WILD SALMON POLICY HABITAT STRATEGY DISCUSSION PAPER

July 23, 2006

INTRODUCTION

Under Strategy 2 of the Wild Salmon Policy, the Department is committed to an assessment of salmon habitat status. The policy states that "An overview of important habitat and habitat issues within Conservation Units (CU's) will be developed and habitat status will be assessed using indicators that combine scientific and local knowledge and recognize sensitive life stages and habitats. Indicators will be selected to be reflective of overall habitat health, then tracked to assist in habitat planning within DFO and other jurisdictions, including First Nations governments, the Province of B.C. and local governments. Habitat data gathered from many sources within and outside DFO will be linked and made more accessible for habitat planning. The assessment will highlight good quality habitat that needs to be maintained and protected, and degraded habitats that need to be restored or rehabilitated on the scale of watersheds and CU's to inform strategic and annual planning for salmon conservation."

A Wild Salmon Policy Habitat Working Group formed in January, 2006 to begin the task of implementing Strategy 2 of the policy. The Working Group is chaired by the OHEB WSP Habitat Coordinator and membership includes Science and OHEB regional and area staff.

Strategy 2 identifies four key action steps for progressive implementation. This discussion paper summarizes the progress of the Working Group to date and proposes an approach for moving forward on each of the action steps.

ACTION STEP 2.1 - Document habitat characteristics within CU's

Background/Considerations

DFO Science and technical staff involved in the implementation of strategy 2, generally agree that the key deliverable of Step 2.1 is to identify the quantity and quality of the habitats that support the production of salmon in CU's. To improve efficiency of information updates and access by internal and external users, it is envisioned that much of this information will be developed in georeferenced data sets and reported visually with maps using a web-based GIS tool, rather than in written technical reports.

Quantifying CU habitat descriptors such as accessible stream length, lake, off-channel and estuarine habitats, require updates and improvements of the Fisheries Information Summary System (FISS) and other fish habitat inventory and species distribution databases. For example, at the currently used 1:50K map scale, up to half of the stream courses in coastal watersheds are not identified, while many interior stream courses are mapped where none exist (David Tesch, BC Ministry of Environment, personal communication). Furthermore, current predicted species distribution or species range maps are based on models using documented fish observations and known migration barriers. In data poor CU's, this may not accurately reflect the distribution and quantity of habitats that support fish production in a CU. Further collaborative work is required with the Province to model predicted fish distribution beyond known sample or observation points.

Describing habitat quality, requires the development of a tool for classifying the relative value and productivity of salmon spawning and rearing habitats that support the production of a CU. While localized projects have been undertaken, a habitat classification scheme has not yet been adopted for broad scale application across the Pacific Region. Progress on this front will assist in operationalizing WSP Strategy 2 as well as Habitat Management's, EPMP Risk Management Framework.

In addition to the above information layers, the standardized capture of local agency staff and community knowledge will be key in identifying and mapping known habitat threats and productivity constraints. This information will contribute to the documentation of habitat characteristics within CU's. As described in the policy, a CU overview report "will provide sufficient information on key habitats to identify initial priorities for protection, rehabilitation, and restoration. It will also identify information gaps and factors….that potentially threaten the future health and productivity of habitats in the CU."

Progress to Date and Proposed Approach

An initial piece of work undertaken by the WSP Habitat WG, was to complete a literature review and describe the current understanding of Pacific salmon species life history strategies and key habitat requirements/thresholds for each life history stage. This work has been completed for the following 10 species life history strategies:

- Chum (2) – southern, northern(Yukon, MacKenzie)
- Coho (2) – coastal, interior
- Chinook (3) – immediate ocean migrants, 90-120 day stream residence, overwinter stream residence
- Pink (1)
- Sockeye (2) – lake rearing, stream/estuary rearing

An example of the species life history description and accompanying life history stage habitat requirements table, is provided for coastal coho in Appendices 1 and 2, respectively. This information will be used to identify and document habitat limiting factors to production in a particular CU.

Work has commenced to define the information requirements for a CU Status Report. The current thinking from a habitat perspective, is that we will need to provide high level overview information for the CU Status Report and more detailed stock/watershed level information for priority CU's where integrated planning processes are undertaken. This is particularly evident for large CU's comprised of a number of stocks utilizing multiple watersheds. Habitat threats and limiting factors to production can vary widely between watersheds supporting a CU. Consequently, when developing recovery strategies for a threatened CU, priorities for habitat protection and restoration may be quite different from one stock to the next within that CU.

Joint OHEB/Science/MOE workshops were convened to define the information requirements for a CU Status Report. The key habitat information requirements identified for these reports include the following:

- CU map highlighting those watersheds contributing to CU production and marine distribution of CU;
- High level habitat classification description, e.g. Ecoregion, Ecological Drainage Unit, Biogeoclimatic Zone(s), hydrologic profile, etc.;
- Summary of habitat quanitities contributing to CU production, e.g. accessible stream length, off-channel/wetland area, lake area, estuary area;
- Land use map layer and accompanying watershed statistics for a yet to be determined suite of habitat pressure indicators;
- Brief overview of major CU habitat threats, production constraints and trends.

It is anticipated that this is the minimum level of habitat information that will be required for all CU's in the Region when reporting status.

For priority CU's, this high level habitat information will not suffice. The development of sound and defensible recovery strategies will require more detailed habitat anlayses at the stock/watershed level. Given resource constraints, this might only be undertaken for priority stocks/watersheds within priority CU's.

The Working Group has developed a template for summarizing stock specific habitat information such as relative productivity or sensitivity of various habitats, habitat limiting factors to production at each life history stage, and habitat protection and restoration priorities. An example of the level of information that might be assembled is provided for the Englishman River coho stock within the ECVI Coho CU (Appendix 3). In order to standardize the approach for describing relative productivity or sensitivity of various habitats, a proposed draft habitat classification scheme (DFO 2001) is under review by the Working Group. If an acceptable habitat classification scheme can be developed, a phased approach to classifying habitats is proposed. Initial efforts would focus on identifying the location and extent of the most highly productive and sensitive habitats for selected priority stocks within priority CU's. An examination of current fish habitat modeling tools such as FHAT http://ilmbwww.gov.bc.ca/risc/pubs/aquatic/fhat20/index.htm is required to determine the potential for classifying habitats from GIS modeling of spatial data and imagery.

Finally, the Working Group is undertaking a joint project with the Province to update the Fisheries Information Summary System (FISS). The proposed workplan includes:

- Data conversion of waterbody codes from 1:50K map scale to 1:20K Corporate Watershed Base;

- Modernizing system capability to link and access data from existing databases in the Province's Land & Resource Data Warehouse, relevant to a particular business question;
- Georeferencing NuSEDS at 1:20K scale;
- Updating known fish observation, migration obstruction and predicted fish distribution information at 1:20K scale;
- Linking references from various databases (WAVES, FISS, Ecocat, etc) for priority CU's to improve information accessibility;
- Updating Fisheries Project Registry information.

Recommendations for Moving Forward in Fiscal 2006-07

- **Advance the development of a web-based GIS tool to present CU maps and spatial habitat quantity and quality information from the integrated data management system described later in this report (Step 2.4, pg.17);**

- **Collaborate with the Province to agree upon data management standards to support WSP, including updating and improving FISS, data conversion of waterbody codes from 1:50K map scale to 1:20K corporate watershed base, georeferencing NuSEDS at 1:20K scale, updating fish observation, migration obstruction & known fish distribution at 1:20K scale, and linking references from various databases for priority CU's;**

- **Collaborate with Province to model predicted fish distribution, fish habitat characteristics and capability beyond known sample or observation points, at 1:20K or better resolution;**

- **Complete high level CU Status Reports for priority CU's - habitat content to include CU map highlighting watersheds contributing to CU production, marine distribution, high level habitat classification, habitat quantity summaries, updated land use map layer and accompanying watershed statistics relevant to selected suite of Pressure indicators, and high level overview of major CU habitat threats, production constraints and trends. Given the wide gap between available resources and the resources required to complete status reports for all CU's, propose a pilot scale approach to gain a better understanding of feasibility, implementation costs and cost-sharing opportunities;**

- **Complete detailed habitat status reports for priority stocks/watersheds within priority CU's for which integrated planning processes are intiated – info to include the identification of highly productive, limiting or sensitive habitats, habitat limiting factors to production at each life history stage, and habitat protection and restoration priorities. Given DFO resource constraints, propose pilot scale approach as above;**

- **Initiate the development of freshwater and estuarine habitat classification schemes to standardize the approach for describing relative productivity or sensitivity of habitats – phased approach proposed with initial efforts focused on the identification of highly productive, limiting or sensitive habitats for selected priority stocks/watersheds within priority CU's on a pilot scale as above.**

ACTION STEP 2.2 – Select indicators and develop benchmarks for habitat assessment

Background/Considerations

The policy states that "Indicators for CU's on a watershed scale will be selected to assess the **quantity** and **quality** of the habitats identified in Action Step 2.1. Benchmarks will be developed to reflect the desired values of each indicator." The intent is to track these indicators over time, to assist in habitat planning and management.

In the fall of 2005, the Pacific Fisheries Resource Conservation Council contracted G.A. Packman and Associates and Winsby Environmental Services to undertake a review of background information relevant to the selection of habitat indicators for wild Pacific salmon. A technical workshop was convened in November, 2005 to review the information compiled and build consensus on selection of candidate indicators. The PFRCC issued a report (G.A. Packman and Associates & Winsby Environmental Services 2006) http://www.fish.bc.ca/reports.php?report_id=104 of its key findings in February, 2006 and plans to issue a Ministerial Advisory regarding wild Pacific salmon indicators in the fall of 2006.

The report acknowledges that considerable work has already been done by a number of agencies, particularly in the U.S. Pacific Northwest, in reviewing and identifying wild Pacific salmon habitat indicators. It also states that while indicator selection has been completed on a number of occasions, implementation has not been so successful. Unfortunately, the report did not investigate the challenges or lessons learned by those who have already attempted to undertake Pacific salmon habitat indicators work.

The PFRCC proposes that a mix of Pressure and Status indicators be applied at a number of different geographic scales, including: Ecoregion, Watershed, Reach and Site. Pressure indicators represent the level of stress related to human activity that affects a value of interest (e.g. % forest cover converted to other land uses such as timber harvest, agriculture, urban development). They are correlates or surrogates of the status or potential productivity of fish and fish habitat. Status indicators are direct measures of the condition of a resource such as fish habitat and are used to detect a change in a value of interest (e.g. water temperature, flow, channel stability) as a result of a pressure. The PFRCC report recommends a list of indicators in seven major categories:

- Water Quantity
  - Instream flow
  - Water Abstraction
  - Flow Hydrology

- Water Quality
  - Temperature
  - Chemical – D.O., pH, TDS, Alkalinity, TSS, Turbidity, Nutrients, BOD
  - Biological – Benthic Macroinvertebrates, Zooplankton, Phytoplankton, Chlorophyll *a*

- Physical Habitat
  - Channel Width/Depth
  - Sediment Loading
  - Substrate
  - Spawning Habitat area
  - Off-channel & Wetland Habitat area
  - Migration Obstructions
  - Large Woody Debris

- Aquatic and Riparian Ecosystems
  - Area, Distribution and Types of Riparian & Wetland Vegetation

- Estuarine Ecosystems
  - Change in Area, Distribution & Types of Tidal & Submerged Wetlands
  - Index of Biotic Integrity

- Ecosystem Biodiversity
  - At Risk Species

- Land Use Conversion
  - Land Use/Land Cover Change Effects
  - Road-induced Effects
  - Land Conversion to Impervious Surface Effects

In addition to a potential list of habitat indicators, the PFRCC report identified three key initiatives as a means to move forward with collaborative wild Pacific salmon indicator confirmation and implementation:

- Analysis of Recommended Indicators: Interdisciplinary groups should undertake a detailed analysis of each recommended indicator against a list of technical and feasibility criteria, synthesizing results from analysis of all indicators into a summary matrix;
- Provincial Snapshot: For a selection of indicators considered most likely to advance to implementation, undertake a trial examination of federal and provincial databases to determine availability of data from these sources;

- Pilot Implementation in Selected Watersheds: A pilot program should be implemented in selected watersheds to test the availability of data sources, inter-comparability of data, viability of various partnership approaches and utility of the findings in terms of informing management decisions related to the habitat status of salmon CU's.

Finally, an adaptive management approach is recommended to maximize the potential for selected indicators to be implemented effectively. The approach would be guided by recognizing the advantage of beginning early on a smaller scale, and adapting and growing as experience among relevant parties is gained.

The PFRCC did not investigate the cost of implementing the proposed suite of habitat indicators, however, an April, 2006 NHQ internal memorandum to the Assistant Deputy Minister regarding the PFRCC report advised, "**The implementation of the proposed initiatives would require a significant commitment in human and financial resources. A cost analysis and implementation plan would have to be completed before committing to the proposed initiatives.**"

In response to the PFRCC report, the Pacific Marine Conservation Caucus, in an April 27, 2006 letter to the PFRCC and DFO, issued the following recommendations:

- WSP implementation and proposed activities related to strategy 2 must include and support immediate action to address current habitat threats;
- Habitat indicators should be directly linked to relevant management questions and clearly stated objectives; effective habitat indicator selection requires definition of these questions and objectives;
- Given high uncertainty, particularly with a constrained monitoring system, suitable Pressure indicators with thresholds that trigger action should be used to support a precautionary habitat management system;
- An ecosystem perspective must be applied to all WSP strategies; in particular strategies 2 and 3 must be integrated under an ecosystem-based management approach.

<u>Progress to Date and Proposed Approach</u>

Early efforts of the Working Group focused on gaining a better understanding of why the implementation of a Pacific salmon habitat indicators monitoring program has been difficult to achieve in other jurisdictions. In a word, **COST** has been the most significant constraint. There has been considerable effort devoted to developing and implementing a suite of indicators for salmon ecosystems in the U.S. Pacific Northwest. Some of the agencies endeavouring to make progress on this front include:
The National Marine Fisheries Service (NMFS 1996)
http://www.nwr.noaa.gov/Publications/Guidance-Documents/upload/matrix_1996.pdf ,
U.S. Environmental Protection Agency (USEPA) Environmental and Monitoring Assessment Program (EMAP)
http://yosemite.epa.gov/R10/OEA.NSF/af6d4571f3e2b1698825650f0071180a/d4ea8bc31

230b63d88256877007ab4a9?OpenDocument , Washington State Conservation Commission Salmon Habitat Limiting Factors Program http://www.salmon.scc.wa.gov/programs/ , and Washington State Department of Ecology Status and Trends Statewide Monitoring Framework Project http://www.ecy.wa.gov/programs/eap/stsmf .

A number of Canadian agencies are also involved in, or considering, the collection of indicators data. None, other than DFO, have the explicit objective of monitoring Pacific salmon habitat indicators.

The Province of B.C.'s, Forest and Range Evaluation Program http://www.for.gov.bc.ca/hfp/frep, is developing a stream channel and riparian indicators monitoring program (Peter Bradford, BC Ministry of Forests and Range, personal communication) for Crown forest lands (Tripp et al. 2006) http://www.for.gov.bc.ca/hfp/frep/site_files/indicators/Indicators_Fish-Protocol_for_Streams_and_Riparian_Management_Areas_Monitoring.pdf . MOE utilizes a variety of indicators in their State of the Environment reports http://www.env.gov.bc.ca/soe/index.html and is considering an indicators monitoring program for designated Fisheries Sensitive Watersheds (Lars Reese-Hansen, BC Ministry of Environment, personal communication) http://www.env.gov.bc.ca/wld/fsw .

Environment Canada has established the Canadian Aquatic Biomonitoring Network (CABIN) to develop a network of reference sites that can be used in assessing and monitoring the biological condition of fresh water systems in Canada http://cabin.cciw.ca/Main/cabin_about.asp . A recent draft report submitted to the Working Group (in press) examines CABIN and will provide recommendations regarding the utility of CABIN data as a Pacific salmon habitat indicator. To date, the network of reference sites has been developed for flowing waters only. In British Columbia, the CABIN database contains 274 reference sites in the Fraser/Georgia Basin region and more than 100 in each of the Skeena and Yukon regions. Using a Reference Condition Approach (RCA), benthic invertebrate indicator data from potentially impaired sites are compared to those at a group of regional reference sites that have had minimal human impact. Based on this comparison, the status of the potentially impaired site is determined (e.g. unstressed to severely stressed).

Environment Canada also collects hydrometric and water quality data at a network of stations throughout Pacific Region http://scitech.pyr.ec.gc.ca/climhydro/welcome_e.asp . The agency maintains 500 hydrometric stations in the Region, 450 in B.C. and 50 in the Yukon (Bruno Tassone, Water Survey of Canada, personal communication). These monitor stream discharge, water temperature, and in some cases, sediment concentrations. The agency has entered into cost-sharing arrangements to maintain the network of stations in Pacific Region. Approximately 40% of the cost is funded by Environment Canada, 40% by the Province and 20% by B.C. Hydro, forest companies and other private interests. The estimated cost to establish a new drive-to flow and temperature monitoring station is $10K - $15K for installation and $10K annually to operate and maintain the station.

In addition to government agency efforts, volunteer stewardship organizations such as the Pacific Streamkeepers Federation http://www.pskf.ca/program/program.html , and their U.S. Streamkeeper colleagues http://www.streamkeeper.org , actively monitor and collect stream ecosystem indicators data.

American agencies have probably been the most prolific in assembling and testing comprehensive suites of fish habitat indicators specifically for Pacific salmon. Until recent times, Status indicators have been the predominant type of indicator employed in their monitoring programs. As discussed earlier in this report, Status indicators are direct measures of the condition of various fish habitat attributes and require expensive field sampling programs.

From 1998 to 2003, the Washington State Conservation Commission completed a salmon habitat limiting factors analysis for 45 basins using 9 habitat indicator categories: fish access, floodplain connectivity, sedimentation, riparian, LWD, pool, water temperature, peak flows and base flows (Smith 2005). http://filecab.scc.wa.gov/Special_Programs/Limiting_Factors/Statewide_LFA_Final_Report_2005.pdf Data were collected for each category to develop an indicator rating. The 9 indicator rating scores were then combined to produce an overall basin habitat condition rating. Over the 5-year duration of the project, an average of 9 basin habitat analyses were completed annually at a cost of approximately $1M per year (Carol Smith, Washington State Conservation Commission, personal communication). 8 biologists and 1 GIS specialist were employed full time to complete this work. The program did not involve a field sampling component, as only existing data were used.

Since the completion of this one time effort, the State of Washington has endeavoured to initiate an ongoing habitat indicators monitoring program to report habitat status and trends. To date, none of the budget proposals submitted to the State Legislature have been funded because of the considerable resourcing requirements. Discussions are now focusing on the potential of Pressure indicators, many of which can be monitored remotely at lower cost due to advances in remote sensing technology.

There are reasons other than cost for considering a monitoring program that stresses the use of Pressure indicators for broad scale application. A number of indicators limitations are discussed in a review of aquatic habitat indicators undertaken by the Environmental Protection Agency (Bauer & Ralph 1999). http://yosemite.epa.gov/R10/ecocomm.nsf/37aa02ee25d11ce188256531000520b3/74476bae1ae7e9fb88256b5f00598b43/$FILE/Ahi_fina.pdf. Due to the high degree of natural variability of most Status indicators and sampling precision issues, large sample sizes and years of data collection may be required to detect a statistically significant change in condition. For some Status indicators, there is also the issue of a time lag between a habitat pressure being applied and the resultant change in condition of the indicator. By the time a signal is detected in a Status indicator, it may be too late to mitigate the pressure causing the change. For example, in the case of stream channel Large Woody

Debris (LWD), it may be more useful to monitor a Pressure indicator that measures watershed riparian loss than a Status indicator of stream channel LWD abundance.

Kirk Krueger, Washington State Department of Fish & Wildlife, is currently involved in the development of a multi-agency Pacific salmon habitat indicators monitoring plan for the state (WDOE 2006) http://www.ecy.wa.gov/programs/eap/stsmf/docs/QA_monitoring_plan.pdf . He highlights some of the key issues with an indicators monitoring program in the following exerpts from a May, 2006 e-mail message to the Working Group:

"One of our biggest challenges is simply the spatial and temporal scale of analysis and the associated costs. The US Environmental Protection Agency Environmental Monitoring and Assessment Program (EMAP) has developed some very useful statistical approaches, and they have a pretty good (but extensive) field method for wadeable streams.

The state of Oregon has implemented the EMAP approach for their coastal coho program. Their results were good, but the necessary sample sizes were very large for changes in fish distribution and abundance, and the cost was very high.

The US Forest Service is using a similar approach, but is now transitioning to methods that use remotely sensed data due to cost considerations and their failure to detect trends with several (perhaps 9) years of field data. The Washington Department of Fish and Wildlife is also interested in such an approach, but we've not found funding for implementation.

I guess that we'll likely end up making a decision regarding what to monitor and how to monitor it based largely on the cost and how easily inferences to changes in salmon numbers can be made. We may end up using a hybrid approach that uses remote sensing data from available sources, some purpose-collected remotely sensed data, and perhaps some field measurements of non-random, but important locations.

The cost will vary greatly with the spatial extent, number of sub-regions, type of data, and desired confidence in the results. If field measurements are required (as opposed to aerial photographs or satellite images) the cost of travel to sites will be most of the budget. For a standard EMAP-based approach supplemented with aerial photographs of non-wadeable streams, our very rough estimate was about $200,000 USD per year for each region sampled. Sampling intensity was 50 samples per sampling domain (i.e., 50 wadeable, 50 non-wadeable, and 50 riverine-tidal samples). The sample size (50) is pretty standard, regardless of spatial extent, for each domain. For Washington we estimated a cost of about $ 1.5 million USD per year for 15 to 20 years, just to sample physical habitat.

Personally, I think the EMAP-based approach is technically sound and very well developed. However, it may simply not be possible to maintain funding for such work for the necessary period of time. Questions also remain regarding the usefulness of many habitat parameters for monitoring ..... for many habitat attributes, we cannot expect to detect recovery in such relatively short time periods, for example we can't expect riparian vegetation that is old growth forest to increase (but can expect decreases) in 10 or 20 years."

Following our initial inquiries to learn more about the experiences in other jurisdictions, the Working Group began the task of assembling and categorizing a comprehensive list of potential Pressure and Status indicators from a number of sources (Appendix 4, pgs. 39-40). A matrix was created which lists potential indicators on one axis and key Pacific salmon fresh water habitat attributes and objectives on the other. The list of habitat attributes was derived from NMFS, the Washington State Conservation Commission and the species life history strategy documents completed by the Working Group.

We then assessed the value of each Pressure and Status indicator for each salmon habitat attribute according to how strong the link was between the indicator and the habitat attribute (Appendix 4, pgs. 41-44). The scoring was based on expert opinion of the group. If consensus opinion was that the indicator linked directly to the habitat attribute it was scored as a 1, an indirect link was scored as a 0.5 with a comment explaining the link, and if no link, there were no points given. For example, group opinion scored a direct link between the Pressure indicator, water withdrawal, and the habitat attribute, water temperature (score=1), no link to the habitat attribute, LWD (score=0), and an indirect link to the habitat attribute, % substrate fines (score=0.5), with the following comment: water withdrawals that result in a reduction of peak flows may lead to accumulation of fines in gravel, however, water withdrawl associated with reservoirs generally results in reduced sediment loads d/s of dam. Total scores were tallied and indicator utility ranked as follows:

<u>Pressure Indicators</u>

1. stream length channelization/floodplain alienation
2. stream length riparian zone alteration
3. road density
4. % watershed area converted to various land uses (forestry, agric, urban)
5. % watershed area impervious surface
6. % wetlands loss
7. water abstraction
8. % lake foreshore alteration
9. % estuary foreshore alteration

For status indicators, the habitat quanitity measures described in Step 2.1 will be adopted. Most of these habitat quantity indicators are listed in the Appendix 4 Status indicators table (highlighted yellow), but were not included in the analysis.

There are also a number of biota Status indicators (fish, benthic macroinvertebrates, periphyton, ecosystem biodiversity) in use in the Pacific Northwest. However, they were not included in this analysis for the following reasons: fish community abundance may vary substantially from year to year for reasons unrelated to habitat; a separate analysis of the utility of benthic macroinvertebrates has been undertaken (pg. 9); the periphyton indicator is not widely used, nor is data readily available; and the ecosystem biodiversity indicator should be considered under Strategy 3.

The remaining Status indicators in the table ranked as follows:

Status Indicators

1. stream discharge measures (base & peak flows)
2. channel stability measures (pool:riffle, channel width:depth ratios, etc)
3. water temperature
4. water chemistry parameters
5. LWD, instream cover
6. sediment load measures

This preliminary analysis focused on indicators that link to stream habitat attributes and objectives. Further work is required to develop useful lake and estuary habitat attributes/objectives and indicators.

Additional analysis of indicator utility is under way in a Working Group project to complete a literature review of the current state of knowledge regarding Pacific salmon habitat productivity models (in press). Potentially useful models were identified based on a match between the variables used in the productivity models and the preliminary Pressure and Status indicators. A total of 104 potentially useful documents containing habitat models were identified in the literature search. Further analysis will be undertaken to determine the relationship between the proposed indicators and the habitat model variables, and the potential utility of some of the proposed indicators as estimates of fish production.

Following our preliminary indicators work, the Working Group convened a meeting with Science habitat experts in early July, 2006 to review the proposed indicators lists and begin the task of identifying key lake and estuary habitat attributes and potentially useful indicators. There was general support for the ranked lists of Pressure and Status indicators, however, it was felt that Water Abstraction should be ranked higher on the list of Pressure indicators. Two additional indicators were recommended: human population density and exotic species.

Some preliminary ideas were put forward for lake and estuary habitat indicators as follows:

- For lakes, key habitat attributes include lake area, trophic level, shoreline complexity, inflowing stream delta integrity and water quality parameters such as water temperature, D.O, pH, nutrient level and alkalinity. It was felt that lake area, shoreline complexity and stream delta integrity may be adequately represented in the existing list of indicators, but further work is required to define useful lake Status Indicators for trophic level and water quality attributes. For Pressure Indicators, the existing % lake foreshore alteration and watershed land use indicators may be adequate and additional indicators unnecessary.

- For estuaries, habitat attributes include total estuary area and area of key vegetation communities such as sedge and eelgrass, shoreline complexity, # of in-flowing non-natal streams, LWD and degree of sediment aggradation or degradation. While estuarine area and shoreline complexity may be adequately represented in the existing list of indicators, follow-up was recommended to further define key habitat attributes and potential Status Indicators. For Pressure Indicators, the existing % estuarine foreshore alteration indicator is a start, but there also needs to be an indicator that captures total estuarine surface area habitat pressures caused by activities such as shipping traffic and log booms. A measure of shipping traffic volume was suggested as a potential Pressure Indicator. Further work is required here.

Given DFO's limited resources, a general recommendation from the Science meeting was to emphasize the application of Pressure indicators for CU's across a broad landscape. Indicator benchmarks or thresholds need to be established and a cumulative stress index rating system developed to identify those CU's most at risk to habitat pressures. Status indicators monitoring would then be applied strategically to identify specific habitat threats and constraints in a stressed CU.

The application of Pressure indicators across a broad landscape is also of interest to the Province of B.C. Data for a number of the proposed Pressure indicators exist in the Integrated Land Management Bureau's, standard watershed statistics product. For most of the Province, the statistics have not been updated since the mid-90's and much of the road density data is from work in the late 80's. The watershed statistics coordinator, Malcolm Gray, estimates the cost of providing updated watershed statistics using satellite imagery, at $0.05 - $0.40 per square kilometer (Malcolm Gray, BC Integrated Land Management Bureau, personal communication). The cost varies depending on the number of indicators required and the size of the watershed.

The Province is interested in updating watershed statistics data in areas such as the Mountain Pine Beetle (MPB) zone, Vancouver Island and the North Coast. DFO will want to consider collaborative funding arrangements to update selected watershed statistics for priority CU's that overlap with Provincial LRMP priorities.

<u>Recommendations for Moving Forward in Fiscal 2006-07</u>

- **Complete work to develop a list of useful lake and estuary habitat attributes/objectives and potential indicators;**

- **Finalize the selection of a suite of Pressure and Status indicators and initiate work on the development of a cumulative stress index rating system for identifying CU's exposed to significant habitat pressures;**

- **Undertake literature review to determine state of knowledge regarding metrics and benchmarks used in the application of selected Pressure indicators. Determine Pressure indicator metrics that match up well with those reported in the Province's watershed statistics product;**

- **Initiate further research and analyses that link watershed-level Pressure indicators to habitat condition/fish production. This is key to setting indicator thresholds and interpreting temporal functional relationships (e.g. riparian vegetation link to long-term LWD supply);**

- **Given DFO resource constraints, focus on the application of Pressure indicators for priority CU's located in regions where the Province has expressed interest in updating the watershed statistics product (MPB zone, Vancouver Island, North Coast). Undertake an indicators analysis for selected test watersheds/CU's to better understand issues such as data availability/correction, spatial matching of habitat to Pressure indicators, indicator interpretation, costs, etc.;**

- **For CU's with a poor cumulative stress index rating, test the strategic application of Status Indicators, applying threshold values from Working Group species life history stage habitat requirements tables, NMFS and Washington State Conservation Commission to identify specific habitat threats and constraints. Propose a pilot scale approach to gain a better understanding of feasibility, implementation costs and partnering opportunities.**

ACTION STEP 2.3 – Monitor and Assess Habitat Status

Background/Considerations

The third step of Strategy 2 is essentially the implementation of the monitoring and assessment framework developed in the first 2 steps. The policy states that "The implementation of monitoring and assessment of habitat status will provide four key inputs to guide habitat management. These are:

- Important habitat in need of protection to maintain salmon productivity;
- Habitat risks and constraints that are adversely affecting that productivity;
- Areas where habitat restoration or rehabilitation would be desirable to restore or enhance productivity;
- Investigations to fill information gaps."

These key inputs are viewed as essential pieces of information to bring to the integrated strategic planning processes identified in the WSP's Strategy 4.

Progress to Date and Proposed Approach

Some habitat quantity and quality elements of a monitoring and assessment framework have been described in Steps 2.1 and 2.2. However, considerable work is still required to develop the habitat indicators element of the framework. Preliminary work has been undertaken to learn more about the indicators sampling design and monitoring plan being proposed in Washington State (WDOE 2006).

The Working Group has proposed a preliminary list of habitat Pressure and Status indicators. Work now needs to commence with Science and external partners to select the appropriate mix of indicators and design a monitoring and assessment framework for application on a pilot scale in priority CU's. A pilot project will help DFO and its partners learn about the feasibility and costs of an indicators monitoring program before undertaking to design a framework for implementation across the Region. This work will also benefit the implementation of the Habitat Compliance Modernization (HCM) element of EPMP. One of the primary objectives of HCM is to improve the measurement of habitat management results by monitoring the health and status of fish habitat at the ecosystem level to assess cumulative impacts.

Recommendations for Moving Forward in Fiscal 2006-07

- **In addition to the habitat monitoring and assessment framework elements recommended in Steps 2.1 and 2.2, further consultation required with U.S. colleagues and potential partners to refine a sampling design and monitoring and assessment framework for selected Pressure and Status indicators;**

- **Implement monitoring and assessment framework on a pilot scale in priority CU's as per recommendations in Steps 2.1 and 2.2. Given the link to EPMP/HCM, HCM staff should play a key role in the implementation of the habitat monitoring and assessment element of WSP's Habitat Strategy.**

ACTION STEP 2.4 – Establish linkages to develop an integrated data system for watershed management

Background

Given the limited resources DFO has available to undertake new work and the considerable resources required to implement a habitat indicators monitoring program, successful implementation of Strategy 2 will require the establishment of data sharing and management partnerships with key agencies. Many of the proposed indicators will rely on data currently collected and managed by other agencies.

A key objective is to increase access to information on fish habitat status. The policy states that "A more unified salmon habitat data system can be achieved by improving common access to the extensive data holdings of DFO, Provincial and Territorial agencies, other levels of government, and stakeholders that describe watersheds and habitat conditions. Improved sharing of information will accelerate and strengthen assessment and reporting of habitat status for CU's." The policy does not explicitly refer to other federal department data holdings, but partnerships are required with other

Federal agencies such as Environment Canada, Parks Canada and Natural Resources Canada.

Meaningful support of data sharing agreements between partners requires long term resourcing commitments and well-defined custodial roles to ensure important data sets are adequately maintained. This has been a challenge for DFO and other agencies. Those partners who are funding data collection efforts must also ensure that a condition of funding is for projects to comply with data standards and submission to a centralized data warehouse.

Progress to Date and Proposed Approach

The Working Group has identified a number of opportunities for collaboration (Step 2.2, pgs.8-11) in the development of an integrated data system for watershed management.

There has been much discussion in recent months about the need to establish an interagency, interdisciplinary team to develop a watershed status and threats decision support tool that integrates watershed information from a variety of sources. It has been a common theme in Working Group discussions with other agencies and is the approach adopted in the Washington State Habitat Status and Trends Monitoring proposal, discussed earlier in this report. A revitalized joint Federal/Provincial MOU to formalize collaboration in the development of a shared data management system would assist in advancing partnership opportunities. One approach would see data custodians manage data to shared standards and make data and GIS layers accessible to map viewing tools such as Mapster which allow the user to overlay relevant data layers. During WSP consultation sessions, First Nations and stakeholders strongly expressed the need for improved interagency cooperation in data management and data sharing, for WSP Strategy 2 implementation to be successful.

A key objective of the Fraser Basin Living Rivers Program, is to bring together key partners to develop an integrated decision support tool that evaluates watershed status and threats. This is also an objective identified in WSP's habitat strategy. The interest level of potential partners is high and the opportunity now exists to advance the development of an integrated data system for watershed management. It is unclear how this will work, but the Fraser Basin Living Rivers Program could be viewed as a test case for interagency collaboration.

Recommendations for Moving Forward in Fiscal 2006-07

- **Revitalize joint Federal/Provincial MOU to formalize collaboration in the development of a shared data management system including, adopting shared data standards, clearly defining data management custodial roles, committing long-term resources to database maintenance, and ensuring that conditions of funding for data collection projects include compliance with data standards and submission of data to a centralized data warehouse;**

- **Given the common interest of a number of agencies in the development of indicators monitoring approaches, establish an interagency technical team to identify common indicators and data sources, establish common data standards, define data management roles and responsibilities and develop partnership budgets.**

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APPENDIX 1

EXAMPLE SPECIES LIFE HISTORY DESCRIPTION

Habitat Requirements for Coastal Coho Salmon Populations

General Life History

Coho salmon are found in coastal streams throughout British Columbia. Mature adults return to their river of origin to spawn during the fall or early winter. Coho tend to stray from their home streams and spawn in other locations at a greater rate than other salmon species. This strategy helps protect against the loss of an entire stock due to some environmental catastrophe in the home stream and also extends the normal range of a stock into new and potentially more productive areas. Coho spawning habitat is very diverse ranging from large river systems to small headwater streams and in some cases even includes drainage ditches. The majority of coho mature in their third year of life. The exceptions to this pattern include males (referred to as jacks) that return to spawn in their second year of life after only a few months at sea and four year old coho that have spent an additional year rearing in either fresh or salt water. When fish reach the spawning grounds, the female selects a nest site and begins digging a pit referred to as a redd, where eggs will be deposited. The digging process removes sand, silt and fine gravel from the nest site creating a favourable environment for incubation of the eggs. Once the nest is complete, the female deposits the eggs which are fertilized by one or more males and then moves to the area immediately upstream of the nest and begins digging another pit. The material removed by this digging action covers the fertilized eggs to protect them from predation and from being washed away by the scouring action of the river or stream. This process may be repeated several times resulting in multiple nests containing eggs from one female.

The length of time required for the eggs to incubate depends to a large extent on water temperature. In general, the lower the water temperature, the longer the incubation period required. Upon hatching, the juvenile coho (called alevins) move downward in the gravel varying distances depending on gravel size. At this point, the young fish have an attached yolk sac that provides the required nutrition. Towards the end of incubation, alevins move up through the gravel to emerge as fry. This occurs between mid March and late June and generally coincides with the complete absorption of the yolk sac. Many factors influence survival to this life stage but under average conditions, 15 to 30% of the fertilized eggs will emerge from the gravel.

After emergence, fry take advantage of any cover that is available hiding under boulders and along stream banks under overhanging branches. The young juveniles tend to seek out quiet backwaters, side channels and small creeks during early development. In some watersheds, fry will migrate into nearby lakes or ponds to rear. In stream environments, coho juveniles are found in both pool and riffle areas, though they generally prefer holding in pools where they set up and defend territories. While juvenile coho eat a variety of food items, adult and larval insects make up the bulk of their diet. As they grow in size, coho become predatory on small fish, adding fry of their own and other species to the food consumed.

By late fall/early winter, feeding activity decreases as water temperatures drop. At this point, coho move into deep pools or into a variety of off-channel habitats preferring those with logs, exposed roots and overhanging vegetation that provide cover. The high flows associated with winter run-off in coastal streams often results in the displacement of juvenile coho from the system. Refuge areas such as side channels, small tributaries, ponds and lakes become important for survival as they provide shelter from flood events. The productivity of many coastal systems depends on the availability of good winter refuge habitat and those with abundant off-channel refuge areas lose fewer fish during extreme winter flood events.

The migration of juvenile coho downstream to the sea begins in the spring and continues over a period of three to four months. In most southern British Columbia coastal systems, this migration peaks in May. The coho at this stage of their life are referred to as smolts and generally measure between 90 and 115 mm in length. In the majority of southern coastal systems where water temperature and food availability are favourable, coho become smolts after spending only one year rearing in fresh water. In some less productive northern coastal systems, many coho juveniles spend two years in fresh water before smolting. During migration to the estuary, coho smolts are vulnerable to a wide range of predators that include larger fish, birds and marine mammals. In some cases, this predation can have a large impact on survival.

When they first enter salt water, coho smolts primarily feed on marine invertebrates, but as they grow larger, smaller fish begin to dominate their diet. Growth during the marine phase is rapid due to the abundance of high quality food items. For the majority of coastal coho salmon, sexual maturation occurs during their second summer at sea when the journey back to the river of origin begins. Most mature adult coho finish their ocean rearing phase after about 16 months at sea when they are three years old.

Habitat Requirements by Life History Stage

The decline in abundance of coastal coho salmon populations over recent years is due in large part to reduced marine survival. However, major concerns have also been raised over the loss and degradation of fresh water habitat due to increasing economic and developmental pressures. The loss of habitat is associated with the increase in the number of people living near coho rearing streams and also with the increased intensity of resource use. Low-gradient streams within 100 km of the coast make up a significant proportion of the fresh water habitat for coastal coho salmon populations in British Columbia. These are also the most desirable areas for human settlement and economic development activities. Consequently, coho habitat remains threatened throughout Pacific coastal regions. This is especially true of small streams and off channel areas which have often not been properly protected from development.

Spawning

Adult salmon require unimpeded access to their home spawning grounds in order to successfully reproduce. Features such as dams, debris jams, waterfalls, or rock/mud slides that block upstream migration can limit access to spawning areas and impact production. Also, if conditions such as high water temperature or extreme high or low flows are encountered when spawners arrive at their river or stream of origin, fish often mill about in the vicinity of the river mouth, waiting for conditions to improve. This delay in river entry can have a detrimental affect on survival and on spawning success as fish are exposed to predation from marine mammals and, since feeding has stopped in preparation for spawning, vital energy reserves are used up. As a result, ***it is important to critically assess any activities that impact river flows or water temperatures when mature coho are returning to spawn and to ensure that fish have unimpeded access to spawning grounds.***

Spawning coho salmon require gravel that is small enough to be moved by the fish and large enough to allow good intragravel water flow to the incubating eggs and developing alevins. This ensures that the environment in the nest is supplied with a constant flow of water that delivers oxygen and removes waste. ***A lack of clean spawning gravel of the appropriate size can limit coho production in some systems*** as spawners may be forced to build redds in secondary locations where egg survival will be reduced.

Incubation

During incubation, eggs and alevins require a stable environment with an uninterrupted supply of clean, oxygen rich water. The percentage of eggs and alevins that survive the incubation phase depends to a large extent on stream and stream bed conditions. ***Flooding during winter*** months can result in a large amount of gravel movement which ***reduces survival by causing eggs or alevins to be exposed and swept downstream***. Also, silt loads associated with flooding may hinder water circulation through the redd reducing available oxygen to harmful or lethal levels. Studies have shown that ***a higher proportion of fine sediment in the spawning gravel reduces survival*** and results in smaller emergent fry. Activities that contribute to flooding or siltation of incubation areas can magnify the impact of extreme winter conditions and reduce survival to emergence.

Juvenile Rearing

Stream Habitat:

Due to an extended fresh water rearing phase, coho salmon populations are often limited by the amount of quality freshwater rearing habitat available. Juvenile coho salmon require a variety of habitats during each season of their fresh water rearing phase. ***During the summer, the stream's carrying capacity may be constrained due to low flows which limit the quantity of pool habitat*** and therefore, the number of suitable territories that are available. In addition, low summer flows can reduce the overall wetted area available to coho and strand juveniles in isolated pools. This results in increased vulnerability to starvation, disease and predation. ***High summer water temperatures can affect juvenile coho distribution, abundance and survival*** in coastal streams. While it may be rare for water temperatures to reach lethal levels, sub lethal water temperatures can negatively impact juvenile coho by increasing metabolism, lowering the amount of dissolved oxygen available in the water, and by forcing coho out of preferred habitat.

During the winter, juvenile coho salmon require habitats with low water velocities such as side channels, back waters, beaver ponds, deep river pools, and pools formed by large woody debris and root wads. Research indicates that ***in many coastal systems, it is the amount of suitable winter habitat that limits coho production***. These habitats provide protection from high discharge as well as protective cover from predators and there is often a strong relationship between smolt abundance and the amount of off-channel habitat available in a system.

Streamside (riparian) vegetation plays an important role in regulating the temperature in coho rearing streams. Cooler winter water temperatures may occur if the stream canopy is absent or reduced while warmer summer temperatures may make the habitat unsuitable or may increase the mortality of fry from disease. Also, ***streamside vegetation acts as a habitat for terrestrial insects and a source of leaf litter utilized by stream invertebrates***. Both of these factors act to increase the food available to juvenile coho rearing in streams. Finally, ***riparian vegetation provides cover from predators and stabilizes stream banks***, which reduces the amount of sediments that enter the stream. Any activities that negatively impact the riparian habitat of coho rearing streams will have a detrimental effect on coho juveniles and act to reduce coho production.

Juvenile coho salmon require clean, unpolluted water during their entire freshwater rearing phase. Waste water, pesticides, toxic chemicals, organic compounds and sediments all have a negative impact on stream habitats. Of these, ***sediments*** may pose the most common and significant risk as the inputs to streams from both natural and human related activities can ***have a very detrimental effect on fish habitat***. Fine sediments in the water irritate gills, impair feeding and reduce the quality of the habitat for the aquatic insects which are a very important food source for coho.

Floodplain and Estuarine Habitat:

The wetlands associated with ***floodplains*** are important habitats for juvenile coho salmon. Floodplains provide nutrient rich seasonal wetlands, temporary tributaries, off-channel ponds, sloughs and seasonal drainages. Juvenile coho salmon require access to these important habitats which ***perform many vital functions including flood energy dissipation, filtration, trapping of sediments and nutrients, and the partial removal of pollutants***. Coastal coho that utilize these regions have adapted behaviors that enable them to successfully exploit seasonally flooded lands. Activities such as diking and road and rail development have greatly reduced the amount of salmonid floodplain habitat in many systems. As a result, it is critical that remaining floodplains are protected.

While juvenile coho salmon do not generally spend long periods in estuaries, studies have indicated that coho smolts enroute to the ocean migrate more slowly through these areas than they do through stream or river environments. This observation suggests that ***estuaries are important areas for young coho salmon***. The time spent in the estuary may be ***necessary for them to adjust to a saltwater environment*** that is dramatically different from the freshwater habitat that has been their home during the first part of their life. ***Estuaries are productive feeding areas that also provide cover from predators during the transition from fresh to salt water.*** Consequently, clean, unaltered estuaries are important for sustaining coho populations.

Ocean Phase

When coho smolts enter salt water they begin a critical phase in their life history. Studies have indicated that coho remain in the near shore environment for varying periods depending on factors such as food availability and that overall ***survival is largely driven by ocean conditions during early salt water residence***. Throughout this period, kelp and other vegetation provide important refuge from predators. Since survival at sea is generally size-selective, favourable near-shore ocean productivity is important as it can result in faster growth and a shorter time to reach the size required to escape from predators.

The distribution of coho in offshore waters is dependent on ocean environmental conditions and on food availability. While migration patterns and other aspects of their marine ecology remain poorly understood, ***ocean residence is recognized as a very important component of the life cycle of all Pacific salmon***. During their time at sea, coho migrate varying distances while increasing in size and acquiring the energy reserves required for reproduction. While distribution patterns vary between years and stocks, all coho utilize coastal and off shore habitats during a period of rapid growth that is critical to reproductive success.

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APPENDIX 2

EXAMPLE SPECIES HABITAT REQUIREMENTS BY LIFE HISTORY STAGE

Key Habitat Requirements for Coastal Coho Salmon by Life History Stage

Life Stage	Habitat Parameter	Acceptable Values	Source
Spawner / Egg / Alevin	General Temperature	Proper functioning for all adult Pacific salmon between 10.0 and 13.9 ^{0}C.	NMFS 1996
		Adult Pacific salmon at risk between 13.9 and 15.5 ^{0}C.	NMFS 1996
		Many fish diseases become more virulent at temperatures over 15.6 ^{0}C.	McCullough 1999
		Disease infection rates in coho increase at temperatures above 12.7 ^{0}C.	Groberg *et al.* 1978 in McMahon 1983
		Preferred temperatures for coho range from 11.7 to 14.4 ^{0}C.	Bell 1986
		Lower lethal limit = 0 ^{0}C; upper lethal limit = 25.6 ^{0}C.	Bell 1986
	Migration Temperature	Upstream migration to the spawning grounds occurs when the water temperature is between 7.2 and 15.6 ^{0}C.	Bell 1986
		Temperatures of less than 13 ^{0}C have been recommended to minimize prespawning mortality in coho during upstream migration.	McMahon 1983
		Upstream migrations of coho salmon are delayed at temperatures over 21.1 ^{0}C.	Bell 1986
		Water temperatures over 25.5 ^{0}C are lethal to migrating Pacific salmon.	Bell 1973
	Spawning Temperature	Coho spawn at temperatures of 6 to 12 ^{0}C.	Briggs 1953 in Hassler 1987
		Coho spawn at temperatures of 4.4 to 9.4 ^{0}C.	Bell 1986
		Optimum water temperatures during spawning are from 5.6 to 13.3 ^{0}C.	Sandercock 1991

	Incubation Temperature	Optimum temperature for incubation of coho eggs is between 4.4 and 13.3 ^{0}C.	Bell 1986
		Degree days to hatch = 1036 ± 136.	Fraser *et al.* 1983
Spawner / Egg / Alevin	Water depth	18 cm is the minimum depth required for upstream migration and for spawning.	Thompson 1972 in Reiser and Bjornn 1979
		Water depth of 10 to 540 cm required for spawning.	Hassler 1987
		Preferred redd construction sites in riffle areas that are greater than 15 cm deep.	Smith 1973 in McMahon 1983
	Flow	Maximum velocity during adult upstream migration is 2.44 m/s.	Thompson 1972 in Reiser and Bjornn 1979
		Prefered spawning at flows from 30 to 91 cm/s.	Thompson 1972 in Reiser and Bjornn 1979
		Spawning occurs at flows from 0.3 to 0.75 m/s.	Sandercock 1991
		Preferred redd construction sites in riffle areas that have velocities of 0.21 to 0.70 m/s.	Smith 1973 in McMahon 1983
	Flow Through Redd	Intragravel flows of 3.0 cm/s were measured through artificially constructed redds.	Zimmerman and LaPoint 2005
	Gravel Size & Sedimentation	Lower survival with smaller particle size.	Barnard 1992
		Suitable spawning substrate ranges from 1.3 to 15 cm in diameter.	Hassler 1987
		Particles of less than 6.4 mm have the potential to infiltrate redds and prevent the emergence of fry.	Lisle 1989
		When fines (particles less than 6.4 mm) exceeded 30% of the substrate, survival to emergence was reduced by 50%.	Kondolf 2000

		Study of coastal Washington streams found that if more than 13% of the substrate was less than 0.85 mm in size, almost no coho eggs survived.	McHenry *et al.* 1994
		Redds with 1.3 to 10.2 cm diameter substrate sizes and a low percentage of fines result in high survival of embryos.	Thompson 1972 in Reiser and Bjornn 1979
Spawner / Egg / Alevin	Turbidity	Silt loads of less than 25 mg/l preferred.	Reiser and Bjornn 1979
		Levels of 1400 to 1600 ppm result in reduced survival of coho adults.	Lloyd 1987
		Silt loads exceeding 4,000 mg/l may stop the upstream migration of adult salmon.	Bell 1973
	Dissolved Oxygen	DO levels greater than 6.3 mg/l are recommended for successful upstream migration of anadromous salmonids.	Davis 1975
		Any reduction below saturation reduces survival.	Chapman 1988
		Survival of coho eggs to emergence drops off dramatically when intragravel DO levels fall below 8 mg/l.	Reiser and Bjornn 1979
		Minimum concentrations should remain at or near saturation with temporary reductions no lower than 5 mg/l for all anadromous salmonids.	Reiser and Bjornn 1979
		DO levels of less than 3 mg/l are lethal.	Davis 1975
Fry/Juvenile Summer	General	During the summer, a streams carrying capacity for coho juveniles may be constrained due to low flows which limit the quantity of pool habitat. High water temperatures can also affect coho distribution, abuncance and survival.	Sandercock 1991; McMahon 1983; Hassler 1987

	Flow	Age 0 coho generally prefer flows from 0.9 to 0.30 m/s; preferred riffle velocities range from 0.31 to 0.46 m/s; preferred pool velocities range from 0.09 to 0.24 m/s.	Reiser and Bjornn 1979
		Low flow pools of 50 to 250 m^2 in size are optimum for production.	Sandercock 1991
		A pool to riffle ratio of 1:1 provides optimum conditions.	McMahon 1983
Fry/Juvenile Summer	Temperature	Preferred temperature range is from 12 to 14 ^{0}C.	Brett 1952
		Lower lethal limit = 1.7 ^{0}C; upper lethal limit = 26.0 ^{0}C.	Brett 1952
		Juvenile coho growth stops at 18 to 20.3 ^{0}C.	Armour 1991; Stein *et al.* 1972
		Optimum growth occurs between 9 and 15.6 ^{0}C.	Brett 1952; Armour 1991; Stein *et al.* 1972
		Many fish diseases become more virulent at temperatures over 15.6 ^{0}C.	McCullough 1999
		Juvenile coho migration occurs between 7.2 and 16.7 ^{0}C.	Bell 1986
	Riparian Buffer	Streamside vegetation plays an important role in regulating the temperature in coho streams.	Sandercock 1991; McMahon 1983
		One potential tree height for all salmon bearing streams.	Spence *et al.* 1996
		A minimum 100 foot buffer strip surrounding all agricultural lands for protection of all aquatic resources.	Welch 1991
		As defined in the BC Forest Practices Code.	
	Water Depth	Age 0 coho prefer depths from 0.3 to 1.22 m.	Reiser and Bjornn 1979
		Coho juveniles are most abundant in large pools that are greater than .3 m in depth.	McMahon 1983

	Substrate	Juvenile coho refer gravel substrates ranging from 2 - 100 mm in particle size.	Dolloff and Reeves 1990
Fry/Juvenile Summer	Turbidity	Levels of 509 to 1217 ppm are fatal to juveniles.	Lloyd 1987
		Levels of 500 ppm result in stress responses in juveniles.	Lloyd 1987
		Levels of 100 to 300 ppm result in reduced feeding of juveniles.	Lloyd 1987
		Turbidities as low as 25 nephlometric units (ntu) caused a reduction in juvenile coho growth.	Sigler *et al.* 1984
	Dissolved Oxygen	Maximum growth for juvenile coho occurs at about 8.3 mg/l.	Colt *et al.* 1979
		Growth rate and food conversion efficiency is optimum at DO concentrations above 5 mg/l.	McMahon 1983
		Mortality of juvenile coho was high at DO levels averaging 2.1 to 2.3 mg/l and those surviving showed reduced consumption and weight loss.	Colt *et al.* 1979
Fry/Juvenile Winter	General	Many studies indicate that it is the amount of suitable winter habitat that limits coho production. During winter, coho juveniles seek out a variety of off channel habitats that provide protection from high winter flows.	Sandercock 1991; McMahon 1983; Hassler 1987
	Temperature	Preferred temperature range is from 12 to 14 ^{0}C.	Brett 1952
		Lower lethal limit = 1.7 ^{0}C; upper lethal limit = 26.0 ^{0}C.	Brett 1952

Fry/Juvenile Winter	Water Depth	As water temperatures decrease, juvenile coho seek out water that is more than 45 cm in depth.	Bustard and Narver 1975 in McMahon 1983
	Flow	During winter, coho juveniles prefer slow moving water with flows of less than 15 cm/s.	Bustard and Narver 1975 in McMahon 1983
	Cover	Since swimming ability is reduced as water temperatures drop, winter cover such as log jams, exposed roots and flooded brush areas become crucial as they provide prtection from predation, freezing and high flows.	Bustard and Narver 1975 in McMahon 1983; Mason 1976
Smolt	General Migration	Require adequate migration corridors between rearing areas and the ocean; these areas must have appropriate cover and food for migrating smolts.	McMahon 1983
	Temperature	Elevated water temperatures can accelerate smoltification and shorten the smolting period which may result in seaward migration of smolts at a time when the conditions are unfavourable.	Wedemeyer *et al.* 1980 in McMahon 1983
		Temperature should not exceed 10 ^{0}C in late winter to prevent accelerated smoltification; temperatures should not exceed 12 ^{0}C during smolting and seaward migration in the spring to prevent shortened duration of smolting and onset of desmoltification as well as to reduce the risk of pathogens.	Wedemeyer *et al.* 1980 in McMahon 1983

Smolt	General Estuary	May remain in the estuary for a short period while preparing for life in saltwater; require food, cover and conditions that are intermediate between fresh and saltwater to complete smoltification.	Sandercock 1991
Marine Coastal	General	May rear in outer estuary or off tidal flats until fall.	Williams 1989
		Tend to migrate north along the coast; remain in the near shore environment for varying periods depending on such parameters as food availability; utilize cover such as kelp and other vegetation to minimize exposure to predators.	Sandercock 1991
		Survival at sea is generally size-selective, so salmon must enter the ocean at a large size or grow rapidly if they are to survive.	Quinn 2005
Marine Offshore	General	May migrate far offshore; feed primarily on small fishes; distribution associated with ocean environmental conditions and food availability.	Sandercock 1991
		The migration of salmon at sea remains poorly known, as does their marine ecology in general. The effects of changing environmental conditions on migration, growth and survival are recognized but not well understood.	Quinn 2005