded under the PARR program.

Costs have been estimated assuming that a maximum of 2 populations are studied and that sampling frequency and intensity is the same as for the 2010-2011 survey.

Field Costs:

273 K per year for 4 years (180K sample collection[a]; 50K technical support; 33K diagnostic costs[b], 10K genotyping.)

Laboratory Costs:

IHNV Study: 69K for each of 2 years (60K for PDF or technician salary, 9K reagents and supplies)

a. Assumes samples from point of origin and the lower river can be collected by other DFO groups without cost to this program. 165K of PARR funding is available in each of 2011-2012 and 2012-2013 for sampling in the Strait of Georgia.
b. 10K of PARR funding is available in each of 2011-2012 and 2012-2013 for sea lice analysis.

Total Costs: Field Program 1092K (based on a 4 year program), Laboratory Program 138K (based on a 2 year program)

Available Funding: 398K from PARR program

Expanded Program:
Field Program - Freshwater
We estimate that it would cost an additional 50 K per year to expand the disease survey work to include spawning adults and pre-smolt stages. This estimate is for a survey of 2 systems and it takes into account costs associated with sample collection.
Total cost = 200K over 4 years

Field Program - High Seas
We estimate that it would cost an additional 35 K (diagnostics and genotyping costs) per year to expand the disease survey work to include samples from the select stocks collected on the high seas. This assumes that these samples would be collected for us during the high seas program.
Total cost = 140K over 4 years

Laboratory Studies:
Several of the pathogens known to be present in Fraser River sockeye have been demonstrated to have an effect on fish performance. For example, the presence of *M. arcticus* in the brain of sockeye salmon smolts in Alaska was shown to reduce swimming performance by approximately 30%. We are proposing to study the effects of pathogens on processes such as smoltification, growth and cardiac/swimming performance under laboratory conditions. Cardiac/swimming performance studies would be conducted in collaboration with Dr. K. Gamperl who is a leading scientist in this area. The pathogen/s selected for study would be based on the results of our field studies. To conduct these studies, we would need a dedicated PDF or senior technician (60K) and 10K for supplies per year for a period of 2 years.
Total cost = 140K over 2 years.

[Miller]
Genomic monitoring of wild-caught sockeye salmon smolts and adults has yielded a wealth of new knowledge on the condition of migrating salmon and has identified potentially maladaptive signatures associated with poor growth, nutrition, starvation, hypoxia, stress and disease (including potential pathogen exposure). This is the only program that provides a comprehensive assessment of salmon health and condition, but Genome BC funding for this program ends in June of 2011. Moreover, in 2010, the smolt genomic studies were shifted from sockeye to coho and Chinook (as planned in our original research proposal). We have collected >1,500 sockeye salmon smolts over the first 9 months of migration to the ocean in each of 2008, 2009, and 2010, and hope to continue these collections, in collaboration with Beamish, Trudel, and Patterson, into the future. In collaboration with Patterson and the Environmental Watch Program, we also have extensive collections of returning adult sockeye salmon. These adult and smolt samples are highly valuable both to the department and to our research. The following is a list of proposed studies that utilize these hard to come by samples to aid in our understanding of potential causal mechanisms behind the salmon declines.

I. A new high throughput biomarker technology (our top priority)

Microarrays provide a genomic tool to assess the condition of fish utilizing the expression profiles of 10's of thousands of genes at once. This technology has been utilized to **discover** the range of conditional differences among co-migrating fish, and to hypothesize which may be maladaptive (i.e. associated with elevated mortality). While highly informative, microarrays are too expensive and labour intensive to apply on a large scale. High throughput biomarker technologies is the next step required to assess the prevalence of specific conditional states identified through microarray analysis over 1,000's of individuals, allowing assessments to be made over multiple years, stocks and species. We propose to develop this biomarker technology first on our unhealthy signature, hypothesized to be the result of a novel virus that is adversely affecting the survival of adult sockeye salmon, and potentially juvenile salmon as well. But before this can be accomplished, we need to purchase the equipment required to implement this technology.

Funding Required:
Purchase of **Fluidigm BioMark System MX/HX**: 190K
Optimal: purchase of the system and technical salary and supplies to get it up and running (300K total)

Moderate: Equipment and ½ technical salary (225K)
Low: Equipment only (190K)
This is a one year proposal—for implementation on 1,000's of samples, see next proposal

II. Large-scale Biomarker screening of the Unhealthy Profile

(collaboration between Miller/Patterson/Parr program—for samples)
We have been developing biomarkers for the unhealthy signature to assay with the Fluidigm system, but these need to be validated on the system before being applied on a large scale. Ideally, this assessment will include a biomarker for the purported virus itself (see proposal III). 2010 is the first year that we will have samples of the smolts and adults from the same year-class, which will provide important information on the prevalence of the unhealthy signature in smolts leaving the river and returning as adults. With these data, we can begin to assess the potential impact of this signature on survival from smolts to spawning adults. If we extend our analysis to the broad array of smolt samples collected from 2008 to present, representing multiple stocks within and outside of the Fraser River, we can begin to establish whether stocks that are doing well (e.g. Harrison) are also affected by this signature and the prevalence in sockeye outside the Fraser River. By conducting longer term monitoring, we can establish whether prevalence of the unhealthy signature has shifted over time during the decline, whether there is a correlation with recruitment/escapement, and the impact of environmental conditions on shifts in prevalence (i.e. potential mortality) associated with this signature.
In 2010, in conjunction with the Parr program, we also obtained histology samples associated with some of our smolt collection, and we propose to analyse a portion of these, through collaboration with fish health, to obtain a histological profile associated with our unhealthy signature. .

Funding Required
A. Technician Salary: 70K/year
B. Consumables cost of assessing unhealthy signature in 5,000 samples (which could include 5,000 individuals or fewer individuals at multiple tissues): 175K
C. Continued assessment of this signature in smolts and adults in subsequent years (2-5+): $35 per sample plus technical salary.
D. Histology of 2010 healthy/unhealthy samples: 10K

Optimal: A-D with C being enough to run >1,000 samples/year
Moderate: A-B, D to at least get started on the samples in hand
Low: A and some portion of B, targeted for specific assessment of Fraser River only

III. Identify an infectious agent associated with the unhealthy signature

(Miller/Garver Collaboration) - see proposed research sent to Mark Saunders 2 weeks ago

- **Identify and sequence the virus and develop a molecular tool for screening (required for further analysis) (36K)**

  For the past few months, we have been attempting to concentrate and sequence a virus from unhealthy signature tissue. Sucrose gradients applied to healthy and unhealthy tissues, with IHNv infected tissues used as a control, have yielded a "viral-density" band in unhealthy liver tissue from smolts and adults and from IHNv infected tissue, but none from our healthy tissue controls. This is very promising. We now propose to take these density isolates and contract out high throughput 454 sequencing to obtain a sequence of our purported pathogenic agent. This approach has worked for other viruses that were not culturable (e.g. the recently identified HSMI virus causing devastation in Europe). We will use the sequences obtained to develop qRT-PCR assays, and apply these to "healthy" and "unhealthy" tissue samples to assess their potential to associate with our known signatures. We will also use the same "viral band" from the sucrose gradients and the negative control for electron microscopy to determine whether viral particles can be visualized in these isolates. EM can sometimes provide additional clues as to the potential viral family, which at present we hypothesize could be retroviral.

  Funding Required:

  A. The McGill University and Genome Quebec Innovation Centre has costed the 454 sequencing analysis out at **15 K**

  B. EM work from University of Montana is approximately **2 K**

  C. 3 months tech time for viral isolation, bioinformatics, qPCR development and testing: **19 K** (one month of this may be used to contract out the bioinformatics)

  Total: **36 K**

- **Infectivity Study: Does Unhealthy-profile tissue contain a transmissible infectious agent? (46.25 K)**

  We hypothesize that the unhealthy signature is associated with a pathogen infection, likely of viral origin. A holding study conducted to assess stock-specific differences in high water temperature susceptibility and response, we found that the prevalence of the unhealthy signature nearly doubled after one week of holding, potentially indicative of the infective spreading of disease. However, as this experiment was not designed for this purpose, we had no negative control. As such, we propose to conduct injection challenges using homogenized unhealthy and healthy-profile liver tissue as the source of infectious agent to determine whether unhealthy-profile tissue is infective in (presumably) naive fish. Because most of our already profiled samples have been preserved in RNAlater, not conducive for maintaining active virus, we have recently obtained a small number of tissue samples from sockeye salmon smolts that have been rapidly frozen. In order to identify "unhealthy" tissues, we will have to conduct a small scale microarray experiment on the RNA from a sub sample of these tissues to obtain tissues for the challenge work. , which will provide the basis for both homogenized and sucrose gradient concentrated challenge material. Fish from these challenges will be analysed via histology and microarrays of liver tissue five weeks post exposure..

  Funding Required

  A. Initial microarray determination of healthy/unhealthy signature tissue: 20 slides x $375/slide=$7,500

  B. Challenge work: $3,000

  C. Microarray experiment based on challenged fish (5x6=30) x 375=$11,250

  D. Tech time (Genetics) 1.5 months: $9,500

  E. Tech time (Fish Health) 2.5 months: $15,000

  Total: $46,250

Note: The only way to reduce the cost of this analysis would be to wait until we have a viral sequence to identify infected tissues, reducing the necessity for the initial microarray assessment (decreasing cost by 7.5K).

IV. <u>Unhealthy signature salmon in Aquaculture: Is there a potential role of Aquaculture in transmission of this *potential* disease? (25-47 K)</u>

(Collaboration between Miller, aquaculture industry, Garver)

While our research on smolts suggests that salmon are leaving the river already carrying the unhealthy signature, given the intense scrutiny that salmon aquaculture is under with the spread of any disease, it is important to assess whether or not Atlantic salmon is similarly effected by this signature and if so, what their potential role in the propagation of the disease may be. We have never before assessed Atlantic salmon for this "unhealthy" signature. As well, as we have observed this signature in the brain tissue of Chinook salmon, another, albeit much smaller in scale, aquaculture species, it is important to assess the prevalence of this signature in cultured Chinook salmon as well. This research can be used as a proactive response to recent assertions of Alexandra Morton that there is some connection between the spread of viruses and salmon aquaculture (see her latest blog updates). Note: Dr. Miller has been contacted by Mary Ellen Walling who has expressed interest in our doing these experiments, and will facilitate our obtaining the fish for these analyses, and may be able to convince the industry to contribute financially.

<u>Funding Required</u>

A. 50x375 K for Atlantic salmon = $18,750

B. 40x375 K for Chinook salmon = $15,000

C. Genetics tech time: 1-2 months depending upon whether one or both species are surveyed: $6,500 to $13,000

Total: 25 K to 47 K

Optimal: A-C with experiments on Chinook and Atlantics. Immediate results, no waiting for viral sequence or biomarker validations

Moderate: A and C, no Chinook salmon

Low: wait for viral sequence and conduct survey of Atlantics when available (it may still be important to establish whether they are susceptible and responding to a virus, if one is present).

<u>V. Continued Microarray Discovery Research to identify maladaptive conditional states in sockeye smolts in the ocean</u>

(Collaboration between Miller, Patterson, Beamish, Trudel, Parr program for samples)

We have only had the funding to assess the range of conditional states in migrating sockeye salmon smolts in one year (2008), which was a year of optimal ocean conditions where very little variation in growth and feeding was observed. We also ran a very small number of samples from 2007, which yielded novel profiles potentially associated with hypoxia (harmful algal blooms?) and starvation/food deprivation (consistent with Beamish's observation of reduced feeding). While these profiles will be used in future to generate biomarkers for targeted screening, we have likely not yet identified the full range of conditions that salmon may experience, especially in years where ocean conditions are suboptimal. Therefore, we propose to continue with our microarray screening program, perhaps on a smaller scale. The size of this program (for sockeye) really depends upon the amount of funding available and the need for information in other species (e.g. Chinook and coho for the PSF research).

<u>Funding Required</u>:

Technical salary: 1-2 technicians at 70K each/year

Microarrays: $375 per individual, propose to run 100-200 individuals/3 tissues per year: 110-225 K/year over 3 more years.

Optimal: 2 technicians, 600 arrays per year
Modest: 1 technician, 300 arrays per year
Low: 1 technician, 200 arrays per year

VI. Development, validation and large scale (Fluidigm) screening of biomarkers associated with growth and feeding related profiles

(Collaboration between Miller/Beamish/Trudel/Patterson)

Beamish and others have hypothesized that salmon smolts that do not grow quickly upon entry into the ocean and reach an optimal size by the end of the summer will suffer higher mortality in the first 6 months in the ocean. With this context in mind, we aimed in our genomics program on smolts to identify genomic signatures associated with high and low growth, to identify physiological factors that may undermine rapid growth, and to identify signatures indicative of the switch point between rapid growth and the accumulation of lipids for overwintering that was proposed by Beamish. This was the first research to actually test the physiological basis of this critical size, critical period hypothesis. While we are still working on the latter two goals, we have identified, in Chinook salmon, two distinct profiles associated with slow growth, one with rapid growth, and potentially one that indicates a switch point between rapid and slow growth. We have also identified signatures associated potentially with starvation in sockeye smolts in the ocean in 2007. We propose to develop biomarkers from these signatures and apply them to assess the prevalence of low growth/poor feeding in smolts in additional years. We have in hand samples for 2007-2010, and hope to continue collecting more samples in subsequent years.

Funding Required

A. Technical cost of developing biomarkers for additional conditional profiles: 70K

B. Consumables cost for development of 100 biomarkers for growth/nutrition assessments: 50 K

C. Continued annual assessment of smolts/adults, 1,000 individuals per year two tissues (muscle to assess growth, liver to assess feeding): 70 K/year consumables plus technical salary of 20K=80K

VII. IHNv Research to determine whether sockeye salmon smolts can carry IHNv in the brain during ocean migration

Alexandra Morton is presently putting pressure on the department to explain the potential role of IHNv, and transfer of IHNv from aquaculture (Atlantic salmon) to wild fish in the declines in sockeye salmon. Departmental scientists do not believe there is any evidence that IHNv is a major factor in these declines, however, given the scrutiny that this disease is still under, it is important that we begin to fill in some of the gaps in knowledge pertinent to the transmission of this virus in the wild. One such question is “Do smolts that have been previously challenged by IHNV still carry a residual signature associated with viral activity in the brain in saltwater, and is that signature associated with inactive viral particles harboured in brain cells?” IHN disease has never been observed in sockeye salmon from the marine environment, and adult sockeye salmon are not prone to disease caused by the IHN virus. However, adult salmon sampled in the river are known to carry and shed the virus, potentially affecting juvenile salmon in the river. The question is, are they picking the virus up when they enter the river, or is it potentially laying dormant and being reactivated upon their return to freshwater? Kyle Garver recently conducted an IHNv challenge study in sockeye salmon juveniles, and then reared individuals that recovered from the virus to smolts, and transferred them to saltwater. While he was unable to recover infectious virus from the brains of recovered individuals in saltwater, some fish were still positive for the virus via RT-PCR. Kristi Miller has previously profiled the IHN virus in the head kidney and gill of multiple salmonid species, but never the brain. Miller and Garver propose to profile the brains from salmon in his “recovery” experiment.

Required Funding

A. Microarray Experiment 24: $9,000

B. 1 month genetics technician time: $6,500.
Total: 15.5 K

12. Stock ID (coupled to relevant projects above—i.e., smolt monitoring, etc.) [Terry Beacham]

This project would provide stock identification support to freshwater and marine projects. Freshwater projects could include hydroacoustic assessments of juvenile abundance (separation of kokanee from sockeye juveniles, cheaper than other techniques on a cost per fish basis), and population-specific relative abundance of migrating smolts, possibly at a sampling site in the lower Fraser River. Marine projects would include projects centered on determination of juvenile migration routes, relative survival, and possibly marine mammal diet and contaminants load.

Under the present structure of funding for the MGL, staff salaries are charged to a variety of SPA accounts. If this funding structure is maintained, a charge of $17 per fish would be applicable for this project. Costs for the project would be:

Low level – 1,000 fish analyzed, project cost $17,000
Mid level – 5,000 fish analyzed, project cost $85,000
High level – 10,000 fish analyzed, project cost $170,000

13. Synthesis/Modelling - ecosystem-based [Jim Irvine, Ian Perry]

[Irvine]

Fraser River sockeye salmon are among the most intensively monitored salmon anywhere. Long time series of spawner escapements exist for many populations and the stock recruitment dynamics have been well-studied. Yet for only two populations, Cultus and Chilko, can one partition mortality into events occurring in fresh water and the ocean. For the Chilko, with six decades of data, marine survivals have declined since the 1989 regime shift. Although changes in the environment are clearly related to changing survivals, we are uncertain of the locations and mechanisms for marine and freshwater effects controlling survivals.

Our objective is to improve our understanding of factors controlling variability in the survival of Chilko Lake sockeye salmon. The project will build on work initiated by Dr. Jim Irvine with Scott Akenhead of the Ladysmith Institute. Our approach is to partition the environmental variability affecting survival and growth of Chilko sockeye salmon at three main scales: local (Chilko Lake and watershed), regional (Fraser River and estuary, Strait of Georgia, Queen Charlotte Strait and Sound), and oceanic (North Pacific Ocean including Alaska Gyre).

A life history survival model in R using *Simcecol* for simulation and *mgcv* for analysis will be completed. We propose to fit our model to environmental data operating in major “habitats” (e.g. natal streams, Chilko Lake, Fraser River, Strait of Georgia, Queen Charlotte Sound, Alaska Gyre, fisheries), initially within three climate regimes. By keeping separate track of smolts that leave Chilko Lake at age 2 as well as age 1, our model will allow us to track various life history strategies through different environments in different years. Combining marine and freshwater survival models and their environmental covariates will provide a comprehensive “cumulative effects” model of multiple environmental effects on multiple life history stages. We have already had good results by making more effective use of age data than has been done previously.

Milestones of this project are:

1. Review datasets with experts – document error and bias from *changes* in sampling, ageing, catch allocation etc. (This milestone is not unique to this project.)
2. *Piece-wise analysis*: correlate environment to new indices of survival and growth
3. *Integrated analysis*: survivals across all habitats in all life paths in all years
4. Develop and fit survival model to environmental data for multiple habitats
5. Separate and fit environmental covariates by scales: decadal-oceanic *vs.* interannual-regional (cross-spectral analyses with IOS collaborators?)
6. Prepare scientific publication in primary literature
7. Compare findings with complementary Bayesian Belief Network systems
8. Expand findings to other sockeye populations.

Results from this modeling exercise should help to generate hypotheses that can be tested in the field. Because in-house modeling expertise is not available for this research, we propose to employ Scott Akenhead who has begun work on the simulation model. The chief cost in the following scenarios is his employment at 7.5K/ month. Scott would work closely with Dr. Irvine and other DFO science staff.

Low Cost (22.5K)
Milestones 2-6 only (assume Milestone 1 is covered elsewhere). Note that the nature of the analyses (cross spectral?) are not finalized and contractor input to the publication that he would co-author would be limited.

Medium Cost (37.5K)
Milestones 1-6. As above except involve contractor in data verification (Milestones 1) and, to a greater degree, in scientific publication (Milestone 6).

Full-Cost (90K)
Milestones 1-8. As above but also have contractor compare results from simulation modeling with other modeling activities (Milestone 7) and expand simulation model to other sockeye populations (Milestone 8). Costs would need to be spread over 2 fiscal years.

[Perry]

The "12 hypotheses" provide the bases for a strong research program on the scientific issues relating to the declines (both long term and recent) of Fraser River sockeye. However, while several of these have overlapping elements, they are largely unconnected with each other (at least as often presented). Yet several (perhaps all) of these hypotheses may play roles in the declines.

In the context of developing a research plan, a 'synthesis' project is needed which would take a "big picture" view of the ecosystems that Fraser River sockeye occupy during their various life history stages. It would build on work conducted and findings from the DFO Strait of Georgia Ecosystem Research initiative to build an ecosystem approach to Fraser River sockeye and attempt to integrate all hypotheses into one overview picture.

Such a synthesis project would have three elements, and would build strong links with groups working on all hypotheses, in particular the life history survival model project proposed by Irvine:

1) a Bayesian network model which would be constructed early in the research project based on existing data and expert knowledge, to structure the variables and their linkages. It would be used to identify key knowledge and data gaps, and could be used to guide priority-setting of research issues. This model would be updated throughout the research program to track progress and guide research planning, and would be an important

management tool when “completed” at the conclusion of the program by integrating the knowledge obtained during the studies. (Perry, Johnson, others?);

2) analytical and numerical models of ecosystem processes. Process-oriented models have become standard tools in large fisheries ecosystem programs, and they permit evaluation of the mechanisms underlying ecosystem processes. For Fraser River sockeye, two types of process models would be constructed:

   a) coupled physical-biological oceanographic models, which would simulate environmental conditions occupied by FR sockeye during all their life stages (e.g. Fraser River, Strait of Georgia, coastal BC) and would include the potential impacts of climate change and variability downscaled from global and regional climate models (Masson, Pena, Foreman, Crawford). This work would provide a natural continuation of the Strait of Georgia Ecosystem Research Initiative, which ends in 2010-11, and an extension of the Fraser River Environmental Watch Program, which presently only monitors and forecasts upstream migration conditions, to downstream migration conditions. In addition to the customary century-scale projections, the next round of IPCC global models (which are expected to become available for analysis over the winter of 2010-11) will also include decadal-scale predictions which should have some skill in forecasting specific conditions during the ocean phase of the sockeye life cycle. This research will have strong links to ongoing work in the Climate Change Science Initiative and the new PICES FUTURE program.

   b) food-web models, in particular focussed on the early marine life stage of FR sockeye (e.g. in the Strait of Georgia) which would integrate feeding, predation, and competition impacts on juvenile sockeye. These would include environmental forcing obtained observations and/or oceanographic models, and their projections of future conditions (Preikshot, others?).

3) Integration of these modelling approaches and the hypotheses into a suite of ecosystem indicators which would summarise ecosystem conditions in a form for managers and the public (Perry, Irvine, others?).

Potential budget:

“Volkswagon” version

Element 1:	BI-2 (full time)	$ 60K/yr
Element 2a:	1 Post-Doc or RA (for Masson-Pena-Foreman-Crawford)	$ 75K/yr
Element 2c:	Research Associate	$ 75K/yr
Element 3:	work would be combined with full-time Bi-2 in Element 1	--
TOTAL		$210K/yr

“Honda” version

Element 1:	BI-2 (full time)	$ 60K/yr
Element 2a	1 Post-Doc or RA (for Masson-Pena-Foreman-Crawford)	$ 75K/yr
Element 2b:	Research Associate	$ 75K/yr
Element 3:	BI-2 starting half-way through project duration (annualised)	$ 20K/yr
TOTAL		$230K/yr

“Hummer” version

Element 1:	BI-2 (full time)	$ 60K/yr
Element 2a:	2 Post-Docs or RA’s (for Masson-Pena-Foreman-Crawford)	$150K/yr
Element 2b:	Research Associate	$ 75K/yr
Element 3:	BI-2 (fulltime)	$ 40K/yr
TOTAL		$325K/yr