Canada’s Policy for Conservation of Wild Pacific Salmon: Stream, Lake, and Estuarine Habitat Indicators

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CANADA'S POLICY FOR CONSERVATION OF WILD PACIFIC SALMON: STREAM, LAKE, AND ESTUARINE HABITAT INDICATORS

by

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Strategy 2 of the Wild Salmon Policy (WSP) requires an assessment of habitats associated with salmon Conservation Units (CUs) within the Pacific Region. Habitats that support or limit salmon production within CUs are to be identified and indicators selected to assess these habitats. This paper focuses on the development of the proposed suite of habitat indicators and their related metrics and benchmarks. A consultative strategy was used to identify potential habitat indicators, which involved the creation of a Habitat Working Group (HWG) consisting of expert practitioners drawn from habitat management (principally) and habitat science backgrounds. The HWG systematically applied their knowledge and experience to review and select indicators to track spatial and/or temporal trends in the status of habitats used by wild salmon. Targeted reports were also commissioned by the HWG to further consolidate and ultimately filter down a large, potential list to a relevant subset of habitat indicators that could be feasibly developed for long-term Strategy 2 monitoring. A Pressure-State model was employed to partition indicators into two monitoring streams. Pressure indicators describe external (generally man-made) stressors that would be monitored over broad geographic areas. State indicators describe habitat condition, with related monitoring conducted within areas where pressure indicators indicate potential habitat problems. Nineteen habitat indicators were proposed for Strategy 2 monitoring of streams, lakes and estuary habitats: 7 pressure indicators (*land cover alteration, road development, water extraction, riparian disturbance, marine vessel traffic, estuary disturbance, and permitted discharges*), 8 state indicators (*suspended sediments, water quality, water temperature, stream discharge, lake productive capacity, coldwater refuge zone, estuary chemistry and contaminants, and estuary dissolved oxygen*), and 4 indicators of habitat quantity (*accessible stream length, stream key spawning area, lake shore spawning area, and estuary habitat area*). Quantitative metrics were identified to consistently measure the selected indicators for comparison to benchmarks. Where possible, benchmarks for the metric of each pressure and state indicator were defined based on the risk of adverse effects. Where risk could not be specifically defined, alternative benchmarks such as comparisons over time or space were recommended. Related monitoring is intended to track the status and trends of salmon habitats in CUs. Next steps include filling existing data gaps, defining an overall assessment framework, and linking habitat monitoring to salmon population and ecosystem monitoring under Strategies 1 and 3 of the WSP. Remaining challenges include determining how to combine and roll-up information from the suite of selected pressure, state and habitat quantity indicators to assess overall habitat status within a CU.

RÉSUMÉ

Stalberg, H.C., Lauzier, R.B., MacIsaac, E.A., Porter, M., and Murray, C. 2009. Canada's policy for conservation of wild pacific salmon: Stream, lake, and estuarine habitat indicators. Can. Manuscr. Fish. Aquat. Sci. 2859: xiii + 135p.

La stratégie 2 de la Politique concernant le saumon sauvage (PSS) prévoit l'évaluation des habitats associés aux unités de conservation (UC) du saumon dans la région du Pacifique. On doit procéder à l'identification des habitats qui soutiennent ou limitent la production de saumons dans les UC et choisir des indicateurs pour évaluer ces habitats. Le présent document est axé sur l'élaboration de la série d'indicateurs de l'habitat proposée ainsi que sur la définition des paramètres et des points de référence connexes. On a eu recours à un processus de consultation pour identifier les indicateurs de l'habitat potentiels, ce qui a nécessité la création d'un groupe de travail sur l'habitat (GTH) formé d'experts en gestion de l'habitat (principalement) et en sciences de l'habitat. Les membres du GTH se sont servis de leurs connaissances et de leur expérience pour passer en revue et retenir des indicateurs permettant d'assurer un suivi des tendances spatiales et/ou temporelles de l'état des habitats utilisés par le saumon sauvage. Le GTH a également demandé que des rapports ciblés soient réalisés afin de consolider davantage et, ultimement, d'épurer une longue liste d'indicateurs potentiels afin de produire un sous-ensemble pertinent d'indicateurs qui pourraient être élaborés pour assurer la surveillance à long terme prescrite dans la stratégie 2. On a utilisé un modèle pression-état-réponse pour répartir les indicateurs selon deux types de surveillance. Les indicateurs de la pression décrivent les facteurs d'agression externes (généralement d'origine humaine) dont la surveillance serait effectuée sur de grandes étendues géographiques. Les indicateurs de l'état décrivent la condition de l'habitat et la surveillance connexe menée dans les zones où les indicateurs de la pression soulèvent d'éventuels problèmes au niveau de l'habitat. On a proposé dix-neuf indicateurs de l'habitat pour la surveillance des habitats de cours d'eau, de lac et d'estuaire dans le cadre de la stratégie 2 : sept indicateurs de la pression (*modification de la couverture terrestre, aménagement de routes, extraction d'eau, perturbation des zones riveraines, trafic maritime, perturbation des zones estuariennes et rejets autorisés*), huit indicateurs de l'état (*sédiments en suspension, qualité de l'eau, température de l'eau, débit des cours d'eau, capacité productive des lacs, zone de refuge en eau froide, chimie et contaminants dans les zones estuariennes, oxygène dissous dans les zones estuariennes*) et quatre indicateurs de la disponibilité des habitats (*longueur de cours d'eau accessible, frayères clés dans les cours d'eau, frayères sur le bord des lacs, zone d'habitat en milieu estuarien*). On a établi des paramètres quantitatifs afin d'évaluer de manière uniforme les indicateurs retenus en fonction de valeurs de référence. Lorsque c'était possible, on a défini des valeurs de référence fondées sur le risque d'effets négatifs pour les paramètres de chaque indicateur de la pression ou de l'état. Lorsque le risque ne pouvait être défini de manière précise, on a recommandé des valeurs de référence de rechange, comme des comparaisons en fonction du temps ou de l'espace. La surveillance associée aux indicateurs permettra de déterminer l'état et les tendances concernant les habitats du

saumon dans les UC. Les prochaines étapes consistent à combler les lacunes dans les données, à définir un cadre d’évaluation global et à établir un lien entre la surveillance de l’habitat et la surveillance des populations de saumons et de l’écosystème prescrite dans les stratégies 1 et 3 du PSS. Parmi les autres enjeux, mentionnons : déterminer le mode de combinaison de l’information provenant de l’ensemble des indicateurs de la pression, de l’état et de la disponibilité des habitats retenus afin d’évaluer l’état global de l’habitat à l’intérieur d’une UC.

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The depth of experience brought to the draft report via the reviewers Dr. Carol Smith, of the Washington State Conservation Commission, and Dr. Mike Bradford, Dr. Kim Hyatt, Jason Hwang, and Dr. Jim Irvine, all of DFO, helped refine the report in numerous ways.

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Many thanks,
Heather Stalberg, Ray Lauzier, Erland MacIsaac, Marc Porter and Carol Murray

GLOSSARY

Adaptive management	A process whereby management decisions can be changed or adjusted based on additional biological, physical or socioeconomic information.
Anadromous	Fish that mature in seawater but migrate to fresh water to spawn.
Benchmark	A standard (quantified metric) against which habitat condition can be measured or judged, and by which status can be compared over time and space to determine the risk of adverse effects. Within Strategy 2 of the Wild Salmon Policy benchmarks represent desired values for key indicators and will be used to assess habitat status and identify if/when/where status has changed significantly (DFO 2005). Benchmarks within the WSP reflect DFO's intent to take action to protect or restore habitat on a preventative basis as required, before salmon population abundance declines in response to degraded habitat (DFO 2005).
Biodiversity	The full range of variety and variability within and among living organisms and the ecological complexes in which they occur. Encompasses diversity at the ecosystem, community, species, and genetic levels and the interaction of these components.
Connectivity	The lateral, longitudinal, and vertical pathways that link biological, hydrological, and physical processes.
Conservation	The protection, maintenance, and rehabilitation of genetic diversity, species, and ecosystems to sustain biodiversity and the continuance of evolutionary and natural production processes.
Conservation Unit (CU)	A group of wild salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable timeframe (e.g., a human lifetime or a specified number of salmon generations).
Ecosystem	A community of interdependent organisms and their physical environment interacting as an ecological unit.
Escapement	The number of mature salmon that pass through (or escape) fisheries and return to fresh water to spawn.
Fish habitat	Spawning grounds and nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly to carry out their life processes.
Fry	Actively feeding salmon that have emerged from the gravel and completed yolk absorption.

Genetic diversity	The variation at the level of individual genes, and provides a mechanism for populations to adapt to their ever-changing environment. It refers to the differences in genetic make-up between distinct species and to genetic variations within a single species.
Groundwater	In general, all subsurface water that is distinct from surface water; specifically, that part which is in the saturated zone of a defined aquifer.
Habitat monitoring	Observations (surveys) carried out over time, aimed at detecting changes in habitat features or conditions.
Habitat rehabilitation	Increasing the productive potential of an already degraded habitat by improving some functions but not necessarily restoring all ecosystem components.
Habitat restoration	The return of a habitat to its original community structure, natural complement of species and natural functions.
Hydrograph	A graph showing the variation in water discharge (flow) over time.
Indicators	Characteristics of the environment that, when measured, describe habitat condition, magnitude of stress, degree of exposure to a stressor, or ecological response to exposure. Within Strategy 2 of the Wild Salmon Policy indicators are intended to provide quantified information on the current and potential state of freshwater habitats (DFO 2005).
Pressure indicator	Natural processes or human activities that can directly or indirectly induce qualitative or quantitative changes in environmental conditions. For the purposes of Strategy 2 monitoring environmental changes relate specifically to human-induced changes in fish habitat.
State indictor	Physical, chemical, or biological attributes measured to characterize environmental conditions. For the purposes of Strategy 2 monitoring these are restricted to physical or chemical attributes that characterize fish habitat. Biological attributes will be monitored under WSP Strategy 3.
Indicator of habitat quantity	A physical attribute (as defined for the purposes of Strategy 2 monitoring) that represents the measured extent (e.g., area, length, etc.) and location of a particular habitat, without any inference as to the condition of that habitat.
Instream flow	Any quantity of water flowing in a natural stream channel at any time of year. The quantity may or may not be adequate to sustain natural ecological processes and may or may not be protected or administered under a permit, water right, or other legally recognized means. See also Stream Discharge
LEK	Local ecological knowledge: environmental knowledge of the local environment rooted in local practices of the past and present.

Life stage	An arbitrary age classification of an organism into categories related to body morphology and reproductive potential, such as spawning, egg incubation, larva or fry, juvenile, and adult.
Mainstem	The main channel of a river in a watershed that tributary streams and smaller rivers feed into.
Mean annual discharge (MAD)	The daily discharge of a stream averaged over one or more years.
Metric	A measurable form of an indicator, including specific measurement units.
No Net Loss	A working principle by which Department of Fisheries and Oceans (DFO) strives to balance unavoidable habitat losses with habitat replacement on a project-by-project basis so that further reductions to Canada's fisheries resources due to habitat loss or damage may be prevented.
Pacific salmon	Salmon of the Pacific Ocean regions, of which there are currently eleven species recognized in the Genus Oncorhynchus. The five species addressed in DFO's Wild Salmon Policy are sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), chum (*O. keta*), coho (*O. kisutch*) and Chinook (*O. tshawytscha*). Steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*) are also found in BC.
Population	A group of interbreeding organisms that is relatively isolated from other such groups and is likely adapted to the local habitat.
Precautionary approach	When used in an advisory context in support of decision-making by the Government of Canada, this term conveys the sense that the advice is provided in situations of high scientific uncertainty. It is intended to promote actions that would result in a low probability of harm that is serious or difficult to reverse.
Productive capacity	The maximum natural capability of habitats to produce healthy fish or to support or produce aquatic organisms on which fish depend.
Riparian	Pertaining to anything connected with or adjacent to the bank of a stream or other body of water.
Riparian zone	The area of vegetation near streams and other bodies of water that is influenced by proximity to water. Hydrologic, geomorphic, and biotic interactions within the riparian zone have important influences on adjacent aquatic and terrestrial habitats (e.g., temperature controls, shading, large woody debris).
Salmonid	A group of fish that includes salmon, trout, and char, belonging to the taxonomic Family Salmonidae.

Smolt	A juvenile salmon that has completed rearing in freshwater and migrates into the marine environment. A smolt becomes physiologically capable of balancing salt and water in the estuary and ocean waters. Smolts vary in size and age depending on the species of salmon.
Species	The fundamental category of taxonomic classification consisting of organisms grouped by virtue of their common attributes and capable of interbreeding.
Status	Condition relative to a defined standard. Within Strategy 2 of the Wild Salmon Policy habitat status would be evaluated by comparing habitat state to relevant benchmarks.
Stewardship	Acting responsibly to conserve fish and their habitat for present and future generations.
Stocks	Semi-discrete groups of salmon with some definable attributes which are of interest to fishery managers.
Stream Discharge	The volume of water moving in a stream over time. E.g. Cubic feet/sec, cubic meters/sec
Suspended Sediment	Sediment that is supported by the buoyancy and drag forces of flowing water and that stays in suspension for an appreciable period of time.
Tributary	A stream feeding, joining, or flowing into a larger stream at any point along its course, or into a lake.
Watershed	The area of land that drains water, sediment, and dissolved materials into a stream, river, lake, or ocean.
Wild salmon	Salmon are considered "wild" if they have spent their entire life cycle in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild.
Withdrawal	Water taken from a surface or groundwater source for off-stream use.

1 INTRODUCTION

The Government of Canada released its policy for the conservation of wild Pacific salmon in June 2005 (DFO 2005). The Wild Salmon Policy (WSP) stipulates an overall policy goal for wild salmon, identifies basic principles to guide resource management decision-making, and sets out objectives and strategies to achieve the goal (see Figure 1.1). The WSP's overall goal is to restore and maintain healthy and diverse salmon populations and their habitats, with three identified objectives (DFO 2005) for achieving that goal:

1. safeguard the genetic diversity of wild pacific salmon;
2. maintain ecosystem and habitat integrity; and
3. manage fisheries for sustainable benefits.

All decisions and activities pertaining to the WSP will be guided by four underlying principles (DFO 2005):

1. conservation of wild salmon and their habitats is the highest priority;
2. honour obligations to First Nations;
3. sustainable use; and
4. open and transparent decision-making.

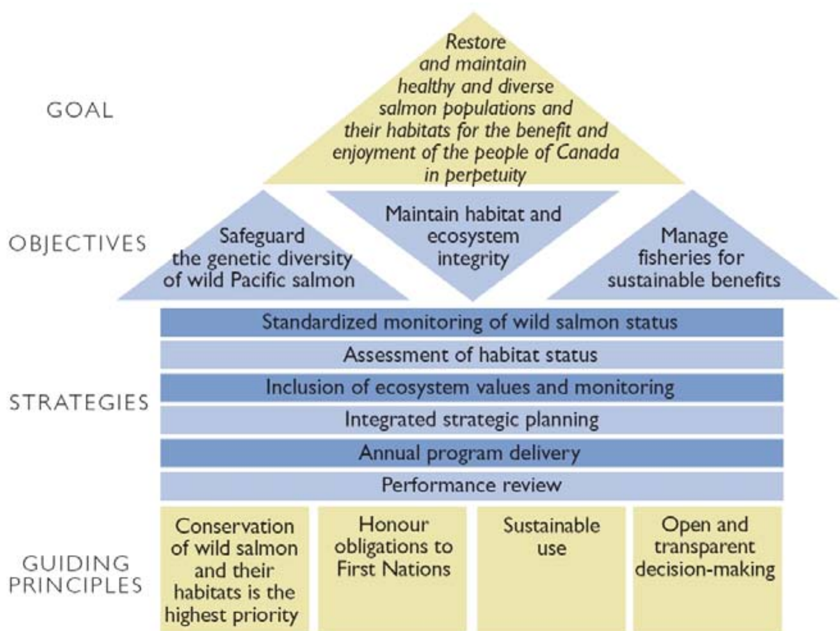

Figure 1.1. Overview of the Wild Salmon Policy structure. Source: DFO (2005).

The WSP will be implemented through six strategies (summarized in Table 1.1), each with specific action steps. Strategies 1 through 3 will provide the information on wild salmon populations, their habitats, and ecosystems required for decision making. Strategy 4 requires the integration of biological, social, and economic information to produce strategic plans for salmon and habitat management for each salmon conservation unit (CU).[4] Strategy 5 is the translation of strategic plans into annual operational plans and Strategy 6 is a commitment to ongoing review of the implementation and success of the Policy (DFO 2005).

Table 1.1 WSP strategies and action steps (adapted from DFO 2005)

Strategy 1 (Standardized monitoring of wild salmon status) 1.1 Identify Conservation Units (CUs) 1.2 Develop criteria to assess CUs and identify benchmarks to represent biological status 1.3 Monitor and assess status of CUs
Strategy 2 (Assessment of habitat status) 2.1 Document habitat characteristics within CUs 2.2 Select indicators and develop benchmarks for habitat assessment 2.3 Monitor and assess habitat status 2.4 Establish linkages to develop an integrated data system for watershed management
Strategy 3 (Inclusion of ecosystem values and monitoring) 3.1 Identify indicators to monitor status of freshwater ecosystems 3.2 Integrate climate and ocean information into annual salmon management processes
Strategy 4 (Integrated strategic planning) 4.1 Implement an interim process for management of priority CUs 4.2 Design and implement a fully integrated strategic planning process for salmon conservation
Strategy 5 (Annual program delivery) 5.1 Assess the status of Conservation Units and populations 5.2 Plan and conduct annual fisheries 5.3 Plan and implement annual habitat management activities 5.4 Plan and implement annual enhancement activities
Strategy 6 (Performance review) 6.1 Conduct post-season review of annual workplans 6.2 Conduct regular reviews of the success of the WSP

[4] A Conservation Unit (CU) is a "*group of wild salmon sufficiently isolated from other groups that, if extirpated is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations*" (DFO 2005). CUs have a defined geographic distribution and vary in size from a sockeye CU which might be at the level of an individual sockeye rearing lake to a pink CU which will be relatively large as they show fewer genetic differences. For example, there are 214 sockeye-lake CUs and 19 pink-odd (year) CUs in BC (Holtby and Ciruna, 2007)

Fisheries and Oceans Canada (DFO) recognizes that to safeguard the long-term viability of wild Pacific salmon in natural surroundings, it must strive to maintain healthy populations in diverse habitats (DFO 2005). Holtby and Ciruna (2007) note that *"protecting the diversity, integrity, spatial extent and interconnectedness of habitat is probably the best way of guarding against the loss of genetic diversity." C*onservation of diverse habitats in which wild salmon populations have adapted and evolved therefore represents a critical requirement for maintaining wild salmon populations. To protect and maintain habitat diversity there is a need to identify important habitat, as well as existing and potential habitat risks and constraints that could adversely affect salmon productivity.

The selection of indicators and initial development of benchmarks that can be used for habitat assessment as required for WSP Strategy 2, Action step 2.2 is the objective of this report. Indicators can represent characteristics of the environment or stressors to the environment (e.g., U.S. EPA 1990). Within Strategy 2 of the WSP indicators are intended to provide information on the current and potential state of freshwater habitats (DFO 2005). Associated metrics provide a means for quantitatively measuring indicators, and benchmarks provide a means for interpreting these measurements (e.g., habitat condition metric relative to a standard). Indicator benchmarks are to be set to reflect DFO's intent to take action to protect and restore habitat on a preventative basis as required, before population abundance declines in response to degraded habitat (DFO 2005).

Example ***indicator*** of Stream Condition: Water Temperature

Example ***metric*** for Water Temperature: MWAT (maximum weekly average water temperature)

Example ***benchmark*** for Water Temperature: Impairment MWAT > $20^{o}C$

This report documents the methodology used by DFO to identify potential Strategy 2 habitat indicators, metrics, and benchmarks (as well as possible sampling protocols). An earlier draft went through a peer review process and this report has been updated to reflect some of the feedback gained. A full proceeding of the peer review process is available in Marmorek and Porter (2009). The proposed list of indicators presented in this report consists of those considered particularly useful for describing salmon habitat condition or man-made stressors on those habitats. The list, however, has also been influenced by considerations of feasibility, as many past monitoring initiatives have faltered between the stage of indicator identification and effective implementation in the medium-to-long term (G.A. Packman & Associates Inc. and Winsby Environmental Services 2005). Therefore rather than representing the ideal suite of all possible indicators, those proposed are believed to be the most practical for Strategy 2 monitoring given current data availability and cost considerations.

2 BACKGROUND

To develop and implement monitoring for Strategy 2 of the WSP, a Habitat Working Group (HWG) was formed in January 2006 and chaired by the WSP Habitat Strategy Coordinator. The HWG was comprised of Oceans and Habitat Enhancement Branch (OHEB) Regional and Area staff as well as Science Branch staff (Appendix 1). HWG activities focused on addressing elements of Strategy 2 Action Steps 2.1 (*Document habitat characteristics within Conservation Units*) and 2.2 (*Select indicators and develop benchmarks for habitat assessment), 2.3 (Monitor and assess habitat status) and 2.4 (Establish linkages to develop an integrated data system for watershed management).* To inform their deliberations the HWG reviewed published reports on indicator development by other agencies, commissioned new reports specific to information needs of the WSP, consulted with agency staff and NGOs, and convened workshops to review and discuss approaches with experts who had previously developed and used habitat indicators for monitoring purposes. While the HWG did develop as part of their activities a pilot monitoring framework for assessing habitat status (Action Step 2.3) and a web-mapping application to support this pilot framework (Action Step 2.4), this report is focused on Action Step 2.2, with some background on Action Step 2.1.

Action Step 2.1 is intended to identify the habitats that support or limit salmon production in watersheds and CUs, and will inform assessment, monitoring and protection priorities (DFO, 2005). It is anticipated that information from multiple sources will be assembled by DFO at appropriate geographic scales to describe habitat conditions for individual CUs and this will serve as an effective initial guide for habitat protection and planning priorities in WSP Strategies 4 and 5. Such information sources will include government agencies, First Nations, watershed-based fish sustainability plans, existing watershed processes, stewardship groups and oceans integrated management (DFO 2005). For Action Step 2.1 the HWG determined that a two-tier structure for reporting on the quantity and quality of habitat within CUs would be appropriate:

1. Overview Reports for each CU that provide sufficient information on key habitats (i.e., highly productive and/or limiting) to identify initial priorities for protection, rehabilitation, and restoration; and
2. Habitat Status Reports that relate habitat conditions within entire CUs (depending on the size of the CU) or watersheds within CUs to salmon life history requirements. Prior conservation and restoration efforts are also identified within Habitat Status Reports. See Appendix 2 for the Habitat Status Report template. Detailed Habitat Status Reports would likely only be developed in priority CUs (e.g., where integrated planning processes are proposed) to identify the variety of mechanisms contributing to actual or potential impacts of concern, the interactions between these impacts, and the locations of important habitats within the CU. The system-specific information developed within the Habitat Status Reports will help inform selection of appropriate habitat characteristics for

monitoring within CUs, and permits interpretation of the resulting data (Reid and Furniss 1998). To support this process, summaries of species and life-stage specific habitat requirements for key life history strategies of Pacific salmon (see Diewart 2007) were commissioned by the HWG and are intended to assist in identification of highly productive and limiting habitats within priority CUs.

Action Step 2.2 is intended to provide a basis for long-term monitoring of the quantity and quality of key salmon habitats identified within CUs in Action Step 2.1. Selected indicators will be used to track status and trends of limiting and highly productive habitats to gain insight into the overall habitat status of a given CU, with this information feeding back into Habitat Status reporting. Habitat indicators for CUs will generally be monitored at a watershed scale, and may be general across CUs or specifically selected on a case-by-case basis for specific CUs or habitat types (DFO 2005). The HWG has endeavoured to develop a standardized pool of useable indicators from which to select indicators for specific monitoring purposes, guided by the species, life-history stage requirements and key habitats identified in Action Step 2.1. It was recognized that there may be circumstances where additional watershed-specific indicators may be required. However, the development of a standardized pool of potential indicators will bring greater consistency to the WSP's habitat assessment framework as it develops. In identifying a provisional suite of indicators, metrics and benchmarks the HWG was also mindful of potential costs as the resources available for long-term and broad scale implementation of Strategy 2 had not been identified. To this end, opportunities for cost efficiencies such as leveraging of ongoing data collection programs were explored by the HWG as they considered potential habitat indicators.

Action Steps 2.1 and 2.2 will provide the basis of monitoring to identify changes in habitat condition over time (Action Step 2.3). The implementation of monitoring and assessment of habitat status within Action Step 2.3 will provide four specific inputs to help guide habitat management. These are:

- *important habitat in need of protection to maintain salmon productivity;*
- *habitat risks and constraints adversely affecting productivity;*
- *areas where habitat restoration or rehabilitation would be desirable to enhance productivity; and*
- *investigations to fill information gaps* (DFO 2005).

Based on feedback received during WSP consultations and a review of indicator approaches elsewhere in the Pacific Northwest, the HWG proposes adopting a two-stage approach to the monitoring required under Action Step 2.3. The first line of information transfer to decision makers would be informed by "pressure" indicators. Pressure indicators will represent proactive measures of impacts on salmon habitats. Based principally (but not exclusively) on remote-sensed and aerial information, pressure indicators would be relatively inexpensive to monitor across broad spatial-scales and over longer time periods. In CUs where benchmarks have been exceeded for pressure indicators, decision making would be informed by "state" indicators – more detailed descriptions of the condition of specific salmon habitats. Although more directly related to biological responses than pressure indicators, state indicators will be used more sparingly for a variety of reasons. First, a requirement for field measurement means that state indicators are generally more expensive to monitor. Second, high natural variability in habitat conditions may require a high sampling effort to reliably detect meaningful changes in habitat condition (i.e., low statistical power). Finally, lags in response of freshwater and estuarine ecosystems to natural and human disturbances mean that measurable changes in habitat state may not be observed until after habitat degradation has occurred. Thus, the intention is that state indicators would be monitored across a much smaller area, for a subset of watersheds or CUs across the Pacific Region.

Within this general framework, habitat indicators will then be used to inform two scales of decision making and management action: regional and local scales. For instance, at a regional scale (i.e., B.C. and Yukon) managers may look to the pressure indicators to understand the types of regional policies that could be effective in alleviating pressures on habitats across CUs. At a local scale (i.e., watershed or individual CU), Area habitat managers may use both pressure and state indicators to evaluate habitat status and better understand conservation or restoration priorities.

Monitoring of habitat indicators for Strategy 2 will be integrated with salmon assessments (WSP Strategy 1) and ecosystem evaluations (WSP Strategy 3). The intent of integration will be to better understand the relationship between changes in habitat condition and changes in salmon production and distribution within the CU (DFO 2005). Monitoring will also be used to assess the effectiveness of regulatory decisions and rehabilitation measures. All monitoring results will inform both longer-term strategic planning and annual operations in habitat management (DFO 2005).

The following sections of this report describe the methods used to develop an indicator framework, select habitat indicators, and present the final proposed set of indicators for Strategy 2 monitoring (Section 3), describe suggested metrics and benchmarks (Section 4), and discuss key challenges within the overall process and the intended next steps in implementing Action Step 2.3 (Section 5). Final summary comments are provided in Section 6. This report was prepared and peer reviewed by a panel in a workshop in January 2009 and subsequently revised based on the workshop feedback and reviewer comments (Marmorek and Porter 2009).

3 INDICATORS

3.1 METHODS AND RESULTS

The following steps were undertaken by the HWG to identify habitat indicators. While presented here in sequential fashion, there was a certain degree of overlap, with some activities occurring in parallel. Figure 3.1 illustrates the step-wise process and identifies sources of information (either in this report or elsewhere in the literature) used by the HWG for indicator development. In addition, extensive internal and external consultations took place throughout the process.

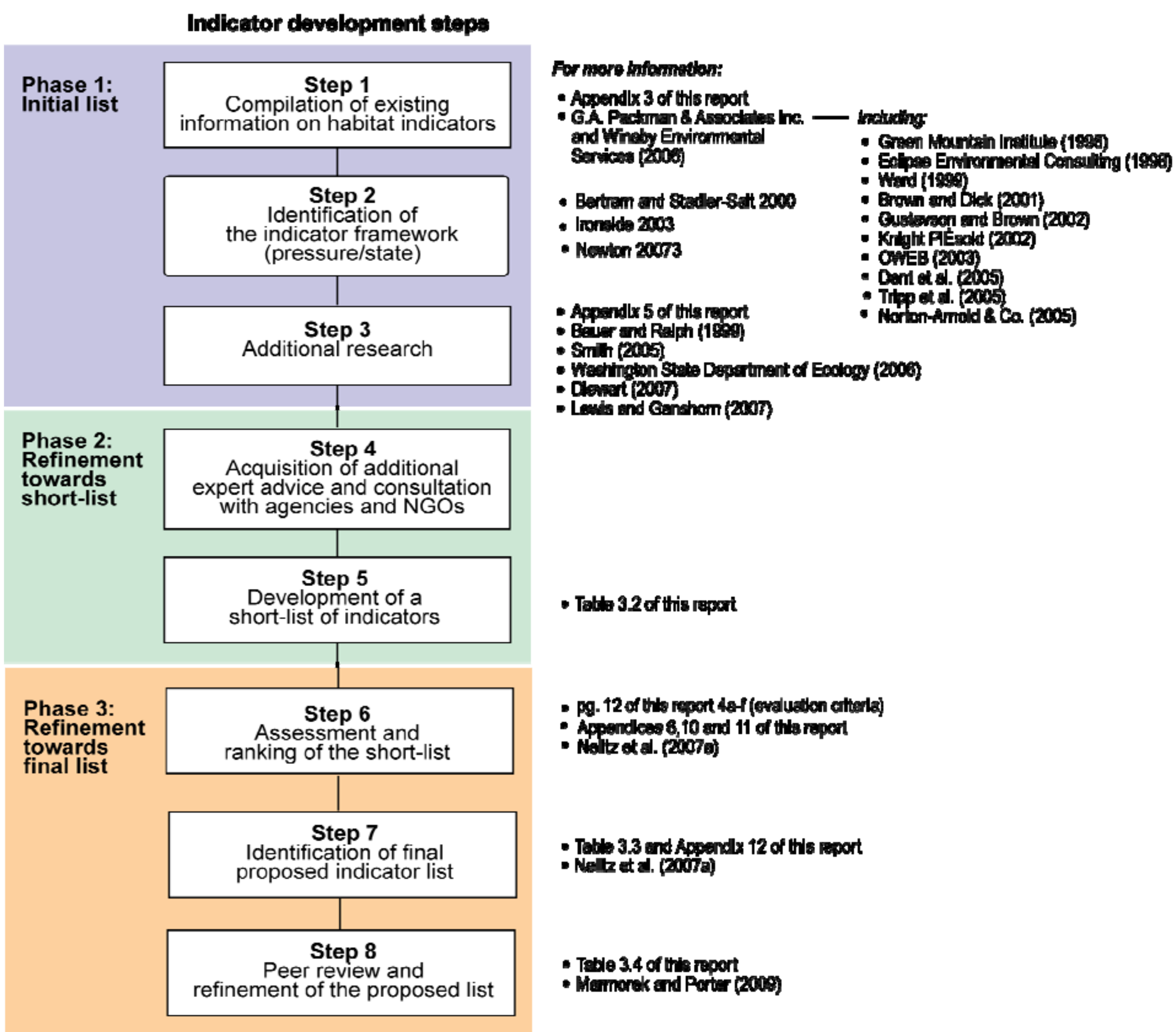

Figure 3.1 The eight steps used by the HWG in the habitat indicator development process.

1. Compilation of existing information on habitat indicators. This was done through a review of background information in 2005 by G.A. Packman & Associates Inc. and Winsby Environmental Services, using as primary references the following set which were believed to reflect the latest thinking on indicator development for wild Pacific salmon habitat:
    - Green Mountain Institute (1998);
    - Eclipse Environmental Consulting Ltd. (1998);
    - Ward (1999);
    - Brown and Dick (2001);
    - Gustavson and Brown (2002);
    - Knight Piésold (2002);
    - Oregon Watershed Enhancement Board (OWEB) (2003);
    - Dent *et al.* (2005);
    - Tripp *et al.* (2005); and
    - Norton-Arnold and Company (2005).

   Eight of these already contained rationalized indicator lists, and the authors felt that these would provide a solid foundation for considering wild salmon habitat indicators for BC. A general assessment of the potential indicators was undertaken by G.A. Packman & Associate and WInsby Environmental Services (2006) using the criteria defined in Table 3.1. After addressing overlaps among the lists, a total of 66 potential indicators emerged and served as an initial candidate list for subsequent analysis and refinement and are listed in Appendix 3.

   This list of potential indicators was further reviewed at an Expert Technical Workshop on Wild Pacific Salmon Habitat Indicators held on November 17, 2005 in Vancouver, BC (G.A. Packman & Associates Inc. and Winsby Environmental Services 2006). Workshop participants consisted of DFO and science and technical specialists from other federal and provincial government and non-government organizations (NGO) as well as experienced fisheries habitat consultants. Workshop participants are listed in Appendix 4.

Table 3.1. Indicator selection criteria. (Adapted from G.A. Packman & Associates Inc. and Winsby Environmental Services 2006).

Criteria	Description
Relevance	- Is relevant to wild Pacific salmon (species and life history stages), and to other fish species - Has DFO policy relevance and management relevance - Is relevant to First Nations and the general public
Scientific validity	- There is a link to wild Pacific salmon production (species and life history stages) - Standard methodology, protocols and QA/QC are available - Amendable to statistical analysis - Is robust

Criteria	Description
Data availability and accessibility	- Baseline data are available - Indicator data are currently available and will be available on a continuing basis through an existing program - Data are readily accessible - Metadata are available and accessible
Data quality	- Reliability and robustness - Supported by appropriate data collection protocols and QA/QC procedures/documentation
Data compatibility	- Data medium and format (paper files, reports, electronic, in format that facilitates integration with other data)
Cost effectiveness	- Data are not inordinately expensive to collect
Responsiveness	- Reflects both short-term and long-term response and trends - Indicator data do not have a lag time that compromises effectiveness and/or utility
Spatial scale	- Data are amenable to providing appropriate geographic scale of coverage at the Broadscale, Sentinel and Detailed Study levels - Data can support decisions at both the strategic and site specific levels
Temporal coverage	- Time-series data are available - Databases are updated at appropriate time intervals
Data management	- A database update process exists and is supported by QA/QC procedures, metadata, etc.
Overall feasibility	- Implementation will be effective and feasible

2. Definition of the indicator framework. The use of a defined framework provides an analytical context for the indicators, assists in the indicator selection process and the identification of gaps, and enhances interpretation (Ironside 2003). The HWG decided on a Pressure-State-Response (PSR)[5] framework, with a focus on a two-tiered Pressure-State approach as a practical means to maximize implementation success. Under this approach, pressure indicators would be evaluated across a broad scale or within CUs, and in locations where pressure indicator benchmarks are being exceeded, more costly state indicators would be considered for a smaller geographic area (e.g., used for a subset of CUs, representative watersheds or where more precise information is required on a localized scale). For example, should road density (a potential pressure indicator) exceed a certain proportion of a watershed, then sediment and substrate (potential state indicators for streams and lakes) would be considered for targeted areas. Similarly if riparian disturbance exceeds a certain levels, then stream temperature would be evaluated and monitored, and if land cover alteration exceeds a certain proportion of the total land cover, then stream discharge would measured and monitored.

[5] This was simplified from an initially-discussed Pressure-State-Impact-Response (PSIR) framework, in recognition of the fact that for practical purposes habitat state indicators will reflect habitat impacts – i.e., changes in the state due to various pressures.

The PSR[6] model is the most commonly-used indicator framework (Bertram and Stadler-Salt 2000, Ironside 2003, Newton 2007). While concerns have been raised that it is overly simplistic and not reflective of the complex relationships among environmental components and forces of change (Ironside 2003), it is one of the most widely accepted classification schemes for environmental indicators *because* of its simplicity and broad applicability (Bertram and Stadler-Salt 2000). Uses in Canada include Annual reporting under the Canadian Water Act (Environment Canada 2007), regular reporting on the state of the Great Lakes (Bertram and Stadler-Salt 2000), and many other status-and-trend and state-of-environment reporting initiatives that do not explicitly adopt a given framework but rely heavily on state and pressure indicators.

3. Additional research. Additional technical documents were reviewed by the HWG for insights and lessons on indicator approaches from other jurisdictions, including aquatic habitat indicators and their application to water quality objectives under the U.S. Clean Water Act (Bauer and Ralph 1999), limiting habitat factors for salmon in Washington State (Smith 2005), and indicators used to monitor watershed health and salmon recovery in Washington State (Washington State Department of Ecology 2006).

   Targeted literature reviews were commissioned by the HWG on: 1) life history strategies and key habitat requirements/thresholds for 10 major Pacific salmon/life history categories (Diewart 2007) and 2) the current state of habitat productivity models for five species of Pacific salmon (Lewis and Ganshorn 2007). Both reviews provided important information for further assessing candidate indicators for relevance and scientific validity (the first two criteria in Table 3.1).

4. Acquisition of additional expert advice. Further expert technical and experience-based advice to refine and hone the candidate indicators into a short-list was obtained by the HWG through numerous internal discussions and through workshops in July 2006 with DFO Science Branch staff and with professionals in ecosystem-based management working in U.S. Government agencies (including the National Oceanographic and Atmospheric Agency, United States Forest Service, and Northwest Fisheries Science Centre), academia (Universities of Montana and Washington), industry (Weyerhaeuser).

   Discussions and correspondence were also undertaken with colleagues in DFO, with staff at provincial NGOs, as well as multiple agencies in other jurisdictions with an interest in or mandate for developing habitat and ecosystem indicators, including US Federal and State agencies and the Pacific Northwest Aquatic Monitoring Partnership.

[6] Note: the "response" refers to *human* responses to the pressure and the consequent change in state, not to *ecological* response.

5. Development of a short-list of indicators. The HWG used what was learned during the previous steps to compile an initial short-list of potential pressure and state indicators for stream, lake, and estuarine habitat. This short-list is shown in Table 3.2, in approximate order of relevance and scientific validity as defined by how strongly they relate to key habitat attributes. Appendix 5 shows which of these indicators have been used by programs and agencies within the US Pacific Northwest and Canada, including federal, state/provincial and non-governmental organizations. Appendix 6 provides a more detailed analysis of the strength of the linkage between each indicator and the salmon habitat attributes.

Table 3.2. Short-list of indicators developed by the HWG.

Pressure Indicators	**State Indicators**
Streams	
% stream length channelization/floodplain connectivity % stream length riparian zone alteration Road density % watershed area impervious surface % watershed area converted to various land uses (forestry, agric, urban) Wetland loss Water withdrawal as % MAD (surface, groundwater) Permitted outfall discharges % lake foreshore alteration % estuary foreshore alteration	Accessible stream length/barriers Accessible off-channel habitat area Channel stability measures (pool:riffle, channel width:depth ratios, etc) Stream discharge measures (base & peak flows) Water temperature Sediment, substrate LWD, instream cover Water chemistry (nutrients, D.O., pH, conductivity, contaminants)
Lakes	
% watershed land cover alterations % lake foreshore altered % watershed area impervious surface % riparian zone altered Road density Recreational pressure Invasives	Accessible shore length, barriers Accessible off-channel habitat area Water chemistry (nutrients, D.O., pH, conductivity, contaminants) Presence of river deltas Sediment substrate Temperature Wetland loss
Estuaries	
% estuary foreshore altered (carex, typha, riparian zone) % surface area disturbed inshore (eel grass zone) % surface area disturbed offshore (e.g., log booms – subtidal) Amount of vessel traffic Invasives	Accessible off-channel habitat area Estuarine habitat area River or stream discharge Aquatic invertebrates Marine riparian vegetation Spatial distribution of wetlands, mudflats Fish Flux of detrital organic matter (C,N,P) between marsh and other habitats

Pressure Indicators	State Indicators
	Extent of eel grass Sediment, TSS Micro and macro algae Water chemistry (nutrients, D.O., pH, conductivity, contaminants)

6. Assessment and ranking of the short-list. ESSA Technologies Ltd. was then contracted to further assess and rank the short-list of indicators developed by the HWG using a six-task process (Nelitz *et al.* 2007a):

    1) *Clarification of indicators*. The stream, lake and estuary short-lists included a mix of indicators and metrics. The list was re-organized to make this separation clear, and to show which metrics align with which indicators. The clarified list is presented in Appendix 7.

    2) *Development of conceptual diagrams*. Simple conceptual diagrams were developed for each species using the list of indicators in Appendix 7 to clarify cause-effect pathways on salmon life stages, as well as to ensure indicators are those responsive to changes in management actions, are representative of habitat state and pressures on a variety of salmon species and life stages, and are linked to effects on survival. Use of conceptual models has been advocated by others (e.g., Jones *et al.* 1996) and is consistent with the "Pathways of Effects" approach being applied as part of DFO's Environmental Process Modernization Plan (EPMP).The diagrams are presented in Appendix 8.

    3) *Identification of potential data sources*. Published, grey and web literature was reviewed to identify potential data sources for habitat indicators. Data sources were also identified from telephone interviews with numerous agency and NGO contacts.

    4) *Practical assessment of indicators against evaluation criteria*. Indicators were then evaluated against the following key criteria from Table 3.1 and the experience of the authors:

        a) data source;
        b) data availability;
        c) relative cost, existing and incremental;
        d) spatial scale, extent and resolution;
        e) temporal scale, extent and resolution; and
        f) scientific relevance (using the rankings in Appendix 6).

        A total of 68 data sources were identified and used to assess the indicators against these practical assessment criteria using Assessment Worksheets. An example worksheet and a list of the data sources are provided in Appendix 9. Nelitz et al. (2007a) acknowledged that while this practical assessment focused on data sources that could be applied across the Region there were numerous other information sources that could be applied to more localized areas (e.g., Local Ecological Knowledge (LEK) and specific studies)).

The anticipated cost for developing particular indicators (the third criterion) was categorized qualitatively as low: $0–$50K, moderate: $50–$100K and high cost: >$100K. Cost categories were based on existing program costs to derive available information by non-DFO entities, incremental costs to DFO of using data generated by others (e.g., user fees), whether the relevant data could be collected simultaneously with other data (e.g. remote-sensing), whether there were any related operating fees, and estimated operating costs to DFO of using these data (e.g., processing and updating).

5) *Review of practical assessment results*. This was done during a workshop designed to obtain feedback on the practicality, feasibility, and comprehensiveness of the habitat indicators and their identified data sources, and suggestions for filling any remaining data gaps. The workshop was attended by HWG members, staff from DFO Areas across the Pacific Region, and NGO stakeholder representatives from the Salmon Enhancement and Advisory Board, Raincoast Conservation Society, and Pacific Streamkeepers. An exercise at the workshop to identify high priority indicators by watershed and by species demonstrated the importance of understanding the local context and habitat type in the selection of appropriate habitat indicators. While a few indicators repeatedly appeared as priorities across species and watersheds, priority designation for others was much more variable depending on species and watershed.

6) *Qualitative ranking of the indicators*. Based on the results of tasks 1 through 5, the stream, lake and estuarine habitat indicators were qualitatively ranked according to the level of effort required to generate them, given current data availability (Appendix 10). From these rankings the indicators were grouped into three distinct categories based on data availability:

   - Type I had significant data gaps;
   - Type II had sufficient data to inform baseline variation; and
   - Type III had appropriate data to generate metrics.

   The results and annotations regarding data availability and limitations for each Type are provided in Appendix 11.

7. <u>Identification of a proposed indicator list.</u> Following Step 6, two options were proposed (Nelitz *et al.* 2007a):

   1. A Basic Option, with all Type III indicators having high relevance which would be feasible to implement at relatively low cost. This option included 14 indicators (6 stream, 5 lake, and 3 estuary indicators) which could be derived from 7 separate analytical projects.
   2. An Ideal Option, with all indicators from the basic option plus an additional four Type III and two Type II indicators that are scientifically relevant and could feasibly be implemented at lowest cost relative to other Type II indicators. This option recommends 20 indicators (8 stream, 6 lake, and 6 estuary indicators), drawing from 12 analytical or monitoring projects.

Both options are presented in Appendix 12.

After review of these options against in-house expertise (e.g., on water quality parameters and existing monitoring programs), consideration of other indicators recommended from all previous steps, ongoing and continuing in-house consultation with staff[7], extensive external consultations[8], and assessment of overall feasibility, a suite of habitat indicators was proposed by the HWG. The proposed selection, shown in Table 3.3, closely resembled the Ideal Option proposed by Nelitz *et al.* (2007a) with the addition of the following indicators:

- *Riparian, sedge, eelgrass, and mudflat habitats.* Quantifying and reporting on the extent of these habitat types should be possible in localized areas. For example, data for the Fraser River estuary may be available through the Fraser River Estuary Management Program. As well, the Provincial Coastal Resource Inventory System might be able to provide information on riparian condition as inventory overflights are typically conducted on a five-year return rate.
- *Permitted discharges.* Provincial and Territory permitted waste management discharges have value as a pressure indicator for streams, lakes and estuaries as it could provide insight into further stresses on the quality, and possibly quantity, of salmonid habitats.

Due to the challenges in gaining reliable information on indicators of habitat quantity (primarily due to limited data), the HWG also felt that the following additions and refinements were prudent:

- Stream accessible length/barriers – while originally considered as providing background information for the Overview Reports only, there is a need to track it more broadly.
- Stream key spawning areas – delineates very important high quality spawning areas.
- Lake cold water refuge zone – would be relevant to sockeye in particular and be a function of water depth, dissolved oxygen and temperature.
- Lake shore spawning area – is relevant to lake spawning sockeye.

[7] Those involved in internal consultations included Hatchery Managers, B.C. Interior Area staff from multiple Branches and B.C. Interior OHEB staff, and staff having particular expertise such as ocean planning, water quality monitoring and invasive species.

[8] External consultations included sessions in 10 communities throughout B.C. as well as individual sessions with academia (Simon Fraser University), NGOs (Pacific Marine Conservation Caucus; Salmon Enhancement and Advisory Board (SEHAB); Pacific Streamkeepers; Watershed Watch), First Nations (Shuswap Nation Fisheries Commission), the B.C. Fisheries Sensitive Watersheds Program lead and Environment Canada's Water Quality reporting team

Table 3.3. First indicator list proposed by the HWG.

Habitat type	Indicator type	Indicator
Stream	Pressure	Total land cover alterations
Stream	Pressure	Watershed road development
Stream	Pressure	Water extraction
Stream	Pressure	Riparian disturbance
Stream	Pressure	Permitted discharges
Stream	State	Sediment
Stream	State	Water quality
Stream	State	Temperature, Coho juvenile rearing
Stream	State	Temperature, migration Spawning – all species
Stream	State	Stream discharge
Stream	State	Benthic invertebrates
Stream	Quantity	Accessible stream length, barriers
Stream	Quantity	Key spawning Areas (length)
Lake	Pressure	Total land cover alterations
Lake	Pressure	Watershed road development
Lake	Pressure	Riparian disturbance
Lake	Pressure	Permitted waste management discharges
Lake	State, for sockeye lakes	Coldwater refuge zone
Lake	Quantity, for sockeye lakes	Lake productive capacity
Lake	Quantity	Shore spawning area (length)
Estuary	Pressure	Marine vessel traffic
Estuary	Pressure	Disturbance of riparian, intertidal (e.g., Carex and Typha) and sub-tidal (e.g., eel-grass) habitats
Estuary	Pressure	Discharge Permits
Estuary	State	Chemistry (e.g., N, P, N:P) and contaminants (e.g., Metals, PAHs, PCBs)
Estuary	State	Dissolved oxygen
Estuary	Quantity	Estuarine habitat area (riparian, sedge, eelgrass and mudflat)

8. Peer review and refinement of the proposed indicator list.

The proposed indicator list from Step 7 underwent peer review at a workshop in Vancouver in January 2009. This review entailed an assessment of the efficacy of the proposed habitat indicators in meeting Strategy 2 objectives, and recommendations for best use of these indicators in view of available resources. Further details about this workshop are available in Marmorek and Porter (2009). Workshop participants included representatives from DFO, BC Ministry of Environment, Washington State Conservation Commission, Pacific Fisheries Resource Conservation Council, Salmon Enhancement and Habitat Advisory Board, Upper Fraser Conservation Alliance, Pacific Salmon Foundation, Watershed Watch Salmon Society, Streamkeepers, Skeena Wild Conservation Trust, Skeena Fisheries, and Simon Fraser University. The comments and recommendations from the peer review led to a final refinement of the HWG's proposed indicator list. This refinement consisted of removal of "benthic invertebrates" from the list of habitat indicators with the intention (as suggested by peer reviewers) that all biotic state indicators will instead be captured under Strategy 3 monitoring. The final list of habitat indicators proposed by the HWG for Strategy 2 monitoring is presented in Table 3.4 followed by a narrative description of their rationale for inclusion.

Table 3.4. Final refined indicator list proposed by the HWG.

Habitat type	Indicator type	Indicator
Stream	Pressure	Total land cover alterations
Stream	Pressure	Watershed road development
Stream	Pressure	Water extraction
Stream	Pressure	Riparian disturbance
Stream	Pressure	Permitted waste management discharges
Stream	State	Suspended sediment
Stream	State	Water Quality
Stream	State	Water temperature: juvenile rearing – stream resident species
Stream	State	Water temperature: migration and spawning – all species
Stream	State	Stream discharge
Stream	Quantity	Accessible stream length, based on barriers
Stream	Quantity	Key spawning areas (length)
Lake	Pressure	Total land cover alteration
Lake	Pressure	Watershed: road development
Lake	Pressure	Riparian disturbance
Lake	Pressure	Permitted waste management discharges
Lake	State for sockeye lakes	Coldwater refuge zone
Lake	State for sockeye lakes	Lake productive capacity
Lake	Quantity	Lake shore spawning area (length)
Estuary	Pressure	Marine vessel traffic
Estuary	Pressure	Estuary habitat disturbance
Estuary	Pressure	Permitted waste management discharges
Estuary	State	Estuary chemistry and contaminants e.g., N, P, N:P, Metals, PAHs & PCBs
Estuary	State	Estuary dissolved oxygen
Estuary	Quantity	Estuarine habitat area (riparian, sedge, eelgrass and mudflat)

3.1.1 Selected stream indicators

Stream habitats are used by all salmon species for migration, spawning and egg incubation and as rearing habitats by coho, Chinook and river-type sockeye (Groot and Margolis 1991). They require suitable clean spawning gravels with adequate intergravel water flows for spawning, and good stream water quality and complex channel morphology to provide feeding and refuge habitats for juveniles (Roberge *et al.* 2002). Habitat indicators were selected that could reflect many of the stream and watershed changes that can affect salmon productivity at different life stages. Total land cover alteration and watershed road development capture changes in cumulative watershed processes such as peak hydrologic flows and sediment generation that affect downstream spawning and rearing habitats (Poff *et al.* 2006). Water extraction (pressure) and stream discharge (state) are indicators that can capture expected impacts to stream habitats related to reduced water quantity (e.g., spawner access, the extent of accessible stream habitats, and altered hydrologic processes) (Richter *et al.* 2003; Hatfield *et al*. 2002). Suspended sediment, water quality and water temperature were habitat indicators chosen to reflect physical and chemical stream attributes that will directly affect growth and survival of all salmon life stages (Beschta *et al.* 1987; Richter and Kolmes 2005). Riparian disturbance is considered an important indicator of streamside changes that affect stream shade and temperature, wood and organic matter inputs, bank stability and many other riparian processes that maintain fish habitats (Gregory and Bisson 1997). Lastly, accessible stream length and key spawning areas were selected by the HWG as both indicators quantify stream habitat elements that are critically important to salmon (i.e., extent of useable rearing and spawning habitat).

3.1.2 Selected lake indicators

Lakes can act as migratory habitats for the five species of Pacific salmon, rearing habitats for Chinook, coho and sockeye and provide shoreline spawning areas for lake spawning sockeye (Roberge *et al*. 2001). The shorelines provide important early rearing habitat for Chinook and coho juveniles until higher summer temperatures make foreshore conditions unsuitable; adults migrate in pelagic waters to spawn in tributary streams. Lake-rearing sockeye spawn in the tributaries, lake shores and occasionally the outlet streams of their nursery lakes and they disperse directly to the lake after fry emergence (Roberge *et al*. 2001; Quinn 2005). Lake habitat indicators were selected to reflect changes in watershed conditions that affect lake water quality and quantity (total land cover alteration, watershed road development), and shoreline stability and vegetation that affect the growth and survival of shore-oriented early fry (riparian disturbance). Other indicators reflect changes in lake productivity that affect the growth and survival of rearing juvenile sockeye (lake productive capacity) and changes in the water quality conditions of the lake that affect sockeye utilization of the lake rearing environment (coldwater refuge zone). Lake shore spawning area was also considered an important indicator that could capture the quantity of spawning habitat available for sockeye.

3.1.3 Selected estuary indicators

Estuary habitats play important roles at two critical times in the transition of salmon life stages: during the juvenile emigration to marine habitats and the immigration of adults to their natal spawning grounds (Quinn 2005). For emigrating juvenile salmon, estuary habitats provide feeding areas which must sustain increased growth rates; temporary refuge from marine predators during a reduced activity phase in the smoltification process; and a transition zone for acclimation when the basic physiology of the fish changes from a freshwater to marine fish (Bottom *et al.* 2005). It is also a key period when migrating juveniles acquire the necessary olfactory information for successful homing (Dittman *et al.* 1996 as cited in Bottom *et al.* 2005). For adults returning to spawn, estuaries provide a holding area until there are appropriate cues to proceed upstream to the natal spawning grounds, as well as the transition zone for acclimation when the basic physiology of the fish changes back from a marine to freshwater organism.

Despite the important role of estuary habitats in salmon life histories, estuarine habitat information is collected on fewer parameters and much less frequently than stream or lake habitat information. Because of the dynamic nature of estuaries with twice daily tides, the concentration of human activity in close proximity to estuaries as well as the variable resident times and degree of use between the different species and life-history types of salmon, it can be difficult to select appropriate indicators to adequately assess the functional performance of estuarine habitats in relation to salmon (Quinn 2005). Marine vessel traffic, estuary habitat disturbance and permitted waste management discharges were pressure indicators selected by the HWG to reflect the large suite of potential physical and chemical impacts to estuary habitats related to increased human activities within estuaries. Estuary chemistry, contaminants and dissolved oxygen are indicators that directly capture chemical conditions in the estuary that could be affecting growth and survival of rearing and migrating salmon, particularly for species such as chum, pink and underyearling Chinook and sockeye that may spend longer periods in estuary habitats (Quinn 2005; Diewart 2007). Lastly, estuarine habitat area provides an indicator of the existing quantity of key estuarine habitat elements that are critically important to different salmon species either feeding within or migrating through an estuary.

3.2 HABITAT INDICATORS IN RELATION TO SALMON CUs

Habitat indicators proposed by the HWG have focused on segregation into stream, lake and estuary categories as these represent a logical organization into distinct habitat types typically evaluated for watershed management purposes. Within the WSP, however, CUs represent the targeted management unit of concern. CU's are not directly geographically based but instead represent species-specific groupings of populations that show little genetic or life history variation. The species have widely varying life histories and habitat requirements within freshwater and coastal ecosystems and a single watershed can contain complete CUs or only portions of several CUs. The decision was made to develop a suite of indicators that could be collected on a watershed basis and rolled up to represent a CU, including some species specific indicators such as length of lakeshore spawning for lake rearing sockeye. Eventhough many habitat indicators are conventionally organized by watershed or region, the habitat indicators proposed by the HWG represent reporting needs for species-specific habitat factors that affect CU productivity (and human impacts on that productivity). Certain of the proposed indicators across streams, lakes and estuaries may be more or less critical to monitor for a particular species depending on their life history characteristics. In many areas more than one salmon species is present, so that a mixed suite of indicators might be used dependent on the salmon species being considered. Table 3.5 presents a summary of how the HWG's proposed habitat indicators would be used in CU-focused assessments by species and life-history types.

Table 3.5. The HWG's proposed list of habitat indicators (pressure and state indicators and indicators of habitat quantity) re-organized in relation to salmon species-life history specific habitat factors that affect CU productivity (and human impacts on that productivity). Indicators that are considered of importance for a particular species and life history combination are indicated by a checkmark ✓. Blank cells reflect where an indicator is not perceived as relevant to a particular species and life history combination. Categorizations are based on characteristics for key salmon species life histories reported in Diewart (2007).

Indicator type	Indicator	Coastal Coho	Interior Coho	Ocean-type Chinook	Immediate-type Chinook	Stream-type Chinook	Lake Rearing Sockeye	Estuary Rearing Sockeye	Northern Chum	Southern Chum	Pink
Pressure	Total land cover alterations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Watershed Road development	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Water extraction	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Riparian disturbance (streams)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Riparian disturbance (lakes)		✓	✓		✓	✓	✓			
Pressure	Permitted waste management discharges (lakes)	✓	✓			✓	✓				
Pressure	Permitted waste management discharges (estuaries)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Permitted waste management discharges (streams)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Marine vessel traffic (estuary)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pressure	Disturbance of riparian, intertidal and sub-tidal habitats (estuary)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State	Suspended sediment (streams)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State	Water Quality (streams)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State	Chemistry and contaminants (estuaries)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State	Water Temperature (streams), Coho juvenile rearing	✓	✓	✓	✓	✓					

Indicator type	Indicator	Coastal Coho	Interior Coho	Ocean-type Chinook	Immediate-type Chinook	Stream-type Chinook	Lake Rearing Sockeye	Estuary Rearing Sockeye	Northern Chum	Southern Chum	Pink
State	Temperature (streams), Migration Spawning all species	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State	Discharge (streams)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State	Coldwater refuge zone (lakes)	✓	✓				✓				
State	Productive Capacity (lakes)	✓	✓			✓	✓				
State	Dissolved Oxygen (estuaries)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quantity	Accessible stream length (based on barrier location)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quantity	Length of key spawning areas (streams)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quantity	Length of shore spawning areas (lakes)						✓				
Quantity	Estuarine habitat area (riparian, sedge, eelgrass and mudflat)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

3.3 SUPPLEMENTAL INDICATOR INFORMATION

During the process of converging on a proposed list of habitat indicators a number of indicators that were excluded from this final list were recognized as potentially useful if supporting data could be generated through the processes of other agencies, or additional activities could be initiated by DFO in the future. Projects that could address some of these data-gaps and allow for additional indicators to be considered in the future were identified and recommended by the HWG. Detailed information on these supplemental indicators and potential projects to fill perceived data gaps are provided in Appendix 13.

3.4 INDICATORS NOT SELECTED

The HWG evaluated a considerable number of indicators through the refinement process, while acknowledging that some indicators likely escaped evaluation and others were simply not included. The number of indicators proposed for this report was constrained by the need for reasonable implementation and cost implications. There was also a need to provide room for future flexibility in the WSP Strategy 2 so as to allow possible incorporation of additional indicators that are perceived as important, and supported by LEK and future data availability. In general, however, the HWG has included many indicators commonly used or recommended for habitat monitoring. The rationale for exclusion of some of the more prominent habitat indicators used in other programs is provided below.

3.4.1 Juvenile salmonid densities

This was requested as an important indicator during the consultation process. The HWG did not include it within their proposed list due to the multitude of influences on production of juvenile Pacific salmon. For instance, the extensive migratory behaviour of salmon means they are subject to numerous external forces beyond the freshwater environment which can ultimately affect their freshwater numbers (e.g., ocean temperatures, climate change, effects of human development, and harvesting pressures). As a result, these influences confound the relationship between juvenile salmonid densities and the inherent productivity of freshwater habitats. Consistent with the intended flexibility in the WSP the HWG did, however, note that juvenile salmonid density could be used as a habitat indicator in watersheds where stakeholders request it based on local knowledge and data availability. Trends of salmon and various life history stages are intended, however, to be an important class of indicators under Strategy 3 monitoring so it may be more appropriate to consider it as an ecosystem indicator (Kim Hyatt DFO pers. comm.).

3.4.2 Groundwater exploitation

Groundwater exploitation was requested as a habitat indicator during consultations, including the session with DFO’s Science Branch. The HWG agreed with the importance of capturing this information. However, there are very limited data on either volumes used or aquifer impacts. Where data becomes available, it is expected to be integrated into the water extraction metric. Further to monitoring groundwater use, it was suggested that irrigation circles could be monitored, with circle densities being used as an indicator of irrigation pressure. Irrigation circles are the crops that show enhanced growth when viewed aerially (e.g., richer in color reflecting more robust growth than surrounding vegetation), and are in a circular pattern as a result of the stationary rotating spray irrigation units. While this form of monitoring of water use has been used in limited locations, it was not considered sufficiently standardized for broad-scale implementation.

3.4.3 Threats

A measure of threats was also suggested as an indicator during public consultations (e.g., potential extent of mountain pine beetle infestation; the number of industries within productive salmon watersheds). This indicator was also considered important by the HWG, however, it was expected that threats could be described in the narrative of the Overview reports. Pressure indicators themselves also capture many potential threats to the environment. Additionally, Permitted Waste Management Discharges was considered by the HWG as a future indicator once data systems are available and confidence in geo-referencing has increased. Finally, WSP Strategy 3 – *Inclusion of Ecosystem Values and Monitoring* looks to integrate with programs investigating climate variability which could help address some of the uncertainty surrounding threats posed by climate change.

3.4.4 Stream crossings

Stream crossings were recognized as having significant impacts on fish habitat that range from destabilizing habitat to limiting fish passage (Harper and Quigley 2000). However, both road development and accessible stream length are included as indicators, and these were considered a reasonable surrogate given strong correlations between stream crossings and road development and actual impacts to fish (e.g., passage barriers created by stream crossings) (FPB 2009).

3.4.5 Invasive species

The HWG recognized the significant impact of invasive species on salmon habitats and ecosystem functioning (Sanderson *et al*. 2009). Given the wide-ranging impacts invasive species have across individuals, habitats, and trophic levels, they were considered more appropriate as an ecosystem indicator and recommended for deliberation under WSP Strategy 3.

3.4.6 River-bed composition

This indicator was also raised during consultations and was initially considered useful by the HWG. This indicator was not included in the proposed list of indicators due to the often high natural mobility and spatial variability of stream sediments (Neuhold *et al*.

2009). Related to this, however, is the proposed indicator “Key Spawning Area”, which could be used to focus supplementary monitoring of river-bed compaction in specific areas, if shifts in patterns of fish distribution are observed.

3.4.7 <u>Wetland disturbance</u>

This indicator was initially recommended because of the recognized value of wetlands in moderating watershed hydrology (Brydon *et al*. 2006). This indicator would be specific to those wetlands not directly connected to fish bearing watercourses. It was not retained in the proposed list because this type of disturbance would be partially captured in Total Land Conversion.

3.4.8 <u>Benthic invertebrates</u>

The HWG recognized the importance of stream benthic invertebrates to salmon populations (Covich *et al*. 1999). Benthic invertebrates are also a sensitive indicator of localized aquatic environmental changes (Jenderedjian *et al*. 2007) and standardized methodologies have been developed for their use in monitoring programs (e.g., StreamKeepers, CABIN). The techniques require field monitoring with reference sites and taxonomic identifications by trained individuals, so they are best applied in monitoring situations where other pressure or state indicators have identified potential impacts on salmon habitats. Given the wide-ranging importance of invertebrates as a prey base across multiple trophic levels they were, however, considered more appropriate as an ecosystem indicator and are recommended for deliberation under WSP Strategy 3.

4 METRICS AND BENCHMARKS – TOWARDS STRATEGY 2 IMPLEMENTATION

The selection of a proposed suite of habitat indicators represents a first stage in the development of Strategy 2 monitoring. A more involved and likely iterative process will be the selection of associated metrics and benchmarks that can be used to quantify change in these indicators and relate such changes to assessments of habitat status. Developing a suite of consistent (but also regionally flexible) metrics and benchmarks for managers will facilitate broad development of a monitoring assessment framework that can be used to compare indicator condition across watersheds and CUs. An initial list of metrics and benchmarks that could inform selected Strategy 2 indicators was developed for the HWG by Nelitz *et al.* (2007b; see Appendix 14). The HWG expanded on this information through further consultation with agency experts to select an initial list of suggested metrics and benchmarks for the identified indicators.

Metric selection for each indicator was primarily based on the availability and costs of acquiring data to measure the metric, the existence of published relationships between the metric and some measures of fish habitat condition or fish productivity, and the availability of appropriate benchmarks for that metric. Benchmarks for the pressure and state indicators were either comparisons over time or space such as relative rankings of changes in habitat conditions among watersheds (e.g., the top percentile of a frequency distribution) or were based on identified transition points where changes in habitat conditions as indicated by the metric show effects on the productivity of the fish or the habitat, i.e. set to reflect risk of adverse effects. Expert opinion and LEK could guide the delineations of the categories for the comparative benchmarks. Benchmarks were not considered applicable for the indicators of habitat quantity at this time as more complete understanding of co-variance between changes in the extent of habitat and fish production would be required. It must be noted that the metrics and benchmarks identified here by the HWG are provisional, given the expectation that full development of useable metrics will be part of later discussions around implementation of the assessment framework, and the possibility that benchmarks may be customized on a regional, CU or watershed basis.

The HWG's provisional list of metrics and benchmarks linked to each indicator are described in Table 4.1. During HWG deliberations, complimentary data projects were identified that could improve and supplement available information on metrics and benchmarks. These projects, as well as recommendations for sampling protocols and return-rates, are also listed in Table 4.1. It should be recognized that the proposed sampling protocols, particularly in regards to the rate of sampling, are early recommendations, and will require further evaluation during development of a habitat assessment framework.

The narratives following Table 4.1 provide a rationale that expands upon the table entries for each of the stream, lake and estuary indicators and refer to the Nelitz *et al.*

(2007b) assessments of feasibility in developing metrics and benchmarks for the different indicators, including cost, data availability and scientific relevance.

Table 4.1. WSP suggested metrics, benchmarks and sampling protocols for Strategy 2 monitoring of proposed habitat indicators.

Habitat type	Indicator type	Indicator	Suggested Metric	Suggested Benchmark(s)	Complimentary Projects	Suggested Sampling Rate	Suggested Sampling Methodology
Stream	Pressure	Total land cover alterations	Roll-up data e.g., Watershed Statistics and report out on Total, and sub-indicators e.g., forestry, fires, urban, agriculture, other (possibly range)	Relative ranking of watersheds (e.g., low, med, high) of total from distribution curve across watersheds	To enable weighting of different land use types, do probability analysis of different types of land use impacts.	Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required.	As per metric.
Stream	Pressure	Watershed road develop-ment	Density kilometer/km^2	<0.4 km/km2 lower risk, > 0.4km/km2 higher risk	Develop correlation between road density, road network (via spatial analysis), stream network (S1, S2, etc.), fish distribution and crossing type e.g., culvert, bridge, etc.	Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required	Roll-up satellite imagery data (e.g., Watershed Statistics) that is augmented by provincial reporting systems until such time as reporting systems consistently utilized and up to-date.
Stream	Pressure	Water extraction	Volume licensed for consumptive use e.g., m3/yr, as a proportion of total yield summarized by watershed	Compare watershed ratios and rank based on proportion		Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required	Tracking Nature Conservancy of Canada concurrent development of similar indicator.
Stream	Pressure	Riparian disturbance	% of a stream's riparian area developed within 30 meters of the streambank, reported on a watershed basis	5% as first benchmark, subsequent categories determined via distribution curve of watersheds within the CU		Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required	Satellite imagery data e.g., (Watershed Statistics) or Streamkeepers methodology.
Stream	Pressure	Permitted waste management discharges	TBD When data available will evaluate for potential metric and benchmark	TBD	TBD	TBD	TBD

Habitat type	Indicator type	Indicator	Suggested Metric	Suggested Benchmark(s)	Complimentary Projects	Suggested Sampling Rate	Suggested Sampling Methodology
Stream	State	Suspended sediment	Total Suspended Sediments (mg/l, ppm)	• CCME • 25 mg/L in 24 hours when background is less than or equal to 25 • mean of 5 mg/l in 30 days when background is less than or equal to 25 • 25 mg/ when background is between 25 and 250 • 10% when background is greater than 250	Develop correlation curve of Turbidity Units to TSS	Use Environment Canada sampling to report out on trends (@ 60 sites across Region). New monitoring on 1 or 2 key streams in a CU. Monitor continuously and on stochastic events relating these to life history stages.	Initially physical sampling until correlation curves developed and then turbidity sensors.
Stream	State	Water Quality	N/A	N/A			
Stream	State	Water temp-erature: juvenile rearing – stream resident species	Maximum Weekly Average Water Temperature	Upper Optimum Temperature Range (UOTR) and Impairment Temperature (IT). Temperatures between UOTR and IT low/medium risk and temperatures above IT high risk. UOTR 15 degrees C IT 20 degrees C	Augment Temperature Sensitive streams database, Yukon water Temperature Data, WATEMP database where needed with Mean Weekly Average temperature.	New monitoring on 1 or 2 key streams in a CU. Monitor continuously and on stochastic events relating these to life history stages. Locate in a spawning and incubation site e.g., ch, pk and if rearing is in a different area, then also install there e.g., coho.	Data loggers and install these with turbidity sensors.
Stream	State	Water temperature: migration and spawning – all species	Maximum Daily Water Temperature during migration/spawning period	Upper Optimum Temperature Range (UOTR) and Impairment Temperature (IT). Temperatures between UOTR and IT low/medium risk and temperatures above IT high risk. • Chinook UOTR 14 degrees C IT 20 degrees C • Coho UOTR 14 degrees C IT 20 degrees C • Sockeye UOTR 15 degrees C IT 18 degrees C • Pink UOTR 15 degrees C IT 21 degrees C • Chum UOTR 15 degrees C IT 21 degrees C		New monitoring on 1 or 2 key streams in a CU. Monitor continuously and on stochastic events relating these to life history stages. Locate in a spawning and incubation site e.g., ch, pk and if rearing is in a different area, then also install there e.g., coho.	Data loggers and install these with turbidity sensors. Also Streamkeepers protocol.

Habitat type	Indicator type	Indicator	Suggested Metric	Suggested Benchmark(s)	Complimentary Projects	Suggested Sampling Rate	Suggested Sampling Methodology
Stream	State	Stream discharge	m3 during Aug/Sept	Discharge (m^3) less than 20% Natural Mean Annual Discharge during July /Sept.	Review water data i.e., Coulson and Obedkoff (1998), Rood and Hamilton (1995), BC MOE "Sensitive Stream Listing" spreadsheet (1997) unpublished data and BC MOE "Fish/Water Database" (2001) unpublished data; Imap BC and Ron Ptolemy, BC Ministry of Environment (pers. comm. Jan. 2008 based on above and archived WSC hydrometric station data) and where gaps for data exist, examine augmenting and updating with current information.	Every 5 years.	As per project.
Stream	Quantity	Accessible stream length, based on barriers	Kilometres	N/A	Predicted/Potential fish distribution of juveniles and adults-Investigate if Yukon Habitat Suitability or Provincial FSW models could work for WSP.	Need to update obstructions database so that it is species and lifestage specific and ID's when barriers fixed plus have different groups contribute their data to it. This will enable annual reporting similar to that in WA State of the Salmon model.	
Stream	Quantity	Key spawning areas (length)	Total length (km) of spawning area per watershed and roll-up for the CU		Need to ID the extent of the habitat and track changes over time. Need to augment data where it doesn't exist. May need to ID representative streams for a CU.	Report out annually.	Fisheries Information Summary System paper audit and field GPS for updates and missing Key Spawning Areas.
Lake	Pressure	Total land cover alteration	Roll-up data e.g., Watershed Statistics and report out on Total, and sub-indicators e.g., forestry, fires, urban, agriculture, other (possibly range)	Relative ranking of watersheds (e.g., low, med, high) of total from distribution curve	To enable weighting of different land-use types, do probability analysis of different types of land use impacts.	Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required.	As per metric.

Habitat type	Indicator type	Indicator	Suggested Metric	Suggested Benchmark(s)	Complimentary Projects	Suggested Sampling Rate	Suggested Sampling Methodology
Lake	Pressure	Watershed: road development	Km/km^2	$<0.4\ km/km^2$ lower risk, $> 0.4 km/km^2$ higher risk	Develop correlation between road density, road network (via spatial analysis), stream network (S1, S2, etc.), fish distribution and crossing type e.g., culvert, bridge, etc.	Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required	Roll-up satellite imagery data (e.g., Watershed Statistics) that is augmented by provincial reporting systems until such time as reporting systems consistently utilized and up to-date.
Lake	Pressure	Riparian disturbance	% of a lake's riparian area developed within 30 meters of the shoreline, reported on a watershed basis	5% as first benchmark, subsequent categories determined via distribution curve of watersheds within the CU		Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required	Satellite imagery data e.g., (Watershed Statistics) or Streamkeepers methodology.
Lake	Pressure	Permitted waste management discharges	TBD Not currently, when available will evaluate for potential metric and benchmark	TBD	TBD	TBD	TBD
Lake	State for sockeye lakes	Coldwater refuge zone	Width (m) as measured through Dissolved Oxygen and Temperature profiles	Develop distribution curve of width of all sockeye lakes coldwater refuge zones and rank e.g., low, med, high risk.	Recommend Sockeye Lakes group also measure DO profiles when undertaking lake assessments to enable refuge width to be calculated.	Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required	As per DFO's Sockeye Lakes Group methodology plus include DO profile.
Lake	State for sockeye lakes	Lake productive capacity	Nitrogen and Phosphorous x Lake Surface Area. See Project.	Relative ranking of sockeye lakes (e.g., low, med, high) of total from distribution curve	Nutrients (N&P) and photosynthetic rate (chlorophyll) correlated for most sockeye lakes (cold glacial lakes excepted). Track DFO's Sockeye Lakes Group's investigations into this correlation to enable direct estimate of productive capacity from N&P and replace N&P with chlorophyll if chlorophyll better correlation with smolt production.	All sockeye lakes within the Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years as required.	As per DFO's sockeye Lakes Group methodology.

Habitat type	Indicator type	Indicator	Suggested Metric	Suggested Benchmark(s)	Complimentary Projects	Suggested Sampling Rate	Suggested Sampling Methodology
Lake	Quantity	Lake shore spawning area (length)	Total length of spawning area per watershed and roll-up for the CU	N/A	There are currently lat/long's for @ 70 sites where sockeye spawning distribution noted. However, need to ID the extent of the habitat and track changes over time. Need to augment data where it doesn't exist.	Report out annually.	TBD if FISS and/or NuSEDS to be repository(ies) for this information.
Estuary	Pressure	Marine vessel traffic	#vessels or density	Develop rate of change for those estuaries where most relevant of the 5 Coast Guard monitoring sites i.e., Tofino, Vancouver, Prince Rupert, Victoria, Comox		Entire Region initially and on a five year return rate. Utilize results and Regional expertise to select areas for updating every 2 years if necessary.	Analysis of Coast Guard reporting information/MoE State of the Environment reporting.
Estuary	Pressure	Estuary habitat disturbance	Rate of increase of crown tenures (licences and leases) within all estuaries/ five years	N/A, rate of increase will guide recommendations for possible status monitoring	Model for coarse particulate matter in estuaries-use estuarine gradient from CHS data and lease information for log-storage. May be able to use deposition model from Scotland for log-storage.	Report out on Pacific Estuaries and Ducks Unlimited schedule every five years.	Report out on Pacific Estuaries and Ducks Unlimited reports.
Estuary	Pressure	Permitted waste management discharges	TBD When data available will evaluate for potential metric and benchmark	TBD		TBD	TBD
Estuary	State	Estuary chemistry and contaminants e.g., N, P, N:P, Metals, PAHs and PCBs	Reporting out only e.g., links in web-mapping application and in Habitat Status Reports where generated	N/A			
Estuary	State	Estuary dissolved oxygen	Percent saturation and stratification	See Project	In a sub-set of estuaries determine DO saturation and stratification.	Study TOR could state undertake on a 5 year basis.	

Habitat type	Indicator type	Indicator	Suggested Metric	Suggested Benchmark(s)	Complimentary Projects	Suggested Sampling Rate	Suggested Sampling Methodology
Estuary	Quantity	Estuarine habitat area (riparian, sedge, eelgrass and mudflat)	Hectares	N/A		Currently no large scale monitoring on quantity of mudflat, marsh and eelgrass habitats at sufficient resolution. Through Provincial CRIS program, riparian is monitored in sufficient resolution in developed areas. Province plans to do every five years. One estuary FREMP does have status monitoring of marsh and mudflat. May be undertaken by groups on individual estuary basis.	Field, aerial photography

4.1 STREAM INDICATORS – PROVISIONAL METRICS AND BENCHMARKS

4.1.1 <u>Total land cover alteration</u>

There are direct correlations between land cover alterations and declines in salmon productivity (Beechie *et al.* 1994; NOAA 1996; Bauer and Ralph 1999; Bradford and Irvine 2000; Bilby and Mollot 2008). The provisional metric for this indicator is the "total percent land cover alteration" in a watershed, ranked (e.g., low, med, high) based on a frequency distribution. Land cover categories include agriculture, forestry, urban development, fire disturbance, mining activity and road development. From this overall analysis, the individual land cover categories and changes over time in these categories could also be examined and ranked similarly based on a frequency distribution. Measured data from 1990s to present is readily available for BC and the Yukon from BC Watershed Statistics and Yukon Biophysical mapping, but at a relatively high cost. The scientific relevance was ranked as moderate by the HWG and the overall feasibility was estimated to be medium by Nelitz *et al.* (2007b) as classifying land cover alterations is complex requiring both satellite imagery and GIS data.

One weakness in a total land cover alteration indicator is that different land uses have different types, levels and durations of impacts on aquatic habitats. For example, while the impacts of forest harvesting and fire disturbance in watersheds on stream habitats will eventually recover with forest re-growth, the impacts of urban and agricultural development are relatively permanent. While there is guidance on thresholds for specific types of land conversion (e.g., effective impervious area and forestry equivalent clear-cut area) there is no threshold that reflects the combined and potentially synergistic effects of these multiple land uses. A thorough literature review is recommended by the HWG to fully explore how to weight different land-use categories and establish relevant benchmarks based on the expected magnitude and duration of each land use impact in isolation or in combination with other land use activities.

4.1.2 <u>Watershed road development</u>

Watershed road development is closely associated with watershed land cover alterations. As a metric, "road density" has been related to declines of salmon populations in the Pacific Northwest (Bradford and Irvine 2000, Paulsen and Fisher 2001). The scientific relevance of watershed road development and the road density metric was ranked high by the HWG and the overall feasibility was estimated to be high by Nelitz *et al.* (2007b). Road densities are correlated with the extent of land-use in watersheds and they can be the primary source of increased sediment generation in watersheds. Road stream crossings can also create fish passage problems that can reduce available habitat depending on the types of crossing structures used (B.C. MOF 2002). Annual data on road densities, road length and stream crossings from 1979 to present are available from the National Road Network database as well as BC Watershed Statistics. The estimated costs, however, to access and collate the data are high.

Numerous studies have shown negative relationships between road densities and salmon production, with effects evident at densities as low as 0.4 km/km^2 (Bradford and Irvine 2000, Thompson and Lee 2000, Pess *et al.* 2002, Opperman *et al.* 2005). Accordingly the HWG is suggesting a reference point of 0.4 km/km^2 for road density be used as a general benchmark for delineating a higher risk of negative effects to habitat.

It may be possible to improve the applicability and sensitivity of this indicator in the future by using additional metrics that account for the spatial distributions and overlap of the road and stream networks, the distribution of fish within watersheds, and the types of roads and stream crossings prevalent in particular watersheds.

4.1.3 Water extraction

Data on location and type of water extraction are readily available by waterbody for surface water and at a number of locations for groundwater in BC within the Imap BC program (Ron Ptolemy, BC Ministry of Environment, pers. comm.). Localized data are also available from a number of other sources in BC and the Yukon, with temporal extent dependent on the data source. The metric of “volume of licensed flow for consumptive use” as a proportion of cumulative watershed water yield will require generation of the watershed yield information by climatic and runoff modelling, as these quantitative data are generally lacking. Watersheds could then be ranked by the proportion of water volume extracted to identify where the extent of water extraction may be most problematic. The cost to obtain the information is uncertain, although not expected to be excessive and the overall feasibility was estimated to be high by Nelitz *et al.* (2007b). The Nature Conservancy of Canada (NCC) has concurrently developed a similar approach to investigating water extraction on a watershed scale whereby they are comparing the sum of water licences (via data gained from the BC Provincial Land and Resource Data Warehouse) to the accumulated annual precipitation yield (data found in the EauBC database) (Sarah Loos, NCC, pers. comm.). The outcomes of the NCC analysis have yet to be assessed by the HWG.

4.1.4 Riparian disturbance

Riparian disturbance is a commonly used pressure indicator for both streams and lakes and was ranked high for scientific relevance by the HWG. Mapped areas of riparian vegetation are available from 1990s to present on a multi-year basis throughout BC and the Yukon at relatively high cost using satellite imagery data, BC Watershed Statistics, and Yukon Biophysical Mapping. The metric of “% of a stream’s riparian area developed within 30 meters of the streambank”, reported on a watershed basis was recommended by the HWG. A 30 meter delineation was chosen for a number of reasons. It is has been a commonly referenced width for managing the riparian zone during development within BC (e.g., *The Land Development Guidelines for the Protection of Aquatic Habitat* (DFO and Ministry of Environment, Lands and Parks 1992)) and is cited in provincial regulations (e.g., *Riparian Area Regulations* ((BC) Ministry of Water, Land and Air Protection 2004 pursuant to the Provincial *Fish Protection Act*)). Also, the 30 meters criterion is used in the BC Integrated Land Management Bureau's Watershed Statistics program (which calculates percent of various land uses within watersheds) and has been used by many watershed assessment procedures over the last decade (e.g., Coastal and Interior Watershed Assessment Procedures). In essence 30 meters has become a defacto standard in the province for consideration of riparian issues, at least at the overview level of analysis (Malcolm Gray, Integrated Land Management Bureau, pers. comm.). The Watershed Statistics program provides a recommended sampling method for gaining both Total Land Conversion and Riparian Disturbance data. A benchmark of 5% of riparian disturbance as a point of concern was suggested based on studies of juvenile Chinook distribution in relation to various developments. This included riparian zone impacts in Yukon drainages (Steve Gotch, Fisheries and Oceans Canada, pers. comm.) which suggested that non-natal distribution of juvenile Chinook salmon was reduced in watersheds where development of riparian areas adjacent to non-natal rearing streams exceeded 5% of overall stream length. It is also suggested that subsequent benchmarks of concern be determined via a distribution curve of riparian condition across watersheds. The Pacific Streamkeepers have a detailed field protocol in place for determining the level of disturbance within the riparian zone which is supported by the HWG. The overall feasibility of evaluating this metric was considered to be moderate by Nelitz *et al.* (2007b).

4.1.5 Permitted waste management discharges

Permitted waste management discharges could provide insight into pressures on the quality, and possibly quantity, of salmonid habitats and was considered similarly important for lakes, streams or estuaries. The BC Provincial WASTE data program contains details on permitted discharges. However at the time of the HWG's deliberations WASTE was being converted to a different Provincial data-base maintaining both ambient and discharge quality monitoring information. The conversion timing was expected to be lengthy, with a completion date unknown. As well there was uncertainty as to whether a watershed code would be linked to each discharge location, which may be necessary for watershed-based analyses. Given uncertainties with the datasets, the HWG deferred recommending either a metric or a benchmark until the necessary information becomes available for evaluation. Future linkages to this indicator could be provided within the WSP web-mapping application (under development) if geo-referencing information is sufficiently robust.

4.1.6 Suspended sediment

Data on suspended sediment concentrations in streams is available from several sources, but is focused principally on large rivers. Environment Canada's Hydrometric Network measures suspended sediment at 60 stations throughout the Region. In the Yukon the placer water quality monitoring program collects data on total suspended solids in a large number of streams, most of which are associated with placer mining activities. The estimated costs of synthesizing the data from existing sources are presumed to relatively low, but this remains to be confirmed. "Total suspended sediment" (TSS) was the HWG's recommended metric to measure sediment concentrations, as TSS is broadly accepted as the standard unit of measure when evaluating sediment concentrations in freshwater streams and rivers. The benchmarks suggested for TSS are based on the Canada Council of Ministers of the Environment (CCME) sediment guidelines for the protection of aquatic life. The CCME standards reflect a consolidation of the current science and information available on the effects of both short and long term inputs of total suspended solids on aquatic biota.

Although Nelitz *et al.* (2007b) rated the overall feasibility of evaluating this metric as moderate its likely that there may be challenges in developing reliable field-based TSS monitoring. To date, the only scientifically reliable means of analyzing water samples for TSS has been via laboratory analysis (employing non-filterable residue techniques). Over the past several years, however, the Yukon Government has been working closely with Partech Industries to adapt and refine a portable digital meter that is able to produce reliable TSS measurements in the field (Steve Gotch, DFO, pers. comm.). Although the results have been promising, it is unlikely that these units will be widely available for general use in the near-term. In the interim, turbidity (or the cloudiness or opacity in the appearance of a liquid caused by particles absorbing and scattering light) can readily be measured in the field and has been employed as a surrogate measure of water quality with respect to suspended sediment. The near-term use of TSS as a metric for evaluating suspended sediment in streams will likely require development of a robust correlation between TSS and turbidity. Development of this correlation would allow monitoring of suspended sediment to be undertaken quite easily by interested external groups as portable turbidity meters are often readily available, inexpensive, simple to operate and can produce consistent results in the field.

4.1.7 Water quality

Suggested water quality metrics are the “concentrations of contaminants, nutrients, and dissolved oxygen” in stream water. Note that water temperature is treated as a separate indicator. Water quality data for streams are generally only available within BC from localized monitoring or research projects. For example, dissolved metals and hydrocarbon levels may be monitored regularly in particular streams with a history of industrial discharges impacting fish communities, while levels of nitrogen and phosphorous nutrients may be measured periodically where agricultural runoff is suspected of impacting algal growth and oxygen demand in streams. Detailed water quality information is therefore generally restricted to a subset of streams known to have past or ongoing water impacts. Monitoring of proposed pressure indicators, such as streambank riparian disturbance and total land cover alteration, could be used as a future guide for selecting new sites where more intensive water quality monitoring would be useful for Strategy 2 monitoring purposes.

Beyond site-specific studies, the B.C. and Yukon Water Quality Monitoring Network also undertakes ambient monitoring of 36 rivers in British Columbia, and 5 rivers in the Yukon. These stations are primarily operated on large rivers of federal interest where sampling occurs on a bi-weekly basis for a wide range of water quality variables, including trace metals, nutrients, major ions, fecal coliforms, and other parameters of site-specific importance (e.g. dissolved oxygen, pesticides, etc.).

4.1.8 Water temperature

Stream water temperatures have been measured in many British Columbia streams as part of site-specific research and monitoring projects. Temperature metrics and benchmarks assembled by the HWG were based on literature-derived Upper Optimum Temperature Ranges (UOTR) and Impairment Temperatures (IT) that differed on the basis of varied temperature requirements for rearing or migration across different salmon species. Temperatures between the maximum of the UOTR and the IT were considered low or medium risk and temperatures above IT at high risk of causing adverse effects to salmon.

Suggested temperature metrics were partitioned by the HWG into two key categories: (1) “temperatures relevant to juvenile coho rearing conditions”; and (2) “temperatures relevant to migration conditions for all species of Pacific salmon”. Only coho and Chinook juveniles rear consistently in streams with coho preferring the smaller streams where the effects of watershed land-use on water temperatures would be most pronounced. For this reason, coho rearing temperatures were selected as one of the key water temperature metrics. Temperature conditions along adult migration routes were also selected, as high water temperatures can delay migration and increase en-route and pre-spawn mortalities for all salmon species.

Much of the existing water temperature data in the province has been collected and collated for research into the identification of temperature sensitive streams (Nelitz *et al.* 2007c) and water temperature is generally easy and inexpensive to measure as part of any new monitoring project. Statistical spatial models developed by Nelitz *et al.* (2007c) to predict water temperatures in provincial watersheds could be used with spatial data on fish distributions to identify streams where new temperature monitoring projects could be most useful. New information could be used to augment the Temperature Sensitive Streams database, as well as existing Yukon water temperature and WATEMP databases.

4.1.9 Stream discharge

Stream discharge or stream flow is a commonly used stream state indicator that was ranked high for scientific relevance by the HWG. Carrying capacity of streams and their seasonal suitability for use by different salmon species and life-stage are directly related to aspects of the annual hydrograph and “mean annual discharge” (MAD). The suggested benchmark for stream discharge is when the 1 in 2 year 30-day duration summer minimum flow is less than 20% of MAD, which generally occurs in BC streams from July through September. It is particularly relevant to those salmon species that reside in streams during the summer low flow period (i.e., coho and Chinook). A MAD of 20% is considered adequate flow for maintaining the required riffle widths, depths and velocities necessary for the production of benthic invertebrates that maintain salmon populations. This benchmark has been developed based upon extensive empirical observation (Ron Ptolemy, BC Ministry of Environment, pers. comm.) and has been commonly used as a flow benchmark by provincial fisheries managers. The 20% MAD benchmark is intended for application to small and medium sized streams.

It is important to note that some systems naturally drop below this 20% MAD benchmark during summer low flows, which presumably limits their natural productive potential. In some of these situations, alternative life-history strategies are employed by juvenile salmonids (e.g., moving into lakes and ponds where food resources are greater, such as in Black Creek, Vancouver Island). Flows less than 20% MAD during the winter months of January and February can also decrease productivity due to the increased potential for icing events which may cause overwintering mortality for invertebrates and juvenile salmonids. If uncertainty exists as to limiting factors within the stream, evaluating the same 20% MAD benchmark in the winter period could provide further insight into mechanisms of stream production.

Archived and real-time hydrometric data are available at relatively low costs from several sources, the main one being the Environment Canada Hydrometric Network (with data served up through HYDAT). This network, however, tends to only monitor larger rivers and the temporal extent is highly variable depending on the stations of interest. There are numerous cases, however, where specific fisheries and water surveys have supplemented the network by collection of periodic baseflow measurements, in particular below and above known points-of-diversion during major drought events. Where data gaps exist though, particularly on smaller streams, supplemental information may be desired. Although not yet evaluated thoroughly HYDAT flow data could be supplemented by information sources such as the BC Streamflow Inventory (Coulson and Obedkoff 1998), BC MOE's unpublished Flow Sensitive Stream Listing, BC MOE's Fish/Water Database and BC MOE's Imap BC program. Localized hydrology information may also exist in regional action plans, such as described for the Quesnel Habitat Management Area (Rood and Hamilton 1995a).

Where insufficient flows are found to meet the suggested 20% MAD benchmark more rigorous and localized examinations related to additional benchmarks can be initiated, particularly during water licensing reviews. For example, the *BC Instream Flow Thresholds for Fish and Fish Habitat* can be applied to provide guidance in determining required flows for non-fish and fish bearing streams; for the latter setting monthly flow targets to achieve the more natural range of variability found within an annual hydrograph (Hatfield *et al*, 2003). This more detailed approach, however, requires daily flow data so the costs of data collection and analysis can be high.

4.1.10 Accessible stream length

Data on "accessible stream length" (based on barrier locations) are available throughout the Pacific Region from the 1970s to present through both the BC Fisheries Information Summary System and the BC Obstructions Database. The overall feasibility as a quantity indicator was estimated to be high by Nelitz *et al.* (2007b). Data will, however, require auditing and updating as pilot work for the Habitat Status reporting has shown that barrier information may not be species-specific or recently updated (e.g., retaining obstacles which have been removed or failing to identify new obstructions such as recent road culverts). The cost of collecting the initial information from the databases and auditing is minimal as per the pilot outcomes. The costs of addressing any uncertainties through ground-truthing would be higher and will range depending upon the geographic extent.

4.1.11 Key spawning areas

Key spawning area is defined by the HWG as "*those areas of spawning habitat used foremost annually regardless of escapement*" to enable more focused monitoring and reduce variation in extent brought about by changing escapement levels. Wetted area could change as a result of discharge, thus "stream length of the spawning area" is recommended by the HWG as a metric for this indicator. The "regardless of escapement" element of the definition was to focus on the spawning areas that the salmon selected, or keyed in upon, even during low escapement when multiple sites could be available. Data on key spawning areas are available for the province, but the overall coverage of this information has not yet been determined. The need to identify the extent of key spawning habitat and track changes over time was recognized by the HWG (e.g., if the quantity of spawning habitat is changing this information could trigger assessment of potential causes such as compaction). Data on the extent of spawning areas will need to be augmented where it is not currently available. As it may not be possible to evaluate this metric broadly there may also be a need to identify representative streams in CUs that could be used for tracking.

4.2 LAKE INDICATORS – PROVISIONAL METRICS AND BENCHMARKS

4.2.1 Total land cover alteration

See above Section 4.1.1.

4.2.2 Watershed road development

See above Section 4.1.2

4.2.3 Riparian disturbance

See above Section 4.1.4, with the appropriate metric restated as "% of a lake's riparian area developed within 30 meters of the shoreline".

4.2.4 Permitted waste management discharges

See above Section 4.1.5

4.2.5 Lake productive capacity

Productive capacity is a function of the size and productivity of the lake habitat which often defines its ability to produce smolt biomass (Hume *et al.* 1996). Data are currently available for 40 sockeye lakes which have direct photosynthetic rate (^{14}C primary production) measurements and estimates of productive capacity. The DFO Freshwater Ecosystem Section is currently investigating the possibility of estimating productive capacity using static measures such as euphotic zone depth, chlorophyll concentrations and nutrient levels. The HWG recommended tracking these efforts to determine the most flexible and easily obtained metrics, which could be used for monitoring lake productive capacity. Although no specific benchmark was set for this indicator, the HWG noted that a frequency distribution curve generated from historical data from past monitored sockeye lakes would provide insight into the natural range of lake productivity levels and could be used to select specific benchmarks in the future.

4.2.6 Coldwater refuge zone

Juvenile sockeye exhibit diel vertical migrations in lakes, ascending during the evening into the epiliminion to forage on zooplankton, and then descending to the hypolimnion to take refuge from predators (Levy 1990; Scheuerell and Schindler 2003). A coldwater refuge in the hypolimnion also allows juvenile sockeye to avoid or limit exposure to high summer surface water temperatures in warm water lakes. The coldwater refuge zone can be quantified as the “width of the zone of water below the depth of the bottom of the thermocline but above the depth of 50% oxygen saturation” (Ruggerone 2000). Seasonal or late summer depth profiles of temperature and dissolved oxygen are required to estimate the seasonal width of the coldwater refuge zone and these data are available for a few sockeye lakes (e.g., Osoyoos, Saginaw, Cultus). The width of the coldwater refuge zones for all sockeye lakes with available data could be plotted on a distribution curve. This exercise would identify sockeye nursery lakes with relatively narrow cold-water refuge zones that are most susceptible to changes in oxygen and temperature conditions. Pressure indicators such as total land conversion could be used as triggers to identify a subset of lakes where additional monitoring of coldwater refuge zones would be particularly useful.

4.2.7 Lake shore spawning area

Lake shore spawning area data are available for about 70 locations in BC. Data will need to be augmented where they are not available or do not exist. The “length of lake shore spawning areas” was recommended as the metric because linear extent (as opposed to area) could be more easily assessed from surface surveys, with acceptable accuracy. Determination of spawning occurring off-shore that would be required to calculate spawning area was not incorporated into the suggested metric, as spawning often extends below depths that can be observed from the surface and will be further obscured in turbid systems.

4.3 ESTUARY INDICATORS – PROVISIONAL METRICS AND BENCHMARKS

4.3.1 Marine vessel traffic

Vessel traffic could potentially affect key estuarine attributes such as estuary water quality, shoreline wave action and shoreline complexity (Vasconcelos *et al*. 2007). The amount of vessel traffic could also indirectly impact the transport and export of detrital matter and could serve as a surrogate for contaminants resulting from spills and fleet operations while representing a potential source for invasive species (Ruiz *et al*. 1999). The metrics recommended by the HWG for tracking marine traffic are the "number of vessels per month" or "density of vessels" within estuaries where the Canadian Coast Guard regularly monitors traffic (i.e., of Tofino, Vancouver, Prince Rupert, Victoria, and Comox). In lieu of any specified benchmarks evaluation of rate of change is recommended by the HWG. While data can be gained directly from the Canadian Coast Guard from 2002 to present (on a monthly to annual basis for B.C.), summaries of these data are readily available, and have already been analysed for the trends in key estuaries, within BC State of the Environment reporting. The estimated cost to collect data on these metrics is therefore low.

4.3.2 Estuary habitat disturbance

General disturbance of different estuarine habitats could reflect impacts to a suite of key estuarine attributes such as estuary water quality; the salinity boundary layer; the sediment supply/rate of aggradation or degradation; transport/export of detrital material; number of streams flowing into the estuary; the habitat mosaic and connectivity; shoreline complexity; shoreline wave action; large woody debris; native biological communities and assemblages; or plankton productivity. Broad data sources that could directly inform assessment of estuarine disturbance at appropriate resolutions are not currently available. The HWG has recommended the "rate of increase in crown tenures" (licences and leases) within all estuarine components (riparian, intertidal and subtidal) over 5 years" as an appropriate metric that could serve as a surrogate to a direct measure of estuarine disturbance. No benchmarks were identified for this metric, but comparisons of rate of increase could be generated across estuaries and over time for a particular estuary. This would facilitate recommendations for any proposed status monitoring. The data would be drawn from Pacific Estuaries reports prepared by Ducks Unlimited every 5 years. The estimated cost to synthesize the data for WSP purposes is low. The HWG also recommends investigating the development of a model for estimating the impacts of log-storage deposition that incorporates bathymetry data from the Canadian Hydrographic Service data and lease information for estuary log-storage sites.

4.3.3 Permitted waste management discharges

See above Section 4.2.4

4.3.4 Estuary chemistry and contaminants

There is an abundance of monitoring of water quality parameters within estuaries in BC, with data collected for specific industrial developments or through ambient monitoring. Data are collected for a range of variables including Total N, P, N:P ratio, mercury compounds, PCBs, dioxins, furans, PBDEs, PAHs and DDT, each of which often have numerous benchmarks within the literature (summarized in Nelitz *et al.* 2007b). While exact costing has not yet been determined, it is known that chemical analyses will typically incur very high costs. To minimize costs and avoid duplication, the HWG recommends linking within the WSP web-mapping application to work that is being undertaken in estuaries by the Province, such as State of the Environment Monitoring and Provincial Water Quality Monitoring Objectives. Within priority CUs, a narrative on any outstanding water quality issues could then be provided within either the Overview or Habitat Status reports.

4.3.5 Estuary dissolved oxygen

Dissolved oxygen levels and stratification in estuaries have been shown to be important in the freshwater-marine transitions of migrating juvenile and adult salmon (Alabaster 1988; Curran and Henderson 1988; Birtwell and Kruzynski 1989; Birtwell *et al.* 1994). In addition, the toxicity of contaminants has been shown to be dependent on dissolved oxygen saturation. The metric suggested by the HWG is “dissolved oxygen saturation at each stratified layer”. Since such data are currently unavailable, the HWG identified a project to determine the dissolved oxygen saturation profiles in a yet to be determined subset of estuaries. This work would inform the development of a suitable benchmark.

4.3.6 Estuarine habitat area

Estuarine habitat area was selected by the HWG as an indicator of habitat quantity. The selected metric was the “area of riparian, sedge, eelgrass and mudflat habitats”. Because a component of this quantification is biotic in nature (i.e., extent of estuarine plants) this indicator overlaps with anticipated Strategy 3 (ecosystem) indicators. However, as it would be difficult to partition estuary habitat without incorporating this biotic component the HWG felt warranted in including this indicator within a Strategy 2 monitoring frame. It is anticipated that there will be an integration of Strategy 2 and 3 monitoring approaches at some point in the future (R. Lauzier, pers. comm.) so that ultimately such distinctions may become less relevant. Nelitz *et al.* (2007b) identified an existing baseline inventory (Ryder *et al.* 2007) for larger delineated estuaries across BC which provides a standardized methodology for repeat mapping of overall estuary extents. However, the resolution of this monitoring was found to be insufficient for mapping distinct areas of estuarine marsh, mudflat and eelgrass habitats. Riparian habitat is currently monitored by the BC CRIS program near more urbanized centres, and is considered of sufficient resolution for WSP monitoring purposes.

5 DISCUSSION

The health and long-term well-being of wild Pacific salmon is inextricably linked to the availability of diverse and productive freshwater, coastal, and marine habitats. The integrity of salmon habitat is challenged by human competition for accessible land and fresh water, for ocean spaces, and for the interconnecting estuarine and coastal areas. To maintain wild salmon populations into the future there will be a growing need to more effectively manage existing habitats. WSP Strategy 2 monitoring is intended to allow tracking of the status and trends of limiting and highly productive salmon habitats, and to provide insight into the overall habitat status of the CU. Implementation of monitoring and assessment of CU habitat status under WSP Strategy 2 will ultimately provide key inputs to guide long-term management of salmon habitats. Appendix 1 provides an example (for a hypothetical coho CU in the BC Interior) of how the Strategy 2 action steps 2.1 – 2.4 will link so as to provide managers with updated information on the status of key habitats within a salmon CU. To establish a foundation for Strategy 2 monitoring the HWG has endeavoured within this report to develop an initial list of feasible, cost-effective habitat indicators for stream, lake and estuary habitats (marine habitats will be considered under Strategy 3) that could be used to assess and track habitat status within salmon CUs.

5.1 CHALLENGES AND OPPORTUNITIES

The proposed list of indicators (and suggested associated metrics, benchmarks and potential sampling protocols) presented in this report is the result of deliberations by the HWG that drew on the groundwork of other agencies, commissioned literature reviews, communication with habitat and ecosystem experts, consultations with stakeholders, workshop discussions, a practical assessment of indicator feasibility, and consensus decisions among DFO habitat management and habitat science staff. Data availability, spatial extent, spatial resolution, temporal extent, temporal frequency, scientific and management relevance, cost, and overall feasibility were all considered in the final selection of indicators. The HWG did, however, experience a range of challenges in developing habitat indicators that could be used for the purposes of Strategy 2 monitoring. Serious data-gaps often exist for evaluating specific indicators, metrics, and benchmarks. For these issues the HWG has identified projects that could lead to refinement of potential indicators or establish more meaningful and useable benchmarks. In addition to such indicator-specific challenges, there are also a set of WSP-specific challenges and opportunities (that relate to multiple indicators) which are discussed below.

5.1.1 Track the status and trends of limiting and highly productive habitats

The strength of relationships between habitat condition and associated fish production are uncertain. This highlights a need to develop improved analyses within integrated WSP monitoring strategies that can accurately track how habitat and fish production vary together over time. In the interim, however, there is substantial published support for the relationships between the suite of indicators recommended by the HWG and salmon productivity. Lewis and Ganshorn's (2007) literature review found that the habitat state indicator categories of streamflow, water temperature, water chemistry, physical habitat quality and habitat area in particular were well supported as strong indicators of salmon abundance. Lewis and Ganshorn (2007) also found support, though less extensive, for the habitat pressure categories of terrestrial development (land use), riparian and foreshore development, and water use.

A further challenge in understanding the co-variance between habitat and fish production is that a number of indicators proposed by the HWG do not directly sample the habitat, thus creating additional uncertainty. For example, in some cases the indicators are either remotely gained (e.g., land-use conversion uses satellite imagery) or rely on proxies (e.g., estuary disturbance as characterized by the rate of increase of crown tenures). However, given the overarching direction to minimize costs, a desire by NGOs to use indicators that allow for proactive responses, the larger areas that can be efficiently measured remotely, the high field sampling intensity required to reduce statistical uncertainty, plus the previously described linkages between pressure indicators and resultant impacts on fish habitat, the use of remotely gained information and proxies was considered acceptable for broad Strategy 2 monitoring.

It will also be challenging to accurately evaluate state indicators as there is potential for habitat condition to have been influenced by cumulative, synergistic, and legacy effects. Legacy effects are the consequence of disturbances that continue to influence environmental conditions long after the initial appearance of the disturbance (Allan 2004). Presently, there is no differential weighting of the indicators to reflect these potential interactions. Directed research is required to address this gap. It should be recognized that any identified relationships among indicators will likely need to be revisited as they could change as a result of specific land-use practices or the environment itself (Allan 2004). In the interim, either consistent weighting of the indicators, or the use of LEK to differentially weight the indicators on a CU basis could be adopted and tested on a pilot basis.

Additional indicators of habitat quantity were initially considered by the HWG but not pursued due to limited data at the appropriate resolution. A strength of the proposed indicators of habitat quantity lies in the data availability, much of which is within existing DFO programs or obtainable via modest modifications to those programs. For example, lake productive capacity and coldwater refuge zone can be gained from data collected by DFO's Freshwater Ecosystem Section. As well, DFO's stock assessment programs and external groups undertake salmon spawning escapement work; the extent and intensity varying among salmon species, so that the key spawning habitat indicator could be monitored within an existing program. Through its regulatory responsibilities, and habitat restoration activities, DFO could also track the losses and gains of various types of habitat; of particular relevance would be the highly productive and limiting habitats. Such tracking is not currently being undertaken, which also limits DFO's ability to determine whether the agency is achieving a net gain of habitat for Canada's fisheries resources (as identified within the *Policy for the Management of Fish Habitat* (DFO 1986) - currently under review). This habitat accounting is recommended by the HWG, recognizing that consistency and coordination among programs is required to determine status and trends. Ideally, external groups undertaking projects would similarly track and report on habitat quantity changes so that a more extensive and accurate inventory and analysis of trends in habitat quantity could be developed.

There are two clear strengths associated with the HWG's suggested metrics. First, they are all considered technically feasible (although some will require supporting analyses). Second, in many instances metrics suggested are those that interested groups outside of DFO can measure (e.g., riparian disturbance, stream sediment), thus improving accessibility. A challenge recognized with metrics, as with other evolutionary programs, will be a need for them to be adaptable as technology changes and new means of monitoring are developed. The challenge will be in ensuring technological advances are well understood, relationships are developed between the old and new metrics where needed, and the information is communicated broadly to ensure consistency in application.

As per the WSP, Action Step 2.2, "*indicator benchmarks must be developed that reflect the desired value of a particular indicator and set to reflect DFO's intent to take action to protect and restore habitat on a preventative basis as required, before population abundance declined in response to degraded habitat*" (DFO 2005). Benchmarks set to reflect risk of adverse effects were suggested by the HWG for the pressure indicators of watershed road development and riparian disturbance and, for the state indicators of: stream sediment, stream temperature and stream discharge. A recommended project to investigate dissolved oxygen in the different strata of a number of estuaries could also generate information to establish benchmarks for dissolved oxygen.

In other cases, no specific benchmarks could be determined by the HWG due to lack of supporting literature and research guidance. In these situations, comparative benchmarks for reporting out risk could be used. For example, creation of a frequency distribution of the indicator metric values across watersheds within a CU and then reporting out on the watershed's relative ranking category (e.g., low, medium and high), was recommended. This form of relative comparative ranking will not directly identify a desired metric value for the particular indicator but this approach could determine which categorized watersheds are considered acceptable based on professional judgement and LEK. The indicator value dividing acceptable and unacceptable categories could then become the future benchmark to reflect desired condition beyond which would represent a significant risk of adverse effects. The strength of this approach is that it provides for a geographically local analysis with the potential to develop local benchmarks. Further, it helps to address the challenge of defining valid benchmarks in potentially and pervasively altered systems (Reid and Furniss 1998). The proposed indicators with comparative benchmarks are the pressure indicators of total land conversion, riparian disturbance (beyond 5%), water extraction and marine vessel traffic and; the state indicators of: coldwater refuge zone and lake productive capacity. The pressure indicator of estuarine habitat disturbance utilized the metric of rate of increase of crown tenures over a five year period. A benchmark was not determined, however, comparisons could be generated across estuaries and also over time for a particular estuary.

Monitoring return rates suggested by the HWG for sampling protocols should allow for generation of habitat trend data. Five years is recommended by the HWG for many of the pressure indicators and annually for many of the state indicators. The HWG recognizes that monitoring schedules will be revisited during the development of a habitat assessment framework.

5.1.2 Gain insight into the overall habitat status of the CU

Simply reporting out individually on the large number of indicators would present a challenge in providing an assessment of the overall health of the CU habitat (e.g., is it generally improving, stable, or decreasing). The suite of proposed indicators is instead intended to combine physical and chemical data to provide a more holistic overview of habitat status. It will, however, be necessary to develop a classification system as part of the assessment framework that can be used to rate the "health" of individual CUs based on an integration of the suite of indicators. This classification will need to be informed and adjusted by known natural regional variations in general habitat state.

An additional consideration to this objective is the flexibility desired within the WSP. As per Action Step 2.2, "*Indicators may be general across CU's or specifically selected on a case-by-case basis for specific CU's and habitat types. Government agencies, First Nations governments, watershed planning processes and stewardship groups will be asked to provide advice on the development or selection of key indicators for their watersheds, based on local knowledge and information on the kinds of data that are available"* (DFO 2005). A strength of the proposed indicator suite is that it provides a large standardized pool from which to select specific indicators, based on the species or life history strategies and anticipated habitat types requiring monitoring. If, after examining this suite for suitability, it doesn't meet the needs of a particular issue within a CU, additional indicators could also be used as per the WSP's intended flexibility. A specific classification system could be developed to report out on overall habitat status for that particular CU, although this would be outside broader efforts to develop a standardized regional classification system.

Assessment of the availability of data that could inform indicators was focused on larger data-sets that spanned either BC and/or the Yukon. There are, however, likely to be numerous more localized habitat monitoring data sets maintained by various groups that were not evaluated by the HWG. It will be useful to further identify these and incorporate these into the overall Strategy 2 program (i.e., reflecting the flexibility aspect of the WSP). Incorporating localized information into habitat status evaluations for a specific CU would support more reliable assessments. Again, this would however be outside of efforts to create a broadly standardized regional classification system.

Given the challenges relative to this objective, it is suggested that the primary focus of the monitoring program initially be on tracking the status and trends of the highly productive and limiting habitats within CUs and incorporating, where necessary, additional watershed specific indicators. This will serve the immediate needs of focusing conservation and restoration efforts and informing integrated planning processes.

5.1.3 Key inputs to guide habitat management

Implementation of Strategy 2 monitoring is intended to provide four key inputs (WSP 2005) to guide habitat management. Two of these inputs are to identify: *important habitat in need of protection to maintain salmon productivity* and *habitat risks and constraints adversely affecting that productivity*. The strength of the approach the HWG has developed to meet Action Step 2.1 – *Document habitat characteristics within CUs* – is to use LEK and existing documentation to identify watershed issues and the highly productive and limiting habitats. Adoption of the Pressure-State model also provides for pressure indicators that can be utilized to examine potential constraints on productivity and state indicators that reflect the affect of these constraints on habitat condition. These constrained or limited areas can be the focus of restoration or rehabilitation which fulfills the third key input to guide habitat management (i.e., identify *areas where habitat restoration or rehabilitation would be desirable to restore or enhance productivity)*.

A further opportunity provided by the indicators is that application of the composite suite could also identify issues and threats not previously recognized, thereby aiding in prioritizing strategic management actions. The approach recognizes that salmonid habitat use can shift as can productivity levels. Consequently, return-rates associated with both monitoring and reporting on the indicators will need to be defined that can capture these dynamics and allow for adaptive management.

The fourth key input to guide habitat management (i.e., identify *investigations to fill data gaps*) has in part been fulfilled by the HWG's efforts to identify projects that could fill data gaps in regards to the proposed suite of indicators and further develop the suggested metrics and benchmarks. It is likely that further information gaps will be identified as Strategy 2 is implemented, especially if additional indicators are required. Development of habitat indicators and related metrics and benchmarks should be considered an iterative process and those proposed in this report should not be considered final.

5.2 NEXT STEPS

A number of further steps are needed to complete development of Strategy 2. These steps include: (i) undertaking directed projects to address data-gaps and refine the indicators, metrics and benchmarks; (ii) developing a habitat assessment framework for indicator monitoring that integrates with Strategies 1 and 3; and (iii) implementation of habitat monitoring, which represents the core activity of Action Step 2.3.

i) The list of possible projects needs to be prioritized and undertaken as resources and opportunities permit. Outcomes from these projects could inform changes to the monitoring program over time.

ii) Development of the assessment monitoring framework is a major next step that could further determine appropriateness of the proposed indicators, and inform final selection of metrics and benchmarks. Linkages will need to be clearly identified between pressure indicator thresholds and the specific state indicators that will be evaluated if a particular pressure threshold is exceeded. The framework will also need to identify the recommended distribution and intensity of sampling effort, as well as responsibilities for those involved in data collection and reporting (both within DFO and across supporting agencies). Strategy 3 is a work in progress wherein ecosystem based management objectives by DFO sector will be identified which will define the structure for determining the indicators; there will be a need to integrate the habitat objectives of Strategy 2 into this structure. Given the nested nature of habitats within ecosystems, the monitoring framework needs to be developed in concert with Strategy 3 indicators, plus be flexible enough to accommodate further indicators that fill gaps such as near-shore indicators. Linkages with Strategy 1, including opportunities for coordinating data collection need to be further investigated. It will be highly beneficial if, to the greatest extent possible, effective means are identified for integrating indicators under Strategies 1, 2 and 3 for use in Strategy 4, *Integrated Strategic Planning.*

iii) Implementation of monitoring and assessment will involve both field-work and data analysis. Both components can be time-consuming, labour intensive and ultimately expensive. The level of effort and cost to DFO and other agencies needs to be realistically reflected in any monitoring proposal. Working towards shared access to watershed specific datasets across agencies (e.g., through electronic interoperability) would be an asset for the overall WSP monitoring program.

6 SUMMARY

To guide selection of habitat indicators, the WSP outlined a process to document habitat characteristics within CUs. A two-tier report structure (i.e., completion of Overview and Habitat Status reports), complemented with Local Ecological Knowledge was developed by the HWG to document habitat characteristics. Through this approach, the HWG has provided specific, relevant, and appropriate guidance for selecting indicators to monitor the status and trends of both constrained and highly productive habitats. Management actions are then linked back to these habitats through monitoring of the indicators.

The adoption of the Pressure-State model for Strategy 2 monitoring of habitat indicators was widely endorsed. The use of pressure indicators allows for broad insight into potential impacts and provides a precautionary approach to managing habitat across CUs, an approach promoted by DFO and desired by NGOs. The use of state indicators provides detailed information on the actual condition of fish habitat at more localized scales.

The proposed pressure and state indicators were ranked for scientific relevance and underwent a rigorous practical assessment. The proposed list of indicators is considered reasonable in number, technically feasible, and provides for citizen involvement. As outlined by the objectives, pressure indicators can clearly be linked to the quality of habitats that support or limit salmon production. Similarly, state indicators can clearly be linked to the key factors enhancing or limiting wild salmon production, and will be useful for identifying and prioritizing areas for protection, rehabilitation, and restoration.

A number of data gaps were identified throughout the indicator selection process, particularly for the indicators of habitat quantity, thereby limiting the ability to report out on gains and losses of fish habitat. Recommendations were made to consistently track changes in status internally and externally, and projects were suggested to fill these data gaps and improve upon the list of indicators.

While the list of challenges in meeting Strategy 2 objectives is long, they are not insurmountable. *Assessing the overall habitat status of the CU* is particularly challenging and meeting this objective will require further development within a broad assessment framework.

The thoughtful recommendations provided to-date on implementation (e.g., take a pilot approach, be adaptive with the indicators and integrate with Strategies 1 and 3) are helpful as DFO and others move the WSP towards operational reality. Implementation of the assessment framework will certainly have another set of challenges to meet that will require organizational, funding and intellectual capital resources.

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APPENDIX 1.
DFO WSP HABITAT WORKING GROUP MEMBERSHIP

DFO Staff	Data Mgmt.	Planning	Policy	Stewardship	HPSD[1] Regulatory	HPSD Monitoring	Habitat Restoration	Science
Karen Calla	*							
Dwight McCullough	*							
Cheryl Lynch	*							
Lidia Jaremovic		*						
Carol Cross			*					
Brad Mason				*				
Brian Tutty				*				
Gary Taccogna (Chair November 2005-July 2006)				*				
John Patterson					*			
Corino Salomi					*			
Steve Gotch					*			
Heather Stalberg (Chair July 2006-present)					*			
Tom Pendray					*			
Murray Manson					*			
Ryan Galbraith						*		
Al VonFinster							*	
Mel Sheng							*	
Shannon Anderson							*	
Sean Bennett							*	
Ray Lauzier								*
Erland MacIsaac								*

1. HPSD-Habitat Protection and Sustainable Development

APPENDIX 2.
HABITAT STATUS REPORT TEMPLATE

Note, this reporting structure was piloted in a number of CUs within the Pacific Region in 2006. The columns of life stage; known limiting factors and high value habitats; possible measures to address limiting factors; possible measures to maintain productivity and habitat protection and restoration measures undertaken were requested to be filled in during the pilot. At that time, the habitat requirements for each life history stage documented by Diewart (2007) had not been completed, nor the proposed list of indicators and benchmarks developed. The indicators (performance measures) and benchmarks (thresholds) listed here were mocked-up to show how these could provide the link between life stage requirements, and management actions.

East Coast Vancouver Island Coho Conservation Unit – Englishman River Coho Habitat Status Report								
Coastal Coho Habitat Requirements:		Englishman River:						
Life Stage	Habitat Requirement for each life stage	Known limiting factors & high value habitats	Performance Indicator(s) for habitat limiting factors	Performance Indicator(s) Status	Performance Indicators Thresholds	Possible measures to address limiting factors	Possible measures to maintain productivity	Habitat Protection & Restoration Measures Undertaken
Spawner/Egg/ Alevin	-	use lower 16 kms, spawn area 73,000m^2 not limiting, but spawning habitat quality compromised, excessive bank erosion & lateral channel migration, poor pool-riffle development, elevated sediment inputs from upper watershed	* peak discharge events * % riparian integrity * % land use conversion * channel stability	* e.g., #daily max discharges exceeding some value (link to gauging station real time data)	* e.g., a value for max flow threshold	remediate important point sources of sediment esp. upper basin & clay bank near South Englishman confluence, speed recovery of riparian, riffle enhancement at 4 identified rapids to provide gradient control & reduce riffle scour	secure riparian corridors long-term, ensure forest companies private land use practices minimize potential for peak flow & sediment input increases in upper basin	significant riparian portions secured into public trust through purchase or conservation agreements

Coastal Coho Habitat Requirements:		Englishman River:						
Life Stage	Habitat Requirement for each life stage	Known limiting factors & high value habitats	Performance Indicator(s) for habitat limiting factors	Performance Indicator(s) Status	Performance Indicators Thresholds	Possible measures to address limiting factors	Possible measures to maintain productivity	Habitat Protection & Restoration Measures Undertaken
Fry/Juvenile Summer (N/A for immediate ocean migrants, i.e., pink, chum, some chinook & sockeye poplns)	-	lower 16 kms, low summer discharge, 37 water licences (Bocking and Gaboury 2001, pg 18), poor instream cover, habitat most degraded kms 4-8, limited quality rearing pools (Gaboury 2005, pg 3), bank instability & riparian loss, 20% ↓ channel length, ↓ sinuosity, ↑ gradient (Gaboury 2005, pg 7), LWD scarce	* peak discharge events * 7day-low-flow discharge * % riparian integrity * % land use conversion * channel stability * water extraction data * max daily water temps			LWD-boulder placement, bank stabilization & channel realignment, intensive riparian treatments, sediment source stabilization, water storage opps Shelton & Healy Lks, increase min flows to 20% MAD or 2.74cms (Bocking and Gaboury 2001, pg 18)	" " " maintain water supply intake at current location d/s of Hwy 19 bridge and do not move upstream unless min. discharge of 1.6cms maintained and stipulated in a new water licence,	Arrowsmith dam completed 1998, summer flow supplement from Arrowsmith reservoir since 1999 (min 10%MAD) (Bocking and Gaboury 2001, pg 18), some LWD structures placed
Fry/Juvenile Winter (N/A for immediate ocean migrants as above)	-	same as above re channel & riparian condition, over-winter refuge limiting, 2 existing off-channel habitats in reach E3 important, juvenile access/water quality concerns in some tributaries	* hectares accessible off-channel habitat * kms accessible stream length			off-channel habitat development, remediate tributary upstream juvenile migration access problems and address possible water quality issues	ensure protection of and access to off-channel habitats and tributaries, establish tributary flow & temperature monitoring stations	2 side-channels built 1990s at km 7 (length 1300 m, area 17,700 m^2) & km 6 (length 950m, area 6000 m^2)
Smolt	-	use lower 16 kms & estuary, estuary may not be operating at full biological potential given late summer low flows & storm water discharge and retention ponds in estuary	* hectares estuarine habitat * % estuarine foreshore altered			restore estuary ecological & hydrologic function, reduce pollution discharges to estuary	assess estuary & develop estuary mgmt plan to control further development & ensure maintenance of sloughs & small tidal channels	1979 dike breach increased estuary area by 35ha, most of estuary secured into public trust
Marine Coastal	-	Georgia Strait trawl surveys show correlation between coho & euphausiid abundance, marine smolt-adult survival rates known for 1996 (9.4%) & 1997 (11.1%) broods						

East Coast Vancouver Island Coho Conservation Unit – Englishman River Coho Habitat Status Report

Coastal Coho Habitat Requirements:		Englishman River:						
Life Stage	Habitat Requirement for each life stage	Known limiting factors & high value habitats	Performance Indicator(s) for habitat limiting factors	Performance Indicator(s) Status	Performance Indicators Thresholds	Possible measures to address limiting factors	Possible measures to maintain productivity	Habitat Protection & Restoration Measures Undertaken
Marine Offshore	-	see annual Oceans Status reports http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htmfor large scale oceanic influences on coho marine survival						
Returning Adult Migration	-	Mainstem barrier falls 16km, limited quality holding pools kms 4-8, Shelly Ck culvert barrier 0.2km	* kms accessible stream length			remediate impassable culvert & mainstem restoration noted above	maintain adult & juvenile passage capability at all stream crossings	
Habitat Productivity Model Output								

APPENDIX 3. INITIAL CANDIDATE INDICATOR LIST, FROM THE LITERATURE

Table A3.1 Initial Indicator List Compiled from the Literature. (From G.A. Packman & Associates Inc. and Winsby Environmental Services 2006.)

Category	Indicator
Water Quantity (Green Mountain Institute 1998, Ward 1999)	▪ Instream Flow—% of stream miles with instream flow meeting regulatory requirements, seasonal flow requirements for salmonids and/or sufficient to allow salmonid access (Eclipse Environmental 1998, Green Mountain Institute 1998, Ward 1999, Knight Piésold 2002, Gustavson and Brown 2002) ▪ Flow Hydrology—% of waterbodies with minimal, moderate, extreme changes in hydrology from historical patterns (captures low and high flow extremes-deviation) (Green Mountain Institute 1998, Ward 1999, Knight Piésold 2002) ▪ Stream Flow (OWEB 2003)
Water Quality (Green Mountain Institute 1998, Ward 1999)	▪ Temperature—% of assessed waterbodies where the daily maximum falls into: <10 degrees C—no impairment; 10–15 degrees C—potential impairment to sensitive species; 15–20 degrees C—moderate impairment; >20 degrees C—severe impairment (Green Mountain Institute 1998, Ward 1999, Knight Piésold 2002, Gustavson and Brown 2002, OWEB 2003)
Physical Habitat and Hydrology (Knight Piésold 2002)	▪ Channel Width / Depth ▪ Instream flow ▪ Substrate (Knight Piésold 2002)
Physical Habitat (Green Mountain Institute 1998, Ward 1999)	▪ Impediments and Accessibility to Salmon Habitat—# of locations where salmon are impeded, by type, and the amount, by type, of historically anadromous salmonid habitat rendered inaccessible (Green Mountain Institute 1998, Ward 1999, Gustavson and Brown 2002) ▪ Barrier by type (Eclipse Environmental 1998) ▪ Large Woody Debris—Counts of debris pieces with lengths equal or greater than channel widths, noting presence/absence of root wads, per historically anadromous salmonid stream mile (Eclipse Environmental 1998, Green Mountain Institute 1998, Ward 1999, Gustavson and Brown 2002) ▪ Channel Width / Depth (Green Mountain Institute 1998, Ward 1999, Knight Piésold 2002, Gustavson and Brown 2002) ▪ Stream Depth—variance of thalweg depths (Ward 1999, Gustavson and Brown 2002) ▪ Sediment—change in sediment loading rates (Eclipse Environmental 1998, Green Mountain Institute 1998, Ward 1999, Gustavson and Brown 2002) ▪ Spawning Area—% change in spawning areas (Green Mountain Institute 1998, Ward 1999, Gustavson and Brown 2002)

Category	Indicator
	▪ Habitat Type Associated with Water—the amount of habitat, by category (e.g., riparian forest, offchannel, wetland, estuary) associated with the margins of the water course in a watershed and the value of the habitat to the salmonid life-cycle (Green Mountain Institute 1998, Ward 1999) ▪ Riparian condition ▪ Wetland change (WOEB 2003) ▪ Channel bed disturbance ▪ Channel bank disturbance esses (jams) ▪ LWD supply and proc ▪ Channel morphology ▪ Aquatic connectivity ▪ Fish cover dive ▪ Fine sediments ▪ Windthrow frequency ▪ Riparian soil disturbance ▪ Shade and microclimate (Tripp *et al.* 2005)
Biological Water Quality (Knight Piésold 2002)	▪ Macroinvertebrates ▪ Zooplankton & algae (periphyton, phytoplankton & chlorophyll a) (Knight Piésold 2002) ▪ Biological Water Quality Index—% of water rated excellent, good, fair, poor (possible parameters would include fish community and benthic macroinvertebrate species or taxa composition and richness using similar bioassessment protocols (Green Mountain Institute 1998, Ward 1999) ▪ Coldwater Index of Biotic Integrity—combines measures of multiple biological indicators, such as species richness, relative abundance of specific organisms, and health of the organisms) (Dent *et al.* 2005) ▪ Aquatic invertebrate diversity (Tripp *et al.* 2005)
Chemical Water Quality (Eclipse Environmental Consulting 1998, Green Mountain Institute 1998, Ward, 1999, Knight Piésold 2002)	▪ Temperature ▪ Dissolved oxygen ▪ pH ▪ TDS ▪ Alkalinity ▪ Nutrients (Knight Piésold 2002) ▪ Chemical Water Quality Index—B.C. Water Quality Index and Objectives for Aquatic Organisms (Eclipse Environmental Consulting 1998) ▪ Chemical Water Quality Index—% of waters rated excellent, good, fair, poor (possible parameters would include temperature, dissolved oxygen, biological oxygen demand, pH, ammonia+nitrate nitrogen, total phosphorus, total suspended solids, and bacteria to produce a single number) (Green Mountain Institute 1998, Ward, 1999)

Category	Indicator
	▪ Water Quality Index—estuarine, freshwater and wetlands, % streams rating poor, fair or good (Dent *et al.* 2005)
Aquatic and Riparian Ecosystems (Eclipse Environmental Consulting 1998, Dent *et al.* 2005)	▪ Riparian quality by type (Eclipse Environmental Consulting 1998) ▪ Coldwater Index of Biological Integrity (IBI) for fish and macroinvertebrates ▪ Water Quality Index (WQI) ▪ Area, distribution and types of riparian and wetland vegetation ▪ Riparian function index based on vegetation and site capability (e.g., large wood recruitment, shade, and nutrient input) and wetland function index based on hydrogeomorphic (HGM) typing) ▪ Physical aquatic habitat and estuarine habitat condition ▪ Access to freshwater and estuarine habitat (miles of habitat accessible or limited; further analysed by habitat quality) ▪ Regulatory compliance (Dent *et al.* 2005) ▪ Moss abundance and condition ▪ Disturbance—increaser plants ▪ Vegetation vigour, form and structure (Tripp *et al.* 2005) ▪ Habitat Associated with Water—includes riparian forest (Ward 1999)
Estuarine Ecosystems (Dent *et al.* 2005)	▪ Area, distribution, type, and change in area of tidal and submerged wetlands ▪ Index of Biotic Integrity for estuaries (Dent *et al.* 2005)
Ecosystem Biodiversity (Dent *et al.* 2005)	▪ Number of native plant and animal species and distribution over time ▪ At risk species (aquatic, estuarine, and terrestrial; plant and animal) ▪ Percent of non-invasive species present (Dent *et al.* 2005)
Land Use Conversion (Eclipse Environmental Consulting Ltd. 1998, Green Mountain Institute 1998, Ward, 1999, OWEB 2003, Dent *et al.* 2005)	▪ # of acres in a watershed converted from land use/land cover to other classifications (Eclipse Environmental Consulting Ltd. 1998) ▪ # of acres in a watershed converted from land use/land cover classification (e.g., forestry, agriculture, rural residential, industrial, protected status, etc.) to other land use/land cover types over time with emphasis on floodplain to riparian area ▪ miles of road by type, and road crossings, within one mile of historically anadromous salmonid streams, floodplains, and marine shorelines ▪ % of impervious surface (roads, rooftops, and parking lots) in a watershed (Green Mountain Institute 1998, Ward 1999) ▪ Land use ▪ Land cover ▪ Ecoregion characteristics (OWEB 2003) ▪ Change in land use and land cover (Dent *et al.* 2005)

APPENDIX 4. PARTICIPANTS AT THE EXPERT TECHNICAL WORKSHOP

Table A4.1 List of participants at Expert Technical Workshop on Wild Pacific Salmon Indicators, Vancouver, BC, November 17, 2005.

Pacific Fisheries Resource Conservation Council	
Paul LeBlond	Chair
Mark Angelo	Vice-Chair
Jeff Marliave	Council Member
Gordon Ennis	Managing Director
Glen Packman	Consultant, G.A. Packman & Associates
Malcolm Winsby	Consultant, Winsby Environmental Services
Fisheries and Oceans Canada	
Karen Calla	Senior Program Review Biologist, Oceans/Watershed Planning and Restoration
Blair Holtby	Head, Salmon Section
Brad Mason	Habitat Inventory Coordinator, Geographical Information Systems & Habitat Inventory
Jim Irvine	Research Scientist, Conservation Biology Section
Brian Riddell	Senior Scientist, Pacific Biological Station
Heather Stalberg	Senior Habitat Management Biologist, Oceans, Habitat and Enhancement Branch
Gary Taccogna	Area Chief, Oceans and Community Stewardship
Neil Schubert	Area Chief, Stock Assessment
Jeremy Hume	Research Biologist, Cultus Lake Salmon Research Laboratory
Mike Bradford	Head, Freshwater Rearing, Cooperative Resource Management Institute
Environment Canada	
Risa Smith	Senior Science Advisor, Biodiversity Convention Office, Environment Canada Pacific and Yukon Region
BC Ministry of Forests and Range	
Dan Hogan	Research Scientist, Geomorphology, Fish-Forestry Interaction and Watershed Research
BC Ministry of Environment	
Art Tautz	Manager, Research and Development, Ecosystem Branch
David Tesch	Head, Fisheries Business Programs, Ecosystem Information Section
Ministry of Agriculture and Lands	
Malcolm Gray	Team Leader, Remote Sensing Services, Integrated Land Management Bureau
Skeena Fisheries Commission	
Allen Gottesfeld	Head Scientist
Kenny Rabnett	Senior Fisheries Technician
Okanagan Nation Alliance	
Howie Wright	Senior Fisheries Biologist
Non-governmental Organizations and Consultants	
Patrick Slaney	P Slaney Aquatic Science Ltd
Mark Nelitz	ESSA Technologies Ltd
Jeffrey Young	David Suzuki Foundation
Kristy Ciruna	Coordinator of Conservation Programs, Nature Conservancy of Canada
Margaret Branton	Graduate Student, Faculty of Forestry, University of British Columbia

APPENDIX 5.
USE OF THE SHORT-LISTED INDICATORS IN OTHER PACIFIC COAST PROGRAMS

This appendix shows which of the short-list of indicators are used across Pacific coast programs. The indicator lists for streams and estuaries are divided into “pressure” and “state” indicator tables. For lake indicators only one monitoring program was evaluated: the Washington State Department of Ecology which uses the state indicator of water chemistry (nutrients, D.O., pH, conductivity, contaminants) (Slaney *et al.* 2005).

STREAM INDICATORS

Table A5.1. Stream pressure indicators used by agency monitoring programs.

	Pressure / Stressor Indicators Used									
User Group	permitted outfall discharge	road density	% water-shed area imperv-ious surface	% stream length riparian zone altered	% water-shed area various land cover alterations	% lake fore-shore altered	% estuary fore-shore altered	water with-drawal % MAD (surface, GW)	% stream length channel ized, flood-plain conn.	wetl-ands loss
FRAP[1]			✓	✓	✓			✓	✓	
Streamkeepers[2]				✓				✓	✓	✓
Yukon-Reynoldson[3]										
DFO Hab.Monitor.				✓						
B.C. FREP[4]				✓						
U.S. NMFS[5]		✓		✓	✓				✓	
U.S. EPA				✓						
Wash.Cons.Comm.[6]		✓	✓	✓	✓				✓	
Wash. State Dept.Ecol.[7]		✓	✓	✓	✓			✓	✓	✓

1. Komori (1997)
2. BC Streamkeepers Manual (Taccogna and Munro 1995)
3. Reynoldson *et al.* (2006)
4. British Columbia Forest and Range Evaluation Program
5. NOAA Fisheries (1996)
6. Smith (2005)
7. Cusimano *et al.* (2006)

Table A5.2. Stream state indicators used by agency monitoring programs.

User Group	State / Impact Indicators Used												
	accessible stream length, barriers	accessible off-channel habitat area	estuarine habitat area	stream discharge (base, peak)	water temp	water chem. (nutrients, D.O., pH, conductivity, contaminant)	sediment, substrate	LWD, in-stream cover	channel stability (pool: riffle, width: depth ratios, etc)	aquatic invertebrates	fish	periphyton, plankton	ecosystem biodiversity
FRAP[1]	✓				✓	✓							
Streamkeepers[2]	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		
Yukon-Reynoldson[3]										✓	✓		
DFO Hab.Monitor.				✓	✓	✓	✓		✓	✓	✓	✓	
B.C. FREP[4]	✓	✓					✓	✓	✓	✓			
U.S. NMFS[5]	✓	✓		✓	✓	✓	✓	✓	✓				
U.S. EPA					✓	✓	✓	✓	✓	✓	✓		✓
Wash.Cons.Comm.[6]	✓	✓		✓	✓	✓	✓	✓	✓				
Wash. State Dept.Ecol.[7]													

1. Komori (1997)
2. BC Streamkeepers Manual (Taccogna and Munro 1995)
3. Reynoldson *et al.* (2006)
4. British Columbia Forest and Range Evaluation Program
5. NOAA Fisheries (1996)
6. Smith (2005)
7. Cusimano *et al.* (2006)

ESTUARY INDICATORS

Table A5.3. Estuary pressure indicators used by agency monitoring programs.

	Pressure / Stressor Indicators Used				
User Groups	% surface area disturbed off-shore (e.g., log booms)	% surface area disturbed in-shore	% estuary foreshore altered	Invasives	Amount of shipping traffic
B.C. Coast/Env[1].	✓	✓	✓		✓
Streamkeepers[2]	✓	✓	✓		
PNAMP			✓	✓	
CAL-FED[3]			✓	✓	
U.S. EPA, EMAP[4]					
U.S. EPA[5]					
Wash. DNR[6]		✓	✓		

1. BC MOE (2007)
2. Taccogna and Munro (1995)
3. CAL-FED Bay-Delta Program (Thom and O'Rourke 2005)
4. Hayslip *et al.* (2006)
5. US EPA (2007)
6. Berry *et al.* (2001)

Table A5.4. Estuary state indicators used by agency monitoring programs.

	Statue / Impact Indicators Used											
User Groups	Eel-grass	Marine riparian veg.	Spatial distribution of wetlands, mudflats	Flux of detrital organic matter (C,N,P) between marsh & other habitats	Access-ible off-channel habitat area	Estuar-ine habitat area	Stream Discharge (Base, Peak)	Sedi-ments TSS	Water Chemistry (Nutrients, D.O., pH, conductivity contamin-ants)	Aquatic Inverte-brates	Fish	Peri-phyton plank-ton
B.C. Coast/Env[1].							✓		✓			
Stream-keepers[2]												
PNAMP	✓	✓	✓				✓		✓			
CAL-FED[3]									✓	✓		✓
U.S. EPA, EMAP[4]					✓			✓	✓	✓		
U.S. EPA[5]				✓					✓	✓		
Wash. DNR[6]	✓									✓		

1. BC MOE (2007)
2. Taccogna and Munro (1995)
3. CAL-FED Bay-Delta Program (Thom and O'Rourke 2005)
4. Hayslip *et al.* (2006)
5. US EPA (2007)
6. Berry *et al.* (2001)

APPENDIX 6.
RANKING OF INDICATORS BY STRENGTH OF LINKAGE TO KEY HABITAT ATTRIBUTES

This appendix provides rankings of the short-list of indicators according to the strength of their linkage with key habitat attributes, based on the collective expert judgement among the HWG members. If there was consensus that an indicator was directly linked to a habitat attribute, it scored 1.0; an indirect link scored 0.5; and if there was no link, a zero score was given. For example, the HWG concluded that there was a direct link between water withdrawal and water temperature, an indirect link between water withdrawal and gravel substrate, and no link between water withdrawal and percent riparian reserve intact, the resulting scores would be 1.0, 0.5, and 0, respectively.

Habitat attributes were derived from numerous sources including the National Marine Fisheries Service (NMFS), the Washington State Conservation Commission, the CALFED Bay-Delta program (Thom and O'Rourke 2005), Environmental Trends Monitoring in B.C. (BC MOE 2007), salmon life history strategies outlined by Diewart (2007), and the collective expertise of HWG members.

Indicators of habitat quantity (accessible stream/shore length, accessible off-channel habitat area, and estuarine habitat area) were not ranked as they were considered essential indicators.

STREAM INDICATORS

Table A6.1. Stream pressure indicator rankings based on linkage to habitat attributes.

Key Fresh Water Habitat Attributes & Objectives for Pacific Salmon	Pressure / Stressor Indicators (Indicator causes change to attribute) direct link=1, indirect links= 0.5									
	permitted outfall discharge	road density	% water-shed area imper-vious surface	% stream length riparian zone altered	% water-shed area various land cover alterations - forestry, agri, urban	% lake foreshore altered	% estuary foreshore altered	water withdrawal % MAD (surface, GW)	% stream length channel-ized, flood-plain conn.	wetlands loss
water temp < 15C	1	0.5	0.5	1	0.5	0.5	0.5	1	1	0.5
gravel substrate <12% fines (<0.85mm diam.)	1	1	1	1	1	1	1	0.5	1	0.5
D.O. > 8 mg/L	1	0.5	0.5	1	0.5	0.5	0.5	1	1	0.5
low level of chem. contaminants	1	1	1	0.5	1	0.5	0.5			0.5
<10% known/potential habitat blocked by artificial barriers	0.5	1	0.5	0.5	0.5	0.5	0.5	1	1	1
LWD: coast >50 pieces/km>0.6m diam>15m length; dry inter. >12 pieces/km>0.3m diam.>10m length	0	0.5	0.5	1	0.5	1	1		1	0.5
pool freq: 1 per 5-6 channel widths	0.5	0.5	0.5	1	0.5				1	0.5
<10% stream length with lost floodplain connect.	0	1	0.5	1	0.5			1	1	0.5
Chan. width:depth ratio < 10	0	0.5	0.5	1	0.5				1	0.5
<10% of stream bank active erosion	0.5	0.5	0.5	1	0.5				1	0.5
> 80% riparian reserve intact	0	1	0.5	1	0.5	1	1		1	1
peak & base flows, timing characteris-tics mimic natural hydrograph	0	1	1	0.5	1			1	1	1
Total Score	5.5	9	7.5	10.5	7.5	5	5	5.5	11	7.5

During the ranking process, the HWG recognized that both % lake and foreshore alterations would be more appropriately considered during the lake and estuary indicators evaluation process.

Table A6.2. Stream state indicator rankings based on linkage to habitat attributes.

Key Fresh Water Habitat Attributes & Objectives for Pacific Salmon	State Impact Indicators (Indicator causes change to attribute) direct link=1, indirect links= 0.5												
	access-ible stream length, barriers	access-ible off-channel habitat area	estuarine habitat area	stream dis-charge (base & peak)	water temp	water chem. (nutrients, D.O., pH, conductivity, contaminant)	sedi-ment, sub-strate	LWD, in-stream cover	channel stability (pool:riffle, width:depth ratios, etc)	aquatic inverte-brates	fish	peri-phyton, plank-ton	eco-system biodiver-sity
water temp < 15C				1	1				1				
riffle substrate <12% fines (<0.85mm diam.)				1			1	1	1				
D.O. > 8 mg/L				1	1	1			0.5				
low level of chem. contaminants						1							
<10% known/potential habitat blocked by artificial barriers				1	1	1	0.5		1				
LWD: coast >50 pieces/km>0.6m diam>15m length; dry inter. >12 pieces/km>0.3m diam.>10m length				1	0.5			1	1				
pool freq: 1 per 5-6 channel widths				1	0.5		1	1	1				
<10% stream length with lost floodplain connect.				1			0.5		1				
chan. width:depth ratio < 10				1	0.5		1	1	1				
<10% of stream bank active erosion				1	0.5		1	0.5	1				
> 80% riparian reserve intact					1	0.5	1	1	1				
peak & base flows, timing characteristics mimic natural hydrograph				1	1	1	1	1	1				
Total Score				10	7	4.5	7	6.5	10.5				

The biotic stream state indicators used in the Pacific Northwest were not included in the analysis (e.g., fish, benthic macroinvertebrates, periphyton and ecosystem biodiversity). They were removed for the following reasons:

(a) fish community abundance and diversity may vary substantially from year to year for reasons unrelated to habitat, such as fishing pressure;

(b) benthic macroinvertebrate assessments, such as CABIN were undergoing a separate analysis for utility and applicability for WSP (Branton *et al.* 2006);

(c) periphyton abundance is not commonly used as an indicator, and there are very little data available, and;

(d) all biotic indicators would be more useful as ecosystem indicators pursuant to Strategy 3 rather than as habitat indicators.

LAKE INDICATORS

Table A6.3. Lake pressure indicator rankings based on linkage to key lacustrine habitat attributes.

Key Lacustrine Habitat Attributes & Objectives for Pacific Salmon	Pressure / Stressor Indicators (Indicator causes change to attribute) direct link=1, indirect links= 0.5						
	Road density	% watershed area impervious surface	% riparian zone altered	% watershed area various land cover alterations	Invasives	% lake foreshore altered	Recreational pressure
Water Temperature		0.5	1	1		0.5	
Littoral substrate quality	1	1	1	1	1	1	.05
Dissolved Oxygen		0.5	0.5	1		.05	0.5
Low level of chemical contaminants	1	1	1	1		.05	1
Limit known/potential shoreline habitat blocked by artificial barriers	1	0.5	.05	0.5	1	1	0.5
Large Woody Debris	0.5	1	1	1		1	1
Shoreline erosion	1	1	1	1		1	1
Benthic complexity		0.5	1	0.5	1	1	
Riparian reserve intact	1	1	1	1		1	1
Shoreline complexity	1	0.5	0.5	1		1	
Integrity of river deltas	1	1	1	1		1	
Lake mixing regime							
Lake surface area						1	
Trophic level		1		1			
Total Score	7.5	9.5	9.5	11	3	10.5	5.5

Table A6.4. Lake state indicator rankings based on linkage to key lacustrine habitat attributes.

	State / Impact Indicators (Indicator causes change to attribute) direct link=1, indirect links= 0.5						
Key Lacustrine Habitat Attributes & Objectives for Pacific Salmon	Accessible shoreline length, barriers	Accessible off-channel habitat area	Temperature	Water chemistry (nutrients, D.O., pH, conductivity, contaminants)	Sediment Substrate	Wetlands Loss	Presence of river deltas
Water Temperature			1	1		1	0.5
Littoral substrate quality				1	1	0.5	1
Dissolved Oxygen			1	1	1	0.5	.05
Low level of chemical contaminants				1	1	1	
Limit known/potential shoreline habitat blocked by artificial barriers			1	1	0.5		1
Large Woody Debris							1
Shoreline erosion					1	1	1
Benthic complexity			1	1	1		1
Riparian reserve intact			1	1	1	0.5	
Shoreline complexity							1
Integrity of river deltas			0.5		1	1	1
Lake mixing regime			1	1			
Lake surface area							1
Trophic level				1		1	
Total Score			6.5	9	7.5	6.5	9

ESTUARY INDICATORS

Table A6.5. Estuary pressure indicator rankings based on linkage to key estuarine habitat attributes.

Key Estuarine Attributes & Objectives for Pacific Salmon	Pressure / Stressor Indicators (Indicator causes change to attribute) direct link=1, indirect link=0.5				
	% surface area disturbed off-shore e.g., log booms	% surface disturbed in-shore (eel-grass zone)	% foreshore altered (carex, typha, riparian zone)	Invasives	Amount of shipping
Water quality (N,P.O)	1	1	1	1	1
Freshwater inflow and salinity patterns (2%)	1	1	1		1
Sediment supply/rate of aggradation or degradation	1	1	1	1	1
Transport/export of detrital matter	1	1	1	1	0.5
Number of non-natal streams flowing into estuary			1		
Habitat mosaic and connectivity	1	1	1	1	1
Shoreline complexity	0.5	1	1	1	1
Shoreline wave action	1	1	1	1	1
Large woody debris	1	0.5	1		
Native biological communities and assemblages	1	1	1	1	1
Levels of plankton productivity sufficient to support plankton-dependent fish populations	0.5	1	1	1	1
Total Score	9	9.5	11	8	8.5

Table A6.6. Estuary state indicator rankings based on linkage to key estuarine habitat attributes.

Key Estuarine Habitat Attributes & Objectives for Pacific Salmon	State / Impact Indicators (Indicator causes change to attribute) direct link=1, indirect links= 0.5											
	Extent of eel-grass	Marine riparian veg.	Spatial distribu-tion of wet-lands, mudflats	Flux of detrital organic matter (C,N,P) between marsh & other habitats	Access-ible off-channel habitat area	Estuar-ine habitat area	Stream Dis-charge (Base, Peak)	Sedi-ments TSS	Water Chemis-try (Nutri-ents, D.O., pH, conduct-ivity contami nants)	Aquatic Inverte-brates	Fish	Peri-phyton plank-ton
Water quality (N,P.O)	1	1	1	1			1	1	1	1	1	1
Freshwater inflow and salinity patterns (2%)	1	1	1	0.5			1	0.5	1	1	1	1
Sediment supply/rate of aggradation or degradation	1	1	1	0.5			1	1	1	1	1	1
Transport/export of detrital matter	1	1	1	1			1	1	1	1	1	1
Number of non-natal streams flowing into estuary		1	1	1			1			1	1	
Habitat mosaic and connectivity	1	1	1	1			1	1		1	1	1
Shoreline complexity	1	1	1	1			1	0.5		1	1	
Shoreline wave action	1	1	1	1			1	1		1	0.5	1
Large woody debris		1	0.5	1			1	1		1	1	1
Native biological communities and assemblages	1	1	1	1			1	1	1	1	1	1
Levels of plankton productivity sufficient to support plankton-dependent fish populations	1	0.5	1	1			1	1	1	1	1	1
Total Score	9	10.5	10.5	10			11	9	6	11	10.5	9

RANKING SUMMARIES

Table A6.7. Ranking results summary.

Rank	Stream Pressure Indicators
1	% stream length channelization/floodplain connectivity
2	% stream length riparian zone alteration
3	Road density
4	% watershed area impervious surface % watershed area converted to various land uses (forestry, agric, urban) Wetland loss
7	Water withdrawal as % MAD (surface, groundwater) Permitted outfall discharges
9	% lake foreshore alteration % estuary foreshore alteration
Rank	**Stream State Indicators**
1	Channel stability measures (pool:riffle, channel width:depth ratios, etc)
2	Stream discharge measures (base & peak flows)
3	Water temperature Sediment, substrate
5	LWD, instream cover
6	Water chemistry (nutrients, D.O., pH, conductivity, contaminants)
Rank	**Lake Pressure Indicators**
1	% watershed land cover alterations
2	% lake foreshore altered
3	% watershed area impervious surface % riparian zone altered
5	Road density
6	Recreational pressure
7	Invasives
Rank	**Lake State Indicators**
1	Water chemistry (nutrients, D.O., pH, conductivity, contaminants) Presence of river deltas
3	Sediment substrate
4	Temperature Wetland loss

Rank	Estuary Pressure Indicators
1	% estuary foreshore altered (carex, typha, riparian zone)
2	% surface area disturbed inshore (eel grass zone)
3	% surface area disturbed offshore (e.g., log booms – subtidal)
4	Amount of vessel traffic
5	Invasives
Rank	**Estuary State Indicators**
1	River or stream discharge Aquatic invertebrates
3	Marine riparian vegetation Spatial distribution of wetlands, mudflats Fish
6	Flux of detrital organic matter (C,N,P) between marsh and other habitats
7	Extent of eel grass Sediment, TSS Micro and macro algae
10	Water chemistry (nutrients, D.O., pH, conductivity, contaminants)

APPENDIX 7.
CLARIFICATION OF LAKE, STREAM, AND ESTUARY HABITAT INDICATORS VERSUS METRICS

Table A7.1. Clarification of indicators versus metrics in the short-list (from Nelitz *et al.* 2007a)

Indicator Type	Indicator	Habitat type			Example metrics and parameters of interest
		Lake	Stream	Estuary	
Status	Estuarine habitat area			x	
Status	Accessible shore length, barriers	x			
Status	Accessible stream length, barriers		x		
Status	Accessible of-channel habitat area	x	x	x	
Pressure	Disturbance of estuary foreshore habitats			x	% estuary foreshore altered (e.g., carex, typha, riparian zone
Pressure	Disturbance of inshore habitats			x	% surface area disturbed inshore (e.g., eel grass zone)
Pressure	Disturbance of offshore habitats			x	% surface area disturbed offshore (e.g., log booms)
Pressure	Marine vessel traffic			x	Amount of vessel traffic
Pressure	Invasives	x		x	
Status	Micro and macro algae			x	
Status	Aquatic invertebrates			x	
Status	Sediment	x	x	x	e.g., TSS, also considers substrates for streams and lakes
Status	Water chemistry	x	x	x	e.g., nutrients, D.O., pH, conductivity, contaminants
Status	Detrital organic matter			x	Flux of detrital organic matter (C,N,P) between marsh & other habitats
Status	Eel grass habitats			x	Extent of eel grass
Status	Spatial distribution of wetlands/mudflats			x	
Status	Riparian vegetation			x	
Status	Resident fish			x	
Pressure	Riparian disturbance	x	x		% riparian zone altered % stream length riparian zone altered
Pressure	Recreational pressure	x			
Pressure	Watershed: land cover alterations	x	x		% watershed land cover alterations (forestry, agriculture, urban development)
Pressure	Watershed: hard surfaces	x	x		% watershed impervious surface
Pressure	Watershed: road development	x	x		road density
Pressure	Lake foreshore development	x			% lake foreshore altered
Status	River deltas	x			Number/presence of river deltas
Status	Water temperature	x	x		
Pressure	Wetland disturbance	x	x		
Pressure	Floodplain connectivity		x		% stream length channelized, floodplain connectivity
Pressure	Water extraction		x		water withdrawal as % mean annual discharge (surface water & groundwater)
Status	Channel stability		x		pool:riffle, width:depth ratios, etc.

Indicator Type	Indicator	Habitat type			Example metrics and parameters of interest
		Lake	Stream	Estuary	
Status	Stream discharge		x	x	Base and peak flows
Status	Large woody debris & instream cover		x		
	Total number of indicators by habitat type	14	15	16	

APPENDIX 8.
CAUSE-EFFECT PATHWAYS AMONG HABITAT INDICATORS AND SALMON LIFE STAGES

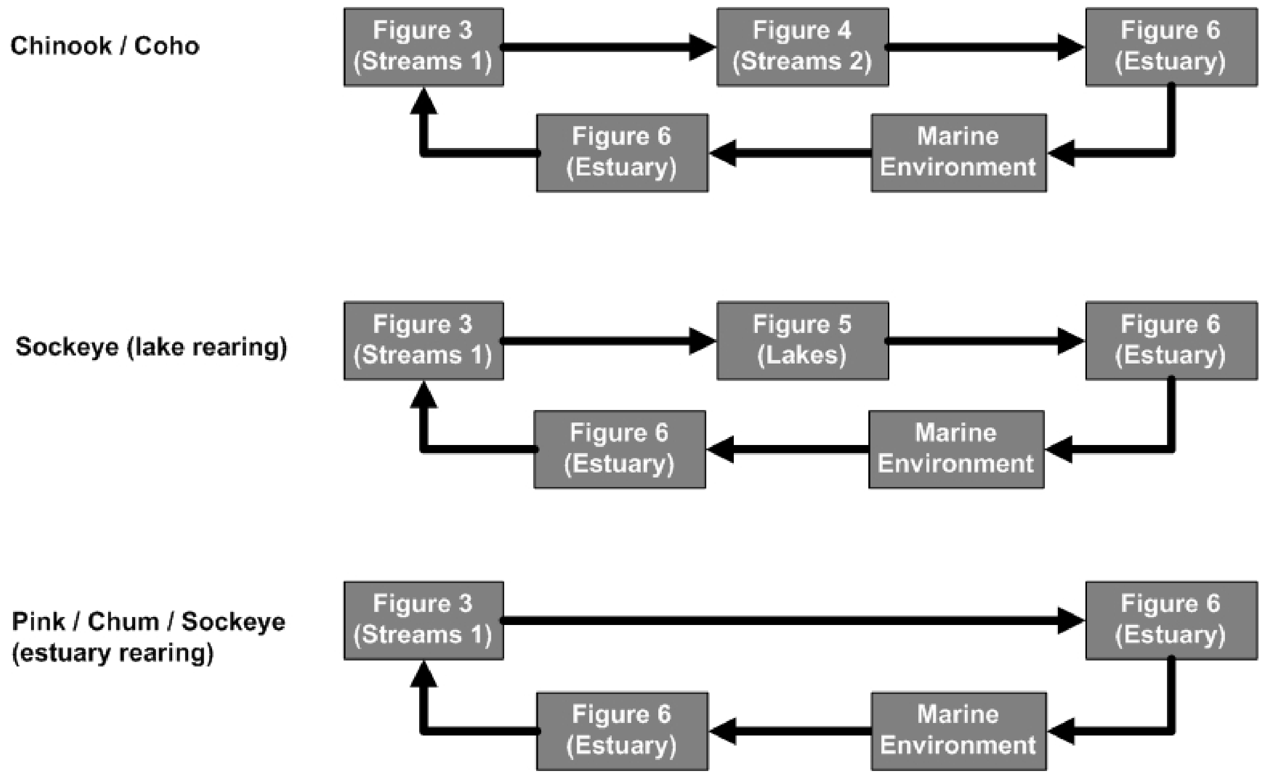

Figure A8.1. Overview diagram illustrating the transition among the habitat-specific conceptual models represented in Figure A8.2 to Figure A8.5 for each salmon species (from Nelitz *et al.* 2007a).

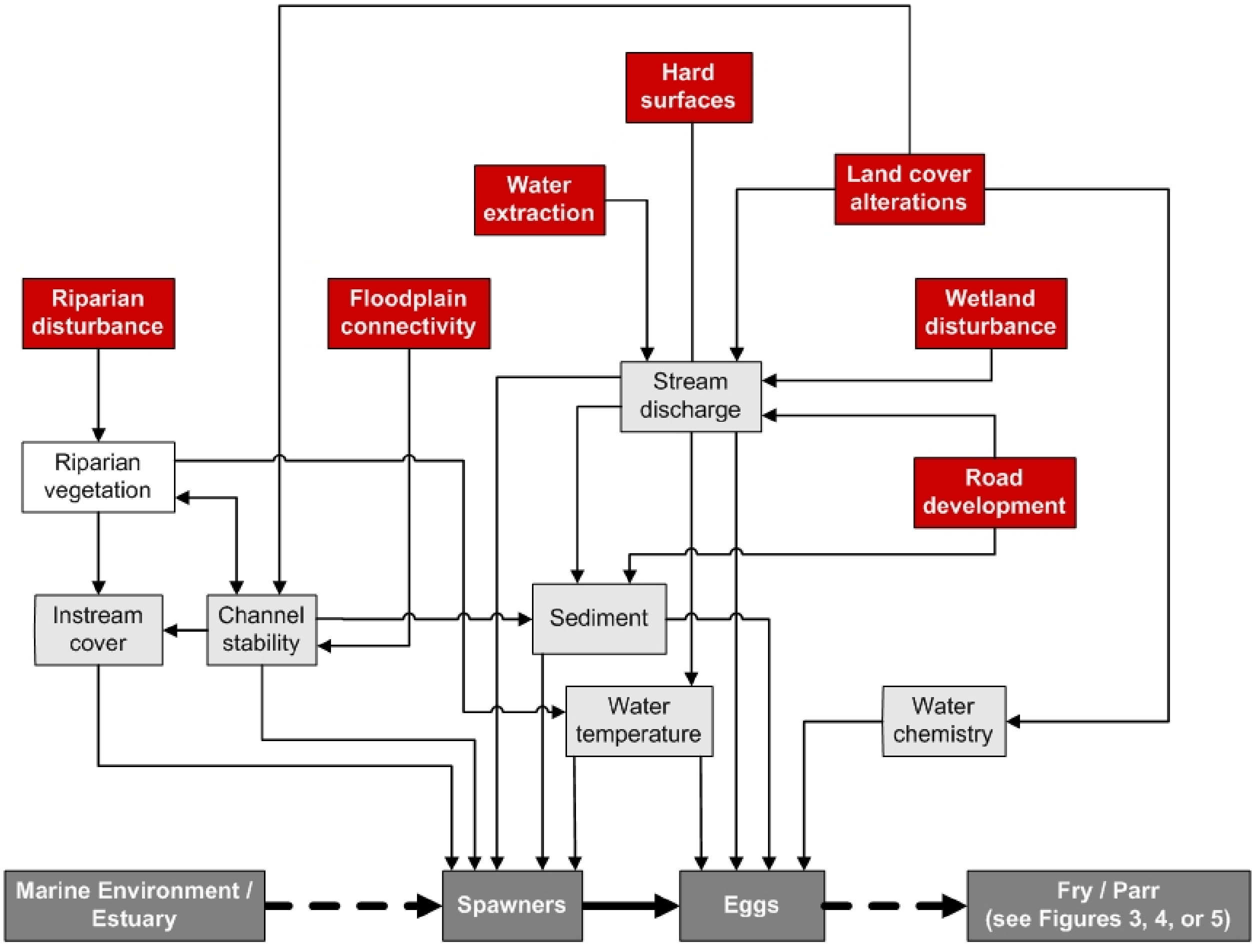

Figure A8.2. Summary of the linkages among the habitat pressures (red boxes), habitat status (white or light grey boxes) and salmon life stages (dark grey boxes) in STREAM habitats. Habitat indicators in the light grey boxes are listed in Appendix I, and habitat indicators in white boxes represent implied linkages that are not represented in the appendix (from Nelitz *et al.* 2007a).

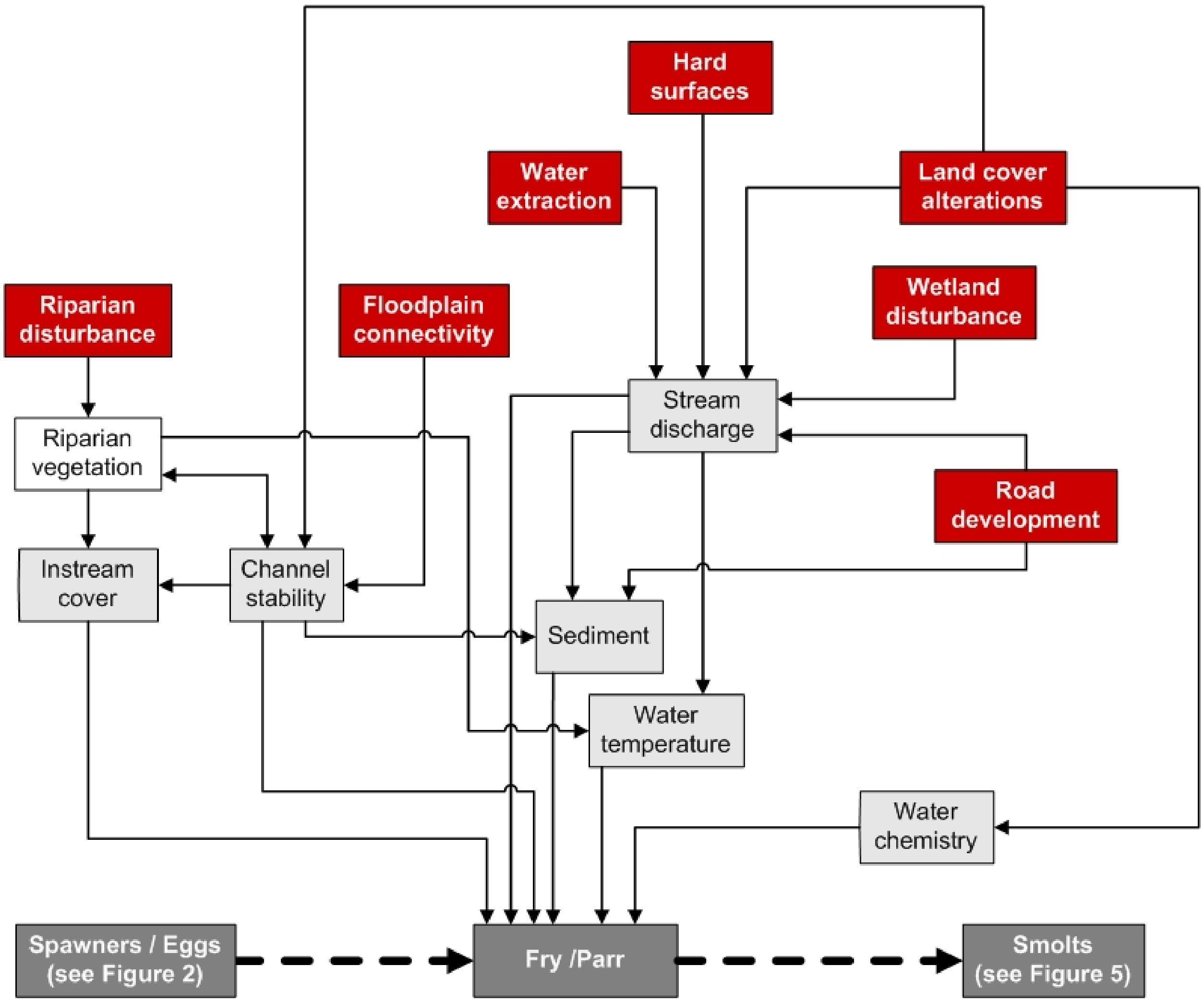

Figure A8.3. Summary of the linkages among the habitat pressures (red boxes), habitat status (white or light grey boxes) and salmon life stages (dark grey boxes) in STREAM habitats. Habitat indicators in the light grey boxes are listed in Appendix I, and habitat indicators in white boxes represent implied linkages that are not represented in the appendix (from Nelitz *et al.* 2007a).

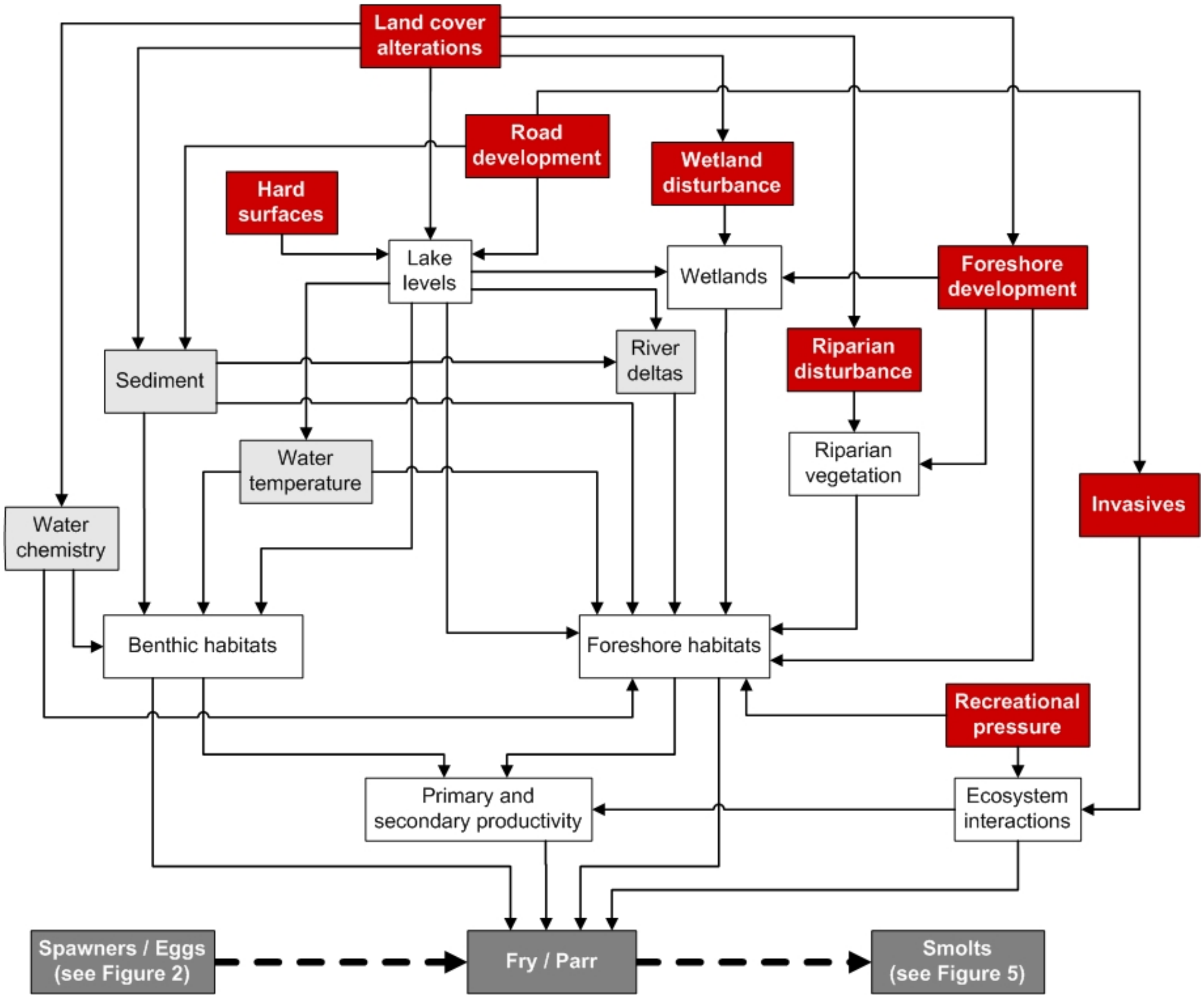

Figure A8.4. Summary of the linkages among the habitat pressures (red boxes), habitat status (white or light grey boxes) and salmon life stages (dark grey boxes) in LAKE habitats. Habitat indicators in the light grey boxes are listed in Appendix I, and habitat indicators in white boxes represent implied linkages that are not represented in the appendix (from Nelitz *et al.* 2007a).

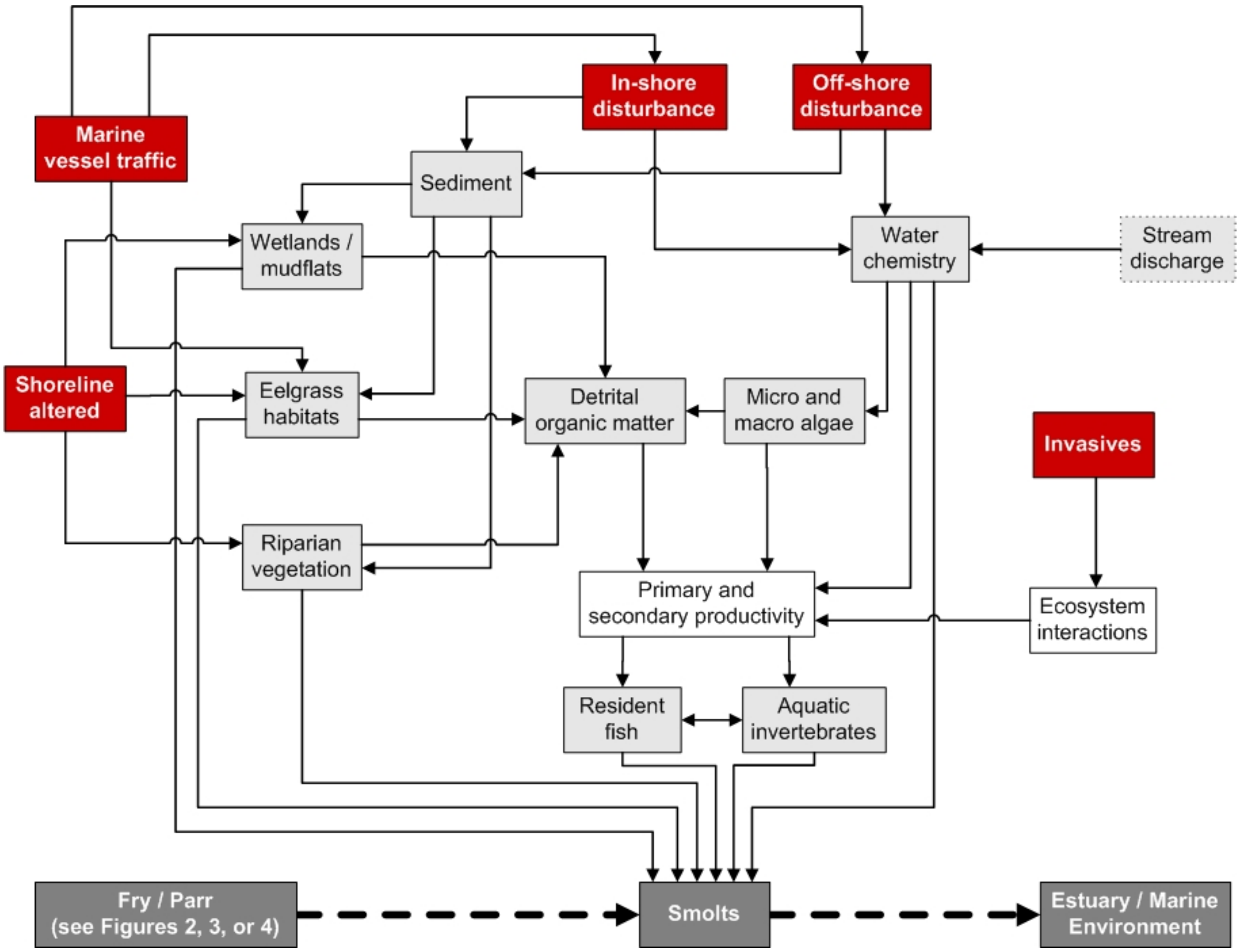

Figure A8.5. Summary of the linkages among the habitat pressures (red boxes), habitat status (white or light grey boxes) and salmon life stages (dark grey boxes) in ESTUARY habitats. Habitat indicators in the light grey boxes are listed in Appendix I, and habitat indicators in white boxes represent implied linkages that are not represented in the appendix (from Nelitz *et al.* 2007a).

APPENDIX 9.
EXAMPLE OF A PRACTICAL ASSESSMENT WORKSHEET

The following is an example of an assessment worksheet used by ESSA Technologies Ltd. to undertake the Practical Assessment (Nelitz *et al.* 2007a). It is followed by Table A9.1 which lists the data sources used to fill out the practical assessment worksheets.

Data Source: WATEMP Database
Indicators informed by data source

Indicator	Indicator Type	Habitat	Comments
Water temperature	Status	Streams	

Data Source
In British Columbia, Fisheries and Oceans Canada has developed a centralized database to store historic and some new in-house stream temperature data collected by researchers across the province.

Contacts
Tracy Cone, Fisheries and Oceans Canada, (604) 666-7269, ConeT@pac.dfo-mpo.gc.ca

Data Availability
These data would be available for use in the Wild Salmon Policy. However, most data are included in the data compilation project being initiated by the Ministry of Environment as part of the requirement for designating "Temperature Sensitive Streams". There are no assurances that any locations in the database will be monitored in the future. Accuracy of data are also questioned given that these data have not gone through a QA / QC procedure before being entered.

Relative Cost.
Limited information is available on cost of development of the database to-date or past data collection Currently, DFO spends approximately $3,000 per year on staff expenses and logger upgrades to monitor and maintain 7 data loggers.

Spatial extent/ resolution Currently, the database stores spatially referenced temperature data from 211 locations across the province. Monitored locations range in size from large rivers (e.g., Fraser River near Mission) to small streams (e.g., Baptiste tributaries).

Temporal extent/ frequency Most locations have daily maximum, minimum, and average temperatures available for summer period. The version of the database that we reviewed includes data from 1938 to 2000, though earlier years of data are spot measurements (i.e., pre-1950).

Table A9.1. Data sources for the practical assessment (from Nelitz *et al.* 2007a).

Data Source	Related Organization
Baseline Thematic Mapping (BTM) (version 1)	BC Ministry of Agriculture and Lands
BC Lake Stewardship Monitoring Program (BCLSMP)	BC Lake Stewardship Society
BC Water License Database	BC Ministry of Environment (MOE)
BC Water Resources Atlas	BC Ministry of Environment
BC Watershed Statistics	BC Ministry of Agriculture and Lands
Biophysical Assessment of Estuarine Habitats	Pacific Estuary Conservation Program / Canadian Wildlife Service/ Ducks Unlimited
British Columbia WELLs Database	BC Ministry of Environment
Broad Ecosystem Inventory (BEI)	BC Ministry of Environment
Canadian Wetland Inventory (CWI)	Canadian Wildlife Service / American Wetland Conservation Council (Canada) / Ducks Unlimited Canada
Coastal Resource Information System (CRIS)	ILMB / BC Ministry of Environment
Community Mapping Network (CMN)	DFO / BC Ministry of Environment
Crown Leases and Licenses Database	Canadian Wildlife Service
DFO Commercial Catch Statistics	DFO
DFO Lake Productivity and Capacity Branch Reports	DFO
DFO Sockeye Lakes Dataset	DFO
Digital Road Atlas (DRA) Program	BC Ministry of Agriculture and Lands
Ducks Unlimited Canada (DUC) Wetland Database	Ducks Unlimited Canada
Environment Canada's Marine Water Quality Monitoring Program	Environment Canada
Environmental Monitoring system – Web Reporting	BC Ministry of Environment
EQ Win Database	Yukon Government
Field Data Information System (FDIS)	BC Ministry of Environment
Fish Passage Culvert Database – Cariboo Region, BC	BC Ministry of Environment
Fisheries Information Summary System (FISS)	DFO / BC Ministry of Environment
Floodplains Mapping Program	BC Ministry of Environment
Foreshore Inventory and Mapping (FIM)	District of Central Okanagan / BC MOE / City of Kelowna / District of Lake Country / The Real Estate Foundation / DFO
Forest and Range Evaluation Program (FREP)	BC Ministry of Forests and Range
Forest Health Mapping	Natural Resources Canada / BC Ministry of Forests
Fraser River Environmental Watch Program	DFO
Fraser River Estuary Management Plan (FREMP) Atlas (hosted by the Community Mapping Network)	Fraser River Estuary Management Plan / DFO / BC Ministry of Environment
Fraser River Estuary Management Plan (FREMP) Sediment Budgeting	Fraser River Estuary Management Plan
GVRD Stormwater Management reports 1997-2002	Greater Vancouver Regional District
Invasive Alien Plant Program (IAPP)	BC Ministry of Forests and Range
Invasive Species Atlas (Hosted by Community Mapping Network	DFO / BC Ministry of Environment
Lake Productivity and Capacity Reports	DFO
Lake Surveys - Physical Characteristics, Chemical Characteristics, and Fish Collection	BC Ministry of Environment
Marine Communications and Traffic Services Statistics (VTS)	Canadian Coast Guard

Data Source	Related Organization
Mariculture Permitting Database (Alaska)	Alaska Department of Fish & Game
Marine Water Quality Monitoring Program	Environment Canada / DFO / CFIA
National Air Photo Library	Natural Resources Canada
National Road Network (NRN)	Natural Resources Canada
Nearshore Fish Atlas of Alaska	NOAA Fisheries
Okanagan Basin Monitoring and Evaluation Program (OBMEP)	Okanagan Nation Alliance (ONA) / Colville Confederated Tribes (CCT)
Okanagan Foreshore Program	BC Lake Stewardship Society
Parkinson, E.A., J.R. Post, and S.P. Cox. 2004. [9]	Primary literature
Provincial Obstacles to Fish Passage	BC Ministry of Environment
Quickbird Satellite Imagery	Private companies
Reporting Silviculture Updates and Land Status Tracking System (RESULTS) Program	BC Ministry of Forests and Range
Sensitive Ecosystem Inventory (SEI)	BC Ministry of Environment
Shorekeepers Database	Shorekeepers
Shorezone mapping Alaska	NOAA Fisheries
State of Environment Reporting: British Columbia's Coastal Environment 2006	BC Ministry of Environment
Streamkeepers Data Entry Tool	DFO / Pacific Streamkeepers Federation
Survey of Sport Fishing in British Columbia	BC Ministry of Environment / DFO
Temperature Sensitive Streams Database	BC Ministry of Environment
Vegetation Resource Inventory (VRI)	BC Ministry of Forest and Range
WATEMP Database	DFO
Water Survey of Canada Hydrometric Network (HYDAT Database)	Environment Canada
Water Use Planning (WUP) Data	BC Hydro
Watershed Statistics	BC Ministry of Agriculture and Lands
Yukon Biophysical Mapping	Yukon Government
Yukon Fire History	Yukon Government
Yukon Forest Cut Layer	Yukon Government
Yukon Habitat Suitability Model	DFO
Yukon Placer Mining Industry Water Quality Objectives Monitoring Protocol	Yukon Government
Yukon Riparian Disturbance Mapping	DFO
Yukon Spatial Data Clearinghouse	Yukon Government
Yukon Water Board - Water Licenses Database	Yukon Government
Yukon Water Resources Hydrometric Program	Yukon Government
Yukon Water Temperature Data	DFO / Yukon Government
Yukon Water Well Registry	Yukon Government
Yukon Wetland Project	Ducks Unlimited Canada / Environment Canada

[9] Linking the dynamics of harvest effort to recruitment dynamics in a multistock, spatially structured fishery. Canadian Journal of Fisheries and Aquatic Sciences 61: 1658-1670.

APPENDIX 10.
QUALITATIVE RANKING OF STREAM, LAKE AND ESTUARINE HABITAT INDICATORS BASED ON OVERALL FEASIBILITY

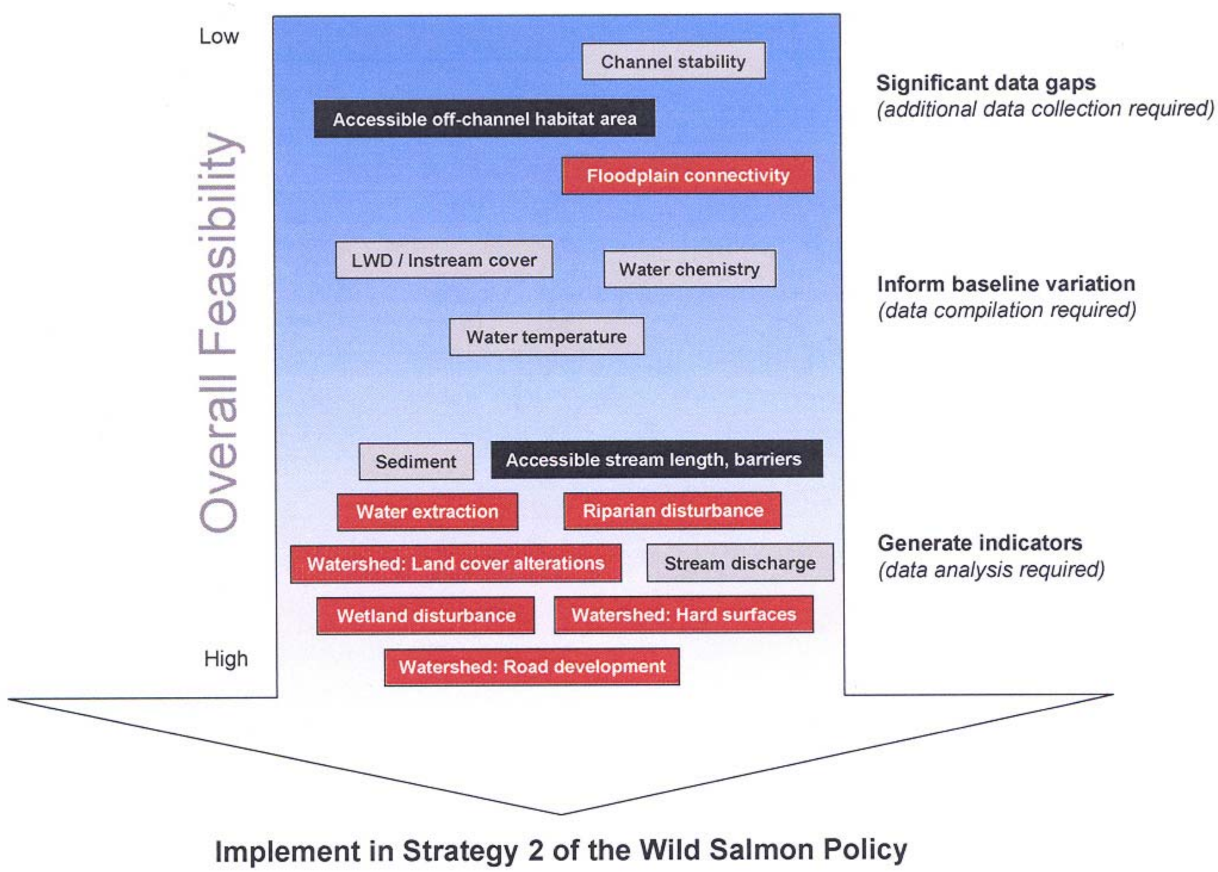

Figure A10.1. Qualitative representation of the level of effort required to generate stream habitat indicators under Strategy 2 of the WSP (from Nelitz *et al.* 2007a). Pressure indicators are in red boxes, state indicators are in grey boxes, and quantity indicators are in black boxes.

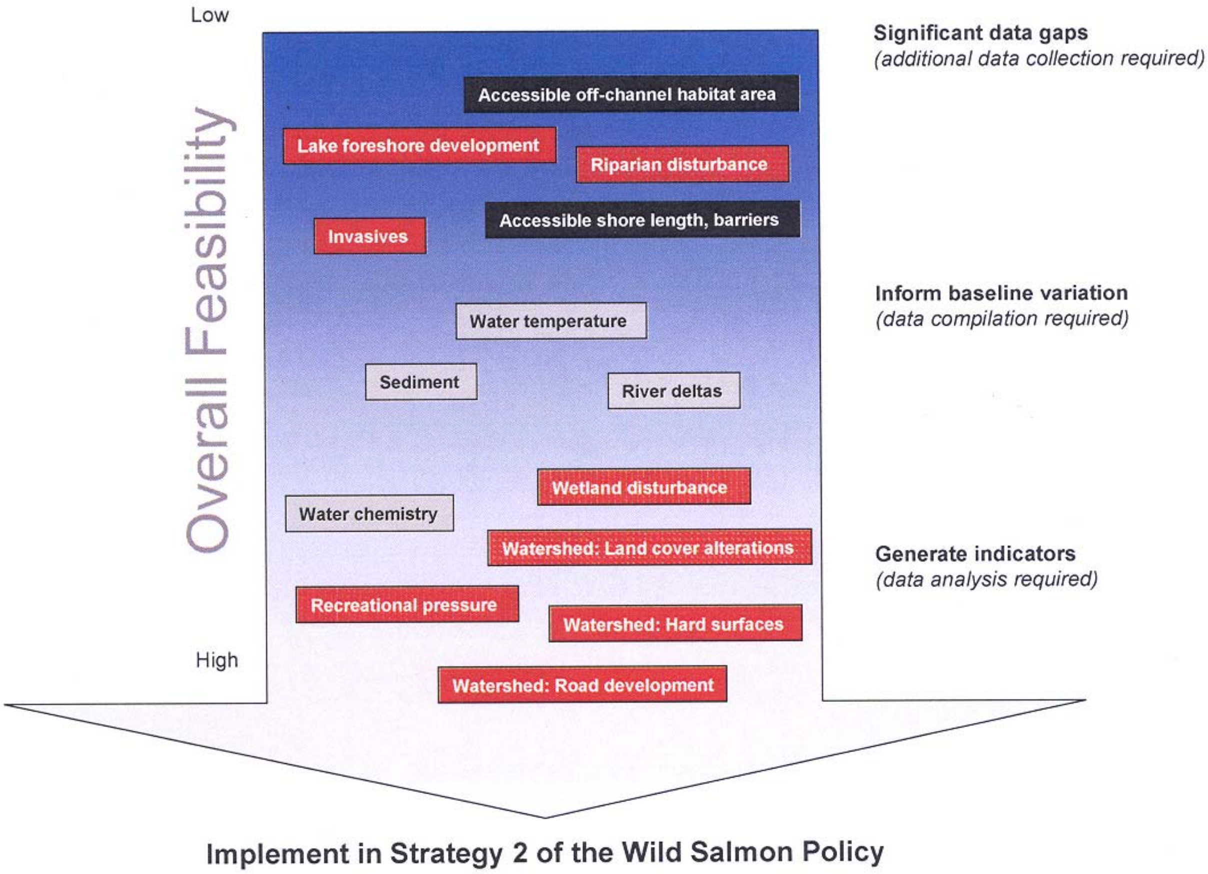

Figure A10.2. Qualitative representation of the level of effort required to generate lake habitat indicators under Strategy 2 of the WSP (from Nelitz *et al.* 2007a). Pressure indicators are in red boxes, state indicators are in grey boxes, and quantity indicators are in black boxes.

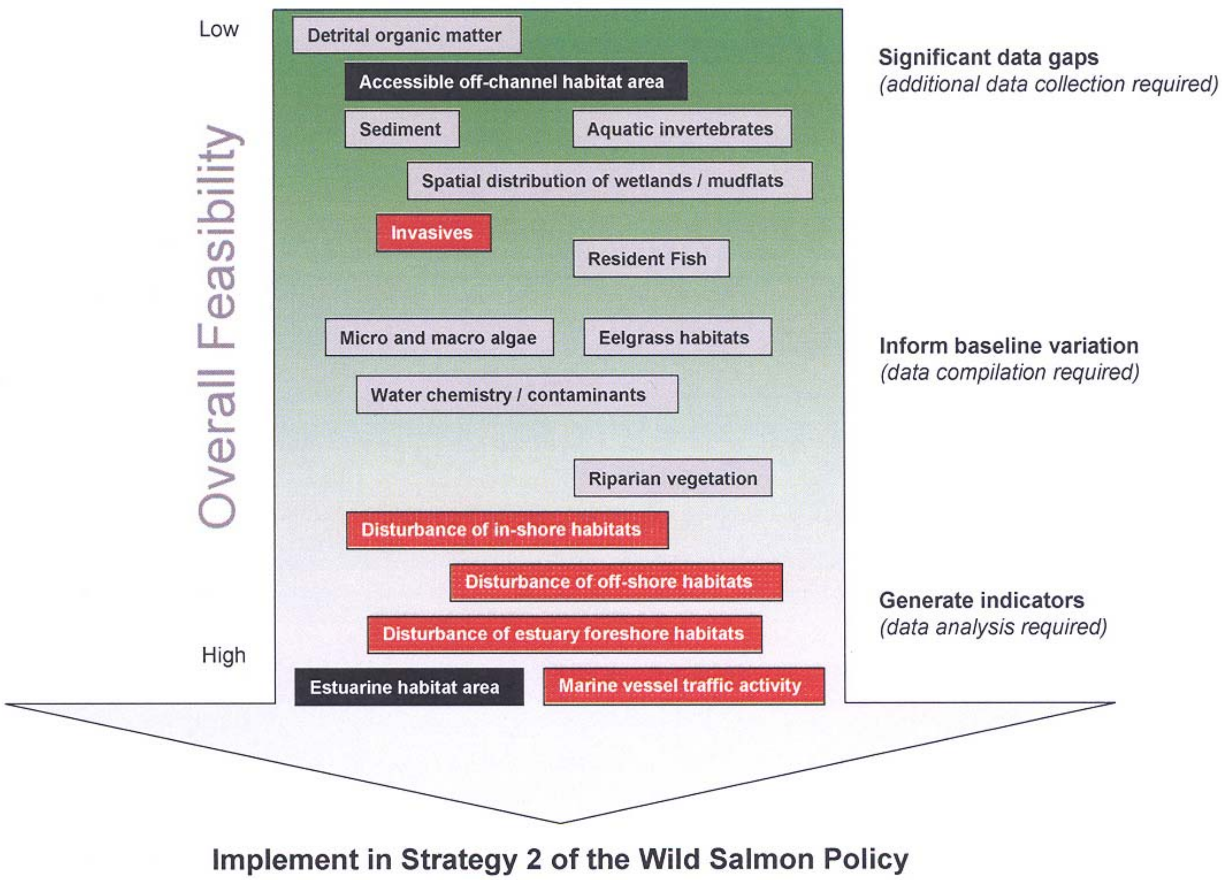

Figure A10.3. Qualitative representation of the level of effort required to generate estuary habitat indicators under Strategy 2 of the WSP (from Nelitz *et al.* 2007a). Pressure indicators are in red boxes, state indicators are in grey boxes, and quantity indicators are in black boxes.

APPENDIX 11.
DATA AVAILABILITY TO INFORM HABITAT INDICATORS

This appendix presents the three different categories of indicators identified in the practical assessment of the indicator short-list conducted by ESSA (Nelitz *et al.* 2007a): habitat indicators for which there are significant data gaps (Table A11.1), indicators for which there are sufficient data to inform baseline variation (Table A11.2), and indicators for which there are currently sufficient data to generate metrics (Table A11.3).

Table A11.1. Habitat indicators identified with significant data gaps (Nelitz *et al.* 2007a).

Habitat Type	Indicator Type	Indicator	Data Gaps
Stream	Quantity	Accessible off-channel habitat	3 potential data sources: Quickbird Satellite, National Air Photo Library. Remote sensing data will require large effort in interpretation, FISS data not centralized & easily accessible
Stream	Status	Channel stability	7 potential data sources identified, but none have level of detail needed to inform indicator across Region
Stream	Pressure	Floodplain connectivity	General data gap in floodplain connectivity in BC. Floodplains mapped once in 1980s-90s, but dykes & other control structures are missing
Lake	Pressure	Riparian disturbance	Not well catalogued on BC, with no ongoing monitoring. Remote sensing methods resolution (BTM & BEI) is too large
Lake	Pressure	Lake foreshore development	Available data for only 5 lakes. Spatial extent is small. Several suggestions offered, including FIM
Lake	Quantity	Accessible off-channel habitat	Difficult to evaluate due to fluctuating lake levels. Could use floodplain mapping with topo sheets and local barrier information
Lake	Quantity	Accessible shore length (barriers)	Very little data on shore length exists in BC. Could use Quickbird Satellite imagery, FIM, and local district permitting. Other remote sensing methods resolution (BTM & BEI) is too large
Estuary	Status	Detrital organic matter	No agency/NGO datasets exist that relate to monitoring detrital matter in estuaries. Research data available on small scale, and broader application could be undertaken at relatively low cost
Estuary	Quantity	Accessible off-channel habitat	Difficult to evaluate due to dependence on seasonal water level. Cannot be captured by single mapping effort. Could use floodplain mapping with topo sheets and local barrier information with flood height levels
Estuary	Status	Resident fish	No broad agency/NGO data monitoring of resident fish in estuaries. Parks Canada evaluating fish in eelgrass beds in BC National Parks, and past research in Fraser R. estuaries. NOAA monitoring fish in eelgrass beds in SE Alaska estuaries of Yukon rivers
Estuary	Status	Aquatic invertebrates	No broad agency/NGO data monitoring of invertebrates in BC/Yukon estuaries. Shorebird counts could be surrogate
Estuary	Status	Sediment	FREMP is only example. Broad scale tracking & evaluating sediment movements could be very expensive
Estuary	Status	Spatial distribution of mudflats/wetlands	No past agency/NGO programs to map & evaluate changing composition of mudflats/wetlands in BC. Campbell R. estuary as single example could provide conceptual foundation to larger program
Estuary	Status	Invasives	General data gap in agency/NGO monitoring of invasive species distribution & status in estuaries. Limited spatial extent for spartina. Recent AIS program getting underway in marine & estuary habitats

Table A11.2. Habitat indicators identified with sufficient data to inform baseline variation (Nelitz *et al.* 2007a).

Habitat Type	Indicator Type	Indicator	Data Availability and Limitations
Stream	Status	Water Chemistry	5 data sources identified in BC & Yukon, and data substantive, but databases are disparate due to different monitoring programs, protocols, and focussing on different attributes
Stream	Status	Water temperature	5 data sources identified in BC & Yukon. Most sources are opportunistic, but Fraser R. Environment Watch is only monitoring program focussed on salmon migration, yet too limited spatially for overall WSP monitoring. Temperature Sensitive Streams modelling would be useful in future
Stream	Status	Large Woody Debris (in-stream cover)	3 data sources identified, but each program has weaknesses which preclude them from being used for WSP monitoring. FDIS has best broad scale coverage in BC. No Broad scale coverage in Yukon. In spite of weaknesses & gaps, data provides appreciation of variation between streams & years
Lake	Status	Sediment	Suspended sediment (SS) available on many lakes in BC (excluding sockeye lakes), but spatially patchy. Two alternatives include using remote sensing to monitor land use practices that lead to high SS levels, and using lake productivity models to predict sediment loads. No mechanism currently exists to collect or record data in a comprehensive and systematic manner in BC
Lake	Pressure	River deltas	No current inventory or monitoring of rivers deltas in lakes in BC. Info on presence/absence could be derived form BC Watershed Atlas, but monitoring of status and changes requires using Quickbird imagery or similar remote sensing.
Lake	Status	Water temperature	No comprehensive and continuous monitoring of lake temperature in BC. Data on 43 lakes collected by ENGO. Not all sockeye lakes have temperature recorded, and data that is collected is not central database with water chemistry data. Workshop suggestion of ecozone approach with index lakes, and also suggestion of using ice-on, ice-off data
Lake	Pressure	Invasives	Very little data available of freshwater aquatic invasive species province-wide. Opportunistic sampling is spatially limited, but there concentrated local efforts, but without standardized monitoring protocols (Cultus & Okanagan)
Estuary	Status	Eelgrass	Mapping has been undertaken by NGOs fairly broadly, using standard methods. Data and past DFO data are on Community Mapping Network's Eelgrass Bed Mapping Atlas. Province also mapping eelgrass as part of CRIS inventory. Also suggestion that Quickbird imagery or similar remote sensing could be feasible in future.
Estuary	Status	Micro and macro algae	Mapping has been undertaken by NGOs fairly broadly, using standard methods. Data and past DFO data are on Community Mapping Network's Habitat Atlas. Province also mapping of macro algae as part of CRIS inventory.
Estuary	Status	Water chemistry/ contaminants	Minimal data collected directly in BC/Yukon estuaries, but inferences possible from Environment Canada's water quality monitoring in shell fish areas and u/s monitoring of provincial EMS system. BC State of the Environment report summarized sediment contaminant levels in selected estuaries

Table A11.3. Summary of practical assessment findings for habitat indicators with appropriate data to generate metrics (from Nelitz *et al.* 2007a).

Note use of the following abbreviations: Data availability: Y – yes, N – no, UNK – unknown; Relative cost: NA – not available, L – low $0-$50K, M – moderate = $50K-$100K, H – high > $100K; Spatial extent: No. of areas, local, regional, provincial; Spatial resolution: NA – not applicable, metres, kilometres; Temporal extent: year(s) of sampling; Temporal frequency: <monthly, monthly, seasonal, annual, multi-year; Scientific relevance: rank (score). Program costs refer to those resources associated with the initial program delivery by non-DFO entity, incremental cost refers to the cost to DFO to use these data for WSP purposes, and operating costs refer to the effort required by DFO to apply the data to generate the relevant habitat indicator.

Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Relative cost			Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
						Program costs	Incremental costs	Operating costs						
Stream	Quantity	Accessible stream length, barriers	Provincial Obstacles to Fish Passage Yukon Habitat Suitability Model	4	YES	HIGH	LOW	LOW	Pacific Region (BC & YK)	Point locations	1970 - present	unknown	Not ranked	High: Barrier information is available for BC. This information would need to be combined with a provincial watershed atlas (1:50,000 or 1:20,000) to calculate an appropriate indicator. Barrier information is lacking for the Yukon, though probably not as extensive a concern as in BC. Yukon also lacks a watershed atlas for the Territory; though the habitat suitability model does provide a framework for building an atlas and calculating this indicator for the Yukon watershed only. Given regional efforts in BC to better understand barriers (e.g., Okanagan and Cariboo), the provincial obstacle database should be supplemented / updated with regional information to improve its accuracy.
Stream	Pressure	Watershed: Land cover alterations	Baseline Thematic Mapping / Watershed statistics Yukon Biophysical mapping Yukon Fire History Yukon Forest Cut Layer	4	YES	HIGH	LOW	HIGH	Pacific Region (BC & YK)	1:250,000	1990s – present	multi-year	7 out of 13 (7.5)	Medium: Classifying land cover alteration is complex in so far that one needs to use multiple data sources (e.g., satellite imagery and GIS shapefiles). Land alterations could include: agriculture, forestry, urban development, wildfire, mining activities, and road networks. Neither BTM nor BEI are updated with new landsat imagery on a regular basis. Updating of landsat imagery is the limiting step in using either of these methods in so far that it will be the most costly both from a monetary and time perspective. The Yukon has not applied a similar approach to measuring land cover alterations, though such a project would be consistent with the Yukon Biophysical Mapping project which is currently under development.

Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Relative cost			Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
						Program costs	Incremental costs	Operating costs						
Stream	Pressure	Watershed : Hard surfaces	Baseline Thematic Mapping / Watershed statistics	4	YES	HIGH	LOW	HIGH	BC	1:250,000	1990s - present	multi-year	6 out of 13 (7.5)	Moderate. To fully catalogue impervious surface for a given watershed roads and parking lots (from NRN) should be coupled with urban centers (from BTM or BEI). BTM offers the best provincial coverage for impervious surfaces; however, it has not been updated with new landsat imagery for the entire province. Updating the landsat imagery is the limiting step in so far that it will be the most costly both from a monetary and time perspective. Extent of hard surfaces are limited in the Yukon.
Stream	Pressure	Watershed : Road developme nt	National Road Network (NRN) / Watershed statistics	3	YES	NA	LOW	MOD	Pacific Region (BC & YK)	metres	1979 – present	Annual	5 out of 13 (9)	High. The NRN is already in GIS format, is updated regularly, includes the best available data from BC and the Yukon, and is not costly to obtain / use. In addition, the effort required to calculate desired metrics from the GIS files should be low. Statistics on road density, stream crossing, and road length are summarized in the watershed statistics. A limitation is that the Yukon does not have a complete watershed atlas against which to calculate road densities or road-stream crossings. The Yukon Habitat Suitability Model is developing an intelligent stream linework that could be used for such purposes.

Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Relative cost: Program costs	Relative cost: Incremental costs	Relative cost: Operating costs	Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
Stream	Pressure	Wetland disturbanc e	Broad Ecosystem Inventory (BEI) / Watershed atlas Yukon Biophysical mapping	6	YES	HIGH	LOW	HIGH	Pacific Region (BC & YK)	1:250,000	1990s to present	Annual	8 out of 13 (7.5)	Moderate. BEI provides the best provincial scale coverage as it distinguishes between different kinds of wetlands; a distinction that is important when thinking about fish habitat. Although, the landsat imagery has only been updated once withing BEI, the methodology and more recent imagery are readily available to upgrade the BEI. Two drawbacks of BEI are: first, the cost of updating the landsat imagery used by the BEI; and second, as a consequence of the scale/resolution of mapping BEI tends to overlook and/or misclassify smaller wetlands. Ideally, the broad scale mapping would be coupled with on the ground monitoring that systematically verifies and catalogues wetlands in the province. The Canadian Wetland Inventory (CWI) aims to do just this, however it is still in an inchoate stage. An inventory of wetlands in BC and Yukon does not presently exist nor is there any on going monitoring of wetlands occurring. Several disparate data sources conducting monitoring do exist (e.g., Ducks Unlimited Canada, Community Mapping Network, SEI projects, and Wetland Keepers projects) and could be used to inform baseline variation; however there is no systematic coherency between the sources and the spatial extent of these sources is too limited to actively inform the indicator. Remote-sensed imagery of wetlands for the Yukon should be coordinated with the Yukon Biophysical mapping.
Stream	Pressure	Water extraction	<u>Surface water:</u> BC Water License Database Yukon Water Board - Water Licenses Database Water Resources Atlas <u>Groundwater:</u> British Columbia WELLs Database Yukon Water Well Registry	7	YES	NA	LOW	LOW	Pacific Region (BC & YK)	Surface water by waterbody; groundwat er by point locations	Depends on data source	Updated regularly	12 out of 13 (5.5), though recognized by DFO this rank should be higher	High: Seven data sources were identified / reviewed. Both surface water and groundwater extraction need to be captured by this indicator. Databases with such information are available for both British Columbia and the Yukon: surface water (BC Water License Database and Yukon Water Board - Water Licenses Database) and groundwater (British Columbia WELLs Database and Yukon Water Well Registry). Monitoring of actual amounts of water taking associated with water licenses is relatively non-existent, however. This poses a challenge to determining actual water extraction in watersheds of interest. Regardless, a summary of these data would be informative to understanding where water supplies are oversubscribed. This indicator should also be accompanied with some measure of stream discharge for nearby, or index watersheds. Maps of areas with restrictions on allocations of water licenses are also available and would be informative (e.g., Water Resources Atlas).

Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Relative cost			Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
						Program costs	Incremental costs	Operating costs						
Stream	Pressure	Riparian disturbanc e	Baseline Thematic Mapping / Watershed statistics Yukon Biophysical Mapping	10	YES	HIGH	LOW	HIGH	Pacific Region (BC & YK)	1:250,000	1990s – present	multi-year	2 out of 13 (10.5)	Moderate: A large number of potential data sources were identified to inform this indicator. Given the need for broad-scale representation of disturbance, the best option is to apply remote sensing imagery across BC and Yukon. Riparian disturbance in the Yukon would likely be the result of Placer mining and wildfire disturbance. To-date the Territory has not comprehensively mapped riparian disturbance. One gap is a complete watershed atlas (i.e., stream linework and watershed polygons) does not exist for the territory, though the Yukon Habitat Suitability model could provide a starting framework to develop the atlas.
Stream	Pressure	Sediment	Water Survey of Canada Hydrometric Network Yukon Placer Mining Industry Water Quality Objectives Monitoring Protocol	5	YES	HIGH	LOW	LOW	Pacific Region (BC & YK)	Emphasis on larger rivers	High variable, depends on stations of interest	daily	10 out of 13 (7)	Moderate: Five data sources were reviewed / identified from across the Pacific Region: Water Survey of Canada Hydrometric Network, Yukon Placer Mining Industry Water Quality Objectives Monitoring Protocol, Streamkeepers Data Entry Tool, EQ Win Database, Water Use Planning (WUP) Data, and Field Data Information System (FDIS). The Water Survey of Canada Hydrometric Network and Yukon Placer Mining Industry Water Quality Objectives Monitoring Protocol are the clear front runners as these represent structured and continuous monitoring of suspended sediments. The limitation with these specific data sets is that they may not be broad-scale enough for DFO purposes. Hydrometric network measures sediments at fewer streams than are being monitored for stream discharge. The Yukon monitoring protocol is associated with placer mining activities only. These data would be informative to helping decision makers understand background variation in suspended sediments. Field Data Information System (FDIS) was the only source capturing stream substrate information using broadly applied and standardized methods.
Stream	Status	Stream discharge	Water Survey of Canada Hydrometric Network (HYDAT Database) Yukon Water Resources Hydrometric Program	6	YES	HIGH	LOW	LOW	Pacific Region (BC & YK)	Emphasis on larger rivers	High variable, depends on stations of interest	Daily	4 out of 13 (10)	High: Two good sediment monitoring programs exist across the region. Although in its infancy, the sediment monitoring associated with placer mining in the Yukon follows a rigorous and repeated sampling design. In addition a subset of the Water Survey of Canada hydrometric stations across the region also monitor sediment. A constraint however, is that these monitoring programs tend to focus on large rivers, meaning smaller streams would not be captured through these efforts.

Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Relative cost			Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
						Program costs	Incremental costs	Operating costs						
Lake	Status	Water Chemistry	DFO Sockeye Lakes Dataset	6	YES	MOD	LOW	LOW	BC	NA	1980s – present	Monthly to multi-year	5 out of 12 (9)	High. The sockeye lakes dataset contains water chemistry data for all sockeye nursery lakes in the province. The only draw back of the dataset is that lake specific data varies in quantity and temporal extent across lakes – surveys are not systematic across the province.
Lake	Pressure	Watershed: Road Development	National Road Network (NRN) / Watershed statistics	3	YES	NA	LOW	LOW	BC and Yukon	m	1979 – present	annual	8 out of 12 (7.5)	High. The NRN is already in GIS format, is updated regularly, covers the desired spatial areas, and is not costly to obtain and use. In addition, the effort required to calculate desired metrics from the GIS files should be low. Statistics on road density, stream crossing, and road length are summarized in the watershed statistics.
Lake	Pressure	Watershed: Land cover alteration	Baseline Thematic Mapping / Watershed statistics Forest Health Mapping	4	YES	HIGH	LOW	HIGH	BC	1:250,000	1990s – present	multi-year	1 out of 12 (11)	Moderate. Classifying land cover alteration is complex in so far that one would need to use multiple data sources. Land alteration would include developments in/of: agriculture, forestry, urban, fire, mining, and road networks. BTM offers the best provincial coverage of land use; however, BTM has not regularly been updated with new landsat imagery. Updating the landsat imagery is the limiting step in using this method in so far that it will be the most costly both from a monetary and time perspective. The watershed statistics provides land summaries of each watershed.
Lake	Pressure	Watershed: Hard surface	Baseline Thematic Mapping / Watershed statistics	4	YES	HIGH	LOW	HIGH	BC	1:250,000	1990s - present	multi-year	3 out of 12 (9.5)	Moderate. In order to fully catalogue impervious surface for a given watershed roads and parking lots (from NRN) should be coupled with urban centers (from BTM or BEI). BTM offers the best provincial coverage for impervious surfaces; however, it has not been updated with new landsat imagery for the entire province. Updating the landsat imagery is the limiting step in so far that it will be the most costly both from a monetary and time perspective.
Lake	Pressure	Recreational Pressure	National Road Network BC Water Resource Atlas Survey of Sport Fishing in British Columbia	5	YES	HIGH	LOW	LOW	BC	1) m 2) 1: 50,000 3) NA	1) 1979 – present 2) 2004 - present 3) 1976 - present	1) annual 2) ongoing 3) every 5 years	11 out of 12 (5.5)	High. A combination of these three data sources would provide comprehensive detail of recreational pressure for the province. The BC water resource atlas recreational sensitivity layer coupled with the distance of lakes from roads would give high level recreational pressure information for the province. At the watershed / CU level, the Survey of Sport Fishing provides lake specific information that could be used to give an indication of lake usership (i.e., relative number of visitors).

Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Relative cost: Program costs	Relative cost: Incremental costs	Relative cost: Operating costs	Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
Lake	Pressure	Wetland Disturbance	Broad Ecosystem Inventory (BEI) / Watershed statistics	6	YES	HIGH	LOW	HIGH	BC	1:250,000	1990s to present	Annual	10 out of 12 (6.5)	Medium. BEI provides the best provincial scale coverage as it distinguishes between different kinds of wetlands; a distinction that is important when thinking about fish habitat. Although, the Landsat imagery has only been updated once within BEI, the methodology and more recent imagery are readily available to upgrade the BEI. Two drawbacks of BEI are: first, the cost of updating the Landsat imagery used by the BEI; and second, as a consequence of the scale/resolution of mapping BEI tends to overlook and/or misclassify smaller wetlands. Ideally, the broad scale mapping would be coupled with on the ground monitoring that systematically verifies and catalogues wetlands in the province. The Canadian Wetland Inventory (CWI) aims to do just this, however it is still in an inchoate stage. An inventory of provincial wetlands does not presently exist nor is there any on going monitoring of wetlands occurring at a provincial scale. Several disparate data sources conducting monitoring do exist (e.g., Ducks Unlimited Canada, Community Mapping Network, SEI projects, and Wetland Keepers projects) and could be used to inform baseline variation; however there is no systematic coherency between the sources and the spatial extent of these sources is too limited to actively inform the indicator.
Estuary	Pressure	Marine vessel traffic	Marine Communications and Traffic Services Statistics (VTS) DFO Catch Statistics	2	YES	HIGH	LOW	LOW	BC	kilometers	2002-present	<monthly to annual	12 out of 14 (8.5)	High. The VTS database provides direct vessel traffic information on larger ships. DFO Catch statistics on catch and vessel days can be used to infer traffic densities of smaller fishing boats. A combination of these 2 datasets should provide comprehensive and regularly updated information on marine vessel activity in and around estuaries along the BC coast.
Estuary	Quantity	Estuarine habitat area	Biophysical Assessment of Estuarine Habitats	1	YES	HIGH	LOW	LOW	BC (442 major estuaries)	meters	2007	One time only	Not ranked	Moderate. The Biophysical Assessment provides a solid baseline inventory of estuarine habitat area for larger delineated estuaries across BC, and a standardized methodology for repeat surveys. Use of this information for monitoring of future changes in estuarine habitat area will depend on a commitment to repeat mapping, at least in selected representative areas.

						Relative cost								
Habitat type	Indicator type	Indicator	Data source(s)	No of reviewed sources	Data availa-bility	Program costs	Incremental costs	Operating costs	Spatial extent	Spatial resolution	Temporal extent	Temporal frequency	Scientific relevance (rank / score)	Overall feasibility / comments on calculation of indicator
Estuary	Pressure	Disturbance of foreshore habitats	Biophysical Shoreline Mapping (CRIS) – Shoreline Hardening Fraser River Estuary Management Program	4	YES	HIGH	LOW	LOW	BC Regional	meters	2002	Annual to Multi-year	1 out of 14 (11)	Moderate. The shoreline hardening inventory undertaken by the province for the CRIS program has provided baseline mapping of estuarine foreshore disturbance in costal southern BC. Further shoreline hardening mapping will be undertaken by BC MOE in additional areas of the province in coming years. This broader scale mapping can be supplemented in the Fraser River estuary (where CRIS has not been undertaken) by the more intensive and regularly updated mapping of foreshore development for FREMP.
Estuary	Pressure	Disturbance of in-shore habitats	Crown Land Leases and Licenses	4	YES	HIGH	LOW	LOW	BC	meters		Multi-year	7 out of 14 (9.5)	High. The province's Crown Leases and Licenses database provides a quantification of the extent of land devoted to industrial or conservation activities within defined estuaries across the province. This information is continually updated with changes in lease status and the CWS has committed to regular summary updates of this information for use in evaluating extent of disturbance (intertidal and subtidal) within estuaries.
Estuary	Pressure	Disturbance of off-shore habitats	Crown Land Leases and Licenses	3	YES	HIGH	LOW	LOW	BC	meters		Multi-year	8 out of 14 (9)	High. The province's Crown Leases and Licenses database provides a quantification of the extent of land devoted to industrial or conservation activities within defined estuaries across the province. This information is continually updated with changes in lease status and the CWS has committed to regular summary updates of this information for use in evaluating extent of disturbance (intertidal and subtidal) within estuaries.
Estuary	Status	Riparian vegetation	Biophysical Shoreline Mapping (CRIS) – Shoreline Hardening Fraser River Estuary Management Program	2	YES	HIGH	LOW	LOW	BC Regional	meters	2002	Multi-year	4 out of 14 (10.5)	Moderate. The shoreline hardening inventory undertaken by the province for the CRIS program has provided baseline mapping of existing estuarine riparian vegetation in some urbanized areas of southern BC. Further riparian mapping using this approach will be undertaken by BC MOE in additional areas of the province in coming years. This broader scale mapping can be supplemented in the Fraser River estuary (where CRIS has not been undertaken) by the more intensive and regularly updated mapping of riparian vegetation for FREMP.

APPENDIX 12.
RECOMMENDED OPTIONS FOR HABITAT INDICATORS

Table A12.1. Recommended habitat indicators for the "basic" option (from Nelitz *et al.* 2007a).

Habitat Type	Indicator Type	Indicator	Data Sources/Analytical Project	Relative Cost	Scientific Relevance
Stream	Pressure	Water Extraction	Project #1 - BC Water Licence database - Yukon Water Board, Water licences database - Water Resources Atlas - BC Wells database - Yukon Water Well Registry	Low	Low*
Stream	Status	Stream Discharge	Project #2 - WSC Hydrometric Network - Yukon Water Resources Hydrometric Network	Low	High
Stream/ Lake	Pressure	Watershed: Road development	Project #3 - National Road Network/BC Watershed Statistics	High	High
Stream	Pressure	Riparian disturbance	- Baseline Thematic Mapping/ BC Watershed Statistics - Forest Health mapping		High
Stream/ Lake	Pressure	Watershed: Land cover alterations	- Yukon Biophysical mapping - Yukon Fire History		Mod/High
Stream/ Lake	Pressure	Watershed: Hard surfaces	- Yukon Forest Cut Layer		Mod/High
Lake	Status	Water chemistry	Project #4 - DFO Sockeye dataset	Low	Moderate
Lake	Pressure	Recreational pressure	Project #5 - National Road Network - BC Water Resource Atlas - Survey of Sport Fishing in BC	Low	Low
Estuary	Pressure	Disturbance of in-shore habitats	Project #6 - Crown Land Leases and Licences	Low	Moderate
Estuary	Pressure	Disturbance of off-shore habitats			Moderate
Estuary	Pressure	Marine vessel traffic	Project #7 - Marine Communications and Traffic Services Statistics - DFO Catch Statistics	Low	Low

*Water extraction has been recognized that it should ranked higher than the original DFO assessment of scientific relevance

Note: 1. Scientific relevance was ranked by DFO in an earlier process

2. Cost categories are: Low = $0-50K, Moderate = $50K-100K, High = > $100K

Table A12.2. Recommended habitat indicators for the “ideal” option (from Nelitz *et al.* 2007a).

Habitat Type	Indicator Type	Indicator	Data Sources/Analytical Project	Relative Cost	Scientific Relevance
Stream	Pressure	Water Extraction	Project #1 - BC Water Licence database - Yukon Water Board, Water licences database - Water Resources Atlas - BC Wells database - Yukon Water Well Registry	Low	Low*
Stream	Status	Stream Discharge	Project #2 - WSC Hydrometric Network - Yukon Water Resources Hydrometric Network	Low	High
Stream/ Lake	Pressure	Watershed: Road development	Project #3 - National Road Network/BC Watershed Statistics	High	High
Stream	Pressure	Riparian disturbance	- Baseline Thematic Mapping/ BC Watershed Statistics		High
Stream/ Lake	Pressure	Watershed: Land cover alterations	- Forest Health mapping - Yukon Biophysical mapping		Mod/High
Stream/ Lake	Pressure	Watershed: Hard surfaces	- Yukon Fire History - Yukon Forest Cut Layer		Mod/High
Lake	Status	Water chemistry	Project #4 - DFO Sockeye dataset	Low	Mod
Lake	Pressure	Recreational pressure	Project #5 - National Road Network - BC Water Resource Atlas - Survey of Sport Fishing in BC	Low	Low
Estuary	Pressure	Disturbance of in-shore habitats	Project #6 - Crown Land Leases and Licences	Low	Moderate
Estuary	Pressure	Disturbance of off-shore habitats			Moderate
Estuary	Pressure	Marine vessel traffic	Project #7 - Marine Communications and Traffic Services Statistics - DFO Catch Statistics	Low	Low
Stream	Status	Water Temperature	Project #8 - New monitoring program building on available data	Moderate	Moderate
Stream/ Lake	Pressure	Wetland Disturbance	Project # 9 - Broad Ecosystem Inventory (BEI)/ Watershed Atlas	High	Moderate/Low
Estuary	Pressure	Disturbance of foreshore habitats	Project # 10 - Biophysical Shoreline Mapping (CRIS) – Shoreline Hardening	Low	High
Estuary	Pressure	Riparian Vegetation	- Fraser River Estuary Management Program		High
Estuary	Status	Eelgrass	Project #11 - New monitoring program building on available data	High	Moderate

*Water extraction has been recognized that it should ranked higher than the original DFO assessment of scientific relevance

Note: 1. Scientific relevance was ranked by DFO in an earlier process

2. Cost categories are: Low = $0-50K, Moderate = $50K-100K, High = > $100

APPENDIX 13
SUPPLEMENTAL INDICATORS

While excluded from the final proposed list of indicators, the HWG did identify the following habitat indicators as being potentially useful to track changes or trends if the data could be generated through other processes or additional work.

1. Stream accessible off-channel habitat.

   This was not recommended as an indicator due to lack of wide-spread data and site specificity. Flood events can also cause large annual changes in channel morphology and there are problems with forest cover masking off-channel habitats and limiting the usefulness of remote sensing imagery. The data sources reviewed also didn't have the resolution or temporal coverage to capture water level changes that would make areas seasonally accessible or not. However the quantity was recognized as an important parameter, just very difficult to measure. The HWG advocated tracking off-channel habitat changes in a data-base for restoration projects.

2. Stream channel stability.

   This was not recommended as an indicator as it is too site specific, and there isn't a consistent metric for channel stability, however bank stabilization works can be captured in a data-base for restoration projects as an indicator of instability.

3. Estuarine accessible off-channel habitat.

   This was not recommended as an indicator due to the lack of wide-spread data, data sources didn't have the resolution to capture this information, site-specificity and the existence of other potential surrogates, but quantity increases could be tracked in a data-base for restoration projects.

4. Stream dissolved oxygen.

   Stream water chemistry as an indicator has many challenges with vast differences between streams, inherent high natural variability, the influences of surficial geology and the difficulty in interpreting changes in conductivity and pH. It is a very expensive monitoring program to set-up baseline for water quality parameters other than temperature and dissolved oxygen (DO). It was widely believed that DO is a very important parameter due to the narrower salmon tolerances. As most streams are saturated due to natural turbulence, DO is not routinely collected by monitoring agencies (R. Grace, BCMOE, pers. comm, D. Patterson, DFO, pers. comm.). However, DO is opportunistically sampled in sewage and pulp mill effluents. There is still the potential of using DO saturation as a state indicator if other pressure indicators reach their threshold e.g., riparian loss as it potentially leads to increased temperatures and thus decreased DO.

To address data-gaps, the HWG identified a number of further projects, that if undertaken could enable more ready tracking of habitat status and trends:

1. Develop a predictive model for stream and estuarine off-channel habitat.
2. Develop sampling program for presence/absence of key indicator species of invertebrates in the estuary as an alternative to Reference Condition Approach or Index of Biotic Integrity.
3. Create a model to ID land conversion on deltas in lakes utilizing Watershed Statistics data.
4. Recommend the DFO Cultus Lake Sockeye Lakes study group also capture shoreline temperatures for further insight into rearing conditions for any salmonids utilizing the shoreline.
5. Increase the Fisheries Project Registry database information to allow for calculations of habitat gains (i.e., include quantity, geo-referenced location and use the same standards that are used to quantify that habitat).
6. Capture gains/losses in stream, lake and estuarine project reviews, mitigation efforts, authorized and unauthorized works.

APPENDIX 14.
SUGGESTED METRICS AND BENCHMARKS

Table A14.1. Table from Nelitz *et al.* (2007b) Recommendations for metrics and benchmarks associated with STREAM habitat indicators. Indicators with an asterisk refer to those listed in the basic (*) or ideal (**) options presented in Appendix 12.

	Recommendation		
Indicator	Related metric(s)	Related benchmark(s)	Rationale for recommendation
Sediment	Total suspended sediments (TSS) (e.g., mg/L, ppm) (EIFAC 1964; DFO 2000)	Use thresholds for total suspended sediments as identified by EIFAC 1964 and DFO 2000: • < 25 parts per million (ppm) of suspended solids - no evidence of harmful effects on fish and fisheries; • 25 - 80 ppm - it should be possible to maintain good to moderate fisheries, however the yield would be somewhat diminished relative to waters with <25 ppm suspended solids; • 80 - 400 ppm - these waters are unlikely to support good freshwater fisheries; and • 400 ppm suspended solids - at best, only poor fisheries are likely to be found. This benchmark would fit within Category 1 – benchmarks based on dose-response relationships. Where TSS data are available across seasons / years, supplement use of thresholds with Category 6 – probabilistic benchmarks to determine likelihood of exceeding thresholds across years / seasons given variation in discharge (e.g., Perry 2002).	These two metrics relate to different effects on salmon. Suspended sediments can smother eggs during incubation, and affect use / survival of habitat for rearing juveniles. These metrics would be measured using different field sampling protocols. Other metrics are more indirect measures of effects on salmon. A TSS metric can be more easily calculated with available data than substrate composition (see page 27, Table 8 in Nelitz *et al.* 2007a).
	Streambed substrate composition (e.g., % of substrate particles < 6.35mm) (DFO 2002; Kondolf 2000; Lisle 1989; BC MOE 2006a, NOAA 1996)	Use common standards identified to protect aquatic life in freshwater (DFO 2002; Kondolf 2000; Lisle 1989; BC MOE 2006a): • fines not to exceed 10% with less than 2mm diameter, 19% as less than 3mm, and 25% less than 6.35mm at salmonid spawning sites This benchmark would fit within Category 1 – benchmarks based on dose-response relationships.	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Water chemistry	Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2) (BC MOE 2006a)	Recommend thresholds used for protection of aquatic life in freshwater (BC MOE 2006a), consistent with Category 1: • Instantaneous minimum of 5 mg/L, 30-day mean of 8 mg/L within water column for all life stages (other than buried embryo / alevin) • Instantaneous minimum of 9 mg/L, 30-day mean of 11 mg/L within water column for buried embryo / alevin • Instantaneous minimum of 6 mg/L, 30-day mean of 8 mg/L within interstitial water for buried embryo / alevin	These metrics are those water chemistry attributes either most strongly affected by or most affecting salmon. Adult salmon provide an important marine nutrient subsidy (MDN) to freshwater and terrestrial environments (Gende *et al.* 2002). Therefore, nitrogen and phosphorous concentrations will be important to monitor so as to understand the relative importance of salmon carcasses in these environments. Concentrations will be affected by discharge, terrestrial inputs, and atmospheric deposition of nutrients. Dissolved oxygen is critical to the survival and development of eggs and juveniles. There is a concern, however, that the data are not broadly available to calculate these metrics. A dedicated water chemistry monitoring program would be needed to capture these measures.
Water chemistry	Total nitrogen (e.g., µg/L) (BC MOE 2006a; MacDonald *et al.* 2000; Johnston *et al.* 2004)	No appropriate benchmarks identified. Recommend developing Category 2 – benchmarks using ranges of natural variation. Intention would be to identify areas / years that are nutrient deficient and salmon are providing marine subsidies to terrestrial and freshwater ecosystems. Management focus would be to maintain nutrient subsidies to important areas.	
	Total phosphorous (e.g., µg/L) (MacDonald *et al.* 2000; Johnston *et al.* 2004)	No appropriate benchmarks identified. Recommend developing Category 2 – benchmarks using ranges of natural variation. Intention would be to identify streams / years that are nutrient deficient and salmon are providing marine subsidies to terrestrial and freshwater ecosystems. Management focus would be to maintain nutrient subsidies to these locations / during those years.	
	Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2) (BC MOE 2006a)	Recommend thresholds used for protection of aquatic life in freshwater (BC MOE 2006a): • Instantaneous minimum of 5 mg/L, 30-day mean of 8 mg/L within water column for all life stages (other than buried embryo / alevin) • Instantaneous minimum of 9 mg/L, 30-day mean of 11 mg/L within water column for buried embryo / alevin • Instantaneous minimum of 6 mg/L, 30-day mean of 8 mg/L within interstitial water for buried embryo / alevin These thresholds are consistent with Category 1 – benchmarks based on dose-response relationships.	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Riparian disturbance*	<u>Proportion of stream length with disturbed riparian zone</u>, accounting (using groupings or weightings) for differences in (MOF 2001; Caslys 2007; Province of British Columbia 2000, 2002; NOAA 1996): • potential for sediment contributions based on upslope (e.g., >60% or ≤60%) or channel gradient • adjacent vegetation type (e.g., Biogeoclimatic zone) • stream order (recognizes river continuum concept, Vannote *et al.* 1980) • type of disturbance (e.g., variable retention, selective logging, recently harvested, recently burned, urban, agriculture)	<u>Functioning condition (NOAA 1996)</u> • proper: < 20 disturbed and > 50% of riparian vegetation similar to natural community composition • at risk: 20-30% disturbed and 25 -50% of riparian vegetation similar to natural community composition • non-functional: > 30% disturbed and <25% of riparian vegetation similar to natural community composition. These thresholds are consistent with <u>Category 1</u> – benchmarks based on dose-response relationships.	Metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. Metric should account for the variation in the function of riparian areas across a watershed (e.g., Hughes *et al.* 2004) by accounting for lateral distance of disturbance from stream, distance from the headwaters, riparian vegetation type, and terrain slope. Accounting for these factors recognizes differences in riparian function across a watershed, ecosystems, or disturbance types. A watershed disturbance index integrating multiple habitat indicators may be the most simple / informative way of accounting for several human disturbances (see Appendix A). A quantitative metric evaluation / selection process would help develop such an index (see recommendations).
Watershed: Land cover alterations*	<u>Percent by land use</u>: sum of the area of all patches of a particular type divided by total area of the basin, including: agriculture, urban development, harvested, burned / diseased, mining, rangeland, landslides, undisturbed. Could also group land uses / patch types using more meaningful classes that more strongly link to watershed-stream processes affecting salmon (e.g., % impervious area, % semi-impervious, % forested, % grass, % exposed). (MOF 2001; UBC Sustainable Forest Management Research Group no date; Caslys 2007; Bradford and Irvine 2000)	<u>No appropriate benchmarks identified</u>. Recommend developing <u>Category 4</u> – benchmark using comparisons to other watersheds, where Conservation Units or watersheds can be ranked by land use type or total land use. Top ranked Conservation Units / watersheds in each category could be targeted for management action. Best approach would be to categorize land uses on the basis of their effects on stream-watershed processes (i.e., using categories of impervious area, semi-impervious, forested, grass, exposed, etc.). In addition, watersheds or CUs could be ranked according to the rate of increase of the more deleterious land use types (e.g., rate of increase of logged area).	Recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. Thresholds for land use types are extremely difficult to identify because there is a linear relationship between land use types and deleterious effects on salmon (Mike Bradford, Fisheries and Oceans Canada, pers. comm.). Noteworthy is the study by Alberti *et al.* (2007) which hypothesized that multiple measures of landscape disturbance (land cover composition, configuration, and connectivity of impervious area) affect the biophysical environment. These other measures may be worth exploring. A watershed disturbance index integrating multiple habitat indicators may be the most simple / informative way of accounting for several human disturbances (riparian disturbance, road development, impervious surfaces, and land use cover). For instance, Fore (2003) noted that integrated

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
	<u>Equivalent clearcut area (ECA)</u>: area harvested, cleared, or burned with consideration given to silvicultural system, regeneration, and location (i.e., elevation) of disturbance within watershed (MOF 2001; UBC Sustainable Forest Management Research Group no date; NOAA 1996; Reksten 1991; Stednick 1996)	<u>Functioning condition as identified by NOAA 1996:</u> • proper: < 15 % ECA with no concentration of disturbance in unstable or potentially unstable areas • at risk: < 15 % ECA with concentration of disturbance in unstable or potentially unstable areas • non functional: > 15 %ECA and disturbance concentrated in unstable or potentially unstable areas There was general consistency in a 15-20% benchmark across reviewed references. These benchmarks fit generally within <u>Category 1</u> – benchmarks based on dose-response relationships.	measures of disturbance were better predictors of biological responses than a single measure of disturbance. In other words, there were many correlations among different disturbance metrics. A measure of Equivalent Clearcut Area is somewhat redundant with a measure of proportion of harvested area (implied in the first metric). It is included here because it is a more accurate and common measure of peak flow hazard in harvested watersheds.
Watershed: Hard surfaces*	<u>Total impervious surface cover (ISC)</u> (% of land covered with buildings, concrete, asphalt, and other "hard," or impervious, surfaces) (The Heinz Center 2002; Paul and Meyer 2001; Guthrie and Deniseger 2001; Booth *et al.* 2002)	<u>Not specified</u> Benchmarks drawn from Paul and Meyer 2001, Guthrie and Deniseger 2001, UBC 2004, Klein 1979, Booth *et al.* 2002. • 10-20% impervious surface cover (ISC) results in rapid degradation of aquatic systems • 2-6% ISC marks a threshold for changes in geomorphology of streams: • > 10 % ISC negatively affects fish diversity • rapid decline in biotic diversity where watershed imperviousness exceeded 10 % • maximum of 10% ISC and minimum of 65% forest cover (Booth *et al.* 2002) General consistency across many paper in North America on these ranges (summarized in Paul and Meyer 2001)	The recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). One of the most consistent and pervasive effects associated with urbanisation and development is an increase in impervious surface cover within watersheds thereby altering the hydrology and geomorphology of water systems (Paul and Meyer 2001). Consequently, total impervious surface cover acts as good indicator of the extent of urbanization and development and the increased loading of nutrients, metals, pesticides, and other contaminants to waterways that are associated with development.
Watershed: Road development*	<u>Road density</u> (length per unit area, e.g., km / km^2) (MOF 2001; Bradford and Irvine 2000; Chu *et al.* 2003; Forman and Alexander 1998; NACSI 2001; Nelitz *et al.* 2007; Sharma and Hilborn 2001; Province of BC 2002; Alberti *et al.* 2007; UBC Sustainable Forest Management Research Group no date; NOAA 1996)	<u>Functioning condition (NOAA 1996):</u> • Properly functioning: < 1.24 km/km2, no valley bottom roads • At risk: 1.24 – 1.86 km/km2, some valley bottom roads • Non functioning: > 1.86 km/km2, many valley bottom roads These benchmarks fit generally within <u>Category 1</u> – benchmarks based on dose-response relationships	Recommended metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A) and have been commonly applied in other studies. Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. We recognize road density and road-stream crossing density may be correlated. Both have been included because each relate differently to impacts on salmon habitats. When calculating a road density metric, it is generally

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
	Road-stream crossings (number of road-stream crossings per unit area, e.g., # / km^2 or # / km) (MOF 2001; Alberti *et al.* 2007; Nelitz *et al.* 2007b; Haskins and Mayhood no date)	No appropriate benchmarks identified. Recommend first exploring development of Category 1 – benchmarks based on dose-response relationships between road density and habitat / biological responses. Although more defensible, development of this type of benchmark could require substantial data analysis. A second option would be to develop Category 4 – benchmarks using comparisons across watersheds / Conservation Units. Areas with the highest road densities could be targeted for management action.	recognized as important to distinguish between paved, unpaved, and deactivated roads; each affect habitats differently. NCASI (2001) recommends further research around developing indices of road disturbance and targets for management. Gucinski *et al.* (2001) provides a good technical synthesis about the effects of roads, while also recommending further work around developing benchmarks. Thus, it will be difficult to develop scientifically defensible thresholds. Similar to the above pressure indicators, a watershed disturbance index integrating multiple habitat indicators may be the most simple / informative way of accounting for several human disturbances (riparian disturbance, road development, impervious surfaces, and land use cover). A quantitative metric evaluation / selection process would help develop such an index (see recommendations).
Water temperature**	7-day average of mean daily temperature (e.g., maximum weekly average temperature – MWAT) (Richter and Kolmes 2005; Nelitz *et al.* 2007b; Brungs and Jones; Sullivan 2000).	Recommend upper optimal temperature criteria for coho, chinook, and chum salmon (Richter and Kolmes 2005): • Spawning and incubation 10ºC • Juvenile rearing 15ºC • Adult migration 16ºC • Smoltification 15ºC These criteria also fit within the optimum ranges for other salmon species). These criteria are represented by Category 1 – benchmarks based on does-response relationships. Where temperature data are available across seasons / years, more defensible benchmarks would integrate Category 6 – probabilistic benchmarks to determine the likelihood of exceeding criteria across years / seasons (e.g., Fleming and Quilty 2007).	Richter and Kolmes (2005) recognize that temperature criteria should consider relevant life stages, waterbodies, and times of year for Pacific salmon. These three metrics capture the most relevant concerns of temperature on Pacific salmon in stream environments: juvenile rearing, adult migration, and egg incubation. These metrics could not be calculated with existing data. A well designed temperature monitoring program would be required to calculate these metrics. Metrics imply collection of both winter and summer temperatures in smaller spawning streams, and larger rivers used as migration corridors.
Water temperature**	Accumulated thermal units over incubation period (Hensen *et al.* 2002; Holtby 1988; Murray and McPhail 1988; Beacham and Murray 1990)	No benchmark identified. Recommend developing Category 1 – benchmarks using dose-response relationships based on variations in accumulated thermal units (ATU) and changes in date of emergence and egg survival. Although not specified in the identified citations, such benchmarks could likely be derived using available data / models to translate optimum daily temperatures to an ATU benchmark. Where temperature data are available across seasons / years, a more defensible benchmark would integrate Category 6 – probabilistic benchmarks to determine likelihood of exceeding benchmark in a given year / location (e.g., Fleming and Quilty 2007).	

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
	Accumulated thermal units over migration corridor / period (D. Patterson, Fisheries and Oceans Canada, pers. comm.)	No benchmark identified. Recommend developing Category 1 – benchmarks using dose-response relationships based on variation in accumulated thermal units over a particular stock's migration corridor and changes in en-route survival and spawning success. Would likely need to account for distance of migration when deriving benchmarks. Where temperature data are available across seasons / years, a more defensible benchmark would integrate Category 6 – probabilistic benchmarks to determine likelihood of exceeding benchmark across years (e.g., Fleming and Quilty 2007). Another option is Category 4 – benchmark using comparisons across Conservation Units to identify stocks under the greatest thermal stress during migration.	
Wetland disturbance*	Ratio of wetland area to watershed area (Fennessy *et al.* 2004)	No appropriate benchmarks identified. Recommend first exploring development of Category 3 – benchmarks using comparisons in time where the base year for comparison would be prior to settlement and developments following the mid 1800s. Where this is not possible the year of the most historical wetland inventory should be used as a benchmark. Subsequently, a Category 4 – benchmarks using comparisons across watersheds / Conservation Units can also be developed allowing for units to ranked against each other with respect to the magnitude of change in the ratio relative to historic records. Areas with the greatest degree of negative change in the ratio (i.e., wetland area decreasing relative to watershed area) could be targeted for management action.	Recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. Quantifying wetland area by type is a valuable metric because some wetland types are more beneficial to salmon by virtue of the type of habitat they provided, their connectivity to streams and lakes, and the rate of transfer of dissolved organic matter to stream and lake systems (Henning *et al.* 2006). Ratio of wetland area to watershed area on the other hand provides a high level picture of the overall status of wetlands in a watershed and can be used as a basis of comparison between watersheds to indicate which wetlands are being disturbed.
Wetland disturbance*	Total wetland area by type (e.g., acres or km^2) (Maryland Department of Environment 2007; Fennessy *et al.* 2004)	No appropriate benchmarks identified. Recommend first exploring development of Category 4 – benchmarks using comparisons across watersheds / Conservation Units. Areas with the lowest wetland area could be targeted for management action. A second option would be to develop Category 3 – benchmarks using comparisons in time where the base year for comparison would be prior to settlement and developments following the mid 1800s. Where this is not possible the year of the most historical wetland inventory should be used as a benchmark.	
Floodplain connectivity	Percent of stream and off-channel habitat length with lost floodplain connectivity due to incision, roads, dikes, flood protection, or other actions (e.g., km channelized / km of stream length).	Functioning Condition for streams < 1% gradient (Smith 2005): • Proper functioning condition: < 10 % • At risk functioning condition: 10-50% • Not functioning: > 50 %	Recommended metric is the one most strongly linked to human pressures on stream channels and that could be more easily derived with available information. Other metrics would be more challenging to calculate or less relevant to salmon.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Water extraction*	Volume of surface water licensed (e.g., m^3 / year) or volume as a proportion of total yield summarized by waterbody (or sub-basin), consumptive (domestic, waterworks, industrial, and irrigation) vs. non-consumptive water uses (power generation, storage, and conservation), and year of issue. (Woodward and Healey 1993; Province of British Columbia 2000, 2002; Rood and Hamilton 1995a, 1995b,1995c, 1995d; Hatfield 2007).	No appropriate benchmarks identified. Recommend first exploring development of Category 4 – benchmark using comparisons to other watersheds, where watersheds can be ranked based on the proportion of available supplies allocated to consumptive uses. Where discharge data area available over multiple years, Category 6 – probabilistic benchmarks could be used to determine variation in proportion of consumptive use across years. A second approach would be to develop Category 3 – benchmarks using comparisons over time to allow for reference to years when freshwater productivity was higher and consumptive water use may have been different.	Although there are concerns that water license information doesn't accurately represent the timing of water extraction and magnitude of actual withdrawals, a metric of allocated water use would be most informative for managers, and relatively easy to summarize with available data. Some questions remain about how the specific metric would be calculated (e.g., by consumptive-non-consumptive water uses or by type of water use). Groundwater extraction cannot be described with the same level of detail as surface water licensing. Regardless, water extraction metrics should include a measure of groundwater withdrawal. Although less informative than metrics of surface water extraction, a simple measure like the number of wells is available from existing data.
	Number of wells summarized by waterbody (or sub-basin), consumptive (domestic, waterworks, industrial, and irrigation) vs. non-consumptive water uses (power generation, storage, and conservation), and year of issue (Woodward and Healey 1993)	No appropriate benchmarks identified. Recommend developing Category 4 – benchmark using comparisons to other watersheds, where Conservation Units / watersheds can be ranked based on the number of wells allocated to consumptive water uses.	
Channel stability	Proportion of stream with disturbed stream channel (e.g., km disturbed / km stream length). (MOF 2001; Tripp *et al.* 2007; MOF and MELP 1996; UBC Sustainable Forest Management Research Group no date)	No appropriate benchmarks identified. Recommend developing Category 4 – benchmark using comparisons to other watersheds, where watersheds can be ranked based on the proportion of stream network with a disturbed channel.	Stream channels are naturally dynamic. Thus, there is a need to account for other factors affecting significance of channel disturbance, specifically the direction of disturbance (aggrading or degrading), severity of disturbance (severe or moderate), and channel type (channel gradient, bankfull width, and morphology). This metric is of interest on alluvial streams only. Calculation of this metric is not trivial; it requires aerial photo interpretation and field assessments. Such assessments were conducted during the Watershed Assessment Procedures (MOF 2001).

	Recommendation		
Indicator	Related metric(s)	Related benchmark(s)	Rationale for recommendation
Stream discharge*	<u>Magnitude of flow events</u> (e.g., m^3/s of peak or low flows, monthly mean flows, mean 7-day low flow event, average winter or summer flow, flow as a percentage of mean annual flow, mean annual discharge (MAD)) (Richter *et al.* 1996, 1997, 2003; Rood and Hamilton 1995a, 1995b,1995c, 1995d)	Generally recommend benchmarks for survival of aquatic life (Richter *et al.* 1997): • 10% MAD minimum instantaneous flow for survival of most aquatic life (though 20% of MAD has been recommended as a minimum instream flow requirement for some streams in BC: e.g., Nicola (Kosakoski and Hamilton 1982) and Englishman Rivers (Wright 2003)) • 30% MAD to sustain good quality habitat • 60-100% MAD to sustain excellent quality habitat • 200% MAD for flushing flows These benchmarks fit generally within <u>Category 1</u>. We recognize that discharge strongly affects accessibility and suitability of salmon habitats, which will vary significantly across different watersheds. Therefore, it is recommended that these benchmarks not be used without careful consideration of instream flow requirements in a particular watershed. Where discharge data area available across seasons for multiple years we recommend using <u>Category 6</u> – probabilistic benchmarks to determine frequency with which flow events would be exceeded in specific streams.	Recommended metrics capture 3 of 4 general characteristics (e.g., magnitude, timing, and frequency of flow events) of a flow regime as recommended by Richer *et al.* (1996; 1997). Critical flow events of interest to salmon worth capturing in a magnitude metric include: (i) peak flows and potential for scouring of incubating eggs in coastal (or managed) streams, (ii) low summer flows in coastal and interior streams (affecting rearing juveniles and adults), (iii) low winter flows in interior streams (affecting incubating eggs), and (iv) flushing flows for downstream migration of smolts. Benchmarks for discharge are not trivial to develop as they require site-specific information about habitat availability. Site-specific methods are available to develop instream flow thresholds in BC (e.g., Hatfield *et al.* 2003). It seems unlikely that these methods can practically be applied across all streams of interest, however.
	<u>Timing of flow events</u> (e.g., date of peak or low flows). Emphasis would be to focus on events occurring during critical salmon periods (e.g., egg incubation, adult migration))) (Richter *et al.* 1996, 1997, 2003)	<u>No appropriate benchmarks identified</u>. Timing of life history events varies significantly across salmon stocks (see Groot and Margolis 1991). Thus, it is difficult to specify timing windows within which optimal flow conditions should be available. These need to be specified for each stock / Conservation Unit. Where discharge data area available over seasons for multiple years we recommend use of <u>Category 6</u> – probabilistic benchmarks to determine variation in timing of flow events and their coincidence with critical life history events.	
Large woody debris and in-stream cover	<u>Fish cover diversity</u> (e.g., number of types present) (Tripp and Bird 2004)	Recommend identified thresholds for functioning condition from Tripp and Bird 2004: • proper: > 3 habitat types • at risk: 3 habitat types • at high risk: 2 habitat types • non-functional: <2 habitat types Basic habitat types include: overhanging vegetation within 1 m of the channel surface; overhanging LWD; in-channel LWD; stable small woody debris (SWD); stable undercut banks; non-embedded boulders and cobbles that are stable at high flows; deep, quiet water; and aquatic vegetation.	This metric reflects a measure that could be derived using a variety of available data sources. Other measures of large woody debris abundance and loading may be more strongly linked to salmon, yet require more onerous field data collection and may not currently be available with existing data sources.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Accessible stream length, barriers	Linear length of streams accessible to salmon (km of accessible streams grouped by species-habitat uses, if available)	Not relevant	An analysis of the 1:20,000 Corporate Watershed Base (new version of provincial 1:50,000 Watershed Atlas) using known / modelled distribution of salmon species and the Fish Barrier database could be used to calculate a linear extent of accessible stream habitats. If available in the future, river-specific habitat capacity / habitat quality models could be used to group accessible stream length according to the potential uses of those habitats.
Accessible off-channel habitat area	Total accessible off-channel habitat area (km^2) or number of accessible off-channel habitat areas	Not relevant	Quantifying extent accessible off channel habitats is difficult due to the dependence on water levels and local off-channel elevation. Water management, flooding events, or water withdrawals can affect inundation of off-channel areas and area of useable habitats. Thus, a more feasible metric to may be the number of accessible off-channel habitat areas, where only presence/ absence of water connectivity is identified. Selection between these metrics depends on the resolution and frequency of data being collected, which are uncertain at this time.

Table A14.2. Table from Nelitz *et al.* (2007b) Recommendations for metrics and benchmarks associated with LAKE habitat indicators. Indicators with an asterisk refer to those listed in the basic (*) or ideal (**) options presented in Appendix R.

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
Invasives	Non-native species and respective status index (Status categories: I) Alien – present but do not form self-replacing populations; II) Naturalised - alien species that reproduce consistently and sustain populations over several generations but do not necessarily invasive; III) Invasive - naturalized species that produce reproductive offspring in very large numbers and able to spread over large area; IV) Transformer - invasive species that change the character, condition, form, or nature of ecosystems over a substantial area relative to the extent of that ecosystem) (e.g., Number of species in each status category) (e.g.,, $N = N_{III} + N_{IV}$) (McGeoch *et al.* 2006). See Appendix A for a worked through example of how this indicator might be implemented.	No appropriate benchmarks identified. Recommend developing a Category 3 – benchmarks using comparisons across lakes. The intention would be to identify what current watersheds are most susceptible to invasive species (e.g., the greater the rate of increase in N, the greater the probability that type III or IV will become established), as well rank watersheds based on the number of invasive species of severe consequence. A second option would be to develop Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be new extensive surveys that would have yet to be undertaken by the province, and the limited, localized invasives plant species mapping that has been undertaken in terrestrial ecosystems to date within the province. May be possible (with additional research) to develop a Category 1 type indicator (based on dose-response relationship) through development of a Proper Functioning Condition indicator as outlined in Tripp and Bird 2004.	The recommended metrics captures the spatial extent of invasive species population and respective disruption of ecosystem function within a watershed as well as the risk posed by the types of invasive species present. The latter is important because it has the ability to act as a warning flag when a status III or IV invasive is identified within a watershed but has not yet reached a spatial extent of concern as outlined under the functioning condition thresholds. Recommended metrics can be calculated with available data for those areas where data exists (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate as they require extensive field data collection.
	Total expanse of land covered by alien plant species (e.g., % of total area per land or ecosystem type inhabited by invasive) (Tripp and Bird 2004; The Heinz Center 2002)	Recommend thresholds for functioning ecosystem condition as identified by Tripp and Bird 2004: • Proper functioning condition: < 5 % • At risk functioning condition: 5-25 % • At high risk functioning condition: 26 – 50 % • Non functioning condition: > 50 % This benchmark would fit with Category 1 – benchmarks based on dose-response relationship.	

	Recommendation		
Indicator	Related metric(s)	Related benchmark(s)	Rationale for recommendation
Sediment	Total suspended sediments (TSS) (e.g., mg/L, ppm) (EIFAC 1964; DFO 2000)	Use thresholds for total suspended sediments as identified by EIFAC 1964: • < 25 parts per million (ppm) of suspended solids - no evidence of harmful effects on fish and fisheries; • 25 - 80 ppm - it should be possible to maintain good to moderate fisheries, however the yield would be somewhat diminished relative to waters with <25 ppm suspended solids; • 80 - 400 ppm - these waters are unlikely to support good freshwater fisheries; and • 400 ppm suspended solids - at best, only poor fisheries are likely to be found. This benchmark would fit within Category 1 – benchmarks based on dose-response relationships. Where TSS data are available across seasons / years, supplement use of thresholds with Category 6 – probabilistic benchmarks to determine likelihood of exceeding thresholds across years / seasons given variation in discharge (e.g., Perry 2002).	These two metrics relate to different effects on salmon. Suspended sediments can smother eggs during incubation, and affect use / survival of habitat for rearing juveniles. Additional sediment input during summer months is of particular concern for lake systems characterised by high summer turbidity and TSS due to glacial runoff (Young and Woody 2007). These metrics would be measured using different field sampling protocols. Other metrics are more indirect measures of effects on salmon. A TSS metric can be more easily calculated with available data than substrate composition (see Nelitz *et al.* 2007a – Appendix A).
	Substrate composition (e.g., % of substrate particles < 6.35mm) (DFO 2002; Kondolf 2000; Lisle 1989; BC MOE 2006a)	Common standards identified to protect aquatic life in freshwater (CCME 1999 in DFO 2002; Kondolf 2000; Lisle 1989): • fines not to exceed 10% with less than 2mm diameter, 19% as less than 3mm, and 25% less than 6.35mm at salmonid spawning sites This benchmark would fit within Category 1 – benchmarks based on dose-response relationships.	
Water chemistry*	Nitrogen to phosphorous ratio (N:P ratio) (Wilson and Partridge 2007)	For aquatic life in freshwater • N:P ratio < 16 may indicate nitrogen-limitation whereas an N:P ratio > 16 may indicate phosphorus-limitation in freshwater systems (Wilson and Partridge 2007) Recommend developing Category 2 – benchmarks using ranges of natural variation taking into account lake trophic type. Intention would be to identify areas / years that are nutrient deficient and could be supplemented using lake fertilisation or nutrient overloaded. Management focus could be to maintain nutrient subsidies to important areas that nutrient deficient and to mitigate excess nutrient input from anthropogenic activities.	These metrics are those water chemistry attributes that are either most strongly affected by or most affecting salmon. Adult salmon provide an important marine nutrient subsidy to freshwater and terrestrial environments (Gende *et al.* 2002). Monitoring nitrogen and phosphorous concentrations for optimal lake productivity will be especially important for systems identified to be heavily reliant on marine derived nutrients and are currently experiencing declines in returning spawner abundance. Currently, the objective of the lake fertilisation program is to double the productivity of existing plankton communities in nutrient deficient lakes (DFO 2007b). In so doing 8-12 L of are added per hectare of lake surface area nutrients (nutrient mixture used is lake dependent) (DFO 2007b). Since 1985, the nutrients used have been a mixture of urea ammonium nitrate (32-0-0 or 28-0-0) for nitrogen deficient lakes and ammonium polyphosphate (10-34-0) for phosphorus deficient lakes (MacKinlay and Buday no date). Nutrient lake
Water chemistry*	Total phosphorous (e.g., µg/L) (BC MOE 2006a; Gregory-Eaves *et al.* 2004; Johnston *et al.* 2004; Shortreed *et al.* 2001)	Recommend range of total phosphorus in freshwater from BC MOE 2006a: • 5 to 15 µg/L (inclusive) This benchmark would fit within Category 1 – benchmarks based on dose-response relationships. Management focus could be to address lakes that are continually eutrophic due to anthropogenic activities.	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
	<u>Dissolved oxygen</u> (e.g., usable volume of water in littoral zone with suitable concentration of dissolved oxygen, mg/L O_2, usable volume of water in pelagic zone with suitable concentration of dissolved oxygen, mg/L O_2,) (Hyatt *et al.* 2007)	Recommend thresholds used for protection of aquatic life in freshwater from BC MOE 2006a: • Instantaneous minimum of 5 mg/L, 30-day mean of 8 mg/L within water column for all life stages (other than buried embryo / alevin) These thresholds are consistent with <u>Category 1</u> – benchmarks based on dose-response relationships.	concentrations are affected by discharge, terrestrial inputs, and atmospheric deposition of nutrients, therefore frequency of treatment is also lake specific. Dissolved oxygen is critical to the survival and development of eggs and juveniles. The useable volume of water with suitable concentrations of dissolved oxygen for stage 2 of the sockeye life cycle provides a measure for a lakes capacity to house fry and parr (i.e., the greater the useable volume the greater the area fry and parr can inhabit).
Riparian disturbance	<u>Proportion of stream length with disturbed riparian zone</u>, accounting (using groupings or weightings) for differences in (MOF 2001; Caslys 2007; Province of British Columbia 2000, 2002; NOAA 1996): • potential for sediment contributions based on upslope (e.g., >60% or ≤60%) or channel gradient adjacent vegetation type (e.g., Biogeoclimatic zone) • stream order (recognizes river continuum concept, Vannote *et al.* 1980) • type of disturbance (e.g., variable retention, selective logging, recently harvested, recently burned, urban, agriculture)	<u>Functioning condition</u> (NOAA 1996) • proper: < 20 % disturbed and > 50% of riparian vegetation similar to natural community composition • at risk: 20-30% disturbed and 25 -50% of riparian vegetation similar to natural community composition • non functional: > 30% disturbed and <25% of riparian vegetation similar to natural community composition. These thresholds are consistent with <u>Category 1</u> – benchmarks based on dose-response relationships.	Metrics should account for the variation in the function of riparian areas across a watershed (e.g., Hughes *et al.* 2004) by accounting for lateral distance of disturbance from shore, riparian vegetation type, vegetation cover, and terrain slope. Accounting for these factors recognizes differences in riparian function across a watershed, ecosystems or disturbance types. A watershed disturbance index integrating multiple habitat indicators may be the most simple / informative way of accounting for several human disturbances (riparian disturbance, road development, impervious surfaces, and land use cover). A quantitative metric evaluation / selection process would help develop such an index (see recommendations). Where fine scale information on disturbances and vegetation type are not available, a % vegetation cover can function as a substitute metric. Both metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses.
	<u>Vegetative cover</u> (e.g., % vegetative cover present in riparian zone. Vegetative cover is not the inverse of bare ground, but the inverse of bare ground directly exposed to the sky.) (Tripp and Bird 2004; NOAA 1996)	Recommend thresholds for functioning ecosystem condition as identified by Tripp and Bird 2004: • Properly Functioning Condition: > 95 % • Functioning, but at Risk: 86 – 95 % • Functioning, but at High Risk: 75 – 85 % • Non Functioning: < 75 % This benchmark would fit with <u>Category 1</u> – benchmarks based on dose-response relationship.	

	Recommendation		
Indicator	Related metric(s)	Related benchmark(s)	Rationale for recommendation
Recreational pressure*	Lake access (e.g., Proximity of a lake to a road (km), proximity of a lake to an urban center (km), number of access points) (Trombulak and Frissell 2000; Hart 2006)	No appropriate benchmarks identified. Recommend developing Category 4 – benchmark using comparisons to other watersheds. The intention would be to identify what watersheds have the most accessible lakes and are therefore the most likely to have greater recreational activity. Watersheds can then be ranked accordingly. Alternatively, the rate of increase in lake accessibility could be used, where watersheds that have the greatest rate of increasing lake accessibility are flagged for management action	Recreational pressure is a function of several things including the physical (e.g., scenic appeal) and structural (e.g., accessibility, facilities) characteristics of the landscape as well as the recreational activities that it supports. To accurately capture recreational pressure the use of a combination of metrics is recommended. These metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A) Other identified metrics such as number of visitors per day would be useful in determining realized pressure on a lake, however this data is not available province wide.
	Recreation Feature Inventory (RFI) (e.g., catalogue biophysical, cultural and historic landscape features by watershed and assesses the recreational value of these features using a standard set of inventory procedures. Will take into account: recreation features; recreation activities that are associated with those features; the significance of the features and the associated activities, and the sensitivity of those features to development or recreation use (MOF 1998). See page 97 in Nelitz *et al.* 2007a for description.	No appropriate benchmarks identified. Recommend developing Category 4 – benchmark using comparisons to other watersheds. The intention would be to rank watersheds according to their recreation appeal and potential.	
Watershed: Land cover alterations*	Percent by land use: sum of the area of all patches of a particular type divided by total area of the basin, including: agriculture, urban development, harvested, burned / diseased, mining, rangeland, landslides, undisturbed. Could also group land uses / patch types using more meaningful classes that more strongly link to watershed-stream processes affecting salmon (e.g., % impervious area, % semi-impervious, % forested, % grass, % exposed). (MOF 2001; UBC Sustainable Forest Management Research Group no date; Caslys 2007; Bradford and Irvine 2000)	No appropriate benchmarks identified. Recommend developing Category 4 – benchmark using comparisons to other watersheds, where Conservation Units or watersheds can be ranked by land use type or total land use. Top ranked Conservation Units / watersheds in each category could be targeted for management action. Best approach would be to categorize land uses on the basis of their effects on stream-watershed processes (i.e., using categories of impervious area, semi-impervious, forested, grass, exposed, etc.). In addition, watersheds or CUs could be ranked according to the rate of increase of the more deleterious land use types (e.g., rate of increase of logged area).	Recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. Thresholds for land use types are extremely difficult to identify because there is a linear relationship between land use types and deleterious effects on salmon (Mike Bradford, Fisheries and Oceans Canada, pers. comm.). Noteworthy is the study by Alberti *et al.* (2007) which hypothesized that multiple measures of landscape disturbance (land cover composition, configuration, and connectivity of impervious area) affect the biophysical environment. These other measures may be worth exploring. A watershed disturbance index integrating multiple habitat indicators may be the most simple / informative way of accounting for several human disturbances (riparian disturbance, road development, impervious surfaces, and land use cover). For instance, Fore (2003) noted that integrated measures of disturbance were better

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
	<u>Equivalent clearcut area (ECA)</u>: area harvested, cleared, or burned with consideration given to silvicultural system, regeneration, and location (i.e., elevation) of disturbance within watershed (MOF 2001; UBC Sustainable Forest Management Research Group no date; NOAA 1996; Reksten 1991; Stednick 1996)	Functioning condition as identified by NOAA 1996: • proper: < 15 % ECA with no concentration of disturbance in unstable or potentially unstable areas • at risk: < 15 % ECA with concentration of disturbance in unstable or potentially unstable areas • non functional: > 15 %ECA and disturbance concentrated in unstable or potentially unstable areas These benchmarks fit generally within <u>Category 1</u> – benchmarks based on dose-response relationships	predictors of biological responses than a single measure of disturbance. In other words, there were many correlations among different disturbance metrics. A measure of Equivalent Clearcut Area is somewhat redundant with a measure of proportion of harvested area (implied in the first metric). It is included here because it is a more accurate and common measure of peak flow hazard in harvested watersheds.
Watershed: Hard surfaces*	<u>Total impervious surface cover (ISC)</u> (% of land covered with buildings, concrete, asphalt, and other "hard," or impervious, surfaces) (The Heinz Center 2002; Paul and Meyer 2001; Guthrie and Deniseger 2001; Booth *et al.* 2002)	<u>Not specified</u> Benchmarks drawn from Paul and Meyer 2001, Guthrie and Deniseger 2001, UBC 2004, Klein 1979, Booth *et al.* 2002. • 10-20% impervious surface cover (ISC) results in rapid degradation of aquatic systems • 2-6% ISC marks a threshold for changes in geomorphology of streams: • > 10 % ISC negatively affects fish diversity • rapid decline in biotic diversity where watershed imperviousness exceeded 10 % • maximum of 10% ISC and minimum of 65% forest cover (Booth *et al.* 2002) General consistency across many paper in North America on this range (summarized in Paul and Meyer 2001) <u>Functioning Condition</u> (Smith 2005) • good: < 3% ISC • fair: 10% ISC • poor: > 10% ISC	The recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). One of the most consistent and pervasive effects associated with urbanisation and development is an increase in impervious surface cover within watersheds thereby altering the hydrology and geomorphology of water systems (Paul and Meyer 2001). Consequently, total impervious surface cover acts as good indicator of the extent of urbanization and development and the increased loading of nutrients, metals, pesticides, and other contaminants to waterways that are associated with development.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Watershed: Road development*	Road density (length per unit area, e.g., km / km^2) (MOF 2001; Bradford and Irvine 2000; Chu *et al.* 2003; Forman and Alexander 1998; NACSI 2001; Nelitz *et al.* 2007; Sharma and Hilborn 2001; Province of BC 2002; Alberti *et al.* 2007; UBC Sustainable Forest Management Research Group no date; NOAA 1996)	Functioning condition (NOAA 1996): • Properly functioning: < 1.24 km/km2, no valley bottom roads • At risk: 1.24 – 1.86 km/km2, some valley bottom roads • Non functioning: > 1.86 km/km2, many valley bottom roads These benchmarks fit generally within Category 1 – benchmarks based on dose-response relationships	Recommended metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A) and have been commonly applied in other studies. Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. We recognize road density and road-stream crossing density may be correlated. Both have been included because each relate differently to impacts on salmon habitats. When calculating a road density metric, it is generally recognized as important to distinguish between paved, unpaved, and deactivated roads; each affect habitats differently. NCASI (2001) recommends further research around developing indices of road disturbance and targets for management. Gucinski *et al.* (2001) provides a good technical synthesis about the effects of roads, while also recommending further work around developing benchmarks. Thus, it will be difficult to develop scientifically defensible thresholds. Similar to the above pressure indicators, a watershed disturbance index integrating multiple habitat indicators may be the most simple / informative way of accounting for several human disturbances (riparian disturbance, road development, impervious surfaces, and land use cover). A quantitative metric evaluation / selection process would help develop such an index (see recommendations).
	Road proximity (number of roads within given distance of a lake (e.g., # of roads within x km of lake), road area within a given distance of a lake (e.g., km^2 of road within x km of lake)	No appropriate benchmarks identified. Recommend first exploring development of Category 1 – benchmarks based on dose-response relationships between road proximity and habitat / biological responses. Although more defensible, development of this type of benchmark could require substantial data analysis. A second option would be to develop Category 4 – benchmarks using comparisons across watersheds / Conservation Units. Areas with the highest road densities could be targeted for management action. Alternatively, the rate of increase in the number of roads or road area within a specified area surrounding a lake could be used, where lakes that have the greatest rate of road increase within the immediate surrounding areas are flagged for management action.	
Lake foreshore development	Foreshore development by type (e.g., length and/or area of lake foreshore altered for human purposes) (Beeton *et al.* 2006)	No appropriate benchmarks identified. Recommend first exploring development of a Category 1 – benchmarks based on dose-response relationships between surrounding land use types and lake habitat / biological response. Although more defensible, this type of benchmark could require substantial data collection and analysis. A second option would be to develop Category 4 – benchmarks using comparisons across watersheds / Conservation Units. Areas with the highest incidence of or rates of increase in land use types that deleterious affect lake quality could be flagged for management action.	Little information and data exist documenting the impact of foreshore development on lake function, consequently it is difficult to identify appropriate metrics. Given what information on lake - foreshore interaction is available two metrics are recommended. Monitoring extent of foreshore development by type provides a high level picture of surrounding land use activities and associated consequences of these activities (e.g., agricultural run-off, urban run-off, sediment from logged slopes). Shoreline hardening on the other hand provides information on structural modification made to

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Lake foreshore development	Shoreline hardening (e.g., extent or % of hardened shoreline, number boat launches per km, number of retaining walls and type, number of gryones per km, number of docks per km) (Magnan and Cashin 2005)	No appropriate benchmarks identified. Recommend first exploring development of a Category 1 – benchmarks based on dose-response relationships between shoreline hardening and habitat / biological response. Although more defensible, this type of benchmark could require substantial data collection and analysis. A second option would be to develop Category 4 – benchmarks using comparisons across watersheds / Conservation Units. Areas with the highest incidence or rates of shoreline hardening could be targeted for management action.	the shoreline that can result in disruption of lake sediment transport and degradation of riparian habitat (EC and US EPA 2005). Combined, these two metrics capture the direct and indirect effects of foreshore development. Foreshore development by type and shoreline hardening could be determined using satellite imagery; however the types of analysis required have not yet be undertaken and would consider considerable effort. Alternatively, it may be possible to assess shoreline hardening by compiling information from the permitting departments in each region as a permit is often required to build a concrete structure, dock, boat launch, etc. (Chris Perrin, Limnotek, pers. comm.)
River deltas	River delta area (e.g., m^3 or km^3)	No appropriate benchmarks identified. Recommend developing a Category 2 – benchmark using ranges of natural variation. For example, acceptable fluctuation in river delta area can be set within a certain range of the average annual area.	Although presence / absence of river deltas was suggested as a possible metric, it is not being recommended because of its lack of responsiveness to environmental change and ability to inform management action in a timely fashion. A preferable alternative is river delta area (analogous to estuary area). This metric will require new data collection or analysis of satellite imagery as no data are currently available. Monitoring river delta area can provide insight into lake levels, water inflow rates, and fish habitat.
Water temperature	Daily average epilimnetic temperature (i.e., surface temperature) (Shortreed *et al.* 2001; Department of Environmental Quality [Oregon] 2006)	Protection of freshwater aquatic life in lakes (Department of Environmental Quality [Oregon] 2006) • Natural lakes may not be warmed by more than 0.3 degrees Celsius above the natural condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life (Department of Environmental Quality [Oregon] 2006) • ± 1 degree Celsius change from natural ambient background (BC MOE 2006a)	Richter and Kolmes (2005) recognize that temperature criteria should consider relevant life stages, waterbodies, and times of year for Pacific salmon. Where thermocline temperature data is available the usable volume of water for Stage 1 and 2 should be used as metrics as they provides a more accurate picture of a lakes capacity to support salmon. Where this type of data is not available, the simpler metric of daily average epilimnetic temperature is recommended. The latter metric can give an idea of temperature trends where long time series are available.
	Total useable volume of water with suitable temperature ranges (for Stages 1 and 2 respectively) (Hyatt *et al.* 2007)	Upper optimal temperature criteria for SK (BC MOE 2006a; Richter and Kolmes 2005; Newell and Quinn 2005) • Spawning and incubation 13ºC • Juvenile rearing 15ºC • Adult (holding for sexual maturation) 13ºC	

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
Wetland disturbance**	Ratio of wetland area to watershed area (Fennessy *et al.* 2004)	No appropriate benchmarks identified. Recommend first exploring development of Category 3 – benchmarks using comparisons in time where the base year for comparison would be prior to settlement and developments following the mid 1800s. Where this is not possible the year of the most historical wetland inventory should be used as a benchmark. Subsequently, a Category 4 – benchmarks using comparisons across watersheds / Conservation Units can also be developed allowing for units to ranked against each other with respect to the magnitude of change in the ratio relative to historic records. Areas with the greatest degree of negative change in the ratio (i.e., wetland area decreasing relative to watershed area) could be targeted for management action.	Recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A). Other identified metrics would be more difficult to calculate and it is uncertain if they would be more strongly related to biological or habitat responses. Quantifying wetland area by type is a valuable metric because some wetland types are more beneficial to salmon by virtue of the type of habitat they provided, their connectivity to streams and lakes, and the rate of transfer of dissolved organic matter to stream and lake systems (Henning *et al.* 2006). Ratio of wetland area to watershed area on the other hand provides a high level picture of the overall status of wetlands in a watershed and can be used as a basis of comparison between watersheds to indicate which wetlands are being disturbed.
	Total wetland area by type (e.g., acres or km^2) ((Fennessy *et al.* 2004; Maryland DOE 2007)	No appropriate benchmarks identified. Recommend first exploring development of Category 4 – benchmarks using comparisons across watersheds / Conservation Units. Areas with the lowest wetland area could be targeted for management action. A second option would be to develop Category 3 – benchmarks using comparisons in time where the base year for comparison. Where this is not possible the year of the most historical wetland inventory should be used as a benchmark.	
Accessible shore length	Total shore length not blocked by barriers (e.g., docks, riprap, boat launches, retaining walls, etc.,) (km)	Not relevant	Little data on accessible shore length exists for lakes in the province of BC. Suggestions to fill the data gap include QuickBird Satellite imagery, Foreshore Inventory Mapping, and regional district permitting applications for lakeside developments. Remote sensing done by BTM or BEI would not be able to capture the small scale of barriers along lake shores such as docks, rip rap, concrete breaks, etc.
Accessible off-channel habitat	Total accessible off-channel habitat area (km^2) or Number of accessible off-channel habitat areas	Not relevant	Evaluating accessible off channel habitats for lakes is difficult due to the dependence lake elevation. Water management, flooding events, or substantial water withdrawals could cause changes in lake water level, affecting access to off channel habitats. A snapshot in time of a lake is insufficient to capture time-dependent events. A more feasible metric to may be the number of accessible off-channel habitat areas, where only presence/ absence of water connectivity is monitored. The metric of choice will depend on the resolution and frequency of data collected, which are uncertain at this time.

Table A14.3. Table from Nelitz *et al.* (2007b) Recommendations for metrics and benchmarks associated with ESTUARY habitat indicators. Indicators with an asterisk refer to those listed in the basic (*) or ideal (**) options presented in Appendix R.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Disturbance of estuary foreshore habitats**	Proportion (%) of estuary foreshore developed or disturbed (FREMP 2006; BC MOE 2006b; CRIS 2002)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be extracted form the existing historical broadscale provincial surveys of foreshore and estuarine tenure status. Estuaries with the greatest rate of increase in disturbance to foreshore habitats could be flagged for management action (FREMP 2006; BC MOE 2006b; CRIS 2002). A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with the greatest extent of estuary foreshore development could be targeted for management action.	Recommended metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A) from different areas of the province and has a strong relationship with extent of overall development within an estuary (JNCC 2004).
Disturbance of in-shore habitats*	Proportion (%) of estuary intertidal habitat in different tenure categories (economic, conservation, and no designation) (BC MOE 2006b)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be extracted form the existing historical provincial database of estuarine tenure status. Estuaries with the greatest rate of increase in disturbance to in-shore habitats could be flagged for management action (BC MOE 2006b). A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with the greatest extent of disturbance to in-shore habitats could be targeted for management action.	Recommended metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A) from different areas of the province and has a strong relationship with extent of overall development within an estuary (JNCC 2004).
Disturbance of off-shore habitats*	Proportion (%) of estuary intertidal habitat in different tenure categories (economic, conservation, and no designation) (BC MOE 2006b)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be extracted form the existing historical provincial database of estuarine tenure status. Estuaries with the greatest rate of increase in disturbance to off-shore habitats could be flagged for management action. (BC MOE 2006b). A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with the greatest extent of disturbance to off-shore habitats could be targeted for management action.	Recommended metrics can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A) from different areas of the province and is related to the extent of overall development within an estuary.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Marine vessel traffic activity*	Vessel density (number of vessel movements per traffic reporting zone or per 5km x 5km grid cell) (BC MOE 2006b)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year(s) for comparison could be extracted form the Coast Guard's historical provincial database of marine vessel traffic densities for different regions of the BC coast. The rate of increase in vessel traffic per estuary or reporting unit could be used, where estuaries that have the greatest rate of increasing vessel traffic could be flagged for management action. (BC MOE 2006b). A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with the greatest extent of vessel traffic could be targeted for management action.	Recommended metric can be calculated with available data from different areas of the province. Estuaries with greatest densities of marine vessel traffic have elevated risks of environmental impacts, such as noise disturbance or emission of pollutants. Greater movement of shipping traffic carries the risk of introducing alien species on ship hulls or in ballast water.
Invasives	Occurrence and extent of non-native fish / invertebrate / microorganism species (total number of non-native species with established breeding populations per estuary and change in distribution (km^2)) (McGeoch *et al.* 2006; The Heinz Center 2002; NOAA 2007a)	No appropriate benchmarks identified. Recommend developing Category 4 – benchmarks. The intention would be to rank estuaries based on the number of invasive species of severe consequence.	The recommended metrics captures the spatial extent of invasive species population and respective disruption of ecosystem function within estuaries as well as the risk posed by the types of invasive species present. The latter is important because it has the ability to act as a warning flag when a invasive is identified within a watershed but has not yet reached a spatial extent of concern as outlined under functioning condition thresholds.
	Proportion (%) of estuary surface area covered by invasive plant species (The Heinz Center 2002)	No appropriate benchmarks identified. Recommend first developing Category 4 – benchmarks using comparisons across estuaries. Areas with the greatest extent of invasive estuarine plants could be targeted for management action. A second option would be to develop Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be new extensive surveys that would have to be undertaken by the province, and the limited, localized invasives plant species mapping that has been undertaken in provincial estuaries to date. Estuaries with the greatest rate of increase in particular invasive species could be flagged for management action. May be possible (with additional research) to develop a Category 1 type indicator (based on dose-response relationship) through development of a Proper Functioning Condition indicator as outlined for streams in Tripp and Bird 2004.	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Micro and macro algae	Occurrence, distribution and areal extent (m^2, km^2) of intertidal micro and macroalgal beds (Pickerell and Schott 2005; McGinty and Wazniak 2002)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year for comparison would be extracted form the existing one-time historical broadscale provincial survey of algae beds along BC's coastline, or from other more detailed algae mapping undertaken at different times for more localized areas. Estuaries with the greatest rate of decline of micro and macro algae beds could be flagged for management action (CRIS 2002). A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with the most limited extent of estuary micro and macro algae beds could targeted for management action (after accounting for natural factors affecting algae extent).	It should be noted that the extent and distribution of subtidal macroalgae can be highly variable naturally and respond to changing nutrients, habitat removal/disturbance, changing aquatic sediments, contaminants, freshwater flow regimes and pest species (Pickerell and Schott 2005). There are currently no set ecological quality objectives or standards for condition of macroalgae. Nor are there standard methods for monitoring macroalgae, although various combinations of aerial photography, remote sensing and measurements on the ground are used in different jurisdictions.
Aquatic invertebrates	Benthic infaunal abundance: total numbers of individuals (total abundance) and total number of species (taxa richness) per m^2 (Wilson and Partridge 2007) Benthic infaunal diversity: e.g., Shannon-Weaver diversity index (measure of community heterogeneity); Swartz's Dominance Index (number of invertebrate taxa comprising the most abundant 75% of individuals) (Wilson and Partridge 2007; US EPA 2007) Presence and abundance of pollution-tolerant species, and the presence and abundance of pollution-sensitive species (Lowe and Thompson 1997, US EPA 2007) or abundance and diversity of invertebrates in relation to invertebrate status at a reference site (Reference Condition Approach – RCA) (Sharpe 2005)	No appropriate benchmarks identified. Recommend developing Category 2 and Category 4 – benchmarks using ranges of natural variation and rank estuaries based on the abundance and diversity of aquatic invertebrates (particularly of taxa that are indicators of specific environmental conditions) and establish reference sites. This would require extensive new estuarine surveys of aquatic invertebrates by provincial agencies. A second option would be to develop Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be extensive surveys that would have to be undertaken by BC agencies. Any estuaries that then showed significant decline in benthic abundances and/or diversity could be flagged for management action.	Development of a standard protocol for monitoring invertebrates in estuaries presents a number of unique challenges. Estuaries vary greatly, in terms of physical structure (e.g., sediment type, depth), aspect (e.g., sheltered, exposed), hydrology (e.g., tidal range) and species composition. The metrics indicated here are commonly used for estuarine invertebrates. However it should be noted that metrics such as the number of taxa, total abundances, total biomass and diversity have several problems in their application. First, there are generally no guidelines as to which exact values one should expect from an ambient reference site (although once reference sites are identified using other indicators, ranges could be calculated). More importantly, those indicators are not usually linearly related to contamination (including organic enrichment). Instead, biological indicators, such as the number of taxa, total abundance, and biomass, are often higher in locations where there is moderate contamination. Here nutrient benefits may dominate over contaminant effects (provided that the contamination is not too high) and benthic populations increase and diversify. Monitoring of specific indicator taxa or assemblages may be more informative of changing estuarine conditions (Lowe and Thompson 1997).

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Sediment	<u>Total suspended sediments</u> (TSS) (e.g., mg/L, ppm) (DFO 2000; Wilson and Partridge 2007)	Use thresholds for total suspended sediments as identified by various sources (DFO 2000): • < 25 parts per million (ppm) of suspended solids - no evidence of harmful effects on fish and fisheries; • 25 - 80 ppm - it should be possible to maintain good to moderate fisheries, however the yield would be somewhat diminished relative to waters with <25 ppm suspended solids; • 80 - 400 ppm - these waters are unlikely to support good freshwater fisheries; and • 400 ppm suspended solids - at best, only poor fisheries are likely to be found. This benchmark would fit within <u>Category 1</u> – benchmarks based on dose-response relationships. Where TSS data are available across seasons / years, supplement use of thresholds with <u>Category 6</u> – probabilistic benchmarks to determine likelihood of exceeding thresholds across years / seasons given variation in discharge (e.g., Perry 2002).	Suspended sediments can affect use / survival of habitat for rearing juveniles or smolts. Other possible metrics are more indirect measures of effects on salmon.
	<u>Maximum induced increase in turbidity</u> (e.g., Nephelometric Turbidity Units, NTUs or % of background) (BC MOE 2006a; DFO 2000)	Use thresholds for turbidity as identified by various sources (BC MOE 2006a; DFO 2000): • 8 NTU in 24 hours when background is less than or equal to 8 • mean of 2 NTU in 30 days when background is less than or equal to 8 • 5 NTU when background is between 8 and 50 • 10% when background is greater than 50 This could fit within <u>Category 1</u> – benchmarks based on dose-response relationships after accounting for natural variation in estuarine turbidity levels.	Turbidity levels are usually much higher in estuaries than those in adjacent coastal waters. Most estuarine communities are used to turbid conditions and increases from man-induced sources are likely to be tolerated. However, increases in turbidity levels brought about by activities such as dredging and disposal may, under certain conditions, have adverse effects on filter feeding organisms, clogging feeding or respiratory structures. Increases in turbidity may also reduce light penetration through the water. This may reduce the growth rate of organisms dependent on sunlight for photosynthesis (JNCC 2004).
Water chemistry / quality	<u>Metals</u> (µg/g, mg/kg dry weight in sediment or µg/L in water) – e.g., key ones for tracking include aluminum, antimony, arsenic, cadmium, chromium, copper, iron, lead, mercury, manganese, nickel, silver, and zinc (Wilson and Partridge 2007; BC MOE 2006b)	Use thresholds for metals as identified by various sources (BC MOE 2006a; MacDonald *et al.* 2000): Various recommended maximum concentrations dependent on the particular metal evaluated e.g., mercury: maximum = 0.1 µg/L at any one time, or 30 day average of 0.02 µg/L These thresholds are consistent with <u>Category 1</u> – benchmarks based on dose-response relationships	The causal relationship between water quality parameters and observed biological changes in estuarine communities is often unclear or unknown. Acute effects in response to a known impact are often straightforward where there is mass mortality, but chronic effects from continued low exposure to a compound that lead to more modest physiological changes are difficult to detect (JNCC 2004). Pollutants such PCBs, polycyclic aromatic hydrocarbons (PAHs),

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
Water chemistry / quality	Polycyclic Aromatic Hydrocarbons (PAHs) (µg/L) (Wilson and Partridge 2007; BC MOE 2006b)	Use thresholds for PAHs as identified by various sources (BC MOE 2006a; MacDonald *et al.* 2000): Varied recommended maximum concentrations dependent on the particular PAH compound evaluated e.g., Naphthalene: maximum = 0.01 µg/g in freshwater or marine sediments These thresholds are consistent with Category 1 – benchmarks based on dose-response relationships	and metals such as mercury readily attach to sediment particles in water. They may settle to the bottom with the particles or be taken up by marine organisms, which pass the contaminants into the marine food chain. However it must be recognized that, the causal relationship between water quality parameters and observed biological changes in estuarine communities is often unclear or unknown. Acute effects in response to a known impact are often straightforward where there is mass mortality, but chronic effects from continued low exposure to a compound that lead to more modest physiological changes are difficult to detect (JNCC 2004). Nitrogen and phosphorus are water chemistry attributes most strongly affecting salmon. Concentrations will be affected by discharge, terrestrial inputs, and atmospheric deposition of nutrients. Dissolved oxygen is critical to the survival and development of developing smolts. There is a concern, however, that the data are not broadly available to calculate these metrics. A dedicated water chemistry monitoring program would be needed to capture these measures. However it must be recognized that patterns in water chemistry within estuarine systems are typically complex and dynamic. Concentrations at any given location in an estuary will be influenced by tidal state (which itself may vary due to meteorological conditions) and by changes in the discharge rate of the river. As well as gradients along the main axis of the estuary, there may be gradients across the estuary due to the influence on local water flow patterns (JNCC 2004).
	Polychlorinated Biphenyls (PCBs) (ng/L) (Wilson and Partridge 2007; BC MOE 2006b)	Use thresholds for PCBs as identified by various sources (BC MOE 2006a; MacDonald *et al.* 2000): • 0.1 ng/L PCBs (total) recommended maximum concentration These thresholds are consistent with Category 1 – benchmarks based on dose-response relationships	
	Total nitrogen (e.g., µg/L) (BC MOE 2006a; MacDonald *et al.* 2000; Wilson and Partridge 2007; LCREMP 2004)	No appropriate benchmarks identified for estuaries. Recommend developing Category 2 – benchmarks using ranges of natural variation.	
	Phosphorous (e.g., µg/L) (Wilson and Partridge 2007; LCREMP 2004)	No appropriate benchmarks identified for estuaries. Recommend developing Category 2 – benchmarks using ranges of natural variation.	
	Nitrogen to phosphorous ratio (N:P ratio) (Wilson and Partridge 2007)	For aquatic life in freshwater/estuaries • N:P ratio < 16 may indicate nitrogen-limitation in whereas an N:P ratio > 16 may indicate phosphorus-limitation in freshwater and estuarine systems (Wilson and Partridge 2007) Recommend developing Category 2 – benchmarks using ranges of natural variation. Intention would be to identify areas / years that are nutrient deficient and could be supplemented or else require mitigation of excess nutrient input from anthropogenic activities.	
	Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2) (BC MOE 2006a; Wilson and Partridge 2007; LCREMP 2004)	These thresholds consistent with Category 1 drawn from BC MOE 2006a; US EPA 2001; Wilson and Partridge 2007: • Instantaneous minimum of 5 mg/L, 30-day mean of 8 • mg/L in water column for all life stages (other than buried embryo / alevin) • system considered moderately hypoxic if DO is < 5 mg/L, and as severely hypoxic if DO < 2 mg/L	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Detrital organic matter	Total organic carbon (TOC) (%) in sediment (Wilson and Partridge 2007; LCREMP 2004)	Use thresholds for TOC as identified by various sources (BC MOE 2006a): • Recommended maximum: ± 20% change from the 30-day median background concentration Recommended minimums: none specified (locale dependent) This would fit within Category 1 – benchmarks based on dose-response relationships for maximum organic carbon levels. For minimum levels could be evaluated as Category 2 indicator. Intention in this case would be to identify areas / years that may be carbon limited, and could be targeted for enhanced management.	Sediments with high TOC are usually a rich food source for benthic invertebrates. However, organic carbon can sequester water-column toxicants in the sediment and can also mediate their bioavailability. TOC content is also to some degree substrate dependent with TOC commonly < 0.5% in sandy or gravelly areas, while in finer sediments TOC may be > 3% in nearshore areas (Wilson and Partridge 2007). A number of additional factors may influence estuarine nutrient levels, including tidal flushing rate of the estuary (which determines the retention time of nutrients within the system), seasonality (which influences the rate of nutrient uptake by actively growing organisms) and climatic factors (such as temperature and rainfall) (JNCC 2004).
	Flux of detrital organic matter (N,P,C) between marsh and other habitats (mg per m^2 per day, or kg per ha per day) (Kistritz *et al.* 1983)	No appropriate benchmarks identified. Recommend developing Category 2 – benchmarks using ranges of natural variation. Intention would be to identify areas / years that may be nutrient depleted, and could be targeted for enhanced management	
Eelgrass habitats**	Eelgrass distribution (e.g., m^2, minimum and maximum depth, patchiness index) (US EPA 2007; Sewell *et al.* 2001; Pickerell and Schott 2005)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year for comparison would be extracted form the existing one-time historical broadscale provincial survey of eelgrass along BC's coastline, or from other more detailed eelgrass mapping undertaken at different times for more localized areas. Estuaries with the greatest rates of decline in eelgrass habitat could be flagged for management action. (CRIS 2002) A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with limited extent of estuarine eelgrass beds could be targeted for management action (after accounting for natural factors affecting eelgrass distribution). Within this category the Canadian Wildlife has already ranked eelgrass rarity for 442 large estuaries along the BC Coast (Ryder *et al.* 2007).	Eelgrass distribution and condition are commonly used metrics in many jurisdictions but it should be noted that change in eelgrass distribution and/or condition will be influenced by a range of environmental stressors such as estuarine temperature, salinity, dissolved oxygen, pH, nutrients and turbidity (Sewell *et al.* 2001). Interactions with other biota can also affect eelgrass. For example, excess nitrogen in an estuary can generate blooms of both micro and macro algae that will shade eelgrass and cause mortality in the eelgrass population (Pickerell and Schott 2005)
	Eelgrass condition (e.g., mean shoot density, leaf area index) (US EPA 2007; Sewell *et al.* 2001; Pickerell and Schott 2005; NOAA 2007b)	No appropriate benchmarks identified. Recommend first exploring development of Category 4 – benchmarks using comparisons across estuaries.	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Eelgrass habitats**	Eelgrass rarity (q_i) For each estuary, a rarity score (q_i) for eelgrass is calculated based upon the species presence and estimated coverage within each of the province's shorezone mapping segments that are found within the particular estuary (Ryder *et al.* 2007).	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year for comparison would be extracted form the existing one-time historical broadscale provincial survey of eelgrass along BC's coastline. This information on eelgrass rarity from this mapped dataset has been extracted and summarized by the Canadian Wildlife Service in their Biophysical Assessment of Estuarine Habitats in British Columbia report (Ryder *et al.* 2007).	
Spatial distribution of wetlands / mudflats	Total area (ha) and proportion (%) of total estuarine area in different habitat type categories / classifications (LCREMP 2004 ; Bain *et al.* 2006; JNCC 2004)	No appropriate benchmarks identified. Recommend developing Category 3 – benchmarks using comparisons in time where the base year for comparison would need to be selected for a relevant period of pre-development and then habitat information determined from historical air photos or other imagery. Habitat types could be categorized and mapped and evaluated for change over time (as has been done by DFO for the Campbell River estuary)	Recommended metric can be calculated with available data (see Nelitz *et al.* 2007a – Appendix A), but requires extensive data workup of historical air photos. Assessment of change in this metric in the future would be much easier due to new advances and availability of remote sensed data.
Riparian vegetation**	Proportion (%) of estuarine riparian zone disturbed (CRIS 2002; FMEMP 2006)	No appropriate benchmarks identified. Recommend first developing Category 3 – benchmarks using comparisons in time where the base year(s) for comparison would be extracted from existing broadscale provincial surveys (CRIS) of shoreline riparian vegetation and other past localized surveys of riparian disturbance. Estuaries showing greatest increase in disturbance could be flagged for management action (CRIS 2002; FMEMP 2006). A second option would be to develop Category 4 – benchmarks using comparisons across estuaries. Areas with most limited extent of riparian vegetation could be targeted for management action (after accounting for natural factors explaining differences).	Recommended metrics can be calculated with available data for many areas of the province (see Nelitz *et al.* 2007a – Appendix A). Although fine scale information on disturbances and riparian vegetation type would be preferable, this broader % riparian vegetation cover can function as a substitute metric.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Resident fish	Fish species abundance (total numbers of individuals per tow) (with emphasis on demersal species) (Wilson and Partridge 2007; NOAA 2007b) Fish species richness and diversity (total number of species per tow or per m^3, Shannon Weaver Diversity Index) (Wilson and Partridge 2007; NOAA 2007b) Gross fish pathology (frequency of gross external pathologies - lumps, ulcers, growths, fin erosion and parasites) (Wilson and Partridge 2007).	No appropriate benchmarks identified. Recommend developing Category 3 – benchmarks using comparisons in time where the initiation date for these new surveys could provide the baseline for comparisons within different provincial estuaries. Estuaries with the greatest rate of decline in abundance and/or diversity of resident fish or showing greatest rate of increase in gross fish pathologies could be flagged for management action. Alternatively develop Category 4 – benchmarks using ranges of natural variation and rank estuaries based on new, extensive estuarine surveys of the abundance and diversity of resident fish species, as well as frequency of pathologies in sampled fish.	Repeated abundance and diversity surveys of resident fish populations are commonly undertaken as part of agency fish habitat monitoring programs in the US (e.g., Alaska Nearshore Fish Atlas). However, it must be recognized that fish abundance can vary widely both temporally and spatially and low catches of fish per unit effort may reflect only the natural variation within that habitat (Wilson and Partridge 2007). It may be best to focus pathology monitoring on demersal fish, including flatfish and species such as sculpins and some types of perch, which are in near-constant contact with the seabed and therefore, presumably, with any contaminants in the sediment. Abundance/condition of pelagic fish species are more difficult to relate to estuarine conditions.
Estuarine Habitat Area	Estuary size (ha) Estuary boundaries defined to include the intertidal (below coastline to lowest normal tide) and supratidal (above coastline) zones as well as habitat features connected to each river or stream above the coastline to an upstream distance of 500m (Ryder *et al.* 2007) Estuary Size Index (ESI) (normalized probit values of estuary size rankings were then scored on a scale of 0-100 as the proportion that each estuary site contributed relative to the highest and lowest probit scores) (Ryder *et al.* 2007)	Not relevant	Standardized methodologies for identifying estuaries and delineating the presumed extent of estuarine habitat area are already well developed and previously deployed by Environment Canada for the BC Coast (Ryder *et al.* 2007). This work should provide the foundation for any continued broadscale quantification or evaluation in this regard by DFO.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Accessible Off-channel Habitat	Total accessible off-channel habitat area (m^2 or km^2) Number of accessible off-channel habitats (#)	Not relevant	Evaluating the full extent of accessible off-channel habitats within estuaries will be difficult due to the interaction with water levels. Maps of estuaries based on a single snapshot in time will be insufficient to capture annual variation in flooded areas of the estuary that could provide off-channel habitats under different conditions. A more feasible metric may be to assess the potential off-channel habitat area using floodplain models based on contours and topographic features. Presumed access to these off-channel areas could then be monitored through presence/ absence surveys of water connectivity and associated presence/absence of associated barriers. The metric of choice will depend on the resolution and frequency of data collected.

APPENDIX 15

LINKAGES BETWEEN STRATEGY 2 ACTION STEPS (EXAMPLE)