Refining habitat indicators for Strategy 2 of the Wild Salmon Policy:

Identifying metrics and benchmarks

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Table of Contents

List of Tables

List of Figures

1. Introduction to habitat indicators and the Wild Salmon Policy

Canada's Policy for Conservation of Wild Pacific Salmon (a.k.a. the Wild Salmon Policy, WSP) was released in June 2005 (DFO 2005). The overarching goal of the Policy is to restore and maintain healthy and diverse salmon populations and their habitats. To help evaluate whether the Wild Salmon Policy is succeeding in this regard Fisheries and Oceans Canada (DFO) intends to use "habitat indicators" to assess and monitor the status of and pressures on stream, lake, and estuarine habitats in British Columbia and Yukon (see *Strategy 2 Assessment of habitat status* and *Action Step 2.2 Select indicators and develop benchmarks for habitat assessment* of the Wild Salmon Policy).

Habitat indicators can track habitat conditions over time and identify salmon habitats that are most productive, limiting, or at most risk of disturbance within Conservation Units (CU).[1] Indicators can also improve understanding of linkages among habitat pressures, habitat status, and management responses (e.g., conservation and restoration actions).

To-date, DFO's process for developing habitat indicators has followed the following three steps:

Step 1: **Indicator Compilation and Ranking:** The first task required developing a list of habitat indicators for streams, lakes, and estuaries used by volunteer groups, DFO, and other government agencies in the U.S. and Canada. Drawing upon the work from other researchers in the Pacific Northwest, DFO's Habitat Working Group (a group of managers and scientists) developed and ranked a preliminary list of habitat indicators based on the (i) number of other groups using / citing these indicators, and (ii) scientific relevance / strength of the linkage to key habitat attributes of interest.

Step 2: **Indicator Practical Assessment:** The second task involves assessing each indicator on the basis of a number of evaluation criteria (described further in Section 2): (i) data source, (ii) data availability, (iii) relative cost, (iv) spatial extent / resolution, (v) temporal extent / frequency, and (vi) scientific relevance (drawn from DFO's efforts in Step 1). This information was then used to identify a suite of indicators that could potentially be implemented by DFO (summarized in *Practical Assessment Report*, pages 31-32, Tables 9 and 10 in Nelitz et al. 2007a).

Step 3: **Indicator Metrics and Benchmarks:** The third step requires identifying alternative ways of measuring an indicator, termed a metric (e.g., mean annual discharge vs. peak annual flow). Associated with alternative metrics are benchmarks, maximum tolerable thresholds or ranges within which managers wish to maintain habitat conditions (e.g., optimal water temperature ranges), or below which managers wish to minimize pressures on habitats so as to avoid adverse effects (e.g., thresholds for equivalent clearcut area).

This report provides results from Step 3, *Identifying Metrics and Benchmarks* for habitat indicators being considered by DFO for Strategy 2 of the Wild Salmon Policy.

[1] Conservation Unit represents genetically similar interbreeding population(s) of salmon distributed across a defined geographic area (DFO 2005).

2. Steps to identifying metrics and benchmarks

To develop recommendations for metrics and benchmarks, we pursued the following three tasks.

2.1 Identify alternative indicator metrics

The full list of habitat indicators being considered by DFO for implementation under Strategy 2 of the Wild Salmon Policy is provided in Table 1. The first four indicators represent habitat quantity indicators which DFO has committed to providing under the Wild Salmon Policy. These indicators are not part of this research because metrics are self-evident (e.g., length of accessible stream length) and benchmarks could not be developed using this relatively simple technical review (e.g., among other factors benchmarks for habitat area would depend on quality of habitats, salmon population status, geographic location, and social values).

Using this list, our first task was to review the scientific / grey literature and identify habitat metrics for each indicator across three habitat types. A metric refers to the measurable form and specific units an indicator may take, such that a single indicator can be described using many alternative metrics. For instance, the indicator *stream discharge* can be described using alternative metrics representing the magnitude, timing, frequency, rate of change, and/or duration of flow events (e.g., Richter et al. 1996; Richter et al. 1997). This review focused on identifying metrics used in alternative (i) research papers, (ii) analytical studies, (iii) monitoring designs, or (iv) indicator reporting systems being applied across salmon habitats in the Pacific Northwest.

Another consideration is that different habitat metrics have different biological relevance. For example, *water temperature* in stream habitats may be represented by the maximum summer stream temperature (a measure representing thermal stress on juvenile coho or chinook in rearing environments) or accumulated thermal units (a measure reflecting time for egg development) (e.g., Nelitz et al. 2007b). Given such linkages, we used the conceptual diagrams (see Section 3) to consider the biological relevance of metrics identified during our review, and if possible documented the linkage with relevant species and life stages.

2.2 Identify alternative indicator benchmarks

Our review of the literature also provided guidance to identifying appropriate benchmarks for indicator metrics. Benchmarks "*reflect the desired values of each key indictor*" (DFO 2005). Benchmarks are clearly specified and quantitative values of a metric against which trends can be compared over time and space. They are important for providing context when interpreting an indicator; increasing trends may look promising, but without a standard, target, or baseline, it is difficult to know if a manager should be concerned or content with the trend of an indicator and the environmental aspect it represents.

We identified benchmarks for as many habitat metrics as possible; no benchmarks were available for many metrics. For other indicators (e.g., *water temperature*), a single benchmark was not available; multiple indicators were needed for different species / life stages of interest. Given differences in terrestrial and freshwater ecosystems across the Region, where possible, we also recommend that benchmarks be specific to geographic areas: coastal, interior, or northern environments (Figure 1).

Table 1. Estuary, lake, and stream habitat indicators being considered for Strategy 2 of the Wild Salmon Policy. Although not explicitly considered as an estuarine indicator, stream discharge is recognized as having an important influence on estuaries (denoted by *).

Indicator type	Indicator	Habitat type: Lake	Habitat type: Stream	Habitat type: Estuary	Example metrics and parameters of interest
Status	Estuarine habitat area			X	
Status	Accessible shore length, barriers	X			
Status	Accessible stream length, barriers		X		
Status	Accessible off-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 in-shore habitats			X	% surface area disturbed in-shore (e.g., eel-grass zone)
Pressure	Disturbance of off-shore habitats			X	% surface area disturbed off-shore / sub-tidal (e.g. log-booms)
Pressure	Marine vessel traffic activity			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., total suspended sediments also considers substrates for streams / lakes
Status	Water chemistry	X	X	X	e.g., nutrients, dissolved oxygen, pH, conductivity, or contaminants
Status	Detrital organic matter			X	flux of detrital organic matter (C,N,P) between marsh and other habitats
Status	Eelgrass habitats			X	extent of eelgrass
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 area various land cover alterations (e.g., forestry, agriculture, urban development)
Pressure	Watershed: Hard surfaces	X	X		% water- shed area 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 a % of mean annual discharge (e.g., surface water, groundwater)
Status	Channel stability		X		pool:riffle, width:depth ratios, etc
Status	Stream discharge		X	*	base and peak flows
Status	Large woody debris and in-stream cover		X		
	Total number of indicators by habitat type	14	15	16	

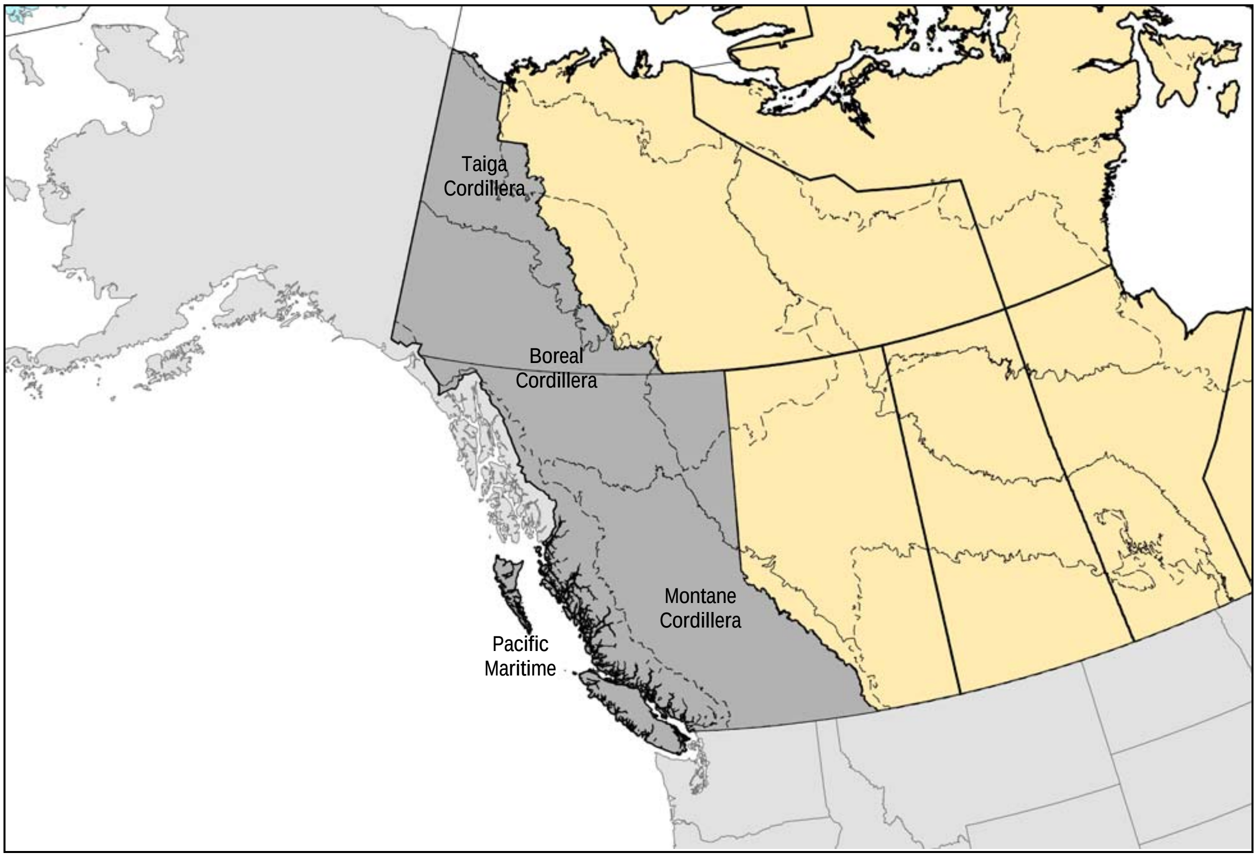

Figure 1. Map of northwestern North America including British Columbia and Yukon (DFO's Pacific Region) and proposed boundaries for coastal (Pacific Maritime), interior (Montane Cordillera), and northern environments (Boreal and Taiga Cordillera). Boundaries are based on a map of Canada's Ecozones (in parentheses above, thatched boundaries in figure, also see www.ccea.org/ecozones/) using spatial data downloaded from Geogratis (geogratis.cgdi.gc.ca/geogratis/en/).

2.3 Develop recommendations

We focused on four considerations when narrowing the long list of identified metrics and benchmarks to a shorter subset. A first emphasis was to identify metrics and benchmarks for those indicators having the greatest chance of being developed further (i.e., Type III indicators with appropriate data to generate metrics, or those listed under basic / ideal options in *Practical Assessment Report*). Second, we considered the biological relevance of a metric to ensure representation across all relevant species / life stages. Third, we considered the scientific defensibility / consensus around a benchmark, focusing on those for which there was greatest agreement. Finally, for those indicators where benchmarks were not readily available, we recommended one of six approaches to consider during future stages of work.

3. Linking habitat pressures, habitat status, salmon species, and life stages

Conceptual models were developed during earlier stages of work (pages 7-11, Figures 1-5, Nelitz et al. 2007a) to explicitly illustrate linkages among human actions (pressures), habitat condition (status), and mechanisms of life-stage specific salmon mortality (biological responses). Such models are consistent with the "*Pathways of Effects*" approach currently being applied by DFO[2] under its Environmental Process Modernization Plan (EPMP), and are advocated as an effective tool in managing fish habitats (e.g., Jones et al. 1996). The purpose of these diagrams is not to illustrate all possible cause-effect linkages, which can lead to confusing spaghetti-diagram. Rather, these diagrams are intended to focus attention on the cause-effect linkages of greatest importance for management decisions. Conceptual models provide a systems perspective of the linkages among physical, chemical, and biological components / processes in an ecosystem. Such a perspective is valuable because it: (i) provides a framework for summarizing the current "state of science" describing cause-effect linkages among indicators, (ii) improves clarity and transparency for discussions around indicators, (iii) ensures indicators are responsive to management actions, and (iv) helps ensure recommendations for indicators, metrics, and benchmarks are representative of habitat pressures and status for all relevant species and life stages. In the context of this report and related research these diagrams also help clarify the link between a metric of interest and salmon life stages. For instance, changes in water temperature (a habitat status indicator) may affect many salmon life stages (e.g., adult migration, egg incubation, juvenile rearing), each of which would be represented by a different metric of water temperature (e.g., maximum temperatures along migration corridors, accumulated thermal units over the incubation period, annual maximum temperatures in rearing environments).

Cause-effect linkages between habitat pressures, habitat status, and biological responses are unique to habitat types with different species of Pacific salmon using these habitats differently. Figure 2 provides an overview of how a sequence of habitat-specific conceptual models relates to each species across their life stages. For instance, lake-rearing sockeye salmon tend to use stream habitats for spawning (Figure 3), lake habitats for juvenile rearing (Figure 5), and estuary habitats (Figure 6) while transitioning between freshwater and marine environments.

Within these diagrams, cause-effect linkages are represented by a series of boxes and arrows illustrating interactions among system components. Indicators of habitat pressures are represented by dark red boxes, indicators of habitat status are represented by white or light grey boxes, and life stage responses are represented by dark grey boxes. Habitat indicators represented by grey boxes have been explicitly considered in DFO's list of indicators (Table 1), while white boxes represent intermediate linkages between this list of indicators and life stage responses. To illustrate, Figure 3 illustrates that *water extraction* (a pressure indicator) affects *stream discharge* (a status indicator). This linkage is supported by our understanding that the amount of water in a stream can affect adult spawners directly by modifying useable area of spawning habitats. Such an effect can alter spawning viability and ultimately salmon production. In addition, changes in stream discharge can also directly affect *water temperature* (another status indicator). In turn, changes in water temperature can affect adult migration, suitability of spawning habitats, as well as survival and development of eggs.

[2] Fisheries and Oceans Canada. Pathways of Effects. Available at: www.dfo-mpo.gc.ca/oceans-habitat/habitat/modernizing-moderniser/pathways-sequences/index_e.asp

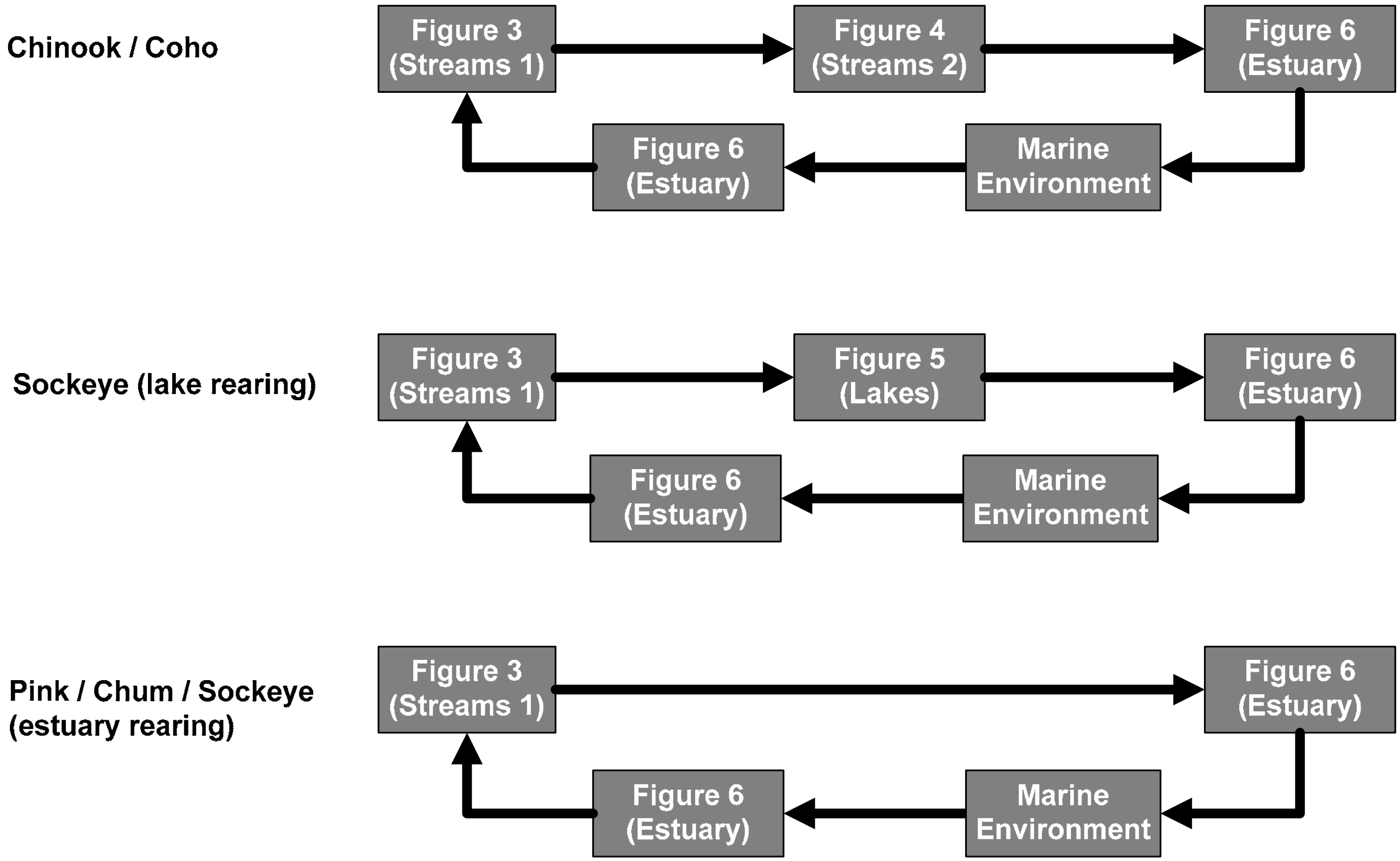

Figure 2. Overview diagram illustrating the transition among the habitat-specific conceptual models represented in Figures 3-6 for each salmon species.

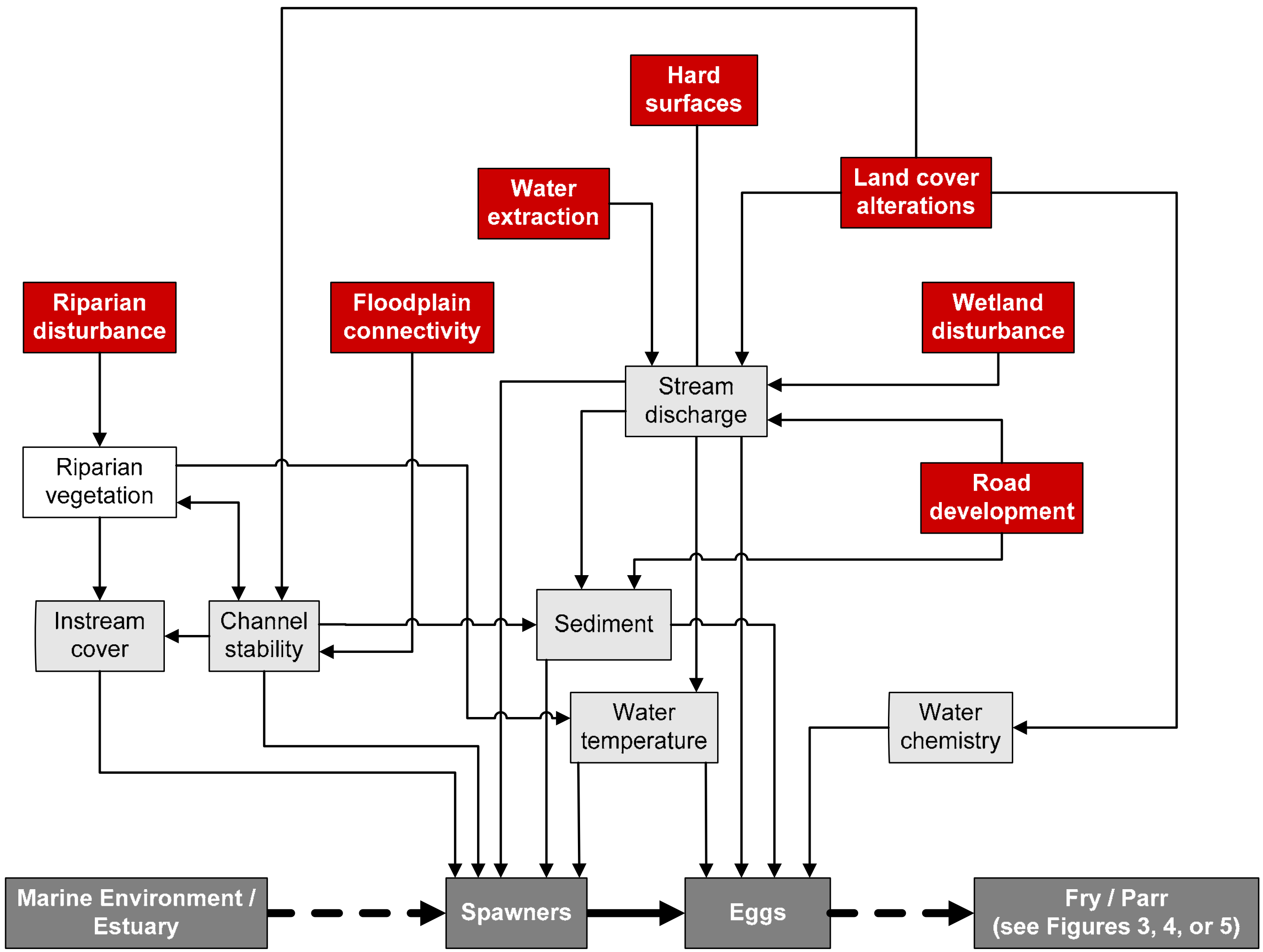

Figure 3. Summary of the linkages among habitat pressures (dark red boxes), habitat status (white or light grey boxes), and salmon life stages (dark grey boxes) in STREAM habitats. Grey boxes represent status indicators listed in Table 1, while white boxes represent implied linkages that are not represented in this table.

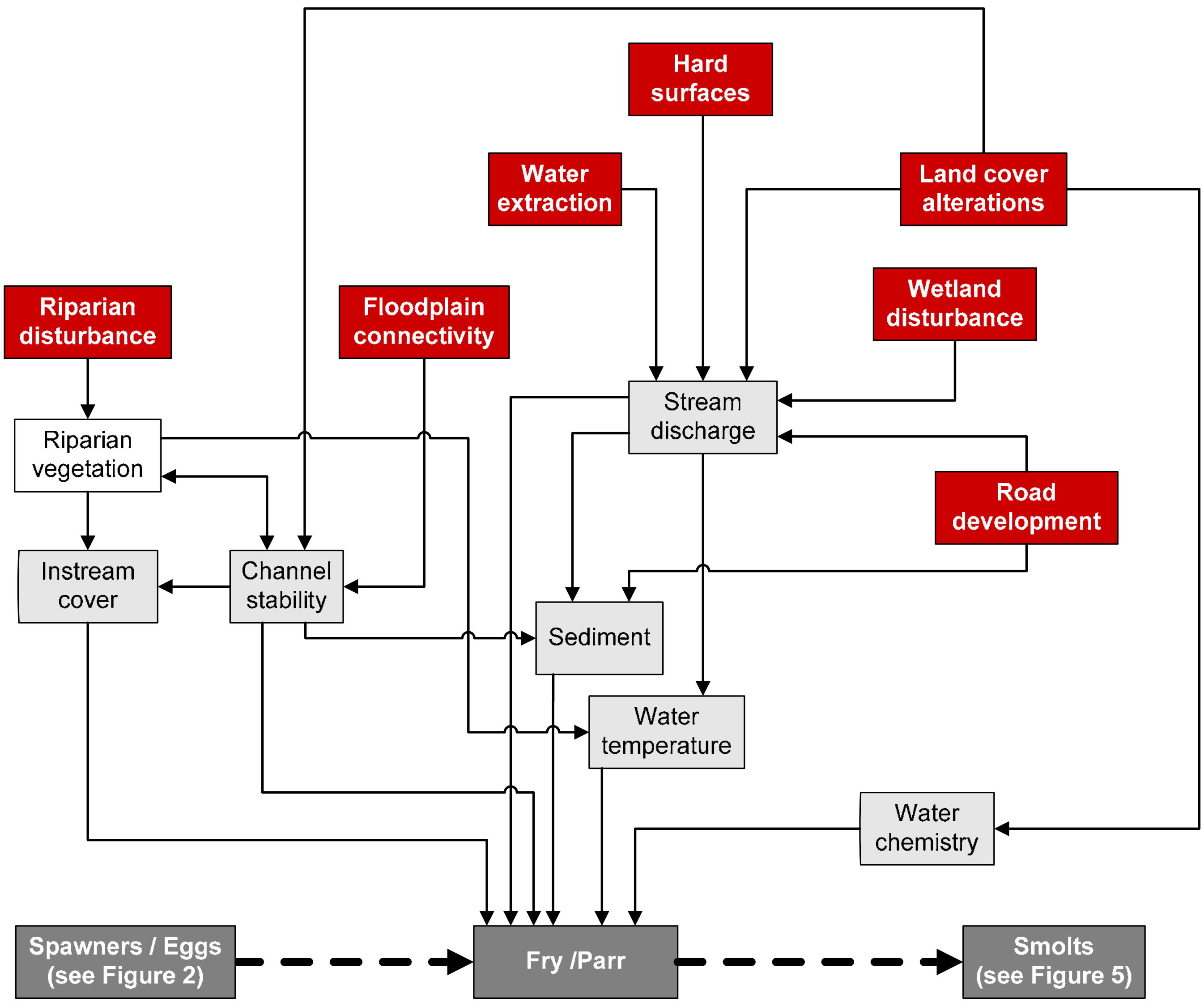

Figure 4. Summary of the linkages among habitat pressures (dark red boxes), habitat status (white or light grey boxes), and salmon life stages (dark grey boxes) in STREAM habitats. Grey boxes represent status indicators listed in Table 1, while white boxes represent implied linkages that are not represented in this table.

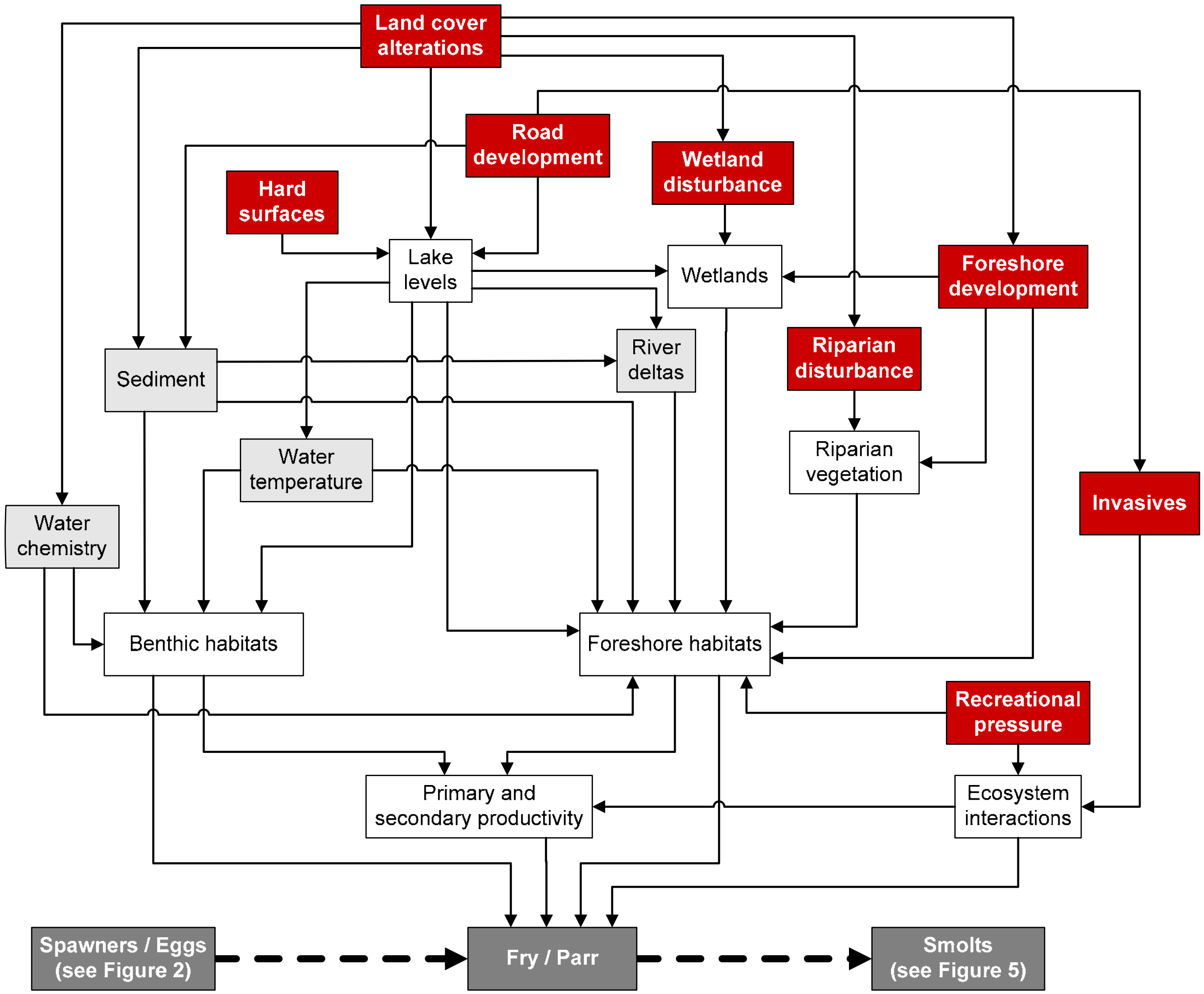

Figure 5. Summary of the linkages among habitat pressures (dark red boxes), habitat status (white or light grey boxes), and salmon life stages (dark grey boxes) in LAKE habitats. Grey boxes represent status indicators listed in Table 1, while white boxes represent implied linkages that are not represented in this table.

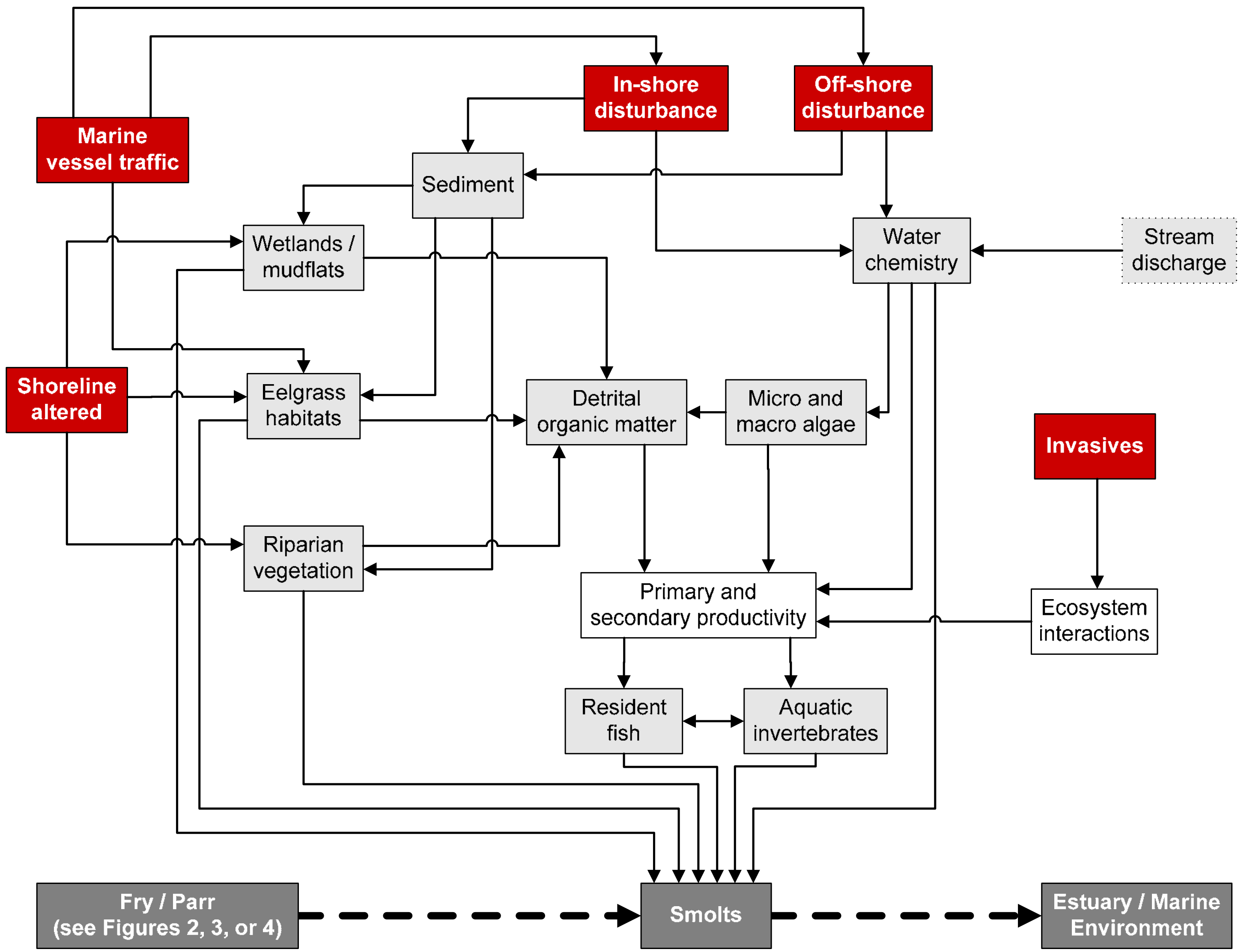

Figure 6. Summary of the linkages among habitat pressures (dark red boxes), habitat status (white or light grey boxes), and salmon life stages (dark grey boxes) in ESTUARY habitats. Grey boxes represent status indicators listed in Table 1, while white boxes represent implied linkages that are not represented in this table. Although not explicitly considered as an estuarine indicator, stream discharge is recognized as having an important influence on estuary habitats (importance denoted by light grey box with thatched outline).

4. Context for developing and using habitat indicators, metrics, and benchmarks

4.1 Relevance to decision making

Building on the Wild Salmon Policy, Fisheries and Oceans Canada has proceeded in drafting an approach for using habitat indicators to inform decision making. To develop a set of habitat indicators, metrics, and benchmarks that are most meaningful / useful to decision makers, it is essential to understand this decision context early on in the process (e.g., Failing and Gregory 2003; US EPA 2000).

Based on feedback received during WSP consultations and a review of indicator approaches elsewhere in the Pacific Northwest, DFO is adopting a two-tiered approach to decision making. *Tier I* decision making, representing the first line of information transfer to decision makers, will be informed by pressure indicators. Pressure indicators are recognized as being more proactive measures of impacts on the landscape and salmon habitats than status indicators. Using Geographic Information Systems and remote sensed information, pressure indicators would also be less costly to monitor over time. Therefore, the intention is to monitor / measure pressure indicators across the broadest spatial-scale (termed *extensive monitoring* under the Wild Salmon Policy).

In management areas where benchmarks have been exceeded for metrics representing pressure indicators, *Tier II* decision making would be informed by status indicators—more detailed descriptions of the condition of salmon habitats. Although more directly related to biological responses than pressure indicators, status indicators will be used as *Tier II* indicators for a variety of reasons. First, a requirement for field measurement means that status indicators are more expensive to monitor. Second, high natural variability in habitat condition implies a limited ability (i.e., low statistical power) to reliably detect meaningful changes in habitat condition without sampling across many locations or long time-series. Finally, lags in response of freshwater and estuarine ecosystems to natural and human disturbances mean that measurable changes in habitat status may not be observed until after habitat degradation has occurred. Thus, the intention is that status indicators will be monitored across a much smaller area, potentially for a subset of watersheds or Conservation Units (CUs) across the Pacific Region (termed *intensive monitoring* under the Wild Salmon Policy).

Within this general framework, our understanding is that habitat indicators will then be used to develop habitat status reports, which in turn can be used to inform two scales of decision making / management action: regional and local scales. 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. At a local scale (i.e., watershed or Conservation Unit), Area habitat managers may use both pressure and status indicators (with appropriate benchmarks) to better understand conservation and/or restoration priorities. A challenge with this two-tiered approach however, is that it may be difficult to identify priority conservation areas (i.e., productive pristine areas) given the emphasis on applying pressure indicators first.

This summary is based on *our current* understanding of how DFO intends to use the habitat indicators and the types of decisions they will inform. We recognize that the decision context for using habitat indicators under the Wild Salmon Policy is still evolving. *Strategy 4 Integrated Strategic Planning* is specifically focused on developing decision processes that integrate information provided by habitat indicators (including other information such as ecosystem indicators) into DFO's strategic-level planning and decision making.

4.2 Clarifying habitat indicators, metrics, biological responses, and benchmarks

As described earlier, an indicator represents a habitat attribute of interest to resource managers (listed in Table 1). Habitat indicators are relevant to Pacific salmon because our scientific understanding indicates there are direct or indirect relations between such indicators and biological responses (see conceptual diagrams in Figures 2-6). These direct and indirect relationships can also be represented using bi-variate plots, such that a habitat indicator defines the x-axis and a biological response defines the y-axis (Figure 7A and B). A habitat metric describes the measurable form and specific units an indicator may take (i.e., scale along the x-axis in Figure 7A and B or y-axis in Figure 7C and D). A single indicator may be described using many different metrics, each of which could have a different relationship with individual or population-level responses of Pacific salmon.

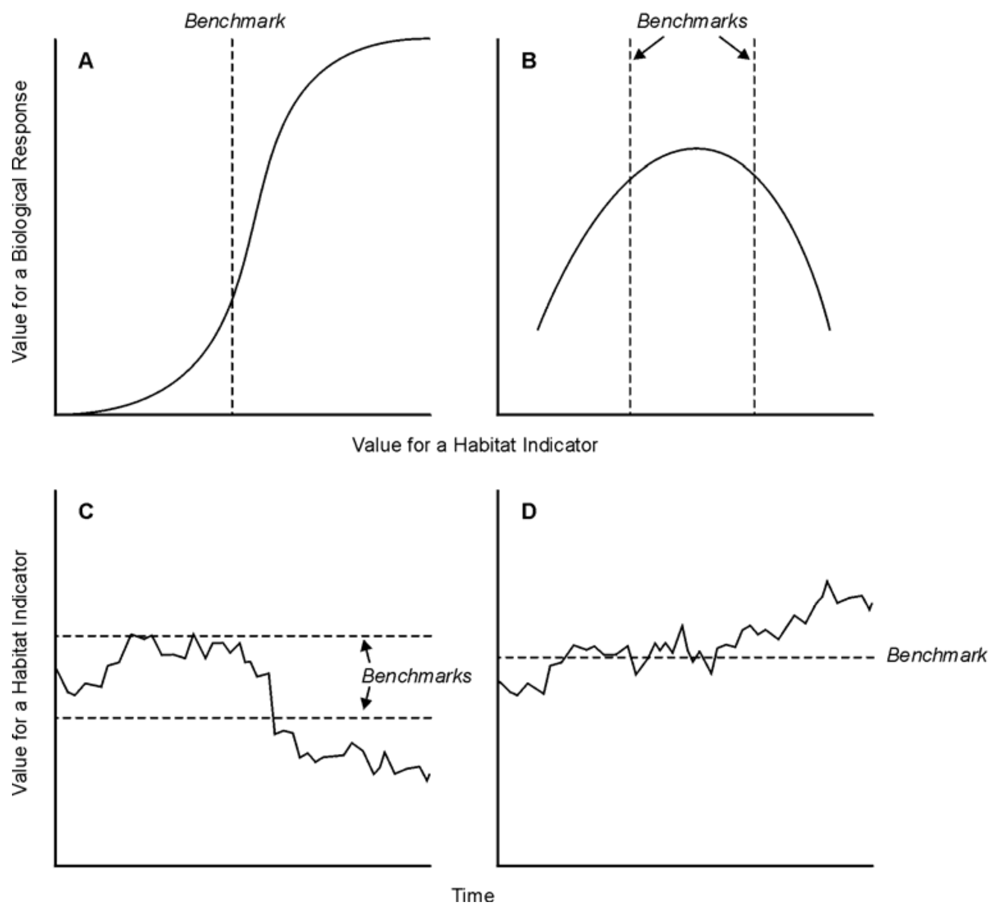

Figure 7. Four hypothetical examples illustrating relations among indicators, metrics, and benchmarks. “A” represents a relationship where increasing values result in increasingly adverse biological responses and the benchmark denotes an upper tolerable threshold. “B” represents a relationship where an optimal range of habitat conditions is marked by an upper and lower benchmark. “C” represents a situation where benchmarks define a desirable range of variation over time in a habitat indicator. “D” represents a situation where a habitat indicator increases over time, and currently exceeds the benchmark.

Benchmarks “*reflect the desired values of each key indictor*” (DFO 2005). They are clearly specified quantitative values for an indicator in units of the metric against which trends can be compared over space and time. Benchmarks can represent thresholds of undesirable and adverse responses (Figure 7A), agreed upon management targets for desirable / optimal habitat conditions (Figure 7B or C), or some desirable historic baseline conditions (Figure 7D). In general, benchmarks for pressure indicators will likely represent thresholds to be avoided, beyond which decision makers would be inclined to pursuing actions to reduce pressures on salmon and their habitats. Benchmarks for status indicators will either represent values for optimal habitat conditions or thresholds of adverse response, beyond which managers would be concerned about habitat quality. More specifically, benchmarks can fall into one of six categories.

Category 1 – Benchmarks based on dose-response relationships: Drawing from language in the toxicological literature, these types of benchmarks are based on field or laboratory studies where the effects of increasing levels of a stressor (e.g., sediment concentrations) are measured against some endpoint of interest (e.g., egg survival). Thresholds for lethal, sublethal (e.g., Figure 7A), or optimum responses (e.g., Figure 7B) are then identified using the functional relationship between the driving variable and endpoint of interest. In some cases, a safety factor can be applied to the threshold to account for uncertainties in such relationships. These kinds of benchmarks are often more scientifically defensible than others. A concern, however, is that they are based on a single point estimate above which undesirable responses are expected to occur. In reality thresholds are not so distinct; environmental variables (i.e., indicators) can follow a continuum of response such that increasing values can lead to a corresponding increase in the endpoint. For instance, habitat suitability models (e.g., McMahon 1983) do not use benchmarks; rather they recognize that changes in habitat variables lead to functional changes in habitat quality. Examples of these types of benchmarks include British Columbia's Water Quality Guidelines (MOE 2006a), the Canadian Environmental Quality Guidelines (CCME 2006), as well as the Total Maximum Daily Load (TMDL) standards developed by the U.S. Environmental Protection Agency for management of water quality (e.g., US EPA 1999; Vondracek et al. 2003).

Category 2 – Benchmarks using ranges of natural variation: A second type of benchmark recognizes that environmental variables vary naturally across space and time, irregardless of human activities. For instance, water temperatures can vary across season / years, as well as within a watershed / across watersheds (e.g., Figure 7C). Human disturbances can, however, alter natural variation in the indicator and benchmarks can be set based on what would be expected in the absence of a disturbance (e.g., Landres et al. 1999; Fowler and Hobbs 2002; Swetnam et al. 1999). As an example, Richter et al. (1997) proposed setting flow management targets within ± 1 standard deviation of the mean value for a flow parameter or within the 25th and 75th percentiles using the "Range of Variability Approach". Some of BC's water temperature guidelines (MOE 2006a) recommend maintaining temperatures within ± 1ºC of ambient natural conditions. An important consideration when developing such thresholds is to explicitly consider covariates and potentially confounding factors (e.g., climate processes or watershed characteristics), thus helping to explain natural variation in an indicator and distinguishing human induced changes from natural ones. Concerns, however, include the need to monitor multiple pristine areas (which may be difficult to locate) and the need to collect data for long periods across large spatial scales. However, if comprehensive data sets are available to characterize spatial and temporal variation, broad-scale / long-term monitoring may not be required (i.e., Type II indicators with sufficient data to inform baseline variation as discussed on pages 24-25, Table 7, Nelitz et al. 2007a). Some argue that developing habitat standards based using ranges of natural variability do not adequately protect salmon populations (e.g., Rhodes et al. 1994).

Category 3 – Benchmarks using comparisons in time: Given limited information about the scientific defensibility of a benchmark, in some cases it may be necessary to set benchmarks based on the historic value for an indicator (e.g., Figure 7D). For instance, the target for carbon dioxide emissions set under the Kyoto Protocol calls for a 6% reduction in emissions below 1990 levels by 2012[3]. The Nature Audit of Canada by the World Wildlife Fund (2003) used a baseline prior to European settlement (circa 1500-

[3] Government of Canada. Canada and the Kyoto Protocol. www.climatechange.gc.ca/cop/cop6_hague/english/overview_e.html

1600) against which to measure change in selected indicators across the nation. If applied to the Wild Salmon Policy, this type of benchmark would likely only apply to pressure indicators for which there may be no way of setting scientifically defensible benchmarks (e.g., marine vessel traffic).

Category 4 – Benchmarks using comparisons across space: Another approach is to compare indicator values to desirable reference location or multiple watersheds via a ranking exercise. In the context of identifying priority areas of concern for the Wild Salmon Policy, this approach could mean ranking all Conservation Units based on the value of a pressure indicator. A benchmark could then be set using a percentage or absolute number of Conservation Units at the top of the list requiring management attention. Geographic rankings are commonly applied by the Organisation for Economic Development and Co-operation when reporting on a range of environmental indicators related to biodiversity, air emissions, water quality, land conversion, and energy consumption for the leading economies in the world (OECD 2007).

Category 5 – Subjectively assigned benchmarks: A further option is to develop expert-based benchmarks. These types of benchmarks suffer from the criticism that they may not be as scientifically defensible as others, being based on subjective opinions or political willingness. One way to minimize subjectivity is to use independent technical experts that are well informed about the indicators of interest. Benchmarks can then be established by accounting for variation across the group or relying on consensus / agreement (e.g., using Delphi methods). An example of a subjectively assigned benchmark is the 12% protected area target recommended by the Bruntdland report on sustainable development (Brundtland 1987). While this is a commonly-used standard, it has no scientific basis.

Category 6 – Probabilistic benchmarks: Accounting for uncertainties in decision making – among other factors, natural variation, measurement error, and uncertainty in our scientific understanding – is a common challenge facing scientists and resource managers. A probabilistic approach or ecological risk assessment framework (US EPA 1992) can help account for uncertainties by: (i) setting benchmarks using one of the above five approaches, and (ii) calculating the chance (i.e., probability) that the benchmark will be exceeded. For instance, one of the above approaches might result in a benchmark for water temperature at 22ºC, where some management action would be taken if temperatures exceeded this threshold. When applying a probabilistic approach, the same benchmark would be used, but it would be accompanied by an estimate of the relative likelihood of exceedance (e.g., there is a greater than 50% chance of exceeding a 22ºC maximum temperature during the summer). Using probabilistic benchmarks requires setting two thresholds: a threshold for the indicator of interest and a threshold for probability. Both of these would need to be exceeded to result in some management action. This approach is more scientifically rigorous than any of the others because it explicitly accounts for uncertainties. Accounting for uncertainties is important because it can lead managers to make fewer errors in decision making. The downside is that this approach is more complex, computationally intensive, and more difficult for non-technical audiences to understand. None of these challenges are insurmountable, however. Probabilistic forecasts are used to estimate pre-season returns in abundance of Pacific salmon[4]. Others have demonstrated how probabilistic approaches could be applied in the context of managing forested landscapes (e.g., Graham et al. 1991).

[4] Pacific Salmon Commission. 2006 Post-season Update (News Release July 13, 2007) Available at: www.psc.org/NewsRel/2007/NewsRelease01.pdf

5. Summary of metrics and benchmarks findings

The full list of the identified metrics and benchmarks are provided in Tables 2, 3, and 4. A narrower set of recommendations specific to each habitat type are provided in Tables 10 (streams), 11 (lakes), and 12 (estuaries). Candidate metrics were identified for all indicators. Appropriate benchmarks could not be identified for all indicators or metrics, however. For these indicators / metrics, we proposed one of the six categories described in Section 4.2 as a type of benchmark that could be developed in the future. In addition, a number of insights emerged during our research. These insights / recommendations are summarized below:

A quantitative analysis using available data would help select among indicators / metrics: For many indicators, a variety of candidate metrics were identified. In some cases, selecting the best among these metrics was based on qualitative criteria: data availability or ease of calculation, and to a lesser extent on scientific relevance (e.g., road development and land cover alterations). Ideally, selection of most informative indicators / metrics should be based on identifying those most strongly and empirically linked to salmon (e.g., measure of smolt survival / productivity) or habitat responses (e.g., changes in sediment concentrations / channel stability). A quantitative analysis exploring correlations among multiple indicators / metrics and relations among indicators and habitat / population responses would help with this challenge (e.g., Hughes et al. 2004). For instance, there may be strong correlations among different measures of watershed disturbance: riparian harvesting, road development, impervious surfaces, or land use. It may be possible to collapse these indicators into a single index or use a subset of these indicators. Therefore, prior to applying habitat indicators broadly across the Pacific Region, we recommend a quantitative evaluation to enable a more defensible selection among indicators and metrics.

Within-site variability should be less than across-site variability: Ideally, metrics should have a high signal-to-noise ratio, such that a “signal” is defined as variability of a metric across all sites and “noise” as variability over repeated visits to the same site during a single year. In other words, to help detect differences in conditions among watersheds / Conservations Units, variation in a metric across a stream or among years should be less than variation across streams / watersheds (Fore 2003). If the variability of a candidate metric within individual sites is higher than its variability between all sites, then the measure is unlikely to detect differences in habitat condition among sites (or differences at sites that change through time, Fore 2003).

Metrics for pressure indicators should be weakly associated with natural gradients: It is important to select metrics for pressure indictors that are not, or are only weakly, associated with natural gradients (Hughes et al. 2004). If such metrics are associated with a natural gradient it is important to adjust for these gradients so changes in a metric are correctly associated with human pressures, not changes in a naturally occurring variable.

Remaining tasks to generate metrics and defensible benchmarks are not trivial: In general, the recommended remaining tasks to generate habitat indicators for Pacific salmon include: Task 1 – compiling available data for most indicators that can most feasibly be implemented (see list of analytical projects in page 31, Table 9, Nelitz et al. 2007a); Task 2 – completing an analytical project to explore correlations among alternative metrics and explore relations with habitat or biological responses for select indicators (see first insight above); and Task 3 – developing benchmarks for those metrics where none have been identified. The level of consultation, specific analytical methods, and defensibility to developing benchmarks will depend on the category of benchmark being pursued.

Propose multiple options for future consideration: Uncertainties remain about how the habitat indicators will specifically be used in decision making, which specific data sources will be used to calculate a metric, and who will be consulted in the next stages of developing metrics and benchmarks. Therefore, in some instances we provided several alternative metrics or benchmarks for DFO to consider as these uncertainties become resolved in the future. We believe this is a prudent approach given that we are not able to anticipate how these issues will be resolved.

Regional differences should be reflected in selection of benchmarks: We were not able to identify benchmarks for each of the unique terrestrial ecosystems across the Pacific Region (i.e., interior, coastal, and northern environments). Where appropriate, benchmarks should ideally be unique to these areas to account for differences in relations among terrestrial ecosystems and salmon habitats.

Account for changes in technology / monitoring methods over time: A future challenge facing DFO will be coping with changes in technologies (sampling devices) or monitoring methods (escapement estimates using aerial overflight vs. mark-recapture methods) so indicators, metrics, and benchmarks are consistently applied. Such differences may exist across the Region or among years, potentially leading to differences in indicator accuracy (bias associated with estimated indicator value) and precision (level of variation or error associated with indicator value) that depend on location or time of sampling. For instance, others have demonstrated the wide variation in esacapement determined through alternative estimation methods (Tschaplinski and Hyatt 1991; Hill and Irvine 2001).

DFO should consider a rigorous approach for standardizing data sets given differences in monitoring technologies / methods. One solution is to operate two or more methods / technologies at a single location so application of all overlap in time. A regression relationship can then be developed relating estimates from the old technology / method to the new technology / method. Such a relationship can then be used to adjust for potential biases in different methods, both retrospectively and prospectively. Alternatively, multiple technologies / methods can be operated across different watersheds to estimate differences and similarities which can be used to adjust for biases and errors across locations.

Table 2. List of metrics and benchmarks identified for STREAM habitat indicators. Indicators with an asterisk refer to those listed in the basic (*) or ideal (**) options presented on pages 31-32, Tables 9-10 in Nelitz et al. 2007a.

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Sediment	Not specified Maximum induced increase in suspended sediments (e.g., mg/L, ppm, or % of background)	MOE 2006a CCME 1999 in 2002 DFO 2000	Not specified • 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/L when background is between 25 and 250 • 10% when background is greater than or equal to 250	MOE 2006a CCME 1999 in 2002 DFO 2000
	Not specified Maximum induced increase in turbidity (e.g., Nephelometric Turbidity Units, NTUs or % of background)	MOE 2006a DFO 2000	For aquatic life in freshwater • 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	MOE 2006a DFO 2000
	Not specified Total suspended sediments (e.g., mg/L, ppm)	EIFAC 1964 DFO 2000	Not specified • < 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.	EIFAC 1964 DFO 2000
	SK, CO / stages 1 and 2 Total suspended sediments (e.g., mg/L or ppm)	Galbraith et al. 2006	SK, CO / stage 1 • Total suspended sediment levels > 9000 mg/L can reduce fertilization success below 80%	Galbraith et al. 2006
	Not specified Streambed substrate composition (e.g., % of substrate particles < 6.35mm)	MOE 2006a DFO 2000 Lisle 1989 Kondolf 2000 NOAA 1996 Taccogna and Munro 1995	For aquatic life in freshwater (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 • Geometric mean diameter not less than 12mm • Fredle number not less than 5mm Functioning condition (NOAA 1996) • proper: < 12% particles < 0.85mm • at risk: 12-17% particles < 0.85mm • non functional: > 17% particles < 0.85mm Habitat Assessment Interpretation (% boulder and cobble, Taccogna and Munro 1995) • Good: 50% • Acceptable: 30-50% • Marginal: 10-30% • Poor: <10%	MOE 2006a DFO 2000 Lisle 1989 Kondolf 2000 Tripp et al. 2007 NOAA 1996 Taccogna and Munro 1995
	Not specified Substrate embeddedness	Tripp and Bird 2004 NOAA 1996 Taccogna and Munro 1995	Functioning condition (e.g., number of yes answers to four questions related to field assessment of amount of channel bed covered or embedded in fine-textured sediment) • proper: 4 • at risk: 3 • at high risk: 2 • non functional: <2 Functioning condition (e.g., dominant substrate and amount of compaction among interstitial spaces) • proper: < 20% • at risk: 20- 30 % • non functional: > 30% Habitat Assessment Interpretation (% cover of gravel and cobble by fine sediment, Taccogna and Munro 1995) • Good: 0-25% • Acceptable: 25-50% • Marginal: 50-75% • Poor: 75%	Tripp and Bird 2004 NOAA 1996 Taccogna and Munro 1995

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Water chemistry	Not specified proportion of sampled water bodies with exceedances of standards for water quality parameters of interest (e.g., CCME Water Quality Index)	CCME 2001 Province of British Columbia. 2002 UBC Sustainable Forest Management Research Group no date	None specified	
	Not specified suitability of various water quality parameters (e.g., temperature, oxygen saturation, pH, turbidity suitability relationships, determination of Q-values and integration in Streamkeepers Water Quality Index)	Taccogna and Munro 1995	None specified • Good: water quality index value 40-45 • Acceptable: water quality index value 30-40	Taccogna and Munro 1995
	Not specified Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2)	MOE 2006a	For aquatic life in freshwater • 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	MOE 2006a
	Not specified Phosphorous (total dissolved phosphorous, soluble reactive phosphorus, µg/L as phosphorous)	MacDonald et al. 2000 Johnston et al. 2004 (SK, stage 1)	For aquatic life in freshwater, total phosphorous 30 µg/L (for chronic exposure limiting growth of algae and aquatic plants in streams/rivers, benchmark from Quebec)	MacDonald et al. 2000
	Not specified Nitrogen (e.g., total nitrogen, concentration of nitrate, concentration of nitrite, concentration of total ammonia, µg/L as nitrogen)	MOE 2006a MacDonald et al. 2000 Johnston et al. 2004 (SK, stage 1)	For aquatic life in freshwater, nitrate: • less than or equal to 40 mg/L (average value, calculated from at least 5 weekly samples taken in a period of 30 days) • 200 mg/L (maximum value) For aquatic life in freshwater, nitrite: • 0.02 mg/L when chloride is less than or equal to 2 mg/L - also see Table 2 (average value, calculated from at least 5 weekly samples taken in a period of 30 days) • 0.06 mg/L when chloride is less than or equal to 2 mg/L (maximum value) • criteria increase with increasing concentrations of chloride For aquatic life in freshwater, total ammonia: • 1.84 mg/L; 30-day average at 10ºC and pH = 7.0 • 20.5 mg/L; maximum at 10ºC and pH = 7.0 • criteria are highly variable; depend on water temperature and pH (i.e., lower criteria at warmer temperature and higher pH)	MOE 2006a MacDonald et al. 2000
	Not specified Chlorophyll a (measured value, µg/cm^2)	MOE 2006a Johnston et al. 2004 (SK, stage 1)	For aquatic life in streams 100 mg/m^2 (maximum) criterion is designed to protect fish habitat and changes in communities of organisms such as invertebrates which are important themselves or which may be important fish-food organisms	MOE 2006a
	Not specified pH (measured value)	MacDonald et al. 2000 MOE 2006a	Protection of freshwater aquatic life 6.5-8.5 (minimum and maximum thresholds) general consistency across many jurisdictions in North America on this range Protection of freshwater aquatic life • existing pH > 9.0: No statistically significant increase in pH from background. Short-term increase (2-3 days) to pH 9.5 are permitted for lake restoration projects. Decreases in pH are permitted as long as carbon dioxide concentrations are not elevated above 1360 µmol/L. Carbon dioxide concentrations above 1360 µmol/L may be toxic to fish. • existing pH between 6.5 - 9.0: Unrestricted change permitted within this range. This component of the freshwater guidelines should be used cautiously if the pH change causes the carbon dioxide concentration to decrease below a 10 µmol/L minimum or exceed a 1360 µmol/L maximum. • existing pH < 6.5: No statistically significant decrease in pH from background. No restriction on the increase in pH except in boggy areas that have a unique fauna and flora. Site-specific ambient water quality objectives to restrict the pH increase in areas with a unique fauna and flora are recommended.	MacDonald et al. 2000 MOE 2006a

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Riparian disturbance*	Not specified proportion of stream length with disturbed riparian zone, accounting (using groupings or weightings) for differences in: • 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) Account for these factors recognizes differences in riparian functioning across a watershed, ecosystems, or disturbance types.	MOF 2001 Caslys 2007 Province of British Columbia 2000 NOAA 1996 MOF 2001	Functioning condition • 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 "Significant watershed sensitivity" represented by watersheds where > 25 % riparian forest along either bank has been logged within last 40 years (MOF 2001)	NOAA 1996 MOF 2001
	Not specified proximity-weighted tally of all near-stream human activities (e.g., weighting based on lateral distance from stream)	Hughes et al. 2004	None specified	
	Not specified riparian–catchment disturbance index (e.g., seven-class disturbance index combining 5-class riparian disturbance metric and 3-class catchment road density metric)	Hughes et al. 2004	None specified	
	Not specified percent shading / retention along stream reach (field measurements)	Tripp et al. 2007 Tripp and Bird 2004 Hughes et al. 2004 Taccogna and Munro 1995	Functioning condition (Tripp and Bird 2004) • proper: >95% • at risk: 86-95% • at high risk: 75-85% • non functional: <75% Habitat Assessment Interpretation (Taccogna and Munro 1995) • good: >90% • acceptable: 70-90% • marginal: 50-70% • poor: <50%	Tripp and Bird 2004 Taccogna and Munro 1995
Watershed: Land cover alterations*	Not specified percent land (PLAND): sum of the area of all patches of a particular type divided by total area of the basin. Patch types can include: • agriculture • urban development • harvested • burned diseased • mining • rangeland • landslides (i.e., exposed soil) • undisturbed ecosystem type Alternatively, could 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).	Alberti et al. 2007 Bradford and Irvine 2000 (CO, CH / stages 1 and 2) Caslys 2007 UBC Sustainable Forest Management Research Group no date	None specified	
	Not specified Shannon diversity index (SHDI): measure of the number of land cover classes across a landscape	Alberti et al. 2007	None specified	
	Not specified mean patch size (MPS): sum of the areas of all patches divided by the number of patches	Alberti et al. 2007	None specified	
	Not specified contagion (C): probability that two randomly chosen adjacent cells belong to the same class. Calculated as the product of two probabilities (probability that a randomly chosen cell belongs to category type i, and the conditional probability that given a cell is of category type i, one of its neighboring cells will belong to a different type)	Alberti et al. 2007	None specified	
	Not specified aggregation index (AI): number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies of that class	Alberti et al. 2007	None specified	
	Not specified percentage-of-like-adjacency (PLADJ): sum of the number of like adjacencies for each patch type, divided by the total number of cell adjacencies in the landscape, multiplied by 100	Alberti et al. 2007	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Watershed: Land cover alterations*	None specified equivalent clearcut area (ECA): 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 (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 Not specified / Rocky mountain – Inland intermountain region (Stednick 1996) • > 15 % harvest area results in a measurable annual water yield increase • > 50% harvest area, annual water yield increases ranged from 25 to 250 mm • complete harvesting (100% harvest) increased annual water yield from zero to over 350 mm "Significant watershed sensitivity" represented by watersheds where > 20 % has been harvested within last 25 years (MOF 2001) Changes in annual runoff from reductions in forest cover cannot be detected when less than 20% of a watershed is harvested (Recksten 1991)	NOAA 1996 Reksten 1991 MOF 2001 Stednick 1996
	CO, CH / stages 1 and 2 semiquantitative index of "habitat concerns" comprised of 10 major categories (forestry, agriculture, urbanization, recreation, mining, industrial development, linear development, hydro development, cumulative impacts, and special biophysical concerns)	Bradford and Irvine 2000	None specified	
Watershed: Hard surfaces*	Not specified Total impervious surface cover (ISC) (% 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 Smith 2005 Booth et al. 2002	Not specified • 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% General consistency across many paper in North America on this range (summarized in Paul and Meyer 2001) Functioning Condition (Smith 2005) • good: < 3% ISC • fair: 10% ISC • poor: > 10% ISC Not specified (Booth et al. 2002) • maximum 10 % ISC and minimum 65% forest cover Coho seldom found in watershed with ISC 10-15% or greater (Luchetti and Feurstenburg 1993)	Paul and Meyer 2001 Guthrie and Deniseger 2001 UBC 2004 Klein 1979 Luchetti and Feurstenburg 1993 Booth et al. 2002 Smith 2005
	Not specified Connectivity of impervious surfaces to a waterbody network (e.g., mean distance of a waterbody from all impervious surface patches, divided by the percent of impervious surface in the watershed / CU	Synder et al. 2005	None specified	
	Not specified Effective impervious surface cover (i.e., impervious areas with direct connection to downstream drainage system)	Alberti et al. 2007	Not specified • ≥ 10% effective impervious surface in a watershed results in loss of aquatic system function	Booth and Jackson 1997
Watershed: Road development*	Not specified road density (length per unit area, e.g., km / km^2)	MOF 2001; Bradford and Irvine 2000 (CO Stage 1 and 2); Chu et al. 2003; Forman and Alexander 1998; NACSI 2001; Nelitz et al. 2007b; Sharma and Hilborn 2001; Province of BC 2002; Alberti et al. 2007; UBC Sustainable Forest Management Research Group no date; NOAA 1996	Not specified Increased peak flows in streams may be evident at road densities of 2–3 km/km^2 (Forman and Alexander 1998) Functioning condition (NOAA 1996): • Properly functioning: < 1.24 km/km^2, no valley bottom roads • At risk: 1.24 – 1.86 km/km^2, some valley bottom roads • Non functioning: > 1.86 km/km^2, many valley bottom roads	Forman and Alexander 1998 NOAA 1996
	Not specified 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	None specified	
	Not specified proportion of watershed covered by roads (e.g., area of roads / area of watershed)	Forman and Alexander 1998	None specified Detrimental effects on aquatic ecosystems, based on macro-invertebrate diversity, evident where roads covered 5% or more of a watershed in California	Forman and Alexander 1998
	Not specified road network structure (e.g., index of variance in mesh size)	Forman and Alexander 1998; Reed et al. 1996; Miller et al. 1996	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Watershed: Road development*	Not specified roadless volume (e.g., integral of horizontal distance to nearest road over the area of interest, metric simultaneously accounts for footprint area and shape of road network)	Watts et al. 2007	None specified	
	Not specified riparian–catchment disturbance index (e.g., seven-class disturbance index combining 5-class riparian disturbance metric and 3-class road density metric)	Hughes et al. 2004	None specified	
Water temperature**	Not specified Hourly water temperature monitored over the year	MOE 2006a	hourly rate of change not to exceed 1ºC	MOE 2006a
	All species / all stages Daily water temperature monitored over the year	MOE 2006a NOAA 1996	± 1 ºC change beyond optimum temperature range for each life history phase of most sensitive salmonid species present (see Table 5) Optimal temperature ranges • Properly functioning: 10 - 13.8 ºC • At risk: 13.9 – 15.6 ºC (spawning), 13.9 – 17.8 ºC (migration and rearing) • Not properly functioning: > 15.6 ºC (spawning), > 17.8 ºC (migration and rearing)	MOE 2006a NOAA 1996
	Not specified Annual maximum temperature	Sullivan et al. 2000 Nelitz et al. 2007b	None specified	
	CH, CM, CO 7-day-average of maximum daily temperature (e.g., maximum weekly maximum temperature (MWMT) over the year)	MOE 2006a; ODEQ 1995; Sullivan et al. 2000; Nelitz et al. 2007b; Richter and Kolmes 2005	18ºC MWMT for streams with unknown fish distribution Upper optimal temperature criteria for CH, CM, CO • Spawning and incubation 13ºC • Juvenile rearing 16ºC • Adult migration 18ºC • Smoltification 16ºC	MOE 2006a Richter and Kolmes 2005
	CH, CM, CO 7-day average of mean daily temperature (e.g., maximum weekly average temperature (MWAT) over the year)	Brungs and Jones Sullivan et al. 2000 Nelitz et al. 2007b Richter and Kolmes 2005	Upper optimal temperature criteria for CH, CM, CO • Spawning and incubation 10ºC • Juvenile rearing 15ºC • Adult migration 16ºC • Smoltification 15ºC	Richter and Kolmes 2005
	All species / stage 1 Accumulated thermal units (ATU) over incubation period	Jensen et al. 2002; Holtby 1988; Murray and McPhail. 1988; Beacham and Murray 1990	None specified, though benchmark could be derived using data / models presented within these references to translate optimum daily temperatures to an ATU benchmark. ATU affects date of emergence and survival during incubation.	
	SK, stage 1 Accumulated thermal units (ATU) over migration corridor / period (unique for each stock)	Dave Patterson, Fisheries and Oceans Canada, pers. comm.	None specified	
	Not specified Classification of thermal regime using single or multiple temperature metrics describing thermal exposure of different salmon stocks (e.g., combination of mean summer temperature, diurnal / seasonal variation, overwinter temperature, migration corridors).	Wehrly et al. 2003 Nelitz et al. 2007b	None specified	
Wetland disturbance*	Not specified Connectivity of the hydrologic network (e.g., perennial surface water connection to other waterbodies, seasonal surface water connection to other waterbodies, presence of wetlands or corridors in target wetland's vicinity)	Aznar et. Al 2003; Maryland Department of Environment 2007; Fennessy et al. 2004	None specified	
	Not specified Ratio of wetland area to watershed area (can be used to determine water inflow among other things)	Fennessy et al. 2004	None specified	
	Not specified percentage of historic wetland acreage achieved (i.e., what is the total current wetland acreage relative to historical acreage)	Salwasser et al. 2002	Not specified • Ecologically optimal value or condition for freshwater wetlands: Restoration to wetland acreage and conditions that existed prior to settlement and developments following the mid 1800s where physically and economically possible. Existing physical and economic constraints limit what is possible. • Ecologically possible value or condition for freshwater wetlands: Choose a benchmark definition (i.e., year) reflects perceptions of what is possible where historic data not available and/or not possible to achieve historic benchmark.	Salwasser et al. 2002
	Not specified Total wetland area by type (e.g., acres or km^2)	Maryland Department of Environment 2007 Fennessy et al. 2004	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Wetland disturbance*	Not specified Wetland acreage change per year (e.g., %)	Salwasser et al. 2002	None specified	
	Not specified Land use by area within a 500 foot zone surrounding the wetland	Maryland Department of Environment 2007 Fennessy et al. 2004	None specified	
	Not specified Plant species richness (Total number of plant species in the wetland)	Chipps et al. 2006 Fennessy et al. 2004	None specified	
	Not specified Proportion of wetland covered by invasive vegetation	Brazner et al. 2007 Chipps et al. 2006 Fennessy et al. 2004	Not specified • Proper functioning condition: < 5 % • At risk functioning condition: 5-25 % • At high risk functioning condition: 26 – 50 % • Non functioning condition: > 50 %	Tripp and Bird 2004
Floodplain connectivity	Not specified percentage of stream and off-channel habitat length with lost floodplain connectivity due to incision, roads, dikes, flood protection, or other actions.	Smith 2005	Functioning Condition for streams < 1% gradient • Proper functioning condition: < 10 % • At risk functioning condition: 10 -50% • Not functioning: > 50 %	Smith 2005
	Not specified channel sinuosity index: length of a reach as measured along the midpoint of the channel divided by the straightline distance between the two end points of the reach	Fukushima 2001	None specified	
	Not specified seasonal / inter-annual variation in wetted width	Woolsey et al. 2007	None specified	
Water extraction*	Not specified volume of surface water licensed (e.g., m^3 / year) 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 Rood and Hamilton 1995a; 1995b; 1995c; 1995d Hatfield 2007	None specified	
	Not specified number of water licenses / 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	None specified	
	Not specified summer water demand as a percentage of flow (e.g., potential demand in Aug as proportion of average August flow)	Rood and Hamilton 1995a; 1995b; 1995c; 1995d	None specified	
	Not specified area of agricultural lands being irrigated compared to area supported through water license amounts (e.g., hectares irrigated through air photo interpretation compared to hectares irrigated through water licensing)	Woodward and Healey 1993	None specified	
	Not specified cumulative number of stream restrictions over time	Province of British Columbia 2000	None specified	
	Not specified per capita water use (e.g., litres / person / day)	Woodward and Healey 1993 Province of British Columbia 2000	None specified	
	Not specified proportion of groundwater observation wells with declining water levels	Province of British Columbia 2000	None specified	
Channel stability	Not specified proportion of stream with disturbed stream channel (e.g., km disturbed / km stream length). Stream channels are naturally dynamic. Thus, there is a need to account for other factors affecting significance of concerns: • direction of disturbance (aggrading or degrading) • severity of disturbance (severe or moderate) • channel type (channel gradient, bankfull width, and morphology)	MOF 2001 Tripp et al. 2007 MOF and MELP 1996 UBC Sustainable Forest Management Research Group no date	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Channel stability	Not specified channel depth variability (e.g., number of pools in a 50 channel bankfull width stream segment)	Tripp and Bird 2004	Functioning condition • proper: >7 • at risk: 6-7 • at high risk: 3-5 • non functional: <3	Tripp and Bird 2004
	Not specified pool frequency (e.g., number of pools in a km of channel with x bankfull width)	NOAA 1996	Functioning condition (see Table 6) • proper: meets pool frequency standards and LWD recruitment standards (see NOAA 1996 benchmarks under LWD and in-stream cover) • at risk: meets pool frequency standards by LWD recruitment inadequate to maintain pools over time • non functional: does not meet pool frequency standards	NOAA 1996
	Not specified bank erosion (e.g., % of survey points with eroded bank)	Tripp and Bird 2004 Smith 2005	Functioning condition • proper: <73 % • at risk: 73-84 % • at high risk: 84-94 % • non functional: >94 %	Tripp and Bird 2004 Smith 2005
	Not specified bar frequency (e.g., % of survey points with a gravel bar)	Tripp and Bird 2004	Functioning condition see Table 7	Tripp and Bird 2004
	Not specified bar stability (e.g., % of survey points with unstable bars)	Tripp and Bird 2004	Functioning condition in mountains • proper: <31 • at risk: 32-36 • at high risk: 37-46 • non functional: >46 Functioning condition in plateaus • proper: <23 • at risk: 24-28 • at high risk: 29-38 • non functional: >38	Tripp and Bird 2004
	Not specified bed scour (e.g., % of survey points with bed scour)	Tripp and Bird 2004	Functioning condition see Table 7	Tripp and Bird 2004
	CH / stage 2 longitudinal profile of stream thalweg: longitudinal profile of stream as measured by (i) average of maximum residual pool depth of profile, or (ii) variability of profile	Mossop and Bradford 2006	None specified	
Stream discharge*	Not specified magnitude of flow events (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; 2002 Rood and Hamilton 1995a; 1995b; 1995c; 1995d	For survival of aquatic life • 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 Range of variability approach (e.g., range, ± 1 standard deviation, 20th and 80th percentiles, etc.)	Richter et al. 1997
	Not specified timing of flow events (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; 2002	Not specified Range of variability approach (e.g., range, ± 1 standard deviation, 20th and 80th percentiles, etc.)	Richter et al. 1997
	Not specified frequency of flow events (e.g., # of times flow events are met or exceeded, flow frequency–return interval curves)	Richter et al. 1996; 1997; 2002 Hatfield 2007	Not specified Range of variability approach (e.g., range, ± 1 standard deviation, 20th and 80th percentiles, etc.)	Richter et al. 1997
	Not specified rate of change in flow (e.g., average positive or negative difference between consecutive days)	Richter et al. 1996; 1997; 2002	Not specified Range of variability approach (e.g., range, ± 1 standard deviation, 20th and 80th percentiles, etc.)	Richter et al. 1997
	Not specified percentage of stream km in forest catchments in which stream flow and timing has significantly deviated from Historic Range of Variation (HRV)	UBC Sustainable Forest Management Research Group no date	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Large woody debris and in-stream cover	Not specified percentage of fish cover by type within a sample reach (e.g., % undercut bank, % LWD, % deep pool, etc)	Tripp et al. 2007 MSRM 2004	None specified	
	Not specified fish cover diversity (e.g., number of types present)	Tripp and Bird 2004	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. Functioning condition • proper: > 3 habitat types • at risk: 3 habitat types • at high risk: 2 habitat types • non-functional: <2 habitat types	Tripp and Bird 2004
	Not specified abundance (number or volume) and nature (estimated time since recruitment, bankfull width, or channel gradient) of LWD per unit area (per 100m). Characteristics for functioning LWD may differ in northern environments (Mossop and Bradford 2004) and different size streams (Chen et al. 2006).	Tripp et al. 2007 Mossop and Bradford 2004 (CH / stage 2)	None specified	
	Not specified woody debris load (e.g., percent of observations where woody debris is recorded at 50 points along a 50 channel bankfull width long stream transect, pieces per metre)	Tripp and Bird 2004 Johnston et al. 2004	Functioning condition in high productivity BEC zone • proper: 16-26 • at risk: 14,28-32 • at high risk: 10-12, 34-40 • non-functional: <10 or >40 Functioning condition in low productivity BEC zone • proper: 26-42 • at risk: 18-24, 44-52 • at high risk: 10-16, 54-66 • non-functional: <10 or >66	Tripp and Bird 2004
	Not specified woody debris frequency (e.g., number of log jams in 50 channel bankfull widths, number of pieces of LWD of specified dimension per km)	Tripp and Bird 2004 NOAA 1996 Taccogna and Munro 1995	Functioning condition in mountains (Tripp and Bird 2004) • proper: 3-6 • at risk: 2, 7-8 • at high risk: 1, 9-11 • non-functional: 0, >11 Functioning condition in plateaus (Tripp and Bird 2004) • proper: 2-3 • at risk: 1, 4 • at high risk: 0, 5-6 • non-functional: >6 Functioning conditions for Coast (NOAA 1996) • proper: > 50 pieces per km of > 60.96 cm in diameter and > 15.24 m in length; and adequate sources of woody debris recruitment in riparian areas • at risk: currently meets standards for properly functioning, but lacks potential for LWD recruitment to maintain standard • non-functional: does not meet standards for properly functioning and does not have potential for LWD recruitment Functioning conditions for East-side (NOAA 1996) • proper: > 13 pieces per km of > 30.5 cm in diameter and > 10.67 m in length; and adequate sources of woody debris recruitment in riparian areas • at risk: currently meets standards for properly functioning, but lacks potential for LWD recruitment to maintain standard • non-functional: does not meet standards for properly functioning and does not have potential for LWD recruitment Habitat Assessment Interpretation (pieces of LWD per channel width) (Taccogna and Munro 1995) • Good: >3 • Acceptable: 2-3 • Marginal: 1-2 • Poor: <1	Tripp and Bird 2004 NOAA 1996 Taccogna and Munro 1995

Table 3. List of metrics and benchmarks identified for LAKE habitat indicators. Indicators with an asterisk refer to those listed in the basic (*) or ideal (**) options presented on pages 31-32, Tables 9-10 in Nelitz et al. 2007a.

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Sediment	SK, CO/ stages 1 and 2 Total suspended sediment (e.g. mg/L or ppm)	Galbraith et al. 2006	SK, CO / Stage 1 • Total suspended sediment levels > 9000 mg/L can reduce fertilization success below 80%	Galbraith et al. 2006
	Not specified Total suspended sediment (e.g. mg/L or ppm)	EIFAC 1964 DFO 2000	Not specified • < 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.	EIFAC 1964
	Not specified Maximum induced increase in suspended sediments (e.g., mg/L, ppm, or % of background)	CCME 1999 in DFO 2000 Gregory-Eaves et al. 2004 MOE 2006a	Not specified • 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/L when background is between 25 and 250 • 10% when background is greater than or equal to 250	CCME 1999 in DFO 2000
	Not specified Maximum induced increase in turbidity (e.g., Nephelometric Turbidity Units (NTUs) or % of background)	Gregory-Eaves et al. 2004 CCME 1999 in DFO 2000 MOE 2006a	For aquatic life in freshwater • 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 • 8 NTU when background is between 8 and 80 • 10% when background is greater than 80	CCME 1999 in DFO 2000 MOE 2006a
	Not specified substrate composition (e.g., % of substrate particles < 6.35mm)	Lisle 1989 Kondolf 2000 MOE 2006a DFO 2000	For aquatic life in freshwater • 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 • Geometric mean diameter not less than 12mm • Fredle number not less than 5mm	CCME 1999 in DFO 2000 Kondolf 2000 MOE 2006a Lisle 1989 Tripp et al. 2007
Water chemistry*	Not specified Proportion of sampled water bodies with exceedances of standards for water quality parameters of interest (e.g., CCME Water Quality Index)	CCME 2001 Province of British Columbia. 2002 UBC Sustainable Forest Management Research Group no date	None specified	
	Not specified / stage 2 Dissolved oxygen (e.g., usable volume of water with suitable concentration of dissolved oxygen, mg/L O_2)	Hyatt et al. 2007	For aquatic life in freshwater • 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	MOE 2006a
	Not specified / stage 2 Dissolved oxygen (e.g., usable volume of water with suitable concentration of dissolved oxygen, mg/L O_2)	Hyatt et al. 2007	For aquatic life in freshwater • Daily minimum dissolved oxygen concentration may not be < 11 mg O_2/L • Daily minimum may not be < 8 mg O_2/L in the intergravel environment • Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 11.0 mg/L or 9.0 mg/L criteria, dissolved oxygen levels must not be less than 95% of saturation	Department of Environmental Quality [Oregon] 2006
	Not specified / stage 2 Dissolved oxygen (e.g., usable volume of water with suitable concentration of dissolved oxygen, mg/L O_2)	Hyatt et al. 2007	For aquatic life in freshwater • Daily minimum dissolved oxygen concentration may not be < 6 mg O_2/L • Daily minimum may not be < 5 mg O_2/L in the intergravel environment (with a 7-d average of 6 mg O2/L in the latter	Department of Environmental Quality [Idaho] 2006
	SK / stage 1 Dissolved oxygen levels in intergravel environment (e.g., concentration of dissolved oxygen, mg/L O_2)	Reiser and Bjornn 1979	SK / stage 1 • Daily minimum may not be < 5mg/L in the intergravel environment	Reiser and Bjornn 1979
	Not specified Organic carbon (e.g., total organic carbon (TOC) µg/L, dissolve organic carbon (DOC) µg/L)	Gregory-Eaves et al. 2004 MOE 2006a	Not specified • 30-day median ± 20% of the median background concentration for both DOC and TOC	MOE 2006a
	Not specified Phosphorous (total phosphorous concentration, soluble reactive phosphorus, µg/L of phosphorus)	MOE 2006a Johnston et al. 2004 (SK, stage 1) Gregory-Eaves et al. 2004 Shortreed et al. 2001	All species in lakes • 5 to 15 µg/L (inclusive)	MOE 2006a

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Water chemistry*	Not specified Nitrogen (e.g., total nitrogen, concentration of nitrate, concentration of nitrite, concentration of total ammonia, μg/L as nitrogen)	MOE 2006a MacDonald et al. 2000 Johnston et al. 2004 (SK, stage 1) Shortreed et al. 2001 Gregory-Eaves et al. 2004	For aquatic life in freshwater, nitrate: • less than or equal to 40 mg/L (average value, calculated from at least 5 weekly samples taken in a period of 30 days) • 200 mg/L (maximum value) For aquatic life in freshwater, nitrite: • 0.02 mg/L when chloride is less than or equal to 2 mg/L - also see Table 5 (average value, calculated from at least 5 weekly samples taken in a period of 30 days) • 0.06 mg/L when chloride is less than or equal to 2 mg/L (maximum value) • criteria increase with increasing concentrations of chloride For aquatic life in freshwater, total ammonia: • 1.84 mg/L; 30-day average at 10ºC and pH = 7.0 • 20.5 mg/L; maximum at 10ºC and pH = 7.0 • criteria are highly variable; depend on water temperature and pH (i.e., lower criteria at warmer temperature and higher pH)	MOE 2006a MacDonald et al. 2000
	Not specified Nitrogen (e.g., total Kjeldahl nitrogen μg/L (originates from decaying organic matter, e.g., salmon carcasses))	Gregory-Eaves et al. 2004	None proposed for lakes	
	Not specified Nitrogen:Phosporus (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
	Not specified Chlorophyll a (measured value, mg/m²)	MOE 2006a Gregory-Eaves et al. 2004 Shortreed et al. 2001 Department of Environmental Quality [Oregon] 2006	For aquatic life in lakes • Natural lakes that thermally stratify should not exceed 0.01 mg·L⁻¹ • Natural lakes that do not thermally stratify should not exceed 0.015 mg·L⁻¹	Department of Environmental Quality [Oregon] 2006
	Not specified pH (measured value)	MOE 2006a MacDonald et al. 2000 Gregory-Eaves et al. 2004 Shortreed et al. 2001	Protection of freshwater aquatic life • existing pH > 9.0: No statistically significant increase in pH from background. Short-term increase (2-3 days) to pH 9.5 are permitted for lake restoration projects. Decreases in pH are permitted as long as carbon dioxide concentrations are not elevated above 1360 μmol/L. Carbon dioxide concentrations above 1360 μmol/L may be toxic to fish. • existing pH between 6.5 - 9.0: Unrestricted change permitted within this range. This component of the freshwater guidelines should be used cautiously if the pH change causes the carbon dioxide concentration to decrease below a 10 μmol/L minimum or exceed a 1360 μmol/L maximum. • existing pH < 6.5: No statistically significant decrease in pH from background. No restriction on the increase in pH except in boggy areas that have a unique fauna and flora. Site-specific ambient water quality objectives to restrict the pH increase in areas with a unique fauna and flora are recommended.	MOE 2006a MacDonald et al. 2000
Riparian disturbance	Not specified Proportion of lake perimeter with disturbed riparian zone, accounting (using groupings or weightings) for differences in: • potential for sediment contributions based on upslope (e.g., >60% or ≤60%) or channel gradient • adjacent vegetation type (e.g., Biogeoclimatic zone) • type of disturbance (e.g., variable retention, selective logging, recently harvested, recently burned, urban, agriculture) Account for these factors recognizes differences in riparian functioning across a watershed, ecosystems, or disturbance types.	MOF 2001 Caslys 2007 Province of British Columbia 2000 NOAA 1996 MOF 2001	Functioning condition • 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 "Significant watershed sensitivity" represented by watersheds where > 25 % riparian forest along either bank has been logged within last 40 years (MOF 2001)	NOAA 1996 MOF 2001
	Not specified proportion of lake riparian zone that is bare ground	Tripp and Bird 2004	Not specified • Properly Functioning Condition: <1% • Functioning, but at Risk: 1-5% • Functioning, but at High Risk: 6-10% • Non Functioning: >10%	Tripp and Bird 2004
	Not specified vegetative cover (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	Not specified • Properly Functioning Condition: > 95 % • Functioning, but at Risk: 86 – 95 % • Functioning, but at High Risk: 75 – 85 % • Non Functioning: < 75 %	Tripp and Bird 2004

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Riparian disturbance	Not specified proximity-weighted tally of all near-lake human activities (e.g., weighting based on distance from lake)	Hughes et al. 2004	None specified	
	Not specified shade cover (e.g., % shade cover along lake shoreline section)	Tripp and Bird 2004	Not specified • Properly Functioning Condition: > 95 % • Functioning, but at Risk: 86 – 95 % • Functioning, but at High Risk: 75 – 85 % • Non Functioning: < 75 %	Tripp and Bird 2004
	Not specified proportion of shore length with disturbed riparian zone	NOAA 1996	Functioning condition • 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	NOAA 1996
Watershed: Land cover alterations*	Not specified percent land (PLAND): sum of the area of all patches of a particular type divided by total area of the basin. Patch types can include: • agriculture • urban development • harvested burned diseased • mining • rangeland • landslides (i.e., exposed soil) undisturbed ecosystem type Alternatively, could classify these land uses / patch types using more meaningful classes that more strongly link to watershed-stream processes (e.g., % impervious area, % semi-impervious, % forested, % grass, % exposed).	Alberti et al. 2007 Bradford and Irvine 2000 (CO, CH / stages 1 and 2) Caslys 2007 UBC Sustainable Forest Management Research Group no date	None specified	
	Not specified Shannon diversity index (SHDI): measure of the number of land cover classes across a landscape	Alberti et al. 2007	None specified	
	Not specified Mean patch size (MPS): sum of the areas of all patches divided by the number of patches	Alberti et al. 2007	None specified	
	Not specified Contagion (C): probability that two randomly chosen adjacent cells belong to the same class. Calculated as the product of two probabilities (probability that a randomly chosen cell belongs to category type i, and the conditional probability that given a cell is of category type i, one of its neighboring cells will belong to a different type)	Alberti et al. 2007	None specified	
	Not specified Aggregation index (AI): number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies of that class	Alberti et al. 2007	None specified	
	Not specified Percentage-of-like-adjacency (PLADJ): sum of the number of like adjacencies for each patch type, divided by the total number of cell adjacencies in the landscape, multiplied by 100	Alberti et al. 2007	None specified	
	None specified equivalent clearcut area (ECA): 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 (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 Not specified / Rocky mountain – Inland intermountain region (Stednick 1996) • > 15 % harvest area results in a measurable annual water yield increase • > 50% harvest area, annual water yield increases ranged from 25 to 250 mm • complete harvesting (100% harvest) increased annual water yield from zero to over 350 mm "Significant watershed sensitivity" represented by watersheds where > 20 % has been harvested within last 25 years (MOF 2001) Changes in annual runoff from reductions in forest cover cannot be detected when less than 20% of a watershed is harvested (Recksten 1991)	NOAA 1996 Reksten 1991 MOF 2001 Stednick 1996
	CO, CH / stages 1 and 2 Semiquantitative index of "habitat concerns" comprised of 10 major categories (forestry, agriculture, urbanization, recreation, mining, industrial development, linear development, hydro development, cumulative impacts, and special biophysical concerns)	Bradford and Irvine 2000	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Watershed: Hard surfaces*	Not specified Total impervious surface cover (ISC) (% 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 Smith 2005 Booth et al. 2002	Not specified • 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% General consistency across many paper in North America on this range (summarized in Paul and Meyer 2001) Functioning Condition (Smith 2005) • good: < 3% ISC • fair: 10% ISC • poor: > 10% ISC Not specified (Booth et al. 2002) • maximum 10 % ISC and minimum 65% forest cover Coho seldom found in watershed with ISC 10-15% or greater (Luchetti and Feurstenburg 1993)	Paul and Meyer 2001 Guthrie and Deniseger 2001 UBC 2004 Klein 1979 Luchetti and Feurstenburg 1993 Booth et al. 2002 Smith 2005
	Not specified Connectivity of impervious surfaces to a waterbody network (e.g., mean distance of a waterbody from all impervious surface patches, divided by the percent of impervious surface in the watershed / CU	Synder et al. 2005	None specified	
	Not specified Effective impervious surface cover (i.e., connectivity of impervious surfaces to a waterbody network) (e.g., impervious areas with direct connection to downstream drainage system)	Alberti et al. 2007	Not specified • ≥ 10% effective impervious surface in a watershed results in loss of aquatic system function	Booth and Jackson 1997
Watershed: Road development*	Not specified road density (length per unit area, e.g., km / km^2)	MOF 2001 Bradford and Irvine 2000 (CO Stage 1 and 2) Chu et al. 2003 Forman and Alexander 1998 NACSI 2001 Nelitz et al. 2007b Sharma and Hilborn 2001 Province of BC 2002 Alberti et al. 2007 UBC Sustainable Forest Management Research Group no date NOAA 1996	Not specified Increased peak flows in streams may be evident at road densities of 2–3 km/km^2 (Forman and Alexander 1998) Functioning condition (NOAA 1996): • Properly functioning: < 1.24 km/km^2, no valley bottom roads • At risk: 1.24 – 1.86 km/km^2, some valley bottom roads • Non functioning: > 1.86 km/km^2, many valley bottom roads	Forman and Alexander 1998 NOAA 1996
	Not specified 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)		None specified	
	Not specified proportion of watershed covered by roads (e.g., area of roads / area of watershed)	Forman and Alexander 1998	Not specified Detrimental effects on aquatic ecosystems, based on macro-invertebrate diversity, evident where roads covered 5% or more of a watershed in California	Forman and Alexander 1998
	Not specified roadless volume (e.g., integral of horizontal distance to nearest road over the area of interest, metric simultaneously accounts for footprint area and shape of road network)	Watts et al. 2007	None specified	
	Not specified road network structure (e.g., index of variance in mesh size)	Forman and Alexander 1998 Reed et al. 1996 Miller et al. 1996	None specified	
	Not specified riparian–catchment disturbance index (e.g., seven-class disturbance index combining 5-class riparian disturbance metric and 3-class road density metric)	Hughes et al. 2004	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Water temperature	Not specified Daily average epilimnetic temperature (surface temperature)	Shortreed et al. 2001 Department of Environmental Quality [Oregon] 2006	Protection of freshwater aquatic life in lakes • Natural lakes may not be warmed by more than 0.3 ºC 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
	SK / Stage 1 Maximum daily temperature in shore spawning areas	Bell 1986 Department of Environmental Quality [Oregon] 2006	Protection of freshwater aquatic life • Limit exposure of spawning areas to 13 ºC or greater	Department of Environmental Quality [Oregon] 2006 Bell 1986
	SK / all stages Daily water temperature monitored over the year	MOE 2006a	Protection of freshwater aquatic life in lakes • ± 1 ºC change from natural ambient background	MOE 2006a
	Not specified Classification of thermal regime using single or multiple temperature metrics relevant to salmon (e.g., mean summer temperature, diurnal / seasonal variation, overwinter temperature).	Wehrly et al. 2003 Nelitz et al. 2007	None specified	
	SK / Stage 2 Lethal water temperature upper limit	Ruggerone 2003	SK / Stage 2 • Lethal water temperatures range from 21 – 25 ºC	Ruggerone 2003 Brett 1952
	SK / stage 1 Accumulated thermal units (ATU) over incubation period	Jensen et al. 2002 Holtby 1988 Murray and McPhail. 1988 Beacham and Murray 1990	None specified, though benchmark could be derived using data / models presented within these references to translate optimum daily temperatures to an ATU benchmark. ATU affects date of emergence and survival during incubation.	
	SK / stage 1 and 2 Total useable volume of water with suitable temperature ranges	Hyatt et al. 2007	Upper optimal temperature criteria for SK • Spawning and incubation 13ºC • Juvenile rearing 15ºC • Adult (holding for sexual maturation) 13ºC	MOE 2006a Richter and Kolmes 2005 Newell and Quinn 2005
Wetland disturbance**	Not specified Connectivity of the hydrologic network (e.g., perennial surface water connection to other waterbodies, seasonal surface water connection to other waterbodies, presence of wetlands or corridors in target wetland's vicinity)	Aznar et. Al 2003 Maryland DOE 2007 Fennessy et al. 2004	None specified	
	Not specified Ratio of wetland area to watershed area (can be used to determine water inflow among other things)	Fennessy et al. 2004	None specified	
	Not specified Percentage of historic wetland acreage achieved (i.e., what is the total current wetland acreage relative to historical acreage)	Salwasser et al. 2002	Not specified • Ecologically optimal value or condition for freshwater wetlands: Restoration to wetland acreage and conditions that existed prior to settlement and developments following the mid 1800s where physically and economically possible. Existing physical and economic constraints limit what is possible. • Ecologically possible value or condition for freshwater wetlands: Choose a benchmark definition (i.e., year) reflects perceptions of what is possible where historic data not available and/or not possible to achieve historic benchmark.	Salwasser et al. 2002
	Not specified Total wetland area by type (e.g., acres or km^2)	Maryland DOE 2007 Fennessy et al. 2004	None specified	
	Not specified Wetland acreage change per year (e.g., %)	Salwasser et al. 2002	None specified	
	Not specified Land use by area within a 500 foot zone surrounding the wetland	Maryland DOE 2007 Fennessy et al. 2004	None specified	
	Not specified Plant species richness (Total number of plant species in the wetland)	Chipps et al. 2006 Fennessy et al. 2004	None specified	
	Not specified Proportion of wetland covered by invasive vegetation	Brazner et al. 2007 Chipps et al. 2006 Fennessy et al. 2004	Not specified • Proper functioning condition: < 5 % • At risk functioning condition: 5-25 % • At high risk functioning condition: 26 – 50 % • Non functioning condition: > 50 %	Tripp and Bird 2004

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Invasives	Not specified species richness (e.g., Total number of species)	Gabbard and Fowler 2007 Rosenthal et al. 2006	None proposed for protection of lakes from invasive species	
	Not specified Shannon's diversity index (a measures of diversity that take into account relative abundance of each species in addition to total number of species)	Gabbard and Fowler 2007	None proposed for protection of lakes from invasive species	
	Not specified 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) (see Appendix A)	McGeoch et al. 2006	None proposed for protection of lakes from invasive species	
	Not specified total expanse of land covered by alien plant species (e.g., % of total area per land or ecosystem type inhabited by invasive)	The Heinz Center 2002 Tripp and Bird 2004	Not specified • Proper functioning condition: < 5 % • At risk functioning condition: 5-25 % • At high risk functioning condition: 26 – 50 % • Non functioning condition: > 50 %	Tripp and Bird 2004
Recreational Pressure*	Not specified number of days per year that people engaged in lake related activities (A "recreation day" for this measure is any day during which a person was engaged in the activity, whether for only a few minutes or for many hours).	The Heinz Center 2002	None specified	
	Not specified lake access (e.g., Proximity of a lake to a road (km), number of access points)	Trombulak and Frissell 2000 Hart 2002	None specified	
	Not specified recreation facilities (e.g., number of public facilities within recreation area by type (i.e., washrooms, boat launches, picnic areas, camp grounds))	Hart 2002	None specified	
	Not specified visitor attendance (e.g., number of people per day or number of people per month)	Hart 2002	None specified	
	Not specified 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	None specified	
Lake foreshore development	Not specified foreshore development (e.g., length and/or area of lake foreshore altered for human purposes)	Beeton et al. 2006	None specified	
	Not specified land use types adjacent to the foreshore (e.g., by area or %).	Magnan and Cashin 2005	None specified	
	Not specified shoreline hardening (e.g., extent or % of hardened shoreline, number boat launches per km, number of retaining walls and type, presence/absence of marinas, number of gryones per km, number of docks per km)	Magnan and Cashin 2005 EC and US EPA 2005	None specified	
	Not specified shore types (e.g., percentage of cliff/bluff, sand beach, gravel beach, vegetated, low rocky shore, and wetland)	Magnan and Cashin 2005	None specified	
River deltas	Not specified River delta area (e.g., m^3 or km^3)		None specified	
	Not specified Presence/absence of river delta		None specified	
	Not specified Presence/absence of anthropogenic modification to river delta (e.g., dams, diversions, etc.)		None specified	
	Not specified Water level elevation (e.g., discharge rate of rivers flowing into deltas (m^3/s))	Peters 2006	None specified	

Table 4. List of metrics and benchmarks identified for ESTUARY habitat indicators. Indicators with an asterisk refer to those listed in the basic (*) or ideal (**) options presented on pages 31-32, Tables 9-10 in Nelitz et al. 2007a.

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Disturbance of estuary foreshore habitats**	Not specified / Stage 3 Proportion (%) of estuary foreshore developed or disturbed	FREMP 2006 MOE 2006b CRIS 2002	None specified Significant deviation from an established baseline condition. Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping (1) Point of broad comparison for changing tenure status across all large BC estuaries dating from 2004, as summarized in BC's Coastal Environment Report : 2006 from data in the province's Crown Leases and Licenses database (2) Point of broad comparison for total length of estuary shoreline under different development categories within the Fraser River estuary evaluated at irregular intervals by the Fraser River Estuary Management Program (FREMP) dating from 1979 (3) Point of broad comparison for total length of estuary foreshore disturbed for the southern Straight of Georgia (approximately 1500 km of shoreline) as summarized in Shore Modification Length data attribute in the province's Coastal Resource Information System (CRIS) database	MOE 2006b FREMP 2006 CRIS 2002
Disturbance of in-shore habitats*	Not specified / Stage 3 Proportion (%) of estuary intertidal habitat in different tenure categories (economic, conservation, and no designation)	MOE 2006b	None specified Significant deviation from an established baseline condition. Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping Point of broad comparison for changing tenure status across all large BC estuaries dating from 2004, as summarized in BC's Coastal Environment Report : 2006 from data in the province's Crown Leases and Licenses database	MOE 2006b JNCC 2004
Disturbance of off-shore habitats*	Not specified / Stage 3 Proportion (%) of estuary intertidal habitat in different tenure categories (economic, conservation, and no designation)	MOE 2006b	None specified Significant deviation from an established baseline condition. Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping Point of broad comparison for changing tenure status across all large BC estuaries dating from 2004, as summarized in BC's Coastal Environment Report : 2006 from data in the province's Crown Leases and Licenses database	MOE 2006b
Marine vessel traffic activity*	Not specified / Stage 3 Vessel density (number of vessel movements per traffic reporting zone or per 5km x 5km grid cell)	MOE 2006b Thom and O'Rourke 2005	None specified Significant deviation from an established baseline condition. Point of broad comparison for changes in annual vessel densities in BC coast guard traffic reporting zones beginning in 1999, with a finer scale documentation of vessel densities in 5km x 5km grid cells along the BC coast for 2003, as summarized in BC's Coastal Environment Report : 2006 from data in the Canadian Coast Guard's Marine Communications and Traffic Services Statistics database	MOE 2006b
Invasives	Not specified / Stage 3 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 Thom and O'Rourke 2005	None specified	
	Not specified / Stage 3 Proportion (%) of estuary surface area covered by invasive plant species	The Heinz Center 2002	None specified Significant deviation from an established baseline condition. Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping	
Micro and macro algae	Not specified / Stage 3 Occurrence, distribution and areal extent (m^2, km^2) of intertidal micro and macroalgal beds	Pickerell and Schott 2005 McGinty and Wazniak 2002 Thom and O'Rourke 2005	None specified Significant deviation from an established baseline condition (adjusted for natural change). Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping Point of broad comparison is the systematic one-time mapping of algae distribution in coastal shorezone units for the entire province as part of the inventory for the province's Coastal Resource Information System (CRIS).	CRIS 2002
Aquatic invertebrates	Not specified / Stage 3 Benthic infaunal abundance: total numbers of individuals (total abundance) and total number of species (taxa richness) per m^2	Wilson and Partridge 2007	None specified	

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Aquatic invertebrates	Not specified / Stage 3 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 Thom and O'Rourke 2005	None specified	
	Not specified / Stage 3 Presence/absence/abundance of invertebrate species (or higher taxa) that are indicators of organic enrichment and/or contaminants, or presence/absence/abundance in relation to invertebrate organisms at a reference site (Reference Condition Approach – RCA)	Lowe and Thompson 1997 Sharpe 2005	None specified	
Sediment	Not specified Maximum induced increase in turbidity (e.g., Nephelometric Turbidity Units, NTUs or % of background)	MOE 2006a DFO 2000	For aquatic life in freshwater • 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	MOE 2006a DFO 2000
	Not specified / stage 3 Water clarity - Secchi depth (m)	Wilson and Partridge 2007	• Low water clarity: < 10% of the incident light reaching a depth of 1 m • moderate clarity: 10-25% of incident sunlight reaching 1 m depth • High clarity : > 25% of incident light reaching 1 m depth	Wilson and Partridge 2007 U.S. EPA 2001
	Not specified / stage 3 Water clarity - light transmissivity (% of light transmitted)	Wilson and Partridge 2007	• High water clarity :transmissivity > 25% • Moderate water clarity: in the 10-25% range • Low water clarity: transmissivity < 10%.	Wilson and Partridge 2007 U.S. EPA 2001
	Not specified / stage 3 Total suspended sediments (TSS) (e.g., mg/L, ppm)	DFO 2000 Wilson and Partridge 2007 Thom and O'Rourke 2005	All species/ All stages • < 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.	DFO 2000
	Not specified / stages 1 and 2 Maximum induced increase in suspended sediments (e.g., mg/L, ppm, or % of background)	MOE 2006a CCME 1999 in 2002 DFO 2000	All species / all stages • 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/L when background is between 25 and 250 • 10% when background is greater than or equal to 250	MOE 2006a DFO 2000
	Not specified / Stage 3 Silt-clay content (%) – grain size analysis The percent fines (silt and clay, < 63 μm particle diameter) in bottom sediments is an important determinant of the composition of benthic community composition	Wilson and Partridge 2007 LCREP 2004	None specified	
	Not specified / Stage 3 Ratio of sediment inputs vs. sediment removed through dredging	FREMP 2006	All species / all stages • A balanced sediment budget. Equilibrium in the Fraser sediment budget can be maintained if dredging volumes are kept at 70% of incoming sediment load. This has been evaluated annually for the Fraser River since 1996.	FREMP 2006
Water chemistry / quality	Not specified *Stratification intensity* change in seawater density between near-surface and near-bottom measurements, and *stratification persistence* frequency of strong stratification relative to the total number of samples at a given location	US EPA 2006	None specified	
	Not specified/Stage 3 Salinity (parts per thousand or Practical Salinity Units – psu	Wilson and Partridge 2007 LCREP 2004	For aquatic life in estuarine waters • oligohaline (salinity < 5 psu) • mesohaline (5-18 psu) • polyhaline (> 18 psu)	Wilson and Partridge 2007 U.S. EPA 2001
	Not specified / Stage 3 Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2)	MOE 2006a; Wilson and Partridge 2007; LCREP 2004; Thom and O'Rourke 2005	All species/Stage 3 • Instantaneous minimum of 5 mg/L, 30-day mean of 8 mg/L in water column for all life stages (except embryo / alevin) • System is considered moderately hypoxic if dissolved oxygen is < 5 mg/L, and as severely hypoxic if DO < 2 mg/L	MOE 2006a U.S. EPA 2001 Wilson and Partridge 2007

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Water chemistry / quality	pH	Wilson and Partridge 2007 LCREP 2004 Thom and O'Rourke 2005	For aquatic life in freshwater (nothing specific for estuaries) • Criterion; > 9.0: no statistically significant increase from background • Between 6.5 - 9.0: unrestricted change permitted • Criterion; < 6.5: no statistically significant decrease from background	MOE 2006a
	Not specified / Stage 3 Chlorophyll a (mg/m^2)	MOE 2006 Wilson and Partridge 2007	For aquatic life in streams (nothing specific for estuaries) 100 mg/m^2 (maximum) criterion is designed to protect fish habitat and changes in communities of organisms such as invertebrates which are important themselves or which may be important fish-food organisms	MOE 2006a
	Not specified Nitrogen (e.g., total nitrogen, concentration of nitrate, concentration of nitrite, concentration of total ammonia, µg/L as nitrogen)	MOE 2006a MacDonald et al. 2000 Wilson and Partridge 2007 LCREP 2004 Thom and O'Rourke 2005	Nothing specific for estuaries, guidelines only for freshwater: For aquatic life in freshwater, nitrate: • less than or equal to 40 mg/L (average value, calculated from at least 5 weekly samples taken in a period of 30 days) • 200 mg/L (maximum value) For aquatic life in freshwater, nitrite: • 0.02 mg/L when chloride is less than or equal to 2 mg/L (average value, calculated from at least 5 weekly samples taken in a period of 30 days) • 0.06 mg/L when chloride is less than or equal to 2 mg/L (maximum value) • criteria increase with increasing concentrations of chloride For aquatic life in freshwater, total ammonia: • 1.84 mg/L; 30-day average at 10ºC and pH = 7.0 • 20.5 mg/L; maximum at 10ºC and pH = 7.0 • criteria are highly variable; depend on water temperature and pH (i.e., lower criteria at warmer temp and higher pH)	MOE 2006a MacDonald et al. 2000
	Not specified/Stage 3 Phosphorus	Wilson & Partridge 2007; LCREP 2004; Thom and O'Rourke 2005	For aquatic life in freshwater (nothing specific for estuaries) • 30 µg/L (for chronic exposure limiting growth of algae and aquatic plants in streams/rivers, benchmark from Quebec)	MacDonald et al. 2000
	Not specified/Stage 3 Nitrogen:Phosporus (N:P) ratio	Wilson and Partridge 2007	For aquatic life in freshwater/estuaries • N:P ratio < 16 may indicate nitrogen-limitation, whereas an N:P ratio > 16 may indicate phosphorus-limitation in freshwater and estuarine systems	Wilson and Partridge 2007
	Not specified/Stage 3 Metals (µg/g, mg/kg dry weight in sediment or µg/L in water) – e.g., key ones for tracking could include aluminum, antimony, arsenic, copper, lead, mercury, manganese, nickel, silver, and zinc	Wilson and Partridge 2007; MOE 2006a; U.S. EPA 2007; Thom and O'Rourke 2005	For aquatic life in freshwater Various recommended maximum concentrations dependent on the particular metal evaluated (e.g., mercury guidelines for estuarine aquatic life: maximum = 2.0 µg/L at any one time, or 30 day average of 0.02 µg/L, also see Table 8)	MOE 2006a MacDonald et al. 2000
	Not specified/Stage 3 Polycyclic Aromatic Hydrocarbons (PAHs) (µg/L)	Wilson and Partridge 2007 MOE 2006a Thom and O'Rourke 2005	For aquatic life in marine and freshwater • Varied recommended maximum concentrations dependent on the particular PAH compound evaluated e.g., Naphthalene: maximum = 0.01 µg/g in freshwater or marine sediments (also see Table 9)	MOE 2006a MacDonald et al. 2000
	Not specified/Stage 3 Polychlorinated Biphenyls (PCBs) (ng/L)	Wilson and Partridge 2007; MOE 2006a; Thom and O'Rourke 2005	For aquatic life in marine and freshwater 0.1 ng/L PCBs (total) recommended maximum concentration	MOE 2006a
	Not specified/Stage 3 Bacterial contamination – fecal coliform (coliforms/L or Most Probable Number – MPN)	MOE 2006a U.S. EPA 2007 Thom and O'Rourke 2005	For shellfish waters Shellfish growing areas are closed to harvesting if the fecal coliform densities in the water exceed a median or geometric mean of 14 Most Probable Number (MPN) or more than 10 % of the samples are greater than 43 MPN per 100 ml.	Shellfish Water Quality Protection Program 2007
	Not specified/Stage 3 Sediment Quality Index - a sediment quality index used by US EPA for its National Estuary Program is based on three component indicators of sediment condition: direct measures of sediment toxicity, sediment contaminant concentrations, and the sediment Total Organic Carbon (TOC) concentration. The concentrations of 91 different chemical constituents in sediments are measured to determine the sediment contaminants component of the index. Sediment toxicity is evaluated by measuring the survival of a marine amphipod following 10-day exposure under laboratory conditions. Sediment TOC concentration is measured on a dry-weight basis (see Appendix A).	U.S. EPA 2007	See Appendix A for US EPA criteria for composite rating of monitoring sites, estuaries and regions for sediment quality (poor, fair, good ratings)	U.S. EPA 2007
	Not specified/Stage 3 Water Quality Index—a water quality index used by the US EPA for its National Estuary Program is based on five water quality component indicators (Dissolved Inorganic Nitrogen (DIN), Dissolved Inorganic Phosphorus (DIP), chlorophyll a, water clarity, and dissolved oxygen)). See Example 3, Appendix A for a description of this derived US EPA metric.	U.S. EPA 2007	See Appendix A for US EPA criteria for composite rating of monitoring sites, estuaries and regions for sediment quality (poor, fair, good ratings)	U.S. EPA 2007

Indicator	Description of metric (by species / life stage)	Relevant citation(s) for metric	Description of benchmark (by species / life stage / geographic region)	Relevant citation(s) for benchmark
Detrital organic matter	Not specified/Stage 3 Total organic carbon (%) in sediment	Wilson and Partridge 2007 LCREP 2004	For aquatic life in freshwater • Recommended maximum: ± 20% change from the 30-day median background concentration • Recommended minimums: none specified (locale dependent)	MOE 2006a
	Not specified/Stage 3 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	None specified	
Eelgrass habitats**	Not specified/Stage 3 Eelgrass distribution (e.g., m^2, minimum and maximum depth, patchiness index)	U.S. EPA 2007 Sewell et al. 2001 Pickerell and Schott 2005 Thom and O'Rourke 2005	None specified Significant deviation from an established baseline condition (adjusted for natural change). Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping Point of broad comparison is the systematic one-time mapping of eelgrass distribution in coastal shorezone units for the entire province as part of the inventory for the province's Coastal Resource Information System (CRIS).	CRIS 2002
	Not specified/Stage 3 Eelgrass condition (e.g., mean shoot density, leaf area index)	U.S. EPA 2007 Sewell et al. 2001 Pickerell and Schott 2005 NOAA 2007b	None specified	
	Not specified/Stage 3 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). See Appendix A for an illustration of how this metric has been included within a composite index used for scoring and ranking the importance of BC estuaries for coastal waterbirds.	Ryder et al. 2007	None specified Significant deviation from an established baseline condition (adjusted for natural change). Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping Point of broad comparison is the systematic one-time mapping of eelgrass distribution in coastal shorezone units for the entire province as part of the inventory for the province's Coastal Resource Information System (CRIS) and used by the Canadian Wildlife Service to generate a derived eelgrass rarity index for 442 estuaries in BC.	CRIS 2002 Ryder et al. 2007
Spatial distribution of wetlands / mudflats	Not specified/Stage 3 Total area (ha) and proportion (%) of total estuarine area in different habitat type categories/classifications	LCREMP 2004 Bain et al. 2006 JNCC 2004 Thom and O'Rourke 2005	None specified Significant deviation from an established baseline condition (adjusted for natural change). Possible sources of baseline data are archived remote sensing, aerial photographs and/or localized intertidal resource mapping	
Riparian vegetation**	Not specified/Stage 3 Proportion (%) of estuarine riparian zone disturbed	CRIS 2002 FMEMP 2006 Thom and O'Rourke 2005	None specified Significant deviation from an established baseline condition (adjusted for natural change). Possible sources of baseline data are archived remote sensing, aerial photographs and/or intertidal resource mapping (1) Point of broad comparison for existing estuarine riparian vegetation for the southern Straight of Georgia (approximately 1500 km of shoreline) as summarized by the % riparian occurrence and total length of riparian vegetation in shoreline units data attributes summarized in the province's Coastal Resource Information System (CRIS) database (2) Point of broad comparison for total extent of riparian vegetation within the Fraser River estuary evaluated at irregular intervals by the Fraser River Estuary Management Program (FREMP) dating from 1979	CRIS 2002 FREMP 2006
Resident fish	Fish species abundance (total numbers of individuals per tow) (with emphasis on demersal species)	Wilson and Partridge 2007; NOAA 2007b; Thom and O'Rourke 2005	None specified	
	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	None specified	
	Gross fish pathology (frequency of gross external pathologies - lumps, ulcers, growths, fin erosion and parasites)	Wilson and Partridge 2007	None specified	

Table 5. Summary of optimum temperatures for salmon (from MOE 2006a).

Species	Incubation	Rearing	Migration	Spawning
Pink	4.0-13.0	9.3-15.5	7.2-15.6	7.2-12.8
Coho	4.0-13.0	9.0-16.0	7.2-15.6	4.4-12.8
Chinook	5.0-14.0	10.0-15.5	3.3-19.0	5.6-13.9
Sockeye	4.0-13.0	10.0-15.0	7.2-15.6	10.6-12.8
Chum	4.0-13.0	12.0-14.0	8.3-15.6	7.2-12.8

Table 6. Summary of recommended values for pool frequency in stream and river reaches (NOAA 1996).

Channel width (km)	Number of pools per km
1.52	102
3.05	60
4.57	44
6.1	35
7.62	30
15.24	17
22.86	15
30.48	12

Table 7. Summary of recommended threshold values for different levels of proper functioning condition by physiographic region, biogeoclimatic zone, and channel type (drawn from Tripp and Bird 2004). Numbers are the percent of observations where gravel bars / bed scour are recorded at 50 points along a 50 bankfull width long transect.

				Functioning condition			
Indicator	Physiographic region	BEC zone productivity	Channel type	Proper	At risk	At high risk	Non functional
Bar frequency	All	High	Pool-riffle	<73	73-90	91-98	>98
	All	High	Step-pool	<48	48-60	61-78	>78
	All	Low	Pool-riffle	<46	47-54	55-66	>66
	All	Low	Step-pool	<65	66-74	75-84	>84
Bed scour	Mountains	High	Pool-riffle	<13	14-18	19-28	>28
	Mountains	High	Step-pool	<19	20-24	25-34	>34
	Mountains	Low	Pool-riffle	<13	14-18	19-28	>28
	Mountains	Low	Step-pool	<11	12-14	15-22	>22
	Plateaus	High	Pool-riffle	<7	8-10	11-16	>16
	Plateaus	High	Step-pool	<13	14-16	17-24	>24
	Plateaus	Low	Pool-riffle	<9	10-11	12-16	>16
	Plateaus	Low	Step-pool	<7	8-9	10-12	>12

Table 8. Summary of marine and estuarine aquatic life guidelines for metals in BC estuaries (BC MOE 2006a).

Metal	30-day averages	Maximum
Copper	less than or equal to 2 µg/L	3 µg/L
Lead	less than or equal to 2 µg/L total lead (80% of the values less than or equal to 3 µg/L total lead)	140 µg/L
Mercury	0.02 µg/L	2.0 µg/L
Silver	1.5 µg/L	3.0 µg/L
Zinc	-	10 µg/L
Arsenic	-	12.5 (interim guidelines)
Chromium	Guidelines under development by BC MOE	
Manganese	For freshwater aquatic life: 0.7 mg/L when CaCo3 hardness 25 mg/L 0.8 mg/L when CaCo3 hardness 50 mg/L 1.0 mg/L when CaCo3 hardness 100 mg/L 1.3 mg/L when CaCo3 hardness 150 mg/L 1.9 mg/L when CaCo3 hardness 300 mg/L	For freshwater aquatic life: 0.8 mg/L when CaCo3 hardness 25 mg/L 1.1 mg/L when CaCo3 hardness 50 mg/L 1.6 mg/L when CaCo3 hardness 100 mg/L 2.2 mg/L when CaCo3 hardness 150 mg/L 3.8 mg/L when CaCo3 hardness 300 mg/L
Aluminium	None proposed for marine and estuarine aquatic life	None proposed for marine and estuarine aquatic life

Table 9. Summary of aquatic life and sediment guidelines for polycyclic aromatic hydrocarbons (PAHs) (BC MOE 2006a)

Polycyclic aromatic hydrocarbons	Freshwater (chronic)	Freshwater (phototoxic)	Marine water	Sediments in freshwater	Sediments in marine water
Naphthalene	1 µg/L	NR	1 µg/L	0.01 µg/g	0.01 µg/g
Methylated naphthalene	NR	NR	1 µg/L	NR	NR
Acenaphthene	6 µg/L	NR	6 µg/L	0.15 µg/g	0.15 µg/g
Fluorene	12 µg/L	NR	12 µg/L	0.2 µg/g	0.2 µg/g
Anthracene	4 µg/L	0.1 µg/L	NR	0.6 µg/g	NR
Phenanthrene	0.3 µg/L	NR	NR	0.04 µg/g	NR
Acridene	3 µg/L	0.05 µg/L	NR	1 µg/g	NR
Fluoranthene	4 µg/L	0.2 µg/L	NR	2 µg/g	NR
Pyrene	NR	0.02 µg/L	NR	NR	NR
Chrysene	NR	NR	0.1 µg/L	NR	0.2 µg/g
Benz[a] anthracene	0.1 µg/L	0.1 µg/L	NR	0.2 µg/g	NR
Benzo[a]pyrene	0.01 µg/L	NR	0.01 µg/L	0.06 µg/L	0.06 µg/L
Naphthalene	1 µg/L	NR	1 µg/L	0.01 µg/g	0.01 µg/g

NR — not recommended due to insufficient data

Table 10. 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 on pages 31-32, Tables 9-10 in Nelitz et al. 2007a.

	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; MOE 2006a, NOAA 1996)	Use common standards identified to protect aquatic life in freshwater (DFO 2002; Kondolf 2000; Lisle 1989; 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.	
Water chemistry	Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2) (MOE 2006a)	Recommend thresholds used for protection of aquatic life in freshwater (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

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
Water chemistry	Total nitrogen (e.g., µg/L) (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.	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.
	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) (MOE 2006a)	Recommend thresholds used for protection of aquatic life in freshwater (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.	
Riparian disturbance*	Proportion of stream length with disturbed riparian zone, accounting (using groupings or weightings) for differences in (MOF 2001; Caslys 2007; Province of British Columbia 2000; 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)	Functioning condition (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 Category 1 – 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).

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
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 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.
	Equivalent clearcut area (ECA): 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 There was general consistency in a 15-20% benchmark across reviewed references. These benchmarks fit generally within Category 1 – benchmarks based on dose-response relationships.	
Watershed: Hard surfaces*	Total impervious surface cover (ISC) (% 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)	Not specified 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.

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
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-stream crossings (number of road-stream crossings per unit area, e.g., # / km^2 or # / km) (MOF 2001; Albeti 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.	
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 (see Table 5). 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.

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
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).	
	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.

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
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.
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; 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.	

	Recommendation		
Indicator	Related metric(s)	Related benchmark(s)	Rationale for recommendation
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).
Stream discharge*	Magnitude of flow events (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, 2002; 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 Category 1. 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 Category 6 – 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.
	Timing of flow events (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, 2002)	No appropriate benchmarks identified. 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 Category 6 – probabilistic benchmarks to determine variation in timing of flow events and their coincidence with critical life history events.	

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
Large woody debris and in-stream cover	Fish cover diversity (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.
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 11. 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 on pages 31-32, Tables 9-10 in Nelitz et al. 2007a.

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
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.	

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
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; 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)

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Water chemistry*	<u>Total phosphorous</u> (e.g., µg/L) (MOE 2006a; Gregory-Eaves et al. 2004; Johnston et al. 2004; Shortreed et al. 2004)	Recommend range of total phosphorus in freshwater from MOE 2006a: • 5 to 15 µg/L (inclusive) This benchmark would fit within <u>Category 1</u> – benchmarks based on dose-response relationships. Management focus could be to address lakes that are continually eutrophic due to anthropogenic activities.	(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 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).
	<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 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.	
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; 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.	

Indicator	Recommendation: Related metric(s)	Recommendation: 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 2002)	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

<table>
<tr><th rowspan="2">Indicator</th><th colspan="2">Recommendation</th><th rowspan="2">Rationale for recommendation</th></tr>
<tr><th>Related metric(s)</th><th>Related benchmark(s)</th></tr>
<tr><td></td><td><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)</td><td>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</td><td>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 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.</td></tr>
<tr><td>Watershed: Hard surfaces*</td><td><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)</td><td><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</td><td>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.</td></tr>
</table>

Indicator	Recommendation: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
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 the shoreline that can result in disruption of lake sediment transport and degradation of riparian habitat (EC and US EPA

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.	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 (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 (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		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
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 12. 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 on pages 31-32, Tables 9-10 in Nelitz et al. 2007a.

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; 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; 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) (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 (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) (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. (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: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
Marine vessel traffic activity*	Vessel density (number of vessel movements per traffic reporting zone or per 5km x 5km grid cell) (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. (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 200)	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: Related metric(s)	Recommendation: Related benchmark(s)	Rationale for recommendation
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, 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	Total suspended sediments (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 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).	Suspended sediments can affect use / survival of habitat for rearing juveniles or smolts. Other possible metrics are more indirect measures of effects on salmon.
	Maximum induced increase in turbidity (e.g., Nephelometric Turbidity Units, NTUs or % of background) (MOE 2006a; DFO 2000)	Use thresholds for turbidity as identified by various sources (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 Category 1 – 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	Metals (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; MOE 2006b)	Use thresholds for metals as identified by various sources (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 Category 1 – 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).

<table>
<tr><th rowspan="2">Indicator</th><th colspan="2">Recommendation</th><th rowspan="2">Rationale for recommendation</th></tr>
<tr><th>Related metric(s)</th><th>Related benchmark(s)</th></tr>
<tr><td rowspan="6">Water chemistry / quality</td><td>Polycyclic Aromatic Hydrocarbons (PAHs) (µg/L)
(Wilson and Partridge 2007; MOE 2006b)</td><td>Use thresholds for PAHs as identified by various sources (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</td><td rowspan="6">Pollutants such PCBs, polycyclic aromatic hydrocarbons (PAHs), 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).</td></tr>
<tr><td>Polychlorinated Biphenyls (PCBs) (ng/L)
(Wilson and Partridge 2007; MOE 2006b)</td><td>Use thresholds for PCBs as identified by various sources (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</td></tr>
<tr><td>Total nitrogen (e.g., µg/L)
(MOE 2006a; MacDonald et al. 2000; Wilson and Partridge 2007; LCREP 2004)</td><td>No appropriate benchmarks identified for estuaries. Recommend developing Category 2 – benchmarks using ranges of natural variation.</td></tr>
<tr><td>Phosphorous (e.g., µg/L)
(Wilson and Partridge 2007; LCREP 2004)</td><td>No appropriate benchmarks identified for estuaries. Recommend developing Category 2 – benchmarks using ranges of natural variation.</td></tr>
<tr><td>Nitrogen to phosphorous ratio (N:P ratio) (Wilson and Partridge 2007)</td><td>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.</td></tr>
<tr><td>Dissolved oxygen (e.g., concentration of dissolved oxygen, mg/L O_2)
(MOE 2006a; Wilson and Partridge 2007; LCREP 2004)</td><td>These thresholds consistent with Category 1 drawn from MOE 2006a; U.S. 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</td></tr>
</table>

Indicator	Recommendation		Rationale for recommendation
	Related metric(s)	Related benchmark(s)	
Detrital organic matter	Total organic carbon (TOC) (%) in sediment (Wilson and Partridge 2007; LCREP 2004)	Use thresholds for TOC as identified by various sources (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	<u>Fish species abundance</u> (total numbers of individuals per tow) (with emphasis on demersal species) (Wilson and Partridge 2007; NOAA 2007b) <u>Fish species richness and diversity</u> (total number of species per tow or per m^3, Shannon Weaver Diversity Index) (Wilson and Partridge 2007; NOAA 2007b) <u>Gross fish pathology</u> (frequency of gross external pathologies - lumps, ulcers, growths, fin erosion and parasites) (Wilson and Partridge 2007).	<u>No appropriate benchmarks identified</u>. Recommend developing <u>Category 3</u> – 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 <u>Category 4</u> – 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	<u>Estuary size</u> (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) <u>Estuary Size Index (ESI)</u> (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)	<u>Not relevant</u>	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.
Accessible Off-channel Habitat	<u>Total accessible off-channel habitat area</u> (m^2 or km^2) <u>Number of accessible off-channel habitats</u> (#)	<u>Not relevant</u>	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.

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Appendix A – Index mock-ups

Example #1: Hypothetical examples illustrating development of a watershed disturbance index

The key to developing the proposed watershed disturbance index would be to group watersheds according to their similarities in disturbance features that most strongly affect salmon and their habitats. Watershed groupings could then be ranked in terms of their relative hazard to salmon and their habitats. For instance, Hughes et al. (2007) used two disturbance features (e.g., riparian disturbance and road density) to create an index of riparian-catchment disturbance. Table A1.1 illustrates the 3 road density and 5 riparian disturbance classes used to group similar watersheds. Each group was then assigned an index value between 1 and 7 to delineate the relative differences in disturbance among groups. This scoring system recognizes that watersheds with the highest road density and riparian disturbance also have the highest index value, or pose the greatest hazard to instream habitats.

Table A1.1. Sample riparian–catchment disturbance index from Hughes et al. 2007.

Road density	Riparian disturbance class				
(km / km^2)	Absent	Low	Medium	High	Very High
<1.3	1	2	3	4	5
1.3–1.9	2	3	4	5	6
> 1.9	3	4	5	6	7

An alternative and more sophisticated approach to developing a watershed disturbance index would be to use more watershed disturbance variables than discussed above (e.g., riparian disturbance, road development, impervious surface cover, land cover alterations, etc.). A disturbance index could then be developed using a multiple regression technique, such a Classification and Regression Tree (CART) analysis (Brieman et al. 1984; Yohannes and Webb 1999; Lamon and Stow 1999; Wing and Skaugset 2002; Nelitz et al. 2007b) to explain differences in impacts on salmon and their habitats across watersheds. CART is a statistical method, similar to multiple regression, in that it can draw upon multiple explanatory variables (i.e., disturbance indicators) to explain variation in a single response variable (i.e., changes in salmon populations or habitat indicators). For some purposes it is more useful than multiple regression because it can cope with non-additive and non-linear relationships among indicators, and document the relative importance among them. The output resulting from this analysis is a tree diagram (see sample Figure A1.1) which can be used in a similar way as a taxonomic key to classify watersheds. For instance, a single watershed can be traced along appropriate branches in the tree to group watersheds with similar features and similar effects on salmon and their habitats. Final watersheds classes can then be ranked according to their anticipated level of disturbance and hazard to salmon. Rankings of watersheds classes according to their significance of impacts could follow either a linear weighting (see Index Score 1, Figure A1.1), or a more sophisticated non-linear weighting (see Index Score 2, Figure A1.1).

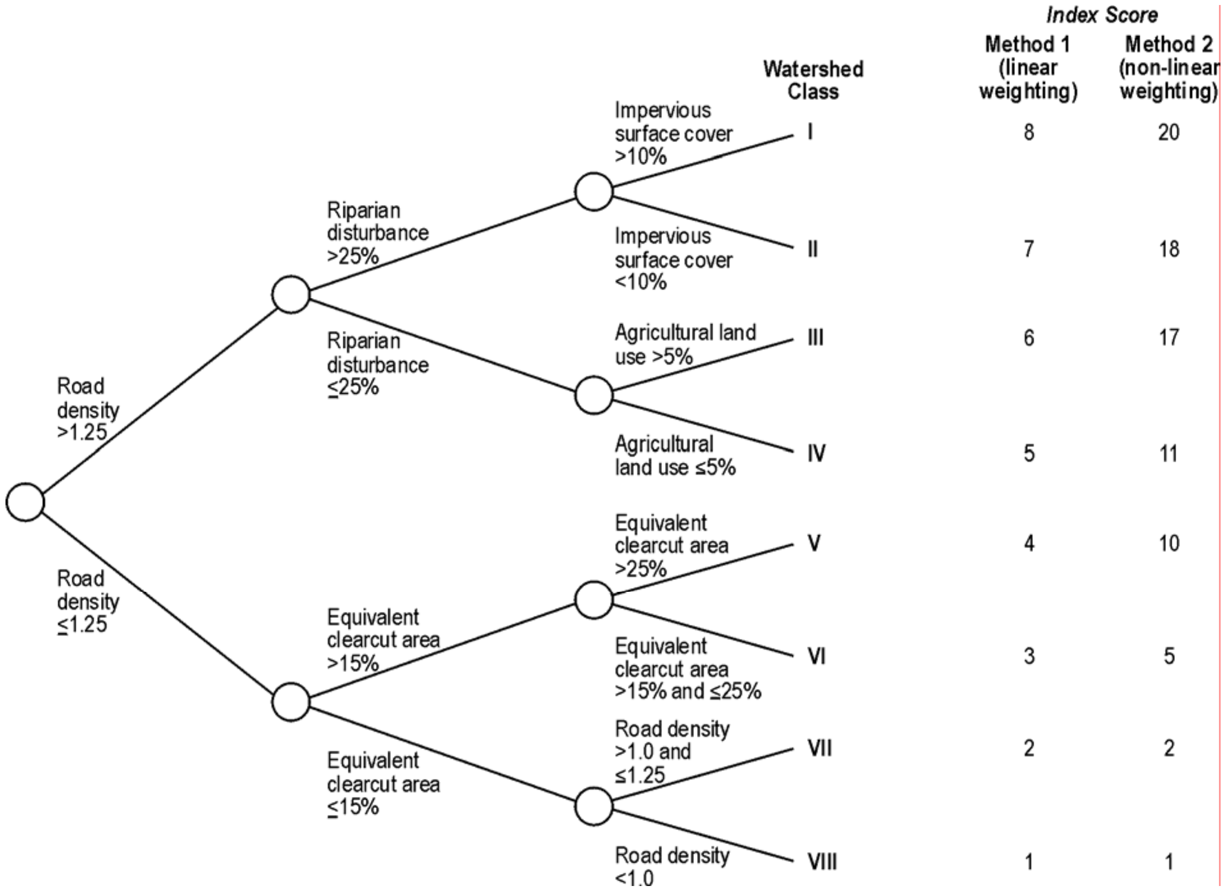

Figure A1.1. Hypothetical tree diagram from a Classification and Regression Tree (CART) analysis. Resulting Watershed Classes could be used to develop an index of watershed disturbance based on the anticipated magnitude of effect on salmon and their habitats. Two alternative methods of assigning Index Scores are illustrated. Method 1 represents a hypothetical linear weighting of significance, while Method 2 represents a hypothetical nonlinear weighting of significance.

Example #2: Illustration of how to generate a non-native status index for Invasives indicator in lakes or estuaries[5]

Invasive species present in each locations:

Watershed A	Watershed B	Watershed C
Eurasion watermilfoil (Type IV)	Hydrilla (Type IV)	Diffuse knapweed (Type IV)
Yellow floating hearts (Type IV)	Scotch Thistle (Type II)	Lady's thumb (Type II)
Bog rush (Type II)	Canada Thistle (Type III)	Yellow toadflax (Type III)
White cockle (Type II)	Bullfrog (Type II)	White cockle (Type II)
Black knapweed (Type IV)	Black knapweed (Type IV)	Canada Thistle (Type III)
Leafy spurge (Type IV)		
Yellow perch (Type II)		

Summary of number of invasive species of each types per watershed:

	Watershed A	Watershed B	Watershed C
N_I	0	0	0
N_{II}	3	2	2
N_{III}	0	1	2
N_{IV}	4	2	1

A working example of a potential index [6] that can be used to rank watersheds relative to each other:

(1) $$N = \alpha N_I + \beta N_{II} + \gamma N_{III} + \lambda N_{IV} \ ,$$

where α, β, γ, and λ are coefficients and can be assigned a value between 0 and 1 that will reflect the desired weight of each type of invasive species (N_I, N_{II}, N_{III}, and N_{IV}), where N is the number of each type of invasive species.

For example, if:

$$\alpha = 0.11,\ \beta = 0.21,\ \gamma = 0.75, \text{ and } \lambda = 0.85$$

Index scores for each watershed using equation 1 and above coefficient values:

	Watershed A	Watershed B	Watershed C
Score	4.03	2.87	2.77

According to these index scores the watershed of highest priority with respect to invasives is Watershed A, Watershed B is second, and Watershed C is last.

[5] Examples described here are fictional as are species classification (i.e., N_I, N_{II}, N_{III}, N_{IV})

[6] Index is only provided as an example and can take any desired form to reflect desired management objectives. Likewise, the coefficients assigned are arbitrary and values chosen should be scientifically defensible and match management objectives.

Notes on potential data sources and species weightings:

Although a fair amount of data collection is ongoing for terrestrial alien plant species in BC (e.g., Invasive Alien Plant Program), there appears to be no equivalent province wide monitoring initiative for aquatic alien species distribution. Data on aquatic invasives are collected either opportunistically with limited spatial coverage (e.g., Community Mapping Network Invasive species atlas and FISS) or are part of a localized effort without a standardised monitoring protocol (e.g., Cultus and Okanagan Lakes Eurasian milfoil eradication program). The data and information on alien species that is available is sufficient to inform baseline variation for those areas where data have been collected and would allow alien species to categorized by type as outlined in McGeoch et al. (2006).

With respect to index formulation and weightings, there are a variety of ways from which this may be approached. McGeoch et al. (2006) only consider type III and IV in their national index for invasive species and the weighting is uniform between the two types. However, it is possible to take into account all four types of invasives and to weight them with respect to their destructive potential as illustrated in the above example. Another approach may be to create an alternative classification scheme along a continuum where type I alien species are those that do not affect salmon in anyway and type IV are those that render ecosystem conditions unfit for salmon. This approach would require the development of rigid and defensible criteria. Weightings between types could be assigned according to some formulary so that watersheds containing species with the greatest negative impact on salmon would be ranked highest in terms of priority. Unfortunately, data on salmon and invasive species interactions is not available for the majority of invasive species in BC; consequently, this approach may not be feasible unless resources are invested in research and data collection in the area.

Example #3: Sediment Quality Index used by US EPA within their National Estuary Program (NEP) for monitoring and comparing estuarine sediment contamination.

Table A3.1 Sediment Quality Index —The US EPA composite sediment quality index is based on three sediment quality component indicators (sediment toxicity, sediment contaminants, and sediment total organic carbon (TOC)).

Overall Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: No component indicators are rated poor, and the sediment contaminants indicator is rated good.	Good: Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: No component indicators are rated poor, and the sediment contaminants indicator is rated fair.	Fair: 5% to 15% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: One or more component indicators are rated poor.	Poor: More than 15% of the NEP estuarine area is in poor condition.

Table A3.2. National Coastal Assessment (NCA) criteria at ecological monitoring sites on the Pacific West Coast for the three individual component metrics within the overall Sediment Quality Index used for assessing NEP estuarine condition.

	Metric rating		
Component metric	Good	Fair	Poor
(1) Sediment Toxicity is evaluated as part of the sediment quality index using a 10-day static toxicity test with the amphipod *Ampelisca abdita*.	Mortality is less than or equal to 20%.		Mortality is greater than 20%.
(2) Sediment Contamination is evaluated as part of the sediment quality index using ERM[7] and ERL[8] guidelines.	No ERM values are exceeded, and fewer than five ERL values are exceeded.	No ERM values are exceeded, and five or more ERL values are exceeded.	One or more ERM values are exceeded.
(3) Sediment Total Organic Carbon (TOC) is measured as part of the sediment quality index.	The TOC concentration is less than 2%.	The TOC concentration is between 2% and 5%.	The TOC concentration is greater than 5%.

[7] ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.
[8] ERL (Effects Range Low)—Determined for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

Example #4: Water Quality Index used by US EPA within their National Estuary Program (NEP) for monitoring and comparing estuarine water quality condition.

Table A41 Water Quality Index—The US EPA composite water quality index is based on five water quality component indicators (dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chlorophyll a, water clarity, and dissolved oxygen).

Overall Ecological Condition by Site	Overall Water Quality Ranking by NEP Estuary or Region
Good: No component metrics are rated poor, and a maximum of one component indicator is rated fair.	Good: Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: One component metric is rated poor, or two or more component indicators are rated fair.	Fair: 10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: Two or more component metrics are rated poor.	Poor: More than 20% of the NEP estuarine area is in poor condition.

Table A4.2. National Coastal Assessment (NCA) criteria at ecological monitoring sites on the Pacific West Coast for the five individual component metrics within the overall Water Quality Index used for assessing NEP estuarine condition.

	Metric rating		
Component metrics	Good	Fair	Poor
(1) Dissolved Inorganic Nitrogen (DIN)	Surface concentrations are less than 0.5 mg/L	Surface concentrations are 0.5–1.0 mg/L	Surface concentrations are greater than 1.0 mg/L
(2) Dissolved Inorganic Phosphorus (DIP)	Surface concentrations are less 0.01 mg/L	Surface concentrations are 0.01–0.1 mg/L	Surface concentrations are greater 0.1 mg/L
(3) Chlorophyll a	Surface concentrations are less than 5 µg/L	Surface concentrations are between 5 µg/L and 20 µg/L	Surface concentrations are greater than 20 µg/L
(4) Water Clarity[9]	WCI ratio is greater than 2	WCI ratio is between 1 and 2	WCI ratio is less than 1
(5) Dissolved Oxygen	Concentrations are greater than 5 mg/L	Concentrations are between 2 mg/L and 5 mg/L	Concentrations are less than 2 mg/L

[9] Note: A water clarity index (WCI) is calculated by dividing observed clarity at 1 meter by a regional reference clarity at 1 meter. This regional reference is10% for most of the United States, 5% for areas with naturally high turbidity, and 20% for areas with significant submerged aquatic vegetation beds or active submerged aquatic vegetation restoration programs.

Example #5: The Canadian Wildlife Service's (CWS) approach to scoring and ranking of BC estuaries for biological importance for coastal waterbirds.

Table A5.1. Summary of attributes used by the Canadian Wildlife Service to estimate a Biological Importance Score for each of 442 BC estuaries.

Attribute	Name	Description
Estuary Size	Estuary Size Index (ESI)	Overall size of estuaries obtained from the mapping procedure
Habitat Type	Habitat Rarity Index (HRI)	An estuary's contribution to the provincial total for intertidal area and saltmarsh and swamp habitat
Intertidal Species	Species Rarity Index (SRI)	An estuary's contribution to the provincial total for the following intertidal species: mussels, kelp, *Salicornia, Ulva*, and eelgrass
Waterbird Density	Waterbird Density Index (WDI)	Density of over-wintering waterbirds using an estuary
Herring Spawn Events	Herring Spawn Index (HSI)	Frequency and size of herring spawn events occurring at an estuary

Data for each of the five variables was analyzed by various methods to calculate a score for each estuary (see Figure A5.1 and Ryder et al. 2007 for details of algorithms used for generating individual component index scores). The Biological Importance Score for each estuary was then calculated by combining the rankings for each category and weighting the categories based upon biological importance and confidence in the data such that:

$$\text{Importance} = 0.3(ESI) + 0.15(HRI) + 0.2(SRI) + 0.1(WDI) + 0.25(HSI).$$

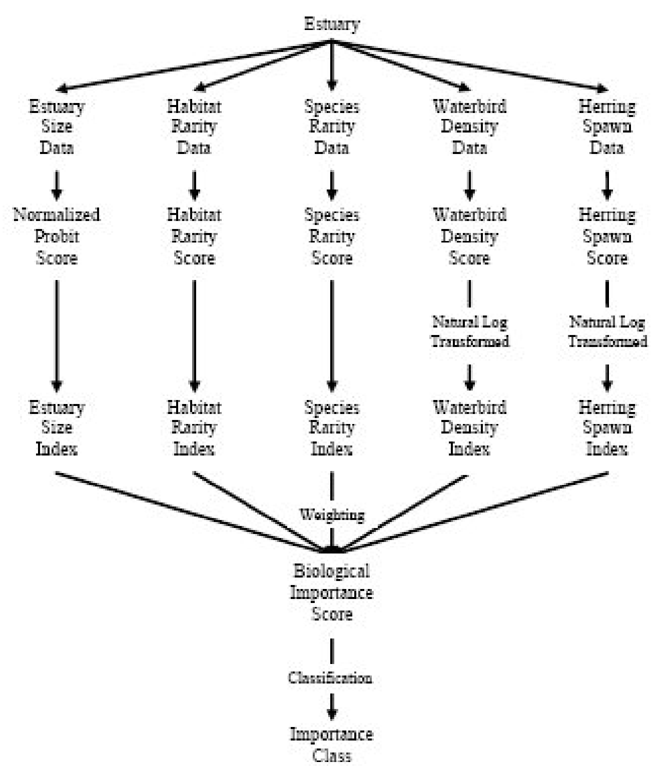

Figure A5.1. Components used to assign estuaries with an importance class for coastal waterbirds. Component data were analyzed using various methods. Each estuary was assigned an Importance Class based on its Biological Importance Score relative to maximum Score (from Ryder et al. 2007).