MINISTRY OF SUSTAINABLE RESOURCE MANAGEMENT

INDICATORS OF FISH SUSTAINABILITY: MANAGED AND RARE FISH IN FOREST ENVIRONMENTS
(REF. NO. VA102-00001/1-1)

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MINISTRY OF SUSTAINABLE RESOURCE DEVELOPMENT

INDICATORS OF FISH SUSTAINABILITY: MANAGED AND RARE FISH IN FOREST ENVIRONMENTS (REF. NO. VA102-00001/1-1)

EXECUTIVE SUMMARY

This draft report provides results of a review and selection of fish and fish habitat sustainability indicators for status and trend monitoring of managed, rare and non-commercial fish in forest environments. The study was prepared for the Ministry of Sustainable Resource Management (MSRM) and the Ministry of Water, Land and Air Protection (MLWAP).

The primary objectives of the project were to:

- review and evaluate fish and fish habitat indicators; and
- recommend a suite of proposed indicators (i.e. tool-kit) that can be used for monitoring of fisheries resources and sustainability.

Based on the objectives of the Request for Proposal (RFP), and subsequent discussions with the clients, MSRM and MWLAP are primarily interested in reviewing and selecting indicators and indices suitable for monitoring fish and fish habitat status and trends. The review included:

Direct indicators: measured biological responses of fish communities, populations, and individuals of interest (e.g. fish age distribution, condition factors, density or biomass; and species richness); and

Indirect indicators: correlates or surrogates of the status or potential productivity of fish populations, communities and fish habitat.

Examples of indirect indicators include:

- biological water quality (macroinvertebrates, periphyton, plankton, and chlorophyll *a*);
- chemical water quality (e.g. pH, dissolved oxygen (DO), total dissolved solids (TDS), alkalinity, temperature, nutrients), and
- physical habitat quality and associated hydrological characteristics (e.g. channel width/depth, instream flow, substrate).

Several assumptions regarding the primary interest of the MSRM and MWLAP were applied to the review, evaluation, and selection process. These included the following:

- emphasis on forest ecosystems, as opposed to urban or agricultural areas;
- indicators were assessed for freshwater ecosystems only (lakes, streams, and rivers);
- the study focused on indicators and indices of fish and fish habitat status, as opposed to indicators or indices of land use, or other anthropogenic stress (e.g. estimated clear-cut area; number of angling licenses issued; number of road crossings; number of permitted discharges).

Section 2 introduces concepts and terminology associated with status and trend monitoring. Sections 3 and 4 identify, review, and discuss potential direct and indirect indicators to develop a preliminary short list for further consideration. Detailed evaluations (i.e. ranking or ratings) for the short list of indicators are outlined in Section 5. Section 6 provides indicator recommendations and conclusions, and identifies options for developing a strategic level monitoring program.

It was understood from the onset that the most effective status and trend monitoring program would necessarily be a suite or mixed group of available indicators. That would provide coverage for a broad range of potential stressors to fish. The results of the review and evaluation led to recommendations for a fish sustainability indicator tool kit on two levels ("tiers").

Tier I Indicators were defined as "ready for use" relevant and sensitive indicators for which extensive B.C. data exist for some species, regions, or environments and included the following:

List of Tier I Indicators (extensive data available)

Indicator	Suitable for use for:		
	Managed species[1]	Rare species	Non-commercial species
Direct indicators			
Population—distribution	Yes	Bull trout[4]	No
Population—abundance	Yes	Bull trout[4]	No
Indirect indicators			
Temperature	Streams	Bull trout[4]	No?
Instream flow(s)[2]	Streams	Bull trout[4]	No
Physical habitat[3]	Streams	Bull trout[4]	No
Chlorophyll *a*	Lakes?	No?	No?
Nutrients	Lakes?	No?	No?

NOTES: Tier I indicators are indicators for which data exist for a reasonably extensive subset of locations or regions

"?"=data exist for the indicator, which is a measure of fish habitat. Inferring the status of fish populations or communities from those data may be problematic

1— Applicable to freshwater life stages of Pacific salmon and steelhead, and to freshwater-resident rainbow trout; less applicable, or not applicable, to other managed salmonids (e.g. cutthroat trout, whitefish, Dolly Varden) and non-salmonids (e.g. walleye).

2— Applies to locations with existing Water Survey of Canada (WSC) and other discharge stations and data; establishing new stations would be costly.

3— Effectively, any habitat indicators or variables recorded as part of Channel Assessment Procedures (CAP) and/or provided in the B.C. Watershed Atlas

4—Bull trout is only useful for interior areas

Tier II indicators were relevant, sensitive, and useful indicators for which existing data are limited. Some analyses of existing data may be possible, but for the most part, the Tier II indicators would be targets for future development (i.e. through pilot programs) and eventual wide-scale use.

List of Tier II Indicators (limited data available)

Indicator	Suitable for use or development for:		
	Managed species	Rare species	Non-commercial species
Direct indicators			
Population—distribution	Non-salmonids[1]	Some	No
Population—abundance	Non-salmonids[1]	Some	No
Population—growth	Yes[2]	Bull trout[4]	No
Population—age structure	Yes[2]	Bull trout[4]	No
Population—reproductive capacity	Yes[2]	Bull trout[4]	No
Community indicators	No	Some	Yes
• Indirect indicators			
Benthic invertebrates	Streams	No?	Streams

NOTES: Tier II indicators are indicators for which data are limited, but which should be considered for research, development and future use for status and trend monitoring

"?"=indicator is an important measure of fish habitat, but may be difficult to relate to status of some rare species

[1]— Excludes freshwater life stages of Pacific salmon and steelhead, and freshwater-resident rainbow trout, but could include other salmonids (e.g. cutthroat trout, whitefish, Dolly Varden) for which existing data are limited

[2]— These indicators would be most useful if measured together and/or in conjunction with abundance. The major concern would be that fish must be sacrificed to measure reproductive capacity, and may have to be sacrificed to determine age and growth.

[4]— Bull trout is only useful for interior areas

The detailed design of a status and tend monitoring was beyond the scope of this project. However, three options for status and trend monitoring were identified. These included:

Option 1: Complete Dedicated Status and Trend Monitoring Program

- regular (probably annual) monitoring of Tier I and Tier II indicators;
- >100 sample locations;
- re-sampling of some or most of the same locations over time;
- committed funds for 10-20 years of sampling (for trend analysis), and
- standards development and validation monitoring or analyses.

Option 2: Reduced Dedicated Status and Trend Monitoring Program

Option 2 would reduce the scope of any conclusions that could be made about status and trends for fish and fish habitat. A reduced program would still require committed funding for 10-20 years, the establishment of dedicated status and trend monitoring locations, sampling of those locations, and standards development and validation.

Option 3: Reliance on Existing or Other Programs

Analyses of existing data may provide some information on status for a limited number of indicators, species, and locations but is unlikely to provide much information on long-term trends. Continued reliance on sampling conducted for other programs is unlikely to provide a representative set of locations or long-term trend data based on regular and repeated sampling over time. The risk is that this may result in a 'patch work' of different indicators monitored sporadically and reactively by different methods.

A complete and dedicated status and trend monitoring program (Option 1) is probably not feasible given funding constraints, although it should be treated as a target or goal. Reliance on other data or programs alone (Option 3) will not be adequate for large-scale status and trend assessment. We recommend combination of Options 2 and 3, plus analysis of existing data for Tier I and especially Tier II indicators.

Critical areas or topics inadequately addressed by other data and programs are:

- long-term trends;
- status and trends for non-commercial species and fish communities in general, and
- development and validation of standards.

Major conclusions and recommendations derived from this review were:

1. Indicators of fish and fish habitat status identified for Tier I and II indicators should be the focus of current and future status and trend assessment.

2. There are sufficient existing data available for some indicators (primarily Tier I) to assess status and perhaps trends. These assessments should be conducted.

3. If the province wants to assess status and trends for fish and fish habitat, they cannot rely only on data and indicators collected or measured for other purposes. Active or dedicated monitoring will have to be conducted to provide data for assessing long-term trends and non-commercial species, and for developing or validating standards.

4. Some dedicated monitoring is required, but there are limited funds available. The obvious solution is to monitor and assess a limited subset of indicators, and adopt efficient and appropriate designs and approaches for any monitoring conducted.

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LIST OF ABBREVIATIONS

AECD	Aquatic Ecozone Classification Data Base
AIB	Aquatic Information Branch
ASCI	Alaska Stream Condition Index

B-IBI	Benthic Index of Biological Integrity
CAP	Channel Assessment Procedure
CCME	Canadian Council of Ministers for the Environment
CDC	Conservation Data Center
CPUE	Catch per Unit Effort
DFO	Department of Fisheries and Oceans, Canada
EC	Environment Canada
EEM	Environmental Effects Monitoring
EMA	B.C. Environmental Monitoring System
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ESU	Evolutionary Significant Unit
FDW	Fisheries Data Warehouse
FHAP	Fish Habitat Assessment Procedures
FMB	Fisheries Management Branch
FPI	Forest Inventory Planning
FRBC	Forest Renewal B.C.
HAI	Health Assessment Indices
IBI	Index of Biological Integrity
IFIM	Instream Flow Incremental Methodology
MAD	Mean Annual Discharge
MOF	B.C. Ministry of Forests
MSRM	B.C. Ministry of Sustainable Resource Management
MWLAP	B.C. Ministry of Water, Land and Air Protection
NMFS	U.S. National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration
PHABSIM	Physical Habitat Simulation System
PNWEIWG	Pacific Northwest Environmental Indicators Work Group
PSFA	Pacific Salmon Fishery Agreement
PSIR	Pressure-State-Impact-Response framework
RIC	Resource Inventory Committee
VRI	Vegetation Resource Inventory
WAP	Watershed Assessment Procedures
WIDMS	Water Inventory Data Management System

WUA	Weighted Useable Area

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MINISTRY OF SUSTAINABLE RESOURCE DEVELOPMENT

INDICATORS OF FISH SUSTAINABILITY: MANAGED AND RARE FISH IN FOREST ENVIRONMENTS (REF. NO. VA102-00001/1-1)

SECTION 1.0 – INTRODUCTION

1.1 BACKGROUND

This report provides the results on the review, evaluation and selection of fish and fish habitat sustainability indicators for status and trend monitoring of managed, rare and non-commercial fish species in forest environments. The project was conducted by a consortium of four companies including Knight Piésold Ltd., Paine, Ledge and Associates, ESSA Technologies Ltd. and Environmental Resolution Services. The project was administered jointly by the Aquatic Information Branch (AIB) of the Ministry of Sustainable Resource Management (MSRM) and the Fisheries Management Branch (FMB) of the Ministry of Water, Land and Air Protection (MWLAP), with funding provided by Forest Renewal B.C. (FRBC).

We used the definitions of indicator and index provided by Brown and Dick (2001):

Indicator – a number of other descriptor, measured in real units, which is assumed to be representative of a larger set of conditions or values.

Index – values, expressed on a simple numerical (e.g. 1-4, 1-10 , 1-100 etc.) or descriptive (e.g. low, medium, high etc.) scale which represents a summations of various conditions and measurements across a broad field.

Indicators = Indicators and Indices

1.2 OBJECTIVES

The main goal of this review and evaluation is to develop a "tool kit" of indicator standards and provide recommendations for status and trend monitoring of fish and fish habitat sustainability in forest environments. The primary objectives of the project were to:

- review and evaluate fish and fish habitat indicators, and
- recommend a suite of proposed indicators for monitoring fisheries resources and sustainability.

Potential indicators were divided into two major groups.

1. **Direct Indicators:** measures of fish communities, populations and individuals of interest (e.g. density or biomass of steelhead parr or spawning adults; species richness of fish communities).

2. **Indirect Indicators:** correlates or surrogates of the status or potential productivity of fish populations and communities (e.g. water quality/quantity, physical habitat, and predictive models of implied habitat capacity).

Indicators were reviewed on a broad scale and a short-list of general indicators was selected for further evaluation based on overall rankings of usefulness. The project scope included the review and evaluation of both indicators and indices and made the following assumptions regarding the interest of the province:

- forest, as opposed to urban or agricultural, environments;
- lakes as well as streams and rivers, and
- indicators and indices of fish and fish habitat status, as opposed to indicators or indices of land use or other anthropogenic activity (e.g. estimated clear-cut area; number of angling licenses issued; number of permitted discharges, barriers).

1.3 METHODS

1.3.1 Review

The review and evaluation of indicators provided below was based on:

- a systematic review of recent issues of several target journals;
- libraries of the project team members and companies;
- reports and publications obtained from the B.C. Fisheries Research Station at UBC;
- relevant web sites, particularly those of B.C. resource ministries and associated agencies;
- other publications of interest cited in the above sources;
- contacts in various institutions and agencies, and.
- the land-use thresholds indicators workshop hosted by Gustavson and Brown (Victoria, B.C. , January 16, 2002).

Journals that were systematically reviewed included:

- *Canadian Journal of Fisheries and Aquatic Sciences (CJFAS)* - applied and basic fisheries and aquatic science.
- *Transactions of the American Fisheries Society (TAFS); Journal of North American Fisheries Management (JNAFM);* and *Fisheries*, three journal publications of the American Fisheries Society (AFS) - primarily applied fisheries science.
- *Ecological Applications;* publication of the Ecological Society of America (ESA) - more research-oriented than the AFS journals, a good source for communities and methods not routinely covered in the more applied literature.

All issues of these journals back to at least 1998 were reviewed for relevant papers. The review effectively extended back to the early 1990s, because most of these journals were systematically reviewed as part of a previous evaluation of fish indicators (EVS and PLA, 1998).

For physical habitat indicators, a long list of indicators was compiled from 13 habitat inventory, assessment, and monitoring programs developed in B.C., Washington, Oregon, Alaska, U.S. EPA Region 10, or as National U.S. EPA initiatives, and two international workshops on salmon habitat indicators.

Additional review items included methods that could link habitat indicators to population indicators, major limitations and advantages of potential indicators, and alternative approaches that may reduce or eliminate limitations of selected indicators.

1.3.2 Evaluation

Primary criteria for evaluating indicators were:

1. relevance/sensitivity,
2. cost, and
3. data availability.

Once a short list of 5-10 suitable indicators was selected, the list was further reduced based on secondary criteria such as redundancy, opportunity, and interactions.

Evaluation and selection of indicators were conducted separately for:

- commercially important versus non-commercial/rare species, and
- lakes versus streams.

It was understood at the beginning of the exercise that there was no single ideal indicator and that the best monitoring option would provide for a suite or mix of indicators to cover all aspects of monitoring fish, water quality and physical habitat related to fish sustainability and status. Our evaluations and proposed set of indicators were compared to those provided by MacDonald et al. (1991); as well as, other relevant report(s) or agencies to provide guidance in recommending the most useful combination of indicators possible.

1.4 REPORT ORGANIZATION

In addition to this introductory section, the report is organized as follows:

Section 2 introduces concepts and terminology associated with status and trend monitoring.

Sections 3 and 4 identify, review, and discuss potential direct and indirect indicators as a means to develop a preliminary short list for further consideration.

Section 5 provides detailed evaluations (i.e. ranks or ratings) for the short list of indicators.

Section 6 provides indicator recommendations and conclusions, and identifies options for developing a strategic level monitoring program.

A technical appendix outlining further information on application, methods, and reference sources for fish community indicators (Appendix A), fish population indicators (Appendix B), descriptions of physical habitat indicators (Appendix C), list of contacts (Appendix D) and a list of web sites (Appendix E).

SECTION 2.0 – MONITORING VARIABLES AND PROGRAMS

This section provides a general discussion of monitoring variables and programs, intended to:

- identify required or desired requirements for provincial fish and fish habitat monitoring programs and indicators, and
- define terms used in this report, which may differ from those used in other sources (e.g. Brown and Dick, 2001).

2.1 MONITORING VARIABLES

2.1.1 Overview

In this report, “variables” is a generic term, referring to all measures that could be used in a monitoring program. Monitoring variables could be:

- measures of stress (usually anthropogenic alteration or activity);
- measures of chemical, physical, biological and habitat (=environmental) responses to stress and stressors, and
- natural supplementary or modifying variables (e.g. stream order, elevation) affecting values and variances of stress and response variables.

Indicators and indices are specific types of monitoring variables, usually simple or summary measures of stress, response, or environmental quality. In this report, indicator refers to environmental response variables or measures.

The terminology or framework for variables used in this report was adapted from Ecological Risk Assessment (ERA) and environmental toxicology/monitoring usage. That framework and terminology differs from the Pressure-State-Impact-Response (PSIR) framework, used by and Brown and Dick (2001) which define response as management response. Figure 2.1 compares the two frameworks. The PSIR framework is more human- and management-oriented, and includes terrestrial as well as aquatic organisms and ecosystems. In contrast, the framework used in this report is primarily concerned with ecological or environmental impacts on fish and fish habitat (i.e. aquatic ecosystems), and stress-response relationships.

2.1.2 Stress Variables

Stress variables or indicators are reviewed separately in the land-use thresholds report by Gustavson and Brown (2002). Stress variables can be considered equivalent to Pressure variables in the PSIR framework (Figure 2.1). In this review, stress variables are important because of their relationship with fish and fish habitat response indicators. Measures of stress variables are also necessary for standards development and validation, and for Environmental Effects Monitoring (EEM) (see Section 2.5).

2.1.3 Response Variables

Response variables or indicators reviewed in this report are equivalent to fish and fish habitat State variables in the PSIR framework (Figure 2.1). Simple or summary response variables (=indicators or indices) are the primary subject of this review. Response indicators are typically interpreted by comparison to standards, which could be based on values from local reference and other field locations, or on generic values from the literature (Section 2.4).

2.1.4 Supplementary or Modifying Variables

Stressors, stress-response relationships, and response indicators are affected by many natural factors or variables. In monitoring programs, these natural supplementary variables are important for:

- reducing natural variance (i.e. "noise") of indicators, and
- assisting analysis, interpretation and presentation of indicator values and monitoring results.

For example, most fish and fish habitat indicators will vary naturally among biogeographic regions, and with elevation and stream size or order. That natural variance can be removed or reduced by analyzing data or setting standards by region or stream order (=stratification). Natural variance can also be reduced by standardizing field sampling methods, locations and times. For example, in long-term monitoring programs, seasonal or within-year effects or variance can be removed by sampling in the same season every year. Natural variance at smaller spatial scales can often be reduced by measuring supplementary or modifying variables in the field and using them as covariates or X variables in data analyses, or to adjust indicator values or standards.

Supplementary or modifying variables, especially those that can be measured (or obtained from other sources) at low cost, should be included in almost any monitoring program. Reducing variances using inexpensive supplementary variables is often more cost-effective than increasing sample sizes (Paine, 2001).

2.2 OVERVIEW OF MONITORING PROGRAMS

Table 2.1 lists the basic types of environmental monitoring programs and groups them according to their general purpose. There are many other classifications available or possible, with considerable overlap among program types and purposes. The important point is that the purpose of specific monitoring programs should be clearly defined. The appropriate numbers and types of sampling locations, sampling duration and frequency, and monitoring variables (including indicators and indices) differ among program types and purposes (MacDonald et al., 1991; Dixon and Chiswell, 1996; Paine, 1998, 2001; Olsen et al., 1999).

Based on the objectives of the RFP, and subsequent discussion, the MSRM and MWLAP are primarily interested in reviewing and selecting response indicators and indices suitable for monitoring fish and fish habitat status and trends. Thus, the focus below is on status and trend monitoring programs. Standards development and validation would be necessary for those programs. The two ministries and other agencies also have an obvious interest in environmental effects monitoring (EEM), particularly for the forest industry and in forest environments.

In the following sections, status and trend monitoring programs and assessment are discussed in some detail (Section 2.3). Status and trend are defined, and requirements for locations, times, variables and standards provided. These requirements should be considered criteria broadly applicable to either existing or future data for indicators reviewed in this report. Then, standards development and validation, and EEM, are defined and described (Sections 2.4 and 2.5). Overlap and differences in requirements for locations, times, and variables versus those for status and trend monitoring or assessment are noted.

The following discussion of monitoring programs of interest addressed two relevant questions for this review of response indicators:

1. To what extent are existing data collected for various purposes suitable for status and trend assessment, or standards development or validation?
2. To what extent can future data (and indicators) be shared among programs or purposes of interest to the province?

Section 2.6 briefly discusses other types of monitoring programs. Section 2.7 summarizes the implications of preceding sections for the review and evaluation of fish and fish habitat indicators in Sections 3 to 6.

2.3 STATUS AND TREND MONITORING

2.3.1 Overview

Status and trend monitoring and assessment ask two basic questions:

1. What is the current environmental quality in some spatial unit (e.g. watershed, region, province) (=status)?
2. Is environmental quality getting better or worse over time (=trend)?

In status and trend monitoring, multiple locations are sampled over time.

Status

Status can be expressed as:

- the frequency of locations in one or more categories (e.g. % of locations with a rare fish species present; % of locations rated poor, fair, or good based on a categorical index), or
- indicator values summed or averaged over multiple locations (e.g. average pool area per location or km; total number of species in a watershed or region).

Spatial differences in status among regions, habitats, administrative units, etc., are often of interest, to provide strata or groups for estimating status over larger spatial scales or to identify areas of greatest concern.

Trends

Trends can be expressed as:

- parametric or non-parametric correlations between indicators and time (usually year), and
- rates of change (=slopes) of indicator values over time.

Trend typically refers to a unidirectional or monotonic increase or decrease over time. Step, or abrupt, changes may also occur after some intervention, and may be of interest.

Combining Status and Trends

In status and trend programs, one can assess:

- trends in status over time, and
- differences in trends over space.

Most indicators reviewed in this report are amenable to either approach.

Relevant Literature

Good reviews and discussions of status and trend monitoring programs can be found in:

- The Invited Feature on "Measuring Trends in Ecological Resources" in *Ecological Applications* Vol. 8, No. 2 (1998), based on a workshop involving the Ecological Society of America (ESA), the American Statistical Association (ASA), and
- the U.S. EPA Environmental Monitoring and Assessment Program (EMAP). Various EMAP documents or reports, cited in this report, or available from the EMAP web site: http://www.epa.gov/html/pubs.

Bradford and Irvine (2000) and Smith (2000) provide local case studies in which trends for B.C. salmonid abundances over ≥10 years were analyzed for multiple populations or locations.

2.3.2 Sample Locations

Sample locations for assessment of status should be representative of larger spatial units of interest. Completely random, stratified random, or more complex probability-based sampling designs should be used. Most available B.C. data for potential indicators come from judgementally selected, or sentinel, locations (=biased or unrepresentative samples). These locations were presumably selected because they were considered of interest or concern, or convenient to sample. Judgementally selected or sentinel locations are rarely as representative as their selectors assume (Green, 1979; Green and Montagna, 1996; Dixon et al., 1998; Jassby, 1998; Stoddard et al., 1998; Edwards, 1998). Regional or large-scale status or trends can rarely be reliably inferred from a limited set of judgementally selected or sentinel locations.

When data are available for large numbers of judgementally (or haphazardly) selected locations, estimates of large-scale status and trends can be made using various weighting schemes or other statistical techniques. However, *effective sample sizes* are usually reduced. For example, there may be existing temperature data for 100 streams, but that might be equivalent to a more representative or suitable sample of 50 streams for status and trend assessment. In some cases, poorly represented or unsampled regions, habitats, or specific types of locations (e.g. references) may have to be excluded, limiting the generality of conclusions.

2.3.3 Sample Times

The standard approach to trend monitoring is to sample at evenly or uniformly spaced intervals (usually annually). Programs are continued for a decade or longer, so trends are not a function of short-term changes or a few unusual years. The standard recommendation is that there should be at least 10 sample years (Berryman et al., 1988). With many locations, annual sampling may not be necessary at each location, and fewer than 10 sample years per location may be required. For example, rotating schedules could be used, with a subset of the locations sampled each year. Urquhart et al. (1998) provide a more complex design, with a subset of locations repeatedly sampled over time, and another randomly selected sample chosen for sampling in each year. This mixed approach was used for the Oregon Coastal Coho Program. Another alternative is to measure less costly variables more frequently than more costly variables.

Requirements for multiple sample years and time intervals of a decade or longer dictate that only a few inexpensive or readily available indicators should (or can) be monitored or measured. Sampling and analytical methods, and in most cases sample locations, must be consistent over time. Funding must also be available or committed on a regular basis over time intervals longer than those typically used for budgeting or planning by agencies or ministries. Available data for most indicators reviewed in this report are unlikely to provide enough sample years for trend assessment.

2.3.4 Monitoring Variables

Response indicators are the primary variables of interest or importance for status and trend monitoring. Relatively few inexpensive indicators and other variables should be monitored in status and trend programs to maximize the number of sample locations and times (MacDonald et al., 1991; Green et al., 1993; Paine 1998, 2001). Supplementary or modifying variables should be used to stratify or classify locations by region, habitat, etc. and reduce natural variance. Stress variables are of minor interest for defining status and trends, although the stressors responsible for differences in status, and for trends, may be of major interest (Section 2.5).

2.3.5 Interpretation

When status and trend monitoring are combined, absolute rather than relative standards for interpreting indicator values are usually required, especially for assessing status. Figure 2.2 illustrates the relationship between status and trend monitoring, and standards. Standards can be considered a "filter" for interpreting status and trend data, however obtained. The data are compared to the standards to determine whether indicator values indicate that environmental quality is, e.g. good, fair (or intermediate) or poor. To assess status, standards development and validation in some form (Section 2.4) is required.

Consider an indicator with a linear or monotonic stress-response relationship, such as fish species richness (number of taxa per spatial unit or sample) (Figure 2.3a). Increasing richness over time would normally be regarded as positive and decreasing richness as negative. Therefore, the increase in richness in both regions shown in Figure 2.3b can be interpreted as an improvement in environmental quality, if sample locations and methods were reasonably consistent over time. This is an example of relative standards and assessment (i.e. higher richness is better). The assumption is that methodological or natural effects or biases are consistent over time and space, which is usually a reasonable assumption (and an argument for standardized methods and sampling designs).

However, suppose one were interested in whether status or environmental quality was good, fair or poor at the end of the time series in Figure 2.3b (or at any other time), and differed between the two regions (since richness was consistently higher in Region 1), these issues can only be addressed using absolute assessment and standards. Richness values will vary with:

- history and biogeography (determine which species are present and could be collected)
- sampling methods and intensity (i.e. how completely the community is sampled);
- scale (i.e. at what level richness is aggregated or calculated), and
- habitat and other natural factors (e.g. stream order, depth, elevation, latitude/longitude).

The time series in Figure 2.3b could represent a trend from severely impacted to marginally acceptable, or from fair to excellent. Management implications of, and responses to, these two scenarios would obviously differ. Similarly, the difference between regions might indicate that environmental quality in Region 2 is worse than in Region 1, or that richness in Region 2 was naturally lower than in Region 1.

If stress-response relationships are non-monotonic, absolute standards must be defined for both status and trend assessment. For example, temperature and habitat preference or suitability relationships will typically be non-monotonic and unimodal (Figure 2.4), with:

- intermediate values considered good, and
- lower and higher values considered fair or poor.

For comparisons over time or space, indicator values must be re-scaled based on absolute standards so that intermediate values are good or high, and values decrease towards either end of the *X* scale. For example, a consistent increase in temperature over time could represent:

- a trend from poor (low or high temperature) to good (intermediate temperature) (=improvement);
- a trend from good (intermediate temperature) to poor (high temperature) (=degradation), or
- both trends combined.

2.4 STANDARDS AND DEVELOPMENT

Standards for interpreting indicator values as good, fair or poor, or on some other scale are necessary for status and trend monitoring or assessment (Section 2.3.5), and would have some value for EEM (Section 2.5). Standards for indicator values must first be developed (Section 2.4.1), then validated (Section 2.4.2), which adds to costs and requirements for analysis of existing data or for future status and trend and EEM monitoring programs.

Standards development and validation also applies to sampling and other methods, as discussed in Section 2.4.5.

2.4.1 Standards Development

As Figure 2.2 indicates, standards can be developed from:

- the literature,
- other agencies or jurisdictions,
- existing monitoring data, or
- dedicated standards development monitoring.

The first three sources or options are obviously less costly than the fourth. The availability of either suitable data or standards is reviewed in Sections 3 and 4, and considered a plus in the evaluations in Section 5. Standards for indicators, however developed, need to be validated, using B.C. field data (Section 2.4.2).

The absence of, or need for, suitable data for standards development or validation should not necessarily be considered a negative. For many indicators, relative trend assessment can be used to determine if environmental quality is improving or deteriorating, which is important. Standards for indicators can be based on:

- reference location values,
- stress-response relationships (e.g. Figures 2.3a and 2.5),
- suitability/preference relationships or models (e.g. Figure 2.4), or
- other relationships between indicators and various *X* variables.

Reference values are widely used for developing standards for direct indicators and for indirect biological indicators and are described in more detail in Appendix B. Reference values are treated as good, and departures from those values as poor. Further distinctions (e.g. between fair and poor) could be based on the magnitude of departures from reference values. Reference values vary spatially among regions and habitats, and with stream or lake size, so extensive reference data are usually required.

Stress-response relationships, such as those in Figures 2.3a and 2.5, can also be used to derive standards. With this approach:

- the response is the indicator value,
- the *Y* (or *X*) axis is subdivided into categories such as good, fair and poor), and
- reference values (=low or no stress) represent only one of several levels of stress.

Using a stress-response approach, or collecting or analyzing data along a gradient, reduces requirements for extensive reference data or locations, and provides simultaneous validation. Reasonable stress variables, and gradients for those variables, are required, and a stress-response relationship must exist.

The last two approaches listed above are variations of the stress-response approach, with different *X* variables. This is effectively the approach used to validate indirect indicators (=*X*), and to adjust indicator values or standards for natural supplementary or modifying variables (=*X*).

2.4.2 Standards Validation

Standards validation is used to determine if:

- hypothesized relationships between response indicators and stress or other *X* variables exist, and
- specific standards are reasonable and applicable to B.C.

Validation is particularly important when standards are obtained or developed from laboratory experiments or from sources outside B.C. Validation should be based on B.C. field monitoring data, which could come from existing data, other programs or dedicated validation monitoring (Figure 2.2). As discussed in Section 2.4.1, standards development and validation can be combined by sampling or analyzing data along a gradient of either stress or response indicator values. Reference values (or locations) are unnecessary for validation, except to determine if reference-based standards can be extended beyond the regions, habitats, etc. for or from which they were developed.

Indirect indicators and associated standards should be validated in two ways. First, the existence of a stress-response relationship should be established. Second, there should also be a relationship between the indirect indicator and one or more direct indicators (e.g. as in habitat suitability or preference models – see Section 4.3.5). Otherwise, the indirect indicators are arguably not biologically relevant, even if they are altered by stressors.

2.4.3 Sample Locations and Times

If standards are developed based on existing or future dedicated monitoring data, large numbers of sample locations (e.g. >10 to >100) are usually required. The sample locations could be a representative sample of reference locations, or a sample of locations along a gradient of stress or response. In the latter case, locations ideally should be judgementally selected, to provide a relatively evenly spaced or uniform distribution of stress or response values. A representative or randomly selected sample of locations is one of the least efficient sampling designs for a gradient approach.

Validation monitoring typically requires fewer locations (smaller sample sizes), with an emphasis on Impact or non-reference locations, or on reference locations not used to develop reference-based standards.

Dedicated standards development and validation monitoring is typically conducted in only one or a few years. However, existing data collected over many years could also be used for developing and validating standards.

In Figure 2.2, a dotted arrow is used to show that only a subset of status and monitoring data, however obtained, is likely to be useful for standards development and validation. Samples for standards validation should be biased towards either reference locations or Impact locations.

2.4.4 Monitoring Variables

Indicators are obviously of primary importance in standards development and validation. Stress variables or measures are important for defining reference or Impact locations, and gradients. Supplementary or modifying variables are important for developing reference-based standards, and adjusting standards for natural variance.

2.4.5 Methods

Standardized methods are also required for status and trend and other monitoring programs. For most if not all of the indicators reviewed in this report, Resource Inventory Committee (RIC) and other standard methods exist and are suitable for most purposes. Therefore, methods standards can be assumed available, and in many cases, validated. Some refinement and further validation for specific indicators or purposes may be necessary.

2.5 ENVIRONMENTAL EFFECTS MONITORING (EEM)

2.5.1 Overview

Two types of environmental effects monitoring or assessment which would be of interest to B.C. MWLAP, MSRM and other provincial ministries or agencies are:

- *post hoc assessment*, or identifying stressors responsible for spatial differences in status, or
- for trends *dedicated EEM*, or assessments of specific projects or activities.

Bradford and Irvine (2000) provide an example of post hoc assessment. They examined correlations between spawner abundances of Thompson River coho salmon, which were declining, and exploitation rates, road density, forest harvest, and other potential stressors. Post hoc assessments could be conducted on either existing data collected for various purposes, or on future dedicated status and trends data. Post hoc assessments are examinations of stress-response relationships, with obvious management implications (Figure 2.1).

Dedicated EEM programs would be equivalent to "results-based" monitoring, which the province proposes to adopt to assess the effects of forest harvest, road construction, etc., as opposed to specifying specific practices. Existing data would rarely be useful for this approach, particularly for small-scale projects or activities. For this review, the important questions are:

1. Can dedicated EEM data also be used for status and trend assessment?
2. Can standards for indicators be used for EEM or results-based monitoring? Can EEM data be used to develop standards?

2.5.2 Sample Locations and Times

Post Hoc Assessment

Post hoc assessment is applied to existing data and sampling designs. Before post hoc assessments are conducted, sample sizes (numbers of locations or times) should be adequate to define status or trends. These are minimum sample size requirements. Larger sample sizes may be required to assess correlations between status or trends and specific stressors. For example, a stress or stressor may not occur at most locations or times, or stress measures may not be available for locations and times used for status and trend assessment.

Dedicated EEM

The basic spatial design for dedicated EEM is a comparison between a reference or Control area, and an Impact area (=CI design). Locations would be replicates within those areas. That basic approach can be extended to:

- include multiple references, or
- assess effects (responses) along a stress gradient.

The first approach compares one or a few Impact areas locations to a larger and representative sample of references. The approach is similar to comparison of status and trend monitoring data to reference-based standards (Figure 2.2). If suitable or local reference data are already available from status and trend or standards development monitoring, those data and any associated standards can be used in place of data from new reference locations. This "reference-condition" approach obviously reduces the costs of multiple-reference EEM programs.

The gradient approach is more useful when the degree of stress or response is expected to vary, usually with distance from a point source or project location. The most effective approach is usually to judgementally select a relatively uniform or evenly spaced distribution of stress levels.

The duration and number of sample years used in dedicated EEM depends on the time interval in which the stress occurs, or is expected to have effects. For example, the effects of road or other construction may be monitored over only one or a few years, whereas the effects of persistent contaminants or clear-cuts may be monitored over one or more decades. Monitoring should be conducted both before (=baseline) and after (=operational) the project or activity begins or occurs.

Data from dedicated EEM programs may have limited value for status and trend monitoring (and vice versa). Across the province, and within individual dedicated EEM programs, locations sampled will not be a representative sample. Instead, EEM sampling will be strongly biased towards Impact locations and areas where specific stressors occur, and nearby reference locations. Most EEM programs would also sample one or a few habitat types (e.g. riffles only) to reduce natural variance, instead of sampling a broader and more representative range. Sample times, and the duration of programs, will also vary widely. The most useful data for status and trend monitoring would probably come from large-scale, long-term EEM programs.

There may be more overlap between dedicated EEM and standards development and validation. Data from gradient and especially multiple reference EEM designs could be used for standards development. Results from Impact locations sampled in EEM programs would undoubtedly be compared to any existing standards. Dedicated EEM programs will also provide some validation of standards and the sensitivity of indicators. Direct measurements of biological indicators (=responses) in EEM programs are often used to determine if water quality criteria for the protection of aquatic biota are over- or under-protective. Federal-provincial sediment quality guidelines are based on matched biological and chemical data obtained largely from EEM programs (CCME, 1999).

2.5.3 Monitoring Variables

Both post hoc and dedicated EEM focus on the stress-response relationship, so stress and response variables or indicators are of primary and equal importance. Response indicators reviewed in this report, and used for status and trend monitoring, would be generally suitable for EEM. Dedicated EEM programs, especially for localized projects or activities, would use only a subset of stress and response variables of broader interest. For example, only one or a few species may be sampled, and stressors such as road density would obviously be of little interest in an assessment of the effects of pesticide spraying. Supplementary or modifying variables are of secondary importance, and used primarily to reduce natural variance.

2.6 OTHER MONITORING PROGRAM TYPES

The effects of management activities, as well as industry and other activities, would also be of interest to B.C. MSRM and MWLAP. Effectiveness monitoring can be considered EEM, with management activities of interest replacing stress or stressors. Implementation monitoring may be used prior to EEM or effectiveness monitoring to determine if (or where) activities of interest are occurring.

Comparison to standards in status and trend monitoring (e.g. Figure 2.2) or EEM could be considered a form of compliance monitoring. However, the standards used would have no legal status. Comparisons to standards are not the primary purpose of status and trend or EEM programs, and are used only as a tool to assist interpretation.

Baseline or inventory monitoring, especially within the FRBC program, was an important source of existing data for indicators reviewed in this report. However, data from baseline and inventory monitoring will presumably be reduced in the future, as the emphasis shifts to results-based or dedicated EEM monitoring.

2.7 SUMMARY AND IMPLICATIONS FOR INDICATOR SELECTION

Table 2.2 summarizes variable types, and sample locations and times, for monitoring purposes of interest. There is a broad overlap among programs, in that similar variables, locations and times are usually measured or sampled in all programs. However, the programs differ in terms of emphasis, or the allocation of sampling effort or costs among variables, locations and times, and among types within those categories.

Given the overlap among programs, data collected for one purpose (e.g. EEM) have *some value* for other purposes (e.g. status and trend monitoring). Thus, the availability of existing data collected for other purposes, and especially the availability of standards or data suitable for developing standards, is an important criterion for evaluating indicators. Similarly, in the future, data and standards can be shared among programs, with some cost savings. Most of the indicators reviewed would also be suitable for multiple purposes. In general, the most sensitive indicators would be preferred, so sensitivity is an important evaluation criterion.

At the same time, data collected for different purposes are rarely if ever as suitable for a specific purpose (e.g. status and trend assessment) as data collected for that purpose. For example, only some status and trend monitoring data may be suitable for standards development and validation, and dedicated EEM data alone will not provide a representative sample or adequate spatial coverage for status and trend assessment. That has two important implications for this review:

1. Existing data collected for other purposes may not be as suitable or extensive for status and trend assessment, and especially standards development and validation, as simple counts of numbers of locations sampled suggest. Only a subset of the existing data may be useful, effective sample sizes may be reduced because of the sampling designs used, data may be limited or non-existent for

some regions, habitats, etc., and methods may vary among studies or programs. Data suitable for trend analysis will be limited or non-existent.

2. In the future, B.C. MSRM and MWLAP cannot rely entirely on other programs to collect data for status and trend assessment. Some dedicated monitoring will be required to provide representative and more complete spatial coverage for assessing status, and especially for standards validation (which must be conducted with B.C. field data) and trend assessment. Therefore, cost becomes an important criterion for evaluating indicators, especially those used for long-term trend monitoring.

SECTION 3.0 - DIRECT INDICATORS REVIEW

3.1 INTRODUCTION

Direct indicators are biological responses measured on fish communities, populations, and individuals (e.g. age distribution, condition factor, density or biomass of steelhead parr or spawning adults, species richness) (Cairns et al., 1984).

Commercially managed fish populations such as salmonids tend to be monitored closely. Data may include detailed distribution data, population data related to biometrics (weight-length, age), population data related to reproduction, and community (presence/absence of other species) information. A general summary of Pacific salmon life histories is provided by Groot and Magolis (1991).

For many rare and commercial fish species, information may be limited to presence/absence distribution data and site-specific assessment programs. A summary of rare fish in B.C. is provided by Cannings and Ptolmey (1998) and the Conservation Data Centre (CDC) Rare and Endangered Species Database (CDC, 2000). Tables 3.1 and 3.2 provides red and blue listed fish species in B.C.

A breakdown of fish monitoring techniques into levels of biological organisation (e.g. individual, population, and community) is provided in Munkittrick and Power (1990), and Addison (1996). All direct indicators require the collection of fish species data, by active capture (e.g. by nets, traps, etc.) or using more passive or indirect methods (e.g. helicopter surveys, redd counts, creel censuses). Common methods are listed in Table 3.3. RIC (Resource Inventory Committee) (1997b, 1999, 2001) outlines fish and fish habitat collection and inventory methods and standards for B.C.

Due to data availability the review of direct indicators was largely based on information and data available for commercially important fish species rather than for non-commercial or rare species (Table 3.4). Our general approach to review and evaluation was similar for both groups of species. However, the specific indicators reviewed and recommended for monitoring differ between the two groups.

3.2 COMMUNITY INDICATORS

Type: All community indicators reviewed are direct indicators of fish status and sustainability.

Scale: Community indicators are typically applied to assess status and trends at watershed and regional scales, although they can be applied to individual sample locations.

Habitat: Community indicators have primarily been used for assessing streams, but can also be used for assessing lakes.

Fish: Community indicators can be used to assess commercial and non-commercial/rare species, which often occur in the same community or assemblage.

Appendix A provides an extensive discussion of fish community indicators, because they are important but rarely used in B.C. A summary is provided below.

3.2.1 Definition/Overview

Fish community indicators and indices are based on occurrences or abundances of multiple fish species. Ross et al. (1985), Berkman and Rabeni (1987) and Hiram et al. (1987) review forestry impacts on fish assemblages or communities. Schlosser (1982, 1985, 1987) reviews the influences of macrohabitat variables on community indicators. Fausch et al. (1990) identified four community approaches and indicator/index types:

1. Sentinel Taxa or Guilds—occurrences or abundances of sentinel or selected species or groups (=guilds) of ecologically, taxonomically or otherwise similar species.
2. Richness Indicators—measures of richness, diversity and evenness.
3. Index of Biotic Integrity (IBI) and Other Multi-metric Indices—indices combining and integrating multiple indicators or metrics.
4. Multivariate Methods—statistical procedures for analyzing multiple variables and metrics.

The standard community data are a species × sample matrix, providing abundances or occurrences of each species at each sample location (or time).

3.2.2 Field Methods/Data Collection

Most community indicators are strongly affected by sampling methods, the size and type of sample locations, and sampling effort (=operational factors). Sampling methods and other operational factors should be standardized, to provide comparability over time and space. Electrofishing is the most common sampling method used, particularly in streams. Table 3.3 lists common sampling methods. In most cases, captured fish can be held live for species identification and enumeration, then released unharmed.

3.2.3 Development and Application

Table 3.5 lists 10 steps in the development, validation, and application of an Index of Biological Integrity (IBI). Most of these steps are applicable to any community indicator. Once an indicator or index has been developed and validated, it is:

- monitored or measured over time or space;
- averaged or summed at some level of interest; and,
- interpreted largely by comparison to standards (typically reference conditions).

Since the 1980s, community indicators and specifically IBI have been developed and widely used in the U.S., particularly in streams. (Simon 1999). Table 3.6 lists community indicators used in IBI in streams of the mid-western U.S. In Canada, Quebec has recently developed an IBI used to assess cumulative effects from pulp mill discharges and other stressors. Steedman (1988) developed an IBI for assessing southern Ontario streams. Hughes and Gammon (1987) describe changes in fish assemblages in relation to water quality for the Willamette River, Oregon.

We are not aware of any case in B.C. in which fish community surveys and indicators were used to assess effects from point and non-point discharges or sources, or assess overall environmental quality (except in relation to habitat suitability). Extensive community studies were conducted on the Blackwater (Porter et al., 1998) and Similkameen (Rosenfeld, 1996) drainages in the Interior of B.C. Emphasis was on relationships between fish distributions or abundance, and physical habitat variables. Porter et al. (1998) also examined relationships between richness in both drainages, and habitat variables.

3.2.4 Data Availability

Map-based variables similar to those used by Porter et al. (1998) or from the B.C. Watershed Atlas can be used to define homogeneous regions for developing and assessing community indicators (Step 1 in Table 3.5). The same sources also provide habitat and other data necessary for Step 2, and development and adjustment of standards (Step 7). Existing land use and other data (e.g. estimated clear-cut area) could be used to define reference locations or disturbance gradients (Step 2). This review of candidate indicators or metrics, the review of ecological characteristics and sensitivities of B.C. fish species by Porter et al. (2001), Simon (1999), plus some additional literature sources would address Step 3.

Community data could be obtained from studies conducted on specific drainages (e.g. the Blackwater and Similkameen). Some single-species data sources listed in Table 3.4 may also provide abundances or occurrences of other species. Theoretically, abundances of all species collected should have been recorded in Forest Renewal B.C. (FRBC) fish inventories. However, most of those data do not appear to have been reported, or at least entered into the Fisheries Data Warehouse (FDW). We queried Fish Wizard for data on the Blackwater, and from two streams surveyed by one of the authors of this report. None of these data appear to have been entered into the FDW.

Based on the above, adequate data to address Steps 4 through 6, and Step 8, in Table 3.5 are available only for selected drainages (e.g. the Blackwater and Similkameen). Distribution records for other drainages may be adequate to calculate and compare some occurrence-based indicators. Existing data are inadequate to address Steps 2, 7, 9 and 10 (effectively standards development and validation). Data gaps could be partially rectified by entering existing FRBC and other fish inventory data (i.e. updating the FDW). However, sampling methods and effort, and the type of data reported, will vary among studies. The streams surveyed are also unlikely to be a representative sample of all streams, or reference streams.

3.2.5 Standards Development and Validation

Standards would have to be developed and validated for sampling methods and for community indicator values.

3.2.6 Costs

Field costs for community surveys and indicators would be similar to those for population surveys and indicators. Laboratory costs would be trivial. Except for complex multivariate methods, data analysis and summary are relatively simple and easily conducted using spreadsheets.

3.2.7 Advantages and Limitations

Community indicators provide measures of ecologically relevant properties such as diversity and biological integrity. Surveys and indicators include managed, non-commercial and rare species. Community indicators are sensitive to many different stressors, and have been widely used in the U.S. to assess biological integrity and environmental quality. In most cases, sampling is non-sacrificial. Community indicators based on multiple species are usually more robust and less variable than indicators based on one or a few species.

Community indicators cannot be used where few fish species are present (e.g. in northern areas, and in small streams or lakes). They may not be useful for specific species of interest or concern, especially when those species are rarely captured in community surveys. Standards for methods and indicator values have not been developed or validated for B.C., and that process may require dedicated monitoring of many sample locations, particularly references.

3.2.8 Recommendations and Conclusions

Based on the review of community indicators, two types of community indicators are recommended for further evaluation:

1. Sentinel taxa or guild indicators - based on sensitivity/tolerance, taxonomy, and/or ecological characteristics, and
2. Richness (total or for sub-groups) indicators; but not diversity or evenness metrics.

Development and application of multi-metric summary indices such as IBI should be an eventual goal. However, one must first establish that the simpler community indicators included in those multi-metric indices are feasible or useful. Multivariate approaches and methods are recommended for exploratory and descriptive analyses of community data, and development and assessment of more comprehensible multi-metric indices.

3.3 POPULATION INDICATORS

Type: All population indicators reviewed are direct indicators of fish status and sustainability.

Scale: Population indicators are typically applied to assess specific fish population status and trends at watershed and regional scales.

Habitat: Population indicators are suited to streams and rivers as well as small and large lakes.

Fish: Population indicators are have primarily been used to assess commercial species but also could be used for and non-commercial species.

Appendix B provides a more detailed discussion of fish population indicators and is summarized below:

3.3.1 Definition/Overview

A population is defined as a group of individuals of the same species, forming a breeding unit, and sharing a habitat. Fish population indicators and indices are used to provide information about individual fish species such as managed species used for commercial purposes (e.g. steelhead, Pacific salmon); rare, threatened, or vulnerable species (e.g. bull trout, Dolly Varden, white sturgeon); and other non-commercial species (e.g. whitefish, suckers). Population indicators can be divided into four general categories:

1. Distribution (presence/absence, occurrence);
2. Abundance (density [adults, smolts, juveniles, redds], recruitment, escapement);
3. Age Structure (age-class distribution age-at-maturity);
4. Growth (size-at-age), and
5. Reproductive Capacity (fecundity [# of eggs per ripe female], size of eggs).

Standard population data are a matrix of abundance and/or occurrence by location and/or date. Most studies include age, sex, and weight/length data for individuals of a population. These indicators can be used to infer population status. Community data can also be used to indicate the status of a particular population within the assemblage.

3.3.2 Field Methods/Data Collection

A list of fish collection/observation methods is provided in (Table 3.3). The field methods used for direct fish population assessments depend on the target species (or taxa). Often, other species that may be simultaneously caught are considered "by-catch" and are not assessed in the same detail as the target species. The gear used also depends on the age class of the target species. Location and density of eggs and larvae is estimated with redd counts or by extrapolating from the number of eggs in a representative sample of individuals. Juvenile salmon are caught with electrofishing, various traps, seine nets and can be observed by snorkelling. Adult salmon are caught with fish fences or weirs, gill nets, seine nets, angling, electrofishing, fish traps. Tagging and recapture is used to estimate abundance from commercial, sport, and aboriginal catches. Studies of threatened fish populations use less invasive methods like fish trapping, snorkelling, and backpack electrofishing to enumerate fish. Peterson et al. (2001) provides protocols used US Fish and Wildlife Service for determining bull trout presence in Washington, Oregon, Montana and Idaho, which would work well in B.C.

3.3.3 Development and Application

In Canada and B.C., several fish and forest related agencies and programs have identified and adopted direct fish distribution and population indicators. Indicators identified for managed fish species; and rare, threatened and vulnerable species by various fish/forestry programs in B.C. are listed in Tables 3.7 and 3.8, respectively.

Pacific salmon populations throughout B.C. have been routinely measured with aims to facilitate management of the resource. Salmonids generally considered sensitive to forest impacts (see Appendix A) and analysis of the freshwater stage of these fish can be used as indicators of fish and fish habitat sustainability (Slaney et al. 1977a,b; Murphy et al. 1986; Dolloff, 1986; Holtby, 1988; Hartman and Scrivner, 1990; Meehan and Bjornn, 1991;

Murphy, 1995; Scrivener et al., 1998; Porter et al. 1998; Bradford and Irvine, 2000). The MWLAP Skeena district includes resident fry assessment as part of its ecological watershed evaluation tool box (MWLAP unpublished presentation).

The relative utility of different steelhead abundance measures [e.g. redd counts, fry density, parr density, smolt production, adult abundance, sport fishery Catch per unit effort (CPUE), commercial by-catch] as status indicators has not been formally assessed. Even the relationship between the more easily determined measures of abundance (fry density, sport fishery, CPUE) and adult abundance trends is not well established. There is no agreed-upon index for combining these potential indices into an overall measure of status. Smolt production is probably the most useful single measure of abundance trends but is difficult to determine (Tom Johnston, pers. comm.).

In B.C., fish age distribution is used as an indicator for provincial monitoring of white sturgeon (Dixon, 1986). Sampling individuals of a population for age class structure, sex ratio, and length/weight distribution provides data that can be statistically analysed to yield more detail about the status and trends of populations (Gibbons and Munkittrick, 1994). Crecco and Savoy (1984) used age class indicators on American shad populations in the Connecticut River. The Pacific Northwest Environmental Indicators Work Group (PNWEIWG) recommended age class distribution (e.g. change in number of salmonids by life stages) as a population indicator (Green Mountain Institute, 1998).

Rates of growth are commonly described by the relationship of size (as weight or length) to age (=size at age), and are recommended for inferring fish growth in EEM adult fish survey programs.

3.3.4 Data Availability

Information on fish distribution is relatively extensive for managed populations and is contained in the provincial Fisheries Data Warehouse

(FDW). Approximately 5,200 of the 18,000 polygons of the watershed Atlas have been surveyed for fish. These data are available in the Fisheries Information Summary System and the Provincial Fisheries Data Warehouse.

Most of the fish population studies conducted in B.C. are assessments of abundances of Pacific salmon and steelhead (Table 3.4). Other direct population studies include the federal aquatic EEM program for pulp mills and mines (sentinel species), and the efforts of B.C. Fisheries Research.

Forest harvesting plans and all other developments in or adjacent to waters containing fish or fish habitat, whether marine or freshwater, require the approval of the Department of Fisheries and Oceans (DFO) and B.C. MSRM. Assessments of the fisheries potential of streams are provided to governments when harvesting or development plans are submitted. The bulk of these data are archived in Victoria, in the records of municipalities, and at the various development company offices (Table 3.4).

Size-at-age, mean age, and age-at-maturity information is likely available for some salmonid populations. The environmental trends monitoring initiative includes age distribution indicators of white sturgeon (percentage of white sturgeon populations that are juveniles, sub-adults, or adults) (BC MELP, 2000).

At the present time, data from development applications and forestry plans is not always standardised, accessible or accurate. For example RIC standards for stream classification are not followed by most forest companies since the forest practices code does not require all the details that the RIC standards call for. The same issue exists for land developments. Since the data is not collected to RIC standards, it is not entered into the provincial Fisheries Data Warehouse. To avoid losing this information, the historic data should be collected from the various sources and fit into the FDW (Peter Bruce and Associates, 2001).

3.3.5 Standards Development and Validation

Historical population assessments have been performed using a wide variety of methods. To provide comparability over time and space, standard sampling methods and other operational factors would have to be developed and validated.

With salmon populations, management is facilitated using stock recruitment data to derive escapement reference points (Johnston et. al., 2000). These reference points are used to set harvest control rules based on smolt production and adult abundance estimates. Such reference points could be used by B.C. to define standards for population levels necessary for the conservation of managed fish (see further discussion Appendix B).

The U.S. National Oceanic and Atmospheric Administration (NOAA) and the U.S. National Marine Fisheries Service (NMFS) provide guidance for determining the conservation status of populations and larger-scale groupings of Pacific salmonids. This initiative uses the viable salmonid population concept. They define a viable salmonid population as an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame. Guidelines are provided on how to relate individual population viability to the viability of the Evolutionary Significant Unit (ESU) as a whole. Four parameters form the key to evaluating population viability status. They are abundance, population growth rate, population spatial structure, and diversity (McElhany et. al. 2000).

3.3.6 Costs

Field costs for fish population surveys depend upon the location and physical habitat of the study area. Most of the expense is field equipment and labour. Laboratory costs (e.g. for fish ageing) are trivial. Data analysis and reporting are relatively inexpensive when compared to field costs.

3.3.7 Advantages and Limitations

Population indicators provide measures of ecologically relevant properties of designated populations of fish. Many species are sensitive to potential impacts of forest harvesting. Historical (and ongoing) data is available for Pacific Salmon and steelhead populations. Distribution (i.e. presence/absence) data is simple to apply and easy to comprehend and can be used to monitor occurrence of rare fish species.

A high variance (= signal to noise ratio) among locations, seasons and years makes interpretation of abundance difficult and existing data for non-salmonid species is inadequate for most watersheds or regions. Standardized methods development is required. Population data may not yield information rapidly enough for effective management.

3.3.8 Recommendations and Conclusions

Based on this overview of fish population indicators, the following are recommended for further consideration:

- Distribution (occurrence) of salmonid species;
- Distribution (occurrence) of red and blue listed fish species;
- Abundance of salmonid (or sensitive/sentinel fish) species;
- Age (especially non-lethal methods such as scales and fin rays), and
- Growth (e.g. size at age).

3.4 INDIVIDUAL INDICATORS

Type: All individual indicators reviewed are direct indicators of fish status and sustainability.

Scale: Individual indicators are typically applied to assess impacts at watershed and site-specific scales (e.g. length-weight data in f, although some such as age distribution can be used to estimate population status on a broad scale.

Habitat: Individual indicators could be used for assessing streams and lakes.

Fish: Individual indicators are used to assess commercial and non-commercial/rare or sentinel species, which often occur in the same community or assemblage.

3.4.1 Definition/Overview

An individual is defined as one member of a population of a specific species. Individual indicators consist of measures of individuals and/or groups (e.g. juveniles/adults) of individuals in sample sizes representative of select population subsets. The following four descriptors summarise the dimensions of the individual fish indicators evaluated in this report.

Individual indicators are based on the premise that fish are good integrators of natural and anthropogenic variables that may affect the general health of fish. Individual indicators of fish health can be extrapolated to assess of fish population, community, and overall ecosystem health. Munkittrick and Power (1990) divide individual level indicators into physiological and morphological indicators. Most physiological indicators are more suited to EEM monitoring and are impact specific (e.g. mixed-function oxidase (MFO) levels). Physiological indicators are generally poorly suited to status and trend monitoring due to the intensive level of effort required in sampling and design and are not included in this review. It is understood that some grey area exists between individual and population and individual indicators, since size-at-age and fecundity require sample sizes representative of subsets of the population (Section 4.3). However, fish biometrics such as length-weight and condition factor (k) (where k = 100 (body weight/length), and other morphological indicators [e.g. tissue somatic indices (TSI) and health assessment indices (HAI)] are measured on individuals (whereas abundance and distribution are true population characteristics) and therefore are included in the following sections.

3.4.2 Field Methods/Data Collection

All individual indicators require field sampling and are strongly affected by sampling methods, the size and type of sample locations, and sampling effort (=operational factors). Table 3.3 lists several common methods for the collection of fish species data. Sampling methods and other operational factors should be standardized, to provide comparability over time and space. Electrofishing is the most common sampling method used, particularly in streams. Methods for length (standard, total, or fork length), wet weight, and sometimes aging, as well as sacrificial methods for tissue somatic indices (TSIs) and health assessment indices (HAIs), are described in EC (2000a, b) and RIC (1997, 1999).

3.4.3 Development and Application

Federal Environmental Effects Monitoring (EEM) programs (Section 2.5) have adopted an individual-level approach for assessment of impacts from point-source discharges and other activities to serve as early indicators of environmental effects (Munkittrick et al., 1997). EEM programs are conducted primarily in response to potential impacts through targeted/specific monitoring programs (Table 2.1).

Biometric weight-length and age information can be used in time series determinations of size-at-age data to assess changes in growth of fish population status as described in Section 3.3. Distributional shifts to younger ages are indicative of over exploitation and metabolic redistribution, whereas shifts to older ages tend to reflect recruitment failure and multiple stressors (Munkittrick et al., 2000).

3.4.4 Data Availability

Individual indicator information (size-age, condition factor) is collected for most adult fish surveys and data would reside in individual project reports (e.g. EEM) and government publications for specific streams or watersheds and thus is difficult to access.

Data for managed species may provide suitable data for time-series analysis on some populations in intensively studies locations; however data for other areas and species is largely unavailable or inaccessible.

3.4.5 Standards Development and Validation

High variability due to species differences, seasonality, reproductive stress, and test conditions limit usefulness of data for status and trend monitoring; and would require establishments of standards for specific populations and require validation monitoring as outlined in Section 2. Standards would be required on an individual stream/lake basis - i.e. comparison to internal (site- or study –specific) references.

3.4.6 Costs

Field costs for collecting individual indicator information would be similar to any community or population survey. Sample processing and laboratory costs may be particularly high for methods requiring more complex analytical procedures.

3.4.7 Advantages and Limitations

Individual indicators are ecologically relevant, sensitive to environmental stressors and good integrators of environmental conditions. Size, age (by scale or fin ray) and condition factor can be collected using non-sacrificial methods and therefore may all or most fish species (i.e. commercial, non-commercial, rare).

Use of indices (e.g. condition indices, TSI) requires the assumption of some relationship between variables, which may not exist and can create statistical problems. Most methods other than size and age require sacrificial sampling (e.g. TSI, HAI, otolith aging). Standards (e.g. normal ranges) would have to be established for target species by region or population). Internal reference sites would be required for developing standards and existing data inadequate for development and application in most drainages or regions.

3.4.8 Recommendations and Conclusions

High variability due to species differences, seasonality, reproductive stress, and test conditions limit usefulness of individual data for status and trend monitoring which is more abundance and distribution oriented. Physiological indicators are particularly poorly suited to strategic status and trend monitoring due to their high specificity and higher analytical cost. As a result recommendations for individual indicators for further evaluation are limited to:

- Size and condition factor (e.g. weight-length), and
- Growth and age (e.g. growth, age distribution, size-at -age) measure are also useful and should be evaluated at the population level as discussed in Section 3.3.

SECTION 4.0 - INDIRECT INDICATORS REVIEW

Indirect indicators of fish sustainability are correlates or surrogates of the status or potential productivity of fish populations and communities. Any variable or measure that can be used to predict fish population or community variables is potentially a suitable indicator of fish and fish habitat status. Many indirect indicators of fish status are direct indicators of fish habitat status. These include:

1. Biological water quality [e.g. macroinvertebrates, zooplankton and algae (periphyton, phytoplankton and chlorophyll *a)*],
2. Chemical water quality (e.g. pH, DO, TDS, alkalinity, temperature, nutrients), and
3. Physical habitat and hydrology characteristics (e.g. channel width/depth, instream flow, substrate).

Appendices for biological and chemical water quality indicators were not included as the information is well covered in the literature reviewed below. For physical habitat variables Appendix C was included to provide descriptions of those indicators evaluated in this report.

4.1 BIOLOGICAL WATER QUALITY

Type: All biological water quality indicators reviewed are indirect (correlate or surrogate) indicators of fish status and sustainability.

Scale: Biological water quality indicators are frequently applied in site-specific permitted discharge monitoring programs; but are also useful for status and trend monitoring over larger spatial scales.

Habitat: Biological water quality indicators are relevant for both streams (benthos and periphyton) and lakes (benthos and zoo- phytoplankton communities).

Fish: Biological water quality indicators are generally good integrators of water quality over time and important indicators of aquatic production for all fish species.

4.1.1 Definition/Overview

Biological variables associated with benthic macroinvertebrates, zooplankton, phytoplankton, periphyton, and chlorophyll a have been all been used as predictors or indicators of fish status (Peters, 1986). Fish growth and productivity is a function of food abundance; thus changes in insect and plankton community structure (richness and abundance) are surrogate indicators of fish productivity. Slaney and Ward (1993) report use of benthos data in accounting for some of the variability in trout growth. Phytoplankton community composition in lakes is one of the first biological parameters to respond to human induced water quality changes.

Table 4.1 summarizes water quality indicators selected or recommended by B.C Fish/Forestry programs and indicator workshops. Biological indicators can be divided into two major categories:

1. *Benthic macroinvertebrates* (e.g. species composition, biomass, % EPT, tolerant versus intolerant species, functional guilds), and
2. *Algae and Zooplankton* - plankton (e.g. zooplankton and phytoplankton species composition, indicator species, biomass), periphyton (e.g. species composition, indicator species, biomass) and chlorophyll *a* (e.g. productivity as measured by biomass).

All of the above groups (except chlorophyll *a* of measure of biomass) can be assessed for taxonomic community structure typically presented in a species x sample matrix, providing abundance and/or biomass values for a known area or volume of habitat.

4.1.2 Field Methods/Data Collection

Provincial and federal technical guidance manuals outlined standard inventory methods for biological water quality monitoring (e.g. macroinvertebrate, and algae sample collection and analysis) (Gibbons et al., 1993; Kilgour and Gibbons, 1993; RIC, 1999; Barbour et al. 1999, EC

2000a,b and EC, 2001). Quantitative sampling methods for collection of benthos zooplankton and algae communities include Ponar/Ekman/Van Veen grabs, Hess/Surber macroinvertebrate samplers, artificial substrates, plankton nets and emergence traps. More qualitative methods (kick nets) have been used for broad scale monitoring programs in B.C. (Reynoldson et al. 2001) and the U.S. (Herger and Hayslip, 2000).

U.S. EPA protocols for rapid bioassessment are provided by Plafklin et al. (1989) and Barbour et al. (1999). The presence or absence, abundance and biomass of each taxon are the basic information to be obtained for community structure analysis.

Multi-metric approaches of assessing community structure include the Alaska Stream Condition Index (ASCI) (Major et al., 1998), Coast Plain Macroinvertebrate Index (Maxted et al., 1999), and Southeast U.S. Biotic Index (De Shon, 1995). The most widely used approach is the Benthic Index of Biotic Integrity (B-IBI) described by Karr (1981), Karr et al. (1987); and Karr and Chu (1999).

Plankton is usually sampled by nets towed through the water at specific depths. Periphyton is usually collected from natural or artificial substrates (Gibbons et al. 1993; Barbour, 1999). Taxonomic analysis of zoo- and phytoplankton require trained specialists. Methods for the determination of chlorophyll *a* include laboratory (APHA, 1995) and in-situ methods (e.g. Yellow Springs Inc. probe) to detect chlorophyll *a* levels.

4.1.3 Development and Application

In B.C. few broad scale programs have used biological water quality as a status and trend indicators. Assessments for surface waters under the U.S. EPA Environmental Monitoring and Assessment Program (EMAP) focus on biological indicators including fish zooplankton, macroinvertebrates, birds, and diatoms (Whittier and Paulsen, 1992).

The majority of benthic macroinvertebrate studies in B.C. have been conducted for the Federal Environmental Effects Monitoring program in the vicinity pulp mills and mines. Reynoldson et al. (2001) provide an example of a broad scale data set on benthic invertebrate species richness in the Fraser Basin and includes approximately 224 reference sites, 98 test or quality assurance/quality control sites (QA/QC), and 20 impact (forestry, agriculture, and mining) sites. Biological water quality data are also reported in the provincial state of the environment reports (BC MELP, 2000). Lowell and Culp (1996) provided an assessment of long-term trends (i.e. 20 years) in benthic macroinvertebrate assessments for pulp mill effects on the Thompson River and recommended an annual sampling frequency to avoid misleading artifacts in the data which may occur in EEM programs that are based on a 3-year cycle.

Several regions in B.C. (e.g. Skeena, Okanagan, Cariboo, Lower Mainland, and Vancouver Island) are currently developing B-IBI standards for use in addressing Forest Product Certification and general use in impact assessment (Ian Sharpe, pers. comm.). Since 1997 the MWLAP Skeena Region has been developing a B-IBI for four forest districts (Kispiox, Bulkley, Morice, and Lakes), as a primary component of an ecological watershed evaluation toolbox (Bennett, 2000; MWLAP, unpublished presentation).

Table 4.2 provides an example of B-IBI metrics for the Kispiox River (Bennett, 2000). The index of biological integrity (IBI) is a multimetric approach that relies on biological data to assess the condition of a stream and is defined further in Section 3.2 - Community Indicators. Table 3.5 lists 10 steps in the development of an IBI. Once an indicator or index is developed it can; averaged or summed at a specific level of interest, monitored over time and space, compared to standards. Repeated measures over time provide data that can be used in trend monitoring. Kleindl (1995) provides a list of sediment tolerant/intolerant taxa. Merrit and Cummings (1996) list functional guilds of taxa (e.g. clingers, shedders). Indicators species are also known in plankton communities of lakes (e.g. *Oscillatoria* sp. blooms from cultural eutrophication impacts).

Plankton studies are usually restricted to case specific lake studies, Marmorek and Korman (1993) use zooplankton in a biomonitoring program to detect lake acidification.

4.1.4 Data Availability

Most biological monitoring data are available only on a site-specific basis (EEM and other permit compliance monitoring programs) and are poorly suited for use in broad scale status and trend monitoring or for developing B-IBI standards.

Little periphyton and plankton information is available on a broad spatial or temporal. There is relatively extensive chlorophyll *a* data available from B.C. environment trends reporting (BC MELP, 2000) and the Aquatic Ecozone Classification Data Base (AECD) (Perrin and Blyth, 1998).

Additional information requirements include physical habitat variables (e.g. flow, water depth, substrate composition), physical and chemical water quality [e.g. temperature, pH, conductivity, dissolved oxygen, nutrients, and TDS, total suspended solids (TSS)], and sediment chemistry [e.g. total organic carbon (TOC)] for helping to factor out problems associated with natural variation in the data sets.

4.1.5 Standards Development and Validation

Macroinvertebrate indicator species for aquatic biota are well known and useful for developing B-IBI standards in B.C. Sensitive versus tolerant taxa are summarized in BENTHOS Version 1.0 (Wisseman, 1997) and the Northwest Taxa Database on the Salmonweb. The B-IBI standards being developed in B.C. have been ongoing since 1997. Calibration of B-IBI's in each region is an iterative process that requires testing and adjustment of metric scores until a level of confidence is reached that the B-IBI scores are representative of the area and sensitive to specific impacts.

There are provincial criteria for water column chlorophyll *a* and periphyton periphyton chlorophyll *a*. Threshold criteria for chlorophyll *a* for aquatic life in streams is provided by Nordin (1985) and Pommen (1991). There are no negative ecological impacts on spawning gravel or interstitial O_2 at 10 ug/cm^2 of chlorophyll *a*. and the Provincial guideline for periphyton is largely an aesthetic judgement.

4.1.6 Costs

Costs for biological water quality monitoring are similar to other aquatic field surveys. Laboratory costs (associated with sample processing and taxonomic identification) are greater than for fish communities. Except for multivariate methods, data analysis and summary are relatively simple.

4.1.7 Advantages and Limitations

Biological water quality indicators (benthic macroinvertebrates and algae) are good integrators over time of environmental conditions (e.g. habitat and water quality) and are sensitive to changes in sediment and water quality (Fore et al., 1996). Benthic macroinvertebrates and periphyton are representative of local conditions and are important as fish food. Sampling methods are non-lethal to fish. Biological water quality analysis can illuminate effects on biodiversity and productivity and can be calibrated for different ecozones and fish species of concern, throughout B.C., even in areas where there are very few fish.

Standardized methods have not been fully developed for biological water quality and historical data is not available for all regions and indicators (Chlorophyll *a* in large lakes is an exception). Biological monitoring requires seasonal specific field sampling, taxonomic laboratory analysis and statistical analysis; and specialist knowledge for design, sampling and interpretation. Benthic IBI must be calibrated for different bio-geographies, rather than being broadly applicable.

4.1.8 Recommendations and Conclusions

Based on the initial review of biological water quality indicators, the following are recommended for further consideration:

- benthic invertebrates (community structure and biomass)
- algae and zooplankton [biomass and community structure of plankton (lakes) and periphyton (streams) and biomass estimates using chlorophyll *a*.

4.2 CHEMICAL WATER QUALITY

Type: All water quality indicators reviewed are indirect (correlate or surrogate) indicators of fish status and sustainability.

Scale: Chemical water quality indicators may be applied in status and trend; as well as, site-specific monitoring programs.

Habitat: Chemical water quality indicators are relevant for both streams (e.g. turbidity) and lakes (e.g. nutrients).

Fish: Chemical water quality indicators are generally applicable to all fish, but standards are mostly based on data for salmonids.

4.2.1 Definition/Overview

Perrin and Blyth (1998) group chemical water quality indicators into three major categories:

1. Electrochemical variables (e.g. water temperature, pH, alkalinity, conductivity, total dissolved solids (TDS) and dissolved oxygen);
2. Indices of fluvial erosion (e.g. total suspended solids (TSS), turbidity, selected metals), and
3. Indices of biological productivity [e.g. nutrients (N,P,C)].

Chemical water quality indicators are well known to be affected by forest activities (Beschta et al. (1987), Holtby (1988), and Servizi and Marten (1991).

Differences in temperature tolerances between families of fish are well documented (Scott and Crossman, 1973; Groot and Magolis, 1991). High summer stream temperatures probably define thermal limits for existence of bull trout and other fish (Keheler and Rahel, 1996). Hass (2001) indicates that rainbow trout may interact with temperature to exclude bull trout from apparently suitable habitat. Seasonal maximum temperature thresholds, calculated over a continuous fixed time interval and based on the habitat requirements of target fish species, are indicators of suitable stream temperature regimes for fish.

Turbidity, conductivity, and total dissolved solids (TDS) are sensitive to changes in sediment levels related to fluvial erosion (Binkley and Brown 1993, MacDonald et al. 1991) and can be used as a surrogate field measurement for suspended sediment (which requires laboratory analysis). Turbidity effects are described by Gardner (1981) for bluegills, and Gregory and Levings (1998) for salmonids. Sedimentation effects on fish are outlined by Newcombe (1985), Newcombe and McDonald (1991), Anderson et al. (1996), Larkin and Slaney (1996), Larkin et al. (1998) and Johnson and Hines (1999).

Northcote and Larkin (1956) found that TDS was a reasonable indicator of biological productivity in B.C. lakes. To date, TDS remains in standard use in B.C. and Canada (e.g. morphoedaphic index (MEI) model – Ryder, 1965) to predict fish yield.

Nutrients, conductivity, dissolved solids (TDS), and alkalinity have been used to estimate salmonid abundance in streams (McFadden and Cooper, 1962; Egglishaw 1968). Ptolemy et al. (1993) developed a maximum density model for trout habitat capability based on total alkalinity. Nutrient levels are commonly used as predictors or indicators of fish production or biomass in lakes. Trophic status (i.e. oligotrophic, mesotrophic, and eutrophic) is an indicator of aquatic productivity or nutrient richness and is one of the most common systems of lake classification (Wetzel, 1983).

The B.C. chemical water quality index provides a multi-variable water quality index based on the % exceedance of B.C. In addition to electrochemical, fluvial erosion, and productivity water quality indicators; the chemical water quality index includes contaminant variables such as organics, trace metals, and fecal coliforms which reduces relevance to fish indicators.

4.2.2 Field Methods/Data Collection

Electrochemical variables commonly lend themselves to in-situ field measurements using various commercial available water quality meters for pH, conductivity, and total dissolved solids (TDS). In particular, instream continuous temperature recorders (e.g. Stowaway by Onset Instruments Inc.) can be highly cost effective. Provincial standards for sampling and interpretation of water quality is provided by Cavanagh et al. (1994, 1997a, b). Required methods for sampling design, collection and analysis are summarized in EC (2000a,b, 2001) and APHA (1995). Standards for electrometric probes are outlined in the RIC Automated Water Quality Monitoring Manual (RIC, 2000).

Indices of erosion (with the exception of turbidity) and biological productivity require laboratory analysis. Most standard chemical water quality data are reported as concentration levels of weight to volume (e.g. mg/L) with the exceptions of temperature (^{o}C), pH (units), conductivity (mS/m), colour (units), and turbidity (NTU).

4.2.3 Development and Application

Table 4.1 summarizes chemical water quality indicators utilized or recommended by various fish/forestry programs and indicator workshops.

Temperature in combination with macrohabitat variables has been used to providing screening information (i.e. regional habitat mapping for target species in B.C.; Porter et al., 1998) and for assessing thermal barriers to otherwise suitable habitat in core and satellite populations (Reiman, 2001).

Other water quality variables (e.g. pH, alkalinity, conductivity, TDS, and D.O. and turbidity) are also important, relatively easy to measure and are common to most environmental surveys in the province (e.g. EEM and other permitted monitoring programs). Winter dissolved oxygen levels are monitored as an indicators of winter fish kill risk for stocking programs in Cariboo lakes (Lirette and Chapman, 1993); and is a key variable of fish/forestry surveys and effects monitoring programs. Nutrients have been used to fertilize streams to increase fish production (e.g. sockeye, steelhead, coho, and arctic grayling) in B.C. for over a decade including the Keogh River (Slaney et al., 1986), Salmon River (Johnston et al., 1990), Big Silver Creek (Toth et al., 1993), the Mesilinka River (Koning et al., 1995; Toth et al., 1997), Carnation Creek (Hogan et al. 1998) and other streams.

4.2.4 Data Availability

Water quality data available from general monitoring program in B.C. include 2 main sources:

1. Federal/provincial databases.
2. Targeted/Specific monitoring programs of permitted waste discharges

The Aquatic Ecozone Classification Data Base (AECD) complied by Perrin and Blyth (1998) contains 300,000 GIS supported records for electrochemical and nutrient water quality variables for lakes and streams in B.C. (primarily southern regions). They are divided into aquatic ecozones (45 Ecoregions in 8 Ecoprovinces) based on homogeneity of water quality within and among 245 watershed groups based on the work of Demarchi (1987, 1995) and Demarchi et al. (1990). The database includes digital and non-digital sources such as the provincial environmental monitoring system (EMS) data-base (formerly the SEAM databases), the environmental trends database (MWLAP, 2000), and Federal Water Survey of Canada (WSC) Hydrometric Stations.

Perrin and Blyth (1998) provide a short-list of variables selected on data coverage and relevance to ecozone classification providing 122,069 lake and 188,178 stream records as follows:

- pH;
- dissolved oxygen;
- conductivity;
- total dissolved solids (TDS);
- total suspended solids (TSS);
- turbidity;
- alkalinity; and,
- total phosphorus (TP).

Although the data set is quite large it has limited use for trend monitoring as sampling times and locations are haphazard especially for areas in northern B.C. and it's main use has been to

The Provincial Water Inventory Data Management System (WIDMS) and includes water quality data (temperature, pH, conductivity, turbidity, and depth) for surface waters in approximately 60 community watersheds. However, this data set is spatially and temporally limited. Similarily for other programs in B.C. the frequency of existing water quality data are insufficient to provide real time series information (Brown and Dick, 2001).

Water quality information alone is generally considered to provide an incomplete picture of environmental conditions (EC, 2000a,b) and additional information requirements may include:

- biological water quality indicators (e.g. benthic invertebrate and periphyton) to provide a temporally integrated indicator of chemical water quality;
- streamflow, discharge, or precipitation data are required for the interpretation of conductivity, TSS and other indicators of fluvial erosion measurements (MacDonald et al. 1991), and
- map-based macrohabitat and microhabitat data.

Chemical water quality indicators can be combined with physical habitat data for use in various habitat capability and suitability models as reviewed by (Korman et al., 1994). Additional background information which use water quality and physical habitat variables for assessing fish production capability and habitat suitability are outlined in Section 4.3.

4.2.5 Standards Development and Validation

Use of chemical water quality standards for monitoring status and trends of fish sustainability would require the development of standards for numeric indicators of productivity (e.g. density, biomass estimates) or stress thresholds (e.g. tolerable temperature, dissolved oxygen, turbidity ranges) for each target fish species.

Temperature thresholds for resident salmonids are provided by: Black (1953), Coutant (1977), Shepard et al. (1986), Buchanan and Gregory (1994), Keleher and Rahel (1996), Parkinson and Haas (1996), Hicks (2000), and Haas (2001). Temperature requirements for percids are described by Hokanson (1977). In Oregon, a stream temperature committee has recommended that no measurable increased in temperature should be allowed in water containing sensitive, threatened, or endangered fish (Buchanan and Gregory, 1994).

Generic water quality thresholds for aquatic life including alkalinity, dissolved oxygen, pH, nutrients, and temperature are provided in provincial water quality criteria (Nagpal and Pommen, 1993). Separate threshold limits for dissolved oxygen (DO) and temperature are provided for salmonids and non-salmonid species due to the increased sensitivity of salmonids to temperature increases and low DO, which have an inverse relationship.

Dissolved oxygen requirements for aquatic life are described by Doudoroff and Shumway (1970) and Davis (1975) and for the fish of the Peace, Athabasca, and Slave River basins by Barton and Taylor (1994). Newcombe and Jensen (1996) provide dose-response data and relationships for effects of total suspended solids (TSS) in streams on fish. "Good" or "bad" values could be defined relatively easily for these D.O. and TSS, at least for commercially important species.

The Blackwater macrohabitat fish distribution study (Porter et al., 1998) found that stream temperature and map-based macrohabitat variables were the most important water quality factor affecting fish communities. Bankfull width and maximum temperature generated best regressions for chinook, large-scale sucker, and peamouth chub. Maximum stream temperature alone generated the best regressions for prickly sculpin. Porter et al. (2001) evaluated the sensitivity of the 91 freshwater fish species in B.C. to the impacts of logging (e.g. temperature). This information can be used to develop species-specific temperature thresholds for other areas; and serve as a strategic screening tool (i.e. habitat distribution maps).

4.2.6 Costs

Costs for chemical water quality monitoring are similar to other aquatic field surveys with the exception of temperature. Other electrochemical variables have higher equipment and sampling costs than temperature. TSS and nutrients have additional associated laboratory costs. Except for multivariate methods, data analysis and summary are relatively simple.

4.2.7 Limitations and Advantages

Stream temperature data has high precision and is relatively inexpensive to collect has a high relevance, sensitivity and good data availability. They are non-lethal to fish, simple to apply and comprehend. Generic standards and criteria are widely available for aquatic life (e.g. federal (CCME 1999) and provincial (Nagpal and Pommen, 1993) criteria). They can be employed throughout B.C., even in areas where there are very few fish and some variables can be measured insitu by automated or hand-held meter.

Chemical water quality indicators are poor integrators of time, and require high sampling frequencies to differentiate seasonal variances. Historical data is not available for all regions (especially in northern areas). Alkalinity, nutrients and TSS variables require laboratory analysis. Standards would have to be developed and validated for species-specific threshold criteria and different ecoregions.

4.2.8 Recommendations and Conclusions

Based on the initial review of indicators; four basic types are recommended for further evaluation.

1. Temperature (e.g. 7-day Mean of Maximum Stream Temperatures, Single Daily Maximum Temperature, Continuous or Index Period Stream Temperature Records) as a habitat quality/survival indicator;
2. Dissolved oxygen (e.g. winter/summer lows) as a habitat quality/survival indicator;
3. Conductivity, total dissolved solids (TDS), turbidity, total suspended solids (TSS) (e.g. during peak flows and base conditions) as a measure of fluvial erosion and/or productivity for TDS, and
4. Nutrients (as a measure of productivity).

4.3 PHYSICAL HABITAT INDICATORS

Type: All physical and hydrological indicators reviewed are indirect or surrogate indicators of fish status and sustainability.

Scale: Physical indicators are typically applied to assess site-specific program at the watershed or reach scale (e.g. watershed restoration programs, instream flow studies for EEM and EIA studies; but also can be applied on a broad scale.

Habitat: Physical indicators are best suited to streams, as stream environments tend to be more dynamic (e.g. channel structure, woody debris etc.); but are also relevant for lakes.

Fish: Physical habitat indicators apply both to commercial, non-commercial and rare species.

4.3.1 Definition/Overview

Physical habitat is defined as the local features associated with the living space of aquatic biota. It is a spatially and temporally dynamic entity determined by the interaction of the structural features of the channel and hydrological regime. Physical habitat is affected by instream and surrounding topographical features and is a major determinant/predictor of fish community potential (Richards, K.S., 1976; Gorman and Karr 1978; Bain et al., 1988, Grossman and Freeman, 1987; Aadland, 1993; Hogan et al., 1998).

Both quantity (e.g. useable habitat space) and the quality (habitat complexity) of available habitat effect aquatic community structure and composition (Ward and Stanford, 1979; Calow and Petts, 1994). In the US, the EPA's EMAP program uses physical habitat attributes as indicators to assess the ecological condition of streams in the United States (Jackson et al., 2000, Peck et al., unpublished draft). Further information on the subject is provided in Bisbal (2001) concerning the conceptual design of monitoring and evaluation plans for fish and wildlife in the Columbia River.

The physical variables used to measure physical habitat indicators of status and trend monitoring can be assigned to one of the following aquatic ecosystems components:

- Landscape/Stream Network;
- Flow Regime;
- Channel Structure and Habitat Quantity/Quality;
- Substrate Characteristics, and
- Streambank and Riparian Condition.

Habitat access related to anthropogenic barriers is also considered an important variable which may exclude species from otherwise suitable habitat; however this indicator was considered an measure of impact (=anthropogenic stress) rather than a status indicator and was not included in this review, but was reviewed in the concurrent study of land-use thresholds (Gustavson and Brown, 2002).

4.3.2 Field Methods/Data Collection

In B.C., fish and fish habitat inventory standards and procedures are outlined by RIC (1999, 2001). Hydrometric standards are provided in RIC (1998). Korman et al. (1994) and Maddock (1999) provide summaries of physical habitat assessment methods and habitat models. Physical habitat and hydrological indicators can be applied at two levels (Table 4.3).

1. **Drainage basin/Reach Level:** (map-based macro/mesohabitat variables): Macro/mesohabitat assessments use map-based or landscape information (i.e. drainage area, gradient, elevation, distance to nearest lake, terrain and vegetation mapping), and historical information (temperature/flow data) for assessing habitat suitability on a broad scale (e.g. watershed/regional scale). Examples are provided by Rosgen (1996), Fox et al. (1996), Thorne and Easton (1994), Maddock and Bird (1996) and Porter et al. (1998).

2. **Reach to Site/Patch Level:** (site measured microhabitat variables and empirical habitat models): Microhabitat assessments use small scale (site/patch) variables (i.e. flow regime, channel structure, habitat quality/quantity, substrate, streambank and riparian condition).

Microhabitat assessments include instream flow methods as described by Tennant (1976) and the instream flow incremental methodology (IFIM) developed by the US Fish and Wildlife Service. Summit Environmental Consultants (unpublished draft) provides a Technical Guidebook for conducting instream flow assessments.

A major component of IFIM is the physical habitat simulation system (PHABSIM) (Bovee, 1996). PHABSIM models utilize physical habitat data (e.g. depth, amount of large woody debris, substrate size or composition) to develop curves which show the relation between flow and habitat (i.e. weighted useable area (WUA). The standard output of a PHABSIM assessment is a flow versus habitat relationship for each reach and target species. This can be combined with historical flow records to produce a physical habitat time series (Maddock, 1999).

Fish habitat assessment procedures (FHAP) and watershed assessment procedures (WAP) are outlined by Johnston and Slaney (1996) and B.C. MOF (1999), respectively. Other methods include reconnaissance level surveys (Thorne and Easton, 1994), Rosgen classifications (Rosgen, 1996), River Habitat surveys (Fox et al., 1996), Alaska Stream Condition Index (ASCI) (Major and Barbour, 1997), and habitat mapping (Maddock and Bird, 1996). Predictive habitat microhabitat models include the habitat quality index (HQI) developed for coldwater trout streams in Wyoming (Binns and Eiserman, 1979).

In B.C., the Channel Assessment Procedure (CAP Guidebook and Field guidebook) was produced under the B.C. Forest Practices Code (Anon. 1996a, b) to provide consistent information on channel changes for developing habitat rehabilitation applications. It is used to classify channels into three stream types (step-pool, cascade-pool, and riffle-pool) based on size (Figure 4.1) and seven relative sizes describing channel morphology based on bed material size, channel attributes (depth, width, slope), bed roughness, large woody debris (LWD) presence, and channel disturbance (Figure 4.2).

4.3.3 Development and Application

In B.C. the Blackwater and Similkameen fish distribution models (Porter et al., 1998) demonstrate the usefulness of map-based habitat information in combination with existing and supplementary temperature and flow information for predicting distribution of target species. Aerial photos have been used to inventory areas of fluvial mass wasting (Rood, 1984) and may be useful for coarse scale assessment of riparian condition.

IFIM is used widely in the US and increasingly in Canada and B.C. to predict fish and fish habitat status and develop instream flow requirements for commercially important species (usually salmonids).

Table 4.4 summarizes physical habitat and hydrology indicators utilized or recommended by various fish/forestry programs and indicators workshops. In B.C. many of the microhabitat assessment procedures (CAP, FHAB, WAP, ASCI, CAP etc.) outlined above use similar indicators or habitat measures, and differ mainly in the way management decisions are made. Korman et al. (1994) provides a review of 91 stream and 87 lake habitat capability and suitability models. This may provide the opportunity for the development of improved standardization of data collection procedures among various programs for ensuring data is usable for a broad range of management applications (i.e. strategic and site-specific monitoring objectives).

4.3.4 Data Availability

Existing physical habitat and hydrological data sources include:

- watershed and site-specific microhabitat data for various permitted monitoring programs and government inventory/research programs (i.e. CAP, FHAB, WAP, ASCI, CAP etc.);
- Federal Water Survey Hydrometric Stations: Currently there are approximately 500 stations in B.C. including data on water flow, water level, sediment concentration or sediment load and water temperature (Brown and Dick, 2001). Past data since 1970 is available for 2400 stations from Environmental Canada; however sampling location and frequency is likely poorly suited to status and trend monitoring.

Data gaps may be partially rectified by utilizing data from FRBC surveys and other site-specific programs; however sampling methods, effort and the type of data report will vary among studies; and streams sampled are unlikely to be representative of all stream or reference streams.

Additional data useful data for conducting preliminary screening studies (i.e. habitat mapping for target species) includes:

- land cover information from SPOT and LANSAT satellite imagery, from the Canada Centre for Remote Sensing (CCRS) (which is distributed by RADARSAT International), and the US Geological Survey EROS Data Centre respectively (Rysavy, 2000);
- Terrain Stability Mapping information for rate on a scale of 1 to 5 is mapped at 1:15,000 to 1:50,000, as well as regional 1:250,000 maps for most of the province. This may be useful for "coarse filter" assessment of habitat stability and may be correlated to erosional impacts on water quality on a watershed basis. Data coverage is limited for the province and focused on stream crossing and areas under licence (T. Cheong, pers. comm.);
- Vegetation Resource Inventory (VRI) and Forest Inventory Planning (FIP) system covers 10-13% of the province on 1:20,000 TRIM maps showing dominant vegetation cover, height, age, and crown closure (average 15 ha polygon). Data are based on air photo interpretation from 1960-1990 for FIP data and from 1990 for VRI data. Archiving of data

has begun to assist future trend monitoring which may be of use trend in monitoring of certain habitat attributes (e.g. riparian cover, stream bankfull width); and,

- Provincial soil survey information.

4.3.5 Standards Development and Validation

Adequate habitat suitability and life history information is required for each target species to initiate the development of standards. General information on status, life history, and habitat requirements for freshwater and anadromous fish are summarized by Scott and Crossman (1973). Bjornn and Reiser (1991) provide a review of habitat requirements for salmonids. Ford et al. (1992) provide a literature review of habitat requirements for 13 species of sportfish in the Peace and Columbia River drainages. Spawning and rearing habitat requirements for bull trout is summarized by Bjornn and Reiser (1991), McPhail and Baxter (1996) and Keeley and Slaney (1996).. Rosenfeld et al. (2000) review habitat requirements/criteria (depths, velocities, redd sizes, spawning habitat suitability) for Pacific salmon and resident trout in B.C. Habitat guilds of fishes for determination of instream flow requirements are reviewed by Moyle and Baltz (1985) and Leonard and Orth (1988).

DFO (1981) provides biostandards for the salmon enhancement program (SEP). Habitat suitability index models and instream flow suitability curves for salmon are described for chinook by Raleigh et al. (1986) and Bjornn and Reiser (1991); and for juvenile chinook and steelhead (Rublin et al., 1991). Standards for habitat suitability and capacity data are available for salmonids. However, few exist for rare or vulnerable fish in B.C. with the exception of bull trout (McPhail and Baxter, 1996; Baxter, 1997; Haas and Porter, 2001). Adams and Whyte (1990) and Koning and Keeley (1997) review current biostandards (e.g. juvenile densities) for various fish habitat restoration techniques. Additional information on non-salmonids is provided for the lake lamprey (Beamish, 1987), mountain sucker (Hauser, 1969), white sturgeon (Lane, 1991), Salish sucker (McPhail, 1987; Pearson, 1998), giant stickleback

(Moodie, 1984), large scale sucker (Dauble, 1986), long-fin smelt (Dryfoos, 1965), innconu (Fuller, 1955), Nooksack dace (Pearson, 1998), brook stickleback (Winn 1960), and chiselmouth (Rosenfeld et al., 1998).

Physical habitat data can be used in combination with water quality data for use in various habitat capability and suitability models (Fausch et al., 1988; Korman et al., 1994). Lirette et al. (1987) and Tautz et al. (1992) provide steelhead production capability estimates for selected streams in B.C. Marshall and Britton (1990) outline carrying capacities for coho streams.

4.3.6 Costs

Use of map-based data is a relatively inexpensive method of extrapolating monitoring efforts on a broad scale; however predictions should be verified with ground-truthing surveys and professional judgement. Field costs for physical habitat surveys depend upon the location and physical habitat of the study area. Most of the expense is associated with field equipment and labour. Data analysis and reporting are relatively inexpensive when compared to field costs.

4.3.7 Advantages and Limitations

Map-based data can be used as a broad scale coarse filter for mapping distribution of target fish species. Standardized CAP microhabitat assessment methods are applied throughout the province and are well suited to database development and integration with similar methods (e.g. WAP, FHAB etc.). Habitat variables are sensitive to forest impacts, are non-lethal to fish and can be calibrated for different ecozones and fish species of concern, even in areas where there are few fish or fish are difficult to collect. There is good evidence for habitat quality and quantity links to biodiversity and productivity of fish. In addition, fish habitat and habitat suitability information is widely available for salmonids.

Habitat suitability information is not widely available for rare fish species, has a slow response time, and generic criteria may not be applicable for all water bodies. In addition, microhabitat data collection requires the expense of field surveys.

4.3.8 Recommendations and Conclusions

While there are many approaches to the assessment of fish habitat as listed in Section 4.3.2, most are based on common macrohabitat or microhabitat attributes. Table 4.5 summarizes 56 physical habitat attributes were identified in 15 information sources reviewed. The initial long-list of habitat attributes was screened based on the recommendations of Bauer and Ralph (1999). These were reduced to an initial short-list of nine key physical habitat indicators (Table 4.6) for further evaluation are summarized below:

- Amount of useable habitat space;
- Bankfull width to depth ratio;
- Variance in thalweg depth;
- Large woody debris;
- Pool frequency and area;
- Substrate composition and size;
- Residual pool volume filled with fine sediment, and
- Canopy cover and streambank stability.

Appendix C provides a brief description (i.e. fact sheet for each of the above), as well as for temperature regimes, and anthropogenic barriers (=fish access) because they are important and closely linked to physical habitat variables.

4.4 ALTERNATIVE APPROACHES

This section considers three alternatives to more traditional field indicators that may be useful for status and trend assessment. These alternatives use unique or novel methods to measure or estimate the same or similar characteristics of fish and fish habitats as other indicators reviewed in this report and are presented to illustrate available options, but are not include in the detailed evaluation as they represent supplementary sources of information to be applied on a case by case basis.

4.4.1 Reconstructive Trend Analyses

Past long-term trends can be reconstructed from cores or age structures obtained in a single sampling trip.

Lake sediment cores can be used to reconstruct trends for contaminants, nutrient, pH and sedimentation levels over centuries, based on abundances and community composition of diatoms, other algae with hard structures, pollen, or contaminants (Smol, 1992).

Growth trends reconstructed from fish age structures are more relevant for this review. Noakes and Campbell (1992) used the growth history of a single sample of the long-lived marine bivalve, geoduck, to examine trends over most of the 20th century. There were changes in growth coincident with changes in stress levels and stressors. This is an extreme example; the time span covered for most freshwater fish species would be limited to ≤10 years. Reconstructed growth trends are also subject to many of the same limitations noted elsewhere for growth. For example, growth trends may simply be the inverse of trends for reproductive capacity or output, or may reflect density-dependent effects.

Reconstructed growth trends would be most useful for large, long-lived species such as sturgeon. Reconstructing growth trends would reduce the frequency of destructive sampling, and maximize the information gained from a single sample. It should also be noted that:

- frequent sampling of sturgeon to measure other population indicators is costly;
- trends based on future sampling for these and other long-lived species may not be apparent until after populations have been irreparably damaged; and,

- reconstructed trends based on existing data or on samples collected in the near future would allow a more rapid management response.

4.4.2 Cages and Artificial Substrates

Variances of direct and indirect biological indicators can often be reduced by using caged organisms or artificial substrates (e.g. for colonization by invertebrates or periphyton). Smaller organisms or life stages are more suitable for this approach, since longer exposures and larger and more costly cages or substrates are required for larger organisms. Cages or artificial substrates can also be used where field surveys are impractical, costly or unsafe.

The most promising and/or widely used approaches are:

- artificial redds or “egg baskets”, and suspended cages, for salmonid and other fish embryos;
- caged juveniles;
- artificial substrates for invertebrates, and
- artificial substrates (typically microscope slides) for periphyton.

Artificial redds and containers for holding embryos are simple and inexpensive to construct and deploy; cages for mobile juveniles may be more complex and expensive, and the juveniles must obtain adequate food. Variables typically measured in caged studies are survival, and growth (or yolk utilization in non-feeding embryos). Artificial substrates have been widely used for invertebrates and periphyton, and variables typically measured are biomass and abundances of taxa colonizing the substrates.

There are three major limitations of cages and artificial substrates:

1. The exposure conditions are partly to largely artificial; for example, predators and usually competitors are excluded from cages.

2. At least two field trips, one for deployment and one for retrieval, are necessary, which can be costly in remote areas.
3. Vandalism can be a serious problem, especially with larger cages or substrates and in more populated areas.

4.4.3 Professional Judgement

Habitat indicators and models are useful tools in the hands of experienced professionals. However, they are tools that should be used to support rather than replace professional judgement. Higgins et al. (unpublished presentation) found that professional judgement consistently provided more reliable results than physical habitat simulations in defining functional relationships between fish and fish habitat. In the Skeena region, the "Delphi method" (i.e. ask a local expert) is one of several tools used to define watershed monitoring priorities (Ian Sharpe, pers. comm.).

SECTION 5.0 - EVALUATION

5.1 EVALUATION METHODS

5.1.1 Evaluation Criteria

Direct and indirect indicators reviewed and recommended in Sections 3 and 4 are evaluated in this section. Three primary criteria were used for evaluating indicators:

1. **Relevance/Sensitivity -** Is the indicator relevant for aquatic habitats in forest environments? Is it sensitive to stressors of concern? Forest harvest, road construction, grazing and exploitation (managed or sport/commercial species only) were considered the primary stressors of concern in B.C. forest environments.
2. **Costs -** What are the field and laboratory costs for collecting and analyzing samples and data?
3. **Data Availability -** Is the indicator currently used in B.C.? If so, what is the quantity and quality of available data in B.C.? Is there sufficient background data available to interpret values and develop and validate standards?

The first two sets of criteria were used by MacDonald et al. (1991; Box 1) to evaluate the usefulness of monitoring variables for assessing effects of forest harvest in Pacific Northwest streams. Where appropriate, their evaluations (primarily for indirect indicators) are provided for comparison.

Box 1. MacDonald et al. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. U.S, EPA Rept. No. 910/9-91-001.

In this review, MacDonald et al. (1991) was used as an information source, and as an objective or external comparison for our indicator evaluations. The manual consists of two parts:

- Part I: Developing a Monitoring Project (an expanded version of Section 2 in this report). This part includes tabular rankings of indicators reproduced in this report.
- Part II: Review of Monitoring Parameters (intermediate in detail between our summaries in Section 3, and more extended discussion/review in Appendices).

We have used this manual extensively for designing monitoring programs for assessing:

- regional water quality trends and status, and
- effects of forest harvest, road construction, mining, and agriculture on aquatic biota and domestic water supplies.

The manual has also been widely used in the design and implementation of EMAP and other monitoring programs in the Pacific Northwest.

For this review and evaluation, there are some important differences between our objectives or approaches and those used by MacDonald et al. (1991):

1. MacDonald et al. (1991) obviously could not consider the applicability of various indicators to B.C., or the availability of existing data in the province. Their approach and evaluations are targeted towards developing new monitoring programs.
2. Evaluations of indicators in MacDonald et al. (1991) addressed a broad range of program purposes, designated uses (e.g. beyond protection or

assessment of fish only), and stressors, some of which are beyond the scope of this report. They also focused exclusively on streams, and did not address lakes.

3. MacDonald et al. (1991) pooled all direct fish indicators into one category ("Fish"). Thus, we could not determine if they thought there were any differences among the direct indicators reviewed in this report.

Despite these differences, there was good agreement between this review and MacDonald et al. (1991), in terms of:

- the indicators selected for evaluation
- the overall evaluations or ranks for those indicators

Copies of MacDonald et al. (1991) can be obtained from:

U.S. EPA Region 10, NPS Section
WD-139
200 6th Avenue
Seattle, WA 98101

5.1.2 Evaluation Process

Indicators were ranked on a scale from 1 (best; good, or excellent) to 4 (worst; poor) based on the primary criteria in Section 5.1.1. Overall usefulness was then derived based on a mix of:

- theoretical (relevance/sensitivity) considerations (i.e. what should be measured), and
- practical (costs/data availability) considerations (i.e. what has been or can be measured).

No indicator will be useful unless it is relevant and sensitive, even if it is measured frequently and extensive data exist. However, costs and data availability may limit the usefulness of some relevant and sensitive indicators.

Evaluations were conducted separately for direct versus indirect indicators. Where appropriate, separate evaluations were provided for managed versus non-commercial species, and for streams versus lakes. Rare species were problematic, in that some should be treated in the same way as managed species of concern or interest, and others should be treated as members of the larger community of mostly non-commercial species.

In some cases, secondary criteria or considerations such as redundancy or interactions among indicators, simplicity, and comprehensibility were used to modify ranks for overall usefulness.

5.2 DIRECT INDICATORS

5.2.1 Relevance and Sensitivity

MacDonald et al. (1991) considered fish, as a general indicator, highly relevant (i.e. rank=1) for assessing biological integrity. They provided the following sensitivity ranks:

Stressor/activity	Sensitivity rank (of 4)
Forest harvest	2
Road construction	1
Grazing	2
Recreation (includes development, angling)	1

Table 5.1 provides our ranks, from 1 (highly relevant/sensitive) to 4 (not relevant/sensitive), for direct individual, population and community indicators. These ranks are in general agreement with those from MacDonald et al. (1991). However, Table 5.1 attempts to make some distinctions among indicators lumped as fish by MacDonald et al. (1991), and between managed and non-commercial species. Differences in relevance were relatively obvious; differences in sensitivity were more difficult to assess.

The ranks in Table 5.1 and elsewhere apply only to species or life stages resident in freshwater. Relevance and sensitivity will be lower for marine life stages of anadromous species, because status may depend largely on factors affecting marine survival and growth (e.g. Bradford and Irvine, 2000).

For managed species and some rare species of concern, population indicators would be the most relevant direct indicators. Population indicators are also likely to be the most sensitive to exploitation. These are the traditional fisheries variables used to assess and manage commercial and recreational species.

Among the population indicators, distribution (occurrence) and abundance would be the most relevant, since these two variables define the status of populations. Growth, age structure, and reproductive capacity would be less relevant, because they are less direct measures of the status of fish populations (i.e. status is inferred rather than directly measured).

Community indicators and data could provide some relevant information on managed species at a gross level (e.g. to classify streams or lakes according to the sport fish present), but would be of limited relevance for assessment of specific species.

Community indicators would be the most relevant and sensitive indicators for most non-commercial species. This is partly a practical issue, since population indicators could not be used to assess each of the >50 non-commercial species in B.C. However, community indicators also measure biodiversity and biological integrity, two highly relevant ecological properties. Community indicators are widely used in the U.S. for assessing and managing non-commercial species.

Population indicators would probably be the most relevant or sensitive indicators for larger rare species (e.g. sturgeon or bull trout), and for rare species with geographically restricted distributions or habitat preferences (e.g. Cultus Lake sculpin). These species are unlikely to occur frequently in community samples. Community indicators would be more relevant or sensitive for locally abundant rare species, particularly where several of these species co-occur. Rare species in B.C. are no more sensitive than other species (Appendix A); so population indicators for most rare species would be of limited relevance for other non-commercial species.

Condition was considered the least relevant direct indicator, because it is the most difficult to relate to overall status.

5.2.2 Costs

Table 5.2 provides field and laboratory costs for direct indicators. Most direct indicators would be measured annually or less frequently, so frequency of measurement is not an important cost issue. Field costs (labour) for collecting fish are much greater than lab costs (primarily for summary and analysis of data). We assumed field costs would be greatest for collecting abundance data. Age determinations or counting ova add to lab costs for growth, age structure and reproductive capacity. Lab costs were also ranked greatest for those three variables because fish must sometimes be sacrificed to remove age structures, and must always be sacrificed to measure reproductive capacity (weigh ovaries; count ova) (=a moral cost?). Equipment costs can range from relatively low, where traps or nets can be used, to high, where boats and elaborate sampling gear are required. In general, equipment costs will be greater for larger fish, and for larger streams and lakes.

MacDonald et al. (1991) also considered field and equipment costs to be the major cost constraints for fish indicators. However, they ranked lab costs higher than we did, perhaps to account for the costs of developing standards, and adjusting for habitat and other factors in data analyses.

5.2.3 Data Availability

Table 5.3 evaluates the extent of available data for direct indicators, for status and trend monitoring, and for standards development and validation. Data are more available for:

- managed species, particularly salmonids, than for non-commercial and rare species (except bull trout);
- population distribution and abundance than for other indicators, and
- occurrence indicators than for abundance indicators.

Existing or available data collected for other purposes may not be as extensive or suitable for status assessment as counts of the number of available records (usually sample locations and times) suggest (Section 2). Available or suitable data for trend assessment and standards development and validation are even more limited. Potential B.C. and other standards are most available for population indicators, particularly for occurrence and abundance (Section 3). Generic standardized methods (RIC and other standards) are widely available for direct indicators, but may require further refinement and validation for specific indicators.

MacDonald et al. (1991) also identified the lack of suitable standards for indicator values and for methods, and data to develop and validate standards, as a major limitation for all direct indicators.

5.2.4 Overall Evaluation

Managed Species

Table 5.4 provides overall evaluations of the usefulness of direct indicators, applied to managed species. These ranks are ranks for relevance/sensitivity, adjusted for costs and data availability.

Population distribution and abundance would be the most useful indicators for managed species and some rare species. There are probably enough data available to conduct some status and trend analyses for Pacific salmon, steelhead, rainbow trout and bull trout, although standards may not be available or may require validation with B.C. field data.

Growth, age structure and reproductive capacity would be useful indicators, especially if measured together, or when occurrences or abundances were measured (=interaction). Major limitations for growth, age structure and reproductive capacity are additional lab costs, the need to sacrifice fish, and limited data availability.

Ranks were also included for community indicators in Table 5.4. There are too few community data in B.C. for those data to be of much use for managed species.

MacDonald et al. (1991) ranked fish in general as somewhat useful (rank=2) to not useful (rank=4). Those ranks seem reasonable, given that they also considered domestic water supplies, for which monitoring fish is not useful.

<u>Non-commercial Species</u>

Table 5.5 provides overall evaluations of direct indicators for non-commercial species. These evaluations also apply to rare species that are locally abundant. For most non-commercial species, community indicators would be the most useful because those indicators are based on multiple species, most of which are not of specific interest. Population occurrence or abundance indicators may be most useful for rare species of specific concern, since those species would rarely be collected in community samples.

The overall usefulness ranks in Table 5.5 are largely “wish lists”, because of the limited available B.C. data. Those data could be collected in the future for the same or lower cost than population indicators for managed species, but that would require a shift in emphasis from managed to non-commercial species.

Lakes

In the evaluations of direct indicators, a distinction was not made between streams and lakes, since the same indicators are likely to be useful in both environments. All direct indicators are likely to be less relevant or sensitive for lakes than for streams because forest harvest, road construction, and grazing directly affect streams, but only indirectly affect lakes by altering their drainage basins. In general, fewer direct indicator data are available for lakes than for streams.

Reasonably extensive data may exist for:

- sockeye salmon juveniles in lakes, or smolts in outlet streams of those lakes;
- adult kokanee in lakes, or in outlet or inlet spawning streams, and
- rainbow trout stocked in lakes (an indicator of dubious value) and numbers of rainbow trout in the recreational catch (e.g. creel censuses; a potentially useful indicator).

Data on species that occur exclusively or primarily in lakes (e.g. Cultus Lake sculpin; several stickleback forms/species; whitefish (*Coregonus spp.)* species, however limited, must also be more extensive and useful for lakes than for streams.

5.3 INDIRECT INDICATORS

5.3.1 Relevance and Sensitivity

Table 5.6 provides evaluations of relevance and sensitivity for indirect indicators ranked, from 1 (highly relevant/sensitive) to 4 (not relevant/sensitive). Ranks from U.S. EPA (MacDonald et al., 1991) are provided for comparison. U.S. EPA ranks apply to streams only, whereas here and elsewhere we have generally provided separate evaluations for streams and lakes.

Most indirect indicators are relevant for assessing fish status and sustainability, and more generally, for assessing environmental quality (see Section 4.3). Indirect indicators can be more clearly associated with particular stressors (causality); however one general weakness is that impacts on indirect indicators may not necessarily be transferred to fish.

For all fish the most relevant and sensitive indirect indicators are similar and include a suite of water quality, water quantity and physical habitat variables. Differences in relevance and sensitivity among indicators generally centre on the type of habitat (stream vs. lakes) investigated.

Among water quality variables, benthic invertebrates would be the most relevant for streams, and plankton/chlorophyll *a* and nutrients the most relevant for lakes. Benthic invertebrates are more relevant and/or sensitive than algae for more monitoring streams, but the reverse may be true for lakes. Perrin (unpublished presentation) reports that periphyton chlorophyll *a* may be relevant only in intensively grazed forest streams.

Temperature is linked to the status of bull trout and other salmonid populations and is probably the most relevant chemical water quality variable. Dissolved oxygen (D.O.), total suspended solids (TSS) and turbidity are relevant and sensitive single measures for monitoring forest streams (e.g. sensitive to erosion and riparian impacts), whereas D.O. and nutrients, would be the most relevant and sensitive indicators for monitoring lakes (e.g. sensitive to nutrient loading). Conductivity, total dissolved solids (TDS), and pH are less relevant and sensitive to forestry activities; however they are easily measured and useful for comparing to historical data. Conductivity is a good estimator of TDS as units are proportional.

The chemical water quality index combines multiple water quality variables, many of which are "extraneous" when monitoring specifically for fish status, and probably add more "noise" than information. As a result of its generality the chemical water quality index is not considered a useful indicator, except where key variables can be used separately to supplement to historical data.

Physical habitat indicators relate to habitat quantity and quality. All of the short-listed habitat variables are generally relevant and sensitive. Instream flow, expressed as a percentage of Mean Annual Discharge (MAD) or in any other way that can be related to requirements for fish, would be the most relevant and sensitive flow indicator. More generally, flow measurements combine depth, width, and current velocity, important variables for fish populations and communities.

Depth, expressed in various forms (e.g. bankfull width/depth), is probably the most relevant single measure, in terms of effects on fish populations and communities. Substrate composition, bank stability, and riparian function conditions that account for or measure siltation and its effects may be correlated with water quality variables such as turbidity/TSS and benthic invertebrate community changes.

Stream flow and physical habitat indicators recommended apply to streams only. For lakes:

- emphasis has generally been on water quality, rather than physical habitat, and
- some of the stream physical habitat indicators could be adapted for use in lake shoreline or littoral habitats, or in small shallow lakes.

Indicators such as bankfull width, bank stability, and canopy cover information can be applied on coarse (map-based data) and fine scales (field survey data). Map-based data are generally less relevant or sensitive than finer scale measures of the same variable, and measures of habitat complexity such as variance in thalweg depth, pool frequency/area, and substrate characteristics. Nevertheless map-based variables are useful in providing habitat-mapping for estimating distribution of target species.

Other commonly measured physical habitat variables, such as lake area or mean depth, are unlikely to be affected by stressors of interest in larger deeper lakes.

5.3.2 Costs

Table 5.7 provides evaluations of costs for indirect indicators. Costs, or at least cost differences among indicators, were assumed similar for streams and lakes. Sampling frequency was included as a cost factor, because some indicators should be measured more then once annually to provide useful data. In general, field and equipment costs are lower for the indirect indicators than for direct indicators (Table 5.2). Common or required sampling frequencies and lab costs tend to be higher for the indirect indicators, and are usually the most important cost constraints.

Sampling frequency is the major cost constraint for chemical water quality indicators with the exception of temperature. Temperature can be monitored on a continuous basis using temperatures recorders (e.g. Onset Instruments temperature recorder, max-min thermometers), with negligible overall costs.

Biological water quality has a distinct advantage of being a good integrator of effects over time, requiring lower sampling frequency and field costs. Lab costs, primarily for identifying invertebrates or algae, are the major cost constraint for biological water quality indicators. Lab costs can be substantially reduced for algae if only biomass or chlorophyll *a* is measured, and the algae are not identified to various taxonomic levels. In lakes, chlorophyll *a* could be included as an indicator of aquatic production.

Costs for other chemical water quality variables are higher. Turbidity requires frequent monitoring during periods of high discharge. Lab costs are negligible for metered variables (e.g. pH, conductivity, temperature, dissolved oxygen, turbidity and TDS), but there are equipment costs for the meters. TSS, ions and nutrients (=”bottle” indicators) in water column samples are measured by analytical laboratories, at costs of $20-100/sample. Costs of the chemical water quality index are higher than for single variable chemical water quality indicators, because the index combines costs for multiple variables.

Costs of flow measurements from MacDonald et al. (1991) assume that gauges must be set up and calibrated at sample locations. That is a considerable expense (depending on equipment type), relative to obtaining discharge data from Water Survey of Canada (WSC) and WIDMS stations. WSC and WIDMS data are unlikely to be available for all existing or proposed fish status and trend monitoring locations, however the existing database covers a long historical record for many stations, may be still provide useful data for coarse scale and verification monitoring.

Stream flow indicators are thus ranked from 1 or 4 to represent differences in cost between use of existing programs (1) and setting up new hydrometric stations and various field methods (4).

Physical habitat indicators need only be measured annually or less frequently, and equipment costs are low; however adequate field time must be designated to ensure observations are completed properly. Field time and costs are greater than for chemical water quality indicators, and some lab and/or interpretation costs may be required to calculate indicator values, particularly for thalweg depth or predictive models (e.g. PHABSIM).

5.3.3 Data Availability

Section 4 provides detailed descriptions of available data on indirect indicators and is summarized below.

Table 5.8 provides evaluations of data availability for indirect indicators, for monitoring, and for standards development and application. Water quality data are probably less available for lakes than for streams, although standards (typically provincial water quality criteria) typically apply to both environments.

The largest integrated database reviewed was for the U.S. EPA's EMAP program. Data on watershed characteristics, water chemistry, benthos and fish surveys in EPA Region 10 (Oregon and Washington) includes sampling at 104 sites. It is doubtful that empirical relationships developed from these data can be reliably applied in B.C., except for the southern regions of the province. However, types of changes that occur could be relevant in general terms.

Among biological water quality variables chlorophyll *a* data is the only one which is widely available (Perrin and Blyth, 1998). Accessible benthic invertebrate data in B.C. are limited (see Section 4.3). Existing data for chemical water quality indicators is biased towards southern regions of the province and potentially impacted, and more accessible, locations.

Time series stream flow data from federal WSC stations are available for some locations but are of limited spatially and unlikely to be available for all existing or proposed fish status and trend monitoring locations, Additional streamflow information would be available from B.C. Hydro and private sector monitoring programs.

Physical habitat data are available at two levels:

- macrohabitat (map/remote sensing based) data useful for a coarse scale application; and,
- microhabitat field survey data (CAP,WAP, FHAP etc).

Existing data may provide useful information for setting baseline conditions for some streams; however coverage is likely to be biased to southern regions of the province and watersheds with increased impacts.

Data availability for standards development was scored as "2-3" if habitat suitability or preference data were available (i.e. managed species), and "3-4" where limited (non-commercial/rare species).

5.3.4 Overall Evaluation

Table 5.9 summarizes indirect indicator rankings by category for streams. Table 5.10 compares overall ranks for streams to U.S. EPA rankings for various stressors. Table 5.11 summarizes indirect indicator rankings by category for lakes and provides overall ranks.

Overall rankings for water quality indicators and habitat were considered similar for managed and other species, since both groups live within the same community assemblages. The main differences observed during the evaluation were related to data availability for threshold or habitat suitability information. Results were generally similar to rankings provided by the U.S. EPA for stream indicators.

Among water quality indicators temperature ranked as the most useful overall indirect indicator for streams having a high relevance/sensitivity, low cost and good data availability. Benthic invertebrates were also considered useful as an indicators of overall water quality.

For actual status and trend monitoring; temperature, instream flow and microhabitat data (bankfull width, thalweg depth, residual pool depth, pool frequency/area, bank stability and canopy cover) were considered the most useful indirect indicators. As discussed above and in Section 4.3 many of the microhabitat assessment procedures used in B.C. measure similar indicators and provides an opportunity to utilize data in status and trend monitoring, collected for other purposes – usefulness will depend on data quality and frequency of data collected in suitable reference areas.

Turbidity is recommended over total suspended solids (TSS) as they are redundant and turbidity does not require lab analysis.

Major differences in stream versus lakes rankings were that; temperature, benthic invertebrates and detailed habitat characterizations were more useful for streams; and nutrients were more useful in lakes.

SECTION 6.0 - CONCLUSIONS AND RECOMMENDATIONS

This section considers:

- the most suitable or useful indicators for assessing fish and fish habitat, how they can best be used, and what remains to be done (=outstanding issues) (Section 6.1)
- other variables that should be measured or used in conjunction with indicators (Section 6.2)
- broad strategies or approaches for future measurement of indicators and other monitoring variables, and assessment of status and trends (Section 6.3)
- the major conclusions and recommendations from this review (Section 6.4)

6.1 RECOMMENDED INDICATORS

Evaluations of indicators in Section 5 were used to identify two categories of recommended indicators:

Tier I - "ready for use": Existing data adequate for some status and trends assessment over large spatial scales, and possibly for developing or validating standards. Costs typically low and/or data likely to continue to be collected for other purposes.

Tier II - "recommended for future use": Useful or desirable indicators for status and trend monitoring of fish and fish habitat. Existing data inadequate for large-scale status and trend monitoring and/or setting standards; costs of data acquisition may also be high. Pilot projects or analyses, based on existing data or new monitoring studies, may be feasible. These indicators have been successfully used elsewhere, and are recommended for development and use in B.C.

Indicators excluded from both tiers are not recommended for use or development in status and trend monitoring, although data may continue to be collected for other purposes.

6.1.1 Tier I Indicators

Table 6.1 lists Tier I indicators for managed, rare and non-commercial species. These are relevant and sensitive indicators for which extensive B.C. data exist for some species, regions or environments. Population distribution and abundance data should be reasonably extensive for freshwater stages of anadromous Pacific salmon and steelhead, and for freshwater rainbow trout and bull trout (see Table 3.4). Some distribution data may be available for other sensitive species (e.g. Dolly Varden trout). Data are probably more extensive for the indirect indicators in Table 6.1 than for the direct indicators.

The province should begin by collating existing data for one or more of the indirect indicators, from sources described in Section 4. Then, matching data on other direct and indirect indicators from the same or similar locations should be collated. Useful starting points would be spatially extensive data sets (e.g. for temperature, or physical habitat/CAP assessments) or longer-term data sets useful for trend monitoring (e.g. WSC discharge stations, or federal or provincial water quality monitoring stations). For streams, some aggregation of locations to higher levels (e.g. reach, watershed) would be required to obtain matches among other indicators. For lakes, there may be little or no direct indicator data to match with chlorophyll *a* and nutrient data. The available database could be expanded by adding data not currently recorded in the FDW, if those data were of good quality and relatively inexpensive to retrieve.

The suggested approach addresses three purposes or objectives. First, some conclusions about status and possibly trends for fish and fish habitat in some parts of B.C. could be made, a useful starting point for any future assessment. Second, preliminary review and some analyses of existing data can be used to refine existing and future programs, and would better define data availability. Third, relationships among indicators, particularly between indirect and direct indicators, are useful for standards development and validation (Section 2). These relationships can also be used to predict values of less commonly measured (or more expensive) indicators from values of more commonly measured (or less expensive) indicators. That is an important approach for expanding existing databases, and reducing costs in future monitoring programs (Section 6.3).

Relationships between direct and indirect indicators would be mostly applicable to a restricted set of managed species, bull trout and possibly Dolly Varden. For example, temperature data may be widely available through WSC/WIDMS and climate data (Haas and Porter, 2001). However, the relevance of those temperature data for most non-commercial species would be difficult to assess without matching data on the occurrence or abundance of those species, and data on their temperature tolerances or preferences.

6.1.2 Tier II Indicators

Table 6.2 lists recommended Tier II indicators. These are relevant, sensitive and useful indicators, for which existing data are limited. Some analyses of existing data may be possible, but most of the Tier II indicators would be targets for future development (i.e. through pilot programs) and eventual wide-scale use.

The Tier II direct indicators in Table 6.2 expand the range of species covered by the Tier I indicators in Table 6.1 and complement existing data and indicators. Population distribution and abundance would be the most useful indicators for managed species for which limited data exist, and for rare species that are of specific concern or unlikely to occur in community samples.

Growth, age structure, and reproductive capacity could be useful and relatively inexpensive additional indicators for any species for which distribution and abundance are extensively monitored. Growth data could also be used to reconstruct trends for long-lived species (Section 4.4.2). Large-scale use of these indicators is not recommended if destructive or sacrificial sampling is required.

For all Tier II population indicators in Table 6.2, existing data and opportunities for preliminary analyses are likely to be limited.

Community surveys and indicators are the only feasible option for directly assessing non-commercial species. Some analyses have already been conducted for the Blackwater and Similkameen drainages (Section 2 and Appendix A). Further analyses of data from these data could include examination of:

- the statistical properties and usefulness of potential sentinel taxa and richness indicators; and,
- relationships between community indicators and variables such as physical habitat, stream order, elevation, gradient, etc.

Assuming that the Blackwater and Similkameen drainages are relatively un-impacted, pilot projects could be conducted in more impacted drainages to assess the sensitivity or responsiveness of proposed indicators. Lake communities are probably of secondary importance, which is why we recommend that community indicators be developed first for streams.

Benthic invertebrate communities were considered a Tier II indirect indicator for two reasons. First, benthic invertebrate communities are an important component of fish habitat, and changes in those communities may be useful predictors of changes in fish populations or communities. Second, invertebrate community indicators are being examined and used in several different B.C. programs and the U.S. EPA EMAP program. Thus, opportunities may exist for agencies or branches within the MSRM and MWLAP to co-operate in developing and using invertebrate community indicators as overall indicators of environmental quality, by sharing costs, sampling locations and data.

6.2 OTHER VARIABLES

6.2.1 Supplementary or Modifying Variables

Table 6.3 provides some recommended supplementary or modifying variables that should be measured in any status and trend monitoring program. The map-based variables are variables for which data can easily be obtained for most sampling locations or larger spatial units. These variables can be used to adjust standards for natural spatial variance, or to remove that variance in analyses of indicators. The map-based variables can also be used to determine if existing data provide a representative sample, and to select a more random or representative sample for future monitoring.

The field-based variables can be used for many of the same purposes as the map-based variables, and most can be measured at little or no cost whenever any field sampling is conducted. Some of these variables, especially for streams, are also relevant and sensitive indirect indicators (Table 6.1).

6.2.2 Stress Variables

For setting standards, and for analyzing and interpreting existing or future data, the province will inevitably require measures of stressors of interest (Section 2). A review of land-use indicators (Gustavson and Brown, 2002) was jointly conducted with this review, and that review should provide a list of recommended stressor measures.

6.3 OPTIONS FOR FUTURE STATUS AND TREND ASSESSMENT

This section provides some options and recommendations for future assessment of fish and fish habitat status and trends. Prior to adoption of these or any other options or recommendations, the analyses of existing data (mostly Tier I indicators) and pilot projects (mostly Tier II indicators) suggested in Section 6.1 should be conducted.

Table 6.4 compares monitoring usefulness of recommended Tier I and II indicators with those of a hypothetical "ideal" indicator. Usefulness was ranked High (H), Medium (M) and Low (L) in regard to their suitability for monitoring fish, water quality and physical habitat conditions related fish sustainability and status (e.g. biodiversity, water quality, habitat complexity, etc.). Direct and biological indicators were generally ranked for all conditions, as any occurrence of 'fish' suggests at least some habitat suitability/capability. Biological indicators such as benthic invertebrates are particularly good integrators of environmental conditions as shown in Table 6.4. However, as mentioned in Section 4.2 effects may not transferred to fish and they are generally non-specific (requiring supporting variables such as water quality and habitat assessments to help identify causal effects). Water quality and physical habitat indicators were more specific and ranked accordingly. This comparison shows the range of indicators required and subsequent need for incorporating a suite or mix of direct and indirect indicators in any status and trend monitoring program.

Providing a detailed design for future fish status and trend monitoring programs is beyond the scope of this project. However, based on requirements outlined in Section 2, and our review and recommendations of indicators, the province has three basic options, outlined below.

6.3.1 Option 1: Complete Dedicated Status and Trend Monitoring Program

This option is obviously the most costly, and would require:

- regular (probably annual) monitoring of Tier I and Tier II indicators, *plus* several other indicators for non-commercial lake species;
- >100 sample locations, chosen specifically for the purpose of status and trend monitoring, and to provide a representative sample of locations of interest (=dedicated status and trend locations);
- re-sampling of some or most of the same locations over time;
- committed funds for 10-20 years of sampling, and subsequent data entry and analyses;
- standards development and validation monitoring or analyses, and

- standardized methods (many of which are already available).

6.3.2 Option 2: Reduced Dedicated Status and Trend Monitoring Program

The scope and costs of the complete status and trend monitoring program outlined in Option 1 can be reduced in many ways. Lakes or non-commercial species could be excluded, only Tier I indicators could be measured, monitoring and assessment could be conducted only in selected regions, or the number of sample locations or sampling frequency could be reduced.

An alternative approach would be to measure or otherwise obtain data on a core set of readily available or inexpensive indicators (mostly Tier I indirect indicators) frequently (e.g. annually) at many locations. Sampling frequency and spatial coverage would be reduced for more expensive or less available indicators. Relationships between core and non-core indicators could be developed, and used to predict values of the latter for locations or times where or when they were not measured (i.e. as recommended in Section 6.1.1).

Option 2 will always provide less complete data, and reduced spatial or temporal coverage, relative to Option 1. Option 2 also requires some active or additional monitoring for the specific purpose of status and trend assessment.

6.3.3 Option 3: Reliance on Other Programs and Data

Past, present and future data collected for purposes other than status and trend assessment are always of some value for status and trend assessment (Sections 2.7 and 6.1). These additional data should be used whenever data quality is good, and the costs of retrieving those data are less than the costs of obtaining new data via Options 1 and 2.

On the other hand:

- existing programs conducted for other purposes may not continue in the future, and
- other data alone can never be completely adequate for status and trend assessment, standards development and validation (Section 2).

For example, routine fish and fish habitat inventories in forest environments are likely to be replaced by results-based or dedicated EEM programs. Our experience with FRBC and related programs also suggests that results-based monitoring will focus more on community or domestic water supplies than on fish and fish habitat.

6.3.4 Synthesis

A complete and dedicated status and trend monitoring program (i.e. Option 1 in Section 6.3.1), is probably not feasible given funding constraints, although it should be treated as a target or goal. Reliance on other data or programs alone (Option 3) will not be adequate for large-scale status and trend assessment. Some combination of Options 2 and 3, plus analysis of existing data (Section 6.1) would be required for Tier I and especially Tier II fish and fish habitat indicators. Critical areas or topics inadequately addressed by other data and programs are:

- long-term trends;
- status and trends for non-commercial species and fish communities in general, and
- development and validation of standards.

6.4 MAJOR CONCLUSIONS AND RECOMMENDATIONS

Major conclusions and recommendations derived from this review were:

1. Indicators of fish and fish habitat status identified in Tables 6.1 and 6.2 should be the focus of current and future status and trend assessment.

2. There are sufficient existing data available for some indicators (primarily Tier I indicators in Table 6.1) to assess status and perhaps trends. These assessments should be conducted.

3. If the province wants to assess status and trends for fish and fish habitat, they cannot rely only on data and indicators collected or measured for other purposes. Active or dedicated monitoring will have to be conducted to provide data for assessing long-term trends and non-commercial species, and for developing or validating standards.

4. Some dedicated monitoring is required, but there are limited funds available. The obvious solution is to monitor and assess a limited subset of indicators, and adopt efficient and appropriate designs and approaches for any monitoring conducted.

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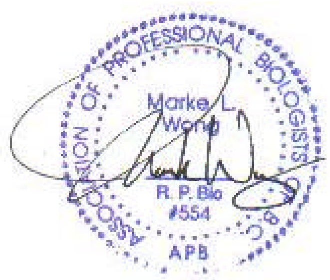
SECTION 8.0 – CERTIFICATION

This report was prepared and approved by the undersigned:



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