Aquatic Habitat Indicators and their Application to Water Quality Objectives within the Clean Water Act

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DISCLAIMER

The purpose of the document is to further the objective consideration of the scientific basis for the use of aquatic habitat indicators under the authority of the Clean Water Act, and to foster the exchange of information and ideas among governmental, non-governmental, tribal scientists and interested citizens. A thorough policy and legal analysis has not been made of the findings described in this document. The views expressed in this document are the authors' and do not necessarily reflect those of EPA, the University of Idaho or other institutions with which the authors are affiliated. Rather, they reflect the opinions of the authors as shaped by their experiences, interpretation of the scientific and technical literature and their understanding of the input provided by their colleagues at workshops and as a result of document review. These contributions are gratefully acknowledged. The authors accept full responsibility for any omissions or misinterpretations of facts, and invite others to share their alternative ideas on advancing the goal of defining objective measures of success for recovery and protection of aquatic ecosystems.

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ABSTRACT

The objective of this paper is to evaluate the application of aquatic habitat variables to water quality objectives under authority of the Clean Water Act (CWA). The project is limited to freshwater, lotic aquatic habitats in the Pacific Northwest and Alaska with an emphasis on salmonid habitat. Habitat variables were placed into one of the following categories – flow regime, habitat space, channel structure, substrate quality, streambank condition, riparian condition, temperature regime, and habitat access. Candidate habitat variables were evaluated for their relevance to the biotic community, responsiveness to human impacts, applicability to target landscapes, and measurement reliability. The most critical obstacles for use of habitat variables at the regional level (state specific water quality criteria for Region 10 EPA) are the quantification of biological effect and the unreliability of the measurement system. Inherent variability and unreliable data quality preclude the use of numeric values for habitat variables as compliance indicators in statewide water quality criteria. Rather, habitat variables should be used as diagnostic indicators of beneficial use attainment and pollution control performance, and should be developed and calibrated at local or ecoregional scales as stratified by landscape and stream characteristics. Currently only a few habitat variables meet the evaluation criteria established by the authors for use under CWA authority, specifically large woody debris, pool frequency, and residual pool depth. It is recognized that this limited set of variables will not satisfy the ecological habitat requirements needed to protect cold water biota. Recommendations to increase the applicability of habitat indicators to CWA objectives include an interagency (and international) effort to evaluate landscape classification of aquatic areas, identify and measure reference area condition at ecoregional scales, and develop a systematic approach for habitat indicator quantification. In the interim the authors recommend a re-examination of the narrative water quality standards in EPA Region 10 to provide more specificity in regards to salmonid habitat protection. Water quality standards should also specify the process whereby numeric criteria can be established at the local or ecoregional scale.

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Available at EPA Region 10 web site,
http://www.epa.gov/r10earth/

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

The objective of this project was to evaluate the potential inclusion of aquatic habitat indicators into water quality programs as one component of a developing EPA strategy to address declining salmonid populations in the Pacific Northwest. Habitat indicators, like water quality criteria and biological indicators, can be used to evaluate the protection of beneficial uses which are the cornerstone of water quality standards. Aquatic habitat indicators (variously referred to as habitat variables, parameters, metrics, etc.) are commonly used to evaluate biotic integrity and fish production capability.

We initially set out to formulate habitat target values based on the best available information from the literature and databases on reference area condition. After consideration of the currently available information, we concluded that developing numeric values at a regional scale would not be technically feasible. The literature supports the importance of habitat characteristics for salmonid fish communities and the documented alteration of habitat quality by human activities. However, both the numeric values that are contained in the literature and numeric values available from reference area databases exhibit too broad a range of expression to identify target values. Using information at this scale to set target values has the potential to contribute either to incremental habitat deterioration or to set inapplicable target values across large geographic areas. Instead, we describe an approach for developing target values at an ecoregional scale; this approach is summarized in the key points and recommendations for future action which follows.

This project includes a bibliography of the literature associated with habitat indicators. The bibliography was not included in the paper copy because of its large volume. The bibliography is available on the EPA Region 10 web site at http://www.epa.gov/r10earth/.

Key Points

1. Relevance of Aquatic Habitat Indicators to Clean Water Act Objectives

Aquatic habitat indicators can address two interrelated objectives of the Clean Water Act (CWA). The first objective is to determine whether designated beneficial uses are attainable in the water body and to what degree these uses are supported. The second objective is to evaluate the effect of pollutant sources on beneficial uses and assess the need for change in pollution controls. The first objective, assessing the status of beneficial use, extends beyond the aquatic organism to the aquatic environment required to sustain a certain aquatic population over time. Habitat quality, like water chemistry and biological integrity, provides a method to determine if the environment supports the target aquatic community.

The second objective reflects a major emphasis of water quality programs to provide feedback on the effectiveness of regulatory and management programs. In nonpoint source programs, monitoring is categorized under implementation and effectiveness objectives: implementation monitoring addresses whether the Best Management Practices (BMP's) were installed according to plans or regulations; and, effectiveness monitoring, as more comprehensive, attempts to determine whether the management practices effectively protect beneficial uses. Habitat indicators can play a role in assessment of practices, but they need to be part of a comprehensive monitoring program that includes on-slope assessment of management practices, watershed processes, and the effect of these pollutants and altered processes on channel and habitat quality.

2. Challenges to Using Aquatic Habitat as an Indicator

Concerns with development and application of habitat variables to water quality programs can be grouped into five primary issues: the high degree of natural variability in stream systems, the lack of reference

conditions to serve as benchmarks, the effect of natural and past land-use disturbance on stream conditions, the problems associated with measuring habitat variables, and lastly the use and application of habitat measures within the context of the CWA.

Although variability is inherent in aquatic systems, there is an observed pattern of habitat conditions that are necessary to support aquatic communities. These requirements are best known for salmonid species and can in turn serve, to some degree, as indicators of cold water lotic communities. Spatial variability can be addressed by grouping similar habitats at different scales, e.g. habitat type, stream reach, sub-watersheds, etc., within a landscape setting. Temporal variability needs to be addressed via an evaluation of the way in which watershed processes, natural disturbance, and human activities interact over short and long-term time frames. Habitat conditions in unmanaged (or minimally managed) watersheds provide the benchmark by which to judge the adequacy of current conditions in supporting beneficial uses. Yet, the lack of adequate representatives of reference areas for many ecoregions has been cited as one of the most difficult challenges in developing numeric indicators. Extreme floods, fire, mass wasting and erosion events, which occur at infrequent but regular intervals, are part of the dynamic environment that shapes stream ecosystems.   Use of habitat indicators in water quality programs must account for the effect of these natural disturbance events on habitat variability.

Although there is a general understanding of the habitat components required to support salmonid species, and by extension aquatic cold water communities, standard protocols similar to the standard methods used for water chemistry have not been developed and agreed upon in a formal manner by the scientific community. The lack of uniform methods with acceptable levels of precision, accuracy, and comparability accepted by a broad cross-section of the scientific community is an obstacle to measuring habitat quality.

Some generic misconceptions regarding the potential use of habitat indicators in the CWA may stand as a roadblock to collaboration and problem solving. For example, there is a perception that establishing a numerical indicator somehow establishes a requirement to manage streams toward some uniform design and, therefore, encourages land managers to use artificial means to achieve these endpoints. Additionally, the perception exists that establishing water quality criteria would provide license to degrade high quality streams. Neither of these outcomes is provided for in CWA guidance or policy.

3. Use of Aquatic Habitat Variables as Diagnostic Indicators

Variables used to measure environmental quality have been categorized as *compliance*, *diagnostic*, and *early warning indicators* (Cairns et al. 1993). There is an implicit requirement that the values used as compliance indicators can be measured with known levels of precision and accuracy, that the biological effects are associated with a numerical value, and that these numerical values are applicable within the prescribed geographic area. The numerical water quality criteria familiar to water quality professionals serve as an example of the variables used as compliance indicators. Criteria for water chemistry variables are set at a threshold of effect for target organisms based on laboratory bench tests of acute and chronic effects. Since these criteria are used in a regulatory context, a high standard for data quality is required.

Our evaluation does not support the use of habitat indicators as compliance indicators at this time for several reasons. First, the habitat value generally cannot be readily tested or reproduced in a laboratory bench test similar to water quality criteria. A quantitative, repeatable biological threshold can not be readily identified for the majority of habitat variables, since the numeric value has to come from observations of the habitat component in unmanaged landscapes in which it will be applied. Second, the high natural variability of habitat conditions prevents the development of defined numerical criteria with the scientific rigor generally required for numerical water quality criteria. Third, the measurement systems for habitat variables, comprised of standard operating procedures and quality control/quality assurance programs, have not been developed to the degree necessary to meet data quality objectives.

At the current state of development, habitat variables may be best suited as *diagnostic indicators* of beneficial use support and as performance measures of nonpoint source controls. Diagnostic measures fit well within the regulatory framework for nonpoint source activities, which depends on the iterative evaluation of management practices.   The habitat variable measures the outcome of management actions on water quality and water resource integrity. In concert with measures of on-slope pollutant sources and evaluation of watershed processes, a habitat indicator assists in diagnosing whether management practices have had an adverse impact on the aquatic environment. Instream measures assess beneficial use support, but they can not be used alone to assess management actions since the current stream condition integrates past activities, current actions, and natural disturbance. Historical and upstream activities in the watershed can readily cause a lag effect in the stream channel condition, thus disconnecting the adjacent management action from the current habitat condition.

4. Indicators Must be Applicable within Diverse Landscapes and Stream Networks.

Landscape and stream geomorphic features strongly influence habitat variables. Classification systems provide a way to partition and account for the variability observed in aquatic habitats as a result of these features.   Ecoregions and stream classification systems provide a framework for organizing habitat components, habitat variables, and numerical indicators. Level III Ecoregions, compiled at 1:250,000 map scale, may provide a sufficient first iteration for categorizing watersheds in order to evaluate potential reference conditions for many habitat variables. Further sub-division of Ecoregion organization may be useful in providing a more homogeneous organization of watersheds but may also be a daunting task given the limited amount of data on reference conditions. A nested hierarchical classification system provides a tool to categorize potential natural conditions and establish expected target conditions in which fish and aquatic communities have developed; yet, a meaningful organization of stream networks ultimately depends on the identification of geomorphically similar stream reaches. Fundamental factors in organizing stream reaches are stream gradient, confinement, and stream power (bankfull width or basin area). Classification systems that incorporate these factors should be useful in developing a spatial framework for habitat indicators.

The habitat indicator needs to be assessed at a spatial scale appropriate to the management or programmatic question. Habitat variables are generally measured at the habitat unit scale (e.g. pool, riffle, or glide), but they should be assessed at the stream reach scale. While localized, site-specific factors can influence the habitat at the habitat unit level, comparison between stream segments or to reference watersheds should be done at the stream reach scale - a level of organization more meaningful to interpretation of external factors.   The stream reach is defined by recognizable, geomorphic characteristics that influence habitat quality. These units can then be scaled up to address questions at the sub-watershed or watershed level.

5. Assessment and Monitoring Issues

Habitat inventory procedures generally lack the sensitivity necessary to detect environmentally significant change. Many habitat protocols were developed for inventory purposes which rely largely on subjective evaluation and are, therefore, subject to observer bias. To be useful in a water quality program context, habitat variables need to be measured with a known degree of precision and accuracy. The monitoring framework that has been developed for water quality variables consisting of established Standard Methods for analytical analyses, Standard Operating Procedures for field methods, and QA/QC procedures serve as a template for habitat measurement systems. Currently no accepted parallel systematic framework for assuring the data quality for habitat monitoring is in place.

Data quality objectives need to be established and evaluated as part of the measurement system if habitat variables are to be useful as diagnostic indicators or as environmental targets for Total Maximum Daily Loads (TMDL's). Measured quantitative data should be selected where feasible to overcome the observer bias inherent in qualitative methods. Quantitative methods for measuring habitat are becoming more accessible and faster with the use of more efficient survey techniques such as Total Station Survey equipment and GPS survey technology.   Quantitative channel measurements that are standard

procedures in hydrology and geomorphology should be adopted as ways to increase quantitative measurement of habitat quality. Measurement goals should place less emphasis on the number of stream miles assessed and more on the ability to measure conditions with an acceptable precision. The trade off between costs of quantitative methods and expected benefits in detecting change will also need to be considered.

6. Potentially Useful Aquatic Habitat Indicators

We evaluated the existing habitat parameters used by state and federal agencies in monitoring programs and the habitat variables used as Riparian Management Objectives (PACFISH, USFS 1995) or as habitat indicators for evaluation of proposed activities under the Endangered Species Act (ESA) (NMFS 1996). Variables that directly measure a habitat characteristic can be grouped into one the following categories of aquatic ecosystem components:

- Flow Regime
- Habitat Space and Channel Structure (including LWD)
- Substrate Quality and Size
- Streambank Condition
- Riparian Condition
- Temperature Regime
- Water Quality Constituents
- Habitat Access

The first five components relate to physical habitat and were evaluated in this paper. Temperature, water quality constituents, and habitat access are listed to illustrate the holistic requirements of cold water biota, but they are outside the scope of this project. To evaluate the utility of habitat variables for CWA purposes, we compared the existing aquatic habitat variables against the recommended characteristics for environmental indicators described in the literature. In summary, there are four major characteristics to consider in assessing habitat measures as environmental indicators:

1) The indicator must be relevant to the environmental/biotic endpoint,
2) be applicable to the landscape and stream network in which they are used,
3) be responsive to human-caused stressors, and
4) exhibit adequate measurement reliability and precision.

Only a few habitat variables satisfy these evaluation criteria. These variables are placed into two categories, Tier 1 and Tier 2, based on our professional opinion of the degree to which they satisfy the evaluation criteria. The categorization into tiers is a communication device and is not intended to provide any policy direction. Tier 1 variables satisfy all the criteria to a large extent and are considered potentially useful to Clean Water Act programs. Tier 2 contains habitat variables that have a known biological effect and are sensitive to human impact but are questionable regarding the measurement sensitivity and reliability or the ability to quantify the biological effect. Tier 1 variables include large woody debris frequency, pool frequency, and residual pool depth. Tier 2 variables include percent fine sediment and bank stability rating. Habitat should be evaluated via a suite of variables as is routinely done in field studies. The limited set of variables are not expected to satisfy an ecological stream protection goal but simply reflect the pragmatic evaluation of currently available habitat measures.

Three routinely measured habitat variables – large woody debris frequency, pool frequency, and residual pool depth – are used to evaluate the component of habitat categorized as Habitat Space and Channel Structure. These habitat variables also serve to evaluate flow effects, since the alteration of water quantity is manifested in the change in channel habitat space. Large woody debris and pool frequency are relevant to aquatic biota, are responsive to human impacts over the long term, and can be measured quantitatively. Salmonid species in forested ecosystems have evolved in streams in which large woody debris plays a major role in forming habitats, providing cover, influencing sediment processes, and

altering stream energy and nutrient cycling. Pool frequency is a critical indicator of habitat space, and residual pool depth is a quantitative measure of pool quality influenced by flow alteration and sedimentation.

Fine sediment deposited in critical spawning habitat has a demonstrated effect on reducing egg-to-fry survival and can fill in the voids in substrate utilized by juvenile fish as cover. However, there are unresolved questions regarding the applicability of field measurement protocols, their precision, and the interpretation of this kind of data in relationship to laboratory defined sediment impacts. While a large body of literature supports the fact that fine sediments are detrimental to salmonid and other aquatic biota, remaining questions about the adequacy of field methods and their comparability to laboratory studies need to be resolved. The authors recognize that other professionals have looked at this issue and have concluded that the existing body of information supports establishing numerical values. These differences of opinion are expected given the current status of the scientific information.

A similar consideration applies to the current evaluation methods for rating bank stability. Naturally stable banks result from the protection afforded by bank material and protective riparian vegetation which resists the force of flowing water and are recognized as providing important space and hiding cover for fish. The majority of bank stability methods involve a subjective rating of some combination of vegetative cover, bank material, and evidence of slumping or sloughing. The concern with current bank stability evaluations is the subjective nature of the measurement system. At the present time, the various methods of rating bank stability do not meet the necessary level of objectiveness and repeatability.

7. Numerical Format and Data Interpretation

The methods used to express the values for physical habitat are important. A single target value or a simple series of values for different stream types are not sufficient to express the inherent variability in aquatic ecosystems. Numeric values need to be expressed in terms of both the central tendency and the spread in a data distribution. The median, interquartile range, and percentiles, for example, are useful ways to display data, as these measures are resistant to the effect of outlying values in comparison to classical parametric measures (Helsel and Hirsh 1995).

Displaying the data as percentiles also provides the opportunity to set the objective within the policy framework. For example, a higher percentile may be established in a stream where watershed protection has been given a high priority, such as for protection of refugia for endangered species.

8. Application to Water Quality Standards and Total Maximum Daily Loads (TMDL).

Current water quality standards in EPA Region 10 states (Alaska, Idaho, Washington, and Oregon) address habitat protection in a very cursory manner. Narrative criteria related to aquatic habitat or, more specifically, salmonid fish habitat could be substantially strengthened based on existing known fish habitat requirements. Narrative criteria could address a number of critical habitat components more explicitly, which would be very useful in program applications such as development of TMDL's. Narrative criteria could also describe the process for development of ecoregional or site-specific numeric criteria. Numeric criteria could be tiered to these narrative statements as more specific information becomes available for individual ecoregions or groups of ecoregions. Development of numeric habitat targets for specific TMDL's can be completed currently at a watershed or sub-basin scales depending on the availability of reference area data or historic information. These localized efforts at developing habitat targets would contribute to the development of ecoregional numeric habitat indicators.

Recommendations for Future Actions

During the process of evaluating the current situation, we identified several primary issues related to application of aquatic habitat indicators. The issues were identified initially in canvassing the literature

and discussing the situation with aquatic specialists. These issues fall into four general categories: reference areas and landscape stratification, monitoring protocols and study design, application to water quality standards and TMDL's, and interagency coordination in addressing these technical issues. These topics can be addressed, if not resolved, via a systematic interagency and interdisciplinary effort at the state and federal (and provincial) level. For example, the definitive approach for landscape stratification of aquatic habitats has not yet been designed, although many of the pieces to this puzzle are likely in place. The first approximation of regional stratification could be pulled together through a working group of geographers, aquatic and terrestrial ecologists, hydrologists, and fisheries biologists. However, sufficient impetus would be required to bring all the appropriate specialists together in pursuit of this goal. There is also a need to emphasize applied research as a vital element of the solution. Oftentimes, state agencies or other governmental units are asked to tackle issues without sufficient resources, information, or expertise. Several of these issues could be addressed if there were sufficient integration of water quality programs and research efforts.

Reference Areas and Landscape Stratification

Landscape and stream network classification provide a logical means for stratifying stream habitats into logical units. Stratification is needed to define the target condition appropriate to the local landscape and reduce the effect of spatial variability. Aquatic specialists are familiar with geomorphic stream classification, stratification by ecoregion, and the hydrologic unit system. What is currently missing is the systematic application of stratification at a regional scale to facilitate identification of potential reference areas across state boundaries. Numerous case studies of stratification have been applied in specific programs or geographic areas which can serve as examples.

Candidate reference areas at various scales (i.e., from isolated tracts to large land blocks) can be identified from the current body of land use planning documents and geographic products. Reference areas at a coarser scale can be identified from roadless areas, designated wilderness areas, national parks, and other protected areas. At a finer scale, there are often small blocks of land that have been protected over time for various reasons that may be useful as reference areas. In addition to the written documentation, natural resource workers in land management agencies have a wealth of experience which could be tapped to identify potential reference areas.

In some areas persistent and widespread habitat alterations have eliminated natural areas that could be used to describe reference condition. There is clearly no easy way to fill in the data gaps on habitat conditions that have been severely altered.   The EPA guidance for developing biological criteria have suggested a logical approach to identifying reference condition where no reference sites occur (Gibson 1996). The decision tree suggests ways to utilize "minimally disturbed" areas and ecological modeling to fill in the information gaps. A related approach is to expand the search for suitable reference conditions outside of the local geographic area or local ecoregional area. There would appear to be good potential for cataloging reference conditions by expanding the geographic scope of the inquiry to British Columbia and Alaska.   These efforts would require some broader research initiative beyond the usual regional approach which focuses on the Pacific Northwest states.

A remaining and persistent challenges to aquatic habitat protection and recovery is the lack of an organized, focused cooperative venture to define and complete the essential field trials necessary to test the use of habitat indicators at discrete basin scales. Given the overwhelming need to judge the success of recovery plans for salmon and bulltrout listed under the ESA, to evaluate the effectiveness of federal court-mandated water quality recovery plans (a.k.a. TMDL's), and to ensure that state water quality standards are fully protective of aquatic species - now seems to be the perfect opportunity for State, Tribal and Federal resource agencies to collaborate in such an effort. To that end, the authors recommend that the agencies seek funding from EPA, the National Science Foundation, or similar groups to conduct the needed research and development. This objective should be identified as a key element in the implementation of the Clean Water Action Plan (EPA 1998). The Clean Water Action Plan provides a framework and potential funding source to facilitate efforts such as these among key natural resource agencies. Some specific action items might include:

- *Identify potential partnerships in this effort within the natural resource agencies - EPA, USFWS, NMFS, USFS, BLM, National Park Service, USGS Biological Survey, etc. as well as agencies in British Columbia and Alberta, Canada.*

- *Initiate a federal interagency and international effort to evaluate the landscape classification of aquatic areas at larger scales to incorporate lands in Alaska and British Columbia.*

- *Identify approaches and organizational units that can contribute to the pool of reference area data and assist in filling data gaps.*

- *Develop a systematic uniform approach to collect further information over the long term in order to describe undisturbed habitat conditions.*

Monitoring Protocols and Study Design

General agreement exists among aquatic scientists regarding which stream habitat components are important to aquatic organisms. There is a lack of consistency, however, in the way that habitat variables are measured and and the degree of quantification necessary for a monitoring objective. Consequently, the data quality (precision and accuracy) of the information is often unknown, and the data from different programs is not comparable. Many of the habitat data collection efforts are only at an inventory level of effort, but the information is used to render decisions that may be unsupported by the underlying quality of the data.

Even well documented habitat inventory methods have been found to be subjective and inadequate to characterize fish habitat for addressing land management questions (Peterson and Wollrab 1999). Inventory scale monitoring using qualitative procedures may be useful for certain natural resource programs, but decisions regarding compliance with water quality standards or adequacy of BMP's need to be based on data with known precision and accuracy. For this reason, it would be useful to initiate a comprehensive review of existing methods with an emphasis on their ability to achieve identified data quality objectives. In the interim, agencies should consider shifting resources to fewer more quantitative surveys that emphasize a decision analysis approach. Several quantitative channel survey protocols provide the basic framework for habitat evaluations (Harrelson et al. 1994, Kuntzch et al. 1998). Some specific actions might include:

- *A comprehensive evaluation of the ability of habitat protocols to produce data of an acceptable quality. This review should be an interdisciplinary, interagency review based on the technical adequacy of the habitat variables rather than on a consensus process.*

- *Development of standardized methods for habitat monitoring similar to the measurement framework that exists for water chemistry variables, e.g., Standard Methods, Standard Operating Procedures manual, and Quality Assurance/ Quality Control procedures.*

- *In the interim, agencies should review their approach to habitat monitoring, evaluate whether current methods are capable of answering the critical water quality program decisions, and consider the long term utility of fewer quantitative surveys over inventory and reconnaissance procedures.*

Application to Water Quality Standards and TMDL's

Narrative criteria for aquatic habitats in state standards should be substantially strengthened based on existing known fish habitat requirements. Narrative criteria could specify the desired condition for a critical habitat components more explicitly, e.g., salmonid spawning and rearing habitat. The narrative criteria should also describe the process by which site specific numerical criteria could be developed and

approved. These process statements would be expected to stimulate regional or local work groups to fill in the information gaps for the region. Since TMDL's are by nature locally specific, the watershed group or agency in charge of the problem assessment could follow the steps (stratification, reference area data, historic conditions, etc.) to develop habitat targets meaningful to the watershed or sub-basin.

Interagency Coordination

As described above, we believe that much of the information needed to make progress on habitat stratification, reference area identification, and monitoring protocols exists in some format within the state and federal natural resource agencies. Bringing the agency resources together toward resolving these questions requires a systematic scientifically based approach. Research units of the federal agencies have the technical resources to accomplish this task, but they would need to be brought together in a focused, goal specific manner. The effort we envision will require funding for a directed project and cannot be accomplished in a less rigorous manner such as an extracurricular consensus process.

Application of Aquatic Habitat Indicators to Water Quality Objectives within the Clean Water Act

EPA Region 10

Steve Bauer and Steve Ralph

"*Biologists are rather better at reinventing wheels than most scientists! We publish more and longer papers, so older seminal ideas, like fossils in geological strata, tend to become quickly buried out of sight.*" H. B. N. Hynes (1994)

The process of science may sound messy and disorderly. In a way it is.
Carl Sagan (1996)
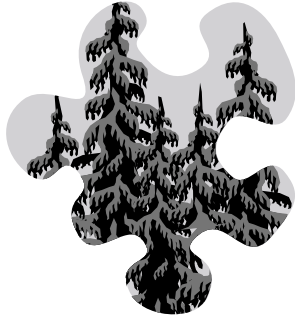
1. INTRODUCTION

In considering measures of stream habitat, we rely on the foundation of work already completed by biologists, hydrologists, and other stream observers summarized in literature reviews, symposia proceedings, and recent collections of papers. Much is to be gained by connecting the information on aquatic stream habitat from the field of fisheries, hydrology, geomorphology, water quality, and bio-assessment. We have compressed the thoughts of various aquatic ecologists and take responsibility for any errors that arise as a result.

Scope of Project

The EPA and state water quality agencies are increasingly asked to evaluate the CWA goals from a holistic perspective that integrates water chemistry, biotic integrity, and habitat integrity. The increased species listings under the ESA and the increase in water bodies listed under Section 303(d) have precipitated the need to

evaluate habitat requirements of beneficial uses as an important component of the overall health of the aquatic ecosystem. As a consequence, EPA initiated this review of the technical basis and feasibility of incorporating aquatic habitat indicators into water quality programs.

The scope of the project is limited to the physical freshwater habitat structure of lotic aquatic ecosystems. We do not discuss key habitat characteristics of associated wetlands, lakes, estuaries or near shore marine environments. We specifically targeted the literature search and information review to salmonid species of fish (salmon, trout, char) as indicators of cold water biotic communities. Salmonid habitat relationships have been extensively studied because of their importance to sport, commercial and tribal fisheries in comparison to other aquatic organisms. In addition, fisheries and land management agencies routinely collect stream habitat information, and consequently there is a better available data base on fish

communities than on other organisms. There is less information on habitat requirements in large rivers and on specific habitat relationships with invertebrate and algal communities. We recognize these biota are critical components of stream ecosystems, but habitat relationships have not been studied as extensively as with salmonid fish.

Degradation of aquatic habitats by nonpoint source activities is recognized as one of the major causes for the decline of anadromous and resident fish stocks in the Pacific Northwest (Williams et al. 1989, Nehlsen et al. 1991). Non-point source activities can modify the physical processes that provide important habitat features. Habitat quality is currently used as supportive information in water quality assessment programs, but habitat is only minimally addressed as an endpoint in state water quality standards. This effort will identify where feasible the rationale and key elements of a plan to develop a set of fish habitat condition indicators for possible inclusion in water quality programs.

Objectives

The original objective of the project was to evaluate the merits and feasibility of defining **numeric** values for desired habitat characteristics for salmonid fish communities in the Pacific Northwest. Comments received at technical workshops and from other agencies suggested that the emphasis on numeric targets was too restrictive. In response, we expanded the scope to address the expression of indicators to include narrative statements. Habitat indicators, whether expressed in a narrative or numeric manner, are needed within the context of the CWA as well as the ESA in order to define conditions required for the protection and recovery of salmonid populations. Without these defined measures of instream habitat, we have a limited basis for judging the adequacy of protection measures and the effectiveness of recovery efforts for salmon and trout populations.

An additional objective was suggested by comments from federal agency professionals involved in implementation of the ESA, since habitat indicators serve a different role in the ESA than in the CWA. We have attempted to compare and contrast the roles and application of habitat indicators between these two laws as we have evaluated these habitat variables.

Methods

Rather than conduct a comprehensive literature review, we focused on the summary of the literature that has been compiled in various synthesis documents and special publications. We then targeted literature sources with a special significance to particular habitat indicators or that provided the conceptual basis for habitat monitoring and assessment. Because of the general lack of agreement evident in agency programs, we canvassed professionals in the field regarding their ideas on the development and use of habitat indicators via workshops in Region 10. A concept paper based on an initial review of the literature was distributed to habitat professionals in the Pacific Northwest. One-day workshops were then held in Washington, Oregon, Idaho, and Alaska with approximately 40 resource professionals to solicit their ideas and discuss potential approaches. Their advice and input provides the basis for this report. A second draft of the concept paper was then distributed for an internal review at EPA Region 10 and to technical habitat specialists within the NMFS and USFWS. In addition, a special work session entitled "*Environmental Indicators of Freshwater Salmonid Habitats*" was held at the October 1998 Western Division meeting of the American Fisheries Society. This approach and other perspectives on this important issue were presented at that forum.

Terminology

It is useful to first standardize some terminology related to habitat indicators. **Habitat component** is used to refer to an element of the habitat where an organism occurs (Armantrout 1998) and is considered generally synonymous with **stream attribute** or **pathway**. A **habitat variable** is a quantifiable measurement of a habitat component (synonymous with **parameter**). **Water quality criteria**, as used in the CWA, refers to elements of state standards, expressed as numerical quantities or narrative statements, that represent the quality of water needed to support a particular beneficial use (USEPA 1994c). The term "**habitat indicator**" is used in this document to emphasize the

condition of the habitat rather than the more regulatory connotation usually associated with the term "*criteria*".

Declines in Fisheries and Water Quality

Habitat Degradation and Fisheries Declines

Decline in salmon and trout populations is a predominant theme in the Northwest closely linked to habitat degradation. Evaluations of the status of Pacific salmon (*Oncoryhnchus* spp.) have concluded that many stocks have become extinct over the last century and that many other stocks currently are declining and risk extinction (Konkel and McIntyre 1987, Nehlsen et al. 1991, Nehlsen 1997). Habitat degradation has been associated with over 90% of the documented extinctions or declines of these fish species (Williams et al. 1989, Nehlsen et al. 1991). Declines in populations of mussels and crayfish have also been attributed to habitat degradation (Williams et al 1993, Taylor et al. 1996). Forest practices, agriculture, livestock grazing, road building, urbanization, and dams have contributed to the habitat decline. Factors not regulated by the CWA - commercial and sport harvest, hatchery production, migration corridors, and ocean conditions - have also contributed to the decline of Pacific salmon (Stouder, Bisson, and Naiman 1997).

The causes for extinctions or declining stocks of Pacific salmon are complex and differ from basin to basin, but habitat degradation (including losses caused by dams) was explicitly identified as a factor in the declines of 194 of the 214 stocks and was believed to be the principal factor in the declines of 51 at-risk stocks (Nehlsen et al. 1991). Modification of aquatic habitats is generally related to one or more fundamental components of stream ecosystems: channel structure, hydrology, sediment input, riparian forest alteration, and exogenous material. Effects of these modifications on salmonid fishes and their ecosystems include: loss of overwintering habitat, shift in species balance, loss of cover from predators, loss of suitable spawning areas, reduced inter-gravel survival of eggs and alevins, reduced survival of

juveniles and outmigrating smolts resulting from altered timing of discharge-related life cycle cues, increased primary production and possible anoxia associated with elevated water temperature, and other effects (Gregory and Bisson 1997).

Water Quality Condition

The increased listings of water quality limited water bodies in Region 10 are symptomatic of the water quality problems in the Pacific Northwest. Litigants have been successful in gaining court orders to increase the number of streams listed on State 303(d) reports. For example, Idaho's 1996 list now contains 951 stream segments (Idaho Division of Environmental Quality 1997). The pollutant category "sediment" provides a surrogate for habitat degradation associated with nonpoint source activities. A summary of the list indicates that 90% of the streams are listed due to sediment impacts. (Fewer stream segments, 15%, are listed under the category "habitat alteration", but this category refers specifically to direct channel alterations and does not provide a dimension of the habitat impacts.) Oregon's 1996 list contains approximately 900 water bodies, half of which are listed exclusively for elevated temperature (Oregon Department of Environmental Quality 1996).

The magnitude of aquatic habitat degradation in the Pacific Northwest and its relationship to the decline of fish populations have been demonstrated. However, an accurate appraisal of the scope of the water quality problem related to habitat decline remains illusive. Identifying habitat quality will not contribute to stream recovery without a connection to action plans. Nonetheless, the identification of habitat as an environmental endpoint is a fundamental tool that is currently missing from the nonpoint source management program despite its wide acceptance as a fundamental component of water quality assessment.

Role of Habitat Indicators in the Clean Water Act and Endangered Species Act.

Introduction

Understanding the purpose and rationale for addressing habitat within the CWA is the initial step in selecting applicable indicators. Two different, but related, objectives for habitat indicators are evident in CWA programs. The first is the assessment of the status of the aquatic environment in supporting beneficial uses. The second is to gauge the effectiveness of management practices in preventing pollution and protecting beneficial uses. These objectives can entail the selection of different sets of indicators.

Although this paper's focus is on habitat indicators for the CWA, we do compare the objectives and application of habitat indicators within the CWA to those uses prescribed within the ESA. There is a desire among federal agencies to use similar indicators to avoid potential conflicts between regulatory programs. However, agency policy in applying habitat indicators may be different for the CWA and ESA, because these laws are intended to fulfill different missions. Understanding the nature of these differences and similarities between the CWA and ESA is necessary to address issues of regulatory overlap.

Clean Water Act Goals

The goal of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the nation's waters." James Karr (1991) highlighted the shortcomings of relying solely on nonbiological measures, such as chemical quality, to evaluate attainment of this goal. Since that time EPA and state agencies have increased efforts to incorporate biological criteria and bioassessment into the water quality programs.

Increased understanding of what is required to support beneficial uses of water has broadened the definition of water resource integrity to include flow regime, chemical quality, biotic factors, energy sources, and habitat structure (Figure 1). Physical and chemical variables form the core set of measures traditionally used in managing water quality programs. Managing these factors alone will not protect beneficial uses, because other biotic and abiotic factors are integral to the expression of water resource integrity.
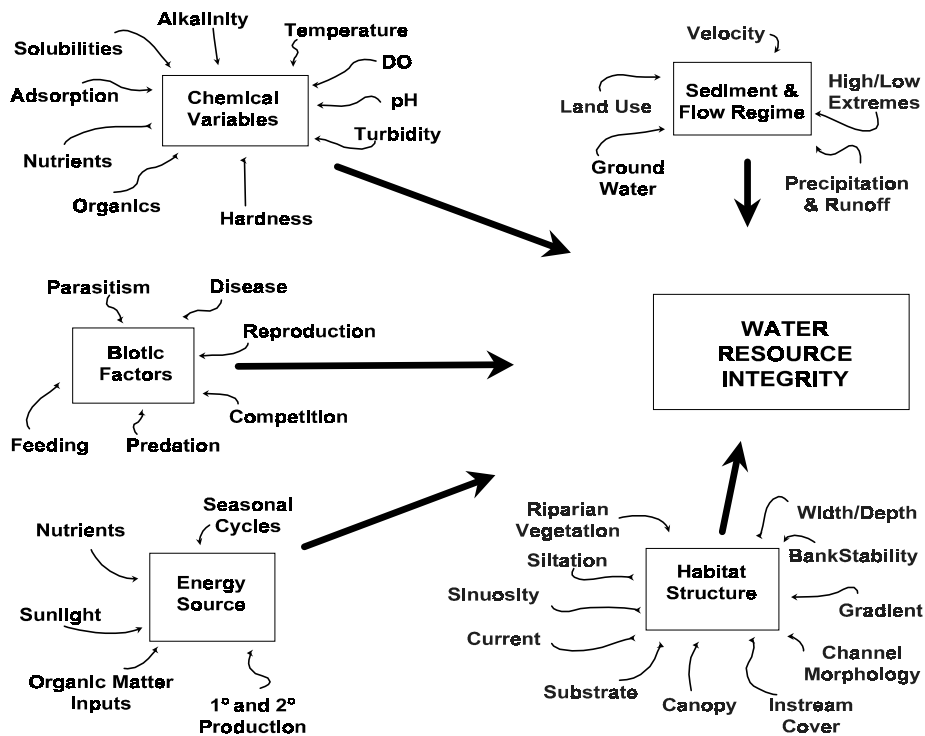
Figure 1. Water resource integrity (Adapted from Yoder 1995).

The importance of direct measurement of biological integrity to water quality programs is formally recognized in EPA policy and guidance (USEPA 1987, USEPA 1991). Forty-seven states employ some form of biological monitoring using macroinvertebrate assemblages, and 25 states have fish assemblage monitoring programs. Three states – Ohio, Maine, and Florida – have incorporated numeric biological criteria into their water quality standards, and many other states have work in progress (Southerland and Stribling 1995).

One potential downside to using biological measures as endpoints is that biological populations, especially migratory fish assemblages, exhibit high natural variability due to factors unrelated to nonpoint source activities such as climate, harvest, natural disturbance, and ocean productivity. For example, interannual variations of 40-70% are the general rule for coho salmon, steelhead, and sea-run cutthroat trout (Summary of studies in Bisson et al. 1997). In a review of fish assemblage studies, Grossman, Dowd, and Crawford (1990) noted that the high variability in fish assemblages can make it difficult to detect the effects of human caused disturbances.

Disturbance events likewise affect habitat variability, but these habitat variables are not subject to the extreme, and often inexplicable, cycles observed with fish populations. Combining habitat, as a measure of the physical integrity of the stream, with direct measures of biological integrity will provide a more powerful way to measure progress in achieving the goals of the Act.

Habitat attributes are collected as an integral part of bioassessment procedures (Plafkin et al. 1989, Hayslip 1993). However, habitat attributes are routinely measured qualitatively and are used primarily as explanatory variables in data interpretation. Developing habitat structure as a direct measure of water resource integrity will improve the linkage to nonpoint source activities. Poff and Ward (1990) address the rationale for using physical habitat as a template for stream biota: "In lotic ecosystems, physical habitat structure is of critical importance to the distributions and abundances of organisms. In general, greater spatial heterogeneity at the scale of organisms results in greater microhabitat and hydraulic diversity and hence in greater biotic diversity." In large areas of the Northwest's forests and

shrub/grasslands, the predominant effect of land management is to reduce stream habitat diversity and, thereby, reduce the complexity of the biotic community.

Incorporating habitat indicators into the existing water quality standards requirement for physical, chemical, and biological criteria fills an important gap in water quality management. The cumulative effects of land (and water) use and related alterations are largely responsible for the degradation of watersheds in the Pacific Northwest by way of the physical alteration of stream ecosystems and the processes accounting for their characteristics. Establishing habitat as a measurable endpoint is an essential tool to improve the cause-and-effect evaluation of nonpoint source activities and to establish programmatic endpoints. Assuring that water quality programs are on target is important environmentally, socially, and economically. Best management practices and TMDL's that are not targeted to problem resolution will waste resources in the interim and exacerbate the environmental problem through inaction and delay.

Nonpoint Source Management Process

Ideally, nonpoint source pollution evaluation and control is implemented through an iterative management process. The CWA's goal of maintaining and restoring the physical, chemical, and biological integrity of the Nation's waters is fundamental to state water quality programs. EPA has authority (Section 303 of CWA, 33 U.S.C. 1313) to review and approve or disapprove state water quality standards based on consistency with the CWA. Water quality standards must contain use designations, water quality criteria (both narrative and numeric) sufficient to protect these uses, and an anti-degradation policy. Numeric criteria for aquatic biota typically address temperature, pH, dissolved oxygen, toxic contaminants, and turbidity.

Best management practices for nonpoint source activities are often comprised of other state agency regulations for forest practices, mining, or channel alteration that have been reviewed for consistency with state standards. Monitoring of BMP efficacy occurs through state-wide audits and site-specific water quality studies. BMP's are updated when they are found to be

ineffective in protecting beneficial uses. The "feedback loop" is also applied at other degrees of resolution - basin, watershed or specific stream reach.

Habitat quality indicators can aid water quality management at a number of programmatic steps: (1) beneficial use designation, attainability, and status, (2) BMP evaluation, (3) project evaluation and water quality certification, (4) National Environmental Policy Act (NEPA) review, (5) watershed analysis endpoints, and (6) restoration endpoints.

Beneficial use designation is a cornerstone of the CWA. Application of criteria and pollution control requirements for each waterbody depends on the use designation. Use attainability is based on physical, chemical, and biological factors including habitat features (USEPA 1994c). A quantitative approach to use attainability decreases the uncertainty in water pollution control programs and helps focus limited resources. In current practice, use attainability and status determinations depend heavily on bioassessment protocols using macroinvertebrate and fisheries assemblages. Habitat is measured primarily in a qualitative fashion in order to assist in the interpretation of the biotic data. Evaluation of potential designated uses would be improved by concurrently evaluating habitat conditions using more quantitative approaches.

Determining beneficial use status, e.g., supported vs. threatened, is the next basic step in the application of a water quality evaluation to management programs. If uses are not fully supported due to water quality impacts, the state has the obligation to identify the cause and take corrective action including development of TMDL's. State 303(d) lists of Water Quality Limited Waters are based on noncompliance with criteria and on beneficial use status evaluations. The more accurate these status determinations are the more appropriate will be the requirements for pollution control.

Role of Habitat Indicators in the

Endangered Species Act

Habitat indicators are used within the ESA to evaluate proposed federal actions as part of Section 7 consultations in terms that define the risks to listed species. Essentially, they serve to

define the components of "proper functioning conditions," which reflect those habitat features necessary to support listed species' recovery. Guidelines for making ESA "*determinations of effect*" for proposed actions are contained in two similar documents by NMFS and USFWS (NMFS 1996 and USFWS 1998). The documents differ with respect to the subject species, but otherwise use a similar process. The described application of habitat indicators to ESA determinations is taken from these documents.

An analysis of proposed activity for Section 7 consultation involves the following steps:

(1) define the biological requirements of listed species;

(2) evaluate the relevance of the environmental baseline to the species' current status;

(3) determine the effects of the proposed or continuing action on listed species; and,

(4) determine whether the species can be expected to survive with an adequate potential for recovery under the effects of the proposed or continuing action, the environmental baseline and any cumulative effects, as well as consider measures for survival and recovery specific to other life stages.

The guidelines are intended to provide a consistent, logical line of reasoning to determine when and where adverse effects occur and why they occur. The guidelines do not address jeopardy nor identify the level of take, adverse effects which would constitute *jeopardy*, or high risk to the species/population of concern. Jeopardy is determined on a case by case basis involving the specific information on habitat conditions and the health and status of the fish population.

The guidance documents contain definitions of ESA effects, a matrix of pathways of effects, and indicators (including habitat indicators) of those effects. A proposed action is evaluated by analyzing the environmental baseline and the effects of the proposed action(s) on the relevant indicators. Using the guidelines, the Federal agencies and non-federal parties can make determinations of effect for proposed projects (i.e. "no effect", "may affect, "not likely to

adversely affect", and "likely to adversely affect"). These determinations of effect will depend on whether a proposed action or group of actions hinders the attainment of relevant environmental conditions identified in the matrix as pathways and indicators, and/or results in "take", as defined in ESA.

The terminology used in these guidance documents provides an indication of how habitat indicators can be used differently in the consultation process than from CWA programs. "*Pathways*" organizes portions of the aquatic ecosystem, e.g. water quality, habitat access, habitat elements, channel condition, etc., in a manner that facilitates connections to input processes. "*Indicators*" refers to specific measures of the pathways and includes a mix of narrative statements and numeric targets. For example, temperature (numeric) and turbidity (narrative) are response variables used to indicate whether the water quality pathway is properly functioning. Narrative statements, for example, about the level of "chemical contamination" are also included as indicators for pathways.

The Pathways and Indicators are used to predict effects of proposed actions. The evaluation involves a holistic approach, since the intent is to prevent harm to the listed species (taking). The evaluation of effects, therefore, includes both input processes and the response of the channel and habitat to the activity. The evaluation also needs to address watershed scale effects and cumulative effects. The evaluation is based on the best available information about the species requirements and the potential effect of the action. Default values for numeric targets are based on available information, which emphasizes a conservative approach to protecting the species. In circumstances where these default values do not apply to a specific watershed, the evaluator is expected to provide more biologically appropriate values and document this decision.

Contrast Between Habitat Indicators in CWA and ESA

The mission of the CWA versus the ESA may lead to a different selection of indicators or the selection of a different numeric value for the same indicator. Implementing agencies need to

understand these similarities and differences and develop a complementary process that in combination contributes to the long-term ecological health of the aquatic resource.

There are similarities as well as differences in the purpose and application of indicators between these two major laws. The habitat components important to the salmonid populations are the same – cool water, water free of contaminants, diverse habitat structure with an alteration of pools and riffles, intact riparian systems, etc. However, the underlying mission and application to programs will necessarily lead to a different selection and usage of habitat indicators. These distinctions involve the different application of indicators within the program framework, the allowable degree of risk, and the justification required for adopting the indicator.

ESA consultation involves predicting effects of proposed actions. The evaluation procedure examines both the upslope inputs and processes as well as the habitat response. Because ESA specifically addresses species at risk of extinction, the selection of default numerical values errs in favor of the species. Federal ESA agencies have the authority to develop and adopt project review procedures administratively with little outside external review.

Water quality standards and criteria focus on the outcomes, i.e. the chemical, physical, and biological integrity of a water body. Habitat indicators, either narrative and numeric, can be integrated into this system. The evaluation of upslope input variables occurs as part of the review of the BMP's adequacy as well as through implementation and effectiveness monitoring. These input variables are not included in water quality criteria since the criteria are directed at defining the quality of the environment necessary to support the beneficial use. Numeric criteria are generally set at the threshold of effect for a parameter – not at the level of least risk for the aquatic species. The process of establishing criteria involves multiple layers of review prior to adoption. The procedure establishes a balance between protection of the beneficial use and the social and economic effects of the decision.

In summary, habitat indicators under the CWA are intended to aid in measuring the quality of the aquatic environment in order to protect and maintain the beneficial uses. As such, habitat variables focus on the in-channel conditions and not on the upslope and input processes. Under ESA, indicators are used to evaluate the effect of future actions and to address both the input (often upslope) variables as well as the in-channel habitat variables. Default numeric values are identified as a starting point for certain habitat components, and these indicator values can be adjusted to fit the landscape where sufficient local information exists. The different missions inherent in these laws, and their implementing policies and regulations, may indeed lead to a different selection of indicators or a different magnitude in the default values of a single indicator. Agencies should seek to understand these similarities and differences and develop a process such that the implementation of these laws is perceived as complementary rather than as conflicting.

2. CHALLENGES IN DEVELOPING HABITAT QUALITY INDICATORS

As an integral part of developing an approach to habitat quality indicators, we canvassed the literature and workers in the field regarding the technical limitations to the development of numerical indicators. Although habitat quality is recognized as a limiting factor for fisheries and aquatic biota, little concensus exists on how to measure habitat quantitatively and how to evaluate the results. Difficulties in implementing biotic/ habitat assessment and criteria development have been addressed in a number of recent summaries - *Biological Monitoring of Aquatic Ecosystems*, Loeb and Spacie (1994)*; Biological Assessment and Criteria*, Davis and Simon (1995); and, *Pacific Salmon & Their Ecosystems*, Stouder, Bisson, and Naiman (1997).

Concerns with development and application of criteria identified in these summaries can be grouped into five primary issues: the high degree of natural variability in stream systems, the lack of reference conditions to serve as benchmarks, the effect of natural disturbance on stream conditions, problems associated with measuring habitat variables, and lastly the use and application of habitat measures within the context of the Clean Water Act. We will summarize these challenges before discussing some possible remedies and approaches to developing habitat indicators.

Natural Variability

Stream ecosystems are inherently variable. Various combinations of climate, geology, vegetation and landform have created a mosaic of habitats in which aquatic biota have evolved. Over geologic time scales, these factors control the characteristics of watershed processes that operate to define instream habitats. The diversity of physical habitats sustains various salmonid species and their life histories and has allowed locally-adapted populations to evolve in order to take advantage of these variable conditions. Habitats vary in their pattern, profile (gradient), and channel dimensions, which, in turn, control flow characteristics, water velocity, substrate, bank shape, overhead cover, temperature, and associated vegetative communities.

Bisson et al. (1997) noted that the most important aspect of identifying Desired Future Condition (FEMAT 1993), a concept similar to habitat quality indicators, is to address the natural variability inherent in both habitat and fish populations and to accommodate for the natural disturbance regime of a watershed. Poff and Ward (1990) describe the potential complexity of aquatic ecosystems as arising from the interaction of spatial, temporal, and ecological scales. The detection of recovery from natural or anthropogenic disturbance depends on selecting the appropriate spatial and temporal scales for the ecological response variable. The return of the system to an endpoint (DFC or habitat criteria, for example) which approximates the pre-disturbance state is the central question. Recovery from anthropogenic disturbance can be conceived as a function of the biota's experience with historical natural variation. Poff and Ward (1990) suggest that streamflow characteristics, thermal regime, and substrate characteristics are the minimum elements needed to characterize the physical template for ecological studies and management evaluations.

Spatial Scale	Small	← microhabitat pool/riffle → watershed region	Large
Temporal Scale	Fast	← diel seasonal → multi-annual geological	Slow
Ecological Scale	Individual	← behavior physiology → species migrations nutrient dynamics	Community Ecosystem
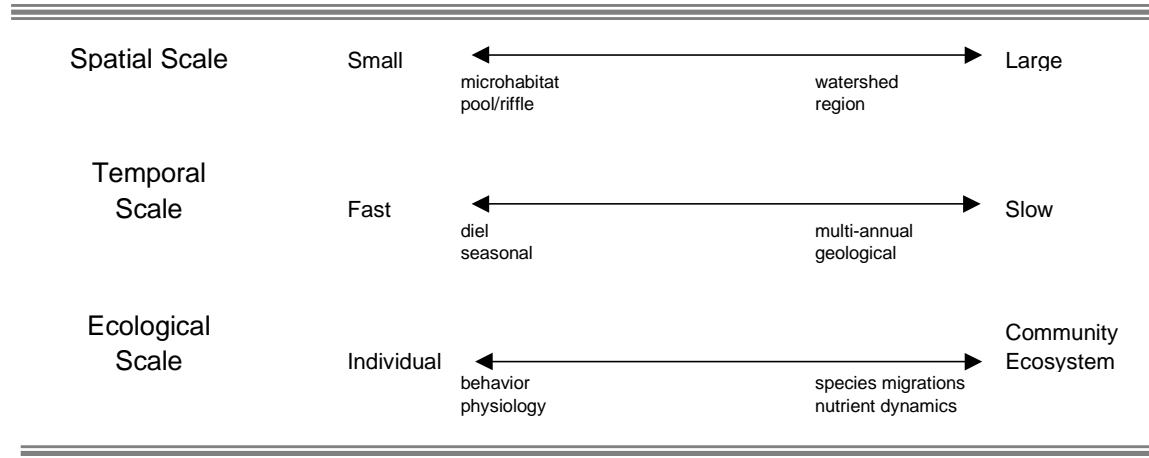
Figure 2 Potential complexity of aquatic ecosystems as the interaction of spatial, temporal, and ecological scales. Poff and Ward 1990.

Lack of Reference Conditions to Serve As Benchmarks

Reference areas provide the template for habitat conditions in which native aquatic biota have evolved. Habitat values from reference areas provide both a measure of what constitutes "good" conditions as well as a measure of the variability of conditions in which native species have evolved.   Reference areas are not used as the target conditions but, rather, as a scalar in order to provide a measure of the potential conditions which result from natural disturbance.

There is little agreement on what areas represent reference conditions and what degree of human disturbance is allowable for sites to be used as reference conditions. In the Pacific Northwest, most grass and shrub land areas have been altered by grazing for decades. In forested zones, roadless areas and mature forests represent the best potential for reference conditions. However, even these areas may have been compromised by historical or current fire management, wildland grazing, mining exploration, or recreational uses.

Experience in the bioassessment program has shown that the determination of the health of individual candidate reference sites is one of the most difficult aspects of biocriteria development (Hughes 1995). For example, it was observed that several states have used fundamentally altered ecosystems to serve as reference sites, which understandably undermines the purpose and intent of identifying reference conditions.

The majority of stream inventory and monitoring programs have been directed at measuring habitat in managed and impacted areas, so little data is available in the areas that potentially represent reference conditions. An exception to this observation is the Natural Conditions data collected by the Intermountain Research Station in the Salmon River Basin of central Idaho (Overton et. al 1995). In this instance, the USFS collected habitat measures in primarily roadless areas in which natural disturbance regimes (such as fire, flood, and drought) were considered the primary influence.

The Effect of Natural Disturbance on Stream Conditions

The quandary for addressing human-caused impacts on aquatic ecosystems is the recognition that natural disturbances play a major role in the development of habitats. Habitat condition can change dramatically as a result of storms, fires, and mass wasting events. If this is so, how does one distinguish the harmful effects of human disturbance from similar changes introduced as part of the natural disturbance regimes?

The concept of natural disturbance as a positive factor in salmonid habitat formation is described

in the following statement from Bisson et al. (1997):

> "The natural disturbance regime is the engine that drives habitat formation for salmon. Short-term impacts of natural disturbances on salmon populations are often negative. Death may result, habitat may be destroyed, access to spawning or rearing sites may be blocked, or food resources may be temporarily reduced or eliminated. However, many types of natural disturbances introduce new materials into stream channels that are essential for maintaining productive habitat. Mass soil movements such as earthflows and debris avalanches contribute coarse sediment and woody debris (Swanson et al. 1987). Wildfires and windstorms contribute both coarse and fine debris as well as nutrients (Minshall et al. 1989). Floods entrain nutrients, sediment, and particulate organic matter of all sizes (Bayley 1995). Volcanic eruptions create new soil, form new riparian terraces, and create new stream channels and lakes."

The distinction between the effects of natural and human induced disturbance on aquatic ecosystems is in the rate of recovery. Natural disturbances occur as pulse disturbances versus human disturbance, which occurs as a continuing or press disturbance. *Pulse* disturbance causes a relatively instantaneous alteration after which the system recovers to its previous state. Invertebrate and salmonid populations can rebound rather quickly following natural disturbance (Wallace 1990, Bisson et al. 1997). A *press* disturbance causes sustained alteration in the ecological processes, thereby moving the system to a new state. In general, press disturbances result in longer recovery times due to alteration of the physical habitat as occurs with mining activity, clear-cut logging, and channelization (Yount and Niemi 1990).

A related problem confounding the application of habitat indicators within a regulatory context has to do with the persistence of disturbances associated with past land management practices (legacy effects). For example, benefits from the use of effective land management practices to abate sediment input can be difficult to judge by measuring instream conditions because of the recovery periods involved with sediment flushing

through a river system. Similarly, because of a lag effect in the result of an action taken on a hillside, it is difficult to judge the true risk and outcome of, for example, clearing and grading activities on unstable terrain.

Measurement Quality Considerations

Habitat inventory and monitoring is usually conducted as a component of fisheries management programs or land management planning and evaluation involving timber, grazing, and mining on public lands. In some cases, study objectives were only vaguely defined, assumptions were never explicitly tested, and study design considerations were not given appropriate consideration. Monitoring programs typically suffer from chronic under-funding and low priority status compared to other management activities. Data collected for an environmental assessment or specific project often are not analyzed beyond a file report. As a consequence, habitat monitoring data often lacks reproducibility at a location, comparability between sites, and continuity of institutional memory in the evaluated watersheds.

Habitat inventories were developed primarily as aids to land management decisions with an emphasis on speed of collection rather than on repeatability. These primarily subjective methods and the data derived from them are not amenable to quantitative analysis. Poole et al. (1997) found that habitat unit classification, a basic foundation of stream habitat surveys, was inadequate for measuring trends over time due to the lack of repeatability. Desired attributes for variables used as habitat quality indicators includes repeatability, transferability, precision, as well as sensitivity to human impacts and natural variability. The subjectivity of many current habitat protocols precludes their ability to meet these necessary attributes.

Concerns with Use of Habitat

Variables Within the Clean Water Act

In part, the concerns with developing habitat quality indicators are related to misconceptions about what role water quality criteria play in both water quality programs and land management activities.

The concerns with developing numerical habitat criteria generally fall into one of three categories: 1) criteria become management targets, thus allowing higher quality areas to be degraded; 2) instream criteria promote technological quick fixes, i.e., a band-aid treatment rather than fixing the cause of degradation; and, 3) national or regional criteria are applied inappropriately at the watershed scale in a one-size-fits–all approach.

Water quality criteria are not intended as management targets, and no provision in the Clean Water Act implies that degradation of streams to the criteria level is acceptable. The philosophy of maintaining high quality waters is a basic tenet of the Clean Water Act, which is explicitly expressed in the Antidegradation Policy (USEPA 1994c). The policy to protect high quality waters at existing levels is a requirement for approval of state water quality standards. The policy, however, has not been applied uniformly by EPA and the states, and consequently, the intent of protecting high quality waters has not been realized.

Criteria for water quality measures have typically been established at a level designed to protect aquatic biota from acute and chronic effects. Setting the criteria level is a balancing act between acceptable risk to aquatic biota and the costs to society. It is not the intent or policy of the Clean Water Act to use criteria as surrogates for management goals. Criteria are assessment endpoints to help evaluate progress toward meeting goals and objectives as well as evaluating BMP effectiveness. Antidegradation policy makes it clear that water quality criteria are not management targets to which streams can be managed down.

A criticism of establishing fixed one-size habitat criteria is that it promotes inappropriate technological fixes that treat the effect and not the cause. Some managers take an active approach to fixing stream problems that is not supported by scientific evaluation of the outcome. Addition of structural elements has been promoted in fisheries management in the past, but there is little evidence of significant and long-term improvement in fisheries production from such practices (Beschta 1997). Judged on the basis of the evolving principles of ecosystem management, many structural approaches cannot be construed as restoration. As the ecosystem management approach is implemented, there will be less reliance on direct manipulation of instream structures. Use of ecologically inappropriate means to achieve instream criteria are not an adequate rationale to abandon criteria development, rather the emphasis should be placed on ecologically sound stream restoration.

Habitat indicators will have to be responsive to the variability in the stream ecosystems to provide a viable tool for assessing and managing nonpoint source activities. One approach to tailoring "criteria" to meet the needs and variable expression of aquatic habitat involves stratification. Methods to spatially stratify stream systems by landscape and channel geomorphology are widely used and integrated into resource management programs (Kratz et al. 1994, Rosgen 1996, Frissell et al. 1986). Although these approaches are not standardized across the Northwest, the underlying principles are well accepted. Habitat indicators should be developed to reflect landscape and aquatic ecosystem variability and system potential. Habitat criteria based on single or limited values, which are not representative of the local environment, will not be accepted by the scientific community. Rather, we should encourage the use of a suite of habitat indicators, both in-channel and upslope, to provide a more comprehensive and reliable basis for interpretation of the cause–effect relationships associated with water resource concerns. These concepts are discussed in detail in the following sections of this report.
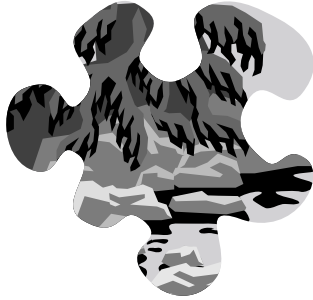
3.   SALMONID HABITAT REQUIREMENTS AND LAND USE EFFECTS

Introduction

Literature which summarizes salmonid fisheries habitat requirements is reviewed in several documents: *An ecosystem approach to salmonid conservation* (Spence et al. 1996*); Habitat requirement of salmonids in streams* (Bjornn and Reiser 1991); *Forestry impacts on freshwater habitat of anadromous salmonids* (Murphy et al. 1995), *Fisheries handbook of engineering requirements and biological criteria* (Bell 1986), and *essential fish habitat for four species of salmon* (NMFS 1998). *Pacific Salmon and their Ecosystems* (Stouder et al. 1997) is an excellent compendium of articles on salmonid fish status, factors contributing to their decline, and restoration needs and opportunities.   The summary table of effects of land uses on salmonid habitats is taken from the article "*Degradation and Loss of Anadromous Salmonid Habitat in the Pacific Northwest*" by S. Gregory and P. Bisson (1997) with permission from the authors.   The following section is adapted from these two documents.

Habitat requirements for salmonid fishes are organized by life-history stages, because the fish utilize different micro-habitats depending on their life stage and size.   Bjornn and Reiser (1991) discuss habitat requirements in relation to five major life stages: migration of maturing fish to natal streams, spawning by adults, incubation of embryos, rearing of juveniles, and downstream migration of fish. Within these life stages, habitat requirements have been divided into physical and chemical attributes that correspond roughly to three of the factors in Karr's organization of water resource integrity (Yoder 1995).   These factors include water chemistry (temperature, dissolved oxygen, and turbidity), flow regime (streamflow, water velocity, and depth), and habitat structure (space, substrate, and cover).

Despite the body of literature on the habitat requirements of salmonids, there is little concensus on the ability to describe these requirements quantitatively for individual species.   Several recent reviews of species status were unable to identify specific habitat thresholds.   Stream channel stability, habitat complexity, substrate composition were identified as prominent factors that influence bull trout populations; however, no tolerance thresholds for these characteristics were recommended (Rieman and McIntyre 1993).   In reviewing the conservation assessment for inland cutthroat trout, Young (1995) states that, although the basic components of habitat are understood, there is little information about what constitutes ideal or optimal habitat for this species.

These examples illustrate the difficulty of developing habitat indicators at the species level from the existing literature.   An alternative approach is to identify and protect the general habitat characteristics of stream ecosystems necessary to support healthy fish populations and, perhaps more importantly, the processes that promote their development. The summary of habitat requirements that follows, adapted primarily from Bjornn and Reiser (1991), focuses on the structural habitat features of stream systems.   It is included here to identify the importance of habitat in supporting salmonid fish as a beneficial use and is directed toward the non-fish biologist in the water quality field.

Migration of Adults

Adult salmon returning to their natal streams must reach spawning grounds at the proper time and with sufficient energy reserves to complete their life cycles.   Stream discharge, water temperatures, and water quality must be suitable

during at least a portion of their migration season.

Salmon and trout respond to stream temperatures during their upstream migrations. Delayed upstream migrations as a result excessively warm water temperature have been observed in salmon and steelhead. Stream temperatures can be altered by removal of streambank vegetation, alteration of the channel shape to a wider and shallower profile, as well as withdrawal and return of water for agricultural irrigation.

Cover for salmonids waiting to spawn or in the process of spawning can be provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects such as logs and rocks, floating debris, deep water, turbulence, and turbidity. Cover can protect fish from disturbance and predation. Some anadromous fish, chinook salmon and steelhead for example, enter freshwater streams and arrive at the spawning grounds weeks or months before they spawn. If the holding and spawning grounds have little cover, such fish are vulnerable to disturbance and predation over a long period.

Spawning and Incubation

Substrate composition, cover, water quality, and water quantity (i.e. seasonal stream flow characteristics) are important habitat elements for salmonids before and during spawning. The quality of the substrate, water depth, and velocity defines the area suitable for spawning, but the suitability of the substrate for spawning depends mostly on fish size; large fish can use larger substrate materials than can small fish. Steelhead, for example, use substrate in the range of 1 - 10 cm compared to rainbow trout that use substrate in the 0.6 - 5 cm range. Cover is important for adults in species that spend several weeks maturing near spawning areas.

Successful incubation of embryos and emergence of fry depend on many chemical, physical, and hydraulic variables: dissolved oxygen, water temperature, biochemical oxygen demand in the water column and deposited in the redd, substrate size (including the amount of fine sediment), channel gradient and configuration, water depth above the redd,

permeability and porosity of the gravel, and velocity through the redd. Water quality standards require more restrictive standards for temperature and dissolved oxygen for salmonid spawning, and standards have generally not addressed the effect of fine sediment due to the difficulty in establishing quantitative thresholds.

Streambed particles in the redd at the end of spawning as well as organic and inorganic particles that settle into the redd affect the rate of water interchange, the oxygen available to the embryos, the concentration of wastes, and emergence of alevins. During redd construction, spawners displace fine sediments and organic material, which improves the conditions for the survival of embryos. Fine sediment inevitably moves back into the redd environment after construction. The amount of fine sediment deposited and the depth to which it intrudes depend on the size of substrate in the redd, flow conditions in the stream, and the amount and size of sediment being transported. Intrusion into the redd is higher with smaller particle sizes and these particles have a higher potential to reduce survival. Larger intruding particles can create a seal or a clogged layer within the gravel preventing fry from emerging from the redd. Relation between embryo survival and particle size has been investigated in lab studies; however, the degree to which these studies simulate the conditions found in the egg pocket of a natural redd is unknown.

Rearing Habitat

The capacity of a stream to support salmonid fish populations depends on the spawning and incubation success, the quality and quantity of suitable habitat, abundance and composition of food, and interactions with other fish and predators. Environmental factors can affect the distribution and abundance of juvenile salmonids at various scales. Temperature, productivity, suitable space, and water quality can regulate fish populations at a reach or stream system scale. Fish respond to velocity, depth, substrate, cover, competition and predation at a habitat unit or micro-habitat scale. Temperature, dissolved oxygen, turbidity, and nutrients are important water chemistry factors that regulate the distribution of salmonids. These factors for the most part are addressed in state water quality standards or programs and are not discussed further.

Space suitable for use by salmonids is a function of streamflow, channel morphology, gradient, and various forms of instream or riparian cover. Space requirements are related to sufficient depth and quality of water flowing at appropriate velocities. The addition of cover – extra depth, preferred substrates, woody debris, etc. – increases the complexity of the space. The amount of space needed by fish increases with age and size class. Physical space in a stream is reduced over time as dikes and levees are built to contain flood flows, roads are built in the riparian zone, and streams are ditched or moved to one side of the valley floor.

Given adequate flow in a stream, velocity is probably the next most important factor in determining the amount of suitable space for rearing salmonids. If the velocities are unsuitable, no fish will be present. Natural streams contain a diversity of velocities and depths. The velocities required and used by juvenile salmonids vary with size of fish and sometimes with species. Some juvenile salmonids, as they grow, select sites in streams with increasingly faster velocities, presumably to gain access to more abundant food. Preferred depth of water is subject to needs for suitable velocities, access to food, and security from predators. The relation between water depth and fish numbers depends on the mixture of fish species and sizes, amount of cover, and size of stream. Fish abundance likely rises with increasing depth up to a point.

Substrates are important habitats for incubating embryos and aquatic invertebrates that provide much of the food for salmonids; substrates also provide cover for fish in summer and winter. Juvenile salmonids will hide in the interstitial spaces of stream substrates, particularly in winter, when the spaces are accessible. The summer or winter carrying capacity of the stream for fish declines when fine sediments fill the interstitial spaces. For example, it has been observed that steelhead and chinook salmon migrate downstream in fall and winter until areas with larger substrate are encountered. In summer, clean substrates contribute to carrying capacity by providing habitat for invertebrates that fish utilize as prey. In winter, the substrate is more important as a source of cover.

Cover is an important, but difficult to define, aspect of salmonid habitats in streams. Features that provide cover include water depth, water turbulence, large-particle substrates, overhanging or undercut banks, overhanging vegetation, woody debris, and aquatic vegetation. Cover provides security from predation for fish and allows them to occupy portions of streams they might not use otherwise. Fish abundance in streams has been correlated with the abundance and quality of cover in studies of cutthroat trout, steelhead, and chinook salmon. Large woody debris is an important form of cover linked to abundance of juvenile coho salmon and steelhead.

Alteration of Salmonid Habitats by Land-Use Practices

Modification of aquatic habitats generally affects one or more of six fundamental components of stream ecosystems: channel structure, hydrology, sediment input, environmental factors, riparian forests, and exogenous material (Table 1). Actions that change channel structure, hydrology, or sediment delivery essentially alter the physical habitat that can be occupied by anadromous salmonids. Environmental factors change either the physical environment or water chemistry, which either directly affect the physiology of salmonids or indirectly influence their food resources. Riparian forests influence numerous processes such as flood routing, sediment trapping, nutrient uptake, energy inputs, wood, shade, stream temperature, and root strength. Exogenous materials, including dissolved chemicals, particulate material, and exotic organisms, represent factors commonly not part of the evolutionary history of the aquatic ecosystems. Responses to these introduced materials can be severe and can persist as long as the material remains in the ecosystem.

Conversion of lowland forests, coastal tide lands, floodplains, and headwater forests, as well as alteration of water quality have affected anadromous salmonids and aquatic ecosystems throughout the Pacific Northwest. Much of the habitat of lower main rivers is no longer in forest lands but instead is in areas zoned for agriculture, urban, and industrial development. Many of these lands have been converted from coniferous forests to grasslands, meadows, deciduous forests, or paved surfaces. As a consequence of settlement, many historical lowland or floodplain forests have been eliminated, and recent society has little memory

of the conditions of those riparian forests and the roles that they played. Riparian forests in lower valley floodplains, particularly secondary channels and off-channel ponds, were particularly critical for the survival of rearing salmon during winter floods and provided cold-water refuges during warmer periods of the year.

Assessment of habitat loss is limited to a few case studies. Comparison of current conditions of the upper Willamette River with maps constructed by the cadastral land survey of the 1850s reveals extensive simplification. Sections of the river, originally braided and containing side channels and floodplain lakes, are now single channels with little or no lateral connections. Lowland streams and rivers have been simplified and channelized so extensively that it is rare to find reaches that resemble natural channels and floodplain forests.

Land-use practices differ in their impacts and on the portions of the landscape and river drainages that are altered. Forested lands make up 46% of the land cover of Washington, Oregon, and Idaho, and the federal government manages or supervises ~60% of the forest lands. Rangelands account for 32% of the land base, and croplands and pasture make up another 20%. Only 2% of the Pacific Northwest is represented by urban or developed lands.

Habitat Loss Associated with Forest Management

Forest practices,e.g., timber harvest, yarding, road building, alter many processes of watersheds and aquatic ecosystems. These interactions have been evaluated and synthesized in several major symposia, reports, and books. These works provide detailed reviews of the effects of forest practices on aquatic ecosystems; the following summary highlights some of the major changes related to habitat alteration in forest lands.

Historical Habitat Change

When commercial logging began in the mid-19th century rivers served as the early routes for transportation. Splash dams were constructed to generate sufficient flows for moving the logs

down stream channels. During relatively low flow conditions, a slurry of water and logs was suddenly released, destroying riparian zones and aquatic communities as it moved downstream. Structurally complex habitats within these streams were channelized and cleared to facilitate transportation. Splash damming and log drives from the 1870s through the 1920s altered streams and rivers to such an extent that they have not yet fully healed.

The history of logging on both public and private lands in the Pacific Northwest left a legacy of altered habitats that will require considerable time for recovery, and the return to historical conditions will probably never occur on a large proportion of the forested landscape. Stream surveys by federal agencies have shown that habitat is in fair to poor condition (BLM 1991, FEMAT 1993, Hessburg 1993, Thomas et al. 1993). The BLM estimated that 64% of the riparian areas on their lands in Oregon and Washington and 45% of their riparian areas in Idaho did not meet the objectives of their management policies (BLM 1991). FEMAT (1993) concluded that "aquatic ecosystems in the range of the northern spotted owl exhibit signs of degradation and ecological stress.... Although several factors are responsible for declines of anadromous fish populations, habitat loss and modification are major determinants of their current status."

One of the few quantitative studies of habitat change was based on a survey of pools in Pacific Northwest streams, conducted by the USFWS from 1934 to 1946. The Pacific Northwest Research Station of the USFS and its cooperators resurveyed the same streams 50 years later to determine changes in channel conditions. Frequencies of very large pools in 658 km of stream in 13 basins in Washington and Oregon decreased by an average of 58%. On the basis of habitat surveys from 1934 to 1946, McIntosh et al. (1994) concluded that the frequency of large pools in watersheds with forest management in eastern Oregon and Washington declined by an average of 31%, while pools in unmanaged basins increased by 200%. These changes have occurred since 1934, which followed more than 80 years of extensive habitat alteration in all of the surveyed basins. Loss of large-pool habitat has been caused by various forest management-related factors, including the removal of large wood and large boulders, an increase in the amount of fine

sediment (sand and gravel) deposited in pool bottoms, and in some instances, by channelization (FEMAT 1993).

A study of streams in old growth forests, forests with moderate harvest (<50% harvested within the last 40 years), and forests with intensive harvest (>50% harvested within the last 40 years) in western Washington documented significant changes in pool habitat and amounts of large wood. Pool areas and depths were significantly lower in streams in old-growth forests than in harvested basins, and pools >1 m in depth were almost eliminated in harvested basins. A reduction in the abundance of large pieces of wood was also related to logging.

Channel Structure

One of the most profound changes in habitat related to forest practices is alteration of channel structure. Channel structure can be affected directly by sedimentation, mass failure, changes in rooting and vegetative cover, and direct channel modification by heavy equipment. Channels can respond differently to physical change depending on geology, climate, sediment loading, vegetation, slope, and basin position. Decreased heterogeneity of channel units and loss of pool habitat are common responses to forest practices in the Pacific Northwest.

The 1970s marked the first well-documented recognition of the role of wood in stream ecosystems. Numerous studies have demonstrated that clearcutting, often in combination with stream clean-up, have dramatically reduced the volumes and types of wood in streams throughout the region. Removal of mature trees along streams reduces natural loading rates for centuries. Loss of wood from channels directly influences the distribution and abundance of fish populations and is one of the longest lasting effects of forest harvest on anadromous salmonids.

Floodplains are fundamental and often overlooked components of stream channels and alluvial valleys. Secondary channels provide important refugia in moderate to high-gradient streams during floods. Seasonally flooded channels and riverine ponds support a major component of the populations of coho salmon and other fish species during winter months

(Peterson 1982, Peterson and Reid 1984, Brown and Hartman 1988). Loss of floodplain habitats in both montane and lowland riparian forests has been one of the most pervasive and unregulated forms of habitat loss in the Pacific Northwest (NRC 1996).

Habitat Loss Associated with Agriculture and Livestock Grazing

Agricultural lands (including croplands and pastures) make up ~20% of the land base of the region, and rangelands account for >30% of the land. In combination, lands used for production of crops or livestock account for ~50% of the northwestern states. These lands are located in the lower portions of the river basins where stream gradients are low and valleys are formed primarily by alluvial deposition. Agricultural and rangelands usually contain more species of fish than steeper headwater streams in forests and often some of the more productive aquatic habitat within the basin. These lands also contain the mainstem reaches essential for the migration of anadromous salmonids.

Land-use practices on agricultural and range lands have greatly reduced the availability and quality of salmonid habitat. Agricultural lands generally occur in lowland valleys that historically contained the majority of floodplains and wetlands within the region. Most of these aquatic habitats were eliminated by channelization, draining, road building, and filling operations prior to World War II. Fishery biologists have no quantitative measures of the degree to which the elimination of lowland aquatic systems affected salmon, but recent evidence indicates that these were some of the most productive habitats within the landscape. Studies of the effects of livestock grazing on aquatic ecosystems and salmonids generally have observed responses consistent with studies of habitat relationships on forest lands. Where riparian vegetation is heavily grazed and channel structure is changed, populations of some fish species decline, the balance of species is altered, and stream flows are negatively affected.

Habitat Loss Associated with

Urbanization

Urban lands make up only 2% of the land base of the Pacific Northwest. They, however, exert a disproportionate influence on salmonid production, because urban areas are frequently located in important salmonid migration corridors and wintering sites. In spite of their relatively small area, >70% of the population of the region lives in cities and towns (76%, 70%, 57%, 93% for Washington, Oregon, Idaho, and California, respectively [American Almanac: Statistical Abstracts of the United States 1994]). The urban sector primarily dictates regional resource management, though constraints on land use are borne almost entirely by the rural sector. Increases in the proportion of the urban population will only create greater conflicts between interests of the general public, private landowners, and natural resource agencies that manage the majority of the land base.

Though total urban area may be small, cities and towns are located at critical positions on major rivers, tributary junctions, and estuaries. The confluences of major rivers in the Pacific Northwest, e.g. the Willamette and Columbia rivers, Puget Sound, and its tributaries, are centers of major regional metropolitan. Aquatic habitats in urban areas are more highly altered than in any other land-use type in the Pacific Northwest, and the proportion of the streams within the urban areas that are degraded is greater than the proportion of highly altered streams on agricultural, range, or forested lands.

Most urban areas are located on historical wetlands, but drainage requirements for residences and urban centers have eliminated ~90% of these productive aquatic habitats in some drainage systems. Water quality and habitat conditions in these critical migration pathways within river networks potentially restrict movement of salmonid smolts from their natal streams, survival in winter rearing areas, or return of adult salmon to the headwaters. In addition, habitat degradation and direct effects on invertebrate communities reduce food supplies for fish assemblages. Loss of wetlands, tidal sloughs, and estuaries in heavily urbanized or industrialized river basins have been extensive. In some areas of Puget Sound, over 95% of estuarine and coastal wetland habitats have been eliminated since the 19th century. Though forest practices and, to a lesser degree, agricultural practices have drawn intense scrutiny resulting in more protective land-use regulations, urbanization and industrial development tend to cause the most extensive alteration of aquatic ecosystems. Future population increases in the Pacific Northwest will expand the spatial extent of this source of habitat loss.

Table 1. Types of habitat alteration and effects on salmonid in the Pacific Northwest. From Gregory and Bisson 1997, copied with permission.

Ecosystem feature	Altered component	Effects on salmonid fishes and their ecosystems	Selected references
Channel structure	Floodplains	Loss of overwintering habitat, loss of refuge from high flows, loss of inputs of organic matter and large wood	Peterson and Reid (1984), Sedell and Froggatt (1984),Brown and Hartman (1988), Booth (1991)
	Pools and riffles	Shift in the balance of species, loss of deep water cover and adult holding areas, reduced rearing sites for yearling and older juveniles	Hawkins et al. (1983), Bisson and Sedell (1984), Sullivan et al. (1987), Bisson et al. (1988), Moore and Gregory (1988), Sedell and Everest (1991), Ralph et al. (1994)
	Large wood	Loss of cover from predators and high flows, reduced sediment and organic matter storage, reduced pool-forming structures, reduced organic substrate for macroinvertebrates, formation of new migration barriers, reduced capacity to trap salmon carcasses	Narver (197 1), Swanson and Lienkaemper (1978), Bryant (1983), Cederholm and Peterson (1985), Harmon et al. (1986), Bisson et al. (1987), Andrus et al. (1988), Murphy and Koski (1989), Aumen et al. (1990), Gregory et al. (1991), Naiman et al. (1992)
	Substrate	Reduced survival of eggs and alevins, loss of interstitial spaces used for refuge by fry, reduced macroinvertebrate production, reduced biodiversity	Burns (1972), Murphy et al. (1981), Hawkins et al. (1982), Everest et al. (1987), Swanson et al. (1990), Montgomery and Buffington (1993)
	Hyporheic zone	Reduced exchange of nutrients between surface and subsurface waters and between aquatic and terrestrial ecosystems, reduced potential for recolonizing disturbed substrates	Stanford and Ward (1988, 1992), Triska et al. (1989, 1990)
Hydrology	Discharge	Altered timing of discharge-related life cycle cues (e.g., migrations), changes in availability of food organisms related to timing of emergence and recovery after disturbance, altered transport of sediment and fine particulate organic matter, reduced biodiversity	Swanson et al. (1982), Bilby and Bisson (1987), Chamberlin et al. (1991), Naiman et al. (1992)
	Peak flows	Scour-related mortality of eggs and alevins, reduced primary and secondary productivity, long-term depletion of large wood and organic matter, involuntary downstream movement of juveniles during freshets, accelerated erosion of streambanks	Cristner and Harr (1982), Berris and Harr (1987), Culp (1988), Anderson (1992), Borchardt (1993), Luchetti and Fuerstenburg (1993)

*See original document for Table references.

Ecosystem feature	Altered component	Effects on salmonid fishes and their ecosystems	Selected references
	Low flows	Crowding and increased competition for foraging sites, reduced primary and secondary productivity, increased vulnerability to predation, increased fine sediment deposition	Smoker (1955), Mason and Chapman (1965), Chapman (1966), Wissmar and Swanson (1990), Hicks et (1991a)
	Rapid fluctuations	Altered timing of discharge-related life cycle cues (e.g., migrations), stranding, intermittent connections between mainstem and floodplain rearing habitats, reduced primary and secondary productivity	Puff and Ward (1989), Reice et al. (1990)
Sediment	Surface erosion	Reduced survival of eggs and alevins, reduced primary and secondary productivity, interference with feeding, behavioral avoidance and breakdown of social organization, pool filling	Cordone and Kelly (1961), Bums (1972), Iwamoto et al. (1978), Noggle (1978), Bisson and Bilby (1982), Berg and Northcote (1985), Everest et al. (1987), Chapman (1988), Platts et al. (1989)
	Mass failures and landslides	Reduced survival of eggs and alevins, reduced primary and secondary productivity, behavioral avoidance, formation of upstream migration barriers, pool filling, addition of new large structure to channels	Beschta (1978), Cederhohn et al. (1981), Everest et al. (1987), Swanson et al. (1987), Chapman (1988), Benda (1990), Chamberlin et al. (1991), Megaban et al. (1992)
Water quality	Temperature	Altered adult migration patterns, accelerated development of eggs and alevins, earlier fry emergence, increased metabolism, behavioral avoidance at high temperatures, increased primary and secondary production, increased susceptibility of both juveniles and adults to certain parasites and diseases, altered competitive interactions between species, mortality at sustained temperatures >23-29°C, reduced biodiversity	Brett (1952), Averett (1969), Hall and Lantz (1969), Brown and Krygier (1970), Bisson and Davis (1976), Wurtsbaugh and Davis (1977), Newbold et al. (1980), Tschaplinski and Hartman (1983), Hughes and Davis(1986), Beschta et al. (1987), Reeves et al. (1987), Holtby (1988), Platts and McHenry (1988), Bjornn and Reiser (1991), Karr (1991)
	Dissolved oxygen	Reduced survival of eggs and alevins, smaller size at emergence, increased physiological stress, reduced growth	Davis (1975), Ringler and Hall (1975), Brett and Blackburn (1981), Scrivener (1988), Bjornn and Reiser(1991)

Aquatic Habitat Indicators

Ecosystem feature	Altered component	Effects on salmonid fishes and their ecosystems	Selected references
Nutrients		Increased primary and secondary production, possible anoxia during extreme algal blooms, increased eutrophication rate of standing waters, certain nutrients (e.g., non-ionized ammonia, some metals) possibly toxic to eggs and juveniles at high concentrations	Dimick and Merryfield (1945), Warren et al. (1964), Triska et al. (1984), Gregory et al. (1987), Bothwell(1989), Nelson et al. (1991), Bisson et al. (1992)
Riparian forest	Production of large wood	Loss of cover from predators and high flows, reduced sediment and organic matter storage, reduced pool-forming structures, reduced organic substrate for macroinvertebrates	Narver (1971), Swanson and Lienkaemper (1978), Bryant et al. (1983), Grette (1985), Harmon et al. (1986), Bisson et al. (1987), Andrus et.al. (1988), Murphy and Koski (1989), Aumen et al. (1990), Shirvell (1990), Van Sickle and Gregory (1990), Bilby and Ward (1991), Gregory et al. (1991)
	Production of food organisms and organic matter	Reduced heterotrophic production and abundance of certain macroinvertebrates, reduced surface-drifting food items, reduced growth in some seasons	Mispagel and Rose (1978), Naiman and Sedell (1979), Vannote et al. (1980), Minshall et al. (1985), Gregory et ai. (1987), Wissmar and Swanson (1990), Gregory et al. (1991), Bilby and Bisson (1992), Naiman et al. (1992)
	Shading	Increased water temperature, increased primary and secondary production, reduced overhead cover, altered foraging efficiency	Murphy et al. (1981), Shortreed and Stockner (1983), Wilzbach (1985), Gregory et al. (1987), Culp (1988), Bilby and Bisson (1992)
	Vegetative rooting systems and streambank integrity	Loss of cover along channel margins, decreased channel stability, increased streambank erosion, increased landslides	Burroughs and Thomas (1977), Beschta (1991), Platts(1991), National Research Council (1992), Forest Ecosystem Management Assessment Team (1993)
	Nutrient modification	Altered nutrient inputs from terrestrial ecosystems, altered primary and secondary production	Berg and Doerksen (1975), Minshall et al. (1985), Gregory et al. (1991), Stanford and Ward (1992)
Exogenous material	Chemicals	Reduced survival of eggs and alevins, toxicity to juveniles and adults, increased physiological stress, altered primary and secondary production, reduced biodiversity	Dimick and Merryfield (1945), Seiler (1989), Karr(1991), Nelson et al. (1991), Norris et al. (1991)
	Exotic organisms	Increased mortality through predation, increased interspecific,competition, introduction of diseases	Li et al. (1987), Karr(1994), National Research Council(1996)

*See original document for Table references.

4. A LANDSCAPE CONTEXT FOR HABITAT INDICATORS

Temporal and Spatial Scales

Pacific Northwest stream communities respond to environmental variability in different ways at different scales of time and space. Gaining an understanding of these biological and physical habitat-shaping processes is, therefore, a matter of understanding temporal and spatial scale. Assessments conducted at one scale cannot reliably evaluate the effects of processes that are most important at other scales, and may in fact produce misleading results (Wiens 1981). Spatial scales for habitat studies are often dictated more by resource constraints than by sound study design. Results from studies at a few local plots in various habitats that are then generalized to the broader realm can lead to the application of a correct insight to the wrong situation (Wiens 1981, Conquest and Ralph 1998) A solution to this potential confusion is to understand how the physical processes that produce the patterns in populations and habitats vary as a function of scale. Recent advances in the physical sciences help considerably in providing the perspective tools to aid our understanding of patterns and processes operating at the landscape and watershed scale.

Hierarchical Context

Variability in Pacific Northwest freshwater and estuarine ecosystems mirrors interactions of processes that operate at multiple scales. Recognizing the existence and importance of these scales and sorting out their interactions helps make sense of this variability. Hierarchy theory advances the idea that ecosystem processes and functions operating at different scales form a nested interdependent system where one level influences other levels above and below it. Understanding one level in a system is greatly informed by those levels immediately above and below it, but much less

so by those levels a long way from it (Greenland 1998). In reality, there is a continual shifting of aquatic habitat conditions (over space and time) that reflects the fact that controlling processes are highly variable across the landscape. The rate, pattern, duration and magnitude of changes to these controlling processes are occasionally reset by high impact events (*pulse disturbances*), which helps explain why we see opposing areas of habitat abundance and scarcity (Greenland 1998). These features are expected as part of the natural character of watersheds. *Press disturbances* (more frequent, less dispersed or chronic occurrences) are more often associated with human activities and also drive the quality and quantity of aquatic habitats, although often at smaller scales. Salmon and trout populations native to the Pacific Northwest streams have adapted over the millennia to these variable conditions and, until recently, have been able to maintain large, diverse and distinct runs within the larger populations of the various species. The cumulative effects of watershed processes accelerated by human activities can impose persistent, widespread declines in habitat quality throughout the historic range of salmon and trout.

Control Factors and Scale

How can these fundamental principles be used to stratify assessment information and to help distinguish between landscape scale factors (ultimate controls) and local scale factors (proximate controls) that affect the characteristics of watersheds and streams? What are the principle factors that could be used to stratify our focus? How can we use these principles as we try to identify and apply a suite of appropriate variables (factors, parameters) that reflect meaningful habitat changes and relate to processes affected by human activities?

Ultimate controls, such as climate, geology (landform) and vegetation (land cover), refer to factors that operate over large areas, are stable over long time periods (hundreds to thousands of years), and act to shape the overall character and attainable conditions within drainage networks. ***Proximate controls*** are a function of ultimate factors and refer to local conditions of geology, landform and biotic processes operating over smaller areas (e.g. reach scales)

and over shorter time spans (decades to years). These factors include such physical processes as precipitation patterns, discharge, temperature, localized hill-slope erosion and mass slope failures, channel migration, sediment input and routing, and associated biological processes. All of these proximate factors are influenced as well by an equally diverse mix of human activities (Naiman et al. 1992, Figure 3).
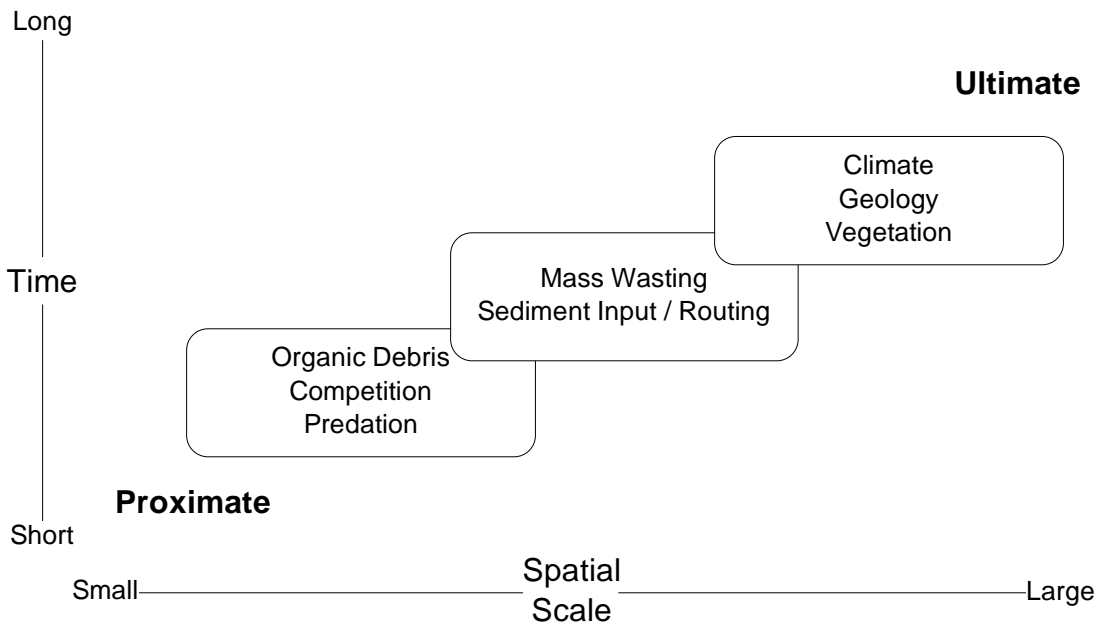
Figure 3. The role of ultimate vs. proximate factors in determining watershed and stream characteristics (Naiman et al. 1992).

Classification Systems

Objectives of Classification

The term "classification" suggests that sets of characteristics and observations can be organized into meaningful groups based on measures of similarity or difference. Experience suggests that each stream type possesses a set of inherent and presumably predictable attributes (e.g. channel pattern, dimensions and profile, bio-geo-chemical signature, resistance and response to change, and biotic productivity), which reflect the expressions of local climate, geology, landform and disturbance regimes.

Basin characteristics (size, climate, geology) help define flow (water and sediment) characteristics which in turn help shape channel characteristics within some broadly predictable ranges (Rosgen 1996, Orsborn 1990).

Understanding these inherent relationships is the key to identifying the appropriate factors for the assessment of the *status and trends* of aquatic systems, including the communities of organisms they support. Understanding how various geologic and climatic processes interact within a watershed gives a more thorough picture of the natural conditions (actual and potential) as well as of the direction and

magnitude of possible changes triggered by natural or human disturbances.

Early efforts were made to develop a more systematic approach for understanding the natural variability found in stream channels, their riparian zones, and floodplains. These systems tried to identify those common characteristics which when compared among streams allowed for some assessment of relative stream "health" (Naiman et al. 1992). These efforts have lead to an evolving legacy of stream channel classification systems, most of which are based on the assumption that patterns in channel morphology can be used to simplify the wide array of stream conditions encountered. Many of the systems developed were driven by the desire to associate key habitat types with certain fish life stages. Much effort has been expended on data collection and comparison in an attempt to find commonalties and patterns across the broad range of stream types and sometimes without the benefit of a logical basis to limit the confusion of inherent differences. Organization of stream types is possible, once it is recognized that the stream is a product of the landscape and that landscapes sharing common climatic and geologic features likely produce streams of a similar character. A common geo-climatic setting will impart certain common characteristics of instream habitat features. This setting does not, however, explain the range within certain stream characteristics, particularly those often associated with what we interpret as "biotic health". Factors which operate at a more local level also influence the habitat features and ultimately the biotic health of the system.

One view of aquatic classification is to nest stream and watersheds within a broader landscape scale using the concept of ecoregions, an area with relative homogeneity in the characteristics and components that constitute an ecosystem (Omernik and Bailey 1997). At the ecoregion scale, ranges of expected values for habitat quality indicators can be developed empirically from data representing reference conditions. The reference conditions should allow us to understand better the range in expression of several variables and - by inference - reflect the actual potential stream habitats within a particular basin context.

As discussed previously, we recognize that this approach has several immediate limitations.

First, there is little agreement currently on what constitutes reference areas to cover the ecoregions identified at the Level III scale. Identification and use of reference areas is an ongoing effort at the state and regional level. Secondly, the currently available databases generally are not sufficiently robust to provide statistically reliable values. Third, there are some ecoregions or regional areas, such as grass/shrub lands, where land management has been so pervasive as to eliminate entirely the potential for reference conditions. Regardless of these current limitations, we believe it is useful to outline an approach and then initiate the search for appropriate data sets or encourage the collection of appropriate data. In the interim, we will need to depend on the published data sets available and use them with appropriate caution.

Derivation of Habitat Indicator

Variables and Stream Classification

The challenge of selecting appropriate habitat indicators is one of determining from what level on this continuum of controlling factors should habitat variables be derived. Variables drawn from processes associated with ultimate controls lack the resolution to allow for meaningful comparison of stream habitat over time and space. Variables associated with proximate controls vary enough in space and time to allow tracking of changes in habitat quality, but the dynamic nature of these processes does not allow for meaningful comparisons between streams and within the same stream over time. To assure comparable stream conditions, the framework of ultimate controls must be incorporated into the analysis when data comparisons are made.

In order to factor in the wide range of processes inherent in both ultimate and proximate controls, ecologists, hydrologists and geographers have developed a number of classification systems (Table 2). These systems can be placed on a scale ranging from micro-habitat features, such as individual pools, to regional features, such as geologic provinces. A defensible classification system will incorporate the entire spectrum of processes influencing stream features and recognize the tiered/nested nature of landscape and aquatic features.

Table 2. Summary of contemporary spatial scale classifications.

Classification System	Spatial Scales Addressed by the Classification System						
	Ecoregion	River Basin	Watershed	Sub-watershed	Valley Segment	Stream Reach	Habitat Unit
Bisson et al. 1982							X
Frissell et al. 1986			X	X	X	X	X
Maxwell et al 1995	X	X	X	X	X	X	
Montgomery & Buffington 1997				X	X	X	
Omernik & Bailey 1997	X	X	X				
Paustian 1992				X	X	X	
Rosgen 1996			X	X	X	X	
Seaber et al. 1987		X	X	X			

Aquatic/Landscape Classification Systems

Frissell et al. (1986) were among the first to describe a spatially-nested hierarchical system for channel classification consisting of *stream system, segment system, reach system, pool-riffle system,* and *microhabitat systems*. This approach emphasizes the watershed-dependent nature of river systems and the importance of physical habitat in controlling biotic organization within a regional bio-geo-climatic framework. Watershed characteristics reflect the geologic and climatic history of the drainage basin. *Stream system* places the entire drainage network in a watershed context. *Segment systems* are portions of streams bounded by such major discontinuities as tributaries or changes in underlying bedrock. Within segments, *reach systems* are defined by breaks in characteristics such as channel slope, bank material, floodplain characteristics, substrate character, and riparian canopy cover. *Pool-riffle systems* are characterized by breaks in bed topography and water surface slope, depth, and velocity pattern. *Micro-habitat systems* are components of pool-riffle systems similar in such morphologic features as substrate type, water depth and velocity (see also Bisson et al. 1987, Hawkins et al. 1993).

Frissell's original nested hierarchy scheme has been expanded to include forces which operate on a more regional basis (ultimate controls) than individual stream systems. Each ecoregion is in turn potentially subdivided into river basins and watersheds. However, it should be recognized that hydrologic boundaries do not neatly fit within the boundaries drawn around similar terrestrial landscapes. Figure 4 is an illustration of a simple hierarchical system that shows watersheds nested within the ecoregion setting. Various other hierarchical schemes are possible and appropriate depending on the purpose for the hierarchical framework.

The geomorphic stream classification system (Rosgen 1986) classifies stream channel systems at the broad scale by their pattern, profile and channel dimensions. At the stream reach level, it has been useful in evaluating suitability of proposed fish habitat structures, livestock grazing systems, and stream restoration projects. Montgomery and Buffington (1993) describe a process-based classification system to delineate streams as sediment source, transport, and response (deposition). In Alaska a functional system was developed for use on the Tongas National Forest (Paustin et al. 1992), which has been widely accepted and is being used to define appropriate forestland management approaches and the overall design of the aquatic monitoring program. The hierarchical framework of aquatic ecological units described by Maxwell et al. (1995) is a comprehensive system that integrates surface water systems, geoclimatic settings, and ground water systems and spans the spatial hierarchy from ecoregion to river reach scale. The highest recognized level in the landscape hierarchy is a broad physiographic area termed 'ecoregion'.

A Hierarchical Approach for Habitat Indicators

The illustration in Figure 4 shows a hierarchical system that integrates the ultimate controls that

operate at the landscape scale (ecoregions) with the proximate controls that operate at the stream channel and stream reach level. Other intermediate levels in the hierarchical system integrate these factors at different geographic scales. We have eliminated the segment level, since this hierarchical level is somewhat arbitrary and not used consistently.

The hierarchical system offers a number of advantages, including:

1. classification at higher levels narrows the set of variables needed at lower levels;
2. it allows for integration of data from diverse sources and of different levels of resolution;
3. it allows the scientist or manager to select the level of resolution most appropriate for their objectives;
4. and, it allows the distinction between inherent differences and those associated with the imprint of human activities, thus aiding in the interpretation of observations.

Ecoregions

Geology and climate are ultimately responsible for setting the stage on which factors that operate at more local scales and shorter time frames act to shape channel conditions. For habitat variables, it is, therefore, appropriate to select a top tier, the ecoregion, that is stratified primarily on these factors. The *ecoregion* delineation not only provides a framework for a landscape hierarchical scheme (Omernik 1995), but ecoregions have also been used as the initial basis for classifying streams (Whittier et al. 1988); the authors use geology, vegetation and climate as the basis for their initial stream stratification. Ecoregions are further delineated based on soils, land use, wildlife, and hydrology.

Ecoregions have been used successfully to stratify the landscape for description of aquatic biological communities. Fish assemblage patterns corresponded well to ecoregions in three statewide assessments (Hughes et al. 1990). Ecoregions have been recognized as the initial stratification level for some statewide monitoring and bioassessment programs (Hughes et. al. 1994, Hughes 1995).
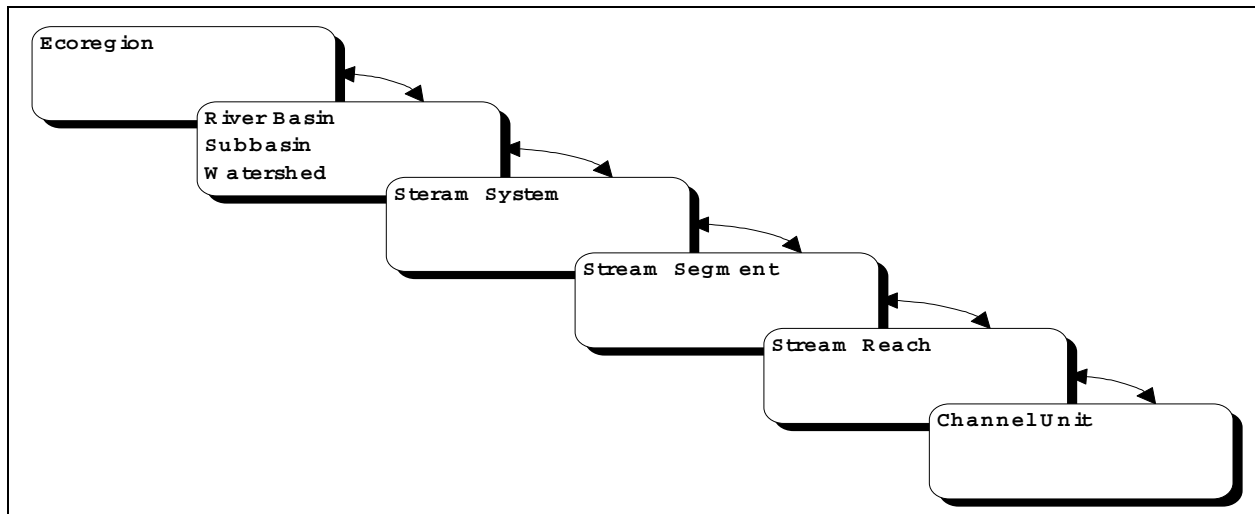
Figure 4. Hierarchical scheme of landscape and stream network.

River Systems, Watershed, Sub-watershed

These levels have been grouped together here for the purpose of common discussion. They all display clear hydrographic boundaries with increasing similarities in geologic and topographic features as one moves downscale within the hierarchical framework. Distinguishing features include relative basin area and position in the drainage network. These levels correspond to the fourth and fifth "field" of the Hydrologic Unit Code system

(Seaber et al. 1987) commonly used by many state and federal agencies. Basins within a given "field" vary in size by an order of magnitude (e.g., 5th field HUC can be 10 km. sq. – 100 km. sq. in area), so simple comparisons of one 5th field watershed to another should be done with caution. Stratification based on lithology and topography would seem to offer greater opportunity to compare similar basins.

Stream System

The stream system incorporates features of the lowest level of the hierarchical system, i.e. those features which directly define biotic health. Assessment at the stream system level is usually necessary to address cumulative effects (Frissel et al. 1986) but requires information of sufficient rigor and resolution to be useful. Stream systems are of similar geologic structure within any given area and operate on a time scale of tens to hundreds of years, responding to major geologic events and trends. Channel features such as pattern are usually similar within any given stream system, while features such as slope may display a predictable pattern or range.

Stream Reach

Stream reach is probably the most critical level of the hierarchy with respect to habitat variables. This is due to the fact that the stream reach exists at the crossroads where both ultimate controls and, for the first time in the hierarchy, proximate controls are evident. For example, geology and landform dictate stream gradient, but the influence of organic debris can influence the character of a defining habitat component such as plunge pools. As such, the features that delineate the stream reach are critical variables when defining and comparing habitat quality.

The stream reach is the level most commonly associated with assessment of biologic integrity. This level also displays the influence of the major "inputs" to the stream of water, sediment, and wood. It is, perhaps, the least physically discrete unit in the hierarchy and has been the subject of the most confusion with respect to terminology. Common geomorphic parameters, such as channel pattern, profile, entrenchment, stream and valley width, channel materials, and

vegetation, define stream reach (Maxwell et al. 1995). Reaches operate on a scale of tens to hundreds of years, and stream reach is the highest level in the scheme which can display the influence of stream biota (i.e. wood formed pools).

Channel Unit

Channel units represent specific habitat units (pools, riffles, and glides) and can be quite uniform with respect to their morphologic and hydraulic condition. Channel units are assessed in the context of their stream reach and are often used as a diagnostic tool for assessing apparent status and trends in the overall quality of aquatic habitat. They are less useful in determining cause and effect relationships, since they often are the cumulative outcome of events that happened upstream even years before. For example, pool filling by gravel wedges could result from slope failures decades before. Channel units operate on very short time scales of years and respond readily to natural and human caused changes associated with sediment and discharge input processes.

Stratification at the Stream Reach Level

Ideally, aquatic indicator variables are those which are most biologically relevant, quantitative, and repeatable. The variables must reflect the various inputs (water, sediment, and wood) that influence all levels of the aquatic hierarchical scheme. The stream reach and stream segment levels appear to be most logical level to derive suitable indicator variables (Frissel et al. 1986, Rosgen 1996, Montgomery and Buffington 1993). The level below stream reach, the channel unit, inherently displays significant variability over short periods of time and space, which limits its potential utility in organizing habitat variables. The stream reach scale integrates (smoothes out) the variability inherent at the finer scale and provides a grouping level of the stream that can be used for comparison of stream reaches over time or between stream reaches.

The common set of defining features for stream classification systems at the *Stream Reach* scale are channel gradient and confinement

(Rosgen 1996, Montgomery and Buffington 1993). The third variable, which commonly defines a stream reach, is some measure of stream power such as bankfull width. Bankfull width, along with the associated discharge regime, serves as a consistent morphological index that relates to channel formation and maintenance. The Channel Type Users Guide for southeast Alaska (Paustian et al. 1992) is channel classification system that uses all three criteria (bankfull width gradient, and confinement) along with incision depth as the principal criteria to define stream reach.

Stream Gradient

Stream gradient is the change in water surface elevation over a given distance expressed as a percentage. Gradient is directly related to both bed-material load and grain size and is inversely related to discharge (Schumm 1977). In practice, gradient is usually first determined approximated from topographic maps and then field verified with reliable techniques. Error in either technique is greatest in low gradient (<3%) channels. Longitudinal profiles using engineer survey equipment is the most accurate means of determining channel gradient.

Gradient classes are useful in grouping streams with a similar response to flow and sediment inputs. The following gradient classes illustrate some grouping of channels but are sensitive to lower gradient streams (see Montgomery & Buffington 1993, Rosgen 1996). Twenty percent is selected as the upper level due to the dominance of terrestrial, rather than fluvial, processes that define the morphologic characteristics of these steep channels.
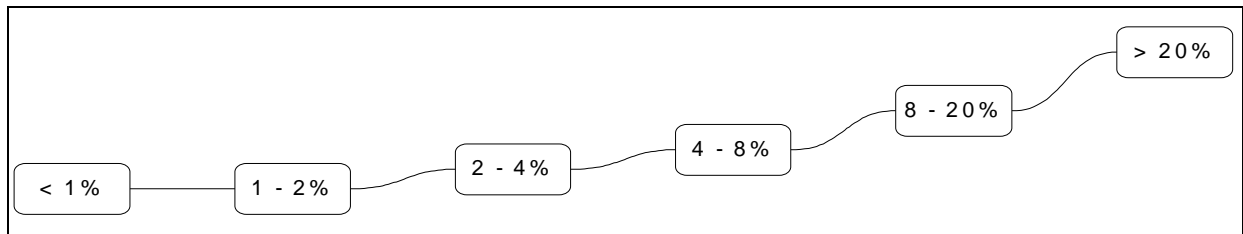
Figure 5. Gradient classes for channel grouping.

Stream Confinement

Determination of stream *confinement* is the subject of considerable confusion. This is unfortunate, since the ability of a stream to move laterally is always of prime concern to land managers and biologists. Most definitions of stream confinement refer to the ratio of the active channel (i.e. the bankfull width) to the valley bottom or floodplain width (Ralph et al. 1992, Moore et al. 1993, and Rosgen 1996).

Much of the confusion relates to interpretation of valley bottom or floodplain width. Some classification systems utilize the width of some defined event such as the 100 year flood, while others employ total valley width regardless of whether the valley floor is a historic remnant isolated from the current day channel.

An appropriate definition identifies confinement as the ratio of the bankfull width to the width of the modern floodplain. The modern floodplain may be synonymous with the 100 year floodplain or channel migration zone. Determination of bankfull width requires some careful observation and field calibration with known flow – stage information.
Commonly used confinement classes include:

- U-unconstrained: Floodplain width > 4 times bankfull width.
- M-moderately constrained: Floodplain width 2 – 4 times bankfull width.
- C-constrained: Floodplain width < 2 times bankfull width.

Bankfull Width

Bankfull width is used as a surrogate for bankfull discharge. Bankfull discharge can be described as that flow (Q) volume which transports the largest portion of the annual sediment load, including bedload, over a period of years

(Wolman and Miller 1960). It is that flow which mobilizes the majority of the bed material as well as developing and maintaining the form of the channel (Olsen et al. 1997). It is a critical discharge, as channel forming forces do not increase proportionately at flows greater than bankfull due to over-bank dissipation of energy. Bankfull flows generally correspond to the 1.5 to 2 year recurrence flow event (Bray 1982). Measurement of bankfull width is a repeatable variable but often difficult to identify in non-entrenched channels.

Summary

Landscape scale factors (ultimate controls) and local scale factors (proximate controls) influence the expression of stream habitats.   The landscape scale factors, such as climate, geology, and vegetation operate over large areas, are stable over long time periods (hundreds to thousands of years) and act to shape the overall character and attainable conditions within drainage networks.   Local scale factors are a function of ultimate factors and refer to local conditions of geology, landform and biotic processes that operate over smaller areas (e.g. reach scales) and over shorter time spans (decades to years).   A hierarchical classification system that integrates both landscape scale factors and local scale factors provides the organizational framework necessary to address the spatial variability inherent in aquatic habitats.

Ecoregions provide a first-tier of organization which are stratified on the basis of ultimate factors - climate, geology, and vegetation. At the ecoregion scale, the ranges of expected values for habitat quality indicators can be developed empirically from data representing reference conditions. The reference conditions allow us to better understand the range of values that reflect the actual potential stream habitats within a particular basin context.

The hierarchical stream system, tiered within ecoregions, provides a way to organize the local scale factors which influence the stream condition.   The stream reach and stream segment levels of the stream network are the most logical level from which to derive suitable indicator variables.   The level below stream reach, the channel unit, inherently displays significant variability over short periods of time

and space, which limits its potential utility in organizing habitat variables. The stream reach scale integrates (smoothes out) the variability inherent at the finer scale and provides a grouping level of the stream that can be used for the comparison of a stream reaches over time or between stream reaches.

The common set of defining features for stream classification systems at the *Stream Reach* scale are channel gradient, channel confinement, and bankfull width. Bankfull width, along with the associated discharge regime, serves as a consistent morphological index that relates to channel formation and maintenance. Bankfull width provides a measure of stream power. Drainage basin area is a closely related hydrologic variable that has proven to be useful in explaining the variability in geomorphic channel characteristics and habitat variables.

Ecoregions and stream classification systems provide a framework for organizing habitat components, habitat variables, and narrative as well as numerical indicators.   The Level III Ecoregions may provide a sufficient first iteration for categorizing watersheds in order to evaluate potential reference conditions for many habitat variables.   Further sub-division of Ecoregion organization may be useful in providing a more homogeneous organization of watersheds but may also be a daunting task given the limited amount of data on reference condition.   A meaningful organization of stream networks ultimately depends on the identification of geomorphically similar stream reaches. Fundamental factors in organizing stream reaches are stream gradient, confinement, and stream power (bankfull width or basin area). Classification systems that incorporate these factors should be useful in developing a spatial framework for habitat indicators.

5. AN APPROACH TO HABITAT QUALITY INDICATORS

A framework for developing habitat quality indicators will address the challenges that we summarized above, namely accounting for natural variability, legacy effects of past land uses and natural disturbance patterns, improving measurement methods, and addressing the lack of habitat data from undisturbed areas to serve as reference conditions. A fundamental issue relates to how the indicator is used within the context of the water quality management program. Different approaches to the application of indicators in environmental and natural resource programs have been discussed in the literature and provide a useful context for thinking about approaches to the use of aquatic habitat indicators.

Types of Indicators

Cairns et al. (1993) proposed organizing indicators into three general types*: compliance indicators*, *diagnostic indicators*, and *early warning indicators*. *Compliance indicat*ors are those chosen to judge the attainment and maintenance of ecosystem objectives. Traditional water quality criteria generally fit within this category. Criteria for toxic chemicals or heavy metals, for example, are established at some threshold of effect intended to protect the aquatic biota. In many cases, the most useful parameters in judging compliance with a specified objective are not the best for determining why objectives are not being met. *Diagnostic indicators* are those parameters and processes that provide insight into the cause of noncompliance. *Early warning indicators* are those that assist in maintaining the desired condition by detecting impending deterioration before substantial impact occurs. Water temperature serves as an example of a compliance indicator, while shade and overhead canopy can be considered to be diagnostic

indicators. Early warning indicators for temperature are land management measures such as the percentage of timber harvest in the riparian zone or number of road miles adjacent to the channel.

Closely related to early warning indicators is the concept of *leading edge variables*. Leading edge variables refer to an approach of watershed management that detects problems with ecological processes before they result in irretrievable damage. Conceptually, one should be able to detect changes to the hydrologic regime or sediment regime at the watershed scale before the cumulative effects of upslope activities reach a damaging condition for instream resources. An example of leading edge indicators is the hydrologic analyses of anticipated change in peak flows due to clearcutting and the extension of road networks in forested areas or due to the increase in impervious surfaces in urban areas. Leading edge variables are an important concept to assist in preventing damage to streams at the watershed to river basin scale. However, these concepts are at an early stage of development, and there is no general understanding of what they are or how they might be applied.

No single set of variables fulfills all of the objectives for the different types of indicators. Aquatic habitat indicators likely best fit the description of diagnostic indicators. Aquatic habitat measures do not function as early warning indicators, since they are measured instream after the land management activity has occurred and integrate the effect of both natural disturbances and impacts due to the legacy of management actions over time (i.e. cumulative effects). Potential early warning indicators of habitat damage are measured upslope of the stream channel or upstream as cumulative inputs. Effective early warning indicators will address the management activities in the

watershed such as road density, riparian condition related to shade and large wood recruitment, or sediment sources.

Aquatic habitat variables can be used to assess the quality of the habitat in meeting the needs of beneficial uses. However, because of the high variability in habitat measurement and the lack of a ready connection to source assessment, it appears that habitat variables are best used as diagnostic indicators rather than as compliance measures. The habitat measurement should be used to detect when the environmental condition is outside the expected range supportive of the beneficial use. The reason for such deviation should then be further evaluated by investigating the historical, current, and potentially natural causes of low habitat integrity. A complete monitoring and management program which is effective in protecting beneficial uses will need to address the entire management system from evaluation of on-slope activities to the evaluation of watershed and instream processes and functions. Habitat indicators by themselves can only be expected to fulfill one facet of the role of environmental indicators.

Input vs. Output Approaches to Ecosystem Management

Related to the functional types of indicators is the conceptual model for resource management used to approach problem definition and resolution. The current water quality model for landscape scale management relies primarily on the output-oriented strategy (Montgomery 1995). Output management responds to ecosystem conditions and defines limits to acceptable resource damage. This style of management is considered reactive rather than preventative, since land use activities are modified only after degradation has occurred to levels beyond which further degradation is considered unacceptable. Input management implies a preventative approach based on modifying land use practice to reduce or preclude adverse environmental impacts. The shift in emphasis under the input-oriented approach is toward changing management upslope of the problem before it occurs.

The nonpoint source management program within the CWA can accommodate both the input and output-oriented strategies. Traditional

nonpoint source programs have emphasized the reactive mode by developing and implementing a system of BMP's after significant cumulative damage has occurred. This is in part a function of the lag effect between the legacy of land management activities and the passage of environmental laws. This has also led to some extent to the current backlog of streams listed as 303(d) waters and the need to focus state and federal agency resources on reducing pollutant input to these water bodies through development of TMDL's.

Using Indicators in ESA Review

The NMFS and USFWS use indicators to evaluate the effect of land management activities for conferencing, consultations, and permits under the ESA. Since the purpose is to evaluate the effects of proposed actions on listed species, the decision documents (NMFS 1996, USFWS 1998) address the pathways and indicators of management effects. The pathways include water quality, habitat access, habitat elements, channel condition and dynamics, hydrology, and watershed effects. These pathways and their associated indicators, therefore, address the watershed process and input variables (e.g. road density and disturbance history) as well as outcome variables (e.g. substrate quality, LWD frequency, and W:D ratio). The indicators in the matrix represent a mix of diagnostic, early warning indicators, and outcome variables appropriate to the purpose of the document. These purposes have corollaries in the CWA, but there are also differences due to the different regulatory framework between the two laws. ESA requires the federal regulatory agencies to address habitat protection for endangered species from a very conservative approach. This influences the interpretation of the literature and the selection of default numerical targets.

Suggested Approach for Habitat Quality Indicators under the CWA

The purpose and organizational framework for habitat indicators may differ in a subtle, but important, manner from their use under the ESA. We have identified two purposes for habitat indicators within the CWA. One objective is to assess the status and condition of the habitat

which supports the beneficial use. The second is to evaluate the adequacy of BMP's within the framework of the nonpoint source feedback loop. Because physical habitat features are indeed outcome variables, they function best as an index of the habitat's ability to support the beneficial use and less efficiently as a way to judge the adequacy of the management practices.

Habitat features (as outcome variables) reflect the cumulative effect of all the influences upstream of the assessment reach and, therefore, act as an integrator of the cumulative and interactive effects of upstream processes; these effects can be both attributed to natural sources and management actions, both past and present. The ability to detect the "signal" of management effects within the context of natural disturbance and legacy effects depends on the site-specific conditions and the efficiency of the study design. For this reason, nonpoint source monitoring programs have always recognized (but not fully actualized) the need for implementation and effectiveness monitoring which incorporates the assessment of input variables.

There are two CWA programs where an emphasis on the habitat condition as an outcome variable is clearly needed. One is the establishment of water quality criteria which provides the environmental endpoint desired or expected. The second, and closely related, program is to establish targets for stream segments for TMDL's.

We suggest that the strategy for the use of habitat indicators for CWA purposes should incorporate the following elements:

- An emphasis on the use of habitat variables as diagnostic indicators rather than as compliance criteria.

- Establishing indicators within a spatial framework that accounts for variability in landscape patterns and channel type to specify numerical criteria.

- An emphasis on the quantitative measurement of aquatic habitat indicators to achieve needed precision and repeatability.

- An interagency recognition of the need to identify reference conditions within the ecoregion framework.

- Recognition that, as we learn more, adjustments should be made to the suite of indicators themselves, and the interpretation of what they tell us about the aquatic resources.

The diversity of landscapes and the high natural variability of habitat characteristics preclude the ability to readily identify numerical habitat criteria at regional scales. Habitat indicators must reflect the diversity in habitat quality across the landscape; hence, the need for landscape and stream stratification systems. Within a stream type, the indicator needs to reflect the variability that occurs under a natural setting. The indicator needs to be measured in a reliable and repeatable manner that expresses both the central tendency and the spread of the data.

Habitat indicators are best used within the framework of the nonpoint source feedback loop (see Introduction section) as diagnostic tools of water resource integrity rather than as compliance endpoints. Habitat quality integrates cumulative effects in the watershed from both natural disturbance and from cultural activities. The interpretation of habitat quality for a given stream reach requires consideration of a number of potential sources and watershed processes. Some example scenarios for evaluating the outcome of habitat quality studies are listed below.

Scenarios for Interpretation of

Diagnostic Indicators

Three possible situations are briefly presented below to illustrate common problems and remedies. It is important to stress that knowing what indicators are appropriate depends upon careful assessment and an understanding of what drives the expression of factors important to aquatic habitats. Typically a suite of parameter or factors will contribute relevant information to understanding the nature and significance of the problem that limits the habitat capacity rather than a single indicator.

1) The indicators are applied correctly, but the expected value for a given parameter is

inappropriate at the scale of watershed organization or for the stream classes under consideration. In this case, the land manager or water quality agency can conduct a watershed/basin specific evaluation and suggest more appropriate watershed values. Quality control procedures including scientific peer review would need to be in place to assure the acceptance of the revised indicator value.

2) Anthropogenic impacts, either historic or ongoing, have altered the watershed processes. In this case, the landowner needs to evaluate alternative practices including passive and active means of restoration (See Kaufmann et al. 1997).

3) Natural disturbance events have recently altered the stream condition. In this case, human activities should be evaluated with respect to their contribution to the effect of the event as well as the stress that will be placed on the resource in the future.

Assessment Scale

Another important consideration is the scale at which the evaluation is made. Stream habitat variables are measured at the habitat unit scale – that is, at the scale of pool, riffle, and glides. However, the appropriate scale for evaluating changes to habitat is likely at the next unit of organization, namely at the reach scale. The reach scale describes a uniform section of stream with respect to channel morphology (gradient, confinement, width and depth).

Variability in habitat measures is expected to decrease as one moves upward in scale, i.e. from individual habitat units toward groups of habitat units aggregated at the reach scale. Individual channel habitats can be highly variable in comparison to the expected range of condition, but the spread of the data around the mean or median should decrease as the channel habitat units are aggregated. Evaluating information by geomorphically similar reaches facilitates comparison between managed and unmanaged or reference reaches. Within a watershed context, habitat indicators can be used to identify stream reaches or sub-watersheds outside the expected range. These areas should then be investigated further for causal linkages to watershed activities.

Narrative and Numeric Criteria

Water quality standards provide for specification of narrative and numeric criteria. Numeric criteria are generally specified when the quantitative relationship between the pollutant and the beneficial use are well established in the scientific literature and the criteria are applicable across large geographic areas such as at a state, ecoregion, or river basin scale. Environmental endpoints for water quality criteria are specified no further than the narrative stage when the pollutant-beneficial use relationship is highly variable across the landscape as well as dependant on site-specific factors and, therefore, requires local scale adjustment before numeric targets can be established. Narrative criteria could be used to describe the process for developing the numeric criteria at the local scale.

The NMFS/USFWS matrix uses the terminology of pathway to identify the process by which a management action can have an impact on aquatic biota. Where feasible default numerical criteria are specified that indicate the proper functioning of this pathway. The specification of the pathway is a corollary to the concept of narrative criteria within the CWA. The use of default numeric criteria in the matrix is a corollary to numeric criteria established at the national or statewide level under the CWA. Both approaches provide for a process that identifies site-specific numeric criteria more applicable at a local scale. The fact that this option is rarely exercised is an area of contention between the regulatory and regulated community.

The following sections of this document expand on the suggested approach. In Section 5, we evaluate the existing recommendations of habitat variables as useable for aquatic habitat indicators within the context of CWA water quality programs. Section 6 describes the landscape and stream network considerations for establishing habitat variables. Section 7 describes the context for assessment and monitoring of habitat variables. Section 8 discusses application of habitat indicators to CWA programs.
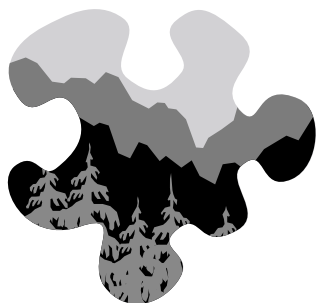
6. EVALUATION OF POTENTIAL AQUATIC HABITAT INDICATORS

Indicators in Relation to Clean Water Act Objectives

Habitat variables have been developed to meet various purposes including assessment of fisheries production, determining limiting factors, identifying the effects of land management, and evaluating habitat improvement activities. Two major interrelated objectives for habitat assessment are evident in CWA programs. The first objective is to determine whether designated beneficial uses are attainable and assess the current status of the beneficial uses in a waterbody. The second objective is to evaluate the effect of pollutant sources on a beneficial use and assess the need for change in pollution controls for point sources or change in management practices for nonpoint source activities. Meeting these two major monitoring themes will dictate the different criteria for the selection of habitat indicators.

The first objective, assessing the status of the beneficial use, identifies the indicator as having an intrinsic importance itself; the indicator is the environmental endpoint. Macroinvertebrate and fish communities are measured directly to assess the status of beneficial uses identified in the water quality standards. A criticism of using aquatic biota as a monitoring indicator is the same one raised in the discussion of habitat measures. The variability in the biotic community can be so high that its direct practical use as an indicator in detecting response to environmental stress is low. With certain types of stressors, the reality is that by the time an effect shows up it is too late for effective management or mitigation (Kelly and Harwell 1990).

The second objective encompasses a major emphasis of water quality programs in providing feedback to regulatory and management programs. In nonpoint source programs, monitoring is categorized under implementation and effectiveness objectives. Implementation monitoring addresses whether the BMP's were installed according to plans or regulations, while effectiveness monitoring is more comprehensive in attempting to determine if the management practices were effective in protecting the beneficial uses (MacDonald et al. 1991). A desirable characteristic of an early warning indicator is rapid responses to the environmental stress. A related trait is that the indicator has a high fidelity in characterizing an effect from disturbance. Strong evidence of a causal relationship between the stressor and a relevant response to the beneficial use is required.

To accomplish either objective in the CWA, habitat indicators need to meet certain expectations for measurement reliability. Expectations of high quality assurance and quality control should be similar to those described for other physical and chemical variables. Signal-to-noise ratio is a particularly important consideration for indicators in a highly variable environment. The sensitivity and, therefore, the utility of the indicator is dependent on detecting the signal of human effects from the background noise in the measurement system. Kelly and Harwell (1990) provide a thorough review of these characteristics of environmental indicators. The following four criteria summarize the major considerations we believe are important in selecting habitat indicators.

1. Relevant to the Environmental/Biotic Endpoint

The qualitative relationship between in-stream habitat variables and their effect on salmonid populations is well established as described earlier in Section 3. Salmonid fish and other aquatic biota are sensitive to the quality and

quantity of physical habitat that can be altered by human activities.

2. Applicable to the Landscape and Stream Network

The importance of habitat features in supporting salmonid populations varies across the Pacific Northwest as climate, geology, and landform interact. Large woody debris plays a major role in the evolution of channel habitat characteristics and hiding cover in a forest ecosystem. This contrasts to the development of habitat characteristics (pools and riffles) within meadow and grass/shrub ecosystems where large woody debris is a minor or absent element of physical structure. Grouping streams within a hierarchical stream network is necessary to assure that the variables and the range of magnitude of the variable are appropriate to the stream reach, stream segment, or watershed under consideration.

3. Responsive to Human-Caused Stressors

Human actions can cause effects on aquatic ecosystems either as individual or cumulative actions. The linkages between nonpoint source activities and habitat elements are generally understood. Habitat variables generally will not satisfy the objective of rapid response desired in providing feedback for adaptive management. For this reason, many professionals believe that effectiveness monitoring should focus on upslope processes associated with specific projects (Reid and Furniss 1998).

Habitat variables measure cumulative changes over time and space; this is an important consideration in meeting CWA goals. To a large degree, *cumulative effects are the issue* driving both the increased listings of threatened and endangered species and the increase in TMDL listings. The accumulation of localized or small habitat modifications, which can go unnoticed and unregulated, results in regional and global change in fisheries populations (Burns 1991). These cumulative effects cannot be addressed by the close focus on site-specific application of BMP's. For this reason, evaluation of human impacts on water resources will likely need to address both on-slope evaluation of inputs to the aquatic system as well as the response variables measured instream.

4. Measurement Reliability

Every environmental indicator needs to satisfy the data quality objectives of accuracy, precision, and repeatability. These data quality objectives must be balanced against the real-world tradeoffs related to the ease of monitoring, cost, and required expertise. In providing this balance, the ability to meet the desired monitoring objective is a critical factor often overlooked for the sake of expediency.

Habitat Indicators Currently in Use

Various agency programs currently use a number of variables to measure habitat quality. Some of these habitat variables can either be redundant or be measured at different levels of intensity. In addition, other variables are collected during stream surveys to aid in data interpretation or stream classification. A compilation of habitat variables for which a numeric value has been suggested is provided in Appendix C for background information.

To get a sense of the variables commonly evaluated, we have included the variables from three sources in this discussion. First, there is a list of habitat variables compiled by Spence et al. (1996). They inventoried the existing monitoring programs in Washington, Oregon, and Idaho and compiled variables applicable to salmonid conservation. The applicable subset of physical habitat variables from this inventory are listed in Table 3. The placement into functional categories is somewhat arbitrary, but their inventory helps in identifying similar and redundant variables. This data is collected by agencies in the Pacific Northwest for a variety of environmental, fisheries, and land management programs.

The second and third lists of habitat variables comes from two documents that have been important to the management on federal lands. The document referred to by the acronym 'PACFISH' (USFS 1995) described the Riparian Management Objectives (RMO) for pool frequency, water temperature, large woody debris, bank stability, lower bank angle, and width/depth ratio (Table 4). The RMO's establish instream and streamside-habitat conditions intended to define good habitat for anadromous fish at the landscape scale. The RMO's serve as indicators against which

attainment, or progress toward attainment, of the overall program goals can be measured. The interim values were developed using stream inventory data within the geographic extent of the anadomous fish species. The objectives were described as "interim" since the RMO's could be modified to reflect conditions in a specific watershed or stream reach based on local geology, topography, climate, and potential vegetation.

The National Marine Fisheries Service's matrix document (NMFS 1996) lists "pathways and indicators" for evaluating management actions under ESA (Table 5). The document was developed to address management actions on federal lands in relation to the Northwest Forest Plan, the Recovery Plan for Snake River Salmon, and consultation on the Land Resource Management Plan for eight national forests in Idaho and Oregon. The matrix is explicit that the numerical values are considered default values to be adjusted for local conditions. Under circumstances where the default values do not apply, the analyst is to provide documentation for development and use of locally and biologically appropriate values.

Regardless of the caveats made regarding the ability to modify the default values, the users of these documents have voiced several concerns that generally focus on: 1) problems in applying a limited set of criteria across a highly variable landscape which are not stratified as to scale, 2) not accounting for the effect of natural disturbance on the habitat variables, and 3) the problems associated with lack of known precision and accuracy of habitat measures. Stream ecologists also are concerned that setting instream criteria focuses managers on the wrong kinds of stream restoration practices, such as adding LWD or creating pools artificially.

Table 3. Habitat variables used in monitoring programs in the Pacific Northwest.

<u>Channel Features</u>

Velocity / depth
Channel shape
Channel type
Width/depth ratio
Stream / valley type
Gradient
Sinuosity
Discharge
Depths and widths
Large woody debris
Residual pool depth
Floodplain width
Thalweg profile

<u>Stream Substrate</u>

Percent Fines (fine sediment)
Embeddedness
Bottom substrate
Substrate Size

<u>Fish Habitat Descriptors</u>

Fish cover
Pool / riffle ratio
Pool character
Winter refugia
Habitat units / (habitat type)

<u>Streambank</u>

Bank stability
Bank vegetation
Bank character
Bank height
Bank incision
Bank undercut
Bank erosion

<u>Riparian Area</u>

Canopy cover
Canopy closure (densiometer)
Riparian buffer
Stream disturbance
Insolation
Riparian vegetation structure
Aspect

Table 4. Selected habitat criteria used in federal programs in the western United States.

USFS & USBLM. 1995. PACFISH. Decision Notice/Decision Record, Findings of No Significant Impact Environmental Assessment, for the interim strategies for managing anadromous fish-producing watersheds in eastern Oregon and Washington, Idaho, and portions of California.

Habitat Feature	Interim Objectives									
Pool Frequency (all systems)	Wetted width	10	20	25	50	75	100	125	150	200
	Pools per mile	96	56	47	26	23	18	14	12	9
Large Woody Debris (forested systems)	East of Cascade Crest in Oregon, Washington, Idaho: > 20 pieces per mile; > 12 inch diameter; > 35 foot length									
Bank Stability (non-forested systems)	> 80 percent stable									
Width/Depth Ratio (all systems)	< 10, mean wetted width divided by mean depth									

National Marine Fisheries Service. 1996 . Making endangered species act determinations of effect for individual or grouped actions at the watershed scale.

Indicator	Properly Functioning								
Sediment / Turbidity	< 12% fines (<0.85mm) in gravel, turbdity low								
Substrate	Dominate substrate is gravel or cobble (interstitial spaces clear), or embeddedness < 20%								
Large Woody Debris	Coast : > 80 pieces/mile > 24" diameter > 50 ft. length; Eastside : > 20 pieces/mile > 12" diameter > 35 ft. length; and adequate sources of woody debris recruitment in riparian areas								
Pool Frequency	channel width	5	10	15	20	25	50	75	100
	# pools/mile	184	96	70	56	47	26	23	18
Width/Depth Ratio	< 10								
Streambank Condition	> 90% stable; i.e., on average, less than 10% of banks are actively eroding								

Note: See documents for complete description of criteria and the context in which they are to be used.

Table 5: Summary of pathways and habitat indicators for ESA determinations (modified from NMFS 1996).

Pathway	Narrative Statement	Numerical Indicator	Properly Functioning Value for Numerical Indicator
1. Water Quality	• Chemical contamination • Nutrients	• Temperature • % Fines	50-57 F
2 Habitat Access	• Physical barriers		
3 Habitat Elements	• Dominant substrate size	• Percent embeddedness	< 20 % embeddedness
	• LWD recruitment	• LWD frequency	**Coast:** > 80 pieces/mile **East-side**: > 20 pieces/mile
	• Pool frequency & LWD recruitment standards	• Pool frequency	Table: pools/mile specified by channel width.
	• Pool quality (depth, cover, sediment filling)	• Pool depth	Pools > 1 meter depth
	• Off-channel habitat		
	• Refugia		
4. Channel Condition & Dynamics		• Width/Depth ratio	< 10
	• Actively eroding banks	• Percent stable banks	> 90% stable
	• Floodplain connectivity		
5. Flow & Hydrology	• Change in peak/base flows		
	• Increase in drainage networks		
6. Watershed Conditions	• Road location (no valley bottom roads)	• Road Density	< 2 miles/sq. mile
	• Disturbance history (unstable areas, refugia, riparian areas)	• Equivalent clearcut area. • Percent Late successional old growth	< 15% ECA ≥ 15% retention of late successional old growth
	• Riparian reserves (shade, LWD recruitment, connectivity)	• Intact refugia for sensitive aquatic species • Riparian vegetation, % similarity	> 80% intact > 50% potential natural community composition

Sorting Potential Narrative and

Numerical Indicators

As described in the previous section, there are a number of variables to consider as habitat indicators. Some confusion arises because of the various objectives, methods, and terms that have been used to describe habitat variables.

A reminder regarding terminology may be useful. *Habitat component* refers to an element of the habitat where an organism occurs (Armantrout 1998) and is considered generally synonymous with *stream attribute* and *pathway*. A *habitat variable* is a quantifiable measurement of a habitat component (synonymous with parameter*). Water quality criteria*, as used in the CWA, refers to the elements of state standards, expressed as numerical quantities or narrative statements, that represent the quality of water needed to support a particular beneficial use (USEPA 1994c). The term '*habitat indicator'* is used in this document to emphasize its application for assessing the condition of the habitat rather than the more regulatory connotation usually associated with the term '*criteria*'.

As described at the beginning of this section, there are four primary considerations in deciding whether an indicator should be used as a habitat indicator. A decision process for sorting through potential habitat components and variables is shown in Figure 6.

1. **Relevance to Biota**. The first criterion evaluates whether the habitat component is relevant to the biota, in this case salmonids. At a broad level the components that comprise salmonid habitat are well known and can be readily described qualitatively. This would result in a list of candidate narrative criteria. Habitat Components for narrative criteria may include:

*   Flow regime
*   Habitat space
*   Channel structure
*   Substrate quality
*   Streambank condition
*   Riparian condition
*   Temperature regime
*   Water quality constituents
*   Habitat access

These components are generally synonymous with the pathways listed in the NMFS matrix. In addition, the NMFS matrix includes input variables and watershed components used to further evaluate management actions.
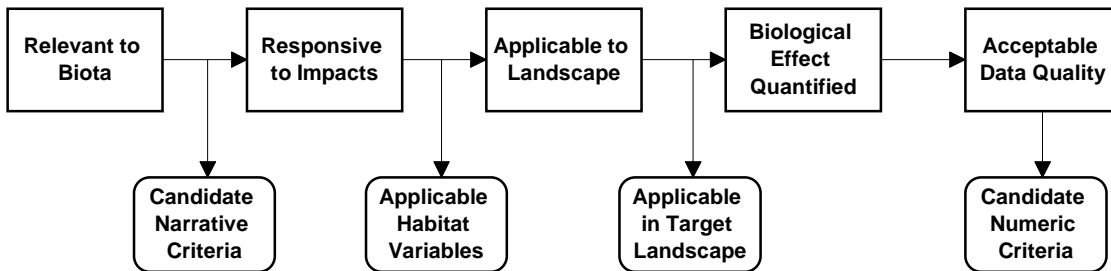

Figure 6. Decision diagram for selecting habitat variables.

2. **Responsive to Management**. The second criterion evaluates whether the variable is responsive to the types of impacts caused by management activities. Often the outcome of management activities - as manifested instream - are similar to those associated with natural disturbance events and are, therefore, not readily distinguished from natural causes. The distinction between human causes and natural causes is made through careful monitoring design (e.g. upstream vs. downstream of pollutant sources) or via the study of processes in natural systems and their comparison to the alteration of response and recovery rates in managed systems. For example, measuring residual pool depth does not distinguish between the source of sediment, but comparing residual pool depths to undisturbed watersheds of a similar channel type provides an indication of whether human activities have altered the sediment regime enough to decrease pool depth. In contrast, annual fluctuations in flow rate can largely reflect natural climatic cycles, which in turn can overwhelm our ability to detect the additive effect from human influences. Therefore, it follows that residual pool depth is a useful habitat variable, whereas variation in annual discharge alone may have little utility as a stand alone indicator unless evaluated in the context of a carefully designed analysis that looks at more detailed flow statistics The predominant land use within a basin can substantially affect the choice of variables. For example, in an urban context where the influence of impervious surfaces highly alters seasonal instream flows, storm flow peaks increase in frequency, duration and magnitude.

3. **Appropriate to the Landscape**. Channel forming processes within similar landscapes form recognizable patterns in fisheries habitat. Therefore, it is appropriate to identify habitat variables grouped by similarities in the landscape. Variables that measure habitat space such as pool frequency, W:D ratio, and residual pool depth can be useful across many types of landscapes – forested, grassland, and cropland streams. However, the habitat forming processes vary by landscape, and this will influence the selection of habitat variables. An obvious example is the importance of large woody debris in forested ecosystems in contrast to streams located in grass/, shrublands and desert ecosystems.

4. **Linkage to Beneficial Use.** The final two criteria address the question of whether it is feasible and technically defensible to establish numeric criteria for a habitat component. The first issue is whether sufficient information exists to quantify the linkage between habitat and the beneficial use.

The traditional way quantifying the biological effect is by using test organisms in a laboratory setting and studying the acute dose response relationship. Even with the controlled experimental approach, there is a wide variability in the response of test organisms and different reported toxicity values. Chronic exposure or multiple toxicant tests (synergy) are seldom part of the protocol.

The response of salmonids to declining habitat conditions is not readily replicated in the lab but can be documented through field studies with some difficulty. Transfer of this information to other stream systems in quantitative terms is difficult if not infeasible. Field studies confirm the pathways of effects and the biological response in terms of declining fish distribution or populations. The quantification of habitat effects is best accomplished through the comparison of habitat conditions to least disturbed or reference condition watersheds. An exception to this general observation is the use of laboratory studies in evaluating the effect of fine sediment on egg to fry survival. However, even with this variable, some significant questions arise in regards to the transferability of observed effects to field conditions.

5. **Quantifiable as Numeric Criteria**. If significant natural resource policy decisions are going to be based on monitoring data, there must be confidence that the data is reliable and the interpretations sound. The final criterion in selecting numeric criteria addresses the issue of the measurability of habitat variables, that is, the ability to achieve desireable levels of accuracy and precision. Two primary considerations influence the potential usefulness of a habitat parameter. One is the signal-to-noise ratio which is a function of the natural variability and the sample error associated with the monitoring protocol. The second consideration is the accuracy, precision, and repeatability associated with a specific monitoring technique. Many of the habitat variables in current use (Table 3) are measured at various levels of intensity from

qualitative surveys to quantitative measurements. Data that results from these methods have different data quality characteristics and are generally not comparable. Some quantitative habitat protocols are so time-consuming that agencies have opted to rely on ocular estimates.

Potential Habitat Components and

Habitat Variables

In the previous sections, we identified habitat variables commonly used in monitoring and land management programs. These variables address a mix of purposes – watershed input variables, outcome variables, pathways of habitat effects, and associated explanatory variables used to establish status and trends in aquatic resource conditions.

How might these potential variables be applied as narrative and numeric water quality criteria? To answer this question, the variables are sorted by habitat component in Table 6 to facilitate comparison to the evaluation criteria illustrated in Figure 6. The column headings for Table 6 are explained below.

Narrative Criteria. Narrative criteria might be appropriately developed at the *Habitat Component* level of organization. Habitat components represent the major elements of the aquatic habitat necessary to support salmonid species of fish – adequate flows, habitat space, substrate quality, streambank and riparian condition, water column chemistry, habitat access and connectivity. Incorporating narrative criteria into state water quality standards would be a major step in the right direction of recognizing the importance of habitat within water quality programs.

Pathways. The second column in the table*, Pathway Elements*, are generally addressed under the CWA as elements of pollution control programs rather than as environmental endpoints. The pathways of effect are regulated via state BMP's, standards, and guides in land management plans or as pollution abatement measures in TMDL implementation plans. Pathways of effects are generally addressed in state water quality standards by way of reference to approved management practices for specific nonpoint source activities.

Habitat Variables. *The Habitat Variables* listed in the table are outcome variables that are likely candidates as aquatic habitat indicators. The last column in the table shows some of the associated explanatory variables needed to interpret outcome habitat variables.

In the next section, the rationale for evaluating the candidate habitat variables as aquatic habitat indicators is presented. The emphasis of this discussion will be on the last two sorting criteria, quantifiable biological effect and data quality, since these two criteria generally determine whether it is technically feasible to specify numeric criteria.

Table 6: Habitat components, pathways of effects, and potential habitat variables.

Habitat Component	Pathway Elements	Habitat Variables	Associated Explanatory Variables
1. Flow Regime	• Peak flow • Low flow • Rapid fluctuations • Increase in drainage networks	• velocity, depth, wetted perimeter, useable habitat space.	Discharge
2. Habitat Space & Channel Structure	• Off-channel habitat • Flow modification	• Pool frequency • Residual pool depth • Pool/riffle ratio • W:D ratio • LWD frequency • Area of suitable spawning & rearing habitat	Geomorphology Stream & valley types Reach characteristics • gradient • bankfull width • channel confinement • sinuosity
3. Substrate Quality	• Surface erosion • Mass wasting • Streambank erosion • Pool filling	• Percent surface fines • Fines at depth • Embeddedness • Substrate composition	• Rock type & soils • Physiography • Stream type
4. Streambank & Riparian Condition	• Streambank disturbance • Channel modification • LWD recruitment • Vegetative rooting/ bank stability • Shading • Nutrient modification	• Bank Stability • Undercut banks • Overhanging vegetation • Greenline vegetation • Canopy cover	• Rock type & soils • Stream type • Riparian community composition
5. Water Column Chemistry	• Various pathways associated with nonpoint source pollution activities.	• Temperature • Dissolved oxygen • Turbidity & suspended sediment • Nutrients • Toxics	Soils & geology Geochemistry Landscape patterns
6. Habitat Access	• Physical Barriers		Discharge
7. Watershed Condition & Connectivity	• Road density • Disturbance history • Riparian reserves • Floodplain connectivity		• Ecoregion • Land use • Soils & geology • Hydrology • Mass wasting & erosion potential

Sorting Potential Aquatic Habitat Indicators

The *Habitat Components* listed in Table 6 are relevant to aquatic biota and salmonid fishes, have been related in some manner to management effects, and therefore, would be useful to consider as narrative criteria in state water quality standards.

The next step is to identify which habitat variables are likely candidates as quantitative indicators. The potential habitat variables need to pass the final litmus tests of applicability within landscapes, whether the biological effect has been quantified, and lastly, whether the habitat variable can be measured with acceptable data quality.

A best-professional-judgement approach is used to evaluate potential variables. This step is highly subjective, since other evaluators using a similar logic path may arrive at different conclusions. Also, there is the continually evolving state of science. Better monitoring tools or evidence of improved data quality over current methods can readily change the results of this evaluation. At a minimum, evaluations of habitat indicators should consider the suggested criteria and document their assumptions and logic processes.

Flow Regime

Alteration of flow regimes is considered a significant factor in the decline of fish populations in the NorthWest. Changes in discharge regime have altered migration patterns, changed sediment deposition and scour, contributed to mortality of eggs and fry, and reduced available habitat space.

Many studies have documented the increases in annual water yield and peak discharge (frequency, magnitude and duration) associated with timber harvest (Burton 1997). Since most of the studies were conducted in small, experimental watersheds, the evidence for water quantity change has been less conclusive in larger watersheds. Timber harvest and road building can increase peak flows of streams in several ways: alteration of snowmelt patterns, interception of subsurface flows by the road network, and alteration of evapotranspiration patterns. However, the long-term effect, good or bad, of peak flows on channel stability and aquatic habitat is an issue that is not yet resolved (Troendle and Stednick 1999).

The effect of low flows on fish community habitat has also been documented. How much streamflow is required to protect aquatic resources has been examined from the perspective of instream fish habitat, (Orth 1987), channel maintenance flows (Rosgen et al. 1986), and riparian zone influence and valley maintenance flows (Hill et al. 1991). Over appropriation for water withdrawals from surface and groundwater sources have seriously reduced fish habitat in many streams throughout the Pacific Northwest, especially in the drier interior basins of Washington, Oregon and Idaho. The instream flow incremental methodology has been used for some time to evaluate the effects of decreasing streamflow on usable quantities of physical habitat space.(Bovee 1982). Micro-habitat preferences have been described for a number of salmonid species using velocity, depth, and substrate size (Bjornn and Reiser 1991).

We can visualize that minimum stream flow can be addressed in a narrative statement format, since the effects of altered low flows on fishery habitat are fairly well understood. The effects of peak flows on channels and aquatic habitats are less resolved, especially with respect to predicting the magnitude of effect and channel response or making a narrative or numeric criteria untenable. However, the outcome of hydrologic watershed alteration would be manifested as changes to the habitat space and channel structure of the stream. For this reason, potentially useful habitat variables that are responsive to flow alteration are those that measure channel morphology as described in the section below.

Habitat Space and Channel Structure

For our purposes, we have divided the channel components into two parts – channel dimension and channel structure variables.

Channel Dimension

Habitat space can be visualized as the interaction of three dimensions of the channel – length, width, and depth. Length and width measures potential habitat space directly proportional to the size of the watershed and

magnitude of the flow regime. Channel depth provides the third dimension important to aquatic habitat. The volume of water (flow expressed at "Q") moving through a channel at any given time (velocity "V" expressed at cubic feet per second or cfs) is affected by these channel dimensions (width and depth) as $Q = W \times D \times V$. Channel gradient affects velocity. As the channel narrows (width decreases) at a given location, the velocity and depth increase. As the channel widens, velocity falls and depth decreases. As flow increases, velocities at the channel margin also increase shear stress which controls the sediment transport capacity of the stream at high flow events.

Stream channel bankfull width is a function of streamflow occurrence and magnitude, size and type of transported sediment, and bed and bank materials of the channel (Rosgen 1996). Bankfull channel widths generally increase downstream as the square root of discharge (Leopold et al. 1964) and, therefore, serve as an element of stream classification systems.

Channel width can be modified by human disturbance – diking and channelization, changes in riparian vegetation, and changes in flow and sediment regime due to watershed alterations. The bankfull cross-sectional shape corresponds to changes in the magnitude and frequency of bankfull discharge. The bankfull dimensions can be altered by management activities in the watershed such as water diversion, clear cutting, vegetative conversion, and over-grazing. Channels can become over-widened, which reduces habitat (depth, velocity) especially during summer low flow periods.

Over-grazing from livestock in the riparian zone reduces vegetation and damages stream banks, which leads to an altered channel form characterized as wider and shallower than normal (Elmore and Beschta 1987, Platts 1991). Stream channel response to cattle exclosures have been variable, but in many studies a reduction in bankfull dimensions (indicating a recovery of width/depth ratio) has been observed a decade or more after cattle were excluded (Magilligan and McDowell 1997).

Width:Depth ratio integrates cross-sectional shape into one variable. In Rosgen stream classification (Rosgen 1996), W:D ratios are associated with stream types based on empirical measures of a large number of streams. The stream types are categorized by fairly broad break points in W:D ratios (less than or greater than 12 and greater than 40). These broad categories demonstrate the high natural variability even within a stream type, which suggests the difficulty in attempting to establish a regional numerical value for W:D ratios even if stratified by stream type.

The other concern with stream width and W:D ratios is the methodology used to measure these variables. At a stream inventory level, bankfull width is estimated by using field characteristics such as sediment surfaces and vegetative breaks to identify the elevation of the active floodplain surface. The definitions of bankfull width are vague and the actual selection of bankfull width is subjective (Johnson and Heil 1996), thereby leading to highly variable interpretation of bankfull level. Some field methods measure only wetted width, which tells very little about the channel characteristics of the measured stream. When bankfull is measured at monumented cross sections, subjectivity is decreased and the precision of the method improves substantially (Harrelson et al. 1994). Nelson et al. (1992) rated precision and accuracy of the W:D measurement as good with an average confidence interval of 7% of the mean.

Given the variability in natural channel dimensions, the variability in channel type response (i.e., some channel types increase in widths, while other types are resistant to bank erosion), and the subjective nature of identifying bankfull, we would not suggest the use of bankfull width or W:D ratio as a numeric habitat indicator alone. The bankfull dimension is useful as one measure of a suite of variables to characterize channel dimensions, but this should be used at the site-specific or reach-specific level and be measured at monumented cross-sections to assure precision and repeatability (see Harrelson et. al. 1994, Olson-Rutz and Marlow 1992, for methods and interpretation).

In comparison, stream depth, measured as residual pool depth, is a less ambiguous measure of habitat space and structure that may be useful as a habitat indicator as discussed in the next section.

Pools and Large Woody Debris

A high frequency of quality pools is required to support salmonid populations in streams and rivers. Adult fish utilize pools as resting areas during migration and for hiding cover during spawning, and pools are important habitats for juvenile rearing. The combination of depth and cover primarily determine the quality of the pools. Cover elements are generally evaluated using subjective ratings of overhanging bank; overhanging vegetation; and the presence of wood, roots, and large substrate. Deep pools also provide better hiding cover.

Salmonid species in forested ecosystems have evolved in streams where large woody debris plays a major role in forming habitats, providing cover, influencing sediment processes, stream energy, and nutrient cycling.

Human disturbances strongly influence pool indicators. Reduction in pool frequency and depth occurs through cumulative activities in the watershed by altering channel morphology, changing discharge and sediment equilibrium, modifying the active channel, and decreasing or eliminating riparian vegetation (Section 3, Table 1). Large woody debris size, frequency, and loading potential have been altered by historic activities that actively removed wood from channels or decreased input from riparian forest stands. Residual pool depth integrates the effect of several management alterations – pool filling from excessive sedimentation, decrease in channel obstructions, and changes in channel dimensions and bed stability.

The effects of human disturbance, however, on these channel features may not be detected due to the lag-time in effects and the insensitivity of the monitoring methods In general, pool frequency, pool depth, and LWD frequency are not sensitive to disturbance over the short-term (with the exception of direct channel modifications). There is a long lag-time between activities on the landscape and the response in the channel, both in response to detrimental effects of management and in response to restoration actions. Stream channels, where large wood was removed and where adjacent riparian forests have been harvested, will require decades (or centuries) to return to natural loading rates.

Several studies have evaluated the value of using habitat unit classification (e.g. pool vs. riffles) to monitor trends over time. Poole et al. (1997) found that the subjectivity of habitat unit classification seriously compromised the repeatability and precision of the method. Pools and riffles are not separated by distinct boundaries; this lack of clearly defined boundaries contributes to observer bias. Aggregating sub-categories of habitat units into fewer broader categories *(such as with the REMAP variable, Percent Slow in Section 7)* improves precision; however, it reduces the sensitivity of the method to land use impacts, because even larger shifts in channel morphology are needed to observe a response in the data. Again, linking residual pool depth measurements with thalweg profiles and bed particle size characterization may help resolve some of these problems, but the interpretation of the cause–effect relationship can remain elusive unless tied to a whole watershed assessment of sediment input sources (Madej and Ozaki 1996)

Visual assignment of habitat unit classification alone lacks the sensitivity and precision required to document incremental changes due to management effects in stream channels at the reach scale. Habitat units may not be sensitive enough to land use effects at this scale and multiple crew observer error introduces a high source of variability (Poole et al. 1997). Transforming the data into pool-to-riffle ratios further reduces the sensitivity of the data. Expressing the data in habitat units per length (pools per mile) retains the original measurement scale of the data.

In contrast, analyses conducted at the regional scale have been successful in detecting land-use patterns, because sample sizes were sufficient to overcome the large variance associated with habitat unit classification (McIntosh et al. 1995, Ralph et al. 1994, Poole et al. 1997).

Residual pool depth is a quantitative measure less subject to observer error than other measures of stream dimension and is independent of streamflow at time of measurement (Lisle 1987). The residual pool depth is measured as the difference between the maximum pool depth and the pool crest outlet depth. Although pool depth varies along the stream profile, the average residual pool depth for a stream channel type is sensitive to

land management alterations (Ralph et al. 1994, McIntosh et al. 1995, Woodsmith and Buffington 1995).

LWD frequency is influenced by the methodology – the size definition of LWD, the position of the wood influencing the channel, and the procedure for counting pieces in a log jams. However, when LWD is operationally defined, it can be measured with some precision. Ralph et al. (1994) concluded that LWD volume and position are easily measured and are objective and repeatable. Additionally, they appear sensitive to even moderate land use practices. Stratifying the data by channel gradient and basin area reduced the variation imposed by larger scale factors.

LWD frequency can be expected to be highly variable in natural stream systems, since recruitment occurs through periodic disturbance such as high winds, floods, and mass wasting events. Regardless, these random events generally result in higher LWD loading and higher LWD volumes in natural systems over the long term in comparison to altered streams.

Pool frequency, residual pool depth, and large woody debris are three habitat structure variables relevant to aquatic biota and can be used to discern management effects over larger geographical scales. These variables measure cumulative effects of management and so are not expected to be responsive to changes in management over shorter time frames. Observer bias hampers the precision and repeatability of pool frequency, however. The subjective nature of pool frequency measures could be more objective if thalweg profiles were combined with ocular habitat typing.

Pool frequency, residual pool depth, and large woody debris are variables that could logically be specified as numeric indicators, if they are stratified by landscape and channel types, specifically basin size and gradient.

Reid and Furnis (1998) summarize some thoughts counter to the rationale described above. It is instructive to be aware of these concerns about using physical channel features. These issues include the channel response time, interpretation of cause, addressing the ecosystem health objective, background variability, and cost effectiveness. Measures of channel form (e.g., pool frequency and width-depth ratio) exhibit a lengthy lag time in response to disturbance, while channel form responds slowly to management-related changes in driving variables such as changes in water, large wood, and sediment. Interpretation of the cause is not feasible, since channels respond in the same way to multiple stressors. Channels can widen due to an increase in sediment load, alteration of riparian vegetation, an increase in runoff, and for other reasons. Application of single set of variables over broad areas is likely to be ineffective, because ecosystem health is being impaired by vastly different suite of influences in different geographic areas. Lastly, a healthy lotic ecosystem requires that different parts of the channel system exhibit very different in-channel conditions over time; this variation is an essential characteristic of naturally functioning aquatic ecosystems. For these reasons, Reid and Furnis (1998) suggest that monitoring strategies should focus on upslope and riparian condition indicators rather than on instream channel and habitat measures.

Substrate Quality

Sediment is one the most pervasive pollutants identified as an issue in Pacific Northwest streams, yet little consensus exists among scientists on how to quantify the effects of sedimentation on aquatic ecosystems. Substrate material is also an essential component of salmonid habitats, including spawning substrate, cover for juveniles, and the media that supports the primary and secondary production of the bacteria, algae and insects that support aquatic communities. Again, different land uses seem to have somewhat predictable outcomes on the input and routing of sediment into streams, which varies depending upon the terrain characteristics of the landscape on which they occur. Sediment in transport is operationally divided into suspended sediment and bedload sediment. Suspended sediment consists of the finer grained particles, namely silt and clay size particles. Sand sized and greater material moved along the stream bottom comprise bedload. Suspended sediment is a water column pollutant that has traditionally been addressed in state water quality standards as a narrative criteria or as a turbidity standard. Sediment deposited in critical aquatic habitats, such as salmonid spawning and rearing areas, is treated here as an issue of fine substrate quality (< 0. 85 mm, particularly because it can

affect intergravel dissolved oxygen concentrations. Another size fraction < 6.35 mm has been of concern because of its tendency to infiltrate into gravel nests and prevent oxygen uptake and alevin emergence (Bjornn and Reiser 1991).

Establishing quantitative criteria for deposited fine sediment remains an illusive target for several reasons. No general agreement exists in the scientific literature on a numerical target although several numerical values have been suggested and are in common use as default criteria. Secondly, practical and technical limitations prevent direct comparability between field measurements and the numerical value obtained in laboratory studies. A large body of literature illustrates that fine sediments are detrimental to salmonid populations through alteration of the habitat and direct effects on egg survival and developing embryos (Havis et al 1993, Bjornn and Reiser 1991). However, questions about the adequacy of field methods and laboratory studies for setting numerical criteria remain. Laboratory studies that established thresholds for fine sediment do not adequately reflect conditions faced by embryos or emerging alevins (Everest et al. 1987, Chapman 1988) due to the difficulty of replicating conditions found in the egg pocket of natural redds. Field studies of redds confirm the concern about adequately representing the sediment composition actually encountered by eggs and young fry in these studies (Thurow and King 1991).

In a review of this issue, Spence et al. (1996) identified two recommendations for setting specific sediment targets for spawning habitat in the literature. Rhodes et al. (1994) concluded that survival to emergence for chinook salmon in the Snake River Basin is probably substantially reduced when fine sediment concentrations in spawning gravel exceed 20%. Peterson et al. (1992) proposed a target of 11% fine sediments in spawning gravels for low-to-moderate gradient streams in Washington *with the caveat that this criteria not be applied across geologic boundaries* and secondly that exceeding the criteria should initiate a review of potential causes. Spence et al. (1996) made no specific recommendations for targets in rearing habitats because of a lack of available information in the literature. An important precaution implied in these papers is that locally developed criteria

should not be generalized for use outside of the area in which they were intended.

A related issue that is a cause for caution in using values for fine sediment is data comparability between methods. A number of methods with various levels of monitoring intensity report values as "*percent fines*". Stream inventory procedures use a diversity of methods such as visual observation, sampling grids, and Wolman pebble counts to estimate percent fines. Wolman pebble counts are biased against detecting substrate particles < 0.85 mm in diameter (Wolman 1954). More quantitative methods use systematic sampling of surface fines, cobble embeddedness, or core sampling (fines at depth) to measure percent fines. Various levels of precision, accuracy, and repeatability are associated with each method and level of sampling intensity. Yet, all of these methods only indirectly measure the problem factors that would affect egg-to-emergent survival of salmon embryos. Workers in northern California (Randy Klein pers. comm.) are measuring gravel permeability near known redd sites and calibrating these sequential readings to egg-to-emergent survival. These field trials are also linking measurements of turbidity to storm events. More such field tests are needed to develop and refine reliable methods in order to capture this important sediment parameter. Resolution of these issues requires an interagency effort to develop standardized methods and agreement on their application and interpretation. Recent work by L. Reid in northern California (personal communication) to evaluate linkages between turbidity and fish survival shows promise in that it suggests a detectable correlation between land disturbance (road building and logging, traffic volumes on gravel roads, etc.) and elevated turbidity levels as well as fish survival. At the very least, these methods might prove a useful tool to document the effectiveness of fine sediment abatement techniques applied within a basin.

Given the uncertainty in the measurement of fine sediment and in quantitatively describing its effect on salmonids and other aquatic organisms, we do not believe it is appropriate to specify a numeric habitat indicator. Fine sediment has a demonstrated effect on aquatic resources and should be included in state standards as a narrative criteria, as is already done in many cases. It may be feasible to fine

tune the narrative criteria to provide a greater degree of specificity than is currently described. State, federal, and tribal agencies should pool their efforts to develop appropriate measures.

Another aspect of sediment involves the input of large volumes of both coarse and fine sediment associated with bank failures, bank erosion, and the hill-slope process of mass wasting (mass slope failures, shallow rapid landslides, soil creep, etc.). When the rate, magnitude, and pattern of these processes are disrupted through land management (timber harvest, road building, mining, residential construction), the volume of sediment entering a stream channel can quickly overwhelm its capacity to convey the material. Large increases in sediment input volumes have been shown to alter substantially habitat features (pools and riffles) and can create highly unstable spawning areas subject to gravel scour and fill events when seasonal peak flows approach bankfull discharge. When coincident with spawning sites selected by adult fish, these events can reduce the overall success of spawning, which in turn can reduce the overall recruitment for an entire year's population (Frissell, in preparation 1999, Orsborn and Ralph 1994). In some areas, redd scour and fill related mortality can be a significant factor limiting overall stock recovery, and yet, this is largely unaccounted for in current assessments. Timely management solutions to these problems are limited.

At a much larger scale, EPA is currently applying an assessment technique (Fitzgerald et al. 1998) to address watershed level sediment input sources. This method is the basis for several ongoing TMDL's that attempt to quantify both background and management induced sediment sources and volumes. A sediment reduction target is then established that focuses management actions towards preventing further inputs and reducing chronic sources (such as road surface sources).

Streambank and Riparian Condition

Bank Stability

The stability of the streambank and associated riparian vegetation are important characteristics that contribute to aquatic habitats. These factors are more important in some areas than others

and are directly related to land use, such as cattle trampling of range-land stream banks (Bauer and Burton 1993). Streambanks with a protective vegetative root structure develop undercut banks which are important hiding areas for juvenile and adult fish. Woody and herbaceous riparian species of plants have deep fibrous roots that resist erosion and hold the bank together. The plant mass above ground resists the force of water and provides a protective layer that prevents lateral bank erosion. Overhanging vegetation provides cover, shade, organic material for stream energy, and vegetative structure for terrestrial and emerging aquatic insects.

Naturally stable banks result from the bank material (rock or clay content) and/or the riparian vegetative community associated with the streambank. Natural low gradient river systems exhibit bank erosion at low rates in dynamic equilibrium such that banks are eroded in one location and rebuilt in another to retain the overall cross-sectional dimensions over the long term. This is especially evident where one sees lateral movement of a river meander or bend.

The objectives for stable banks are to prevent streambank erosion processes from delivering fine sediments to critical spawning and rearing habitats, to create conditions favorable to the development of undercut banks, to protect deep-rooted vegetation in order to add to stability and provide shade, and to maintain channel dimensions favorable to fish habitat development (McCullough 1999). Banks can be destabilized by livestock grazing through vegetative removal and bank trampling which results in bank calving, by road building along stream channels, and by logging riparian vegetation that eliminates the root strength and physically disrupts the soil surface.

Bank stability is intended to portray the absence of processes that result in bank erosion. The majority of bank stability methods involve a subjective rating of some combination of vegetative cover, bank material, and evidence of slumping or sloughing (Platts et al. 1987, Bauer & Burton 1993, Shuet-Hames et al. 1994). McCullough (1999) describes a modification of earlier systems that is more objective because measured data or categorical observations are recorded in the field for each factor. Bank stability is assessed by measuring bank angle and height, bank material composition, and bank

vegetative cover for both the upper and lower bank. The measured bank angle, percentage of stream bank covered by stable rock material, and percentage of vegetative cover are converted to a value based on a scoring system. The system reduces some of the inherent subjectivity associated with earlier systems by measuring and recording the bank angle and by closely defining categories for the other factors. This method (McCullough 1999) should improve accuracy and precision over previous methods, but, has not been tested to date in other systems and by other observers. The field observations are converted to interpretive information by using a scoring system. This method may prove to be advantageous in reducing observer error; however, the method needs to be tested in other stream systems, in response to other kinds of stressors, and evaluated for precision and repeatability before its general applicability to water quality programs is demonstrated.

CRITFC proposed a standard of 90% bank stability for managed watersheds (CRITFC 1995). The 90% bank stability criterion is considered an anticipated average minimum performance level possible under various geomorphic conditions which will provide favorable biological conditions over time (McCullough 1999). In a review of the literature, Spence et al. (1996) noted that there is no or little quantitative information to support regional target values for bank stability. Given the great diversity in stream types and the associated differences in inherent bank stability, it may be more appropriate to use bank stability as one of the monitoring characteristics that should be evaluated as part of an overall habitat quality survey.

Given the subjective nature of bank stability measurement and the uncertainty about setting appropriate targets, we suggest that bank stability be evaluated, if at all, in relation to specific stream types within a landscape setting. Intensive channel survey methods that utilize monumented cross-sections, as described in Harrelson et al. (1994), may provide the best means of quantitatively evaluating bank change over the long term. Cross-section methods evaluate a single point on the stream bank such that multiple cross-sections are needed to survey even a small portion of the stream length. Hence, field rating methods have understandably been the method of choice for evaluating management practices.

Water Column Chemistry, Habitat Access & Watershed Condition

These habitat components are recognized as important factors in the aquatic ecosystem which are necessary to support beneficial uses. The habitat elements are listed in Table 6 to provide consistency with the Services matrix documents. Habitat Access, Watershed Condition, and Connectivity components are topics that may be appropriate as narrative statements in water quality standards, but these topics are outside the scope of this paper.

Water quality chemistry has been the primary focus of state and federal water quality programs with a long history of scientific inquiry and discussion regarding appropriate criteria. Some chemical parameters are more reflective of specific land use effects than others. The states and EPA engage in a periodic review, the Triennial Review, to evaluate the need to revise the water quality criteria.

One issue that crosses over between "water chemistry" measures and habitat quality is the effect of suspended sediment on habitat quality. State agencies have adopted various narrative criteria and, in some cases, numeric criteria for turbidity, a surrogate measure of suspended sediment effects. With the increase in TMDL listings, the interest in identifying targets for suspended sediment has increased. A logical method to address these targets are dose-response models, which evaluate the effects of target fish communities to suspended sediment.

Dose-response models have been developed to evaluate the biological response to suspended sediment concentration and duration using meta-analysis of a large number of studies (Newcombe 1994, and Newcombe and Jensen 1996). The effect of suspended sediment pollution is integrated into a Scale of Severity (SEV) of ill effects. The scale of effects includes behavioral effects (e.g. avoidance), sublethal effects such as feeding rates and minor physiological stress, and lethal and sublethal effects.

The SEV rating incorporates the effect of habitat damage. Habitat damage is characterized in

biological and physical terms. Biological signals of habitat damage include underutilization of stream habitat, abandonment of traditional spawning habitat, as well as displacement and avoidance of habitat. Physical changes included in the SEV scores are degradation of spawning habitat, damage to habitat, and loss of habitat (Newcombe and Jensen 1996).

Six SEV empirical equations were developed from the published data to model the fish response to suspended sediment dose, the product of sediment concentration and duration of exposure. The models address various life stages and include juvenile and adult salmonids, eggs and larvae of salmonids, as well as non-salmonids. These models provide the ability to target a life stage in response to a specific suspended sediment pollution event, and they appear to provide a very useful method of integrating the concentration and duration into an analysis tool. The method provides a means of developing TMDL targets for suspended sediment concentrations for specific water bodies and sensitive life stages. The article by Newcombe and Jensen (1996) summarizes the previous efforts and refines the dose-response model.

7.   ASSESSMENT AND MONITORING

The Silver Bullet: "While the motivation to find tools that are relatively simple to implement, that can be used directly and consistently by field personnel, and are sensitive enough to provide a direct measure of impact is understandable, there is no a priori reason to expect that any monitoring protocol can necessarily possess all of these attributes. In other words we can not assume that a silver bullet exists to solve our problems." Kondolf (1997).

Introduction

The critical question for evaluating habitat that needs to be addressed is *what is our ability to detect ecologically significant change with a given set of monitoring methods?* Although no silver bullet exists, there are established systematic approaches to environmental monitoring applicable to the task of habitat measurement (MacDonald 1994, MacDonald et. al. 1991, USEPA 1997). This systematic approach involves the development of monitoring design, the selection of appropriate variables and methods, quality assurance (QA) and quality control (QC), and data interpretation. These considerations are important because water quality programs require a high degree of confidence in the resulting conclusions. The outcomes of evaluating pollution control measures and establishing targets for TMDL's, for example, have significant ecological, economic, and social implications.

This section focuses specifically on the issues related to data quality. The other elements of monitoring design have been addressed in more detail in other documents and statistical texts (Ward et al. 1990, Gilbert 1987, Sokal and Rohlf 1987, Helsel and Hirsch 1995, Snedecor and Cochran 1980). Habitat indicators are measured using a variety of methods for varying purposes. There are no accepted standard methods for habitat protocols comparable to the standard methods for water quality parameters. Habitat variables are monitored with a mix of measured and observed types of data leading to difficulties in data comparability. It is important to understand and resolve these data quality issues, if habitat indicators are to be used to measure progress in meeting water quality objectives.

Systematic procedures have been established for controlling data quality associated with water quality monitoring. Since water quality professionals should be familiar with these concepts, we address data quality issues for habitat variables by comparison and contrast to these procedures. Standard methods address the analytical laboratory procedures, standardized procedures for collection and handling of water quality samples, and established QA/QC procedures. This comparison focuses on the estimation of <u>precision and accuracy</u>, since this issue is fundamental to detecting ecologically significant change.

Monitoring Design

For water quality programs, we earlier identified two primary sets of objectives for habitat variables.

1) Assess the aquatic environment's status in terms of supporting the "beneficial uses", i.e. fish communities.
2) Assess the effectiveness of BMP's or nonpoint source pollution controls.

These purposes require different monitoring designs, a different mix of indicators (input variables, watershed characteristics, outcome variables), and a different degree of quantification. Monitoring design issues for

water quality and habitat studies have been addressed in MacDonald et al. (1991); Conquest, Ralph, and Naiman (1994); and Hubert (1997). In a recent article entitled "*Statistical design and analysis considerations for monitoring and assessment*", Conquest and Ralph (1998) present guidance on how to develop statistically reliable monitoring designs based on assessment objectives, and from there, how to proceed to proper data acquisition, information management and data analysis. Some general characteristics of good monitoring design described in these documents include:

1) clearly articulated goals and objectives,
2) selection of variables and protocols based on the needs defined by those objectives,
3) standard monitoring procedures,
4) field methods training program and integrated quality control,
5) QA/QC procedures as described above,
6) statistical design, and
7) data management.

Nonpoint source monitoring has primarily focused on BMP evaluation in order to reduce pollutant discharge, though somewhat in isolation from the watershed processes that control its expression. Much of the guidance on nonpoint source monitoring has, therefore, focused on this objective – either in examining the utility of variables in implementation and effectiveness monitoring or on the statistical design of these studies. The objective of evaluating habitat status in supporting beneficial uses has been addressed to a lesser degree. Therefore, we address the monitoring design of BMP effectiveness studies first and consider designs for habitat status as a subset or special case of the first type of studies.

Effectiveness of BMP's - Objectives

Three types of monitoring are commonly described as relating to the monitoring success of nonpoint source controls or restoration activities: *implementation monitoring, effectiveness monitoring, and validation monitoring* (MacDonald et al. 1991, Kershner 1997). Validation monitoring is a research level of monitoring that addresses cause and effect relationships of watershed processes or fish population response to habitat manipulation. These types of studies require long-term commitment of resources and manipulation of

watersheds over long term periods, such as the Rural Clean Water Program experimental watersheds (USEPA 1992).

Implementation Monitoring asks *did managers implement BMP's or restoration activities in accordance to guidelines and regulations designed to reduce unintended environmental impacts?* Implementation monitoring during the activity can lead to mid-course corrections. Implementation monitoring at the end of the project provides necessary feedback to determine whether guidelines and regulations were met. Implementation monitoring can be as simple as counting the number of structures installed and evaluating if the structures were installed as designed. The actual monitoring activity can be limited to visual inspections, field notes, and photographs.

Effectiveness Monitoring asks *were BMP's or restoration activities effective in attaining the desired condition and in meeting the restoration objectives?* This kind of monitoring is more complex than implementation monitoring, because we need to determine if the desired outcome of the BMP's were attained. The answer to this question cannot be ascertained until the interaction of management practices and natural disturbance regimes can be considered (e.g. after several cycles of high stream flows). It has been common for stream restoration projects, such as artificial placement of Large Woody Debris, to be deemed effective under low flow cycles then to unravel during years of higher flows.

Effectiveness of BMP's – Study Design

Statistical design for BMP effectiveness studies are based on experimental units, treated versus non-treated stream reaches. In an idealized simple experiment, the experimental units would be randomly selected and assigned some treatment, while another set would be left untreated as controls. These experimental units are considered representative samples of the larger population about which inference will be made. Repeated measurements generate the data used to describe the sampled populations. Most water quality studies do not readily fit this idealized statistical design. The experimental units cannot be randomly assigned, since the treatments occur across large, rarely uniform, watershed areas. Many extraneous factors

affect the experimental units that often cannot be accounted for in the data gathering or statistical treatment. The experiment necessarily occurs over a long time period as BMP's are implemented, and therefore, the seasonal and annual variations also are dominant factors affecting the results.

Nonpoint source studies have generally targeted water quality variables rather than habitat variables in assessing BMP effectiveness. Three monitoring designs common to water quality studies are paired watershed, upstream/downstream, and before/after (Grabow et al. 1999). A **paired watershed design** (Clausen and Spooner 1993) comprises two watersheds (control and treatment) of similar location, land use, and two time periods of study (calibration and treatment). The goal is to establish a relationship between the control and treatment watersheds to evaluate the effect of changed land management in one of the watersheds. An **upstream/downstream** (before/after) design (Spooner et al. 1985) also requires calibration and treatment periods; however, unlike the paired watershed design, only one watershed is monitored with sampling stations positioned upstream and downstream of the treatment area. With a **before/after** monitoring design, water quality data from one downstream station is collected for a period of time before and after BMP implementation.

Habitat /Beneficial Use Status– Study Design

Studies that address the objective of habitat status will primarily take the form of comparison between "managed" streams, those that are influenced by human activities, to those stream segments that are reference streams. Because of the difficulty in obtaining data for comparable reference streams, stream segments that represent some gradient of "least disturbed" or "proper functioning" have been used for comparison in biological monitoring programs. However, there are recognized difficulties in using streams that have had some degree of management as a reference condition (Hughes 1995). A primary consideration in monitoring design is to compare similar stream reaches as stratified by landscape and stream network characteristics as described in Section 6.

Data Quality Objectives

Data quality objectives are integrated into EPA water quality monitoring programs as described in quality assurance documents (USEPA 1994a and 1994b). The abbreviated description of QA/QC methods is taken from the EPA publication, <u>Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls</u> (USEPA 1997). The document specifically addresses water quality monitoring but does provide data quality concepts transferable to habitat monitoring.

What is quality assurance and quality control?

Quality Assurance is an integrated system of activities used to verify that the quality control system is operating within acceptable limits. Quality Control is a system of technical procedures and activities implemented to produce measurements of requisite quality. QC procedures include the collection and analysis of replicate samples and the evaluation of the degree to which the samples represent the true environmental condition. QA procedures are more operational in nature and address the selection of qualified personnel, training, development of data quality objectives, and maintenance of complete records. For water quality monitoring, specification of QA/QC procedures and the development of *Quality Assurance Project Plan* are required of all EPA funded projects.

The EPA documents (USEPA 1994b, USEPA1997b) describe an iterative planning procedure, the *Data Quality Objectives Planning Process,* to develop a monitoring program. The objective of this process is to determine the qualitative and quantitative data needs for the project. The process, intended to improve the effectiveness and defensibility of data, is documented in a *Quality Assurance Project Plan. The Project Plan* identifies the resulting monitoring design and identifies data quality objectives for the project. The data quality is expressed in terms of precision, accuracy, comparability, representativeness, and completeness.

The difference between precision and accuracy is illustrated in Figure 7. Accuracy can be thought of as being on target – that is, the samples are clustered around the bull's eye. Precision is represented by the closely placed marks on the target; the individual samples

repeatedly come up with a similar result, even if it is not the correct one. These are simplistic illustrations, as other complex outcomes are possible; yet, they should convey the basic

conceptual differences between precision and accuracy.

High accuracy, low precision   **High precision, low accuracy**   **High accuracy and high precision**
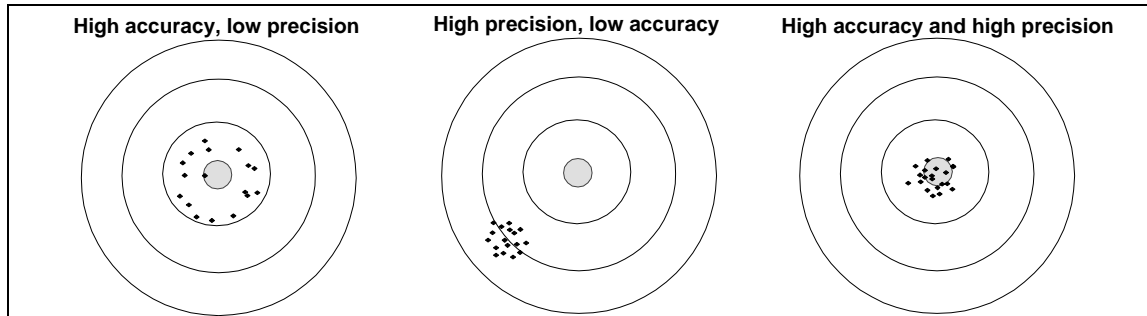
Figure 7. Illustration of precision and accuracy.

Precision is a measure of the mutual agreement among individual measurements of the same property. Precision is expressed as the coefficient of variation (CV), also referred to as the percent relative standard deviation (USEPA 1997).

$$CV = (s/x)*100.$$

where $s =$ sample standard deviation
        $x =$ the arithmetic mean
        $CV =$ Coefficient of Variation

Precision measures the reproducibility of the measurement method; it answers the question: how close is the result when the same quantity is measured repeatedly? For water quality studies, precision is estimated by evaluating a series of replicate samples. The replicates, usually duplicate samples, are taken from a stream using the same exact field procedure and submitted to the laboratory for analysis. When the results from the duplicate samples are similar in value, the Coefficient of Variation is low, for example in the 5 to 15 percent range. Various potential sources of error influence the precision of water quality sampling, e.g.failure to mix the samples adequately, random contamination of the sample container, analytical error, etc.

For habitat variables, measuring precision is not as straightforward as with water quality samples. The replicate sample is accomplished by repetition of the sampling method by field crews – either the same field crew at different times or

by a different crew at the same location. As with water quality samples, the estimation of precision can be influenced by a number of factors which contribute to sampling error, e.g. differences between observers or slight differences in selection of the monitoring location, like the placement of a transect across the channel. It is also feasible for the actual value of the variable to change in a short time between repeated visits to the site.

The precision of habitat variables has been evaluated in other ways than the Coefficient of Variation. The mean Percent Agreement (PA) among observers has been used as an estimate of precision when measuring habitat types – that is, pool vs. riffles. Mean PA is defined as the consensus score divided by the number of observers (Roper and Scarnecchia 1995). A modified method uses an expression called the Adjusted Percent Agreement (APA) to estimate precision (Poole et al. 1997). The APA characterizes how much better (or worse) than randomness the observed agreement is as a percentage of the distance between randomness and complete agreement. Refer to the paper by Poole et al (1997) for details on how to calculate this expression.

Accuracy is the degree of agreement of a measurement with an accepted reference or true value. To estimate accuracy in water quality sampling a known concentration, a "spike sample", is added to the stream or lake sample in the field. The field procedure of spiking is used to gain an understanding of whether the

ambient water chemistry has an influence on recovery of the known spike concentration. Percent recovery is calculated as the difference between the known concentration and the result of the spiked sample. The Average Percent Recovery from completing a series of such spiked samples is calculated as an expression of accuracy.

$$Percent\ Recovery = A\text{-}B/C*100$$

Where: A = spiked sample result
              B = sample result
              C = spike added

For habitat variables, the actual or true value can never be known with complete confidence, since we do not have the same easy ability to create the known value as with water quality samples. Accuracy of habitat variables can only be readily determined by comparing one method of measure, considered more accurate, to the test protocol being evaluated. For example, one may compare the value for gradient obtained from a clinometer (a less accurate method) to gradient measured with a Total Station Engineering Level that more accurately measures distance and change in elevation. Both methods are estimates of the "true value" and are subject to sources of error, but the Total Station value can be considered the standard against which the other field method is evaluated.

Estimating the accuracy of field measurements is technically difficult or infeasible. However, accuracy as a data quality objective may not be as critical as precision and repeatability to the monitoring purpose. This statement may seem counterintuitive, since we are always interested in high data quality – that is, data with known precision and accuracy. However, consider that, if the objective in habitat evaluations is to compare one site to another (e.g. a study reach to a reference reach), then repeatability and comparability are of utmost importance. This assumes that the method is accurate (or inaccurate) in a consistent direction. Comparison of habitat measures with known precision will answer the question of whether the study reach is different from the reference reach even if the accuracy is unknown. Contrast this situation to comparison of habitat measures to a specified numeric target – a compliance objective. In this situation, accuracy becomes as critical as precision, since we are now interested in knowing that we have measured the study reach in a manner that provides direct comparison to a target value – that is, how far is the study reach value from the bull's eye or criterion value.

The other data quality measures are more qualitative but are, nonetheless, an important consideration in monitoring procedures. **Comparability** is the confidence with which one data set can be compared to another. Comparability is particularly a problem with categorical habitat variables due to the variation in methods, monitoring crews, and associated training. **Representiveness** relates to the degree to which the samples are typical of the measured population. This condition depends on the ability of the procedure to select samples with a minimal bias from the target population. **Completeness** is defined as the amount of valid data obtained from a measurement system compared to the amount that was expected. Samples can fail to be collected, or their information value can be compromised in countless ways – failure to use Write-in-the-Rain paper, a cassette tape dropped in a pool, field personnel and notebooks that disappeared in a hole in the ice, an automatic sampler lost in a flood event, etc. (And they all have happened to the authors).

Use of Physical Habitat Variables in Monitoring

Habitat variables have a role in monitoring design for both the water quality objectives described above – habitat status in supporting beneficial uses and effectiveness monitoring. In addition to habitat variables, cause and effect studies of nonpoint source activities need to address the pathway elements (such as listed in Table 5, Section 5). The studies can look at a variety of physical factors related to soils, vegetation, hydrology and the ways that nonpoint sources ultimately alter the watershed and channel processes. These studies and their associated variables encompass a potentially wide spectrum of the natural resource field – hydrology, geology, soils, geomorphology, riparian, and wetlands, etc. Published monitoring guidelines have addressed application to specific sources: *forestry* (MacDonald et al. 1991, Dissmeyer 1994), *rangeland grazing* (Bauer and Burton 1993), and

agriculture (USEPA 1992). The EPA monitoring guidance document (USEPA 1997 in Appendix A) lists fifty-four monitoring guidance documents for nonpoint source activities.

Measurement of Habitat Variables

Habitat variables are monitored using different scales of measure which influence the flexibility in interpreting the data. Four measurement scales are commonly used when collecting scientific data: *nominal, ordinal, interval, and ratio scales* (from Poole et al. 1997*).* The *nominal scale* is used when items are classified. This scale assigns names to categories, but the names alone tell us nothing about the relationship between objects, except that objects in the same category are more similar to one another in some respect than objects in different categories. "Pool," "riffle", and "cascade" are categories without inherent rank and are, therefore, nominal measures. The *ordinal scale* is a scale of order or rank. Categories can be placed in ascending or descending order, but the magnitude of change when moving from one category to another is not constant. "Sand, "Pebble," and "Cobble" are ordinal measurements of particle size. The *interval scale* specifies rank and quantifies the magnitude of change between any two measures; any zero point on the scale is arbitrarily located. Temperature measured in C (zero is the point at which water freezes) or F (zero is 32 below the point at which water freezes) are interval measurements. Finally, the *ratio scale* is an interval scale with an absolute zero. Stream width and pool depth measured in linear units such as inches or cm are ratio measurements. These scales are described in order of ascending flexibility with respect to statistical techniques - the nominal scale is the least flexible and the ratio scale is the most. A greater variety of arithmetic operations and statistical techniques is available for data collected at more flexible scales (Schuster and Zuurling 1986). Generally speaking, using the nominal scale for data that could be recorded using other measurement scales can unnecessarily limit the statistical tools available for analyzing the data and, therefore, limit the utility of the data set.

Categorical data (nominal and ordinal scale) can provide useful information but has shortcomings associated with inherent observer bias. Habitat unit classification (pool, riffle, glides, etc.) has been used to quantify aquatic habitat in order to monitor the response of individual streams to human activities. Poole et al. (1997) found that habitat unit classification data collected in this manner was not useful for this purpose because: 1) observer bias seriously compromised repeatability, precision, and transferability of the information; 2) important ecological change was not always manifested as changes in habitat frequency; and, 3) classification data are nominal which can intrinsically limit their amenability to statistical analysis.

Habitat components have been measured by a variety of different methods based on different scales of measure. These variables are not comparable with respect to data quality objectives, although the variable name may imply that the same habitat component is being measured. For example, the *variable "percent fines sediment"* has been measured based on a variety of monitoring protocols: ocular estimates by an observer looking across an entire transect and making a mental average; ocular estimates of specific sub-samples along a transect using a view box; tallies of percent fines based on observations of percent fines from a grid placed on the stream bed; placement of substrate particles into descriptive size classes such as sand, gravel, cobble based on ocular means; and, via a diversity of modifications of the Wolman pebble count method. The "*percent fines sediment*" values obtained from these different procedures can be quite different. Little specific information exists on the precision of these various methods, and so, the degree of reproducibility and comparability is mostly unknown. This example illustrates the current confusion in habitat monitoring and the difficulty of applying these measures to water quality programs until the method as well as method precision and accuracy are defined. One program that has systematically evaluated precision of habitat parameters is the EPA Regional Ecosystem Monitoring and Assessment Program. Estimates of precision for the habitat variables collected during this program are described in the next section.

Case Study of Precision of Physical

Habitat Variables

A project that is part of US EPA's Regional Environmental Monitoring and Assessment Program (REMAP) has examined the issue of precision of measures of physical habitat in wadeable streams (Kaufmann et al. *in progress*). The study evaluated the precision and repeatability of a number of habitat variables collected using visual, semi-quantitative, and quantitative procedures. Data was collected in several hundred streams in Oregon, the Mid-Atlantic States, and the Midwest. For this report, we have only summarized the precision estimates from streams in Oregon.

The REMAP study is interested in comparing streams from a broad regional context. Estimates of precision are specific to the REMAP objectives and protocols, but they do provide a good example of how the scale of measurement affects the precision of the result. We selected a sub-set of variables (metrics) from this paper that measure the habitat components described in the previous section. The description of variables are simplified to illustrate the topic of precision. The reader should refer to the EPA publication (Kaufmann et al. 1998) for information on specific field methods and variable selection to answer any questions regarding transferability and comparability to their monitoring methods.

Precision was estimated as the *standard deviation of replicates*, as the *Coefficient of Variation* (CV), and as the *Signal to Noise ratio*. The lower the value of the *standard deviation of replicates* the more precise is the measurement. These values are reported in the units of measure, and so, they do not readily convey the magnitude of precision. The *Coefficient of Variation* is expressed as a percentage of the mean and, therefore, provides a common method of expressing the degree of variation. The lower the CV the greater is the precision. The CV is sensitive to the magnitude of the mean (the CV increases as the value of the mean decreases regardless of the actual precision of the measurement) and can, thus, be misleading. The third expression of precision is the *Signal to Noise ratio* (S/N). The higher the value the more precise the metric is and the greater is the ability to discern differences between streams. S/N values for this study

above 10 are considered precise for most uses, 7-10 are relatively precise, 3-7 are moderately precise, 1-3 are relatively imprecise, and less than 1 are imprecise.

Precision of variables described as visual (qualitative), semi-quantitative, and quantitative is compared in Table 7. *Percent Pool* habitat is a visual estimate that is flow-dependent and, therefore, exhibits low precision. Precision of this observation increases when habitat types are aggregated and only reported as *Percent Slow* (i.e. all pools and glides combined). Note the S:N ratio increases from 2.1 for *Percent Pools* to 7.5 for *Percent Slow* habitat. *Mean Residual Depth* is a quantitative measure based on average residual depth for a reach using the thalweg profile. We would expect the precision to be higher for repeated measures of residual depth from the same pool, though this statistic is not shown in this data set. The *LWD Frequency* methods used in REMAP is a semi-quantitative method; the logs are visually placed into size classes and tallied. The substrate metrics such as *Percent Fines* + *Sands* variable used is a semi-quantitative procedure, since the substrate particles are placed visually into size classes. The sample size used in the procedure consists of 55 particles. If the sample size were increased to 100 particles, the CV would be expected decrease.

Percent Tree Canopy Present has a high precision, because the classification that observers are asked to evaluate is simple and clear (i.e., either there is a tree canopy or there is not). *Proportion Overhanging Vegetation* and *Proportion Undercut Banks* are based on visual estimates, which are relatively imprecise. *Canopy Density*, measured with a densiometer, increases the repeatability to a high level of precision.

In summary, quantitative channel morphology and riparian canopy measurements are considered precise when applied to clearly defined and less flow dependent features. Semi-quantitative measurements are intermediate in precision. Visual estimates of riparian canopy cover and areal fish habitat cover exhibit low to moderate precision. Commonly used measures, such as riffle/pool and width/depth ratios, as well as qualitative visual assessments tend to be affected by flow and, therefore, are imprecise.

Table 7. Precision Estimates for selected quantitative and semi-quantitative variables from REMAP studies in Oregon (Kaufmann et. al. 1988).

Habitat Variable (reach scale)	Standard Deviation of Replicates*	Grand Mean	Coefficient of Variation*	Signal/Noise Ratio
Habitat Space				
% Pool Habitat (Visual)	16	33	48%	2.1
% Slow (Pools + Glides, Visual)	12	52	23%	7.5
Mean Residual Depth (quantitative, cm)	2.2	11.6	19%	9.0
LWD Frequency (Semi-quantitative, %)	0.4		n.a.	7.0
Substrate Quality				
Percent Fines + Sand (Semi-quantitative)	11	30.5 %	36%	7.1
Streambank & Riparian Condition				
Percent Tree Canopy (Qualitative)	8.0	92	8.7	10
Undercut Banks (Semi-quantitative)	0.038	0.068	56%	6.2
Overhanging Vegetation (Semi-quantitative)	0.069	0.19	36%	5.1
Canopy Density (Quantitative)	5.8	71.6 %	8.1	15

Detecting Differences

Precision and accuracy issues directly affect the potential application of habitat measurements used in CWA programs. If the monitoring method is too imprecise to detect differences considered ecologically significant, then these habitat variables will not be useful in managing water quality. The interaction of three primary factors – sample size, variability, and the size of the detection difference (Figure 8) – influences the ability to detect differences. Variability includes the natural variability of the measured habitat component plus the variability (sampling error) associated with the monitoring method.

Sample Size   Variability

Size of Detectable Difference
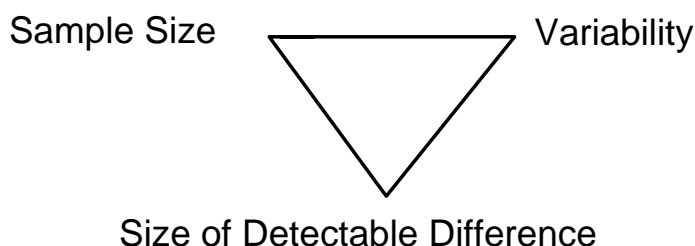
Figure 8. Detecting differences – The triangle of factors.

In order to detect a statistically significant difference among populations, the size of detectable difference must be substantial enough such that the difference is not subsumed by variation in the data. Use of an imprecise method imparts additional variance into a data set. Data resulting from a methodology with absolute precision would have no variance, while a less precise method would result in data with some variance attributed solely to the measurement procedure. This additional variance can distort conclusions by decreasing the '*power*' of the test.

The *power* of a statistical test is a measure of that test's ability to detect differences between populations. A test with less power will require a larger sample size and, therefore, greater sampling effort than a test with more power in order to detect the same differences among populations. The magnitude of the difference in central tendency (the mean or median) among populations, the sample variance in the data set (including error attributed to the method) and the sample size all affect whether a significant difference will be detected among populations.

Since the use of precise methodologies lowers the variance in the resulting data by eliminating sample error variance, a monitoring protocol that uses more precise methods will be able to detect change in the stream more readily than a protocol that uses less precise methods. Further, if the variance imparted by the methodology is large enough to mask the difference between the populations, that methodology will likely never detect difference between the populations of interest. Using the most precise methods available increases the sensitivity and, therefore, the utility of the monitoring protocol. Applying sufficiently imprecise methodologies renders the resulting data of little or no use toward meeting a monitoring program's goals.

The information on precision from Table 7 illustrates the influence of methods on detecting differences. The CV provides a measure of the ability to detect differences between populations or between the sampled population and a habitat target value. *Percent Pool Habitat*, a visual estimate, has a CV of 48%. If our target value is to have a stream with 50% pools, we could not expect to detect a difference from the criteria until the pool frequency was 48% away from the criterion - roughly 25% pools. The

measure of the habitat target is too imprecise to be useful, since a change of this magnitude would be damaging to the beneficial use. Our ability to detect differences improves with the *Percent Slow* metric; with a CV of 23%, we should be able to distinguish streams from the 50% target when Pool Frequencies are 38% or less.

Utility of Existing Habitat

Assessment Methods

A recent survey of habitat assessment methods by American Fisheries Society and USFWS identified 52 method documents in use by state, provincial, and federal governments (Bain, Hughes, and Arend 1999). Thirty-one of these methods were aimed at assessing streams and rivers. Most methods assessed the channel dimensions, substrate quality, water movement, riparian zone, fish cover, and stream size as common characteristics. Different approaches are used in these methods to define how much habitat needs to be measured and how study areas are located. Application of the results beyond the site-specific scale is limited by sampling design considerations. No evaluation of the comparability of these measurement methods was described in this report.

The Rocky Mountain Research Station recently assessed the efficacy of a standardized habitat inventory protocol for EPA (Peterson and Wollrab 1999). The R1/R4 fish and fish habitat inventory procedure (Overton et al. 1997) is a well-documented habitat monitoring protocol used throughout the Intermountain West. As with other habitat methods listed in the survey above, the survey protocols have evolved over time with an increased emphasis on standardization. However, the results of the analysis revealed several problems with application of the procedures. Standardized sampling methods were not consistently applied across Forest Service districts or within districts over time. These inconsistencies impede the detection of change and limit the validity of comparisons over time and space. The analysis found the procedures to be subjective, biased, and inadequate for estimating fish populations and characterizing fish habitat. Monitoring protocols that use these procedures will likely fail to detect significant changes or could indicate false changes in fish habitat. The

authors recommend that the inventory procedures be replaced by a more rigorous decision analysis system applied to a specific management question.

If this analysis of the R1/R4 inventory procedures (Peterson and Wollrab 1999) is representative of the existing habitat protocols, then there is good reason to question the utility of inventory procedures for use in water quality programs. The fisheries and aquatic ecology community needs to address the shortcomings of these methods and help review and develop more robust procedures.

Summary

A systematic approach to monitoring addresses monitoring design, selection of variables and measurement methods, and quality assurance/quality control procedures. Quality assurance procedures established for water quality monitoring provide a framework that can be applied to the measurement of habitat variables. The water quality monitoring framework consists of established Standard Methods for analytical analyses, Standard Operating Procedures for field methods, and QA/QC procedures. Currently no accepted parallel systematic framework exists for assuring the data quality for habitat monitoring. However, a number of state and federal have programs that address several of these components, and the experience from these programs could be brought together to build this framework.

Using habitat variables under the CWA as diagnostic indicators, water quality criteria, or environmental targets for TMDL's requires the establishment of data quality objectives. The detection of ecologically significant differences requires data with known levels of precision and accuracy. Measured quantitative data should be used where feasible to overcome the observer bias inherent in qualitative methods. Quantitative methods for measuring habitat are becoming more accessible and faster with the use of Total Station Survey equipment and GPS survey technology (Fisher and Toepfer 1998). Quantitative channel measurements that are standard procedures in hydrology and geomorphology (Harrelson et al. 1994, Rosgen 1996) should be considered as ways to increase quantitative measurement of habitat quality. The Tongass National Forest channel condition assessment protocol for channel morphology, large woody debris, and grain size distribution (Kuntzsch et al. 1998) provides an example of the use of these quantitative methods. The trade off between the costs of quantitative methods and the expected benefits in detecting change will also need to be considered.

8. APPLICATION OF AQUATIC HABITAT INDICATORS TO

CWA PROGRAMS

In the previous sections of this paper, we described the rationale, technical basis, and potential limitations of using aquatic habitat indicators in the CWA. The Executive Summary contains a synopsis of the key conclusions from this review and recommendations for future action. In this section, we describe how the current situation might be applied to water quality standards and TMDLs.

Application to Water Quality Standards

The current Water Quality Standards in EPA Region 10 states (Alaska, Idaho, Washington and Oregon) and certain tribes contain narrative and numeric criteria designed to protect "beneficial uses" of water that include cold water biota, salmonid fish communities, and their habitats. We briefly review the requirements for water quality standards as well as current state criteria and, then, suggest some alternative approaches to water quality criteria relative to aquatic habitats.

The discussion of water quality standards will be brief; the reader is referred to the recent Advanced Notice of Public Rulemaking on Water Quality Standards (Federal Register Vol. 3, No. 129 published Tuesday, July 7, 1998) for more details. Water quality *criteria* are levels of individual pollutants, water quality characteristics, or descriptions of conditions of a water body that, if met, will generally protect the designated use of the water. *Narrative criteria* can include physical criteria such as habitat characteristics and flow regimes. Section 303 (a-c) the CWA requires all states or tribes with water quality program authority to evaluate the need for water quality criteria in order to protect a designated use and then to adopt appropriate water quality criteria to protect existing and

designated uses. Narrative criteria are descriptions of conditions necessary for the water body to attain its 'designated use', such as spawning and rearing habitat supportive of healthy populations of salmon and trout. Narrative criteria may address generic conditions such as surface waters shall be 'be free from' hazardous materials, toxic substances, excess nutrients, and oxygen-demanding materials. Narrative criteria may also describe the process for developing a numeric criteria given certain conditions.

All Region 10 states include **numeric** water quality criteria for certain water column variables, namely dissolved oxygen, total dissolved gas, temperature, pH, turbidity, ammonia, residual chlorine, and toxic substances. The states show a wide diversity in content, however, relative to protection of aquatic habitats (Table 8). Generally, there are policy statements regarding the full protection of existing and designated uses of water, specific use designations applicable to cold water salmonid fish, salmonid spawning, as well as biological criteria and biomonitoring. States have used their antidegradation authority and its requirements to protect existing uses as a basis for incorporating additional requirements for physical habitat into CWA Section 401 certifications. For example, the state of Washington specified a minimum instream flow requirement for the Elkhorn hydroelectric project (in PUD No. 1, Jefferson County vs. Wa. Dept. of Ecology [511US700], 1994).

Our conclusion upon reviewing the existing standards is that **narrative criteria** for salmonid habitat could be substantially strengthened by more fully describing the mix of conditions generally known to constitute suitable habitat. For spawning habitat, these might include, for example, "...maintenance of in-stream flow conditions and suitably-sized gravel substrate

for support of spawning at known historic locations". These criteria could further specify characteristics of stream bottom sediments (bed particle sizes, % fines) as determined by a specific method (e.g. pebble counts using methods of Wolman 1954), as defined for particular spawning locations (which could be fixed using global positioning systems), and as overlain onto spawning ground information (determined by consulting timing and location records of current and historic spawning ground surveys and mapped at the 1:24,000 or 1:12,000 scale). These locations could then serve as a focal point for additional evaluation of water quality, peak discharge event recording, or bed scour and fill events and their significance to egg to emergence survival of the progeny from a given salmon stock. Assessment of sediment

input sources from hillslope failures, and the effect these have on spawning ground characteristics and salmon success could then be evaluated.

The narrative criteria could also describe the process for development of site-specific or ecoregional numeric criteria. Numeric criteria could be tiered to these narrative statements as more specific information becomes available for individual ecoregions or river basins and watersheds nested within these areas. Several of the state standards already provide the framework for this approach. For example, the statements regarding *reference condition* and *site-specific criteria* address two of the critical elements to the approach that we have discussed.

Table 8.   Compilation of State Standards in Region 10 with reference to protection of habitat quality.

Idaho	State Standards with Reference to Aquatic Habitats
Idaho Water Quality Standards **IDAPA 16.01.02** **(compiled through 3/1999)**	**Definition** 12. Biological Monitoring or Biomonitoring. The use of a biological entity as a detector and its response as a measure to determine environmental conditions. Toxicity tests and biological surveys, including **habitat** monitoring, are common biomonitoring methods. (8-24-94) 35. Existing Beneficial Use Or Existing Use. Those beneficial uses actually attained in waters on or after November 28, 1975, whether or not they are designated for those waters in Idaho Department of Health and Welfare Rules, IDAPA 16.01.02, "Water Quality Standards and Wastewater Treatment Requirements". (8-24-94) 40. Full Protection, Full Support, or Full Maintenance of Designated Beneficial Uses of Water. Compliance with those levels of water quality criteria listed in Sections 200, 250, 275 (if applicable), and 299 or with the reference streams or conditions approved by the Director in consultation with the appropriate basin advisory group. (3-20-97) 84. Reference Stream Or Condition. A water body which represents the minimum conditions necessary to fully support the applicable designated beneficial uses as further specified in these rules, or natural conditions with few impacts from human activities and which are representative of the highest level of support attainable in the basin. In highly mineralized areas or in the absence of such reference streams or water bodies, the Director, in consultation with the basin advisory group and the technical advisors to it, may define appropriate hypothetical reference conditions or may use monitoring data specific to the site in question to determine conditions in which the beneficial uses are fully supported. (3-20-97)
	050. ADMINISTRATIVE POLICY. 02. Protection Of Waters Of The State. (7-1-93) a. Wherever attainable, surface waters of the state shall be protected for beneficial uses which for surface waters includes all recreational use in and on the water surface and the preservation and propagation of desirable species of aquatic biota; (8-24-94) c. In all cases, existing beneficial uses of the waters of the state will be protected. (7-1-93)

Idaho Water Quality Standards (Continued)	**053. BENEFICIAL USE SUPPORT STATUS.** In determining whether a water body fully supports designated and existing beneficial uses, the Department shall determine whether all of the applicable water quality standards are being achieved, including any criteria developed pursuant to these rules, and whether a healthy, balanced biological community is present. The Department shall utilize biological and aquatic **habitat** parameters listed below in the "Water body Assessment Guidance," Idaho Department of Health and Welfare, Division of Environmental Quality, 1996, as a guide to assist in the assessment of beneficial use status. These parameters are not to be considered or treated as individual water quality criteria or otherwise interpreted or applied as water quality standards. (3-20-97). 01. Aquatic **Habitat** Parameters. These parameters may include, but are not limited to, stream width, stream depth, stream shade, measurements of sediment impacts, bank stability, water flows, and other physical characteristics of the stream that affect **habitat** for fish, macroinvertebrates or other aquatic life; and (3-20-97). 02. Biological Parameters. These parameters may include, but are not limited to, evaluation of aquatic macroinvertebrates including Ephemeroptera, Plecoptera and Trichoptera (EPT), Hilsenhoff Biotic Index, measures of functional feeding groups, and the variety and number of fish or other aquatic life to determine biological community diversity and functionality. (3-20-97)
	100. SURFACE WATER USE CLASSIFICATIONS. The designated beneficial uses for which the surface waters of the state are to be protected include: (8-24-94) c. Salmonid spawning: waters which provide or could provide a **habitat** for active self-propagating populations of salmonid fishes. (7-1-93)
	275. SITE-SPECIFIC SURFACE WATER QUALITY CRITERIA. 01. Procedures For Establishing Site-specific Water Quality Criteria. *{In summary, this section provides for development of criteria based on site-specific analyses conducted in a scientifically justifiable manner.}*

Washington	State Standards with Reference to Aquatic Habitats
Washington Water Quality Standards **18 AAC 70** (as amended,1999)	**Definitions** **"Biological assessment"** is an evaluation of the biological condition of a water body using surveys of aquatic community structure and function and other direct measurements of resident biota in surface waters. **"Wildlife habitat"** means waters of the state used by, or that directly or indirectly provide food support to, fish, other aquatic life, and wildlife for any life history stage or activity. {Note: list of code citations not included.}
	General water use and criteria classes. WAC 173–201A–030 {Note: Fish and shellfish - Salmonid migration, rearing, spawning, and harvesting - are listed as characteristic uses depending on Class designation. No habitat related criteria are listed.}

Oregon	State Standards with Reference to Aquatic Habitats
Oregon Water Quality Standards **Oregon Administrative Rules OAR-340-41.** **1999**	**Definitions** (32) "Aquatic Species" means any plants or animals which live at least part of their life cycle in waters of the State. (33) "Biological Criteria" means numerical values or narrative expressions that describe the biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use. (36) "Resident Biological Community" means aquatic life expected to exist in a particular habitat when water quality standards for a specific ecoregion, basin, or water body are met. This shall be established by accepted biomonitoring techniques. (37) "Without Detrimental Changes in the Resident Biological Community" means no loss of ecological integrity when compared to natural conditions at an appropriate reference site or region. (38) "Ecological Integrity" means the summation of chemical, physical and biological integrity capable of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region. (39) "Appropriate Reference Site or Region" means a site on the same water body, or within the same basin or ecoregion that has similar habitat conditions, and represents the water quality and biological community attainable within the areas of concern. (40) "Critical Habitat" means those areas which support rare, threatened or endangered species, or serve as sensitive spawning and rearing areas for aquatic life.
	Biological Criteria: Waters of the state shall be of sufficient quality to support aquatic species without detrimental changes in the resident biological communities. 340-041-0027
	Standard applicable to all basins: The creation of tastes or odors or toxic or **other conditions that are deleterious to fish** or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish shall not be allowed;
	Intergravel Dissolved Oxygen: A) For water bodies identified by the Department as providing salmonid spawning, during the periods from spawning until fry emergence from the gravels, the following criteria apply: (B) For water bodies identified by the Department as providing salmonid spawning during the period from spawning until fry emergence from the gravels, the spatial median intergravel dissolved oxygen concentration shall not fall below 6.0 mg/l; (C) A spatial median of 8.0 mg/l intergravel dissolved oxygen level shall be used to identify areas where the recognized beneficial use of salmonid spawning, egg incubation and fry emergence from the egg and from the gravels may be impaired and therefore require action by the Department.

Alaska	State Standards with Reference to Aquatic Habitats
Alaska Water Quality Standards **18 AAC 70** (as amended through May 27, 1999)	**Definitions** (19) "designated uses" means those uses specified in 18 AAC 70.020 as protected use classes for each waterbody or segment, regardless of whether those uses are being attained; (24) "existing uses" means those uses actually attained in a waterbody on or after November 28, 1975; (52) "sediment" means solid material of organic or mineral origin that is transported by, suspended in, or deposited from water; "sediment" includes chemical and biochemical precipitates and organic material, such as humus;
	Sediment Standards – 70.020(b) (C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife The percent accumulation of fine sediment in the range of 0.1 mm to 4.0 mm in the gravel bed of waters used by anadromous or resident fish for spawning may not be increased more than 5% by weight above natural conditions (as shown from grain size accumulation graph). In no case may the 0.1 mm to 4.0 mm fine sediment range in those gravel beds exceed a maximum of 30% by weight (as shown from grain size accumulation graph). (See notes 3 and 4). In all other surface waters no sediment loads (suspended or deposited) that can cause adverse effects on aquatic animal or plant life, their reproduction or habitat may be present.
	Intergravel Dissolved Oxygen Standard – 70.020(b) D.O. must be greater than 7 mg/l in waters used by anadromous and resident fish. In no case may D.O. be less than 5 mg/l to a depth of 20 cm in the interstitial waters of gravel used by anadromous or resident fish for spawning (See note 2). For waters not used by anadromous or resident fish, D.O. must be greater than or equal to 5 mg/l. In no case may D.O. be greater than 17 mg/l. The concentration of D.O. may not exceed 110% of saturation at any point of sample collection.
	. SITE-SPECIFIC CRITERIA. 70.235 The department will, in its discretion, establish a site-specific water quality criterion that modifies a water quality criterion set out in 18 AAC 70.020(b) *{Note: This section describes the process for determining site-specific criteria.}*

Example of Approach to Habitat Indicators

Two examples, described in Appendix A and B, illustrate the approach to developing numerical indicators from empirical data collected in reference areas. One example is based on habitat indices developed as part of the Tongass Land and Resource Management Plan. Three habitat indices (pool area, pieces of large woody debris, and bankfull width-to-depth ratio) were derived from existing watershed-scale stream inventory data for the Tongass National Forest. The data are presented as the 25th, 50th, and 75th percentiles of the data. Refer to Appendix B for a description of these habitat indicators.

The second example comes from data in the Salmon River Basin located in Northern Rocky Mountain Ecoregion in central Idaho. The U.S. Forest Service Intermountain Research Station collected data within this ecoregion to characterize streams under natural conditions. The data collection area focused on the high rugged mountains of central Idaho where there is little human disturbance. We selected this data set for two reasons: first, there is high assurance that natural forces (fire, wind, and flood, and mass wasting events) are responsible for the variation in habitat condition; and second, the data was collected under written monitoring protocols with careful attention to observer training and quality control. This data set is used to illustrate an example of narrative and numeric criteria.

There are many possible formats for habitat water quality criteria. Narrative criteria should designate the importance of the habitat at the *Habitat Component* level as discussed in Section 5. The narrative criteria should further identify the habitat indicators that will be measured to evaluate attainment of the criterion where feasible. We have used the phrase "*based on the range of conditions observed in reference streams of a comparable stream system*" to convey the concept that the target condition is obtained from streams of a similar geomorphology in an undisturbed condition.

Numeric criteria can then be tiered to the narrative statement as information becomes available on a ecoregional basis. This addresses the usual objection of a lack of information on a statewide basis. The numeric criteria refer to data sets compiled from reference areas of a comparable landscape setting and stream system. The example language uses the phrase "*as stratified by basin area, parent geology, or other geomorphic characteristic*" to recognize the need for stratification by landscape and stream network characteristics. The actual stratification as listed in the table, then, relies on an analysis of the data in a manner that best explains the variation due to ecoregional characteristics. We have designated the *third quartile* of the data distribution to act as a red flag to trigger further evaluation with regards to the reason that a stream might fall below this range.

Narrative criteria example

Maintain or restore the physical integrity of the aquatic system necessary to support habitat for salmonid spawning and rearing. Indicators of physical habitat integrity include large woody debris frequency, pool frequency, residual pool depth, and percent surface fines. Numeric habitat indicators will be developed by ecoregional area based on the range of conditions observed in reference streams of a comparable stream system as this information becomes available.

Numeric Criteria example

Large woody debris frequency, pool frequency, and residual pool depth should occur within the third quartile of the data distribution for reference streams in the ecoregion as stratified by basin area, parent geology, or other geomorphic characteristics as determined by stream quantitative stream surveys, see the example in

Figure 9. Comparison to numeric criteria is based on the summary of data by stream reach. Where data falls outside of the expected range, the cause for such deviation shall be determined.

Large woody debris/mile in different basin areas

	0 - 25	25 - 50	50 - 75	75 - 100	100 - 150	150 - 360
N	31	33	17	10	13	12
IQR	170.6	100	44	55.4	42.8	14.5
Median	136.1	83.4	49.8	62.2	79.1	25.8
25%	67.8	47.1	38.6	41.9	50.2	18.8
75%	238.4	147.1	82.6	97.3	92.9	33.3

Pool frequency in Rosgen channel types

	All	A	B	C
N	124	4	92	28
IQR	24.0	23.3	23.4	18.5
Median	20.7	60.2	20.4	19.6
25%	12.6	46.7	11.7	16.7
75%	36.6	70	35.1	35.2

Residual pool depth and basin area

	0 - 25	25 - 50	50 - 75	75 - 100	100 - 125	100 - 150	150 - 360
N	2342	1075	94	66	181	44	49
IQR	0.25	0.24	0.29	0.3	0.35	0.68	0.5
Median	0.35	0.4	0.45	0.54	0.5	0.5	1.3
25%	0.25	0.3	0.35	0.4	0.35	0.33	1
75%	0.5	0.54	0.64	0.7	0.7	1	1.5

Percent fines of different geology and channel types

	All	Plut All	Plut A	Plut B	Plut C	Volc All	Volc A	Volc B	Volc C
N	8459	5733	263	3673	1797	2726	11	2385	330
IQR	20	20	10	10	35	30	22.5	35	7
Median	15	15	10	15	25	20	40	20	10
25%	10	10	5	10	15	10	22.5	10	8
75%	30	30	15	20	50	40	45	45	15

Figure 9. Percentiles of LWD/mile, pool frequency, residual pool depth, and percent fines from the Salmon River Basin natural conditions database.

Application to TMDL Targets

An integral step in developing a TMDL is to establish the water quality target for the pollutant load analysis. The emphasis on quantitative targets, regardless of the technical limitations on establishing such numeric targets, is a controversial issue that has not yet been resolved. This apparent conflict occurs because the legal mandate clashes with practical, technical and scientific limitations. As currently understood, development of a TMDL requires pollutant load estimates, load allocation, and specification of numeric targets. The logical approach for developing numeric habitat targets as described in the example above for numeric criteria should also apply to the development of TMDL targets. However, incorporating the caveats and technical limitations of this approach into TMDLs may be difficult because of the nature of the regulatory framework for water quality limited streams. We have emphasized that habitat indicators should be used as diagnostic indicators rather than as compliance indicators. An appropriate use, therefore, is to incorporate the habitat components into the TMDL as a monitoring and evaluation tool to be used in an adaptive management framework.

The key difficulty in establishing numeric targets, even as diagnostic indicators, is the expected lack of information on reference areas on which to base the TMDL target condition. There is obviously no ready solution for the lack of reference conditions, so the TMDL analyst will have to exert some creativity in looking for suitable information. The information search should not be restricted within the watershed or river basin. As discussed in the landscape section, habitat conditions should be based on (but not restricted to) the broader base of reference streams within the ecoregion. In addition, often isolated tracts of land that have experienced little development can provide some comparable reference data.

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APPENDICES

APPENDIX A: EXAMPLE OF AQUATIC HABITAT INDICATORS IN THE ROCKY MOUNTAIN ECOREGION

Introduction

The Pacific Northwest is characterized by a diversity of landscapes due to the natural variation in climate, geology, and topography. The patterns of vegetation and the distribution of fish and wildlife populations are directly related to this diversity.   Several geographic frameworks have been established to better understand these regional patterns and aid in natural resource management. A geographic framework provides a logical basis for characterizing the range of ecosystem conditions that are realistically attainable, relative to regional patterns of cultural and physical constraints (Omernik and Gallant 1986). Stream systems are a product of landscapes that share common climatic and geologic features. Stream reference conditions within similar landscapes provides a measure of natural conditions in which fish and other aquatic life have evolved. The ecoregion framework provides a method of cataloging stream systems by similar broad scale characteristics of geology, climate, and physiography. Stream networks nested within these broad scale landscapes can be further grouped based on local channel characteristics such as gradient, stream size, and confinement.

The Ecoregion classification scheme presented by Omernik (1995) is a useful framework for delineating landscape by geology, climate, and vegetation characteristics. Ecoregions may be further stratified by these landscape features and by watershed delineation to create nested hierarchical frameworks. Hydrologic Units, described by USGS, is a commonly used system for organizing watersheds using a nested hierarchical system. Stratifying watersheds within ecoregions provides a method to compare stream systems across similar landscapes as well as between streams with similar geomorphic features. Cataloging streams of similar types and characteristics allows managers to better understand the potential capacity of a stream and the effects of activities that have altered that capacity.

The Natural Conditions Database of Salmon River Basin

The U.S. Forest Service Intermountain Region Research Station, U.S. Dept. of Agriculture, surveyed stream characteristics in the Salmon River basin, Idaho, that are representative of reference conditions in this ecoregion. The database and description of stream characteristics represent stream conditions shaped by natural forces in the absence of human disturbance. It is assumed that these streams have channel dimensions, form, and patterns of systems influenced only by natural disturbance regimes (such as fire, flood, drought) and that the frequency distributions for the selected habitat type variables approximate the spatial and temporal variability for the Salmon River basin (Overton et al. 1995).   Data collection procedures were targeted at four landscape scales – watershed, channel reach type, habitat type, and meso-habitat (meso-habitat refers to attributes of the habitat type; bank characteristics, large woody debris). Objectives were to collect information on habitat attributes that were considered both ecologically significant to fish and affected by land management disturbance. The reader should consult the USFS document for a detailed presentation of information from this database. For this example, we have focused on a subset of habitat parameters within a smaller geographic area.

Upper Middle Fork Salmon River

The Upper Middle Fork Salmon drainage is a fourth level HUC located within the Salmon River basin (third level HUC) in central Idaho, Figure 10. The Salmon River basin contains large areas of roadless that provide an opportunity to evaluate aquatic habitat that is influenced primarily by natural disturbances. The area is characteristic of the high elevation mountain forests located within the

Northern Rocky Mountain Ecoregion, a Level III ecoregion, described by Omernik (1995). Landscape characteristics of the Salmon River basin are summarized in the USFS publication (Overton 1995).

> "The Salmon River drains a large, mostly forested basin in central Idaho. The Salmon River country is characterized by high rugged mountains. It's topography is typical of many dendritic drainages with tributaries forming steep v-shaped canyons. Dendritic drainage networks are characteristic of soils with a homogeneous resistance to erosion. Many tributaries have cut steep rock canyons with meadows at the head water areas. The whole Salmon River Basin is an extensive area of forested mountains, sagebrush covered lower slopes, and deeply incised river canyons. Volcanic and plutonic geologies make up the most of the Salmon River basin."

Weathering of rock, grain size, amount of moisture, and vegetation play an important role in finding which soils form and how a stream will develop and behave. There are two major, distinct geologies found in the Salmon River drainage: the Idaho Batholith, a composite mass of granitic plutons, and the Challis Volcanics (Overton1995). The Idaho Batholith's is a plutonic, intrusive geology comprised of granitic and dioritic subclasses, that are unstable and decompose rapidly. The Challis Volcanics is extrusive, and comprised of basalt/andesite and rhyolite. Ryolite erodes similiarly to granitics, where basalts/andesites erode faster than granitics.

To compare similar stream reaches we grouped the habitat variables (response variables) according to the major factors that influence their magnitude. Habitat is characterized by measures of large woody debris, pool frequency, residual pool depth, percent fines, and percent bank stability. These habitat measures are grouped by three major landscape and stream network factors that exert a major influence on their outcome – channel gradient, basin size, and geology.
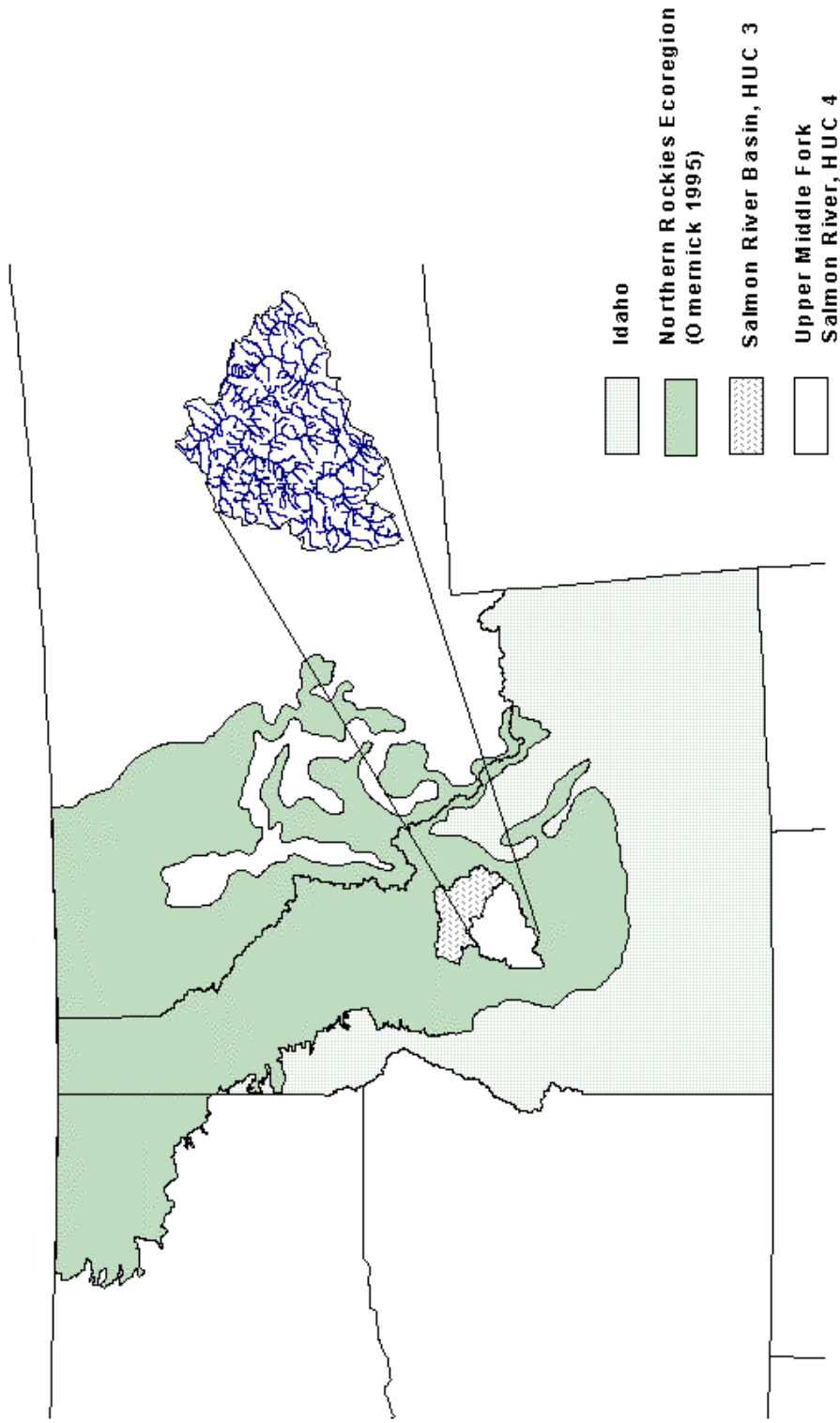
Figure 10. Nested Hierarchy of the Upper Middle Fork Salmon basin, Idaho.

Large Woody Debris

Large woody debris in forested streams is one of most important contributors of habitat and cover for fish populations. Large woody debris can influence channel meandering, bank and substrate stability, and variability in channel width. Large woody debris is a function of stream size, with smaller streams containing more wood than larger streams (Bilby and Ward 1989). These relationships are observed in the Upper Middle Fork Salmon basin; more large woody debris occurs in smaller basins, Figure 11. Variability of data is represented by box and whisker plots. The lower and upper 25 percent of the data is represented by the top and bottom of the box, the median is the central line within the box. The whiskers extending from the box represent the 10th and 90th percentile and points exceeding whiskers are outliers. Inter quartile range (IQR) and quartile values are provided in the table below the figure.
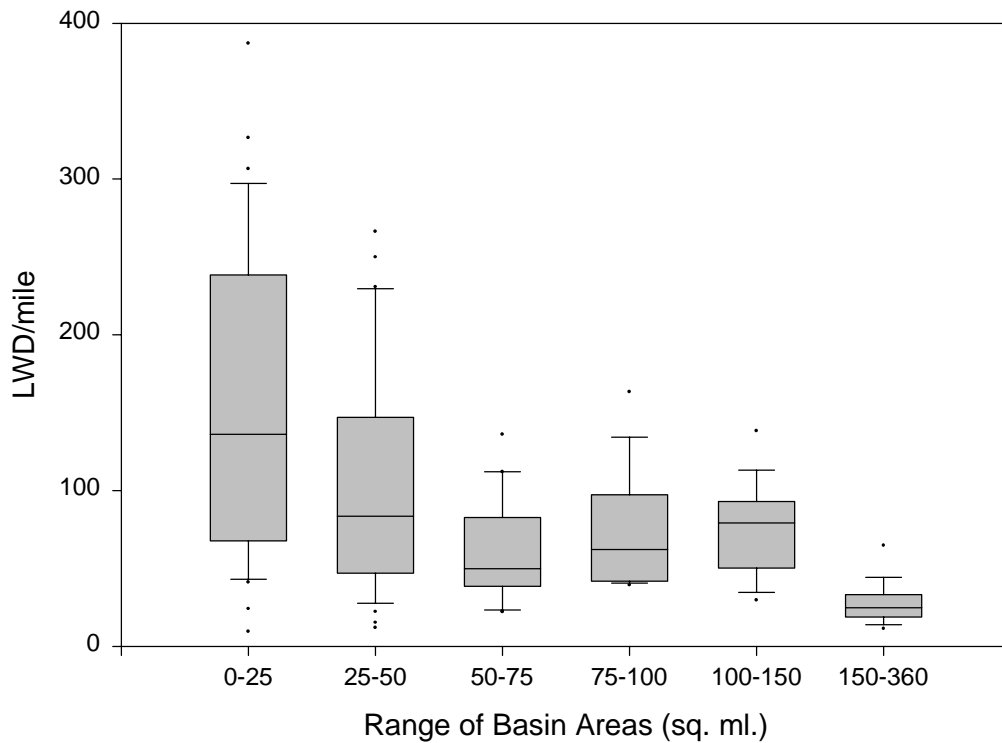
	0 - 25	25 - 50	50 - 75	75 - 100	100 - 150	150 - 360
N	31	33	17	10	13	12
IQR	170.6	100.0	44.0	55.4	42.8	14.5
Median	136.1	83.4	49.8	62.2	79.1	25.8
25%	67.8	47.1	38.6	41.9	50.2	18.8
75%	238.4	147.1	82.6	97.3	92.9	33.3

Figure 11. Box Plot of large woody debris/mile in different size basin areas, in unmanaged streams in the Upper Middle Fork Salmon River basin, Idaho.

Pool Frequency and Depth

Pools provide important habitat throughout all salmonid life stages. Pool spacing in forest channels of mountain drainage basins is controlled by large woody debris loading and channel type, slope, and width (Montgomery et al. 1995). The spacing of pool features is proportional to stream width, and inversely related to channel slope (Rosgen 1996). The influence can be noted in comparing pool frequency to channel type (Figure 12) and basin size (Figure 13). Steeper Type A channels exhibited higher pool frequency than the lower gradient Type C channels. Pool frequency was inversely related to basin size (stream size) in the Upper Middle Fork Salmon, Figure 13.

The residual pool depth is a measure of stream depth that is independent from stream discharge and therefore provides a useful comparable measure of available habitat. Residual pool depth increased in larger systems (larger basin and channel size), Figure 14. Larger streams produce, fewer, but larger pools than smaller streams.
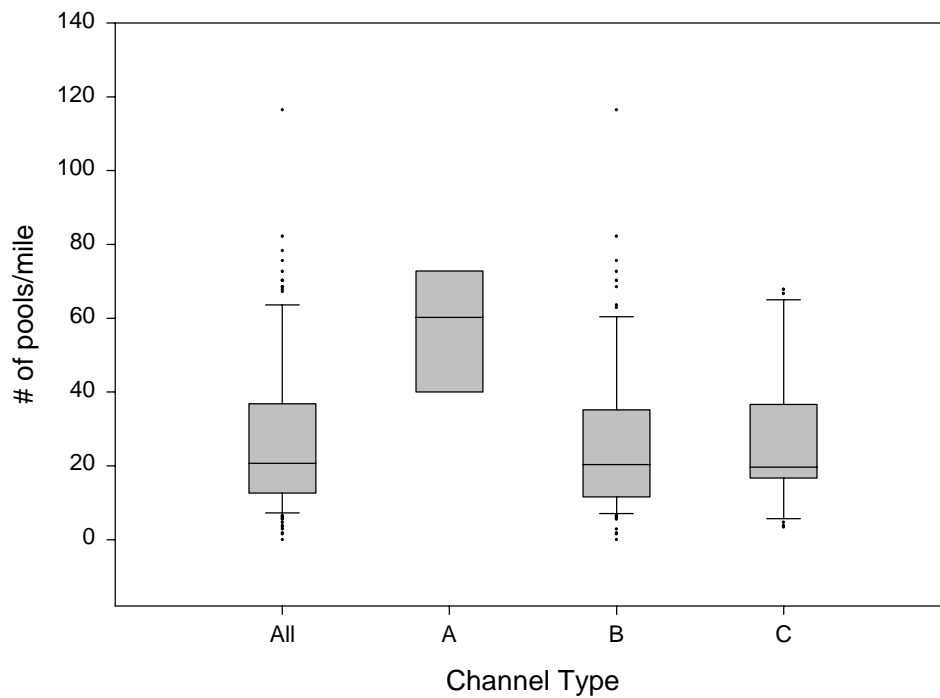
	All	A	B	C
N	124	4	92	28
IQR	24.0	23.3	23.4	18.5
Median	20.7	60.2	20.4	19.6
25%	12.6	46.7	11.7	16.7
75%	36.6	70.0	35.1	35.2

Figure 12. Box plot of pool frequency in Rosgen channel types, in unmanaged streams in the Upper Middle Fork Salmon River basin, Idaho.
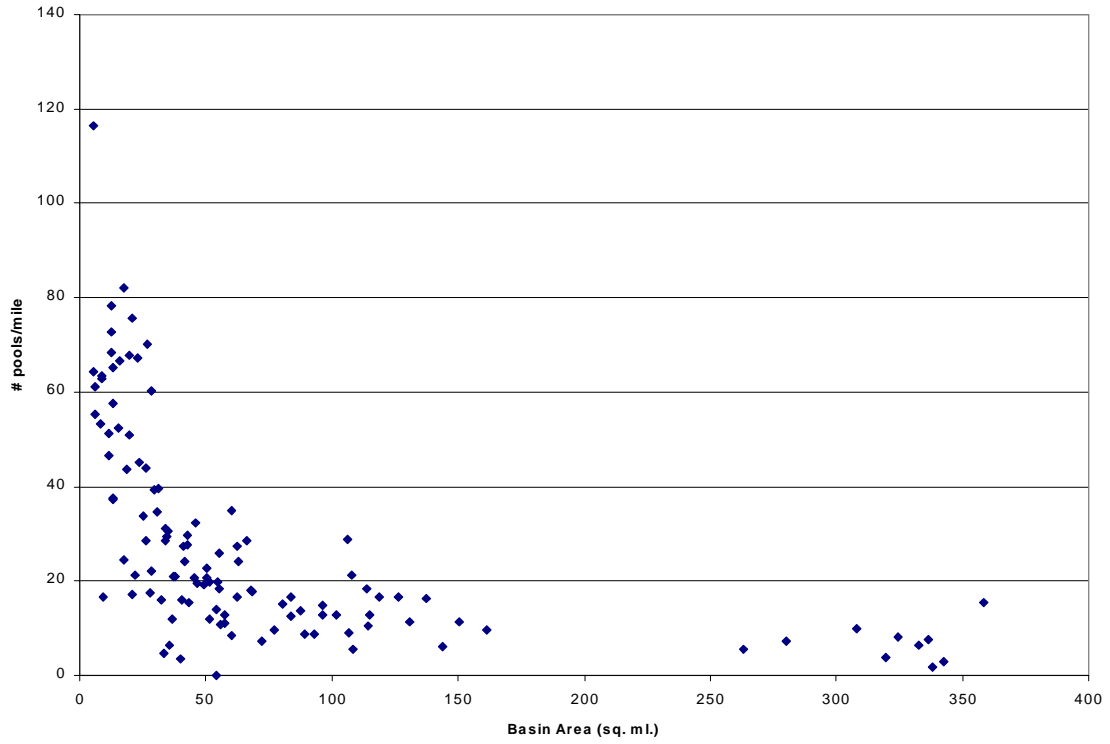
Figure 13. Scatter plot of pool frequency and basin area, in unmanaged streams in the Upper Middle Fork Salmon River, Idaho.
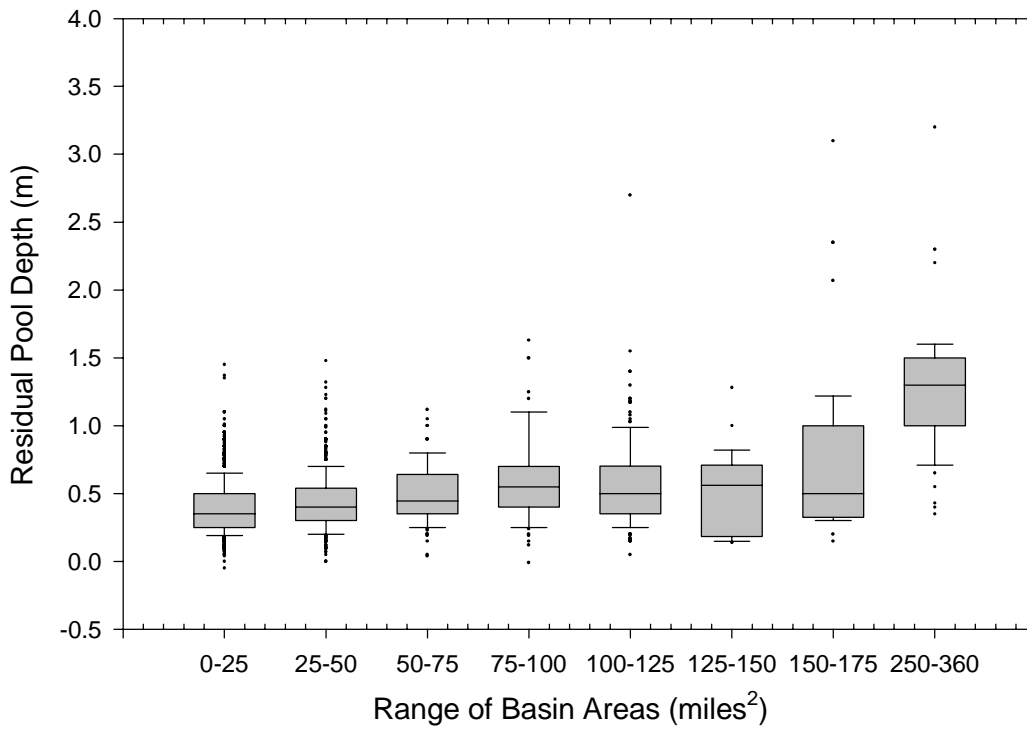
	0 - 25	25 - 50	50 - 75	75 - 100	100 - 125	125 - 150	150 - 175	250 - 360
N	2342	1075	94	66	181	24	44	49
IQR	0.25	0.24	0.29	0.30	0.35	0.53	0.68	0.50
Median	0.35	0.4	0.45	0.54	0.5	0.56	0.5	1.3
25%	0.25	0.3	0.35	0.4	0.35	0.19	0.33	1
75%	0.5	0.54	0.64	0.7	0.70	0.71	1	1.5

Figure 14. Box plot of residual pool depth and basin area, in unmanaged streams in the Upper Middle Fork Salmon River Basin, Idaho.

Surface Fines

Surface fines are defined as those particles less than 6 mm in size (silt/sand). Sediment of this size is generally transported during peak flows and settles out on the pool bottoms and low gradient riffles. Fine sediment can fill pools, reduce spatial variability, reduce egg to fry survival in a salmonid redd. Observation of percent fines is highly variable (Figure 15), which is likely due to a combination of natural variability and sampling error. The box plots show some interesting relationships between geology and channel type. Percent fines increases in lower gradient channels(A to C) in plutonic geology, and decreases in volcanic geology (A to C). Reference lines and arrows have been added to Figure 15 to emphasize this trend.

Geology and Channel Type

	All	Plut All	Plut A	Plut B	Plut C	Volc All	Volc A	Volc B	Volc C
N	8459	5733	263	3673	1797	2726	11	2385	330
IQR	20	20	10	10	35	30	22.5	35	7
Median	15	15	10	15	25	20	40	20	10
25%	10	10	5	10	15	10	22.5	10	8
75%	30	30	15	20	50	40	45	45	15

Figure 15. Box plot of descriptive statistics of percent fines of different geology and channel types, in unmanaged streams in the Upper Middle Fork Salmon River basin, Idaho.

Bank Stability

Stable banks support riparian vegetation that provide shade, cover, and nutrient loading for salmonids. Loss of bank stability reduces bank undercut and increases sediment loading. Bank stability can be altered by natural or human caused events that change sediment load, vegetation type and density, and channel stability. Percent bank stability was high in all samples of the unmanaged basin, Figure 16, with the mean higher than 80% for each sample.
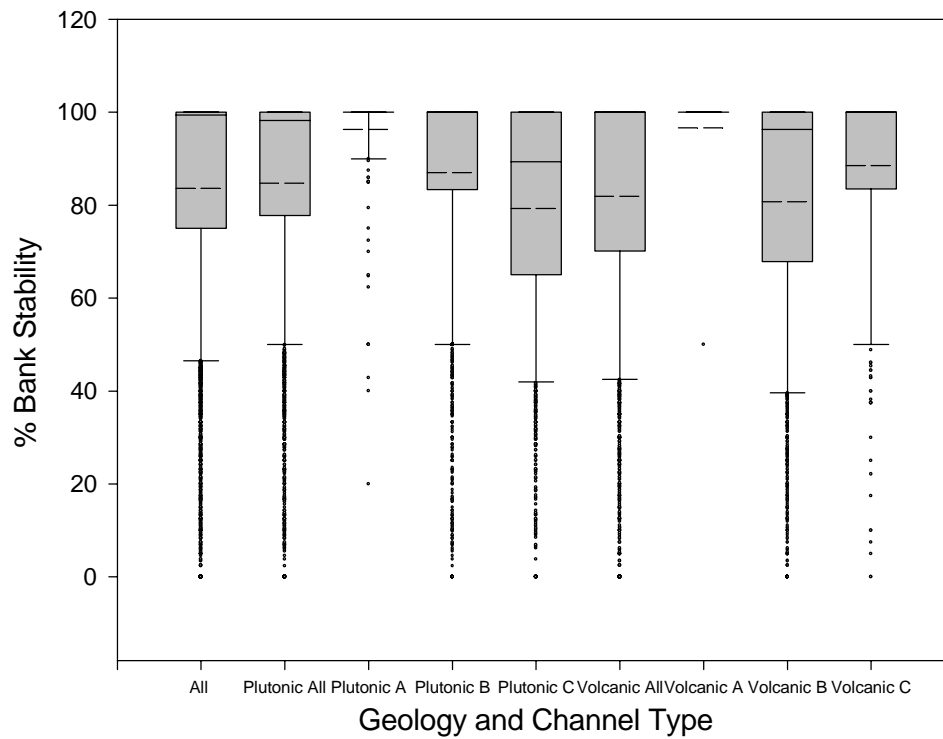
	All	Plut All	Plut A	Plut B	Plut C	Volc All	Volc A	Volc B	Volc C
N	9125	5477	227	3346	1905	3647	15	3121	511
IQR	25	22.2	0	16.7	35.0	29.9	0	32.1	16.5
Median	99.4	98.2	100	100	89.4	100	100	96.3	100
25%	75	77.8	100	83.3	65.1	70.1	100	67.9	83.5
75%	100	100	100	100	100	100	100	100	100

Figure 16. Box plot of percent bank stability of different geology and channel types, in unmanaged streams in the Upper Middle Fork Salmon River Basin, Idaho.

Summary

Data from the Middle Fork Salmon River illustrate the degree of variability that occurs in reference watersheds. However, grouping of stream reaches by landscape and geomorphic factors was useful in accounting for some of this variability. As basin and channel size increase; pool frequency and large wood debris frequency decrease. Residual pool depth increases with an increase in basin size. Percent surface fines was highly variable, but, grouping by geology and Rosgen stream type appeared to show some utility.

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APPENDIX B: SELECTED FISH HABITAT INDICATORS FROM THE TONGASS NATIONAL FOREST, ALASKA REGION

Introduction

The development of quantifiable fish habitat indices for the Tongass National Forest was initiated as part of the Congressionally mandated Anadromous Fish Habitat Assessment in 1994 (AFHA 1995). The AFHA effort identified key attributes of healthy aquatic systems in southeast Alaska; large woody debris, off-channel flood-plain habitat, substrate composition, channel morphology, sediment sources and delivery rate, and salmonid abundance and aquatic community diversity. Three habitat indices (pool area, pieces of large woody debris, and bank full width-to-depth ratio) related to these key attributes, were derived from existing watershed scale, stream inventory data for the Tongass. These indices have been adopted as interim fish habitat objectives in the revised Tongass Land and Resource Management Plan standards and guidelines "to evaluate the relative health or condition of riparian and aquatic habitat" of Forest watersheds (TLMP 1997).

Hierarchical Framework

The Alaska Region has implemented the general frameworks for aquatic and terrestrial ecological units described in Maxwell et al 1995. Landscape stratification at the subsection level of ecological hierarchy provides a basis for stratifying watersheds with similar geoclimatic settings (similar climatic, geology, physiographic patterns) (Figure 17).. Aquatic ecological units within the Riverine System are classified by Stream Process and Channel Types (Paustian et al 1992). These units are equivalent to valley segment and stream reach units in the national framework. These geomorphic ally based stream classes reflect dominant aquatic ecosystem processes and correlate with important aquatic habitat attributes.

Description/Selection of Habitat Indicators

The *pool, large wood,* and *channel width-depth* parameters were selected from a Tongass N.F. - wide stream inventory data base, because these specific indices were judged to have defined measurement standards that were consistently applied by inventory crews across the "million acre forest" (AFHA 1995). This initial set of habitat indicator data were compiled from watersheds that were in a pristine or undisturbed state at the time of the stream surveys. This data set was too small to stratify by broad scale ecological units, so data were pooled for the entire Alexander Archipelago Section (USDA 1993). Individual habitat indicators, however, are categorized by stream process group or channel type ecological units (Figure 18, 19 and 20). This approach reduces the overall variability in reference conditions between stream segments being compared, by grouping habitat data for streams with a common range of size and gradients and which are influenced by similar dominant geomorphic processes.

The Tongass Fish Habitat Objectives are intended to be a first generation diagnostic tool for assessment of stream habitat condition and improvement needs. Each of the indices relate to key processes and habitat features that are directly or indirectly control fish habitat capability. Pool area reflects the balance between sediment inputs and transport rates in a stream over time. Pools provide critical year around rearing habitat and winter refuges for juvenile salmonids. Pool habitat also provides cover for adult spawners and optimum spawning areas at pool tail-outs. Large woody debris is another major factor influencing freshwater habitat diversity in southeast Alaska streams. Woody debris is strongly correlated to pool formation, and provides cover and food sources for many aquatic organisms. Recruitment and depletion of large woody debris is influenced by natural events such as floods, wind storms and landslides, as well as, riparian timber harvest activities. Channel width-to-depth ratio is a general indicator of stream stability for alluvial channels. Streams with consistently high width-to-depth values are indicative of high sediment loads and channels that are susceptible to stream bed aggradation. These conditions can limit aquatic habitat capability especially in systems having low amounts of pool forming large woody debris.

The Tongass habitat objectives are not designed to be used as specific attainment goals. The AFHA (1995) report recommends that these indices be used within the framework of watershed analysis to:

- Assess relative ecological capacities and disturbance regimes within an overall watershed context.
- Identify stream segments that are potentially most susceptible to management or natural disturbances.
- Identify areas with exceptional habitat conditions.
- Identify opportunities for habitat protection, improvement and rehabilitation.

Emphasis for habitat rehabilitation should be directed toward stream systems with low numbers or pool, small amounts of large woody debris and channels exhibiting high width-to-depth ratios. Professional judgement is critical component to evaluate whether assessment results actually reflect conditions outside the range of reference conditions, and whether active habitat management or reliance on natural recovery processes are the most appropriate coarse of action in a given watershed setting.

Summary of Habitat Objectives

Box and whisker plots with table of descriptive statistics are shown in Figure 18, 19, and 20. Box and whisker plots show median, and upper and lower quartile. A table of sample count and percentile values has been added to each Figure.

Summary and Recommendations

The interim fish habitat objectives for the Tongass National Forest should be characterized as an initial step toward development of objective, quantifiable indicators of fish habitat condition and general stream health. These objectives are an important component of ecological based standards for riparian and watershed management in the Alaska Region.

Analysis of the current Tongass stream habitat data base and the associated fish habitat objectives indicate that refinements are needed to improve future utility of these management tools. Limited sample sizes, uneven geographic distribution of samples and lack of fully standardized measurement procedures are major deficiencies (Coghill 1996). The AFHA (1995) report made several recommendations on how to move forward toward the goal of developing more robust stream habitat objectives:

- Standardized data-collection and data-management procedures.
- Fill data gaps with respect to samples within aquatic ecological units and broad geographic areas.
- Establish a network of reference streams to monitor changes in habitat indeces over time.
- Modify and expand upon these initial habitat indicators.

The Alaska Region is implementing a long-term strategy for improving basic aquatic habitat data and habitat indicators for the Tongass and Chugach Forests based on the above recommendations. A Regional Aquatic Ecosystem Management Handbook (in-press) outlines procedures that will improve the precision and reduce observer bias in collection of stream habitat data. Tightened measurement for pools, for example, include hydraulic control criteria, and minimum pool size and residual depth criteria. The new regional protocol has also adopts more consistent, streamlined measurement procedures for large woody debris.

Table 9 compares the interim and revised habitat indices that will be derived from survey and monitoring data collected using the new stream survey protocol. The revised fish habitat indicators will be based on metrics that are independent of stream discharge to help reduce measurement error.

Table 9. Comparisons of Interim (AFHA 1995) and revised (in-press) Fish Habitat Indicators for the Tongass National Forest.

Interim Fish Habitat Indicators 1995	Revised Alaska Region Habitat Indicators
pool area (%)	pools (frequency/unit length of channel)
	pools (frequency/unit channel width)
	max. residual pool depth
large woody debris (# pieces/1000 m$^{2)}$	large woody debris (# pieces/unit length)
	key pieces of wood (# pieces/unit length)
bankfull width-depth ratio	bankfull width-depth ratio
	stream bed substrate (D50/D84)

Finally, a network of stream reference reaches are being established as part of the Tongass Forest Plan monitoring and evaluation strategy.   Measuring trends at permanent reference reaches eliminates between-stream variance when determining changes in stream habitat conditions over time in managed watersheds. Use of control sites in unmanaged watersheds will help determined if measured changes can be attributed to management activities.

References

Coghill, K. 1996. Unpublished report: An evaluation of the statistical power of existing stream survey dat on the Tongass National Forest, with recommendations for an improved monitoring program. PNW Research Station, Juneau, AK. 9p.

Maxwell, J.R., C.J. Edwards, M.E. Jensen, S.J. Paustian, H. Parrott, and D.M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). Gen. Tech. Rep. NC-176. USDA Forest Service, North Central Forest Experiment Station. 72p.

Paustian, S.J., editor. 1992. A channel type users guide for the Tongass National Forest, southeast Alaska. USDA Forest Service, Alaska Region. R10 Technical Report, 26. 179p.

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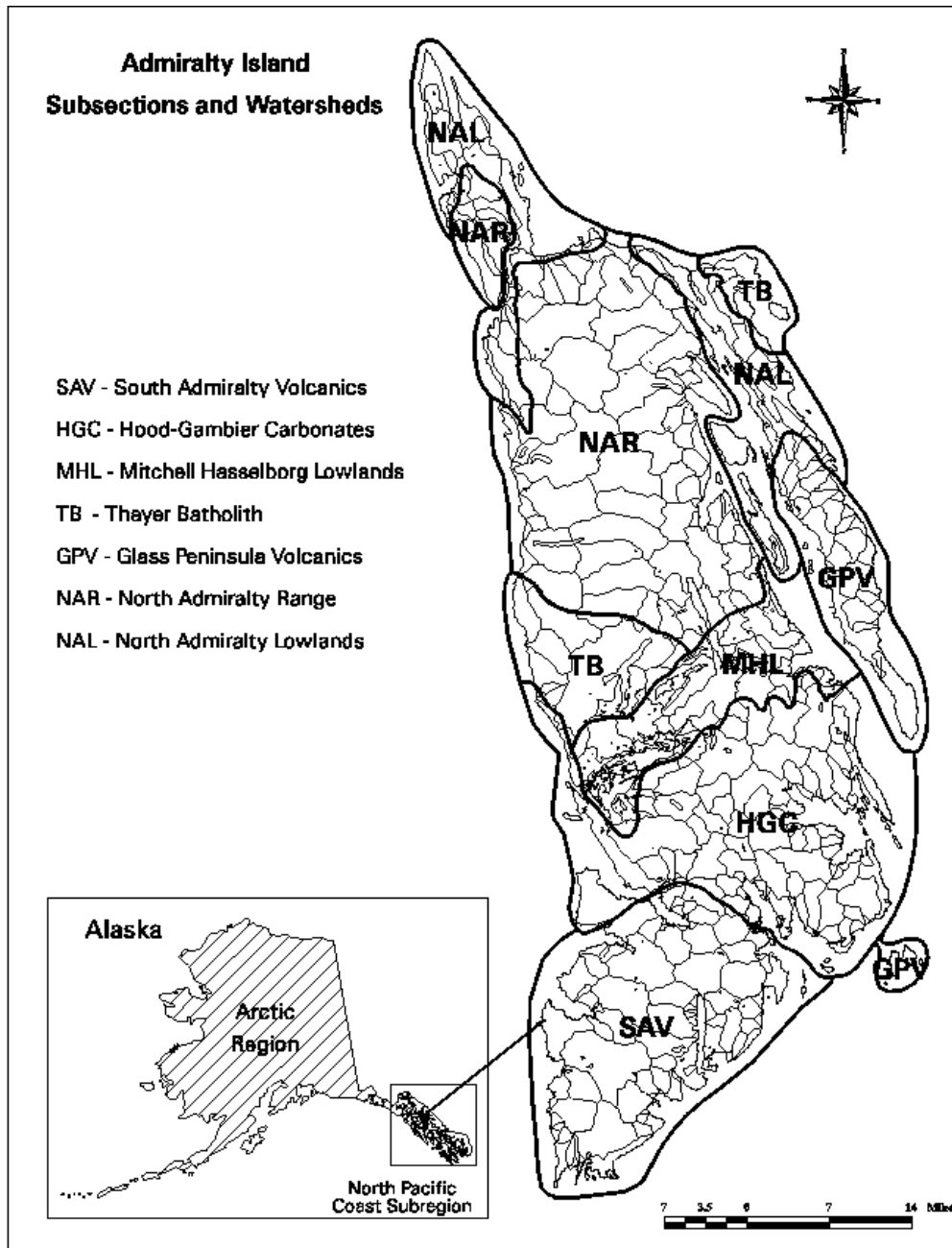
Figure 17. Landscape stratification at the subsection level of ecological hierarchy.
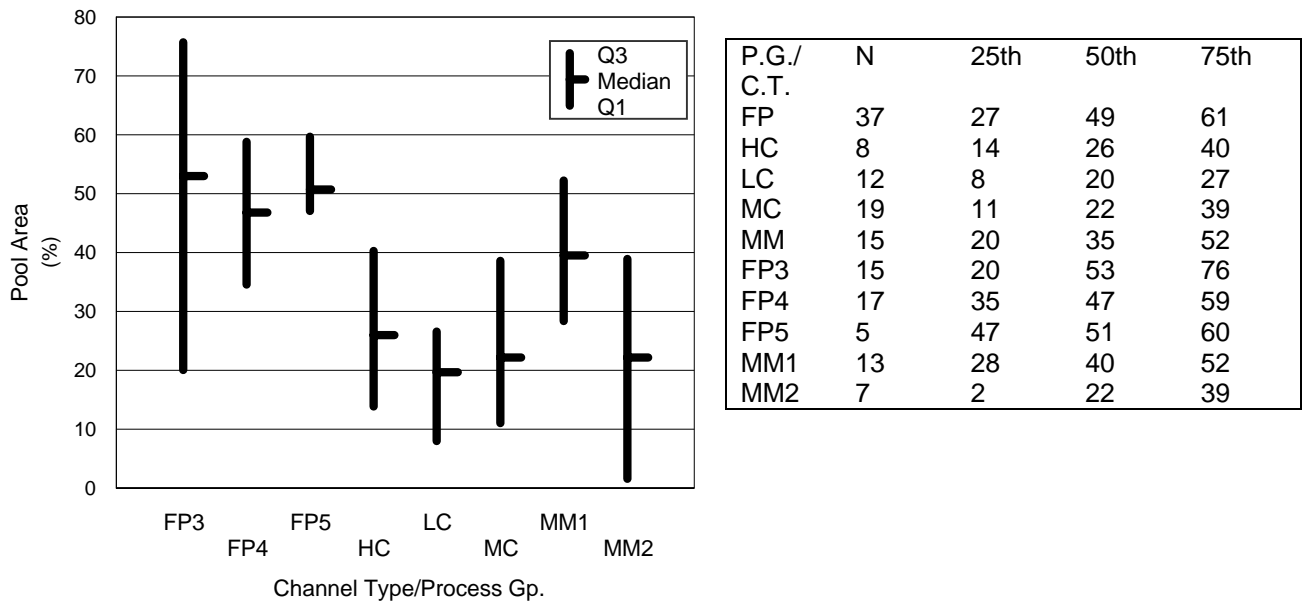
P.G./ C.T.	N	25th	50th	75th
FP	37	27	49	61
HC	8	14	26	40
LC	12	8	20	27
MC	19	11	22	39
MM	15	20	35	52
FP3	15	20	53	76
FP4	17	35	47	59
FP5	5	47	51	60
MM1	13	28	40	52
MM2	7	2	22	39

Figure 18. Quartile ranges and interim pool area (%) objectives by process group and channel type, Tongass National Forest pool indices.

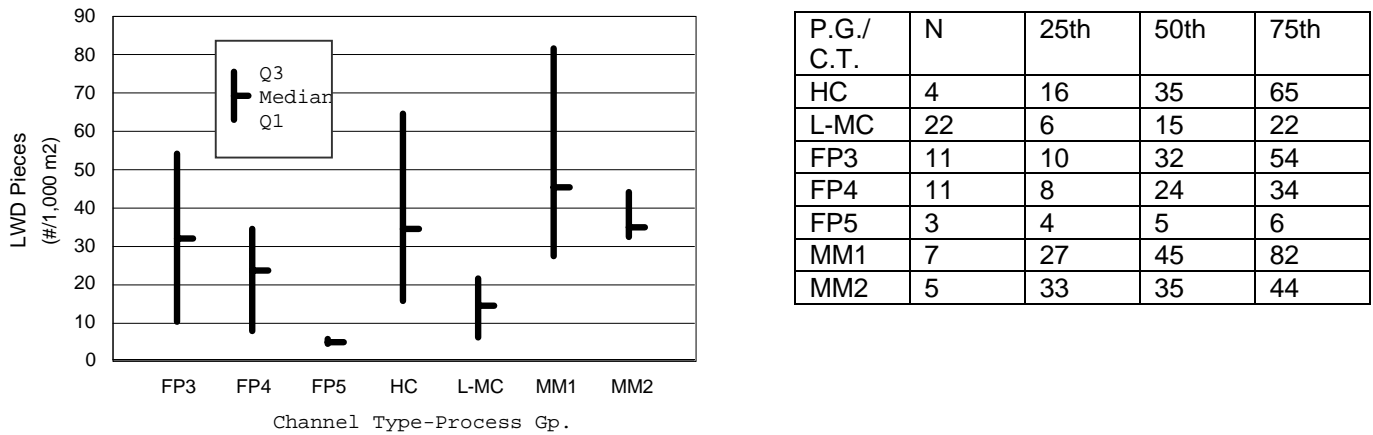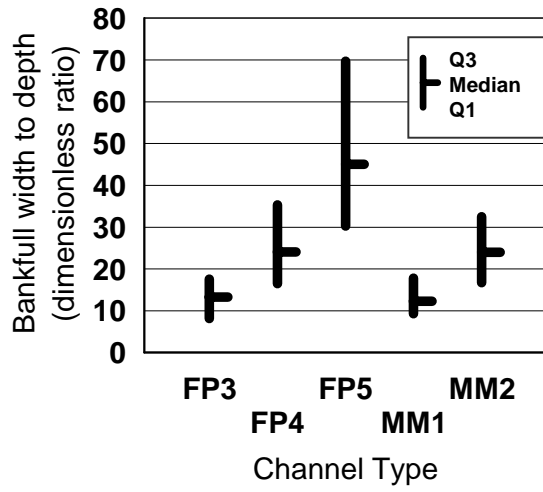| P.G./ C.T.	N	25th	50th	75th
HC	4	16	35	65
L-MC	22	6	15	22
FP3	11	10	32	54
FP4	11	8	24	34
FP5	3	4	5	6
MM1	7	27	45	82
MM2	5	33	35	44

Figure 19. Quartile ranges and interim large woody debris (# pieces/1,000 m2) by process group and channel type, Tongass National Forest large woody debris indices.

P.G./ C.T.	N	25th	50th	75th
FP3	67	8	13	18
FP4	62	16	25	35
FP5	70	30	45	70
MM1	52	9	12	18
MM2	25	17	24	33

Figure 20. Quartile ranges and interim stream width-to-depth ratio indices by process group and channel type, Tongass National Forest width-to-depth indices.

APPENDIX C: SUMMARY OF RECOMMENDATIONS FOR SALMONID HABITAT QUALITY

State and federal agencies or other organizations have examined the habitat requirements and habitat stressors and have made varying recommendations for minimal conditions or observations on the habitat needs.

The table lists papers that have included a recommendation for numerical values for salmonid habitat quality. The summary addresses variables that are commonly evaluated in habitat inventory and assessment. This includes Large Woody Debris, Substrate/Fine Sediments, Pool Occurrence and Quality, Channel Dimension, Turbidity, and Temperature. Vegetation characteristics related to shade and overhead cover have not been addressed.

Numerical Habitat Criteria

Author	LWD	Pool Frequency	Width/Depth	Substrate/Fines	Turbidity/Sediment	Temperature	DO	Velocity
1. Carlson, A.; M. Chapel; A. Colborn; D. Craig; T. Flaherty; C. Marshall; D. Pratt; M. Reynolds; S. Tanguay; W. Thompson, and S. Underwood. Old Forest and Riparian Habitat Planning Project. Tahoe Nat. Forest; 1991.	X							
2. Columbia River Basin Task Force. Fish Habitat Monitoring Protocol for the Upper Columbia River Basin, 4th revision, DRAFT. National Aquatic Ecosystem Monitoring Center; 1994.	X	X	X			X		
3. Department of Environmental Quality, Oregon. Water Quality Standards Review, 1992-1994. 1995 Jun.						X	X	
4. Ford, B. S. et. al.; Literature reviews of the life history, habitat requirements and mitigation/compensation strategies for selected fish species in ...drainages of British Columbia. Fisheries and Oceans, Province of British Columbia; 1995.				X		X	X	X
5. Idaho Division of Environmental Quality. Idaho Water Quality Standards Criteria. 1995 Nov.					X	X	X	
6. Murphy, M. L. Forestry impacts on freshwater habitat of anadromous salmonids in the pacific northwest and Alaska and requirements for protection and restoration. NOAA National Marine Fisheries Service, DRAFT; 1995 Sep.						X	X	
7. National Marine Fisheries Service. Making endangered species act determinations of effect for individual or grouped actions at the watershed scale. 1996.	X	X	X	X	X	X		
8. Overton, C. K. et. al.; User's guide to fish habitat: Descriptions that represent natural conditions in the Salmon river basin, Idaho General. Intermountain Research Station, Forest Service Technical Report INT-GTR-322; 1995 Aug.	X	X						

Numerical Habitat Criteria

Author	LWD	Pool Frequency	Width/ Depth	Substrate /Fines	Turbidity/ Sediment	Temperature	DO	Velocity
9. Peterson, N. P.; A. Hendry, and T. P. Quinn. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions. Timber Fish and Wildlife, TFW-F3-92-001; 1992.	X	X		X				
10. Platts, W. S. et. al. Preliminary status report on bull trout in California, Idaho, Montana, Nevada, Oregon, and Washington. Don Chapman Consultants Inc.; 1993.						X		
11. Raleigh, R. F.; T. Hickman; R. C. Solomon, and P. C. Nelson. Habitat suitability information: Rainbow trout. U.S. Fish and Wildlife Services FWS/OBS-82/10.60; 1984.						X		
12. Rhodes, J. J. et. al. A coarse screening process for evaluation of the effects of land management activites on salmon spawning.... Columbia River Inter-Tribal Fish Commision, Technical Report 94-4; 1994.				X	X			
13. Spence, B. C. et. al. An ecosystem approach to salmonid conservation, Part II: Planning elements and monitoring strategies. DRAFT. Management Technology, TR-501-96-6057; 1996 May.						X		
14. The Independent Scientific Group. Return to the river, restoration of salmonid fishes in the columbia river ecosystem. Columbia River Basin Fish and Wildlife program of the Northwest Power Planning Council. 1996.						X		
15. USFA & USBLM. (PACFISH). 1995 Feb.	X	X	X			X		
16. USFS & USBLM. Eastside Draft Environmental Impact Statement, Volume 1. Interior Columbia Basin Ecosystem Management Project; 1996.			X	X		X		
17. Washington Forest Practices Board. Board Manual: Standard Methodology for Conducting Watershed Analysis, Under Chapter 222-22 WAC. 1994 Nov.	X	X		X				

APPENDIX D: BIBLIOGRAPHY

The annotated bibliography is on the Environmental Protection Agency Region 10
Internet web page at:

http://www.epa.gov/r1oearth