Monitoring Land Use Impacts on Fish Sustainability in Forest Environments

Final Report

Prepared by

Kent Gustavson
Gustavson Ecological Resource Consulting
PO Box 115
Gabriola, BC V0R 1X0
Tel: (250) 247-9734
Fax: (250) 247-9735
E-mail: kent@gerc.bc.ca

and

Daryl Brown
Daryl Brown Associates Inc.
1742 Green Oaks Terrace
Victoria, BC V8S 2B1
Tel: (250) 598-6086
Fax: (250) 598-6050
E-mail: darylbrown@home.com

Prepared for

Ministry of Sustainable Resource Management
Aquatic Information Branch
PO Box 9358 Stn Prov Govt
2975 Jutland Road
Victoria, BC V8W 9M2

15 March 2002

Executive Summary

This study defines criteria, indicators, data sources, and data collection methods for examining land use impacts on fish and fish habitat in forest environments. As part of a larger project that will review indicators of fish and fish habitat sustainability in forest environments, the study is working towards developing a toolkit of monitoring standards. Achieving the objectives of the study involved the following tasks: 1) reviewing accomplishments to date; 2) proposing appropriate indicators; 3) conducting a consultation workshop; and, 4) making final recommendation to define criteria, indicators, and methods, as well as developing a guide for decision-making.

In the review of accomplishments to date, the report describes: 1) indicator and monitoring initiatives related to sustainable forest management; 2) research efforts to identify indicators and monitoring systems; and, 3) related corporate data systems. Indicator and monitoring initiatives to define and track sustainable forest management have been developed at a range of levels. Components of this existing work are potentially relevant for identifying indicators for assessing the effects of forest land use activities on fish and fish habitat. It is critical that the selection process for indicators evaluate existing and developing sources of data and information, particularly those that form part of ongoing collection programs. A selected indicator set must be sufficient, yet take advantage of other government and private sector programs where appropriate.

The ultimate uses of indicator measurements and the monitoring framework that will be implemented to provide information for decision-makers must be understood in order to ensure appropriate indicator selection. To this end, the report discusses: the "business drivers" that supply the underlying motivation to invest in indicator development and implementation (i.e., the questions to which resource managers need answers); the distinct types of uses to which indicators must be applied and the information requirements in order to respond to the business drivers; and the indicator selection framework that will be used. In the environmental management field, indicators are used to answer specific questions from managers and decision-makers about the environmental values for which they are responsible. It is essential for the

"business drivers" (i.e., the objectives that lay behind implementing an environmental monitoring system) to be clearly defined when developing indicators. Without certainty on what the indicator measurements will be used for, it is possible that indicators may be selected that fail to answer the questions that need answers. Three broad types of applications of information are required to answer the questions being asked about land use effects on fish and fish habitat in forest environments: strategic level applications; effectiveness assessments; and planning, permitting and enforcement.

In specifying the indicator selection framework, two basic criteria are assumed for this project – 1) the conservation of habitat; and 2) the conservation of species. Both are essential for the goal of sustainable fish and fish habitat in forest environments. The proposed indicators are presented in two distinct groupings, reflective of two distinct uses – 1) strategic level applications; and, 2) watershed level monitoring. Indicators for strategic level applications focus primarily on pressure indicators associated with forest removal and road and road structures. State indicators associated with fish populations are also called for here given the project's focus on fish. Indicators for watershed level monitoring focus primarily on state indicators associated with water quality and quantity, aquatic habitat, riparian habitat, fish populations, and biological diversity. From use of this framework, in conjunction with a candidate indicator evaluation methodology, a set of indicators is proposed for monitoring land use impacts on fish and fish habitat.

Key Recommendations

Indicators for Assessing Fish Sustainability

Fifteen indicators, at two distinct levels of application, are recommended.

Strategic Level	Watershed Level
Road density	Landslide area density
Road density on steep slopes	Temperature
Road-stream crossing density on forest land	Turbidity
Road-stream crossing density on forest land on steep slopes	Habitat complexity
Equivalent clearcut area (ECA) density	Riparian disturbance
Riparian disturbance	Resident fish populations
Salmon escapement	Benthic macroinvertebrate diversity
Fish species at risk	

Making Indicator Results Relevant to Management Decision-making

A concerted effort is recommended to help ensure that indicator measurements are integrated into resource management decision-making:

- Document the complete scope and nature of the fish sustainability monitoring program, including its goals and objectives, target audiences, methodologies, roles and responsibilities, deliverables and reporting relationships.

- Produce written products from monitoring activities that are customized to the requirements of the key audiences for which the products are developed. Ensure that technical findings are interpreted into policy-relevant advice.

- Establish strategic alliances with key groups and individuals that are known and potential users of monitoring results.

- Fully integrate and rationalize this monitoring initiative with the broader provincial agenda to develop a more integrated environmental monitoring strategy.

Obtaining Data to Support Indicator Implementation

Data is largely, but not completely, available for the above-recommended strategic level indicators, and is far less available for the recommended watershed level indicators. To help bridge gaps in data availability, the following should occur:

- Take a practical and "opportunistic" approach to data acquisition, and combine data from multiple sources as necessary to obtain the best possible datasets for the indicators being measured.

- Collaborate with those involved in developing the provincial strategy for integrated environmental monitoring in British Columbia to ensure that fisheries interests are represented, and promote a commitment towards the collection of reliable time-series information that is essential to effective monitoring.

- Work towards putting watershed level information that exists in various, dispersed watershed assessment reports into a corporate database.

- Continue to promote the collection of environmental data according to RIC standards to ensure data integrity. Where RIC standards for any indicator are lacking, they should be developed under the RIC methodology for developing new inventory standards.

Table of Contents

1. Introduction

1.1. What Are Indicators?

Broadly, indicators are proxy variables for attributes which themselves, are difficult, if not impossible, to measure. Indicators have a significance that extends beyond the properties directly associated with any one particular indicator variable (Braat 1991; Hammond et al. 1995). They are useful wherever obtaining the necessary information requires simplification or amalgamation of an overwhelming amount of data, or when collection of the necessary data to directly measure the phenomenon is not possible. Verbruggen and Kuik (1991) state that the primary function of indicators "...lies in simplification: indicators are a compromise between scientific accuracy and the demand for concise information."

Indicators are chosen to fulfill specific policy needs. That is, indicator systems are developed to provide information to decision-makers to help answer specific questions. Desired uses guide the selection and design of an indicator set. For example, is a methodology required for assessing the impacts of proposed land-based developments (e.g., impacts of forestry on fisheries values) as a basis for making referral comments or making decisions on the acceptability of proposed developments? Or, is a methodology required for monitoring long-term performance and issues of sustainability? Are both or other uses required? Indicators are perhaps most useful as a tool in monitoring as development is initiated and proceeds. Undesirable changes in the indicators, in this context, would provide an "alarm signal" that something was not proceeding as desired. This would then in turn trigger further investigation regarding the specific changes of concern and appropriate remediation or mitigation.

In order to adequately address the issues that a particular indicator set is designed to address, and to organise the development and measurement of the indicators, it is important to select indicators based in an adequate conceptual framework. The number of indicators selected should be minimal yet sufficient to describe and characterise the system components of interest. In fact, it could be said that a measure in itself does not become an indicator until it is related to a larger phenomena through a conceptual framework.

Indicator selection and analysis should be supported by science, but the indicator methodology must also be appropriate for the specific use in support of management and policy decisions. Indicators reference socially desired ecosystem attributes. Assessment requires specification of the social values associated with the overall system performance (e.g., Costanza 1992; Harwell et al. 1999).

1.2. Study Purpose and Scope

This study defines criteria, indicators, data sources, and data collection methods for examining land use impacts on fish and fish habitat in forest environments. As part of a larger project that will review indicators of fish and fish habitat sustainability in forest environments, the study is working towards developing a toolkit of monitoring standards.

2. Methods

Achieving the objectives of the study involved the following tasks: 1) reviewing accomplishments to date; 2) proposing appropriate indicators; 3) conducting a consultation workshop; and, 4) making final recommendation to define criteria, indicators, and methods, as well as developing a guide for decision-making.

2.1. Review of Accomplishments

Many watershed or regional scale indicators for forest environments have been proposed and are in use. Indicator and monitoring initiatives related to sustainable forest management were reviewed, focussing on aspects related to fish and fish habitat. Specific research projects identifying indicators for monitoring were similarly referenced. Input was also solicited from individuals known to be active and knowledgeable in the subject area (see Appendix A).

In the review of accomplishments to date, emphasis was placed on describing the types of information and data that is desirable as identified by other programs and policies, as well as related existing and developing data sources in British Columbia. Attention was also paid to describing the scientific foundation of procedures, including:

- The data collection standards;
- Identified criteria and thresholds; and,
- The understood data biases and limitations.

2.2. Proposing Appropriate Indicators

In order to ensure that a useful indicator set is selected, the "business drivers" that supply the underlying motivation to invest in indicator development and implementation (i.e., the questions to which resource managers need answers) are described. From this synthesis, distinct types of uses to which indicators must be applied and the information requirements are identified. A framework for indicator selection is then presented. The framework guides the initial

candidate indicator evaluation by more explicitly identifying the information that is desirable. That is, the presented framework defines the system characteristics of interest for a monitoring program in relation to the needs of management.

Candidate indicators should undergo further evaluation based on specific desirable properties before a final selection is made. The list presented in Table 1 represents an ideal, not an absolute. In the evaluation of candidate indicators, expert judgement must be used in determining which of these properties are of critical importance and which can be compromised in the context of the desired use.

An initial set of indicators for monitoring land use impact on fish and fish habitat in forest environments was proposed based on a preliminary evaluation of the candidate indicators and the needs of management. This proposed set was then presented for critical comment and further evaluation based on the properties outlined in Table 1.

Table 1. Properties of candidate indicators for evaluation.

1. Existence of a theoretical or empirical link between the indicator and ecosystem characteristics of interest.
2. Known or theoretical linkages to management performance (for necessary attribution of credit to management strategies – i.e., speaks to the business drivers).
3. Information and data availability, including ease of measurement, and feasibility and cost-effectiveness of collection.
4. Information and data quality, including:
    - Use of appropriate collection and analysis methods;
    - Data accuracy, precision and robustness; and
    - Timeliness and completeness of the records.
5. Ease of interpretation and meeting of analysis needs, including the availability of rigorous assessment methods that may need to consider:
    - Known or anticipated sensitivity of the indicator to undesirable changes;
    - Adequacy/appropriateness of the time series and/or coverage available; and
    - Ability of the indicator to meet statistical analysis and modelling needs.

2.3. Workshop Consultation

The study team prepared and facilitated a workshop to discuss the results of the study to date as reported in the Interim Progress Report and to provide expert comment regarding the initial proposed indicator set. More specifically, the workshop obtained input regarding indicators, data sources and data issues, and research needs with respect to monitoring programs for the protection of fisheries values. The attendees of the workshop are listed in Appendix B.

2.4. The Definition of Criteria, Indicators and Methods

Based on the results of consultations and detailed indicator evaluations (Appendix C), final recommendations are made. In addition to recommending indicator sets for monitoring land use impacts on fish and fish habitat at both the strategic and watershed level, methods are defined. This includes the specification of general data collection and analysis procedures for the indicators. Furthermore, it is important not only to collect and analyse the data in a credible manner, but also to interpret the information in an appropriate context and framework to support management decisions. The study provides advice with respect to any thresholds that would raise "alarm signals" and, thus, trigger more detailed investigation. In support of this function, the study also defines how monitoring program results should be interpreted and how such alarms would arise in practice during operation. Recommendations are provided in the context of government management.

3. Results

3.1. Review of Accomplishments

In the review of accomplishments to date, the report describes: 1) indicator and monitoring initiatives related to sustainable forest management; 2) research efforts to identify indicators and monitoring systems; and, 3) related corporate data systems.

3.1.1. Indicator and Monitoring Initiatives Related to Sustainable Forest Management

Indicator and monitoring initiatives to define and track sustainable forest management have been developed at range of levels. Components of this existing work are potentially relevant for identifying indicators for assessing the effects of forest land use activities on fish and fish habitat. The individual initiatives, summarized in Table 2, are outlined below.

Table 2. Indicator and monitoring initiatives related to sustainable forest management.

Level	Initiative
National level	• Canadian Council of Forest Ministers (CCFM) Criteria and Indicators for Sustainable Forest Management
Provincial Level	• Environmental Trends Reporting • State of Forests Reporting • Forest Practices Code (results-based standards)
Regional / Sub-regional Level	• Land and Resource Management Plan Effectiveness Monitoring
Forest Level	• Forest Certification Systems • Model Forests • Innovative Forest Practices Agreements
Watershed Level	• Forest Practices Code Watershed Assessment Procedures

CCFM Criteria and Indicators for Sustainable Forest Management

This initiative by the Canadian Council of Forest Ministers (CCFM) identifies six "criteria" (i.e., objectives) for sustainable forest management in Canada's forests, and a variety of indicators within the criteria for measuring and reporting on whether or not the criteria are being achieved (Canadian Council of Forests Ministers 1995). The criteria and indicators that potentially relate to indicators for assessing fish and fish habitat condition are listed below[1].

[1] Note that some of the indicators listed in section 3.1.1 have been slightly modified, with revised wording shown in square brackets, to indicate their potential relevance to fish and fish habitat.

Table 3. Canadian Council of Forest Ministers' criteria and indicators related to fish and fish habitat.

Criteria	Indicator
Conservation of Biological Diversity	• Number of forest dependent species [aquatic] classified as extinct, threatened, endangered, rare or vulnerable relative to total number of forest dependent [aquatic] species. • Population levels and changes over time of selected (aquatic) species and species guilds. • Number of known forest dependent [aquatic] species that occupy only a portion of their former range.
Incidence of Disturbance and Stress	• Rates of pollutant deposition. • Area and severity of occurrence of exotic [aquatic] species. • [Stream] temperature change.
Ecosystem Resilience	• Percentage and extent of area by forest type and age class. • Frequency of occurrence of selected [aquatic] indicator species.
Conservation of Soil and Water Resources	• Percentage of harvested area having significant soil compaction, displacement, erosion, puddling, loss of organic matter, etc. • Area of forest land permanently converted to non-forest land use. • Water quality as measured by water chemistry parameters, turbidity, etc. • Trends and timing of events in stream flows from forest catchments. • Changes in distribution and abundance of aquatic fauna.

Table 3 (continued). Canadian Council of Forest Ministers' criteria and indicators related to fish and fish habitat.

Criteria	Indicator
Policy and Protection Forest Factors	• Percentage of forest managed primarily for soil and water protection [e.g., riparian zone]. • Percentage of area having road construction and stream crossing guidelines in place. • Area, percentage and representation of forest types in protected areas.
Forest Ecosystem Contributions to Global Ecological Cycles	• Percentage of canopy cover. • Area of forest depletion. • Area converted to non-forest use. • Semi-permanent or temporary loss or gain of forest ecosystems. • Surface area of water within forested areas.
Multiple Benefits to Society	• Animal population trends for selected [aquatic] species of economic importance [e.g., salmon]. • Availability of habitat for selected [aquatic] species of economic importance [e.g., salmon].

Environmental Trends Reporting

This monitoring initiative provides an overview of environmental condition in BC by tracking trends in 15 indicators (Ministry of Environment, Lands and Parks 2000). Two environmental trends reports have been released to date – 1988 and 2000. The intent is to continue to release reports on a biannual interval to continue to build a time series picture of environmental condition. Indicators of potential relevance to monitoring the effects of land use activities on fish and fish habitat are presented in Table 4.

Table 4. Environmental Trends Reporting indicators related to fish and fish habitat.

Indicator	Measure
Surface Water Quality	• Number of water bodies with sampling stations that are experiencing "improving", "deteriorating" or "no change" in water quality. • Number of water bodies with sampling stations that are rated as having "excellent", "good", "fair", borderline" or "poor" water quality (based on water quality index measure).
Surface Water Use	• Cumulative number of restrictions on BC streams by decade (indicative of intensity of water use). • Volume of surface water licensed (by decade).
Species at Risk	• Percentage of known [fish] species that are classified as threatened or endangered. • Percentage of known forest dependent freshwater fish species classified as threatened or endangered. • Number of [fish] species classified as threatened, endangered or vulnerable.
Road Density	• Road density (km/km2) on forest land (shown as density classes by watershed grouping).

Table 4 (continued). Environmental Trends Reporting indicators related to fish and fish habitat.

Indicator	Measure
Fish Stocks	• Percentage of salmonid stocks extinct, at moderate to high risk of extinction or of special concern. • Age distribution of white sturgeon (percentage of white sturgeon populations that are juveniles, sub-adults, adults). • Number of Kokanee spawners in streams that feed Okanagan Lake (by 5 year increment). • Bull trout populations that are "stable" and "declining" (classified by watershed grouping).
Riparian Ecosystems	• Percentage of riparian area logged on forest land (shown as percentage classes by watershed grouping). • Percentage of known riparian dependent vertebrates (mammals, amphibians, fish, birds, reptiles) that are classed as threatened or endangered. • Relative importance of threats to threatened and endangered riparian-user vertebrates (percentage of riparian vertebrate species at risk that are threatened by logging, agriculture, urban development, etc. activities). • Status of streams in Lower Fraser Valley (percentage of streams classed as "endangered" threatened", "lost" or "wild").

State of Forests Reporting

Approximately 40 environmental indicators have been proposed for assessing and publicly reporting the condition of BC's forests (Ministry of Forests 2000). The Ministry of Sustainable Resource Management's (MSRM) Decision Support Services Branch has recently compiled a province-wide data set of forest cover for this purpose (i.e., including Crown land,

protected areas, TFLs and private land). Indicators being considered that have potential relevance to understanding land use effects on fish and fish habitat are shown in Table 5.

Table 5. State of Forests Reporting indicators related to fish and fish habitat.

Indicator	Measure
Forest Cover	• Area of old growth, younger growth and non-forest by BEC zone (potentially relevant if reported by old and young forest cover classes by watershed unit).
Forest Disturbance	• Area of forest disturbance by year and decade (disturbance includes pests, fire, logging). Potentially relevant if reported by disturbance classes by watershed unit.
Riparian Disturbance	• Area of forested riparian zone (within 30 metres of a stream > 200 metres) – fires, pests, logging.
Watershed Fragmentation	• Road density (km/km2) – density classes shown by watershed grouping.
Species at Risk	• Same as above Environmental Trends Reporting initiative.
Soil Disturbance	• Percent soil disturbance in harvested areas by year.
Water Quality	• Turbidity (as one component in provincial water quality index).

Results-based Forest Practices Code

The current "rules-based' Forest Practices Code (FPC) is being replaced by one that is more "results" oriented. This means that licensees will be required to comply with measurable standards of environmental performance. Although some of these standards will relate to fish and fish habitat, the specific standards are not yet defined, and therefore it is not possible to identify indicators that may be relevant for measuring whether or not the standard is being achieved. At the most basic level, a simple standard could be established for riparian management zones according to classes of streams, wetlands and lakes – e.g., as currently

established in the provincial Riparian Management Area Guidebook (1995). Within the zones, licensees would be assessed on whether or not they had retained basal area retention targets, or whether or not they avoided development activity in "fisheries sensitive zones". Results-based code standards related to fish and fish habitat that could potentially be adopted are shown in Table 6. It is not know at this time, however, if these types of measures will be incorporated into the new code.

Table 6. Potential types of standards and indicators to be part of a results-based Forest Practices Code.

Category of Standard	Indicator
Soil Disturbance and Erosion	• Turbidity measure. • Number of landslides attributable to development activity. • Watershed road density. • Sedimentation levels.
Riparian Disturbance	• Amount of development in defined riparian management zones. • Maintenance of "fisheries-sensitive zones".
Water Flow	• Equivalent clear-cut area.

Land and Resource Management Plan Effectiveness Monitoring

The former Land Use Coordination Office adopted a policy and set of procedures for monitoring the effectiveness of the strategies in land and resource management plans (LRMPs) in achieving stated objectives (Land Use Coordination Office 2000). The idea is that each LRMP will monitor the "success" of the plan on a periodic basis and take corrective action at the next opportunity for plan review and amendment. Although monitoring work is underway for a

number of completed LRMPs, only the Kamloops LRMP has so far completed monitoring reports (Kamloops Inter-agency Management Committee 1999). The following indicators (Table 7) in the Kamloops LRMP monitoring report relate to understanding watershed, and fish and fish habitat condition.

Table 7. Indicators in the Kamloops LRMP monitoring report.

Indicator	Measure
Site Disturbance	• Percentage of compliance with site disturbance limits identified in silviculture prescriptions. • Length of roads rehabilitated or deactivated. • Length of new roads constructed. • Number of human-caused landslides.
Watershed Condition	• Forest age class distribution (percentage of forest in various age classes e.g., 1-40 yrs, 41-80 yrs). • Percentage of watershed assessments indicating that watershed rehabilitation is required. • Area of fire disturbance.
Species at Risk	• Number of aquatic species at risk (red and blue listed).
Riparian Disturbance	• Extent of compliance with FPC riparian objectives in approved forest development plans (i.e., number of riparian infractions).
Water Quality	• Turbidity levels and monitoring sites. • Length of roads deactivated.
Water Quantity	• Peak and flow trends relative to historic average.
Fish	• Steelhead and coho escapement in selected rivers.

Forest Certification

Forest certification indicators are used to assess individual licensee's sustainable forest management (SFM) performance according to standards that are set under the certification system under which a licensee is being audited. The main certification systems that are currently relevant to BC are the Canadian Standards Association (CSA) system (Canadian Standards Association 1996), the Forest Stewardship Council (FSC) system (Forest Stewardship Council 2001), and the Sustainable Forestry Initiative (SFI) (American Forest and Paper Association 1995). Indicators related to fish and fish habitat that are either being developed or applied under these systems are shown in Table 8.

Table 8. Forest certification indicators related to fish and fish habitat.

Indicator	Measure
Watershed Condition	• Equivalent clearcut area (ECA). • Road density. • Road cut and fills re-vegetated within 12 months. • Channel stability ratings.
Water Quality	• Water quality. • Number of contaminant spills per year entering a waterbody.
Water Quantity	• Trends in flow regimes.
Biodiversity	• Vertebrate [fish] species lists, [fish] habitat attributes and distribution of [fish] species.
Species at Risk	• Trends in classification of red and blue listed [fish] species. • Habitat condition of red and blue listed species.
Soil Disturbance	• Area of soil disturbance (including roads) as a percentage of the timber harvesting land base. • Precautions in place to prevent sediment from reaching waterbodies.

Table 8 (continued). Forest certification indicators related to fish and fish habitat.

Indicator	Measure
Riparian	• Extent of human caused riparian disturbance. • Width and length of riparian reserve and management areas. • Length of buffer along S3-S6 streams. • Percentage of length of S1 and S2 streams with trees >40 yrs old. • Percent of cutblocks adjacent to streams with riparian management zones in place.
Fish and Fish Habitat	• Fish species at risk identified and protected. • Number of spawning, rearing sites and wetlands identified and protected. • Number of lakes and streams classified. • Number of barriers to fish passage identified and removed. • Coarse woody debris in streams that is added or removed.

Model Forests

BC has two model forests (McGregor and Long Beach) that are part of a national network of model forests. Efforts have been made recently in all model forests to define local level indicators for measuring progress towards sustainable forest management. They are based on the national criteria and indicators for sustainable forest management, but are customized to reflect local conditions. Criteria and indicators being developed for the Long Beach Model Forest (Beasley and Wright 2000) and the McGregor Model Forest (McGregor Model Forest Association 1998; Scott 2001), which are relevant to monitoring fish and fish habitat conditions, are shown in Table 9.

Table 9. Long Beach Model Forest and McGregor Model Forest indicators related to fish and fish habitat.

Criteria	Indicator
Water Quality	• Temperature change over time. • Turbidity. • Area impacted by landslides. • Levels of dissolved oxygen and water nutrients in harvested vs. control streams. • Rates of marine to terrestrial nutrient (nitrogen) transfer. • Nutrient loading by drainage.
Water Quantity	• Water flows (peak / low). • Maximum flow in harvested vs. control streams. • Monthly precipitation at coastal versus inland sites. • Surface area of open water within management unit.
Road Disturbance	• Proportion of management unit (or watershed) in permanent roads road density by road class. • Area of roads / trails by type. • Use levels of roads by type of use. • Length of roads by landscape position (e.g., high slopes, riparian). • Number of stream crossings by road type.

Table 9 (continued). Long Beach Model Forest and McGregor Model Forest indicators related to fish and fish habitat.

Criteria	Indicator
Channel Morphology	• Channel change over time. • Particle size distribution in 1st and 2nd order streams. • Changes in stream bank vegetative cover. • Stream audit comparisons of harvested to control streams for morphology (e.g., channel width, bed material size, substrate size, organic debris). • Number and length of streams by streams persistence class in harvested vs. control areas.
Soil Condition and Productivity	• Number of hill slope failures by source. • Volume of displaced material. • Number of failures reaching main stem. • Percentage of area with soil compaction, mineral soil exposure and/or loss of organic material. • Area of land by yarding technique. • Number of sites with significant soil impacts.
Stream Habitat	• Presence and density of stream habitat characteristics (e.g., coarse woody debris, pooling, sedimentation). • Number and density of stream crossings by road type. • Habitat availability for selected species at risk. • Impacts (area, number of locations and rates of spread) of exotics on special habitats (e.g., riparian).

Table 9 (continued). Long Beach Model Forest and McGregor Model Forest indicators related to fish and fish habitat.

Criteria	Indicator
Aquatic Fauna	• Changes in distribution and abundance of aquatic fauna. • Presence of red and blue listed [fish] species. • Population sizes and reproductive success of salmon species by drainage. • Population size of selected species at risk. • Reproductive size of selected species at risk.
Forest Land Conversion	• Area of permanent forest loss due to development. • Area of long-term forest loss due to land failure (landslides, flooding). • Rate of change of conversion within forest type. • Area of forest cover change by forest type. • Area of conversion to permanent and semi-permanent non-vegetated conditions.

Innovative Forest Practices Agreements (IFPAs)

The Innovative Forest Practices Agreements (IFPAs) initiative is designed to encourage licensees to test new and innovative forest practices. A Forest Act provision gives ministry staff the authority to allow an increase in a licensee's annual harvest level, provided that they can justify an increase through commitments to increase forest productivity. To be eligible, licensees must prepare a forestry plan defining innovative methods, such as early planting, fertilization, cluster planting, and alternative harvesting and silviculture methods. Part of the forestry plan may include the identification of indicators for monitoring the effect of the plan on forest resource values. IFPA pilot projects that are underway include: InterFor operations in the Kamloops and Fraser TSAs; Lignum operations in the Williams Lake and 100 Mile House TSAs; and the operations of all major licensees with replaceable licenses in the Merritt, Arrow and

Lakes and Morice TSAs. Table 10 shows examples of criteria and indicators that are being considered and that potentially provide insights into the effects of land use activity on fish and fish habitat.

Table 10. Innovative Forest Practices Agreement (IFPA) criteria and indicators related to fish and fish habitat.

Criteria	Indicator
Biological Richness	• Extent to which productive habitats of selected [fish] species or species guilds are distributed throughout the range of their habitat.
Forest and Soil Productivity	• Percentage of harvested area having significant soil compaction, displacement, erosion, puddling and loss of organic matter. • Area of forest converted to non-forest land use. • Percentage of forest area having road construction and stream crossings in place.
Ecological Contribution to Global Cycles	• Percentage of forest area under different seral stages (e.g., old, young, recently harvested).
Water Quality / Quantity	• Turbidity, true colour and water temperature, measured over adequate timeframe, relative to natural variability. • Stream flow, measured over adequate time frame, relative to natural range and variability.

Watershed Assessment Procedures under the Forest Practices Code

In support of the regulations that form part of the Forest Practices Code (FPC), Watershed Assessment Procedure (WAP) guidebooks have been developed (British Columbia Ministry of Forests 1999). The watershed assessment procedure is required under the FPC for

certain watersheds (i.e., domestic water supplies, and those with significant fisheries values) before timber harvesting activity may be approved in a forest development plan. The WAP is an "…analytical procedure to help forest managers understand the type and extent of current water-related problems that may exist in a watershed, and to recognize the possible hydrological implications of proposed forestry-related development or restoration in that watershed." (British Columbia Ministry of Forests 1999, p.1). In its current form, it relies on professional assessment, based on map and field work. It appears most appropriate for watersheds of the 5 to 500 km^2 scale (Carver 2001). The impacts assessment focuses on:

1. The potential for changes to peak stream flows;
2. The potential for accelerated landslide activity;
3. The potential for accelerated surface erosion;
4. Channel bank erosion and changes to channel morphology as a result of logging the riparian vegetation;
5. The potential for change to the stream channel; and
6. The interaction of all the above processes (items 1 through 5).

The guidelines specify the preparation of a watershed report card to provide a summary of environmental indicators. The recommended elements are shown in Table 11.

Table 11. Elements of the Watershed Assessment Procedure report card.

Indicator	Description
Percent Area Harvested	• Percent of the watershed that has been harvested.
Equivalent Clearcut Area by Elevation Band	• Clearcut area adjusted based on ages of logging and tree heights in second growth.
Total Road Density	• Total length of road (km) divided by total watershed area.
Length of Road in "High" and "Very High" Erosion Class	• Total length of road in watershed given a "high" and "very high" erosion classification.
Total Number of Landslides	• Total number of landslides in watershed.
Length of Road on Unstable Terrain	• Length of road on areas with terrain stability class 4 or 5, or that is classified P or U.
Number of Stream Crossings	• Total number of stream crossings by mapped roads.
Percent of S1, S2, S3 or S4 Streambanks Logged	• Total "high" riparian impact stream length; total length of "one side logged" streams and "two side logged" streams.
Length of Disturbed Stream Channel	• Total length of disturbed channel (km) and as percentage of total channel, using the Reconnaissance Channel Assessment Procedure.

3.1.2. Research Efforts to Identify Indicators and Monitoring Systems

There have been a number of efforts to identify indicators for monitoring impacts of forest land use on fish and fish habitat. The results of efforts in the Pacific Northwest are outlined here, focusing on the specific indicators they proposed. The review is not intended to be exhaustive, but to provide a representative description of approaches.

Pacific Northwest Salmon Habitat Indicators

The Pacific Northwest Environmental Indicators Work Group (PNWEIWG) (Green Mountain Institute 1998) began development of regional indicators for salmonid stocks at risk. The purpose of the group's work, which includes representation from the environmental management agencies of British Columbia, Alaska, Washington, Oregon, Idaho, the Government of Canada and the Government of the United States, is to identify and develop environmental indicators to:

- Collect and report environmental data in a common fashion;
- Develop a tool to assist in comprehensively measuring the effectiveness of the agencies' environmental programs;
- Help determine the current condition of the Pacific Northwest environment; and
- Use environmental data to set management priorities on a regional basis.

Focussing on habitat as the key management issue, the group initially identified 46 indicators. Subsequently, members of PNWEIWG, lead agency staff and technical experts applied further selection criteria that resulted in the list being reduced to 21 indicators (Table 12). Of the 21 indicators, five (i.e., instream flow, temperature, a biological water quality index, land use conversion, and transportation impacts) were noted to be of high priority. To further organise the selection of physical habitat indicators, the group put forth a "habitat concept", asserting that the essential aspects of salmon habitat can be represented by four components – interrelated impediments and accessibility issues; morphology; sediment; and land types adjacent to water (the land-water complex).

Table 12. Suggested regional indicators for salmonid stocks at risk.

Category	Indicator	Description
Water Quantity	Instream Flow	• Percentage of stream miles with instream flow meeting instream water rights, seasonal flow requirements for salmonids, and/or sufficient to allow salmonid access.
	Flow Hydrology	• Percentage of waterbodies with minimal, moderate, extreme changes in hydrology from historical patterns (captures low and high flow extremes-derivation).
Water Quality	Temperature	• Percentage of assessed waterbodies where the daily maximum falls into: <10ºC (no impairment); 10-15ºC (potential impairment to sensitive species); 15-20ºC (moderate impairment; >20ºC (severe impairment).
	Biological Water Quality Index	• Percentage of water rated excellent, good, fair, poor (possible parameters would include fish community and benthic macroinvertebrate species or taxa composition and richness).
	Chemical Water Quality Index	• Percentage of waters rated excellent, good, fair, poor (possible parameters would include temperature, dissolved oxygen, biological oxygen demand, pH, ammonia/nitrate nitrogen, total phosphorus, total suspended solids, and bacteria).
Land Use/Land Cover	Land Use Conversion	• Percentage of acres in watershed converted from land use/land cover classifications to other land use/land cover types over time, with emphasis on floodplain to riparian area.
	Transportation Impacts	• Miles of road by type within one mile of historically anadromous salmonid streams, floodplains, and marine shorelines.

Table 12 (continued). Suggested regional indicators for salmonid stocks at risk.

Category	Indicator	Description
Land Use/Land Cover	Impervious Surface	• Percentage of impervious surface (roads, rooftops, and parking lots) in a watershed.
Physical Habitat	Impediments and Accessibility	• Number of locations where salmon are impeded, by type, and number of historical anadromous salmonid stream miles rendered inaccessible by these impediments.
	Morphology: Stream Morphology	• Stream morphology assessment.
	Morphology: Habitat Quality Index	• Physical habitat assessment (parameters would include classifying habitat, measuring channel and riparian character, woody debris, stream discharge, and channel morphology).
Physical Habitat	Morphology: Large Woody Debris	• Distribution and characterisation of large woody debris per historically anadromous salmonid stream mile.
	Morphology: Pool-Riffle Ratio	• Change in pool-riffle ratio.
	Morphology: Stream Width-Depth Ratio	• Change in stream width-depth ratio.

Table 12 (continued). Suggested regional indicators for salmonid stocks at risk.

Category	Indicator	Description
Physical Habitat	Sediment: Sediment Loading	• Sediment loading rates.
	Sediment: Spawning Area	• Percentage change in spawning areas.
	Land-Water Complex: Riparian Habitat	• Percentage of riparian habitat or riparian zone altered by stream miles within watershed.
	Land-Water Complex: Estuarine Habitat	• Change in estuarine area, by type and quality.
	Land-Water Complex: Side Channel Habitat	• Change in area of side channel habitat.
	Land-Water Complex: Wetlands	• Change in wetland area.
	Salmonids	• Change in number of fish by life stages, by species.

Salmon Habitat Indicators and Data Sharing Workshop

In 1998, a Salmon Habitat Indicators and Data Sharing Workshop was held under the auspices of the Canada-BC Pacific Salmon Fishery Agreement (SFA) to begin development of salmon habitat indicators (Eclipse Environmental Consulting Ltd 1998). The workshop would provide the basis for a federal/provincial presentation to the Pacific Fisheries Resource Conservation Council, under the SFA. It was the intent of the work to assist in the identification of indicators that would eventually be used for annual state of the environment (SOE) reporting.

Using the results of the previous work on salmon habitat indicators for the Pacific Northwest (Green Mountain Institute 1998) as a starting point, the workshop participants assessed the indicators and provided descriptions of data availability and quality. The workshop results were used to inform the assessment of candidate indicators for this project.

Aquatic Habitat Indicators and the United States Water Quality Objectives

The United States Environmental Protection Agency evaluated the application of aquatic habitat variables to water quality objectives under the *Clean Water Act*, focusing on salmonid habitat in the Pacific Northwest and Alaska (Bauer and Ralph 1999). The range of possible habitat variables was categorised as describing: flow regime; habitat space; channel structure; substrate quality; streambank condition; riparian condition; temperature regime; and habitat access. The study based its analysis of candidate variables on the relevance to the biotic community, responsiveness to human impacts, application to target landscapes, and measurement reliability. The authors stressed the importance of future efforts developing and calibrating diagnostic indicators at local or eco-regional scales, stratified by landscape and stream characteristics. Bauer and Ralph (1999) concluded that the only habitat variables that met their evaluation criteria were large woody debris (LWD), pool frequency, and residual pool depth. Given the recognition that this small set of indicators would not be sufficient for the protection of salmon and salmon habitat, it was recommended that efforts be increased to evaluate landscape classifications, identify and measure reference conditions at eco-regional scales, and develop systematic approaches to indicator quantification.

Local Impact Assessment – Use of the Index of Biotic Integrity in the Skeena Region

A notable example of an indicator system linked strongly to the scientific knowledgebase is the Index of Biotic Integrity (IBI) (Karr 1981, 1991, 1992). It involves the identification of relationships that are well known between ecosystems and humans for which the effects on ecosystems is sufficiently documented by scientific theory and empirical evidence. Each relationship represents a hypothesis regarding the link between human activity and environmental distress. This leads to a list of working assumptions regarding ecological patterns and processes – from this, attributes of the biological system to measure are identified, along with acceptable ranges of values based on known natural variations.

The Skeena Region office of the Ministry of Water, Land and Air Protection has been developing a monitoring system based on the IBI to inform environmental impact assessment (e.g., Bennett and Hewgill 2001). The indicator system will be used to detect changes in aquatic ecosystems due to forest harvesting activities, but is also intended to more broadly inform the development of permits and the establishment of local priorities for land use management. It is not the intent to rely primarily on the IBI to make decisions, but to use the information provided by the index in conjunction with other assessment data. The regional Environmental Impact Assessment Section is 3 years into data collection, calibration and development of the system, focussing efforts in four forest districts.

Watershed Indicators for the Adams Lake IFPA

Spurred by a concern over the differences evident between assessment results from using the Interior Watershed Assessment Procedure (IWAP) indicators and those from more detailed direct field measurements, new indicators were identified and investigated for three case study watersheds in the Adams Lake Innovative Forest Practices Agreement (IFPA) (Keystone Wildlife research 2001). The indicators were based on new map data for the IFPA – specifically, bioterrain mapping and reconnaissance-level Terrestrial Ecosystem Mapping (TEM-r). It is hoped that new indicators would be developed to improve on the accuracy of strategic level analyses (e.g., Timber Supply Review, forest certification).

The indicators are described in Table 13. For assessment, watersheds were divided into three distinct units: 1) riparian management areas of S1-S3 streams; 2) riparian reserve areas for unbuffered S4-S6 streams; and, 3) areas outside of the riparian areas. This division is meant to reflect differences in risks to streams due to the different locations of hazards relative to the streams. From the three case study watersheds, the research found that the risk assessment based on the new indicators more closely resembled direct field assessments by hydrologists. Assessments based on the Interior Watershed Assessment Procedure (IWAP) were more precautionary, attributed to the inability of the indicators to spatially localize high hazard areas. The project is looking to improve on the methodology and interpretation of the new indicators through further research and calibration using additional case studies (Keystone Wildlife Research 2001).

Table 13. System characteristics and corresponding watershed indicators used to estimate potential hazards.

System Characteristic	Indicators	Indicator Descriptions
Surface Erosion	Soil Erodibility; and Vegetation Structure on Erodible Soils	• Risk classification using parent material and slope class information from bio-terrain mapping. High rated areas further stratified according to vegetation structural stage and slope class.
Sedimentation	Sediment Filtration Capacity by Ecosystem and Structure	• Risk classification based on an assessment of the filtration capacity of vegetation species and structure, using ecosystem unit, structural stage and slope class map data.
Peak Flow	Peak Flow Based on Structural Stage	• Risk classification based on canopy height information.
Riparian Buffer Function	Riparian Buffer Function based on Structural Stage	• Risk classification based on canopy height information.
Vegetation Recovery after Disturbance	Vegetation Recovery Potential	• Risk classification based on site index (SI) calculation as a measure of potential site productivity, using forest cover and TEM data.
Fish Habitat	Fish Habitat Risk	• Risk classification based on tabulation of three indicators – riparian buffer function, vegetation structure on erodible soils, and sediment filtration.
Landslides	Risk of Landslides on Unstable Terrain	• Risks classification from Reconnaissance Terrain Stability Mapping.

Monitoring Program Recommendations of the Northwest Indian Fisheries Commission

Based on a review of the literature, recommendations were provided for the design of programs to monitor habitat disturbance and recovery trends in streams affected by forest management (Morgan and Smith 1997). A "process-based" framework was developed to assist

in the interpretation of patterns of disturbance and recovery. Four specific groups of watershed inputs were the focus: 1) sediment; 2) large woody debris; 3) stream temperature; and, 4) peak flows. For each, relationships with habitat attributes, processes controlling delivery and routing, and specific forest practices are identified. Potential monitoring parameters associated with each of the four watershed inputs are outlined in Table 14. This research illustrates a preference for the measurement of key parameters, as apposed to indicators, in monitoring programs. It requires specific field-based measurements, related to land uses through a process model. However, the distinction between an "indicator" on one hand, and a "parameter" on the other, can be artificial.

Table 14. Watershed inputs and corresponding potential parameters for monitoring program.

Watershed Input	Parameters
Sediment	• Sediment delivery processes and rates. • Streambed elevation. • Sediment transport rates in channel. • Particle size of surface substrate. • Volume of large woody debris in channel. • Percent fines in spawning riffles. • Frequency and volume of pools. • Channel width and canopy opening.
Large Woody Debris	• In-channel piece volume per stream surface area.
Stream Temperature	• Water temperature (maximums and minimums).
Peak Flows	• Water discharge. • Gravel scour depths and locations. • Gravel depositions. • Redd locations.

Wild, Threatened and Endangered Streams of the Lower Fraser Valley

The Fraser River Action Plan reviewed the condition of streams in the Lower Mainland of British Columbia (Precision Identification Biological Consultants 1998). Existing streams were classified as endangered, threatened or wild based on certain quantitative and qualitative criteria chosen to reflect impacts. The focus was on strategic level information to help determine needs for habitat protection and restoration. The criteria used in the assessment were as follows:

- Significant loss of riparian vegetation along more than 50% of the fish frequented length of the stream;
- Channelization, armourization or dyking of over 50% of the fish frequented length of the stream;
- Effective impermeable area (EIA) covering approximately10%, or greater, of the stream's watershed;
- Greater than 50% diversion of stream flow (i.e., diversion out of the system), or significant manipulation of flow;
- Significant water quality problems (i.e., temperature; water chemistry);
- Extensive logging in the watershed, with impacts obvious;
- Significant urban settlement in the watershed that has altered the stream basin; and
- Other impacts (i.e., agricultural/urban impacts; cumulative effects).

Streams were classified as threatened if they met one of the above criteria, while they were classified as endangered if they met more than one criterion.

3.1.3. Related Corporate Data Systems

It is critical that the selection process for indicators evaluate existing and developing sources of data and information, particularly those that form part of ongoing collection programs. While scientific knowledge and protocols define the types of data, and collection and analysis methods that are amenable to use in any indicator program, there is often a range of appropriate alternatives available. A selected indicator set must be sufficient, yet take advantage of other government and private sector programs where appropriate.

Provincial land and resource information management is in transition. Efforts are being made to develop an "integrated warehouse" of land and resource data. This warehouse will be the single, authoritative repository of provincial and resource inventory and registry data. The

aim is to ensure that the province's various land and resource data "themes" can be integrated with each other, and to enable simplified access (e.g., web-based) to such data by both government and non-government users.

The Ministry of Sustainable Resource Management, which now consolidates all former provincial inventory and registry programs under one roof, is mandated to develop and operate the corporate integrated data warehouse. Development and full implementation of the warehouse, however, is a longer-term prospect. In the interim, the various inventory and registry products that have been developed by the former ministries and programmes within ministries are still in use. These constitute the primary data sets that will be potentially available for supporting indicator applications. It is anticipated that these provincial data sets will be incorporated into the province's corporate integrated data warehouse as it rolls-out. Federal data that may be valuable for supporting land use indicators of fish and fish habitat condition will, however, not be incorporated into the provincial data warehouse.

The following sections review the primary provincial and federal government data sets that are potentially relevant for assessing land use impacts on fish and fish habitats in forest environments.

Forest Cover Data

The Ministry of Sustainable Resource Management (MSRM) maintains vegetation resource information in the Vegetation Resource Inventory (VRI) and in the VRI precursor (but still in use) called the Forest Inventory Planning (FIP) system. VRI data is available for approximately 10-13% of the province (+/-11 million ha), and it represents an upgrade of the older FIP data to include several new measures to support improved timber supply analyses and to incorporate generally improved data accuracy and precision.

VRI information is one "tile" (layer) in the Incorporated Spatial and Attribute Database (INCOSADA) – other tiles include silviculture information, forest and range tenure information, roads, and recreation information. VRI and FIP data both lay onto the provincial 1:20,000 TRIM base. Data from the two systems can be integrated with each other. Data attributes are tied to polygons that are located to reflect homogeneous stands of common or similar species, height,

age and Crown closure. The average polygon size in the VRI data set is about 15 ha, and there are an average of 900 to 1,000 polygons per TRIM map sheet (approximately 7,000 1:20:000 TRIM mapsheets cover BC).

Vegetation cover data originates from aerial photography of various vintages, depending on geographic location. FIP data is based on 1960s to 1990s aerial photography, whereas VRI data is based on more recent photography. Although the original idea was to update VRI photos every 5 years, budget considerations have forced the updating program, as well as the generation of new VRI to replace FIP, to be done on a needs-driven basis (e.g., to support a Timber Supply Review process).

Various forest attributes are derived for polygons from air photo interpretation (e.g., vegetated vs. non-vegetated; tree and shrub species; tree age and height; stem density). The attributes that can be seen on aerial photos are modelled to populate a number of other fields in the database (e.g., volume estimates). Growth and yield model information is incorporated into the database to reflect estimates of increases in forest age and volume. The location and extent of activities or events (e.g., harvesting, road building, landings, fires), which cause a reduction in forest volume, are also incorporated so that the database provides a relatively up-to-date picture of forest condition. Updates are input by districts on an average of one year after the event. The VRI / FIR data set is extensive – over 250 attributes are stored in a relational database that can be queried by spatial reference.

The database is also highly dynamic. District staff continually amend the database to reflect land and resource use activities. Historically, the data was not archived to enable recovery for time-series monitoring purposes. Archives are now being retained so that change monitoring using VRI data will be able to occur in the future.

Forest cover data is available for some but not all TFLs. However, producing a "seamless" provincial coverage by obtaining and integrating TFL data is a recently stated MSRM priority. Data for private land is not included, and data for some of the older protected areas is either not available or is quite dated.

Vegetation data reports can be generated for administrative boundaries such as provincial forests or forest districts, and for ecological classifications such as BEC variants, but there is currently no capacity within the system itself to report by watershed unit or landscape unit. To report VRI or FIP data according to watershed boundaries, the data would have to be integrated with watershed boundary data in a GIS and manipulated to produce the desired reports.

A "seamless, this point in time", provincial forest cover data set comprising Crown land forests, TFLs, and private lands is being prepared to support BC State of the Forest reporting. The private land component is being developed from satellite image interpretation (BTM data), and the TFL coverages are being obtained from TFL holders. This data set is based on VRI, TFL and BTM data that is available as of 2001– there are no current plans to maintain the currency of this data set beyond its use for State of Forest reporting purposes. Therefore, it will have limited utility for time series monitoring purposes. Also, watershed boundary information is not included in this data set and, unless it is incorporated, there is no capacity to report indicators by watershed unit.

Data on Forest Development Activity

Other possible sources of information on forest disturbance are the Ministry of Forests' (MOF) silviculture database and road database. Silviculture information has traditionally been held in the Integrated Silviculture System (ISIS); however, it is a non-spatial database that does not easily lend itself to reporting by any means other than map sheet number. It is being replaced by MLSys, which will be a spatially-referenced "tile" in the INCOSADA system. However, that system is currently available for only a relatively small portion of the province. When fully operational, it is expected that it will be possible to query MLSys to generate reports on harvesting activity for defined spatial areas.

Similarly, information on road activity is being relocated to the Forest Road Application System (FRMA), which is a tile within INCOSADA. This is only just now beginning. A provincial road system network is being developed for emergency planning purposes that will combine FRMA, TRIM, Ministry of Transportation, and municipal road information on all road locations in the province. This too is only in the development stages.

To obtain spatial information on forest development and disturbance activity in the present environment, it is necessary to take the old FIP files (and VRI where available) and combine that data in a GIS with landscape unit or watershed boundary data, and other available data that may be relevant (e.g., slope or terrain stability). An alternative may exist in using the data sets that have been assembled for landscape unit biodiversity conservation planning and monitoring. The MSRM Decision Support Services Branch is the custodian of this data, which includes forest cover and forest disturbance data from FIP for most (but not all) districts, organized by landscape unit.

Vegetation Change Inventory and Monitoring Data

This federal-provincial data collection initiative involves measuring the condition of various forest attributes at 2,400 permanent, 2 km by 2 km air photo assessment plots on a 20 km grid covering the province. The information being collected is part of a national forest inventory initiative. GIS data from existing available sources will be assigned to the plots (e.g., TRIM, BEC, VRI), and a number of measurements will be recorded for the 2 km by 2 km plots on an annual basis, primarily to enable national level reporting on Canadian Council of Forest Ministers (CCFM) criteria and indicators on sustainable forest management. This exercise is colloquially referred to as the "drilling down" initiative, and analysis and record keeping is expected to begin in Spring, 2002. It was originally anticipated that new aerial photography would be taken at the grid intersections on a 10-year cycle; however, cost implications have lead to a decision to use GIS-based information that exists at the time that the annual measurements are taken.

To obtain stand level information that cannot be generated from the air photo plots, 314 fixed ground sample plots (0.4 ha in size) will be established to measure full vegetation resources inventory attributes, such as vegetative species, tree height, decay, and course woody debris. This level of monitoring, repeated every five years, will produce information that will enable reporting on additional CCFM criteria and indicators that cannot be obtained from air photo interpretation. To date, measurements at 64 ground plots have been taken for two consecutive years.

Watersheds BC Data

This province-wide GIS database summarizes environmental information about land and water resources for over 18,000 watershed units. Approximately 420 measures are calculated and are available each watershed.

The data is derived from 16 different sources, including: the BC Watershed Atlas of watershed boundaries and stream locations; the Fish Inventory Summary System (FISS) containing data on fish distributions; terrain resource information mapping (TRIM) showing streams, roads and elevation; baseline thematic mapping (BTM) that is derived from satellite interpretation and shows 20 classes of land use; and ecosystem boundary mapping (ecosections and BEC units).

The data that is used to generate the watershed statistics is derived from source information of various vintages and scales. For example, watershed boundaries are taken from federal NTS 1:50,000 mapping that was available as of 1999; FISS information on fish distribution is summarized from reported fish observations before 1999 and mapped at various scales between 1:5,000 and 1:50,000; TRIM information is captured from air photographs taken between 1979 and 1988; and 1:250,000 BTM information is produced from LandSat imagery taken between 1992 and 1998[2].

The accuracy or utility of Watersheds BC data for strategic planning and watershed ranking purposes (as opposed to operational planning or detailed reporting purposes) was confirmed recently by an independent study (Iles 2001) that compared Watersheds BC data (i.e., satellite derived data) to air photo-interpreted data in randomly selected watersheds.

---

[2] Work is underway to produce a second generation of BTM data that will enable some time-series interpretation of land use activities. It should be noted, as well, that BTM data constitutes a corporate provincial data set in its own right that could be employed for measuring certain indicators of fish sustainability.

Terrain Stability Mapping

MSRM maintains terrain stability (hazard) mapping for much of Vancouver Island, areas of coastal BC and large areas of the interior. It is mapped at various scales ranging from 1:15,000 to 1:50,000. This mapping uses a five class rating system: class 1 indicates no apparent instability; class 5 indicates high instability and, thus, high risk for landslides and erosion. Regional terrain hazard maps at 1:250,000 are also available that show information about physical processes such as landslides and run-out zones, snow avalanche areas, and areas of active erosion. This information may be of interest from a fish and fish habitat indicators perspective when combined with forest disturbance activity in watershed or landscape units.

Fish Presence and Fish Habitat Data

The BC Fisheries Data Warehouse consolidates available lake and stream data on: physical reports (including average stream channel width and stream gradient), fish obstruction information (such as falls, log jams, bridges, culverts, etc.), and fish presence information by species. It is possible to report this data by watershed unit.

DFO salmon escapement data by species by year is also available for many BC streams in the Salmon Escapement Database and Reporting System (SEDS). Methods for estimating escapement include: visual estimates, stream walks, aerial surveys, tag recapture and fence counts. SEDS is in the process of being updated to enable spatial data presentation (both fish presence and salmon escapement for individual streams may be viewed on the BC Fish Wizard website).

A DFO Stocks at Risk (STAR) database (non-spatial) provides information on anadromous salmon and trout stocks in BC and the Yukon that are considered to be at risk, based on assessments of spawner abundance compared to historical abundance. The STAR database has been archived and will be considered for cyclical updates in the future.

Some detailed fish habitat mapping (e.g., 1:11,000) is available as part of the Georgia Basin Initiative for Nanaimo, Comox-Strathcona, Squamish and Saanich areas. This mapped data shows the location of sensitive fish habitat and fish presence.

Water Quantity and Quality Data

Environment Canada maintains hydrometric records for 2400 hydrometric stations in BC and the Yukon, of which approximately 500 are currently active. Non-spatial data is published annually on a CD Rom called HYDAT. Depending on the recording facilities that are installed at individual gauging stations, data may be available on water flow, water level, sediment concentration or sediment load, and water temperature.

The province maintains the Water Inventory Data Management System (WIDMS). The database holds water quality data and hydrometric data measured by continuous automated monitors. The water quality stations, dating from 1997/98, measure temperature, pH, conductivity, turbidity, depth and conductance. Currently, coverage is restricted to community watersheds that are being logged (approximately 60 watersheds in the province). The hydrometric stations, dating from the 1970s, measure water flow.

Water quality trends information is available for a limited number of water sources in the form of an index measurement that is reported as part of WLAP's environmental trends reporting initiative.

Watershed Assessment Data

Currently, data collected and analysed for Watershed Assessment Procedure (WAP) reports, under the Forest Practices Code, is not retained. Limited numbers of copies of reports for individual assessments exist in various locations within government. There is a recent initiative to bring together all reports and make them available on the internet; however, the information will not be available within a corporate database.

Summary Assessment

The preceding discussion outlines the main corporate data sets that are potentially available for measuring indicators of forest land use effects on fish and fish habitat. Naturally, the usefulness of these data sets will depend on the specific indicators that are selected for measurement.

The most readily accessible and readily useable information is the Watersheds BC data set. It enables watershed level indicators of forest disturbance (e.g., road density, riparian disturbance, etc.) to be easily measured for all BC locations. Similar data could be generated from the MSRM FC1, VRI, ISIS or MLSys databases, but this would require a far greater effort to obtain and manipulate the data into desired formats, and gaps in coverage are a problem (e.g., private land, some TFLs). Although these latter data sets may provide greater accuracy and precision, the level of data reliability that would be gained may not necessarily be worth the effort, provided that the information is being used to measure "coarse filter" indicators at the strategic level (e.g., to rank the relative degree of risk in watersheds to fish and fish habitat). To be valuable for monitoring change in watershed conditions over time, it will be necessary for the Watersheds BC data set to be archived and updated with new releases on a periodic basis.

As another possibility for the supply of data to support fish and fish habitat indicators, actual forest cover data, arranged for landscape unit analyses, has been recently compiled (by the MSRM Decision Support Services Branch) for most of the province's approximately 1,300 landscape units. This data provides a potential foundation to which additions could be made (e.g., fish distribution, terrain stability mapping, DEM data to enable calculation of slope) in order to support fish and fish habitat indicators. Again, periodic updates of this information would be needed if time series monitoring to detect change in conditions is envisioned. A further corporate data set of potential value is the "seamless" forest cover data set (including Crown land, private land, protected areas and TFLs) that is being produced for State of the Forests reporting purposes.

Data to support "finer filter" indicators of fish and fish habitat condition (e.g., changes in stream channel morphology, large woody debris in streams, water temperatures, low/peak flows, etc.) is not generally available in province-wide databases. It exists for selected watersheds or stream reaches, and has primarily been assembled as part of a watershed assessment procedure, or for other specific research purposes. If these types of indicators are selected to be part of the provincial indicator set for assessing land use effects on fish and fish habitat, greater effort must be made to bring the existing data together, and a sampling program

and/or a predictive modelling program will need to be undertaken in order to supply additional data to support indicator measurements.

A corporate initiative is underway to develop an integrated environmental monitoring strategy. The goal is to bring together data for assessing, monitoring and reporting on provincial environmental sustainability. The potential value of this provincial initiative for supporting fish sustainability monitoring is as yet undetermined.

In the foreseeable future it will likely be necessary for fish sustainability monitoring to take an "opportunistic" approach to acquiring suitable data for measuring the indicators of interest. It will probably be necessary to combine data sets in order to fill gaps and overcome weaknesses that are evident in any one data source.

3.2. Selecting Appropriate Indicators

In the review of previous indicator work, a large list of candidate indicators emerged (Table 15). Within each indicator type, a number of different specific measures have been suggested.

Table 15. Summary of candidate indicators review.

Candidate Indicator	Source
Land Use Conversion (from Forest Land)	• The Pacific Northwest Salmon Habitat Indicators Work Group; Canadian Council of Forest Ministers; Model Forests; Innovative Forest Practices Agreement
Forest Cover and Disturbance	• Watershed Assessment Procedures; Canadian Council of Forest Ministers; State of Forests Reporting; Kamloops LRMP Monitoring; Innovative Forest Practices Agreement
Equivalent Clearcut Area (ECA)	• Watershed Assessment Procedures; Forest Certification
Impervious Surface	• The Pacific Northwest Salmon Habitat Indicators Work Group; Wild, Threatened and Endangered Streams of the Lower Fraser Valley
Soil Disturbance (Compaction, Displacement, Erosion)	• Canadian Council of Forest Ministers; State of Forests Reporting; Forest Certification; Model Forests; Innovative Forest Practices Agreement
Landslides and Slope Failures	• Watershed Assessment Procedures; Kamloops LRMP Monitoring; Model Forests
Roads (Density)	• Watershed Assessment Procedures; The Pacific Northwest Salmon Habitat Indicators Work Group; Environmental Trends Reporting; State of Forests Reporting; Forest Certification; Model Forests; Innovative Forest Practices Agreement
Stream Crossings by Roads	• Watershed Assessment Procedures; Model Forests; Innovative Forest Practices Agreement
Impediments and Accessibility	• The Pacific Northwest Salmon Habitat Indicators Work Group; Forest Certification
Riparian Habitat	• The Pacific Northwest Salmon Habitat Indicators Work Group; Watershed Assessment Procedures; Environmental Trends Reporting; State of Forests Reporting; Forest Certification
Aquatic Habitat (Estuarine, Side Channel, Wetlands)	• The Pacific Northwest Salmon Habitat Indicators Work Group; Forest Certification; Innovative Forest Practices Agreement
Rare, Threatened, Endangered or Vulnerable Fish Species	• Canadian Council of Forest Ministers; Environmental Trends Reporting; State of Forests Reporting; Forest Certification
Rare, Threatened, Endangered or Vulnerable Aquatic Species	• Canadian Council of Forest Ministers; Environmental Trends Reporting; State of Forests Reporting; Kamloops LRMP Monitoring; Forest Certification; Model Forests

Table 15 (continued). Summary of candidate indicator review.

Candidate Indicator	Source
Populations of Fish Species	• The Pacific Northwest Salmon Habitat Indicators Work Group; Canadian Council of Forest Ministers; Environmental Trends Reporting; Kamloops LRMP Monitoring; Forest Certification; Model Forests
Populations of Select Aquatic Species	• Canadian Council of Forest Ministers; Model Forests
Occurrence of Exotic Species	• Canadian Council of Forest Ministers; Model Forests
Flow	• The Pacific Northwest Salmon Habitat Indicators Work Group; Canadian Council of Forest Ministers; Kamloops LRMP Monitoring; Forest Certification; Model Forests; Innovative Forest Practices Agreement
Chemical Water Quality (Index)	• The Pacific Northwest Salmon Habitat Indicators Work Group; Canadian Council of Forest Ministers; Environmental Trends Reporting; Model Forests
Temperature	• The Pacific Northwest Salmon Habitat Indicators Work Group; Canadian Council of Forest Ministers; Model Forests; Innovative Forest Practices Agreement
Turbidity	• State of Forests Reporting; Kamloops LRMP Monitoring; Model Forests; Innovative Forest Practices Agreement
Biological Water Quality (Index)	• The Pacific Northwest Salmon Habitat Indicators Work Group; Environmental Trends Reporting
Physical Habitat Quality (Index)	• The Pacific Northwest Salmon Habitat Indicators Work Group
Fish Spawning and Rearing Areas	• The Pacific Northwest Salmon Habitat Indicators Work Group; Forest Certification
Stream Morphology	• The Pacific Northwest Salmon Habitat Indicators Work Group; Model Forests
Large Woody Debris	• The Pacific Northwest Salmon Habitat Indicators Work Group; Forest Certification; Model Forests
Sedimentation	• The Pacific Northwest Salmon Habitat Indicators Work Group; Model Forests
Disturbed Stream Channel/ Channel Stability	• Watershed Assessment Procedures; Forest Certification; Model Forests
Road Erosion	• Watershed Assessment Procedures

The ultimate uses of indicator measurements and the monitoring framework that will be implemented to provide information for decision-makers must be understood in order to ensure appropriate indicator selection. To this end, this section discusses:

- The "business drivers" that supply the underlying motivation to invest in indicator development and implementation (i.e., the questions to which resource managers need answers);
- The distinct types of uses to which indicators must be applied and the information requirements in order to respond to the business drivers; and,
- The indicator selection framework that will be used.

3.2.1. The Business Drivers

In the environmental management field, indicators are used to answer specific questions from managers and decision-makers about the environmental values for which they are responsible. It is essential for the "business drivers" (i.e., the objectives that lay behind implementing an environmental monitoring system) to be clearly defined when developing indicators. Without certainty on what the indicator measurements will be used for, it is possible that indicators may be selected that fail to answer the questions that need answers.

This section describes five possible categories of use (i.e., business drivers) for developing and implementing a suite of land use indicators for assessing fish and fish habitat condition. These are summarized in Table 16. It would be prudent to develop an indicator set that is robust enough to support all of these potential requirements to at least a certain extent, recognizing that some business drivers will be more important than others.

Supporting Regulatory and Policy Responsibilities for Managing Fish and Fish Habitat

Fish managers must make daily decisions on managing fish and fish habitat under their regulatory powers. Examples of the kinds of questions that they must routinely answer include:

- *What streams and fish stocks are experiencing habitat deterioration problems to the point that there are significant adverse effects on fish populations?* Knowing this will inform decision-makers on the streams and stocks that should be afforded protection under the statutory provisions and designations of the provincial *Fish Protection Act*, federal *Fisheries Act*, or the pending *Species at Risk Act*. Comparative knowledge of which watersheds, streams and stocks are in "good" versus "poor" condition (and thus are capable or incapable of "absorbing" future resource development activity) will assist managers in commenting in a timely way on resource development referrals, or participating more effectively in major project review processes (under provincial or federal environmental assessment legislation).

- *What levels of fish and fish habitat maintenance (or disturbance) are appropriate or acceptable in various locations throughout the province?* Knowing this will enable resource managers to set measurable standards at the local level that are prerequisite for a results-based management system.

- *What watersheds are "low versus high" risk from a fish and fish habitat perspective, and thus should be exempted from or subject to closer analysis as part of forest development planning and project review exercises?* Knowing this will help resource managers determine watersheds that should be subject to full watershed assessment procedures as part of developing forest development plans and range use plans, or that should be subject to more intensive investigation as part of referral or environmental assessment reviews.

- *What level of harvest of particular fish stocks should be permitted?* Knowing this will influence management and regulatory decisions on closures, bag limits, or quota limits for commercial angling guides. The information could also assist with decisions on allocating fishing rights among competing user groups.

Determining Priorities for Restoration and Planning Investments

Habitat restoration projects are undertaken to deal with known problems with habitat deterioration. The challenge faced by fish managers is determining where scarce restoration funds should be allocated in order to achieve maximum effectiveness. This issue is likely to

surface more prominently as BC's New Era "Living Rivers" commitment to a 10-year program to correct past habitat damage is implemented.

A similar priority-setting challenge arises in determining where land and resource planning investments should be made to derive watershed-specific objectives or strategies aimed at fish and fish habitat protection (e.g., setting priorities for Watershed-based Fish Sustainability Plans, landscape level plans, water use plans).

The question that resource managers must answer is:

- *What watersheds are experiencing fish productivity declines that could be reversed through investments into habitat restoration or planning initiatives?* Knowing this will enable decision-makers to establish priorities for restoration and planning investments, to make investments into adaptive management trials or further resource inventory; or to seek out partners (e.g., forest licensees, stewardship organizations) for undertaking restoration and planning activities. In a land and resource planning context, information on specific areas of concern can be factored into the planning processes themselves to help guide the technical process of setting spatially-specific resource management objectives, delineating zones and defining appropriate resource management strategies.

Assessing the Effectiveness of Policies and Plans

A multitude of resource management provisions exist in aid of fish and fish habitat protection. These are spelled out on various sources, including:

statutes – e.g., federal *Fisheries Act*, provincial *Fish Protection Act*, pending federal *Species at Risk Act*;

regulations – established pursuant to federal or provincial resource management statutes (e.g., Operational Planning Regulation under *Forest Practices Code of British Columbia Act*);

agency policy statements – e.g., DFO's Policy for the Management of Fish Habitat, which includes the definition of the "no net loss" principle;

guidelines or best management practices – e.g., guidebooks that comprise part of BC's current Forest Practices Code;

standards – e.g., measurable performance expectations that will be adopted under a "results-based" forest practices code; or standards that have been developed as part of forest certification systems designed to assure sustainable forest management; or that exist as permissible thresholds in resource use and development approvals and permits.

land and resource use plans – containing resource management goals, objectives, strategies, zones for specific geographic areas (e.g., LRMPs, Watershed-based Fish Sustainability Plans, local government official community plans).

Resource managers require monitoring information that enables them to answer the question:

- *Are the fish and fish habitat protection and restoration provisions, which are contained in various federal and provincial statutes, regulations, policy statements, guidelines, standards, and land use plans, achieving the desired results for fish and fish habitat values?* Knowing the answer to this question allows resource managers to determine if the provisions should be continued or possibly expanded, or adjusted in attempts to achieve fish protection goals.

Naturally, there are a range of scales at which effectiveness monitoring results need to be known – provincially to gain an overall picture of the combined effectiveness of the federal and provincial policy regime, down to the local level in order to understand the effectiveness of, for example, a particular watershed restoration project.

Enabling Trends Interpretation and Sustainability Reporting

Several initiatives are being developed and implemented to assess and report publicly on the overall state of environmental quality, ecosystem integrity or progress towards sustainable forest management (SFM) practices in BC. These are policy driven initiatives being pursued by individual provincial agencies in support of understanding their own programs or to further

internationally and nationally developed SFM criteria and indicator initiatives. These initiatives include:

Environmental Trends in British Columbia – MWLAP is continuing to track trends in fifteen indicators of environmental condition including: surface water quality, water use, species at risk, status of fish stocks, development in riparian areas, threatened or endangered urban streams.

State of the Forest in British Columbia – MOF and MSRM are developing indicators and methodologies for reporting on the status of BC's forests. As many as 40 environmental indicators are being considered, including those in fish and aquatic fauna, water quality and water use categories.

Criteria and Indicators for SFM (National Level) – the Canadian Council of Forest Ministers has developed a suite of indicators for measuring and reporting progress at the national level towards SFM. These include indicators such as threatened or endangered fish species, abundance and distribution of aquatic fauna, surface water area, and water quality.

Criteria and Indicators for SFM (Local Level) – Model Forests across Canada, including BC's two model forests – the McGregor and the Long Beach model forests – are busy developing local level indicators for tracking SFM performance. They are considering various fish, fish habitat and related land use indicators.

These initiatives are all aimed at answering the question:

- *What positive or negative trends are evident in the indicators that we are measuring?* Knowing this enables decision-makers to determine if they should be concerned about a particular resource or location that is experiencing a negative trend in the indicators being monitored. The information provides a basis for assessing and reporting generally on BC's environmental health, and whether or not environmental and resource management policies and practices are producing desirable results. In this sense, they are a public accountability

tool.[3] Trends interpretation information is also potentially valuable for incorporating into marketing campaigns in support of the provincial forest products industry.

Assessing Compliance with Regulatory and Other Performance Standards

As government moves toward implementing a results-based forest practices code, resource managers will be required to determine whether or not licensees' activities on the land base are in or out of compliance with the required performance standards that are set in regulation, policy or in individual approvals. Forest certification auditors will also need the ability to assess degree of conformance with the performance standards that are established under various forest certification systems.

Fish resource managers are routinely called on to respond to forest (and other resource) development proposals or to participate in reviews of major project proposals under federal or provincial environmental assessment legislation. Having the ability to set priorities out of concerns about significant risks to fish values, versus where they can perhaps "afford" to be somewhat less involved because the risks are lower, will assist with program management decision-making. In summary, the following question needs to be addressed:

- *Are the measurable standards that have been established to protect fish values (as performance measures in regulation, policies, permits, or forest certification systems) being attained?* Knowing this will enable resource managers to take appropriate actions, possibly including decisions to "do nothing" where the standards are being achieved, or holding

---

[3] Another potential business driver that relates to accountability is the requirement for ministries to develop performance standards under the *Budget Transparency and Accountability Act*. The specific indicators that should be selected for this purpose will depend entirely on the performance standards that agencies set for themselves.

licensees to account where standards have not been achieved. This information will also be valuable to forest certification auditors that are assessing the extent to which forest licensees are compliant with the sustainable forest management performance standards against which they are being audited.

Table 16. Summary of business drivers, questions, and applications of information.

Business Driver	Questions that Need Answers	Examples of Applications of Information
1. Supporting Regulatory and Policy Requirements for Managing Fish and Fish Habitat	• What streams and fish stocks are experiencing habitat deterioration problems to the point that there are significant adverse effects on fish populations? • What levels of fish and fish habitat maintenance (or disturbance) are appropriate or acceptable in various locations throughout the province? • What watersheds are "low versus high" risk from a fish and fish habitat perspective and, thus, should be exempted from or subject to closer analysis as part of forest development planning and project review exercises? • What level of harvest of particular fish stocks should be permitted?	• Help decide on whether or not to implement protective designations under *Fish Protection Act*, *Fisheries Act*, or pending *Species at Risk Act*. • Establish measurable performance standards that licensees are expected to achieve as prerequisite for adopting a results-based management system. Enable more effective response to referrals and participation in major project reviews. • Determine watersheds that should be subject to full watershed assessment procedures, or that should be subject to more intensive investigation as part of referral and environmental assessment reviews. • Help decide on regulatory decisions (e.g., closures, quotas), and decisions on allocating fishing rights among competing user groups.
2. Determining Priorities for Restoration and Planning Investments	• What watersheds are experiencing fish productivity declines that could be reversed through investments into habitat restoration or planning initiatives?	• Help decide which watersheds are priorities for investments (e.g., restoration projects, further resource inventory, planning processes). • Assist planning processes to identify appropriate resource management objectives, strategies for fish and fish habitat protection in planning reports.

Table 16 (continued). Summary of business drivers, questions, and applications of information.

Business Driver	Questions that Need Answers	Examples of Applications of Information
3. Assessing the Effectiveness of Policies and Plans	• Are the fish and fish habitat protection and restoration provisions, which are contained in various federal and provincial statutes, regulations, policy statements, guidelines, standards, and land use plans, achieving the desired results for fish and fish habitat values?	• Deciding whether or not to continue, reinforce, or expand fish and fish habitat protection provisions; or to adjust provisions that are not working.
4. Enabling Trends Interpretation and Sustainability Reporting	• What positive or negative trends are evident in the indicators that we are measuring?	• Identifying areas of environmental health concern (early warning system), as a basis for guiding environmental and land use management programming and policy-making. • Public accountability reporting on overall effectiveness of federal and provincial policy regime for protecting and restoring fish and fish habitat. • Supporting marketing campaigns for BC forest (and possibly other) products.
5. Assessing Compliance with Regulatory and Other Performance Standards	• Are the measurable standards that have been established to protect fish values (as performance measures in regulation, in permits, or forest certification systems) being attained?	• Decide on appropriate compliance and enforcement activities. • Assist with forest certification audits.

3.2.2. Information Requirements for Distinct Applications

The preceding discussion suggests that there are three broad types of applications of information required to answer the questions being asked about land use effects on fish and fish habitat in forest environments. These are described below and are summarized in Table 17.

Strategic Applications

Strategic applications are concerned with priority setting and trends assessment. To decide which BC streams or stocks should receive protection under federal or provincial statutes that enable protective designations to be established; to identify which watersheds must be evaluated more carefully than others when responding to development proposals; or to determine which watersheds should receive priority for investing into watershed restoration, resource managers must be able to compare stream or stock conditions throughout the province. Information is needed that identifies certain fish stocks or fish habitat as being under "greater threat" or at "higher risk" than others. In other words, we need complete enumeration (i.e., census type information) of the conditions being measured for all BC watersheds, not a subset of them.

The same need is evident when responding to questions about overall provincial trends in fish and fish habitat conditions. Province-wide coverage on the condition of all streams and stocks (i.e., by measuring selected indicators of stream and stock condition) is preferred, even though comparisons of individual streams to derive relative risk ratings may not be involved.

The implication of these "strategic level" business drivers is that we must select indicators for which data can be provided that covers the *entire* province. It is feasible to produce such information for only certain parameters – typically those that are produced in mapped form that are derived from cost-effective sources (e.g., satellite imagery or aerial photography).

Dealing with mapped information for all streams or stocks for the entire province, however, is not practical without the ability to break the province into a manageable number of "units" to enable assessment of relative stream and stock condition, and which makes sense from

a scientific perspective. It is suggested that the ability to report on *watershed* condition, as a scientifically valid ecological unit, is a basic prerequisite of satisfying these business drivers. This requirement has been anticipated in BC. There already exists an agreed upon subdivision of the province into watershed units, and a body of supporting information on selected watershed attributes. This watershed information was discussed in Section 3.1.3.

Information that is required to meet these provincial-level business needs must be updated on a periodic basis. Fish and fish habitat conditions that are tied to land use impacts change in relation to the scale and nature of land use change. At the watershed level, land use patterns do not usually change dramatically from one year to the next – change is more gradual. However, over a period of several years, conditions can change enough to make a difference for decision-making purposes (e.g., for resetting watershed restoration priorities, or reporting provincial trends on fish and fish habitat condition). Therefore, it can be assumed that province-wide information on selected watershed indicators will be needed for strategic applications on roughly a five-year cycle.

Effectiveness Assessments

There is a second major business requirement that creates a need for a body of information to understand the *effectiveness* of the various *management actions* that are being implemented in efforts to achieve fish and fish habitat protection goals. A diverse array of rules-based regulations, policies, guidelines, plans and results-based standards (e.g., those being developed as part of Forest Practices Code reforms) exist or are being developed to protect fish and fish habitat values. Are they achieving their intended purpose? This must be known so that, if required, rules or standards can be adjusted to improve management effectiveness.

Effectiveness monitoring does not suggest a need for province-wide comparative assessment of watershed condition. Rather, it is possible to gain a sufficient understanding of effectiveness by looking at a subset of watersheds that are representative of the locations where the management actions are being applied. The challenge from an indicators selection perspective is that there are many different management actions being undertaken that apply in many different locations. For example, measuring the effectiveness of a policy or standard on

riparian set-backs would require monitoring different watersheds and different indicators than measuring the effectiveness of a policy or standard on pesticide presence. It will be necessary, therefore, to be selective in identifying which policies and standards are the most critical to understand in terms of their effectiveness in protecting fish and fish habitat. Thus, it is not possible to define a generic set of indicators or measures for this purpose. They must be defined by the needs of the specific investigation.

From a land use impacts point of view, it is possible to categorize the policies and standards that are aimed at fish and fish habitat protection. If we know what the general categories of management actions are, it makes it easier to understand the types of indicators that would be relevant to assess the effectiveness of the management actions. There are policies and standards that:

- Separate conflicting uses *in space* (e.g., prohibiting forest development in specified locations such as within 10 m of a fish bearing streams);
- Separate conflicting uses *in time* (e.g., establishing seasonal restrictions on road building when elevated sedimentation could result);
- Apply *conditions* on how management activities are undertaken (e.g., directing that only certain types of silviculture activities are undertaken, such as selection systems as opposed to clear cutting);
- Define a *measurable limit or threshold* for a particular resource attribute (e.g., establish a permissible or targeted maximum turbidity level);
- Permit damage to habitat to occur, subject to *rehabilitation of the habitat or habitat compensation* elsewhere (e.g., the federal government's "no net loss" policy);

To understand how effective these types of management actions are in protecting fish and fish habitat, you ideally want to be able to measure ultimate *outcomes*. How have actual fish populations or fish habitats been affected by the management measures? This suggests a need to measure the state of fish and fish habitat in representative watersheds where the management

actions have been applied. For example, in watersheds where riparian buffers, green-up requirements, or clearcut size standards have been implemented, what are the resulting fish and fish habitat conditions in those watersheds, as determined through outcome-based measurements that require field sampling or the development of predictive models to derive the measurements for the indicators of interest?

This business requirement demands field-level data in addition to mapped information derived from remote sensing. Scientific analyses are required to determine the cause-effect relationships or to model the behaviour of the human-environment system. Policy variables must be related to land use activities, which in turn must be related to the biophysical condition of the environment and, ultimately, fish and fish habitat. This is, in effect, an information need to conduct experiments to inform adaptive management strategies.

Planning, Permitting and Enforcement

A third category of information requirement is information that enables resource managers to evaluate compliance with established performance standards. Although these standards may apply province wide, or to a particular region of the province (e.g., a results-based standard for a particular land use zone or biogeoclimatic zone), the business requirement is to be able to assess the extent to which the given standards are being achieved in *particular locations*, such as a forest license area that is being audited for conformance with results-based FPC standards, or a forest licensee that is being audited for conformance with forest certification system standards.

Information at the individual watershed level is also needed for planning and permitting purposes, to determine the appropriate level and type of development and resource activity for watersheds (e.g., to develop a forest development plan that is appropriately sensitive to fish and fish habitat). This is essentially what the current Watershed Assessment Procedure under the FPC is about. Resource managers may also wish to collect intensive watershed information if a particular watershed (or stock) is experiencing significant decline and more detailed information is needed as a basis for developing an appropriate management response.

When assessing compliance with established performance standards, it is obviously necessary to know what the performance standards are before you can identify the measures for assessing compliance with the standards. We do not yet know what the final performance-based standards for fish and fish habitat protection will be in a results-based FPC, but it is probable that there will be a need to measure outcome-based indicators of fish habitat condition. Proxies for these outcome-based measures (i.e., indicators) may be selected in the form of pressure indicators (see Section 3.3.3 below). However, there is admittedly much debate over the scientific validity of relied-upon indicators for individual watershed assessments (e.g., see various contributions in Toews and Chatwin 2001).

Thus, to satisfy these business requirements, a combination of sampled field-level information from specific tenured areas or watersheds, plus mapped information on conditions within the tenured areas or watersheds of concern, is needed. Here, the primary need is not scientific inquiry (i.e., conducting experiments to determine the cause-effect relationships or to model the behaviour of the human-environment system). It is the use of indicators or direct measures, as supported by the best available scientific information, to conduct the business of managing land use activities.

Table 17. Information requirements for distinct applications.

Application	Primary Business Drivers	Information and Data Requirements
Strategic Applications	• Comparative evaluation of watersheds to identify those at greater threat, as basis for enacting protective stream and stock designations; for determining watershed restoration priorities. • Provincial level trends interpretation of fish and fish habitat condition.	• Census-type information that is available for all BC streams and stocks (watersheds).
Effectiveness Assessment	• Assessing the effectiveness of both results-based standards and rules-based regulations, policies, guidelines, plans, etc.	• Sampled information in a subset of representative watersheds where rules-based management actions and/or results-based standards have been applied.
Planning, Permitting and Enforcement	• Assess compliance with established performance standards (e.g., results-based code; forest certification standards). • Development planning in individual watersheds (e.g., determine appropriate type and level of forest development through watershed assessment procedures). • Develop appropriate management response for specific watersheds or fish stocks experiencing known decline.	• Combination of sampled and mapped information from specific tenured areas or watersheds.

3.2.3. A Framework for Indicator Selection

The most commonly cited framework for indicator selection is the pressure (or driving force) – state – response (PSR) model. The PSR framework has gained wide acceptance around the world and focuses on the development of a coherent indicator set through the selection of relevant indicators from the three categories (e.g., Hammond et al. 1995; United Nations 1996; Linster 1997; Mortensen 1997).

Pressure indicators measure the extent of human activities, processes and patterns that have an effect on the environment. They can be related to changes in industry or economic sectors, or to social aspects of human activities, and can either have a positive or negative influence (Mortensen 1997). State indicators measure the resulting biophysical condition of the environment at a given point in time, or provide information regarding changes or trends. Response indicators measure society's response to the perceived problems, including directions of policy and decision-making to prevent or mitigate deleterious changes on the environment, or to assist with the achievement of sustainable development. However, pressure indicators more directly measure the success of policy response, while response indicators themselves do not directly measure the result of policy (Hammond et al. 1995, p.12).

In selecting indicators to monitor land use impacts on fish and fish habitat in forest environments, "state" indicators are most desirable because they more directly provide information regarding the actual condition of the environment. But measures for state indicators can be more difficult and costly to obtain. Often, one relies on "pressure" indicators, especially at a strategic level. For example, many of the attributes available from maps indicate land use activities as pressures on the environment (e.g., road density, areas logged), rather than provide information on the state of the environment (e.g., stream sedimentation; water temperatures). Ideally, one would like to quantitatively establish a strong link between pressures and environmental states in order to validate the use of pressure indicators.

At the individual watershed level, where more specific planning, permitting and enforcement needs must be fulfilled, greater reliance must be placed on state indicators. This requires field sampling programs. Information of interest includes such measures as

sedimentation, water temperatures, and water flows. Even if appropriate "proxies" are relied upon (e.g., amount of landslide activity, riparian area logged), more detailed watershed-specific analyses are required.

To respond to provincial strategic level information needs, pressure indicators that can be supported cost-effectively with province-wide mapping information are appropriate. At the individual watershed level, both pressure and state indicators are appropriate. However, the latter will require more detailed field sampling, watershed-specific interpretations or modelling.

The framework for indicator selection will assume some general links between forest development and fish and fish habitat. Four primary hydrologic outcomes of forest development – increased peak flows, reduced low flows, increased suspended sediment, and channel destabilisation – impact water quality, water quantity and aquatic habitat (Carver 2001) (Table 18). The forest development activities (i.e., road building and forest removal) represent *pressures* on the environment. The environmental impacts represent resulting *state* conditions.

Table 18. Linkages between forest development, the hydrologic regime, and impacts on water quality, water quantity and aquatic habitat (adapted from Carver 2001).

Forest Development Activity	Hydrologic Outcomes	Environmental Impacts
Road Building involving processes of: • Cut/ fill and soil exposure; • Drainage diversion; and • Subsurface flow interception. **Forest Removal** involving processes of: • Lost riparian function. • Increased rate of snowmelt. • Locally increased snowpack/ decreased evapotranspiration.	• Increased suspended sediment. • Channel destabilization. • Increased peak flows. • Reduced low flows.	• Reduced water quality. • Lost or damaged aquatic habitat. • Reduced seasonal water availability.

It is desirable to be more specific regarding the environmental impacts of concern before specifying appropriate indicators. Expanding on the environmental impacts related to forest development (Table 18), a more detailed categorisation can be identified. Chosen indicators can relate directly to:

- Species of social importance (e.g., economic, charismatic or endangered species);
- Species of ecological importance (e.g., species with critical roles in relationships between species or in habitats);
- Biological diversity;
- Important ecosystem processes; and,

- Habitat quality and quantity (including water quality and quantity, riparian and aquatic habitat characteristics) (Costanza 1992; Harwell et al. 1999).

This categorisation provides the framework from which environmental impact indicators may be chosen. Forest development activities, as linked to environmental impacts, provide the basis for selecting pressure indicators.

For the purposes of this report, the following definitions will be assumed:

- *Criteria* = stated management or human activity performance objectives (i.e., the desired end results). Criteria identify the c*onditions* or *processes* by which performance is assessed.

- *Indicators* = proxy measures used to determine if management objectives are being achieved. Indicators are used for monitoring the *effectiveness* of approaches to meet management criteria.

- *Thresholds* = defined ranges of indicator values that are desirable to meet the stated criteria. Thresholds may similarly be defined as "levels of criticality" above or below which the management objectives are not being met.

Thresholds can be difficult to define. Often, indicators are identified as important to measure, but desired levels or ranges are not known. In such cases, an indicator may still be a valid part of a monitoring program – as long as desirable and undesirable *directions of change* can be specified. In these instances, management performance is evaluated by the "positive" or "negative" movements as measured by the indicators.

Care must be taken in defining specific thresholds, as it can mislead the analysis. Unless there is strong scientific evidence to the contrary, it is inappropriate to accept an "automatic evaluation" of indicators. For example, the point at which water temperature becomes lethal to juvenile salmonids may be used to identify an upper threshold for the indicator "stream temperature". Anything beyond this level is obviously undesirable and dictates an automatic evaluation (i.e., there are no acceptable alternative conclusions to draw from the

indicator value, other than it is not sustainable for fish). But for many other indicators, the scientific literature does not suggest thresholds that should be so strongly interpreted.

When evaluating the multiple criteria in a sustainability assessment, the evaluation process becomes one of considering the various management objectives in a balanced manner. It will often not be possible to "maximise" performance with respect to all individual criterion. Trade-offs and compromises must be considered, and the importance of achieving certain objectives weighed against achieving others.

Two basic criteria are assumed for this project – 1) the conservation of habitat; and 2) the conservation of species. Both are essential for the goal of sustainable fish and fish habitat in forest environments. Table 19 shows the final framework for indicator selection. The proposed indicators are presented in two distinct groupings, reflective of two distinct uses – 1) strategic level applications; and, 2) watershed level monitoring. Indicators for strategic level applications focus on pressure indicators associated with forest removal and road and road structures. State indicators associated with fish populations are also called for here given the project's focus on fish. Indicators for watershed level monitoring focus primarily on state indicators associated with water quality and quantity, aquatic habitat, riparian habitat, fish populations, and biological diversity.

Table 19. The indicator selection framework.

	Criteria	Indicator Category
Strategic Level Applications	Conservation of Habitat	Road and Road Structures
		Forest Removal
	Conservation of Species	Fish Populations
Watershed Level Monitoring	Conservation of Habitat	Water Quality and Quantity
		Aquatic Habitat
		Riparian Habitat
	Conservation of Species	Fish Populations
		Biological Diversity

3.3 The Indicators

3.3.1. Indicator Sets for Strategic and Watershed Level Applications

A set of land use impact indicators is proposed that will enable the monitoring of fish and fish habitat conditions in forest environments for both strategic and watershed level applications (Tables 20 and 21). The indicator framework (Table 19) guided the selection of the indicator sets. Attention was also paid to the identified desirable attributes of indicators (Table 1), as well as the fulfilment of policy needs as described by the business drivers. A detailed accounting of the indicator evaluation is presented in Appendix C.

A distinction is clear between the indicators for strategic level applications and the indicators for watershed monitoring. Monitoring at the strategic level is based on the use of data supported by existing corporate data sets, although in some cases this will require a refinement of

existing data collection and data management practices. Emphasis must be placed on the use of corporate data that will be continued to be supported by government in the future and provide time-series information. On the other hand, monitoring at the watershed level is currently not readily supported by corporate data. By recommending monitoring at the watershed level using a consistent base set of indicators, we are implicitly advocating for the ongoing collection of the information using commensurable methods. But given the substantial resources that would be required to initiate province-wide monitoring at this scale, it is preferable to focus such monitoring efforts on watersheds where: 1) issues have been identified through strategic level assessments, or data from a specific set of watersheds is desirable as part of province-wide fish management efforts; 2) adaptive management trials are underway as part of a land use management effectiveness monitoring initiative; or, 3) there are local level planning, compliance or enforcement needs that would be well served by watershed monitoring.

We are aware that at the regional level, various efforts are underway with respect to watershed monitoring to support local level land use planning, compliance and enforcement. In addition, current practices will undoubtedly change in the near future (e.g., data collection required to support a results-based Forest Practices Code). By recommending a specific base set of indicators for watershed applications, it is not the intent of this report to negate the value of using other indicators developed with specific local conditions in mind. The intent of our recommendations is to suggest an indicator set that makes the most sense on a province-wide basis for all watersheds, keeping in mind our primary interest in fish sustainability. We feel that the management of land use impacts on fish and fish habitat would be well served by all regions adhering to the use of a base set of indicators. The decision to embark on the collection of other information to support local level planning, compliance and enforcement is best left to the regions as determined by local level conditions and the management issues they face. It is imperative, though, that data collected to support the base set of watershed level monitoring indicators recommended here be brought into a corporate database, and ultimately made available through a central repository (see Conclusions regarding ways in which this could occur).

Table 20. Indicators for strategic level applications.

Indicator Category	Indicator	Description
Road and Road Structures	Road density	• Road density (km/km2) on forest land by watershed.
	Road density on steep slopes	• Road density (km/km2) on forest land on gradients >60% by watershed.
	Road-stream crossing density on forest land	• Total number of road-stream crossings on forest land divided by watershed area.
	Road-stream crossing density on forest land on steep slopes	• Total number of road-stream crossings on forest land on gradients >60% divided by watershed area.
Forest Removal	Equivalent clearcut area (ECA) density	• Area harvested, cleared or burned, adjusted for regeneration growth and elevation within watershed, as a percentage of watershed area.
	Riparian disturbance	• Length of riparian habitat harvested, cleared or burned, as a percentage of stream length on forest land in watershed.
Fish Populations	Salmon escapement	• Trend in salmon escapement by species by watershed.
	Fish species at risk	• Number of fish species endangered, threatened or vulnerable by watershed.

Table 21. Indicators for watershed level monitoring.

Indicator Category	Indicator	Description
Water Quality and Quantity	Landslide area density	• Area of landslides or slope failures as a percentage of watershed area.
	Temperature	• Daily maximum temperature of fish bearing streams.
	Turbidity	• Turbidity of fish bearing streams.
Aquatic Habitat	Habitat complexity	• Variance in thalweg depth of fish bearing streams
Riparian Habitat	Riparian disturbance	• Length of riparian habitat harvested, cleared or burned, as a percentage of S4-S6 stream length on forest land in watershed.
Fish Populations	Resident fish populations	• Trend in resident population levels by species for fish bearing streams.
Biological Diversity	Benthic macroinvertebrate diversity	• Trend in diversity index based on proportional abundance.

It is recommended that analysis, depiction and interpretation of the indicators be based on the geographic information system (GIS) framework provided by the Watershed Atlas. The Watershed Atlas defines watershed and watershed group boundaries from federal 1:50,000 base mapping. Streams are defined from the 1:20,000 TRIM base map database (based on 1986-1988 aerial photography). Third order or higher watershed are defined and coded – coding was designed to facilitate the grouping or "rolling up" of watersheds based on drainage relationships. There are approximately 18,000 distinct watersheds defined by the Watershed Atlas.

Watersheds BC is potentially a very powerful database, built using the Watershed Atlas framework and incorporating data from a wide range of sources. It provides provincial-wide coverage of a number of attributes and, if updated on a regular basis, would currently serve some of the monitoring needs at the strategic level. However, there are also other data sources available to support the recommended indicators.

Similar to what was begun by the Watersheds BC project, attributes key to monitoring fish and fish habitat could be incorporated into and maintained within the Watershed Atlas GIS-based framework. Key existing corporate sources of data, useful primarily for the strategic level indicators (Table 22), include: Watersheds BC; the Forest Cover Inventory (FCI); Fisheries Information Summary System (FISS); and Red-listed and Blue-listed species lists (Conservation Data Centre).

Overall, the development of a program to monitor land use impacts on fish and fish habitat must consider how data collection and analysis will be carried out to support such a program. Options include: 1) the development of a new GIS-based database built off the Watershed Atlas framework; 2) incorporation of data from additional and alternative sources into the Watersheds BC database, at least for strategic applications; or, 3) integration of data required for fish and fish habitat monitoring into the developing provincial integrated environmental monitoring strategy. Alternatively, a combination of these options could be explored.

Table 22. Key corporate data sources in support of the recommended indicator set for strategic level applications.

Database	Indicators Supported	Database Characteristics
Watersheds BC	Road density Road density on steep slopes Road-stream crossing density on forest land Road-stream crossing density on forest land on steep slopes Equivalent clearcut area (ECA) density Riparian disturbance	• Data on approximately 400 watershed attributes, organized by watershed using the Watershed Atlas framework. • Complete provincial coverage. • Data derived from multiple sources, including: BTM satellite products, TRIM 1 and 2, FISS.
Forest Cover Inventory (FCI)	Road density Road density on steep slopes Road-stream crossing density on forest land Road-stream crossing density on forest land on steep slopes Equivalent clearcut area (ECA) density Riparian disturbance	• Data on forest cover and disturbance types, height of dominant trees, and roads. • Data derived from aerial photo interpretation and field mapping; growth models used to grow forest polygons to present. • Mapped on 1:20,000 scale. Some gaps in coverage (notably some provincial park areas, some TFLs, most private land). Special FCI coverage being built for State of Forests reporting purposes corrects for these gaps. • FCI coverage assembled for landscape level planning purposes should help facilitate data accessibility.

Table 22 (continued). Key corporate data sources in support of the recommended indicator set for strategic level applications.

Database	Indicators Supported	Database Characteristics
Fisheries Information Summary System (FISS)	Salmon escapement Fish species at risk	• Data on salmon escapement and fish species and stock presence by stream. • Province-wide coverage, mapped on 1:50,000 scale.
Red-listed and Blue-listed Species (Conservation Data Centre)	Fish species at risk	• Lists of rare, endangered, and vulnerable species for the province. • Data from 1991 to the present; coverage is province wide, with tracking lists summarized by Forest District.

3.3.2. Methods for Strategic Level Indicators

In this section, specific data sources, methods for analysis and interpretation, and directions for future improvements are recommended for strategic level indicators. It is recognised that each key data source that is identified for each indicator has inherent weaknesses – there is no "perfect" database. As stated previously, the methods have been designed to be opportunistic of existing corporate data sets, integrating data from multiple sources for measurement of the proposed indicators (Table 22). Overall, the task is to select the best data sources according to the indicator evaluation criteria (Table 1).

Indicator: Road Density

Indicator Measure: Road density (km/km2) on forest land by watershed	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on roads in forest environments. • Watersheds BC provides information on watershed boundaries, extent of forest land in watersheds, and watershed area.
Analysis and Interpretation	• The total length of roads on forest land is summed by watershed. This is then divided by the total area of the watershed. • The greater the road length density on forest land by watershed, the greater the risk to fish sustainability.
Future Improvements	• Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is reportedly not currently happening, and in some instances the corporate database is 4-5 years old.

Indicator: Road Density on Steep Slopes

Indicator Measure: Road density (km/km2) on forest land on gradients >60% by watershed	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on roads in forest environments. • Watersheds BC provides information on watershed boundaries, extent of forest land in watersheds, watershed area, and slope.
Analysis and Interpretation	• The total length of roads on forest land is summed by watershed, including only those on slopes greater than 60%. This is then divided by the total area of the watershed. • The greater the road density on forest land on steep slopes by watershed, the greater the risk to fish sustainability.
Future Improvements	• Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is not currently happening, and in some instances the corporate database is 4-5 years old.

Indicator: Road-stream Crossing Density on Forest Land

Indicator Measure: Total number of road-stream crossings on forest land divided by watershed area	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on roads and stream location in forest environments. • Watersheds BC provides information on watershed boundaries, extent of forest land in watersheds, and watershed area.
Analysis and Interpretation	• The total number of road-stream crossings on forest land is summed by watershed. This is then divided by the total area of the watershed. • The greater the road-stream crossing density on forest land by watershed, the greater the risk to fish sustainability.
Future Improvements	• Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is not currently happening, and in some instances the corporate database is 4-5 years old.

Indicator: Road-stream Crossing Density on Forest Land on Steep Slopes

Indicator Measure: Total number of road-stream crossings on forest land on gradients >60% divided by watershed area	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on roads and stream location in forest environments. • Watersheds BC provides information on watershed boundaries, extent of forest land in watersheds, watershed area, and slope.
Analysis and Interpretation	• The total number of road-stream crossings on forest land is summed by watershed, including only those on slopes greater than 60%. This is then divided by the total area of the watershed. • The greater the road-stream crossing density on forest land on steep slopes by watershed, the greater the risk to fish sustainability.
Future Improvements	• Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is not currently happening, and in some instances the corporate database is 4-5 years old.

Indicator: Equivalent Clearcut Area (ECA) Density

Indicator Measure: Area harvested, cleared or burned, adjusted for regeneration growth and elevation within watershed, as a percentage of watershed area	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on forest cover, from which to identify types of disturbed areas and derive heights of the forest canopy. In the FCI, cover is "grown" by modelling. • Watersheds BC provides information on watershed boundaries, watershed area, and elevation.
Analysis and Interpretation	• Calculation following Watershed Assessment Procedure description of methods (Ministry of Forests 1999). • Factoring in the elevational location of the areas harvested, cleared or burned within a given watershed, to relate the disturbance to impacts on peak flows, is desirable. For interior watersheds, use the "H60 line" (the elevation above which 60% of the area of the watershed lies). For coastal watersheds, need to define regional "rain-dominated zones, transient snow zones, and snowpack zones" to apply adjustments. • The greater the equivalent clearcut area (ECA) density by watershed, the greater the risk to fish sustainability.

Indicator: Equivalent Clearcut Area (ECA) Density (continued)

Future Improvements	• Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is not currently happening, and in some instances the corporate database is 4-5 years old. • A potential cost-saving method for updating the FCI to incorporate information on changing boundaries of disturbances and disturbance types is use of Landsat imagery information.

Indicator: Riparian Disturbance

Indicator Measure: Length of riparian habitat harvested, cleared or burned, as a percentage of stream length on forest land in watershed	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on forest cover, stream location and stream length. • Watersheds BC or Watershed Atlas provides information on watershed boundaries.
Analysis and Interpretation	• Identify harvested, cleared or burned riparian areas, defined as any of this activity occurring within 30m of any stream. The total length of disturbed riparian area, counting each side of all streams separately, is divided by twice the total stream length in the watershed. • The greater the length of riparian habitat harvested, cleared or burned as a percentage of stream length on forest land by watershed, the greater the risk to fish sustainability.

Indicator: Riparian Disturbance (continued)

Future Improvements	• Digital orthophotography that was collected for FCI / TSA planning purposes or for developing TRIM 2 products may provide another information source for checking accuracy tolerances of riparian disturbance calculations derived from corporate data sets. • Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is not currently happening, and in some instances the corporate database is 4-5 years old. • A potential cost-saving method for updating the FCI to incorporate information on changing boundaries of disturbances and disturbance types is use of Landsat imagery information.

Indicator: Salmon Escapement

Indicator Measure: Trend in salmon escapement by species by watershed	
Data Source and Data Collection	• FISS provides information derived from the federal Salmon Escapement Database and Reporting System (SEDS) – mean and maximum escapement over the last 10 year period available for six salmon species province-wide. • Watersheds BC or Watershed Atlas provides information on watershed boundaries.
Analysis and Interpretation	• Using data on mean escapement by species by watershed over the last ten years, classify watersheds according to increasing, decreasing or stable trends based on changes in the 10-year running averages. • Salmon escapement is notably affected by many factors, forest development being only one of many natural and anthropogenic influences; thus, changes in escapement can not be strongly linked to land use, but does represent an indicator of the overall status of populations. A declining trend in escapement would call for extra caution in land management, despite not knowing the specific causes for such decline.
Future Improvements	• Further research into understanding the links between forest land use and salmon escapement is highly desirable. This must include consideration of the role of other non-land use factors in determining fish population status.

Indicator: Fish Species at Risk

Indicator Measure: Number of fish species endangered, threatened or vulnerable by watershed	
Data Source and Data Collection	• The Conservation Data Centre maintains Red (endangered and threatened) and Blue (vulnerable) species lists. • Watersheds BC and Fisheries Information Summary System (FISS) provides information on species and stock presence by stream. • Watersheds BC or Watershed Atlas provides information on watershed boundaries.
Analysis and Interpretation	• Using information on species and stock presence by watershed (from FISS), the numbers of Red-listed and Blue-listed species (or stocks) are identified for each watershed. • The greater the number of fish species endangered, threatened or vulnerable by watershed, the greater the risk to fish sustainability.
Future Improvements	• Species at risk information is currently "opportunistic", in that species are identified largely through targeted species-specific investigations once a concern is raised rather than through population inventories. As such, data may not be representative of species status across the province. • Fish distribution data in FISS is not complete for the province; however, the completeness of the records is expected to continue to improve over time.

3.3.3. Methods for Watershed Level Indicators

In this section, specific data sources, methods for analysis and interpretation, and directions for future improvements are recommended for watershed level indicators. As stated previously, most indicators for watershed level applications are not currently supported by corporate data. Often, it is not possible to be opportunistic of existing data, simply because it does not exist in an accessible form. This situation must change if the province is to effectively develop a program for monitoring land use impacts on fish and fish habitat at the watershed level.

Indicator: Landslide Area Density

Indicator Measure: Area of landslides or slope failures as a percentage of watershed area	
Data Source and Data Collection	• Data on landslides or slope failures not currently collected on a province-wide basis or available in a corporate database. A centralised collection of the information available in individual watershed assessment reports would provide valid, field-checked data to support the indicator. • In addition, adoption of a result-based Forest Practices Code may involve a requirement for licensees to report landslide occurrences to the Ministry of Forests. A centralised collection of this information would also support this indicator. • Watersheds BC or Watershed Atlas provides information on watershed boundaries and watershed area.
Analysis and Interpretation	• Define landslides related to forest development as first time slumps, rockslides, debris slides, debris avalanches and debris flows originating from an identifiable source. • The greater the area of landslides or slope failures, as a percentage of the watershed area, the greater the risk to fish sustainability.
Future Improvements	• Incorporation of landslide occurrence information, potentially including information provided as a requirement under a results-based Forest Practices Code or that has been provided as part of watershed assessment reports, into the developing corporate Integrated Environmental Monitoring System (IEMS) would facilitate measurement of this indicator.

Indicator: Temperature

Indicator Measure: Daily maximum temperature of fish bearing streams	
Data Source and Data Collection	• Corporate database of stream temperatures available for limited number of streams in HYDAT and WIDMS. Coverage of watersheds of interest will likely require expanding sampling efforts, establishing a consistent representative set of streams. • Watersheds BC and Fisheries Information Summary System (FISS) provides information on species and stock presence by stream. • Watersheds BC or Watershed Atlas provides information on watershed boundaries and stream locations.

Indicator: Temperature (continued)

Analysis and Interpretation	• The greater the daily maximum temperature above that optimal for fish species (and for life history stages of those species), measured from a representative sample of fish bearing streams by watershed, the greater the risk to fish sustainability. • Analysis will require overlaying fish presence data with stream temperature data to determine when thresholds are exceeded. • As recommended by the British Columbia Water Quality Guidelines (Ministry of Water, Land and Air Protection 1998), specific thresholds are suggested – see also Ministry of Water, Land and Air Protection (2001) and Oliver and Fidler (2001). For streams with bull trout and/or Dolly Varden, maximum 10°C spawning, maximum 15°C rearing, maximum 10°C and minimum 2°C incubation. For streams with known fish distribution, temperature should not be beyond ranges as defined for each life history phase of the most sensitive salmonid species present (see Guidelines). For streams with unknown fish distributions, the mean weekly maximum temperature should not exceed 18°C (maximum daily temperature 19°C), hourly rate of change not to exceed 1°C, and maximum incubation temperature 12°C (during spring and fall).
Future Improvements	• Sampling streams and locations should be established for watersheds of interest. Data should be collected and maintained in a central data repository. • Remote sensing technology (i.e., via aerial surveys) may provide an alternative means to provide obtain stream temperature information for a broad area.

Indicator: Turbidity

Indicator Measure: Turbidity of fish bearing streams	
Data Source and Data Collection	• Corporate database of stream turbidity available for limited number of streams in HYDAT and WIDMS. Coverage of watersheds of interest will likely require expanding sampling efforts, establishing a consistent representative set of streams. • Watersheds BC or Watershed Atlas provides information on watershed boundaries and stream locations.
Analysis and Interpretation	• The greater the turbidity or change in turbidity, measured from a representative sample of fish bearing streams by watershed, the greater the risk to fish sustainability. • As recommended by British Columbia Water Quality Guidelines, specific thresholds are suggested (Ministry of Water, Land and Air Protection 1998). Guidelines define maximum induced turbidity of 8 NTU in 24 hours and 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; and 10% when background is greater than or equal to 80.
Future Improvements	• Sampling streams and locations should be established for watersheds of interest. Data should be collected and maintained in a central data repository to enable valid time series comparisons.

Indicator: Habitat Complexity

Indicator Measure: Variance in thalweg depth of fish bearing streams	
Data Source and Data Collection	• Thalweg depth is the deepest portion of the stream at a given cross section. A stream profile (i.e., along the stream axis) provides a number of sample points from which to derive a variance measure. • Corporate database not available. Will require sampling of watersheds using consistent representative set of streams. • Watersheds BC or Watershed Atlas provides information on watershed boundaries and stream locations.
Analysis and Interpretation	• The greater the variance in thalweg depth, measured from a representative sample of fish bearing streams by watershed, the greater the habitat complexity. • A significant decrease in thalweg depth variance in the sample streams from previous year(s), represents a risk to fish sustainability.
Future Improvements	• Sampling streams and locations should be established for watersheds of interest. Data should be collected and maintained in a central data repository to enable valid time series comparisons.

Indicator: Riparian Disturbance

Indicator Measure: Length of riparian habitat harvested, cleared or burned, as a percentage of S4-S6 stream length on forest land in watershed	
Data Source and Data Collection	• Forest Cover Inventory (FCI) provides information on forest cover, stream location and stream length. • Watersheds BC or Watershed Atlas provides information on forest land, stream location and length, and watershed boundaries. • Need to incorporate information regarding fish-bearing stream coding (S1-S6).
Analysis and Interpretation	• Identify harvested, cleared or burned riparian areas, defined as any of this activity occurring within 30m of any S4-S6 stream. The total length of disturbed riparian area, counting each side of all S4-S6 streams separately, is divided by twice the total stream length in the watershed. • The greater the length of riparian habitat harvested, cleared or burned as a percentage of S4-S6 stream length on forest land by watershed, the greater the risk to fish sustainability.

Indicator: Riparian Disturbance (continued)

Future Improvements	• For watershed level applications, a more accurate analysis that that provided by the FCI database is desirable. Supplementing this data with aerial photo interpretation and field work would improve the measurement of this indicator. • Digital orthophotography that was collected for FCI / TSA planning purposes or for developing TRIM 2 products may provide an information source for checking accuracy tolerances of riparian disturbance calculations derived from corporate data sets. • Need to ensure that FCI data is archived at regular intervals (annually) to enable time series interpretation of forest conditions (i.e., FCI is dynamic, constantly changing as updates are entered; a routine is needed to store the necessary portions of FCI at defined points in time to enable time series comparisons). • Need to ensure that Ministry of Forests district updates to FCI (e.g., as done for TSR purposes) are incorporated into central data repository in timely and regular fashion. This is not currently happening, and in some instances the corporate database is 4-5 years old.

Indicator: Resident Fish Populations

Indicator Measure: Trend in resident population levels by species for fish bearing streams	
Data Source and Data Collection	• Corporate database not sufficient to support this indicator. Will require sampling of watersheds using consistent representative set of streams. • Watersheds BC and the Fisheries Information Summary System (FISS) provides information on species and stock presence by stream. Sampling of fish population levels should be opportunistic of existing programs, focusing on species of particular ecological and social importance. • Watersheds BC or Watershed Atlas provides information on watershed boundaries.
Analysis and Interpretation	• Using data on mean resident fish populations by species by watershed over a number of years (i.e., a running average), classify watersheds according to increasing, decreasing or stable trends based on changes in the running averages. • A decrease in the running average of resident fish populations in the sample streams represents a risk to fish sustainability.
Future Improvements	• Sampling streams and locations should be established for watersheds of interest. Data should be collected and maintained in a central data repository to enable valid time series comparisons.

Indicator: Benthic Macroinvertebrate Diversity

Indicator Measure: Trend in diversity index based on proportional abundance	
Data Source and Data Collection	• Corporate database on benthic macroinvertebrate populations is not available. Will require sampling of watersheds using consistent representative set of streams. Related initiative is underway in the Skeena Region from which to develop provincial initiatives. • Watersheds BC or Watershed Atlas provides information on watershed boundaries and stream locations.
Analysis and Interpretation	• Recommend use of a proportional abundance-based diversity index (e.g., Shannon index as a measure of complexity). • The greater the benthic macroinvertebrate diversity, measured from a representative sample of fish bearing streams by watershed, the greater the "options" for ecosystem development and, likely, the greater the stream productivity. • A significant decrease in benthic macroinvertebrate diversity in the sample streams from previous year(s), represents a risk to fish sustainability.
Future Improvements	• Sampling streams and locations should be established for watersheds of interest. Data should be collected and maintained in a central data repository to enable valid time series comparisons.

4. Conclusions

4.1. Use of the Indicators for Decision Support

For monitoring indicators to be truly useful, it is not sufficient to only measure and analyse the specific indicators. The information they provide must be used. Toward this end, we provide comments regarding their use in the context of management.

4.1.1. Linking Monitoring Results with Business Drivers

Section 3.2.1 of this report identified five business needs that potentially drive the development and implementation of indicators for monitoring forest land use impacts on fish and fish habitat in British Columbia. These indicators can be used to:

1. Support regulatory and policy requirements for managing fish and fish habitat;
2. Determine priorities for restoration and planning investments;
3. Assess the effectiveness of policies and plans;
4. Enable trends interpretation and sustainability reporting; and
5. Assess compliance with regulatory and other performance standards.

These potential uses constitute the rationale for investing into the indicators that this report recommends. It is essential, therefore, that bridges are built between monitoring systems and the results that they produce, and the management decision-making processes that relate to the business drivers.

A common difficulty with monitoring systems, however, is that there is a "disconnect" between the scientific and technical staff that do monitoring, and the management and political

personnel that make programming and policy decisions. Evidence of this issue comes from the Washington State Timber-Fish-Wildlife initiative to develop a monitoring strategy for determining the effectiveness of forest practices in protecting aquatic resources. A review of jurisdictions to determine if adaptive management feedback loops to policy decision-making were in effect revealed that there was no formal process in most jurisdictions to ensure that monitoring results are used to inform and influence policy-making (TFW Cooperative Monitoring, Evaluation and Research Committee 1996). In addition, Daryl Brown Associates Inc. and Sustainable Visions (2001), in their study of BC's environmental monitoring business and information needs, concluded that there is little evidence that there are any good mechanisms to ensure that environmental monitoring investments feed into environmental decision-making at the policy level; unless this occurs, the entire motivation for environmental monitoring and the public investment into it is in question.

Lindenmayer (1999) points out that "long-term financial, political, institutional, logistical and intellectual commitment is integral to the success of monitoring programs" and identifies five criteria that define successful monitoring programs:

1. Sufficient funding and support to make them effective and scientifically valid;
2. Continued support, even though prolonged periods may elapse before useful results are generated;
3. Monitoring program persistence for periods that are substantially longer than the short time frames which characterize political and institutional agendas;
4. Acknowledgement by granting bodies and researchers of the importance of monitoring results, thus attracting sustained input from the scientific fraternity; and
5. Extensive dialogue among scientists and between scientists and managers to facilitate the adoption of new findings into modified forest management regimes.

It is argued here that the most effective way for the Ministry of Sustainable Resource Management to begin to achieve Lindemayer's criteria for monitoring program success is to create direct and explicit linkages between monitoring results and the identified business drivers. What does this mean? If we assess our business drivers in terms of the likely audiences for monitoring results (Table 23) it can be seen that there is a wide range of parties with potential interests. These groups include program managers, politicians, the academic community, the private sector, and the public.

Table 23. Business drivers and relevant audiences of monitoring results

Business Driver	**Relevant Audiences for Receiving Monitoring Results**
Supporting Regulatory and Policy Requirements for Managing Fish and Fish Habitat	• Senior government managers • Policy-makers (political level) • Policy enforcement staff
Determining Priorities for Restoration and Planning Investments	• Senior program managers • Budget allocators (political level) • Outside funding organizations (foundations, institutes) • Land and resource use planning agencies • Private sector partners
Effectiveness Assessments	• Senior program managers • Policy-makers (political level) • Private sector (forest companies) • Forest certification auditors • Scientific researchers • Academic community • "Watchdog" organizations (e.g., Forest Practices Board) • General public
Trends Interpretation and Sustainability Assessments	• Senior program managers • Policy-makers (political level) • General public • External audiences (e.g., national state of environment reporting)
Assessing Compliance With Regulatory and other Performance Standards	• Compliance and enforcement agencies (e.g., MOF compliance and enforcement staff, Forest Practices Board) • Forest companies • General public

A comprehensive view is needed of what constitutes a monitoring program. This should include not only the technical work of collecting and compiling indicator measurements, but also well-designed strategies for *communicating* monitoring results with critical audiences. Importantly, there must be a strong capacity for interpreting technical monitoring results into written information that is relevant to the audiences that have a potential interest.

These audiences require solid technical information and justification to successfully perform their own specific programming, policy and compliance/enforcement responsibilities. Ongoing, mutually beneficial relationships should be forged between staff responsible for monitoring program delivery and groups and individuals such as: the MWLAP Environmental Trends and MOF State of Forests reporting offices; certification auditors; land and resource planning program mangers; the Forest Practices Board and results-based Forest Practices Code compliance and enforcement staff; key academic departments; and senior managers and executive members within MWLAP, MOF, MSRM and DFO.

This suggests that it would be valuable to "formalize" the monitoring program with a clear description of its goals and objectives, responsibilities, deliverables, relationships with others, and budget. Formalization of this nature should help stabilize the monitoring program and give it the profile needed to ensure continuity and longevity.

The province has recently identified a need to rationalize the variety of environmental monitoring initiatives that are underway or proposed in BC, and to develop an integrated environmental monitoring strategy that would house selected inventory and monitoring data needed to support provincial environmental monitoring requirements. The initiative to develop and apply indicators for assessing land use impacts on fish and fish habitat should be integrated with the broader corporate provincial monitoring strategy.

In summary, the following should be considered to help ensure that this fish and fish habitat monitoring initiative successfully links to the business drivers that provide the rationale for engaging in monitoring in the first place:

1. Document the complete scope and nature of the monitoring program, including its goals and objectives, target audiences, methodologies, roles and responsibilities, deliverables and reporting relationships.

2. Produce written products from monitoring activities that are customized to the requirements of the key audiences for which the products are developed. Ensure that technical findings are interpreted into policy-relevant advice.

3. Establish strategic alliances with key groups and individuals that are known and potential users of monitoring results.

4. Fully integrate and rationalize this monitoring initiative with the broader provincial agenda to develop a more integrated environmental monitoring strategy.

4.1.2. Separate Indicators or an Index?

An indicator, as defined in the Introduction, is a proxy variable for attributes which themselves are difficult, if not impossible, to measure; they have a significance that extends beyond the properties directly associated with any one particular indicator variable. An index is a composite of a number of indicators. Use of an index is seen as desirable when a single metric is needed to simplify or summarise the information provided by a number of individual indicators. The primary drawback associated with using an index is that information is lost concerning the behaviour of the individual indicators of which it is comprised. There is the danger that use of an index will lead to "automatic evaluation"; that is, the single number will lead to the identification of a situation as either "good" or "bad" without more detailed knowledge of what components or characteristics of the system are driving that conclusion.

It is not recommended that an indicator program for monitoring land use impacts on fish and fish habitat collapse the individual indicator values into a single index. The different indicators were chosen to provide a characterisation of the land use-environment system, based on the derived indicator selection framework (i.e., selection of pressure indicators associated with

forest removal and road and road structures, and selection of state indicators associated with water quality and quantity, aquatic habitat, riparian habitat, fish populations, and biological diversity). Use of an index would compromise the integrity of this procedure[4].

4.1.3. Indicator Thresholds or Directions of Change?

Ultimately, it would be desirable to have thresholds identified for each indicator. In other works, to have specific values, supported by substantial scientific evidence, above or below which there is a notable increase in the risk to fish and fish habitat. But for many indicators, in particular the "pressure" indicators relied upon for strategic level applications, we are not able to identify thresholds.

It is not particularly worrisome that we do not have the scientific knowledge to identify thresholds. Thresholds have "multi-variable determinants", often specific to place. In fact, we must accept that for some indicators the scientific knowledgebase will never provide a reasonable level of evidence to support adoption of particular threshold values. Because of the complexity of the environmental systems we are dealing with, deterministic links may never be identified. This does not invalidate the use of indicators. In fact, it is beneficial for management to simply be able to identify indicators that reflect characteristics of the environment that are important to measure. As long as we can identify undesirable "directions of change" in indicators, the indicators are useful. It must be remembered that indicator systems are not designed to provide management with a scientifically accurate and complete understanding of the processes of environmental change. They are to provide a concise and rapid means with which to provide an *indication* of condition and provide a means to identify areas or activities that require a closer look.

---

[4] The exception to this is that we recommend using a marcroinvertebrate diversity index of aquatic biodiversitiy at the watershed level. This is because there is no single macroinvertebrate species that might be considered as an appropriate indicator species.

4.2. Maintaining the Environmental Monitoring Program

A monitoring system, by definition, must provide time series information. This requires that the necessary information continue to be collected in a consistent manner and a historical record maintained in a centralised database. For the purposes of monitoring fish and fish habitat, it is strongly recommended that assurances be obtained that a time series is maintained, through database management centrally located within BC Fisheries, through agreement with agencies from which the data was sourced, or through a provincial integrated environmental monitoring strategy.

This is not to say, however, that one time inventories are without value for helping to understand the state of fish and fish habitat values. But, information on directional change over time in the condition of attributes (i.e., indicators), or change relative to a pre-defined threshold, is far more informative for management decision-making purposes.

It also must be borne in mind that, although it is best to "stick to" a consistent base set of indicators, periodic review of indicator sets should be conducted to check their continued validity. Advances in scientific knowledge may suggest adjustments to specific indicator measures, or outright replacement with different measures. For many of the indicators recommended in this report, little or no information is available regarding threshold values or points of criticality. In addition, to more meaningfully interpret directions of change in individual indicators, it is desirable to have information that "calibrates" changes in the indicators to changes in fish and fish habitat values (i.e., defining the relationship between the indicator and the ecosystem characteristics of importance), as well as to more fully define the relationships between changes in the indicators and changes in forest land uses. The science of indicators is still very much in its infancy, with much of these relationships ill defined. This will undoubtedly change with future advances in knowledge.

4.3. Some Final Comments Regarding Data and Methods

Data is largely, but not completely, available for the above-recommended strategic level indicators, and is far less available for the recommended watershed level indicators. To help bridge gaps in data availability, the following should occur:

- Take a practical and "opportunistic" approach to data acquisition, and combine data from multiple sources as necessary to obtain the best possible datasets for the indicators being measured.

- Collaborate with those involved in developing the provincial strategy for integrated environmental monitoring in British Columbia to ensure that fisheries interests are represented, and promote a commitment towards the collection of reliable time-series information that is essential to effective monitoring.

- Work towards putting watershed level information that exists in various, dispersed watershed assessment reports into a corporate database.

- Continue to promote the collection of environmental data according to RIC standards to ensure data integrity. Where RIC standards for any indicator are lacking, they should be developed under the RIC methodology for developing new inventory standards.

5. References

American Forest and Paper Association, 1995. *The Sustainability Forestry Initiative Standard*. Available at http://www.afandpa.org/iinfo/iinfo.html

Bauer, SB and SC Ralph, 1999. *Aquatic Habitat Indicators and Their Application to Water Quality Objectives within the Clean Water Act*. EPA-910-R-99-014. United States Environmental Protection Agency, Region 10, Seattle, WA.

Beasley, B and P Wright (Confluence Resource and Environmental Management), 2000. *Long Beach Model Forest Suite of Criteria and Indicators - Updated to December 5, 2000*. Long Beach Model Forest Society, Tofino, BC.

Beaudry, PG and A Gottesfeld, 2001. Effects of forest-harvest rates on stream-channel changes in the central interior of British Columbia. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.151-173.

Bennett, S and K Hewgill, 2001. *Assessment of Forest Harvesting Impacts on Aquatic Ecosystems in the Kispiox and Kalum Forest Districts. Field Season 2000*. Report prepared for Pollution Prevention Program, Skeena Region, Ministry of Environment, Lands and Parks, Province of British Columbia.

Bird, SA, 2001. Streamside logging and riparian hazard assessment in step-pool streams. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.134-142.

Birtwell, IK, 1999. *The Effects of Sediment on Fish and Their Habitat*. Canadian Stock Assessment Secretariat Research Document 99/139. Fisheries and Oceans Canada, Ottawa.

Braat, L, 1991. The predictive meaning of sustainability indicators. In: O Kuik and H Verbruggen (eds.), *In search of Indicators of Sustainable Development*. Dordrecht, The Netherlands: Kluwer Academic Publishers. pp.57-70.

Canadian Council of Forest Ministers, 1995. *Defining Sustainable Forest Management: A Canadian Approach to Criteria and Indicators*. Available at http://www.nrcan.gc.ca/cfs/proj/ppiab/ci/

Canadian Standards Association, 1996. *CSA Sustainable Forest Management Standards, CAN/CSA-Z808-96 and Z809-96*.

Carver, M, 2001. Using indicators to assess hydrologic risk. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.26-43.

Chatwin, S, P Tschaplinski, G McKinnon, N Winfield, H Goldberg, R Scherer, 2001. *Assessment of the Condition of Small Fish-bearing Streams in the Central Interior Plateau of British Columbia in Response to Riparian Practices Implemented under the Forest Practices Code*. Working Paper 61. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC.

Church, M, 1992. Channel morphology and typology. In: C. Callow and G. Petts (eds.), *The Rivers Handbook: Hydrological and Ecological Principles*. Basil Blackwell, Oxford, UK, pp.126-143.

Costanza, R, 1992. Toward an operational definition of ecosystem health. In: R Costanza, BG Norton and BD Haskell (eds), *Ecosystem Health: New Goals for Environmental Management*. Washington, DC: Island Press. pp.239-256.

Daryl Brown Associates Inc. and Sustainable Visions, 2001. *Environmental Monitoring: Business and Information Needs Study.* Prepared for Land Information and Inventory Coordinating Committee, Province of British Columbia, March 30, 2001.

Eclipse Environmental Consulting Ltd, 1998. *Workshop Report: Salmon Habitat Indicators and Data Sharing Workshop*. Institute of Ocean Sciences, Sidney, BC, 22-23 April 1998.

Forest Stewardship Council, 2001. *Regional Certification Standards for British Columbia*. Draft 2. Available at http://www.fsc-bc.org/

Gluns, DR, 2001. Snowline pattern during the melt season: evaluation of the H60 concept. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.68-80.

Green Mountain Institute, 1998. *Toward "A Small but Powerful" Set of Regional Salmon Habitat Indicators for the Pacific Northwest*. Report prepared for the Pacific Northwest Salmon Habitat Indicators Work Group.

Hammond, A, A Adriaanse, E Rodenburg, D Bryant and R Woodward, 1995. *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development*. Washington, DC: World Resources Institute.

Harwell, MA, V Myers, T Young, A Bartuska, N Gassman, JH Gentile, CC Harwell, S Appelbaum, J Barko, B Causey, C Johnson, A McLean, R Smola, P Templer and S

Tosini, 1999. A framework for an ecosystem integrity report card. *Bioscience* 49: 543-556.

Henderson, GS and DAA Toews, 2001. Using sediment budget to test the Watershed Assessment Procedure in southeastern British Columbia. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.189-208.

Hogan, D, 2001. Stream channel assessment in the interior of British Columbia. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.112-133.

Iles, K, 2001. *Accuracy Assessment of Watersheds BC*. Kim Isles & Associates Ltd.

Jordan, P, 2001a. Sediment budgets in the Nelson Forest Region. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.174-188.

Jordan, P, 2001b. Regional incidence of landslides. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.237-247.

Kamloops Inter-agency Management Committee, 1999. *Kamloops LRMP Monitoring Report, 1999*. Kamloops Forest District, Kamloops BC.

Karr, JR, 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6(6): 21-27.

Karr, JR, 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications* 1: 66-84.

Karr, JR, 1992. Ecological integrity: protecting earth's life support systems. In: R Costanza, BG Norton and BD Haskell (eds), *Ecosystem Health: New Goals for Environmental Management*. Washington, DC: Island Press. pp. 223-238.

Keystone Wildlife Research, 2001. *The Investigation of New Watershed Indicators for Three Watersheds in the Adams Lake IFPA*. Report prepared for International Forest Products, Adams Lake Division. Keystone Wildlife Research, White Rock, BC.

Land Use Coordination Office, 2000. *Strategic Land Use Plan Monitoring Procedures: Working Draft May, 2000*. Land Use Coordination Office, Victoria, BC.

Lindenmayer, DB, 1999. Future directions for biodiversity conservation in managed forests: indicator species, impact studies and monitoring programs. *Journal of Forest Ecology and Management* 115: 277-287.

Linster, M, 1997. OECD environmental indicators. In: B Moldan and S Billharz (eds.), *Sustainability Indicators: Report of the Project on Indicators of Sustainable Development*. New York, NY: John Wiley and Sons. pp.157-163.

McGregor Model Forest Association, 1998. *Program Team Summaries and Identification of Potential Local Level Indicators for the McGregor Model Forest.* McGregor Model Forest Association, Prince George, BC.

Millar, RG, 2001. Riparian logging and channel stability. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.143-150.

Ministry of Environment, Lands and Parks, 1995a. *The British Columbia Water Quality Index*. Updated September 1999. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/indexreport.html

Ministry of Environment, Lands and Parks, 1995b. *Derivation of Water Quality Criteria to Protect Aquatic Life in British Columbia*. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/derive.html

Ministry of Environment, Lands and Parks, 1998. *Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments*. Water Management Branch, Ministry of Environment, Lands and Parks, Province of British Columbia, Victoria, BC. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/derive.html

Ministry of Environment, Lands and Parks, 2000. *Environmental Trends in British Columbia 2000.* State of Environment Reporting, Victoria, BC.

Ministry of Environment, Lands and Parks, 2001. *Watersheds BC Data Dictionary*. May 2001. Geographic Data BC, Ministry of Environment, Lands and Parks, Province of British Columbia, Victoria, BC.

Ministry of Forests, 1999. *Coastal Watershed Assessment Procedure Guidebook (CWAP), Interior Watershed Assessment Procedure Guidebook (IWAP)*. Second Edition. Ministry of Forests, Province of British Columbia, Victoria, BC.

Ministry of Forests, 2000. *State of the Forest in British Columbia, 2001: Draft Report Proposal*. October 6, 2000 Draft. Ministry of Forests, Victoria, BC.

Ministry of Water, Land and Air Protection, 1998. *British Columbia Approved Water Quality Guidelines (Criteria)*. Updated August 24, 2001. Water Protection Branch, Ministry of

Water, Land and Air Protection, Province of British Columbia, Victoria, BC. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/approved.html

Ministry of Water, Land and Air Protection, 2001. *Water Quality Guidelines for Temperature: Overview Report*. Water Protection Branch, Ministry of Water, Land and Air Protection, Province of British Columbia, Victoria, BC. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/temperature.html

Morgan, A, and D Smith, 1997. *Trends in Disturbance and Recovery of Selected Salmonid Habitat Attributes Related to Forest Practices: A Literature Review and Monitoring Recommendations*. TFW Monitoring Program, Northwest Indian Fisheries Commission.

Mortensen, LF, 1997. The driving force-state-response framework used by the CSD. In: B Moldan and S Billharz (eds.), *Sustainability Indicators: Report of the Project on Indicators of Sustainable Development*. New York, NY: John Wiley and Sons. pp.47-53.

Oliver, GG abd LE Fidler, 2001. *Towards a Water Quality Guideline for Temperature in the Province of British Columbia*. Prepared for Water Management Branch, Ministry of Environment, Lands and Parks, Province of British Columbia, Victoria, BC. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/temptech/index.html

Precision Identification Biological Consultants, 1998. *Wild, Threatened, Endangered and Lost Streams of the Lower Fraser Valley, Summary Report 1997*. Lower Fraser Valley Stream Review Volume 3. Prepared for the Fraser River Action Plan, Fisheries and Oceans Canada, Vancouver, BC.

Province of British Columbia, 1995. *Riparian Management Area Guidebook*. Forest Practices Code of British Columbia. December 1995.

Scherer, R, 2001. Effects of changes in forest cover on streamflow: a literature review. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.44-55.

Scott, A (ed.), 2001. *The McGregor Story: Pioneering Approaches to Sustainable Forest Management*. McGregor Model Forest Association, Prince George, BC.

TFW Cooperative Monitoring, Evaluation and Research Committee. November 12, 1996. *Proposal for a TFW Monitoring Strategy to Determine the Effectiveness of Forestry Practices in Protecting Aquatic Resources.* Paper No. TFW-AM9-96-007. http://www.nwifc.wa.gov/TFW/reports/report6.htm

Toews, DAA and S Chatwin (eds), 2001. *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC.

United Nations, 1996. *Indicators of Sustainable Development: Framework and Methodologies*. Geneva: United Nations Commission on Sustainable Development.

Verbruggen, H, and O Kuik, 1991. Indicators of sustainable development: an overview. In: O Kuik and H Verbruggen (eds.), *In Search of Indicators of Sustainable Development*. Dordrecht, The Netherlands: Kluwer Academic Publishers. pp.1-6.

Whitaker, A, Y Alila and DAA Toews, 2001 Modelling peak flow change using the DHSVM model. In: DAA Toews and S Chatwin (eds), *Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings*. March 9-10, 2000, Penticton, British Columbia, Canada. Research Branch, Ministry of Forests, Province of British Columbia, Victoria, BC. pp.94-111.

Appendix A: Consultations for Review of Accomplishments

An interview guide was devised to ensure that the consultation process, associated with the initial review of accomplishments to date, utilised a consistent and adequate base set of questions. The interview guide is reproduced here, along with a listing of individuals and organisations contacted.

The Base Interview Guide

Background

The Ministry of Sustainable Resource Management (Aquatic Information Branch) and the Ministry of Water, Land and Air Protection (Fisheries Research Section) of the Province of British Columbia have begun a review of indicators of fish and fish habitat sustainability in forest environments. The objective of this project is to develop recommendations for monitoring. Specifically, it will identify indicators, criteria, data sources and data collection methods for examining land use impacts on fish and fish habitat.

The initial stage of the project is reviewing progress to date. We are seeking your input because of your knowledge and experience with land use impact investigations programs and policies.

Questions

1. What questions about land use impacts on fish and fish habitat do you think need to be answered (i.e., what are the business drivers)? What are the related environmental or ecosystem attributes of concern?

2. What types of information and data are required to answer these questions? What indicators have been developed or would you like to see developed?

3. For these indicators, to what spatial and temporal scales do they apply?

4. Are there defined thresholds for these indicators that trigger some special management action and, if not, what should those thresholds be and why?

5. What existing and developing data sources do you know of that may be of value for measuring indicators of fish and fish habitat sustainability? Where possible, for each of these please comment or provide information on:

    - The data availability (including ease of measurement, feasibility and cost-effectiveness of collection);

    - The data quality (including collection and analysis standards, data accuracy and precision, timeliness and completeness of records); and

    - The ease of interpretation and meeting of analysis needs (i.e., is it clear how to interpret the data and does it permit the scientific analysis necessary to answer management questions?).

6. Are there other related issues you would like to raise or advice you would like to offer?

Individuals and Organisations Contacted

Table A.1. Individuals contacted.

Name	Affiliation
Laurence Bowdige, Coordinator	Vegetation Resource Inventory, Ministry of Sustainable Resource Management
George Butcher, Senior Water Quality Biologist	Water Inventory, Ministry of Sustainable Resource Management
Tony Cheong, Senior Geomorphologist	Water Inventory, Ministry of Sustainable Resource Management
Harry Drage, Strategic Policy Specialist	Integrated Resources Section, Ministry of Forests
Dave Gooding, River Forecast Hydrologist	Water Inventory, Ministry of Sustainable Resource Management
Malcolm Gray, Acting Monitoring Specialist	Decision Support Services Branch, Ministry of Sustainable Resource Management
Graham Hawkins, Forestry and Landscape Planning Specialist	Decision Support Services Branch, Ministry of Sustainable Resource Management
Paul Jeakins	Kokanee Consulting
Olga Kopriva, Manager	Forest Tenures, Ministry of Sustainable Resource Management

Table A.1 (continued). Individuals contacted.

Name	Affiliation
Tom Niemann, Manager	Corporate Policy and Planning Division, Ministry of Sustainable Resource Management
Sam Otukol, Forest Statistician	Vegetation Resource Inventory, Ministry of Sustainable Resource Management
Ian Sharpe, Section Head	Environmental Impact Assessment Section, Pollution Prevention Program, Ministry of Water, Lands and Air Protection
Risa Smith, Coordinator	State of the Environment Reporting, Ministry of Water, Lands and Air Protection
Art Tautz, Manager	Fisheries Research Section, Ministry of Water, Lands and Air Protection
Dave Tredger, Manager	Fisheries Inventory, Ministry of Sustainable Resource Management
Peter Tschaplinski, Manager	Fish/Forest Watershed Assessment, Watershed Hydrology, Ministry of Forests
Andy Witt, Habitat Program Coordinator	Fisheries Management Branch, Ministry of Water, Lands and Air Protection

Appendix B: Consultation Workshop Attendance

A workshop was conducted on Wednesday, 16 January 2002, to discuss the results of the study to date as reported in the Interim Progress Report and to provide expert comment regarding an initial proposed indicator set. More specifically, the workshop obtained input regarding indicators, data sources and data issues, and research needs with respect to monitoring programs for the protection of fisheries values. The list of attendees is shown on Table B.1.

Table B.1. Consultation workshop attendance.

Name	Affiliation
Laurence Bowdige	MOF, Vegetation Resource Inventory
Tony Cheong	WLAP, Inventory, Geomorphology
Diana Dobson	DFO, Stock Assessment Division
Dave Gooding	MSRM, River Forecast Centre
Malcolm Gray	MSRM, Decision Support Services
Graham Hawkins	MSRM, Forestry and Landscape Planning
Dan Hogan	MOF, Watershed Hydrology
Steve MacDonald	DFO, Environmental Science Branch
Erland MacIsaac	DFO, Cooperative Resource Mgmt. Institute
Jeff Monty	MSRM, Terrestrial Information Branch
Art Tautz	WLAP, Fisheries Research
Dave Tredger	MSRM, Fish Inventory
Peter Tschaplinski	MOF, Watershed Planning
Nick Winfield	DFO, Habitat Policy
Marke Wong	Knight Piesold Ltd.

Appendix C: Detailed Accounting of Indicator Evaluation

Before final recommendations were made, candidate indicators were assessed with respect to (Table 1): 1) theoretical or empirical linkages to ecosystem characteristics of interest; 2) theoretical or empirical linkages to management performance; 3) information and data availability; 4) information and data quality; and, 5) ease of interpretation and availability of analysis methodology.

Strategic Level Application Indicators

Candidate Indicator: Land Use Conversion (from Forest Land) **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Canadian Council of Forest Ministers (1995); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Area of forest converted to non-forest land use (IFPA). • Percentage of acres in watershed converted from land use/land cover classifications to other land use/land cover types over time, with emphasis on floodplain to riparian area (Pacific Northwest Salmon Habitat Indicators Work Group). • Permanent and semi-permanent conversions from forest land (Canadian Council of Forest Ministers). • Area of permanent forest loss due to development; area of long-term forest loss due to land failure (landslides, flooding); rate of change of conversion within forest type; area of forest cover change by forest type; area of conversion to permanent and semi-permanent non-vegetated conditions (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Impacts on fish and fish habitat will vary by the type of land use conversion, local geomorphology and biogeoclimatic region (Eclipse Environmental Consulting Ltd. 1998).
Linkages to Management Performance	• Since the use of the indicator set is focused on forest environments, the importance of land use conversions not related to forest development is in question. • Linkage to forest management is not clear, as many other government mandates and jurisdictions come into play.
Information and Data Availability	• Most cost-effective data source would be information derived from satellite interpretation. BTM present land use mapping information would suffice but would need to be updated provincially at regular intervals.
Information and Data Quality	• Satellite-derived data would provide an adequate level of information quality for applying this indicator province-wide at a strategic level.
Analysis, Interpretation and Thresholds	• Analysis and interpretation will require classification of land use conversions in a manner that reflects different levels of risk to fish and fish habitat. • The different timing, and spatial extent and locations of land use conversions with respect to fish streams add to difficulties in generalising impacts.

Candidate Indicator: Forest Cover and Disturbance **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); Canadian Council of Forest Ministers (1995); State of Forests Reporting (Ministry of Forests 2000); Kamloops LRMP Monitoring (Kamloops Inter-agency Management Committee 1999); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Percent of watershed harvested (Watershed Assessment Procedures). • Coverage proportions by forest type and age class (Canadian Council of Forest Ministers 1995). • Area of old growth, younger growth and non-forest by BEC zone (State of Forests Reporting). • Percentage of forest area under different seral stages (IFPA). • Forest age class distribution by percentage (e.g., 1-40 yrs, 41-80 yrs); area of fire disturbance (Kamloops LRMP Reporting). • Area of forest disturbance by year and decade (including by pests, fire and logging) (State of Forests Reporting).

Linkages to Ecosystem Characteristics of Interest	• Relationship between forest cover removal and fish and fish habitat condition is well established, although an indicator measure would ideally reflect differing levels of risk from different "types" of forest disturbance. Excessive "new" logging is of prime concern, as reflected in the ECA indicator (see below).
Linkages to Management Performance	• Linkage to forest management is clear – logging and road building account for most, but not all, changes to forest cover over time.
Information and Data Availability	• Forest Cover Inventory contains information on forest cover, tree age and height of dominant trees, tree diameter, and species composition. Data derived from aerial photo interpretation and field mapping, using forest growth models to grow forest polygons to present. Mapped at 1:20,000 scale. • Data available in Ministry of Forests Forest Cover Inventory database, and also from BTM source.
Information and Data Quality	• Ministry of Forests Forest Cover Inventory contains accurate age classs information but has some coverage gaps (e.g., some protected areas, some TFLs, most private land). These gaps, however, may be overcome by referring to special coverage developed for State of the Forests reporting purposes. BTM information is limited to providing only generalized categories of age class.
Analysis, Interpretation and Thresholds	• Extent of "new" logging activity within watersheds is the information of most relevance to indicating risk to fish and fish habitat. ECA indicator is more focused on this aspect than a general forest cover indicator, and some general ECA thresholds have been defined as maximum desirable levels of new harvesting in watersheds.

Candidate Indicator: Equivalent Clearcut Area (ECA) **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001)	
Suggested Measures	• Clearcut area adjusted based on ages of logging and tree heights in second growth, with elevation taken into account in interpretation (Watershed Assessment Procedures).
Linkages to Ecosystem Characteristics of Interest	• As a proxy for increases in peak flow, as well as advancement of peak flow timing. • A review of studies that examined the relationship between 1) forest cover and 2) spring freshet peak flows, the timing of peak flows, water yield, and low flows, revealed either no consistent relationships or relationships with substantial unexplained variance remaining (Scherer 2001). Also, some evidence that the relationship between ECA and sediment yield to streams is not strong (Henderson and Toews 2001).

Linkages to Management Performance	• Indicator links directly to forest management – ECA is a direct response to operational forestry decisions respecting harvesting rate and location in watersheds.
Information and Data Availability	• British Columbia Ministry of Forests (1999) describes the calculation of ECA. For computation, requires GIS-based data on ages of logging and tree heights in second growth, as well as elevation within watershed. This information is contained in Ministry of Forests Forest Cover Inventory.
Information and Data Quality	• Forest Cover Inventory information is generally of high quality, although there are some concerns about data currency (some areas can be 4-5 years out of date). Also, FCI has certain gaps in coverage (some protected areas, some TFLs and most private land). These coverage gaps could be overcome by using the complete provincial coverage for forest cover that has been developed recently by MSRM in support of State of Forests reporting.
Analysis, Interpretation and Thresholds	• H60 concept (or similar adjustment based on elevational location of harvesting within interior watersheds) supported by literature (e.g., Gluns 2001; Whitaker et al. 2001) – i.e., harvesting in upper forest zones within watersheds has a greater effect on peak flows than harvests in lower forest zones. • Differences in elevation ranges/distributions within watersheds ("flat" vs. "steep" watersheds) and absolute elevations of watersheds not taken into account by H60 concept (Whitaker et al. 2001). This will complicate comparisons between different types of watersheds across the province.

Candidate Indicator: Impervious Surface **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Wild, Threatened and Endangered Streams of the Lower Fraser Valley (Precision Identification Biological Consultants 1998)	
Suggested Measures	• Percentage of impervious surface (roads, rooftops, and parking lots) in a watershed (Pacific Northwest Salmon Habitat Indicators Work Group).
Linkages to Ecosystem Characteristics of Interest	• Impervious surfaces affect peak flow rates and can cause a reduction in riparian habitat availability. These, in turn, can affect in-stream habitat condition and water quality.
Linkages to Management Performance	• Since the use of the indicator set is focused on forest environments, the importance of a measure of impervious surface is in question, although ground compaction can occur as a result of forest management activities (i.e., forest roads and skid trails).
Information and Data Availability	• Complete and detailed DFO data is available as of 1999 for non-forest environments in the lower mainland region. However, data for forested environments is generally unavailable, although BTM can calculate "urban" land use. Road surface area is also unavailable (only road length information is available).
Information and Data Quality	• BTM information on urban land use is sufficiently accurate for strategic applications; however, this data source alone would not permit measurement of this indicator.
Analysis, Interpretation and Thresholds	• Analysis and interpretation will require classification of different types of impervious surface in a manner that reflects different levels of risk to fish and fish habitat (e.g., ranking "imperviousness" with respect to impact; Eclipse Environmental Consulting Ltd. 1998). • As a suggested threshold, effective impermeable area (EIA) covering approximately10%, or greater, of the stream's watershed represented a high risk (Precision Identification Biological Consultants 1998).

Candidate Indicator: Soil Disturbance (Compaction, Displacement, Erosion) **Source for Candidacy:** Canadian Council of Forest Ministers (1995); State of Forests Reporting (Ministry of Forests 2000); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA).	
Suggested Measures	• Percentage of harvested area having "significant" soil compaction, displacement, erosion, etc…(Canadian Council of Forest Ministers). • Percent soil disturbance in harvested areas by year (State of Forests Reporting). • Area of soil disturbance, including roads, as a percentage of the timber harvesting land base (Forest Certification). • Percentage of area with soil compaction, mineral soil exposure and/or loss of organic material; number of sites with significant soil impacts (Model Forests). • Percentage of harvested area having significant soil compaction, displacement, erosion, puddling and loss of organic matter (IFPA).

Linkages to Ecosystem Characteristics of Interest	• Soil compaction can affect surface run-off rates. Soil disturbance can lead to soil erosion in certain soil types, thus leading to potential stream channel impacts, water quality impacts, and spawning habitat deterioration.
Linkages to Management Performance	• Soil disturbance (compaction, displacement, erosion) is a potential consequence of logging and road-building activity and, thus, can be controlled through forest management regulation or best management practices.
Information and Data Availability	• Information on soil disturbance is unavailable in corporate databases. Measurement would require local site level surveys at defined sampling locations. • Prevention of soil disturbance is expected to be a requirement of the results-based Forest Practices Code, with monitoring and audits required to demonstrate compliance with the prescribed performance standards (see below). These audits may provide a future data source for measuring extent of soil disturbance.
Information and Data Quality	• Data is generally unavailable at this time.
Analysis, Interpretation and Thresholds	• Analysis and interpretation may require identification of thresholds or specific disturbance factors that represent substantial risk to fish and fish habitat, although simple trend assessment may be used to infer affects. • Performance thresholds may be available as a consequence of results-based Forest Practices Code implementation (e.g., a possible performance standard is: "soil damage from forest development must not exceed 15% for sensitive soils and 20% for other soils, where damage means scalping, gouging, compacted area, excavated and bladed trails."

Candidate Indicator: Landslides and Slope Failures **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); Kamloops LRMP Monitoring (Kamloops Inter-agency Management Committee 1999); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Total number of landslide in watershed (Watershed Assessment Procedures). • Number of human-caused landslides (Kamloops LRMP Monitoring). • Area impacted by landslides; number of hill slope failures by source; volume of displaced material; number of failures reaching main stem (Model Forests).
Linkages to Ecosystem Characteristics of Interest	• Measurement of landslides or slope failures acts as a surrogate for sediment delivery to streams, although many local level geomorphological factors and distance from stream would affect delivery.
Linkages to Management Performance	• Landslide frequency increases with forest development due to roads and skid trails (leading to road fill failures and drainage concentration and diversion) (Jordan 2001b).
Information and Data Availability	• Information on landslide activity exists for locations where watershed assessments have been undertaken (i.e., Watershed Assessment Procedures methods followed), but is not accessible in a corporate database. Landslide occurrence information is typically derived through aerial photo interpretation. • Terrain Mapping, derived from aerial photo interpretation with field checking of select areas, is available for part of the province (primarily Vancouver Island, coastal areas, and areas of the interior). Mapped on 1:20,000 to 1:50,000 scales. Terrain Stability (Hazards) Mapping interprets Terrain Mapping to classify stability.

Information and Data Availability (continued)	• Resource Terrain Hazards is a central coast mapping of landscape processes including landslides, snow avalanche areas, areas of active erosion, and active floodplains. Database derived from aerial photo interpretation, terrain mapping, and terrain stability (hazard) mapping to generate regional hazard maps. • Results-based Forest Practices Code implementation may provide a data source for landslide activity. Licensees may be required to report landslide and major erosion events in areas they are operating if the event has caused or will likely cause a significant environmental effect.
Information and Data Quality	• Resource Terrain Hazards mapping is generalised on a regional basis, produced on 1:100,000 scale maps. There is no field checking of the data. Currently only covers the central coast LRMP area. • Landslide information in watershed assessment reports is generally of high quality, but is not easily accessible. • Landslide occurrence information that is potentially available from results-based Forest Practices Code implementation should be highly reliable given that the requirement to report landslides would be a legal requirement.
Analysis, Interpretation and Thresholds	• Analysis and interpretation requires a working definition of landslides or slope failures related to forest development. Jordan (2001b) included first time slumps, rockslides, debris slides, debris avalanches and debris flows originating from an identifiable source. • No threshold supported by the literature. To interpret indicator, a greater area of landslide or slope failure, as a percentage of the watershed area, would represent a greater risk to fish and fish habitat.

Candidate Indicator: Roads (Density) **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Environmental Trends Reporting (Ministry of Environment, Lands and Parks 2000); State of Forests Reporting (Ministry of Forests 2000); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Road density (total length of road divided by total watershed area; km/km^2) (Watershed Assessment Procedures; State of Forests Reporting). • Length of road by type within one mile of historically anadromous salmonid streams, floodplains, and marine shorelines (Pacific Northwest Salmon Habitat Indicators Work Group). • Road density, distinguishing between new roads and roads rehabilitated or deactivated (Kamloops LRMP Monitoring). • In addition to road density, also measure road cut and fills re-vegetated within 12 months (Forest Certification). • Proportion of watershed in permanent roads; road density by road class; area of roads and trails by type; use levels of roads by type of use; length of roads by landscape position (e.g., high slopes, riparian) (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Roads influence peak flows by increasing flow concentrations into streams (ditches intercept sub-surface and surface flows; road surfaces reduce infiltration and transfer flows to ditches). Roads also represent a source of sediment production (i.e., during construction and maintenance, and with erosion). • Some evidence that the relationship between road density and sediment yield to streams is not strong; forest roads may represent the delivery of a relatively small part of the sediment to streams compared to natural sources (Henderson and Toews 2001).
Linkages to Management Performance	• Road development is a regulated activity. Increases in road development approvals can affect fish sustainability, particularly those on steeper slopes, unstable soils and in riparian habitats.
Information and Data Availability	• TRIM data available by watershed – length of road by type (primary and secondary; other non-forest; forest service; other forest).
Information and Data Quality	• Data reliability is limited by TRIM data currency. This is potentially a concern since road building activity is highly dynamic (i.e., significant increases in road building in certain watersheds can occur over a relatively short time span).
Analysis, Interpretation and Thresholds	• Using field assessment, Watershed Assessment Procedures (British Columbia Ministry of Forests 1999) rank risk by distinguishing between 6 sediment production classes for roads, combined with a classification of sediment delivery from forest roads to stream channels. • Higher risks assumed with roads on steeper slopes (e.g., >60%), but effects can be pronounced downslope from road despite slope at location of road (landslides caused by "gentle over steep" drainage concentrations; Jordan 2001b).

Candidate Indicator: Stream Crossings by Roads **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Total number of stream crossings by mapped roads (Watershed Assessment Procedures). • Number and density of stream crossings by road type (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Stream crossings by roads represent risk of local sediment and intercepted flow delivery, as well as potential physical impediment to fish (depending on crossing type). • Some evidence that the relationship between stream crossings and sediment yield to streams is not strong (Henderson and Toews 2001).
Linkages to Management Performance	• Road development is a regulated activity. Increases in stream-road crossing approvals may affect fish sustainability, particularly those on steeper slopes and unstable soils.
Information and Data Availability	• Data is available from the Watersheds BC database, and could also be obtained from the MSRM Forest Cover Inventory. • Results-based Code implementation may provide additional data, as it is expected that there will be a performance standard that requires licensees to construct and maintain stream crossings in a manner that allows safe fish passage and protects fish habitat. The number of infractions of this performance standard could be tracked as a response indicator.
Information and Data Quality	• Watersheds BC data reliability on stream-road crossing density is sufficiently high to measure this indicator at this point in time, but is limited by the currency of the TRIM road data that exists in the dataset. As road building activity is highly dynamic, there will be a need to either update the TRIM mapping on a periodic basis, or rely on Forest Cover Inventory to supply the data.
Analysis, Interpretation and Thresholds	• To reflect physical impediment to fish, analysis and interpretation requires information on the engineering of the stream crossing (e.g., size and type of culvert used). • No threshold supported by the literature. To interpret indicator, a greater density of road-stream crossings would represent a greater risk to fish and fish habitat.

Candidate Indicator: Impediments and Accessibility **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001)	
Suggested Measures	• Number of locations where salmon are impeded, by type, and number of historical anadromous salmonid stream miles rendered inaccessible by these impediments (Pacific Northwest Salmon Habitat Indicators Work Group). • Number of barriers to fish passage identified and removed (Forest Certification).
Linkages to Ecosystem Characteristics of Interest	• In-stream impediments to fish movement can affect spawning behaviour and success, and is an effective reduction in habitat supply.
Linkages to Management Performance	• The use of culverts, and the nature and extent of site-specific barriers in streams determined by forest practices, but other natural and anthropocentric watershed features would also have significant effect (e.g., dams).
Information and Data Availability	• The Fisheries Information Summary System (FISS) provides georeferenced information (based on 1:50,000 NTS mapsheets) on obstructions in streams and lists the fish species that are affected. Specifically includes information on obstruction type (e.g., culvert, log jam, persistent debris), height and length of obstruction, and species blocked.
Information and Data Quality	• FISS data on stream obstructions is generally accurate for the locations it exists and as of the date that that the data was captured. Reliability is limited by the ability to maintain updated records for all provincial watersheds.
Analysis, Interpretation and Thresholds	• Defining an impediment as "something that blocks fish" could include dams, culverts and site-specific barriers (Eclipse Environmental Consulting Ltd. 1998). • Interpretation requires the ability to distinguish between natural and anthropocentric impediments to meaningfully link to forest development management performance.

<table>
<tr><td colspan="2">Candidate Indicator: Riparian Habitat

Source for Candidacy: The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); Environmental Trends Reporting (Ministry of Environment, Lands and Parks 2000); State of Forests Reporting (Ministry of Forests 2000); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001)</td></tr>
<tr><td>Suggested Measures</td><td>• Percentage of riparian habitat or riparian zone altered by stream miles within watershed (Pacific Northwest Salmon Habitat Indicators Work Group).

• Percent of S1, S2, S3 or S4 streambanks logged (according to Watershed Assessment Procedures, total “high” riparian impact stream length, as well as total length of “one side logged” streams and “two side logged” streams).

• Percentage of riparian area logged on forest land (Environmental Trends Reporting).

• Area of forested riparian zone disturbed by fires, pests and logging (within 30 m of streams >200 m) (State of Forests Reporting).

• Extent of riparian disturbance; width and length of riparian reserve and management areas; length of buffer along S3-S6 streams; percentage of length of S1 and S2 streams with trees >40 yrs old; percent of cutblocks adjacent to streams with riparian management zones in place (Forest Certification).

• Significant loss of riparian vegetation along more than 50% of the fish frequented length of the stream (Precision Identification Biological Consultants 1998).</td></tr>
<tr><td>Linkages to Ecosystem Characteristics of Interest</td><td>• Riparian habitat important for maintaining stream channel integrity (stability and structure), providing shade over the stream, supplying large woody debris, and preventing windthrow related impacts (disturbance and sediment delivery) on the stream (e.g., Millar 2001; Chatwin et al. 2001).</td></tr>
</table>

Linkages to Management Performance	• The amount and nature of riparian habitat disturbance is directly determined by management of forest development. • Forest Practices Code does not permit streamside logging of fish bearing streams, nor is it permitted for all streams in community watersheds; thus, impacts for these streams largely historical (assuming compliance). Recent and current direct impacts primarily through S5 and S6 streams. • The results-based Forest Practices Code is expected to include performance standards for "stream bank stability", which may include requirements for licensees to ensure that certain riparian features (e.g., stream banks, understory vegetation, gulley side walls, fisheries sensitive zones) are protected from harmful effects. A standard is also expected that limits harvesting activities in riparian reserve zones.
Information and Data Availability	• Data of logged riparian area from the Baseline Thematic Mapping (BTM) Land Use/Land cover interpretation of satellite imagery, air photography and 1:20,000 Ministry of Forests Forest Cover Inventory. • Results-based Forest Practices Code implementaion may provide an additional data source that enables monitoring of a response indicator for riparian habitat (i.e., number of infractions of riparian management performance standards).
Information and Data Quality	• Difficulty of identifying partial and variable retention Riparian Management Areas (e.g., of non-merchantable and deciduous trees). • Forest Cover Inventory data may be up to 4-5 years out of date for some locations.
Analysis, Interpretation and Thresholds	• For interpretation, no threshold is evident; assume a greater risk to fish and fish habitat the greater the extent of riparian habitat disturbance. • Ideally need to define and identify the specific types of disturbance that link to altering the functioning of the riparian system with respect to fish and fish habitat (Eclipse Environmental Consulting Ltd. 1998).

Candidate Indicator: Aquatic Habitat (Estuarine, Side Channel, Wetlands) **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Change in estuarine area, by type and quality (Pacific Northwest Salmon Habitat Indicators Work Group). • Change in area of side channel habitat (Pacific Northwest Salmon Habitat Indicators Work Group). • Change in wetland area (Pacific Northwest Salmon Habitat Indicators Work Group). • Number of wetlands identified and protected (Forest Certification). • Extent to which productive habitats of selected species or species guilds are distributed throughout the range of their habitat (IFPA).

Linkages to Ecosystem Characteristics of Interest	• Estuarine, side channel, and wetland habitats are known to be important fisheries rearing habitats.
Linkages to Management Performance	• Forest development in or in close proximity to aquatic habitats is a regulated activity. Few natural phenomena are expected to affect aquatic habitats to the same extent as logging and road building activities.
Information and Data Availability	• FISS includes data on wetlands; however, corporate data on extent of changes in condition of estuaries and side channels not available. Some information on these aquatic habitat attributes may be contained in watershed assessment reports, but this information has not been compiled for all watewrsheds.
Information and Data Quality	• FISS information on wetland location is thought to be accurate.
Analysis, Interpretation and Thresholds	• Analysis and interpretation may require development of thresholds of impact (risk) to these aquatic habitats, although general trends information on the direction of change could be assumed.

Candidate Indicator: Rare, Threatened, Endangered or Vulnerable Fish and Other Aquatic Species **Source for Candidacy:** Canadian Council of Forest Ministers (1995); Environmental Trends Reporting (Ministry of Environment, Lands and Parks 2000); State of Forests Reporting (Ministry of Forests 2000); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001)	
Suggested Measures	• Number as a percentage of total number of species (Canadian Council of Forest Ministers; Environmental Trends Reporting). • Number of aquatic species at risk (red or blue listed) (Kamloops LRMP Monitoring). • Habitat availability for selected species at risk (Model Forests). • Presence of red and blue listed species, as well as population and reproductive size (Model Forests). • Trends in classification of red and blue listed species, as well as their habitat condition (Forest Certification).

Linkages to Ecosystem Characteristics of Interest	• An indication of the overall status of fish and other aquatic species, identifying those that have been most impacted or are most vulnerable. • Generally not possible to link status to specific types of habitat alteration or human activity, or the causes of species decline.
Linkages to Management Performance	• Government reports on rare, threatened, endangered, and vulnerable species, and can initiate management action through the "identified wildlife species" strategy (which requires the establishment of wildlife habitat areas or zones).
Information and Data Availability	• The provincial Conservation Data Centre (CDC) lists rare and endangered species ("red-listed") and vulnerable species ("blue-listed"). Includes plant species, plant communities, vertebrates and invertebrates, ranked on both a provincial and global basis. Data format varies, but much is available in GIS format. • The federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) database lists species designated "at risk" nationally.
Information and Data Quality	• Provincial and federal data on species occurrences and the subsequent interpretation into red or blue listed species is generally thought to be reliable; however, it is "anecdotal" to the extent that it is based on limited field studies and reports from various sources, including scientists, naturalists, published and unpublished reports, and museum collections. Absence of data at a location may mean either absence of the species or that the area has not been studied (and may in fact be present). • CDC data from 1991 to the present. Coverage is province wide, with tracking lists summarized by Forest District.
Analysis, Interpretation and Thresholds	• Overall requirement of the indicator set is to inform management regarding the conservation of fish and fish habitat; as such, it is an important measure.

Candidate Indicator: Populations of Fish Species **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Canadian Council of Forest Ministers (1995); Environmental Trends Reporting (Ministry of Environment, Lands and Parks 2000); Kamloops LRMP Monitoring (Kamloops Inter-agency Management Committee 1999); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Change in number of fish by life stages, by species (Pacific Northwest Salmon Habitat Indicators Work Group). • Number of fish species occupying a portion of their former range (Canadian Council of Forest Ministers). • Salmonid escapement for select rivers (Kamloops LRMP Monitoring). • Population sizes and reproductive success of salmon species by drainage (Model Forests).
Linkages to Ecosystem Characteristics of Interest	• An indication of the overall status of fish species, assisting in the identification of those that have been most impacted or experiencing declines. • Not possible to link status to specific types of habitat alteration or human activity, or the causes of species decline.

Linkages to Management Performance	• Linkage not direct – land use management actions are aimed at preventing impacts on fish populations, but they do not usually affect fish populations directly. Factors other than land use activity can significantly affect fish populations (e.g., natural low water flows, harvesting levels, disease outbreaks).
Information and Data Availability	• The Fisheries Information Summary System (FISS) provides georeferenced information (based on 1:50,000 NTS mapsheets) on species and stock presence by stream. Specific themes include: distribution (indicating presence and activity – i.e., staging location, rearing location, spawning location), releases, enhancement and management, potentials and constraints, obstructions, habitat type, land use, escapements, life history and timing, resource use, angler access, value, sensitivity, and harvest and use. • For salmon escapement, FISS provides information derived from the federal Salmon Escapement Database and Reporting System (SEDS) – mean and maximum escapement over the last 10 year period available by species. • SEDS database contains salmon escapement numbers by year, species and stream. Data is not yet spatial.
Information and Data Quality	• FISS database is not complete, with partial provincial formation for many themes.
Analysis, Interpretation and Thresholds	• Declining fish populations does not necessarily mean that land use activity is the cause of the decline. However, it can suggest that a precautious approach to land management should be adopted, or that adaptive management experimentation should be undertaken in the watersheds of concern.

Candidate Indicator: Populations of Select Aquatic Species **Source for Candidacy:** Canadian Council of Forest Ministers (1995); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Population levels and changes over time (Canadian Council of Forest Ministers). • Changes in population distributions and abundance (Model Forests).
Linkages to Ecosystem Characteristics of Interest	• An indication of the overall status of aquatic species, assisting in the identification of those that have been most impacted or experiencing declines. • Not possible to link status to specific types of habitat alteration or human activity, or the causes of species decline.
Linkages to Management Performance	• Linkage not direct – land use management actions are aimed at preventing impacts on populations of aquatic species, but they do not usually affect such populations directly. Factors other than land use activity can significantly affect aquatic species' populations (e.g., naturally occurring low water flows, incursion of exotic species, disease outbreaks).
Information and Data Availability	• Data for this indicator is very limited in its availability. No such data exists in corporate data sets; some data will exist in stream, reach or lake specific studies.
Information and Data Quality	• Where data has been collected for individual locations and accepted inventory methods have been followed, the data can be expected to be reliable.
Analysis, Interpretation and Thresholds	• Declining aquatic populations does not necessarily mean that land use activity is the cause of the decline. However, it can suggest that a precautious approach to land management should be adopted, or that adaptive management experimentation should be undertaken in the watersheds of concern. • By focusing on biological indicator species, population information would become more meaningful as an indicator of ecosystem state or condition.

Candidate Indicator: Occurrence of Exotic Species **Source for Candidacy:** Canadian Council of Forest Ministers (1995); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Area and severity of occurrence of exotic species (Canadian Council of Forest Ministers). • Impacts (area, number of locations and rates of spread) of exotics on special habitats (e.g., riparian) (Model Forests).
Linkages to Ecosystem Characteristics of Interest	• Exotic species (plant and animal) can pose substantial risks to native fish species and habitats due to competition and lack of natural predators.
Linkages to Management Performance	• Land use management regulation does not generally deal with exotics, except to the extent that silviculture activities require re-planting of native species.
Information and Data Availability	• FISS data includes information on species presence and distribution, including some information on exotics. • In addition, some data is available on presence of Atlantic salmon in marine and fresh water environments (Atlantic Salmon Watch Program).
Information and Data Quality	• Available data is generally thought to be reliable; however, it is not complete province wide.
Analysis, Interpretation and Thresholds	• Analysis and interpretation would benefit from the development of risk thresholds that link the extent of exotics incursion to the degree of risk that this presents to native fish and fish habitats. In the absence of such thresholds, it can be assumed that increasing trends in numbers of exotic species or increases in their range are a negative impact on native fish and fish habitat.

Watershed Level Monitoring Indicators

Candidate Indicator: Flow **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Canadian Council of Forest Ministers (1995); Kamloops LRMP Monitoring (Kamloops Inter-agency Management Committee 1999); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Percentage of stream miles with instream flow meeting instream water rights, seasonal flow requirements for salmonids, and/or sufficient to allow salmonid access (Pacific Northwest Salmon Habitat Indicators Work Group). • Percentage of waterbodies with minimal, moderate, and extreme changes in hydrology from historical patterns (captures low and high flow extremes-derivation) (Pacific Northwest Salmon Habitat Indicators Work Group). • Trends and timing of events in stream flows (including peak and low), relative to historic averages (Canadian Council of Forest Ministers; Kamloops LRMP Monitoring; Model Forests).
Linkages to Ecosystem Characteristics of Interest	• Adequate flows are required to meet fish requirements, while high peak flows or changes in the timing of peak flows can eliminate fish from habitat, increase mortalities, and reduce fish populations.

Linkages to Management Performance	• Difficulty linking changes in flow regime to forest development without times series studies and adequate control site or background information. To understand land use effects on local water flows requires a dense network of flow stations and the ability to account for climatic variations.
Information and Data Availability	• Water Survey of Canada monitoring data consists of site data that comprise SEAM (System for Environmental Assessment and Management) and EMS (Environmental Monitoring System). • Provincial water monitoring is also conducted in domestic use watersheds. • Requires direct continuous measurement of discharge at select critical or representative points, focusing on peak flows, low flows and mean annual discharge.
Information and Data Quality	• Where data is available, it is generally thought to be of high quality. However, the provincial stream flow monitoring network is limited (and has shrunk over the years), thus limiting the ability to tie stream flow effects to specific land uses.
Analysis, Interpretation and Thresholds	• Flow requirements differ by fish species; the interpretation depends on the species in question and local geomorphological and hydrological conditions (Eclipse Environmental Consulting Ltd. 1998). • Further work could potentially identify flow requirements for select fish species by region given the measurement of other critical local habitat attributes, but this would require extensive field and modelling work. • Focusing attention on potential "low flow problem areas", for which stream flows were below defined thresholds for fish survival, could reduce data requirements for analysis and interpretation (as alternative to looking for changes in stream flows over time).

Candidate Indicator: Chemical Water Quality (Index) **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Canadian Council of Forest Ministers (1995); Environmental Trends Reporting (Ministry of Environment, Lands and Parks 2000); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Percentage of waters rated "excellent", "good", "fair" or "poor" (possible parameters would include temperature, dissolved oxygen, biological oxygen demand, pH, ammonia/nitrate nitrogen, total phosphorus, total suspended solids, and bacteria) (Pacific Northwest Salmon Habitat Indicators Work Group; Environmental Trends Reporting). • As a trend, indicating "improving", "deteriorating" or "no change" in water quality (Environmental Trends Reporting). • Levels of dissolved oxygen and water nutrients (harvested vs. control streams); nutrient loading by drainage (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• As an index, would be composed of a number of parameters to provide a summary of habitat condition – i.e., the British Columbia Water Quality Index (Ministry of Environment, Lands and Parks 1995a).
Linkages to Management Performance	• Land management activities can directly affect some but not all water chemistry parameters (e.g., forest land use activities directly affect sediment delivery to streams and stream temperature).
Information and Data Availability	• Requires adequate spatial and temporal coverage of all parameters that comprise the index, once those are specified. Chemical water quality data generally not available in corporate databases.
Information and Data Quality	• Where data are available, they are accepted as generally high quality.
Analysis, Interpretation and Thresholds	• The British Columbia Water Quality Index (Ministry of Environment, Lands and Parks 1995a) and Criteria (Ministry of Environment, Lands and Parks 1995b; Ministry of Water, Land and Air Protection 1998) provides guidelines regarding development of components of an index and interpretation. • For interpretation, require adequate information of fish requirements with respect to all the parameters that comprise the index. Interpretation is required to convert water chemistry results into ratings (e.g., “excellent”, “good”, “fair”, “borderline”, “poor”).

Candidate Indicator: Temperature **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Canadian Council of Forest Ministers (1995); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Monitoring change over time, comparing to historical patterns (Model Forests). • Percentage of assessed waterbodies where the daily maximum falls into: <10ºC (no impairment); 10-15ºC (potential impairment to sensitive species); 15-20ºC (moderate impairment; >20ºC (severe impairment) (Pacific Northwest Salmon Habitat Indicators Work Group).

Linkages to Ecosystem Characteristics of Interest	• Temperature changes are directly attributable to changes in the health and survival of fish. Temperature is a physical predictor of fish distribution and abundance.
Linkages to Management Performance	• Harvesting or disturbance of the riparian habitat results in the loss of shade, leading to greater stream temperature extremes. Temperature may also be affected through changes in the flow regime due to forest development.
Information and Data Availability	• Corporate database of stream temperatures available for limited number of streams in HYDAT and WIDMS. Coverage of watersheds of interest will likely require expanding sampling efforts, establishing a consistent representative set of streams.
Information and Data Quality	• In the limited areas where data is available, it is thought to be reliable.
Analysis, Interpretation and Thresholds	• Temperature requirements (ranges) are specific to species, life history, and biogeoclimate zone; scientific information is available to help define these threshold values, most notable with respect to maximum daily temperatures. • Based on defined temperature requirements, analysis could define classes representing different degrees of impairment (Eclipse Environmental Consulting Ltd. 1998). • For protection of aquatic life, British Columbia Water Quality Guidelines provide recommendations for stream temperature (Ministry of Water, Land and Air Protection 1998) – see also Ministry of Water, Land and Air Protection (2001) and Oliver and Fidler (2001). For streams with bull trout and/or Dolly Varden, maximum 10°C spawning, maximum 15°C rearing, maximum 10°C and minimum 2°C incubation. For streams with known fish distribution, temperature should not be beyond ranges as defined for each life history phase of the most sensitive salmonid species present (see Guidelines). For streams with unknown fish distributions, the mean weekly maximum temperature should not exceed 18°C (maximum daily temperature 19°C), hourly rate of change not to exceed 1°C, and maximum incubation temperature 12°C (during spring and fall).

Candidate Indicator: Turbidity **Source for Candidacy:** State of Forests Reporting (Ministry of Forests 2000); Kamloops LRMP Monitoring (Kamloops Inter-agency Management Committee 1999); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000); Innovative Forest Practices Agreement (IFPA)	
Suggested Measures	• Monitoring change over time, comparing to historical patterns (Model Forests). • Exists as a component of the provincial Water Quality Index.

Linkages to Ecosystem Characteristics of Interest	• Turbidity caused by the suspension of fine sediments (fine sand, silt and clay), which may be deposited during periods or locations of low stream flows. • Elevated turbidity can decrease productivity of aquatic ecosystems, and have both lethal effects and sublethal effects (e.g., decreased feeding success, avoidance of habitat) on fish (e.g., see Birtwell 1999).
Linkages to Management Performance	• Forest development activity can lead to erosion that, in turn, can cause elevated turbidity levels. Elevated turbidity, however, also occurs naturally during peak flow events.
Information and Data Availability	• Corporate database of stream turbidity available for limited number of streams in HYDAT and WIDMS. Coverage of watersheds of interest will likely require expanding sampling efforts, establishing a consistent representative set of streams. • Requires daily sampling during spring runoff period (e.g. see Jordan 2001a), with more frequent sampling if diurnal flow cycle is evident for the region.
Information and Data Quality	• In the limited areas where data is available, it is thought to be reliable. • The relationship between suspended sediment (the target of measurement) and turbidity (NTUs) can vary by stream, warranting a precautious approach in the use of thresholds.
Analysis, Interpretation and Thresholds	• Interpretation requires the development of thresholds that link turbidity readings to the degree of risk to fish and fish habitats. Scientific information is available to help define these threshold values. • For protection of aquatic life, British Columbia Water Quality Guidelines define maximum induced turbidity of 8 NTU in 24 hours and 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; and 10% when background is greater than or equal to 80 (Ministry of Environment, Lands and Parks, 1998; Ministry of Water, Land and Air Protection 1998).

Candidate Indicator: Biological Water Quality (Index) **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Environmental Trends Reporting (Ministry of Environment, Lands and Parks 2000)	
Suggested Measures	• Percentage of water rated "excellent", "good", "fair" or "poor" (possible parameters would include fish community and benthic macroinvertebrate species or taxa composition and richness) (Pacific Northwest Salmon Habitat Indicators Work Group). • As a trend, indicating "improving", "deteriorating" or "no change" in biological water quality (Environmental Trends Reporting).

Linkages to Ecosystem Characteristics of Interest	• Biodiversity is a measure of the composition of the ecosystem and, in general, provides "options" for ecosystem development. • Benthic macroinvertebrates are a key food source for fish in streams.
Linkages to Management Performance	• Impacts on the physical habitat (stream morphology and water quality) can impact on stream biota. Harvesting of the riparian habitat results in a reduction in organic litter input, impacting on the macroinvertebrate community.
Information and Data Availability	• Indices are data intensive – information is required for each parameter. In the case of a biological water quality index, data are unavailable in corporate databases. • For benthic macroinvertebrate populations, will require sampling of watersheds using consistent representative set of streams. Related initiative is underway in the Skeena Region from which to develop provincial initiatives.
Information and Data Quality	• Unable to assess as little data is available to support this indicator. Data collection using established and consistent methodologies required.
Analysis, Interpretation and Thresholds	• Indices provide a means to summarise results and communicate complex ideas, but have a number of weaknesses: the resulting value is a further simplification of the system; there is subjectivity in the choice of parameters and associated weightings; and there is the greater possibility that important relationships are obscured by using aggregate scoring. • The ability to separate the effects of naturally occurring change in the parameters becomes more difficult when parameters are combined in an index.

Candidate Indicator: Physical Habitat Quality (Index) **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998)	
Suggested Measures	• Physical habitat assessment (parameters would include classifying habitat, measuring channel and riparian character, woody debris, stream discharge, and channel morphology) (Pacific Northwest Salmon Habitat Indicators Work Group).
Linkages to Ecosystem Characteristics of Interest	• Physical habitat provides the space and conditions for sustaining fish populations. Specific linkages between possible indicators and fish and fish habitat is dependent on the individual parameters selected for the index.
Linkages to Management Performance	• Land management activities are known to cause changes in a number of individual physical habitat parameters that could be used in an index.
Information and Data Availability	• Indices are data intensive – information is required for each parameter. In the case of a physical habitat index, data are generally unavailable in corporate databases. • Data for some parameters would be available for selected watersheds in watershed assessment reports.
Information and Data Quality	• Unable to assess as little data is available to support this indicator. Data collection using established and consistent methodologies required.
Analysis, Interpretation and Thresholds	• Indices provide a means to summarise results and communicate complex ideas, but have a number of weaknesses: the resulting value is a further simplification of the system; there is subjectivity in the choice of parameters and associated weightings; and there is the greater possibility that important relationships are obscured by using aggregate scoring. • The ability to separate the effects of naturally occurring change in the parameters becomes more difficult when parameters are combined in an index. • Thresholds would be desirable for determining when index scores represent significant concerns for fish or fish habitat.

Candidate Indicator: Fish Spawning and Rearing Areas **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001)	
Suggested Measures	• Percentage change in spawning area (Pacific Northwest Salmon Habitat Indicators Work Group). • Number of spawning and rearing areas identified and protected (Forest Certification).
Linkages to Ecosystem Characteristics of Interest	• The availability of adequate quality spawning and rearing habitats is required for sustaining fish populations. Fish spawning and rearing areas are key determinants of the condition of fish habitat.
Linkages to Management Performance	• Land management indirectly affects the availability and quality of fish spawning and rearing habitats as a result of management controls (regulations, guidelines) that influence the physical habitat (e.g., flows, stream morphology, riparian condition, sedimentation levels).
Information and Data Availability	• The Fisheries Information Summary System (FISS) provides georeferenced information (based on 1:50,000 NTS mapsheets) on fish distribution, indicating presence and activity (staging location, rearing location, spawning location).
Information and Data Quality	• Time series corporate data is generally unavailable to support measurement of this indicator to detect changes.
Analysis, Interpretation and Thresholds	• More specific definitions of what constitutes fish "spawning areas" and "rearing areas" would be required in order to implement this indicator. • The development of thresholds that define specific levels of concern (e.g., minimum areas required for given watersheds) would be beneficial for meaningful interpretation.

Candidate Indicator: Stream or Channel Morphology **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Change in stream width-depth ratio (Pacific Northwest Salmon Habitat Indicators Work Group). • Comparisons of channel morphology between harvested and control sites (e.g., channel width, bed material size, organic debris) (Model Forests). • Change in pool-riffle ratio (Pacific Northwest Salmon Habitat Indicators Work Group). • Presence and density of pooling (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Change in channel morphology could represent a detrimental impact on fish and fish habitat, via changes in the habitat characteristics of the stream (e.g., changes in sediment budgets and in the distribution and quantity of pools and riffles).
Linkages to Management Performance	• Increases in logging activity may lead to increases in peak flows and sediment delivery to streams, which in turn may lead to channel filling, channel widening, and straightening (e.g., see discussion in Beaudry and Gottesfeld 2001).
Information and Data Availability	• Data for measuring this indicator is not available in corporate databases. Data does exist in various studies for individual watersheds and in watershed assessment reports.
Information and Data Quality	• Where data exists, it can be expected to be reliable provided that it was collected using accepted inventory protocols and standards.
Analysis, Interpretation and Thresholds	• Channel morphology affected by numerous factors, including: flood regime, sediment delivery, parent materials, geological history, local climate, riparian vegetation, direct human impacts, and land use (indirect impacts) (Church 1992). Linking channel morphology characteristics to land use requires expert judgment for specific case context (Hogan 2001). For example, study by Beaudry and Gottesfeld (2001) shows a poor relationship between channel widening and levels of harvest. • As a measure of habitat complexity, variance in thalweg depth is advocated (e.g., Eclipse Environmental Consulting Ltd. 1998). This has been directly related to increases in species number and diversity in streams, and is independent of stream flow at time of measure.

Candidate Indicator: Large Woody Debris **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Distribution and characterisation of large woody debris per historically anadromous salmonid stream mile (Pacific Northwest Salmon Habitat Indicators Work Group). • Coarse woody debris in streams that is added or removed (Forest Certification). • Presence and density of course woody debris (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Important for maintaining channel stability and structure. Provides complex cover over streams, required by fish for shade and predator protection cover, and a "balanced" amount promotes scouring and/or the storage of sediments to maintain channel complexity (e.g., Hogan 1987 as cited in Bird 2001).
Linkages to Management Performance	• Harvesting of the riparian habitat results in a reduction in trees available for maintaining large woody debris supply (i.e., logging can alter the budget, or size and amount of LWD pieces delivered to the channel).
Information and Data Availability	• Data for measuring this indicator is not available in corporate databases. Data does exist in various studies for individual watersheds and in watershed assessment reports.
Information and Data Quality	• Estimates of volumes of large woody debris can be prone to large measurement errors (i.e., not replicable due to differences between individuals doing the measurements and difficulties associated with estimating complex log assemblages or log jams) (Hogan 2001).
Analysis, Interpretation and Thresholds	• Thresholds for what defines desired levels of large woody debris in streams would be needed. More large woody debris is not always better – there are limits. • Measuring the orientation of large woody debris may be another possible measure (i.e., as an indication of stream energy due to water flow regime which, in turn, can be affected by land use activities).

Candidate Indicator: Sedimentation **Source for Candidacy:** The Pacific Northwest Salmon Habitat Indicators Work Group (Green Mountain Institute 1998); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Sediment loading rates (Pacific Northwest Salmon Habitat Indicators Work Group). • Presence and density of sedimentation; particle size distribution in 1st and 2nd order streams (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Sedimentation results in reduced survival of eggs and alevins, loss of interstitial space for refuge, and reduced benthic macroinvertebrate production. Overall, can lead to reduced physical complexity of the channel.
Linkages to Management Performance	• Logging and road building activities can have a direct bearing on sediment load that is delivered to streams: however, natural events (e.g., heavy rainfall events, landslides) can also affect sedimentation levels. • Natural spatial and temporal variations in sedimentation expected to be high, preventing a clear interpretation with respect to land use effects.
Information and Data Availability	• Data for measuring this indicator is not available in corporate databases. Data does exist in various studies for individual watersheds and in watershed assessment reports.
Information and Data Quality	• Where data exists, it can be expected to be reliable provided that it was collected using accepted inventory protocols and standards.
Analysis, Interpretation and Thresholds	• For protection of aquatic life, British Columbia Water Quality Guidelines define maximum induced suspended sediments as 25 mg/L in 24 hours and 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; and 10% when background is greater than or equal to 250 (Ministry of Water, Land and Air Protection 1998). • For protection of aquatic life, British Columbia Water Quality Guidelines define streambed substrate composition as fines not to exceed 10% as less than 2mm, 19% as less than 3mm, and 25% as less than 6.35mm at salmonid spawning sites. The geometric mean diameter must be not less than 12mm, and the Fredle number not less than 5mm (Ministry of Water, Land and Air Protection 1998).

Candidate Indicator: Disturbed Stream Channel/ Channel Stability **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999); Forest Certification (American Forest and Paper Association 1995; Canadian Standards Association 1996; Forest Stewardship Council 2001); Model Forests (McGregor Model Forest Association 1998; Beasley and Wright 2000)	
Suggested Measures	• Total length of disturbed channel (km) and as percentage of total channel length, using the Reconnaissance Channel Assessment Procedure (Watershed Assessment Procedures). • Channel stability ratings (Forest Certification). • Changes in stream bank vegetation cover (Model Forests).

Linkages to Ecosystem Characteristics of Interest	• Changes to stream channel integrity can affect fish and fish habitats, primarily due to impacts on aspects of channel morphology and chemical water quality.
Linkages to Management Performance	• Loss of riparian vegetation and large woody debris through riparian logging, as well as direct channel disturbance (e.g., machinery operating across streams, salvaging logs out of streams), leads to loss on bank cohesion and integrity. • The linkage between channel stability and disturbance of riparian vegetation determined by factors such as channel slope, flow, and composition of bank materials (Millar 2001) (e.g., higher gradient step-pool streams less reliant than riffle-pool streams; Bird 2001).
Information and Data Availability	• Data for measuring this indicator is not available in corporate databases. Data does exist in various studies for individual watersheds and in watershed assessment reports. • Results-based Forest Practices Code is expected to include a performance standard related to "stream bank stability". Licensees will be required to ensure that stream banks are not destabilized or damaged. If this is adopted, it would be possible to measure number of infractions of this standard.
Information and Data Quality	• Where data exists, it can be expected to be reliable provided that it was collected using accepted inventory protocols and standards.
Analysis, Interpretation and Thresholds	• Analysis and interpretation may require development of thresholds of impact (risk) to fish and fish habitat, although general trends information on the direction of change could be assumed.

Candidate Indicator: Erosion from Roads **Source for Candidacy:** Watershed Assessment Procedures (British Columbia Ministry of Forests 1999)	
Suggested Measures	• Length of road in "high" and "very high" erosion class (Watershed Assessment Procedures). • Length of road on unstable terrain (areas with terrain stability class 4 or 5, or that is classified P or U) (Watershed Assessment Procedures).
Linkages to Ecosystem Characteristics of Interest	• Erosion provides the source for sediment input into streams that, in turn, can affect fish sustainability due to impacts on water quality and stream morphology.
Linkages to Management Performance	• Road development in forest environments, which is a regulated activity, is known to be a primary cause of anthropogenic erosion.
Information and Data Availability	• Information generally available only in watershed assessment reports. Classification of road condition requires reconnaissance field work. Not available in corporate database. • An alternative may be to measure the length of road that crosses unstable terrain, or certain soil classes. Data for terrain stability or soil type is not available on a province wide basis.
Information and Data Quality	• Where data exists, it can be expected to be reliable provided that it was collected using accepted inventory protocols and standards.
Analysis, Interpretation and Thresholds	• Using field assessment, Watershed Assessment Procedures (Ministry of Forests 1999) rank risk by distinguishing between 6 sediment production classes for roads, combined with a classification of sediment delivery from forest roads to stream channels.