Ecosystem Diagnosis and Treatment

How the Rules Work:

Translating Level 2 Environmental Correlates into Level 3 Life Stage Survival Factors for Chinook Salmon

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I. Introduction.

This document describes how Ecosystem Diagnosis and Treatment (EDT) Level 2 Environmental Correlate values are translated into Level 3 Focal Species (Chinook) Survival Factors for chinook salmon (*Oncorhynchus tshawytscha*) for tributary habitats[1]. We are developing comparable rule sets for bull trout, steelhead trout, coho salmon, and chum salmon. A similar process has been applied for analyzing performance measures for selected species of wildlife in the Columbia Basin. We refer to these translations of environmental data into survival parameters as biological sensitivity rules.

The rules described here have been developed within the Northwest Power Planning Council's Multi-Species Framework (McConnaha 1999). This provides a structure for relating the performance of different species to the environmental (or ecological) conditions in which they live. Data and information used in the Framework are organized through the Ecological Information Structure. The Information Structure helps us identify and organize hypotheses—rules within EDT—about the environment, key ecological functions, and biological performance for the species being analyzed[2]. EDT is a system of hypotheses that capture our understanding of the Columbia River ecosystem at a point in time. These hypotheses will be tested, refined and developed through research, evaluation and monitoring to improve our efforts to restore and manage natural resources. The hypotheses within EDT document the rationale for how management actions are expected to move the ecosystem closer to achieving the vision (goals) for the basin. EDT is an analytical method that emphasizes the need for explicit operating hypotheses on which to base management decisions.

The document is organized into four parts: I.) Introduction; II) Information Structure; III.) Rule Derivation, Structure and Presentation Format; and IV.) Sensitivity Rules. Three appendices follow the rules.

II. Information Structure

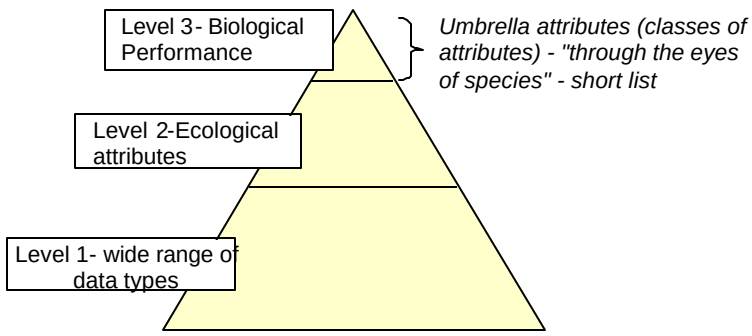


Figure 1. Data/information pyramid -- information derived from supporting.

The Information Structure and associated data categories are defined at three levels of organization. Together, these can be thought of as an information pyramid in which each level builds on information from the lower level (Figure 1). As we move up through the three levels, we take an increasingly organism centered view of the ecosystem. Levels 1 and 2 together characterize the

[1] Survival rates in the mainstem Columbia and Snake rivers are computed independently based on existing models. Assumptions are described elsewhere.
[2] We refer to the species of interest as the *focal species*, which in the present case is chinook salmon.

environment, or ecosystem, as it can be described by data of different types (Figure 2). This provides the

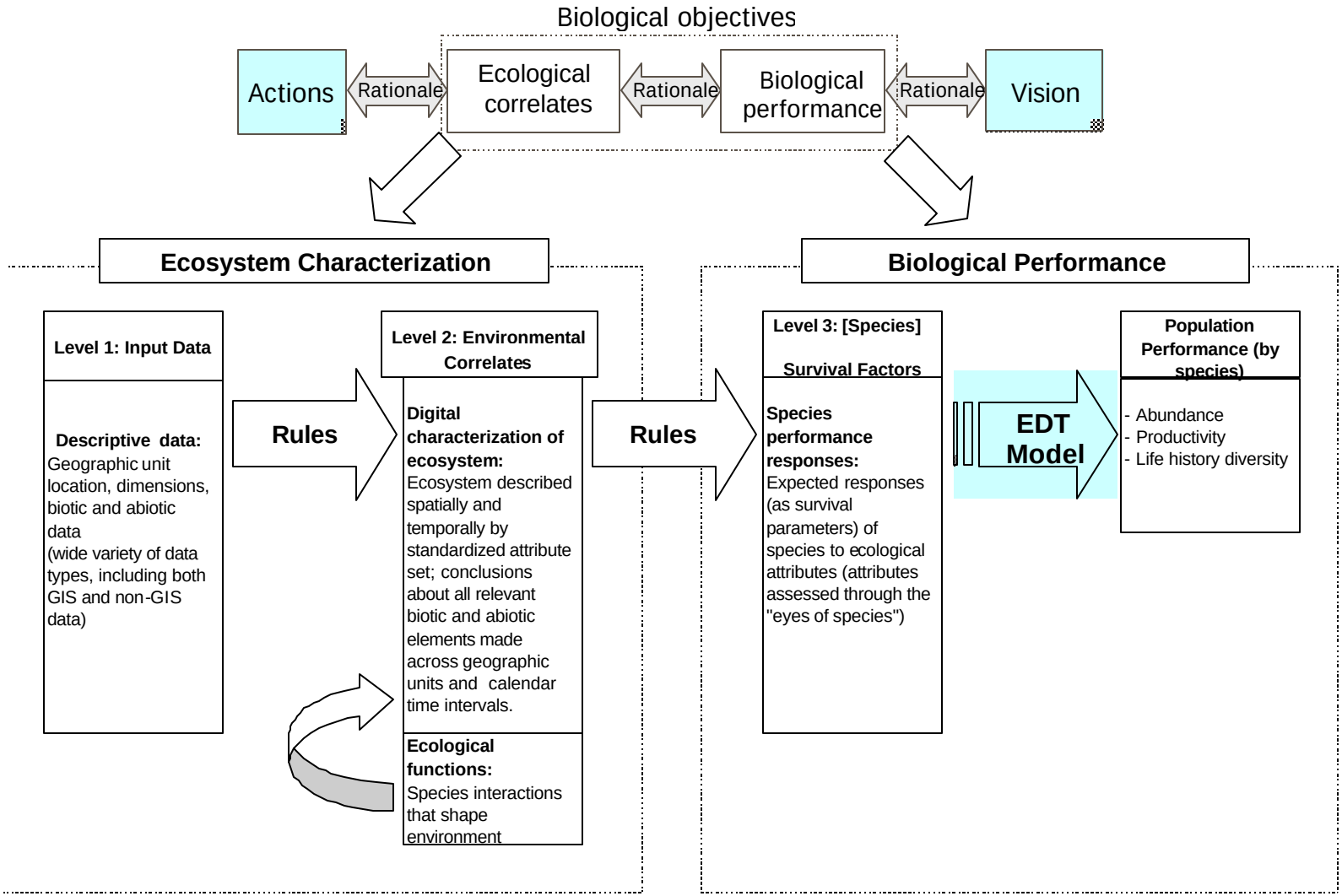


Figure 2. Framework and EDT information structure.

characterization of the environment needed to analyze biological performance for a species. The Level 3 category is also a characterization of the environment, but "through the eyes of the [focal] species" being analyzed (Mobrand et al. 1997). This category describes species-specific survival factors based on the state of the environment described by the Level 2 Environmental Correlates.

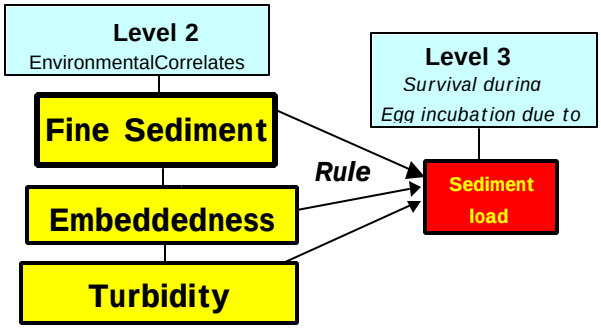
The Information Structure begins with a wide range of environmental data (Level 1 Input Data) that describes the spatial structure of the data, land use and ownership, elevation, slope and so on. These data exist in a variety of forms and pedigrees. Level 1 addresses the fundamental elements that enter into habitat forming processes. These are the basis for the more refined description of the environment in Level 2.

Level 2 creates a generalized depiction of the aquatic environment. Level 2 attributes are termed Environmental Correlates (Table 1) in the sense of Morrison and others [, 1998 #441] to describe the environment in regard to species of interest, in this case native salmonid fishes. The Level 2 Correlates specify physical and biological characteristics about the environment relevant to the derivation of productivity and capacity for specific species in Level 3. Level 2 Correlates describe the condition of the environment (both abiotic and biotic elements) encountered by various species. In concept, a set of Level 2 Environmental Correlates can be described for analyzing the environment with respect to any species. Not all Level 2 Correlates are appropriate for all habitats. In some cases, information is lacking for relevant correlates. Typically, an analysis will use a subset of the correlates listed in Table 1. However, those listed provide a range of features to describe a variety of different habitats and situations.

The rules presented in this document translate the Level 2 characterization of the environment into life stage biological performance for a single species, in this case, chinook salmon (Level 3 Survival Factors). Biological performance for each chinook life stage in Table 2 is assessed in terms of productivity and capacity. Productivity in EDT is equivalent to the concept of intrinsic productivity discussed by McElheny and others [, 2000 #565] to describe viable salmon populations with respect to the Endangered Species Act. Productivity is survival without density dependence effects. It is a function of the quality of the environment, whereas capacity is a function of the quantity of key habitats available.

The rules are defined through the Level 3 Biological Factors(Table 1), which act as "umbrella attributes" grouping Level 2 environmental correlateswith respect to life stage survival (Figure 1). The Level 2-Level 3 rules define life stage sensitivity of the species to one or more Level 2 Environmental Correlates. Chinook salmon life stages used in the analysis are defined in Table 2. In most cases a single rule exists for Level 3 Survival Factors -life stage combination, though in some cases multiple rules were formulated to account for likely differences in biological sensitivity between stream sizes (by channel width) and hydrologic regime (accounting for source of flow, e.g., groundwater vs. rain fed).

Figure 1. Example of the structure of rule relating Level 2 Environmental Correlates to Level 3 chinook life-stage survival.



Rules within EDT are provisional—those described here are under review and refinements are expected. Moreover, the rules are a characterization of our understanding of the ecosystem at a point in time. The rules should periodically be reviewed and refined as new information or understanding becomes available. We intend to develop a formal process for this purpose. We think the rules should be a primary focus of attention by scientists from different fields expertise, providing the region with a common "state-of-understanding" about the effects of different correlates on focal species survival factors. Uncertainty about the ecosystem will always exist, but when described through the EDT rules we can identify research needs, particularly for those correlates most critical to species performance.

Table 1. Hierarchical organization of Aquatic Key Environmental Correlates (Level 2 attributes). Focal Species Survival Factors (Level 3 attributes) are shown in the table opposite one of their Primary Environment Correlates for Chinook Salmon (primaries may vary among life stages). Other attributes may serve as modifiers or may not be used at the present time. Definitions of Environmental Correlates and Survival Factors are found in Appendix 2.

Aquatic Key Environmental Correlates (Level 2)		Species Survival Factors (Level 3
	1 Hydrology and Hydraulics	
1.1 Flow variation	1.1.1 Change in interannual variability in high flows	1a Flow
	1.1.2 Changes in interannual variability in low flows	
	1.1.3 Intra daily (diel) variation	
	1.1.4 Intra-annual flow pattern	
	1.1.5 Water withdrawals	1b Withdrawals (entrainment)
1.2 Hydrologic regime	1.2.1 Natural	
	1.2.2 Regulated	
	2 Stream Corridor Structure	
2.1 Channel morphometry	2.1.1 Channel length	2a Channel length
	2.1.2 Channel width - month maximum width (ft)	2b Channel width
	2.1.3 Channel width - month minimum width (ft)	
	2.1.4 Gradient	2c Habitat diversity
2.2 Confinement	2.2.1 Hydromodifications	
	2.2.2 Natural	
2.3 Habitat type	2.3.1 Backwater pools	
	2.3.2 Beaver ponds	
	2.3.3 Glides	
	2.3.4 Large cobble/boulder riffles	2d Key habitat
	2.3.5 Off-channel habitat factor	
	2.3.6 Pool tailouts	
	2.3.7 Primary pools	
	2.3.8 Small cobble/gravel riffles	
	2.3.9 Obstructions to fish migration	2e Obstructions
2.4 Riparian/ Channel integrity	2.4.1 Bed scour	2f Channel stability
	2.4.2 Icing	
	2.4.3 Riparian function	
	2.4.4 Wood	
2.5 Sediment type	2.5.1 Embeddedness	
	2.5.2 Fine sediment (intragravel)	2g Sediment load
	2.5.3 Turbidity	
	3 Water Quality	
3.1 Chemistry	3.1.1 Alkalinity	
	3.1.2 Dissolved oxygen	3a Oxygen
	3.1.3 Metals - in water column	
	3.1.4 Metals/Pollutants - in sediments/soils	
	3.1.5 Miscellaneous toxic pollutants - water column	3b Chemicals (toxic substances)
	3.1.6 Nutrient enrichment	
3.2 Temperature variation	3.2.1 Daily maximum (by month)	3c Temperature
	3.2.2 Daily minimum (by month)	
	3.2.3 Spatial variation	
	4 Biological Community	
4.1 Community effects	4.1.1 Fish community richness	4a Competition with other fish
	4.1.2 Fish pathogens	4b Pathogens
	4.1.3 Fish species introductions	
	4.1.4 Harassment	4c Harassment
	4.1.5 Hatchery fish outplants	4d Competition with hatchery fish
	4.1.6 Predation risk	4e Predation
	4.1.7 Salmon carcasses	
4.2 Macroinvertebrates	4.2.2 Benthos diversity and production	4f Food

Table 2. *Chinook salmon life stages* for which biological rules are hypothesized in this report. Only life stages relevant to freshwater are shown.

Life Stage	Definition
Spawning	Period of active spawning, beginning when fish move on to spawning beds and initiate redd digging and ending when gametes are released.
Egg incubation	Egg incubation and alevin development; stage begins at the moment of the release of gametes by spawners and ends at fry emergence.
Fry colonization	Fry emergence and initial dispersal; time period is typically very short, beginning at fry emergence and ending when fry begin active feeding associated with a key habitat.
0-age resident rearing	Rearing by age 0 fish that is largely associated with a small "home range"; these fish are generally territorial (note: this behavior typifies the pattern of feeding/rearing by spring chinook in headwater stream reaches).
0-age transient rearing	Rearing by age 0 fish accompanied by directional movement (I.e., these fish do not have home ranges); these fish are non-territorial, though agonistic behavior may still be exhibited (note: this pattern typifies a 0-age fall chinook rearing pattern).
0-age migrant	Directional migration by age 0 fish that tends to be rapid and not strongly associated with feeding/rearing (note: fish displaying strong smolt characteristics typify this life stage).
Inactive	Largely inactive or semi-dormant fish age 0 fish; this behavior is associated with overwintering, when feeding is reduced; fish exhibiting this behavior need to be largely sustained by lipid reserves.
1-age resident rearing	Feeding/rearing by age 1 fish that is associated with a home range; these fish are often territorial.
1-age migrant	Directional migration by age 1 fish that tends to be rapid and not strongly associated with feeding/rearing (note: fish displaying strong smolt characteristics typify this life stage).
Migrant prespawner	Adult fish approaching sexual maturity that are migrating to their natal stream; in the ocean this stage occurs in the final year of marine life, in freshwater feeding has generally ceased.
Holding prespawner	Adult fish approaching sexual maturity that are largely stationary and holding, while en route to their spawning grounds; distance to the spawning grounds from holding sites may be short or long.

III. Rule Derivation, Structure and Presentation Format

The purpose of the rules is to translate Level 2 Environmental Correlate values (ratings on a scale from 0 to 4) into life-stage specific, Level 3 Survival Factors for chinook salmon. The Level 3 Factors combine to describe the biological performance potential of the landscape. Biological performance potential is measured in terms of the productivity and capacity expected from a locally adapted natural salmon population within the habitat. The rules are hypotheses about how environmental conditions affect these performance measures.

The Level 2 correlates comprise the vocabulary we use to describe the key features of each time-space pixel (e.g. 6HUC-Month) across the landscape. Taken together the Level 2 values for a given pixel constitute a descriptive statement about the environmental conditions in the pixel in terms of observable characteristics. The rules constitute a biological interpretation of these statements -- they translate them into hypotheses about the biological performance potential for a given species (e.g. chinook salmon) and life stage (e.g. egg incubation). The biological performance of each habitat pixel is expressed in terms of two values: a productivity (density independent survival) value, and an estimate of the quantity of key habitat available. In concept, the rules convert a physical description of the landscape into a "survival landscape."

In the following we describe how the rules that are currently used in EDT are constructed. They represent a) an attempt to capture our current best understanding of the relationship between chinook salmon and its environment and b) a starting point for having a structured, science based conversation about this relationship. As more data is collected and new insights are gained we expect these rules to change.

A. Rules for Estimating Productivity

Productivity is a measure of biological performance and it is defined as the component of survival that a population experiences regardless of abundance. Productivity is determined by the quality of the environment. The life stage productivity value associated with a specific habitat pixel (e.g. a 6HUC-month) is defined as the density independent survival expected if the entire life stage occurred under the conditions of the pixel.

The rules presented here assume that productivity, P, can be partitioned into a set of (16) independent multiplicative survival factors $(Level3)_i$, i.e.

$$P = P_0 \cdot (Level3)_1 \cdot (Level3)_2 \cdot (Level3)_3 \cdots (Level3)_{16}$$

where $0 < (Level3)_i < 1$ are “relative productivity values” and P_0 is the maximum productivity for the life stage. We refer to P_0 as the “benchmark productivity”, described below.Each $(Level3)_i$ modifies the benchmark productivity for each life stage to reflect the habitat condition of a given pixel. The Level 3 productivity factors are listed in Table 1 and defined in Appendix 2.

We further assume that each $(Level3)_i$ productivity factor can be estimated as a function of one or more Level 2 correlate values for the pixel. The functional form used to estimate the $(Level3)_i$

may differ among the $(Level3)_i$. For the sake of simplicity in the present rule set we assumed that the form of the function could be addressed in two steps. First, the Level 2 correlate with the dominant effect on the Level 3 factor is referred to as the **Primary Level 2** correlate. When this correlate alone affects the Level 3 relative survival factor (P), the sensitivity associated with the Primary Level 2 correlate (S_p) is defined as:

$$S_p = 1 - P$$

The S_p values for each rating (0 – 4) of the Primary Level 2 are tabulated based on published studies, available data or where data is sparse, expert opinion.

In most cases the sensitivity value of the Primary Level 2 correlate is affected by one or more **Modifying Level 2** correlates. These correlates modify overall sensitivity associated with the Primary Level 2, either increasing it or, in some cases, decreasing it. Where data for specific combinations of Level 2 correlate ratings are not available we use as a default hypothesis the following relationship:

$S_p = \left[\sum_j S_j^{1/e} \right]^e$, where S_j's are the sensitivities of all contributing Level 2s (including the Primary). (If S_p>1 we set S_p =1.) Use of natural e in the equation serves to shape the overall combined effect consistent with the way in which ratings were defined for Level 2 correlates (see Appendix 2). In general, the rating system was devised so that values of 1 or 2 would have little effect on survival, whereas values of between 3 and 4 tend to reflect severe conditions for survival. Use of e in the equation serves to retain a minor effect on relative productivity when adding multiple Level 2 modifiers with low ratings, but it allows rapidly increasing sensitivity at higher values for modifying correlates. As more information becomes available this function should be replaced with statistically established correlations.

The benchmark survival P_0 for a life stage is the average survival expected for that life stage under optimal conditions. It is the expected survival when environmental quality conditions are "as good as they get" in nature for that life stage with a typical duration. A summary of chinook benchmark survivals is given in Appendix 1. The values are based on a synthesis of scientific literature with input from noted scientists in the region. They should be treated as provisional and subjected to further review.

Examples are given below to illustrate how this approach was used to develop the set of rules for chinook salmon. The examples focus on the effect of sediment on chinook survival during two life stages: 1) egg incubation and 2) the inactive (or overwintering) stage. Effects of sediment on survival during these two stages are expressed through the Level 3 Survival Factor—Sediment Load (see Table 1). Level 2 Environmental Correlates assumed to contribute to sediment effects differ between the two stages, as shown below:

	Incubation life stage	**Inactive (overwinter) life stage**
Primary correlate	Intragravel fine sediment	Embeddedness

Modifying correlate(s)	(none)	Turbidity

Three different Level 2 Correlates characterize the presence of small sediment particles in the stream environment:

1. Intragravel fine sediment – refers to fine sediment within the stream substrate
2. Embeddedness – refers to fine sediment on or in the very top layer of the substrate
3. Turbidity (or suspended sediment) – refers to sediment particles suspended in the water column

In the first example, addressing effects on egg and embryo incubation, we identify a single Level 2 Environmental Correlate as causing mortality due to sediment. Studies most often describe effects of sediment on salmonid eggs and embryos through the "intragravel fine sediment" correlate. The sensitivity rule, therefore, applies only this Level 2 correlate as comprising the sediment effect. Fine sediment entrained within the salmonid redd is known to cause direct, significant mortality to eggs and embryos by impeding oxygen exchange, smothering, or entombment (Bjornn and Reiser 1991; Waters 1995). The two other Level 2 correlates used to characterize sediment conditions within streams, turbidity and embeddedness, might also be considered as possible contributors to the overall sediment effect on eggs and embryos. These, however, reflect, or contribute to, the conditions that result in the level of fine sediment entrained within spawning gravels. Both of these sediment components, for example, contribute to the re-invasion of fine sediment into egg pockets following the cleaning action that occurs when the nest is constructed (Quinn and Peterson 1994; Rhodes and Purser 1998). This re-invasion occurs even in streams without significant high flow events (Rhodes and Purser 1998). It apparently results in a return to approximately the same level of fine sediment within the redd site as occurred prior to redd construction.

In the second example, we identify two Level 2 correlates, embeddedness and turbidity as contributing to the effect of sediment on juveniles within the inactive (or overwintering) stage. We regard embeddedness as the primary correlate because it often causes significant loss in the quality of substrate for use as refuge sites during winter by juvenile chinook. Overwintering chinook rely heavily on interstitial spaces within the substrate as refuge sites. As these spaces become filled with fine sediment (embedded), overwintering juveniles seek shelter elsewhere, increasing their exposure to mortality agents en route, or increasing the likelihood for mortality if they remain (Hillman et al. 1987; Bjornn and Reiser 1991; Waters 1995). We consider turbidity as a modifying correlate, adding to the likelihood for mortality associated with the primary correlate if the suspended load is high enough (Waters 1995). Intragravel fine sediment, occurring deeper than the level associated with embeddedness, would have minimal effect on overwintering success because juveniles are at or near the substrate surface.

Appendix 3 identifies primary and modifying correlates for each Level 3 Survival Factor by life stage. For any single Level 3 survival factor, the primary and modifying correlates can differ between life stages.

Each Level 2 Environmental Correlate is characterized using ratings on a scale of 0 to 4, spanning a spectrum of environmental conditions. Table 3 shows the index ratings for the two

primary Level 2 correlates in the two examples, intragravel fine sediment and embeddedness. Conditions associated with index values for all Level 2 Environmental Correlates are described

Table 3. Level 2 rating definitions for Intragravel Fine Sediment and Embeddedness.

Intragravel Fine Sediment

Rating	Rating definition
0	<6% fines <0.85 mm particle size
1	>6% and <11% fines <0.85 mm particle size
2	>11% and <18% fines <0.85 mm particle size
3	>18% and <30% fines <0.85 mm particle size
4	>30% fines <0.85 mm particle size

Embeddedness

Rating	Rating definition
0	<10% of surface covered by fine sediment
1	>10% and <25% covered by fine sediment
2	>25% and <50% covered by fine sediment
3	>50% and <90% covered by fine sediment
4	>90% covered by fine sediment

in Appendix 2. The indexing system allows users to specify either continuous or integer values for the correlates. For example, where it exists, a defined mathematical function for an correlate can be used to define specific index values along the continuous scale of 0-4. Where information is coarse, integers would be appropriate, indicating that a reasonable characterization is contained somewhere within the range corresponding to the integer rating.

Generally, there is a consistent direction to correlate ratings, where 0 or low values are usually associated with pristine conditions and higher values tend to occur under managed conditions. This pattern varies for a few correlates, especially those describing stream flow conditions. Correlate ratings for most flow correlates set a rating of 2 as representing pristine conditions, values of 0 and 1, for example, reflect flow modifications that decrease interannual variation whereas ratings of 3 or 4 represent increases in such variation.

Before considering the effects of modifying correlates, each rule is based on an empirical or assumed relationship between its Primary Level 2 Correlate and the corresponding Level 3 Survival Factor by life stage. The two examples for sediment effects on the incubation and inactive life stages illustrate how we formulated these relationships.

General relationships between intragravel fine sediment and egg survival for salmonid species are fairly well understood (Bjornn and Reiser 1991; Waters 1995). We employed the empirical relationship reported by Tagart (1984) regarding the effects of percent fine sediment (<0.85 mm) on survival to emergence (Figure 3). Although Tagart conducted his study on coho, we assumed the same relationship for chinook. Using a benchmark survival to emergence of 60% (average survival under optimal conditions), we can convert Tagart's survivals into sensitivity (as 1 minus survival divided by the benchmark) and plot the values against the appropriate Level 2 rating values on the x-axis (Figure 4). The resulting relationship is the primary correlate's sensitivity

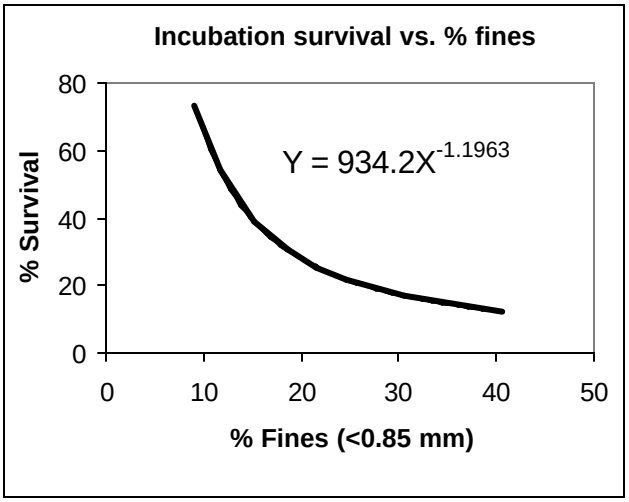


Figure 3. Relationship between percent fine sediment (<0.85 mm) and survival from egg deposition to fry emergence for coho salmon. Adapted from Tagart (1984).

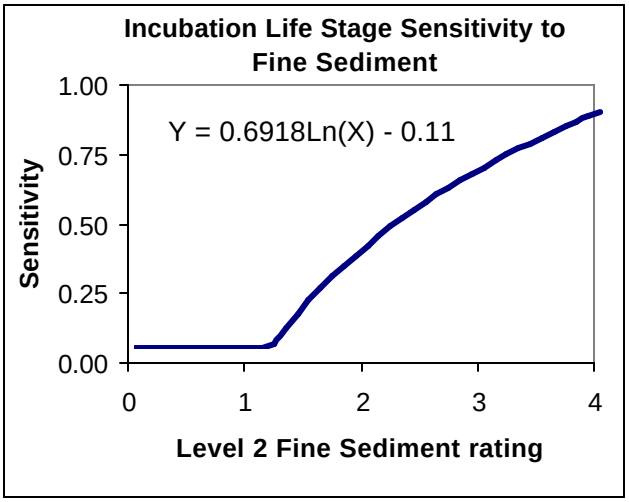


Figure 4. Relationship between ratings for Level 2 Fine Sediment and Sensitivity (as 1 minus relative productivity—see text) derived by converting the relationship in Fig. 3.

rule for sediment effects on the incubation life stage, except when the hydrologic regime is mainly characterized as groundwater fed.[3]

Hydrologic regimes supported by surface runoff affect incubating eggs through downwelling (i.e., flow moves from the water column down into and through the substrate). In these cases, suspended sediment and streambed deposits can maintain high sediment composition within a redd, reducing survival (Waters 1995). However, when the hydrologic regime is groundwater, embryo survival does not so much depend on substrate composition, but rather on the nature and quality of the groundwater (Waters 1995). With suitable groundwater, very high embryo survival can occur with redd construction in riffle or slow-water locations having high fine sediment levels, but with upwelling water. This explains why salmonids can have high rates of reproduction in some streams despite high levels of fine sediment. We therefore formulated a sensitivity relationship for this hydrologic regime that maintained high survivals even at high levels of fine sediment.

The general relationship between embeddedness and the capability of substrate to hold overwintering juvenile chinook is well documented. Bjornn et al. (1977) and Hillman et al. (1987) reported that the density of chinook was reduced by more than half when the cobble substrate became highly embedded. Juveniles are known to emigrate at the onset of winter from areas of high embeddedness, and to keep moving until suitable substrate is found (Bjornn 1978). We are not aware of any studies in which mortality was specifically assessed in relation to embeddedness, though it is believed to be increased under such conditions (Waters 1995). Presumably, fish emigrate because survival conditions associated with embedded substrates would be reduced—and if emigrants do not find suitable substrates (as must occur as sedimentation has increased through land use practices), their penalty might be an even greater reduction in survival. Lacking a quantitative relationship in this case for mortality, we assumed that relative survival of overwintering chinook (compared to a benchmark survival) would be slightly more than 50% if they experienced embeddedness approaching 100% without finding relief (depicted as sensitivity in Figure 5). At embeddedness values of ~38% (rating of 2), we assumed only a small reduction in survival. We assumed no reduction in survival at zero embeddedness. The points were then connected using a curvilinear fit and applied as the sensitivity relationship.

The final step in formulating the rule for the inactive life stage was to add in additional effect for the modifying correlate turbidity. This was done by assuming a very high added effect in cases of extreme turbidity (Waters 1995) but with little or no effect at much reduced levels of suspended sediment.

[3] Hydrologic regime is a Level 2 Environmental Correlate. Five regimes are described through the ratings, of which one is predominately groundwater fed (see Appendix 2).

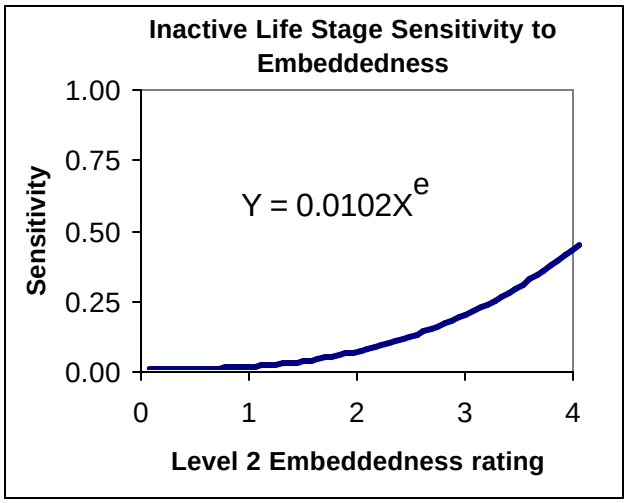


Figure 5. Relationship between ratings for Level 2 Embeddedness and Sensitivity for chinook salmon during the inactive (overwinter) life stage.

We followed the procedure described through these examples to formulate sensitivitiy rules for all life stages and Level 3 Survival Factors related to productivity. The format for displaying these rules is displayed in Figure 6. For each rule, the Primary and Modifying Level 2 Environmental Correlates are labeled, accompanied by a brief rationale for how the correlate is expected to affect the Level 3 Survival Factor. The rationale is assigned a Level of Proof to indicate the relative amount of evidence supporting how the correlate was applied in the rule. Four levels of proof were assigned (Table 4). Each rule is accompanied by seven examples of Level 2 ratings to illustrate the effect on the Level 3 survival factor.

Table 4. Levels of proof assigned to the use of Level 2 Environmental Correlates in rules.

Level of proof	Evidence
1	Thoroughly established, generally accepted, good peer-reviewed empirical evidence in its favor
2	Strong weight of evidence in support but not fully conclusive
3	Theoretical support with some evidence from experiments or observations
4	Speculative, little empirical support

Level 3 Survival Factor: Sediment load

Species: Chinook Life Stage: Inactive

Definition Level 3 correlate – Sediment load: The multiplicative effect of the amount of fine sediment in, or passing through, the stream reach on the relative survival of the focal species.

Level 2 Correlate	Abbrev.	Role	Rationale	Level of Proof
Embeddedness	Emb	Primary	Embeddedness of the substrate surface reduces interstitial spacing between cobbles, reducing the effectiveness of substrate as hiding or refuge cover by overwintering juveniles.	1
Turbidity	Turb	Modifying	Turbidity can cause sublethal and lethal effects on juvenile salmon; turbidity during winter is assumed to be less of a factor than access (embeddedness) to substrate for hiding and refuge.	2

Primary Level 2 Correlate	
Emb	
Rating	**Sensitivity***
0	**0**
1	*2.0E-04*
2	**2E-02**
3	*2.6E-01*
4	**2E+00**

Modifying Level 2 Correlates							
Rating	**Added Sensitivity***						
	Turb						
0	**0**						
1	*7.3E-05*						
2	**8.1E-03**						
3	*1.3E-01*						
4	**8.9E-01**						

***** expressed as percent -- in scientific notation, e.g. 2E-04 = 2 x 10^{-2} % = .02 %. Values not in bold are derived through curvilinear interpolation.

The combined effect of the Modifying Level 2 correlates and the Primary Level 2 correlate on sensitivity is computed using the default hypothesis:

$S_p = \left[\sum_j S_j^{1/e} \right]^e$, where S_j's are the sensitivities of all contributing Level 2's (including the Primary). (If S_p>1 we set S_p =1.). See examples below.

Examples showing how the Primary sensitivity (S_p) value and the survival factor (P) are affected by the ratings for the Modifying Level 2 correlates.

Level 2 Correlate	Rating	Rating	Rating	Rating	Rating	Rating	Rating
Emb (Primary)	0	1	1	1	2	3	4
Turb	0	0	1	1	2	3	4
Sensitivity (S_p)	0.0	0.0105	.0178	.0178	.1539	.5735	1.0
Relative Prod. (P = 1 - S_p)	1.0	.9895	.9822	.9822	.8461	.4165	0.0

Figure 6. Format for rule presentation for Level 3 Survival Factors describing environmental quality. An example rule is shown.

B. Rules for Estimating the Quantity of Key Habitat

The quantity of habitat available to the focal species is called Key Habitat. Key Habitat is life stage specific, and measured as the percent of wetted channel surface area comprised of habitat used by the focal species for the life stage. Key Habitat is the primary habitat type(s) utilized by a species during a particular life stage. Preference for habitat types changes with life stages. Some life stages, like egg incubation, occur almost entirely within three habitat types (i.e., pool-tailouts, glides and riffles), while other life stages, like actively migrating fish, use all habitat types. Level 2 Environmental Correlates for habitat types are all those labeled "Habitat Type" in Table 1.

The use of habitat types by individual life stages of chinook salmon is not necessarily "all or nothing", however. For example, resident rearing by 0-age juvenile chinook does not occur equally in those habitat types that are utilized, some types that show use appear to be more preferred than others, while other types show almost no use.

The rules were formulated by assigning weights to each habitat type to represent relative levels of preference based on patterns reported in literature and consultation with knowledgeable biologists.

Percent Key Habitat (*%KeyHab*) for any life stage was computed to be the sum of the weighted percentages of habitat types *i* within a geographic unit, as follows

$$\%KeyHab = \sum \%HabType_i * Weight_i$$

where $\%HabType_i$ is the percent of wetted channel surface area comprised of habitat type *i* and $Weight_i$ is the preference weight for habitat type *i* in the appropriate life stage.

The format for the presentation of rules for the Level 3 Key Habitat attribute is shown in Figure 7. For each rule, the preference weight is shown for each habitat type accompanied by a brief rationale. The rationale is assigned a Level of Proof to indicate the relative amount of evidence supporting the assigned weight. Levels of proof are those listed in Table 4. Each rule is accompanied by three examples showing different combinations of habitat types and resultant estimates of Key Habitat.

Level 3 Attribute: Key Habitat
Species: Chinook Life Stage: Incubation

Definition: The relative quantity (%) of the primary habitat type(s) utilized by the focus species during a life stage; quantity is expressed as percent of wetted surface area of the stream channel. Environmental quality attributes characterize the quality of this habitat for the focus species.

Rule: The quantity of Key Habitat in a stream reach is computed from reach channel length, channel width, and percent of Key Habitat within the reach. Percent Key Habitat is estimated from habitat type composition based on a weighted sum of seven Level 2 Environmental Attributes (see table below) that quantify stream habitat types.

Contributing Level 2 attributes:

Level 2 attribute	Abbrev.	Weight	Rationale	Level of Proof
Habitat type - backwater pools	HbBckPls	0.00	Eggs placed by spawners; weighting same as for Spawning. Chinook spawning does not occur in backwater pools.	1
Habitat type - beaver ponds	HbBvrPnds	0.00	Eggs placed by spawners; weighting same as for Spawning. Chinook spawning does not occur in beaver ponds.	1
Habitat type - large cobble/boulder riffles	HbLrgCbl	0.00	Eggs placed by spawners; weighting same as for Spawning. Substrate size typically too large for chinook spawning in large cobble/boulder riffles.	2
Habitat type - primary pools	HbPls	0.00	Eggs placed by spawners; weighting same as for Spawning. Chinook spawning does not typically occur in pools.	2
Habitat type - small cobble/gravel riffles	HbSmlCbl	0.60	Eggs placed by spawners; weighting same as for Spawning. Chinook spawn heavily on riffles with substrate sizes suitable for nest building.	1
Habitat type - glides	HbGlide	0.40	Chinook spawn in swifter areas of glides, similar to pool-tailouts in characteristics.	1
Habitat type - pool tailouts	HbPlTails	0.80	Chinook spawning densities are typically greatest on pool-tailouts.	1

Examples:	Example 1			Example 2			Example 3		
Level 2 attribute	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent	Percent of reach	Weight	Weighted percent
Habitat type - backwater pools	10	0.00	0.0	5	0.00	0.0	0	0.00	0.0
Habitat type - beaver ponds	10	0.00	0.0	0	0.00	0.0	0	0.00	0.0
Habitat type - large cobble/boulder riffles	5	0.00	0.0	20	0.00	0.0	50	0.00	0.0
Habitat type - primary pools	40	0.00	0.0	32	0.00	0.0	20	0.00	0.0
Habitat type - small cobble/gravel riffles	15	0.60	9.0	35	0.60	21.0	25	0.60	15.0
Habitat type - glides	10	0.40	4.0	4	0.40	1.6	2.5	0.40	1.0
Habitat type - pool tailouts	10	0.80	8.0	4	0.80	3.2	2.5	0.80	2.0
Sum	100		21.0	100		25.8	100		18.0

Figure 7. Format for rule presentation for the Level 3 Survival Factor Key Habitat. An example rule is shown.

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Appendices

Appendix 1

Chinook Productivity Benchmarks

Appendix 1. Benchmarks

The EDT method associates survival with habitat. The productivity and capacity values derived in the EDT process are characteristics of the environment by time and location as interpreted "though the eyes of salmon" by species and life stage. The procedure for deriving these productivity and capacity values involves what we refer to as a shaping of survival conditions over time and space, as salmon might experience them in completing their life cycle. The shaping of survival conditions is done with reference to a defined set of "benchmark" conditions.

From literature we can identify habitat requirements by life stage for the species. We can take it a step further and describe optimal conditions and hypothesize the expected survival and density limits by life stage. We refer to the survival and density values associated with optimal conditions as reference benchmarks. Thus benchmarks provide us with a set of descriptions for optimal conditions expressed as productivity survival, maximum densities, and habitat characteristics for each life stage. These conditions constitute what can be thought of "as good as it gets" for survival of the species in nature. We have employed a set of benchmark values derived from reviewing relevant sources of information, including discussions with scientists having expertise in survival of salmonids by life stage under various conditions.

The systematic shaping of survival conditions using the habitat rating procedures is intended to assure that productivity and capacity values for each life history segment along a trajectory are: a) bounded by the biological limits of the species, b) scaled consistently across time, space, and life stage, and c) scaled consistently with the benchmark values.

It is important to keep in mind that benchmark or optimal conditions are different from historic (pre-development) conditions. Historic conditions were not always optimal for salmon survival. The benchmark descriptions serve as a point of reference for both the current and historic conditions and for all watersheds.

Table 1 provides a list of productivity survival values for chinook salmon used in the Columbia River analysis for freshwater environments.

Table 1. Benchmark productivity survival values by freshwater life stage for chinook salmon *(Oncorhynchus tshawytscha)*. Values have been rounded. Assumed life stage durations are also shown.

Life stage	Life stage duration (weeks)	Life stage productivity survival
Spawning	1	1.00
Egg incubation	23	0.60
Fry colonization	2	0.75
0-age resident rearing	30	0.70
0-age transient rearing	8	0.36
0-age migrant	2	0.96
Inactive (full winter)	19	0.70
1-age resident rearing	8	0.97
1-age migrant	2	0.98
Migrant prespawner	8	0.92
Holding prespawner	8	0.98

Appendix 2

Definition of Attributes

Table 1: Definition of Environmental Correlates (Level 2)

Table 2: Definition of Survival Factors (Level 3) for Chinook Salmon

Appendix 2 -- Table 1. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Alkalinity	Alkalinity of water (conductivity can be used as a surrogate) (at moderate flows)	Very low (average value typically would be 0-5 mg/l)	Moderately low (average value typically would be 5-25 mg/l)	Moderately high (average value typically would be 25-50 mg/l)	High (average value typically would be 50-150 mg/l)	High (average value typically would be 150-250 mg/l)
Bed scour	Average depth and frequency of scour on small-cobble/gravel riffles during high flow events. The term “frequent” indicates at least one event every 1-2 years. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et al. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 7 inch diameter), large cobble (7 to 11.9 inch diameter), boulder (>11.9 inch diameter).	Pool tailouts and riffles generally very stable, characteristic of conditions prevailing in largely spring fed streams.	Infrequent scour, averaging depths < 10 cm	Frequent scour, averaging depths < 10 cm	Frequent scour, averaging depths > 10 cm and < 25 cm	Frequent scour, averaging depths exceeding 25 cm

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Benthos diversity and production	Measure of the diversity and production of the benthos community.	Macroinvertebrates abundant, multiple species of families Emphemeroptera, Plecoptera, and Trichoptera are present.	Intermediate	Macroinvertebrates common or abundant but 1-2 families among Emphemeroptera, Plecoptera, and Trichoptera are not present.	Intermediate	Macroinvertebrates are present only at extremely low densities and/or biomass.
Channel length	Length of the primary channel contained with the stream reach -- Note: this attribute will not be given by a categories but rather will be a point estimate. Length of channel is given for the main channel only--multiple channels do not add length.					

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Channel width - month maximum width (ft)	Average width of the wetted channel during peak flow month (average monthly conditions). If the stream is braided or contains multiple channels, then the width would represent the sum of the wetted widths along a transect that extends across all channels. Note: Categories are not to be used for calculation of wetted surface area; categories here are used to designate relative stream size.	< 15 ft	> 15 ft and < 60 ft	> 60 ft and < 100 ft	> 100 ft and 360 ft	> 360 ft
Channel width - month minimum width (ft)	Average width of the wetted channel. If the stream is braided or contains multiple channels, then the width would represent the sum of the wetted widths along a transect that extends across all channels. Note: Categories are not to be used for calculation of wetted surface area; categories here are used to designate relative stream size.	< 15 ft	> 15 ft and < 60 ft	> 60 ft and < 100 ft	> 100 ft and 360 ft	> 360 ft

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Confinement - Hydromodifications	The extent that man-made structures within or adjacent to the stream channel constrict flow (as at bridges) or restrict flow access to the stream's floodplain (due to streamside roads, revetments, diking or levees) or the extent that the channel has been ditched or channelized.	The stream channel within the reach is essentially fully connected to its floodplain. Very minor structures may exist in the reach that do not result in flow contriction or restriction. Note: this describes both a natural condition within a naturally unconfined channel as well as the natural condition within a canyon.	Some portion of the stream channel, though less than 10%, is disconnected from its floodplain along one or both banks due to man-made structures or ditching.	More than 10% and less than 40% of the entire length of the stream channel within the reach is disconnected from its floodplain along one or both banks due to man-made structures or	More than 40% and less than 80% of the entire length of the stream channel within the reach is disconnected from its floodplain along one or both banks due to man-made structures or	Greater than 80% of the entire length of the stream channel within the reach is disconnected from its floodplain along one or both banks due to man-made structures or ditching.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Confinement - natural	The extent that the valley floodplain of the reach is confined by natural features—determined as the ratio between the width of the valley floodplain and the bankfull channel width. Note: this attribute addresses the natural (pristine) state of valley confinement only. The extent that reaches are confined by hydromodifications (e.g., diking) is addressed under a separate attribute.	Reach mostly unconfined by natural features -- Average valley width > 4 channel widths.	Reach comprised approximately equally of unconfined and moderately confined sections.	Reach mostly moderately confined by natural features -- Average valley width 2 - 4 channel widths.	Reach comprised approximately equally of moderately confined and confined sections.	Reach mostly confined by natural features -- Average valley width < 2 channel widths.
Dissolved oxygen	Average dissolved oxygen within the water column for the specified time interval.	> 8 mg/L (allows for all biological functions for salmonids without impairment at temperatures ranging from 0-25 C)	> 6 mg/L and < 8 mg/L (causes initial stress symptoms for some salmonids at temperatures ranging from 0-25 C)	> 4 and < 6 mg/L (stress increased, biological function impaired)	> 3 and < 4 mg/L (growth, food conversion efficiency, swimming performance adversely affected)	< 3 mg/L
Embeddedness	The extent that larger cobbles or gravel are surrounded by or covered by fine sediment.	< 10% of surface covered by fine sediment	> 10 and < 25 % covered by fine sediment	> 25 and < 50 % covered by fine sediment	> 50 and < 90 % covered by fine sediment	> 90% covered by fine sediment

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Fine sediment	Percentage of fine sediment within pool-tailouts and riffles.	< 6% fines < 0.85 mm particle size	> 6% and < 11% fines < 0.85 mm particle size	> 11% and < 18% fines < 0.85 mm particle size	> 18% and < 30% fines < 0.85 mm particle size	> 30% fines < 0.85 mm particle size
Fish community richness	Measure of the richness of the fish community (no. of fish taxa).	2 or fewer fish taxa	3-7 fish taxa	8-17 fish taxa	18-25 fish taxa	> 25 fish taxa
Fish pathogens	The presence of pathogenic organisms (relative abundance and species present) having potential for affecting survival of stream fishes.	No historic or recent fish stocking in drainage and no known incidences of whirling disease, C. shasta, IHN, or IPN	Historic fish stocking, but no fish stocking records within the past decade, or sockeye population currently existing in drainage, or known incidents of viruses among kokanee populations within the watershed.	On-going periodic, frequent, or annual fish stocking in drainage or known viral incidents within sockeye, chinook, or steelhead populations in the watershed.	Operating hatchery within the reach or in the reach immediately downstream or upstream	Known presence of whirling disease or C. shasta within the watershed.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Fish species introductions	Extent of introductions of exotic fish species in the vicinity of the stream reaches under consideration.	No non-native species reported or known to be in the sub-drainage of interest.	1-2 non-native species reported or known to be in the sub-drainage of interest.	3-7 non-native species reported or known to be in the sub-drainage of interest.	8-14 non-native species reported or known to be in the sub-drainage of interest.	15 or more non-native species reported or known to be in the sub-drainage of interest.
Flow - change in interannual variability in high flows	A measure of between year variation in magnitude of high flow levels and/or the extent of change in overall high flow level during a month relative to an undisturbed watershed of comparable size, geology, and geography (or as would have existed in the pristine state).	Pronounced decreases in high flow levels and/or amount of between year variation in high flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Some evidence of decreases in high flow levels and/or amount of between year variation in high flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Typical high flow levels and amount of variation in high flows between years relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Some evidence of increases in high flow levels and/or amount of between year variation in high flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Pronounced increases in high flow levels and/or amount of between year variation in high flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Flow - changes in interannual variability in low flows	A measure of between year variation in the severity of low flow discharge during a month. Variation in low flows as applied here is relative to an undisturbed watershed of comparable size, geology, and geography (or as would have existed in the pristine state).	Pronounced increases in low flow levels and between year stability in low flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest). This index level indicates a marked increase in both low flow and stability compared to pristine conditions.	Some evidence of increased low flow levels and between year stability in low flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).This index level some evidence exists of an increase in both low flow and stability compared to pristine conditions.	Typical low flows and between year variation in low flows relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Some evidence of reduced low flows and/or between year variation in low flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Pronounced reductions in low flows and/or between year variation in low flow levels relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest)..

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Flow - Intra daily (diel) variation	Varibility in flow level during a daily period. This attribute is informative mainly for regulated rivers or when flow patterns are influenced by storm water runoff.	Essentially no variation in discharge during a 24-hr period. During a month, this condition would characterize most flow patterns not associated with flow ramping by a hydro project or storm-water runoff.	Little variation, on average, in discharge during a 24-hr period--typical of natural runoff pattern during relatively small rainfall storm	Moderate variation, on average, in discharge during a 24-hr period--typical of low ramping rate associated with hydro facilities or natural change in discharge associated with an average to above average rainfed freshet.	Some evidence of increased variation in discharge during a 24-hr period compared to natural runoff pattern. This pattern typical of moderate ramping condition associated with flow regulation.	Extreme variation on average over a 24-hr period during month. This pattern typical of severe ramping condition associated with flow regulation or highly urbanized areas.
Flow - intra-annual flow pattern	The average extent of intra-annual flow variation during a month -- a measure of a stream's "flashiness" during a season.	Pronounced decreases in variation in daily flow during a month (intra-annual) relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Some evidence of decreased variation in daily flow during a month (intra-annual) relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Typical variation in flow variation during a month (intra-annual) in an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Some evidence of increased variation in daily flow during a month (intra-annual) relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).	Pronounced increases in variation in daily flow during a month (intra-annual) relative to an undisturbed watershed of similar size, geology, and geography (or as would occur in the pristine state for the watershed of interest).

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Gradient	Average gradient of the main channel of the reach over its entire length.	0 - 0.1%	>0.10% and <0.5%	>0.5% and <1%	>1% and <2%	>2% and <4%
Habitat type - backwater	Percentage of the wetted channel surface area comprising backwater pools. Backwater pools are habitat units located along the channel margins but are otherwise enclosed—though still connected to the main channel (or side channel). Note: backwater pools as defined here include "alcoves" as described by Nickleson et al. (1992).	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
Habitat type - beaver ponds	Percentage of the wetted channel surface area comprising beaver ponds. Note: this includes only those sites associated with the main channel or its side channels. Off-channel sites are addressed through the Off-Channel Habitat Factor.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Habitat type - glides	Percentage of the wetted channel surface area comprising glides. A glide is defined as having moderately low velocities (approx. 10-20 cm/sec) with little or no surface turbulence. Glides generally are characterized as relatively shallow type habitat.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>0.5% and <1%	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
Habitat type - large cobble/boulder riffles	Percentage of the wetted channel surface area comprising large cobble/boulder riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et al. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 7 inch diameter), large cobble (7 to 11.9 inch diameter), boulder (>11.9 inch diameter).	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Habitat type - off-channel habitat factor	A multiplier used to estimate the amount of off-channel habitat based on the wetted surface area of the all combined in-channel habitat. Off-channel habitat consist of oxbows, backswamps, riverine ponds, and the channels that connect them to the main channel or its side channels.	No off-channel habitat present	>0 X and < 0.05 X	>0.05 X and < 0.25 X	>0.25 X and < 0.5 X	>0.5 X
Habitat type - pool tailouts	Percentage of the wetted channel surface area comprising pool tailouts.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
Habitat type - primary pools	Percentage of the wetted channel surface area comprising pools, excluding beaver ponds.	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Habitat type - small cobble/gravel riffles	Percentage of the wetted channel surface area comprising small cobble/gravel riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et al. (1991): gravel (0.2 to 2.9 inch diameter), small cobble (2.9 to 7 inch diameter), large cobble (7 to 11.9 inch diameter), boulder (>11.9 inch diameter).	0 - <0.25% of wetted surface area encompasses this habitat type	>0.25% and <5% of wetted surface area encompasses this habitat type	>5% and <25% of wetted surface area encompasses this habitat type	>25% and <50% of wetted surface area encompasses this habitat type	>50% of wetted surface area encompasses this habitat type
Harassment	The relative extent of poaching and/or harassment of fish within the stream reach.	Reach is distant from human population centers, no road access or no local concentration of human activity.	Reach is distant from human population centers, but with partial road access or little local concentration of human activity.	Reach is near human population center, but has limited public access (through roads or boat launching sites).	Extensive road and/or boat access to the reach with localized concentrations of human activity.	Reach is near human population center or has extensive recreational activities, and has extensive road access and/or opportunities for boat access.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Hatchery fish outplants	The magnitude of hatchery fish outplants made into the drainage over the past 10 years.	No stocking records in the past decade.	No more than two instances of fish releases in the past decade in the drainage.	Fish releases made into the drainage every 1-3 years at isolated locations within the drainage.	Fish releases made at multiple sites in the drainage, but only in 1-3 years during the past decade. When the species released is the same as focus species, chance for some superimposition can occur here.	Fish releases made every 1-3 years and at multiple sites in the drainage. When the species released is the same as focus species,superimposition can occur here.
Hydrologic regime - natural	The natural flow regime within the reach of interest. Flow regime typically refers to the seasonal pattern of flow over a year; here it is inferred by identification of flow sources. This applies to an unregulated river or to the pre-regulation state of a regulated river.	Groundwater-source-dominated; strongly buffered peak flows (as in a springbrook or in river like the Metolius in central Oregon)	Spring snowmelt dominated, non-glacial; temporally consistent and moderate peak and low flows	Rain-on-snow transitional; consistent spring peak and low flows with inconsistent and flashy winter or early spring rain-on-snow	Rainfall-dominated; flashy winter and early spring peaks, consistently low summer flows and variable spring and fall flows.	Glacial runoff system; high, turbid low flows, generally buffered peak flows except with occasional outburst floods and infrequent rain-on-snow events

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Hydrologic regime - regulated	The change in the natural hydrograph caused by the operation of hydroelectric facilities in a watershed. Definition does not take into account daily flow fluctuations (See Flow-Intra-daily Variation Correlate)	The project is located off the main channel. The project diverts on average less than 50% of the river/stream in any given month. The project has little impact on peak flows or median monthly flows, except in the bypass reach. Flow is always present in the bypass reach.	The project is located off the main channel. The project diverts on average more than 50% of the river/stream in any given month. The project has little impact on peak flows or median monthly flows, except in the bypass reach. Flow may or may not be present in the bypass reach during some periods.	The project is located in the channel, is operated in run-of –river mode, and therefore has little storage or flood control capability. This results in no variation in the natural hydrograph regime of the basin.	The project is located in the channel, operated as a run-of-river project under flood control constraints. Median monthly flows in general mimic the natural flow regime but the 5, 10, and 20-year peak flows would be reduced by more than 25%.	Project operations have resulted in a major shift in median flows between months or seasons. Typically spring flows (in snow melt systems) have been reduced and winter flows increased in order to meet power demands. However, the pattern varies based on the hydrologic regime of the basin. Peak flows (5, 10, 20-year) have been reduced by more than 25%.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Icing	Extent (magnitufe and frequency) of icing events.	Anchor ice and icing events occur rarely, having little or no impact to physical structure of stream, in-stream structure, and stream banks/bed. No anchor ice nor ice jams or icing events that result short term impacts; these may have long-term beneficial effects.	Intermediate to codes 0 and 1.	Some anchor ice and/or icing events that have a moderate to high probability of occurrence but effects on stream, in-stream structure, and stream banks/beds low to moderate.	Intermediate to codes 2 and 4.	Likelihood of severe anchor ice or overbank ice jams is high, having major effects on stream, in-stream structure, and stream banks. (frequency and severity)
Metals - in water column	The extent of dissolved heavy metals within the water column.	No toxicity expected due to dissolved heavy metals to salmonids under prolonged exposure (1 month exposure assumed).	May exert some low level chronic toxicity to salmonids (1 month exposure assumed).	Consistently chronic toxicity expected to salmonids(1 month exposure assumed).	Usually acutely toxic to salmonids (1 month exposure assumed).	Always acutely toxic to salmonids (1 month exposure assumed).

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Metals/Pollutants - in sediments/soils	The extent of heavy metals and miscellaneous toxic pollutants within the stream sediments and/or soils adjacent to the stream channel.	Metals/pollutants at natural (background) levels with no or negligible effects on benthic dwelling organisms or riparian vegetation (under continual exposure).	Deposition of metals/pollutants in low concentrations such that some stress symptoms occur to benthic dwelling organisms or riparian vegetation root/shoot growth is impaired (under continual exposure).	Stress symptoms increased or biological functions moderately impaired to benthic dwelling organisms; or few areas within the riparian zone present where no vegetation exists (slickens); ecotonal to these areas occupied only by tolerant species; horizons containing metals/pollutant concentrations influencing root growth and composition are common within the riparian corridor.	Growth, food conversion, reproduction, or mobility of benthic organisms severely affected; or large areas of the riparian zone devoid of vegetation; ecotonal areas occupied only by metals/pollutant-tolerant species; few areas in the riparian zones which are unaffected.	Metals/pollutant concentrations in sediments/soils are lethal to large numbers of the benthic species and/or riparian zone is practically devoid of vegetation.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Miscellaneous toxic pollutants - water column	The extent of miscellaneous toxic pollantants (other than heavy metals) within the water column.	No substances present that may periodically be at or near chronic toxicity levels to salmonids.	One substance present that may only periodically rise to near chronic toxicity levels (may exert some chronic toxicity) to salmonids.	More than one substance present that may periodically rise to near chronic toxicity levels or one substance present > chronic threshold and < acute threshold (consistently chronic toxicity) to salmonids.	One or more substances present > acute toxicity threshold but < 3X acute toxicity threshold (usually acutely toxic) to salmonids.	One or more substances present with > 3X acute toxicity (always acutely toxic) to salmonids.
Nutrient enrichment	The amount of nutrient enrichment consisting of such items as ammonia, nitrogen, phosphorous.	No enrichment.	Intermediate	Some enrichment with possible positive production response for some species (possibly negative for others).	Intermediate	Super enrichment (e.g., discharge of sewage in the summer with high densities of grazing animals)
Obstructions to fish migration	Obstructions to fish passage by physical barriers (not dewatered channels or hinderances to migration caused by pollutants or lack of oxygen).	None documented or inferred.	One or barriers to juvenile migrants at certain flow levels.	One or barriers to juvenile migrants at all flow levels.	One or barriers to juvenile migrants at all flow levels and barrier(s) to adult migration at certain flow levels.	One or more barriers to all fish migration at all flow levels.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Predation risk	Level of predation risk on fish species due to presence of top level carnivores or unusual concentrations of other fish eating species. This is a classification of per-capita predation risk, in terms of the likelihood, magnitude and frequency of exposure to potential predators (assuming other habitat factors are constant).	Many or most native predators are depressd or rare, none are greatly increased over natural levels, and there may be some numerical survival advantage to fish as a result compared to historical predator abundance.	Intermediate	Diversity and per-capita abundance of predators exists so that predation risk is at near-natural level and distribution.	Intermediate	Excessive population density or concentrated population of predator species exists due to artifacts of human alteration of the environment (e.g., top-down food web effects, habitat manipulations).
Riparian function	A measure of riparian function that has been altered within the reach.	Strong linkages with no anthropogenic influences.	>75-90% of functional attributes present (overbank flows, vegetated streambanks, groundwater interactions typically present).	50-75% functional attribute rating- significant loss of riparian functioning- minor channel incision, diminished riparian vegetation structure and inputs etc.	25-50% similarity to natural conditions in functional attributes- many linkages between the stream and its floodplain are severed.	< 25% functional attribute rating: complete severing of floodplain-stream linkages

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Salmon Carcasses	Relative abundance of andromous salmonid carcasses within watershed (e.g., HUC 5 level) that can serve as nutrient sources for juvenile salmonid production.	Super abundant -- an average number of carcasses per total miles of main channel habitat >800.	Very abundant -- an average number of carcasses per total miles of main channel habitat >400 and < 800.	Moderately abundant -- an average number of carcasses per total miles of main channel habitat >200 and < 400.	Not abundant -- an average number of carcasses per total miles of main channel habitat >25 and <200.	Very few or none -- an average number of carcasses per total miles of main channel habitat <25.
Temperature - daily maximum (by month)	Maximum water temperatures within the stream reach reach during a month.	Warmest day < 10 C	Warmest day>10 C and <16 C	> 1 d with warmest day 22-25 C or 1-12 d with >16 C	> 1 d with warmest day 25-27.5 C or > 4 d (non-consecutive) with warmest day 22-25 C or >12 d with >16 C	> 1 d with warmest day 27.5 C or 3 d (consecutive) >25 C or >24 d with >21 C
Temperature - daily minimum (by month)	Minimum water temperatures within the stream reach reach during a month.	Coldest day >4 C	< 7 d with <4 C and minimum >1 C	1 to 7 d < 1 C	8 to 15 days < 1 C	> 15 winter days < 1 C

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Temperature - spatial variation	The extent of water temperature variation within the reach as influenced by inputs of groundwater.	Groundwater discharge into surface waters is the major source of flow in reach.	Abundant sites of groundwater discharge into surface waters.	Intermittent sites of groundwater discharge into surface waters and total quantity of groundwater discharge not a major source of flow in reach.	Infrequent sites of groundwater discharge into surface waters and total quantity of groundwater discharge not a major source of flow in reach.	No evidence of concentrated groundwater inputs.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Turbidity	The relative extent of turbidity episodes within the stream reach. Note: turbidity here is described by suspended sediment, measured as mg/L instead of the more usual unit of NTU. It is recognized that relationships between NTU and suspended sediment differ by sediment particle type.	Clear with infrequent (short duration-- several days per year) concentrations of suspended sediment (i.3., <50 mg/L) (a spring creek).	Occasional episodes (days to several weeks--not continuous--annually) of low to moderate concentrations (<500 mg/L), though short duration episodes (<7 days) may occur with of higher concentrations (500 to 1000). These concentrations are always sublethal to juvenile and adult salmonids-though some behavioral modification may occur.	Occasional episodes (days to several weeks) of moderate to relatively high concentrations (>500 and <1000 mg/L), though short duration episodes (<2 weeks) may occur with higher concentrations (500-2000 mg/L). The higher concentrations stated can result in major behavioral modification, some stress and reduced forage success. This condition be associated with various types of land uses where some remedial measures are in place and normal conditions for glacial runoff in many glacial fed rivers in western Washington.	On-going or occasional episodes (periodic events annually lasting several weeks at a time)) of high concentrations of suspended sediment (>1000 and <4000 mg/L), though shorter duration episodes typically occur with higher concentrations (>4000 and <8000 mg/L). These conditions result in prolonged stress to fish unless some form of refuge found and significant loss of forage success.	Extended periods (months) of very high concentrations (>4000 and <8000 mg/L) or shorter durations exceeding 8000 mg/L. These represent extremely severe conditions for survival of fish species.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Water withdrawals	The number and relative size of water withdrawals in the stream reach.	No withdrawals.	Very minor water withdrawals with or without screening (entrainment probability considered very low).	Several of significant water withdrawals along reach though all sites known or believed to be screened with effective screening devices. (Note: one site that withdrawals substantial portion of flow without screening falls into this category.)	Several sites of significant water withdrawals along reach without screening or screening believed to be ineffective. (Note: one site that withdrawals substantial portion of flow without screening falls into this category.)	Frequent sites of significant water withdrawals along reach without screening or screening believed to be ineffective.

Appendix 2 -- Table 1 continued. Definition of Environmental Correlates (Level 2)

Correlate	Correlate Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Wood	The amount of wood within the reach. Note definition of "large wood" under terms/clarification.	A complex mixture of single large pieces and accumulations consisting of all sizes, decay classes, and species origins; cross-channel jams are present where appropriate vegetation and channel conditions facilitate their existence; large wood pieces are a dominant influence on channel diversity (e.g., pools, gravel bars, and mid-channel islands) where channel gradient and flow allow such influences.	Complex array of large wood pieces but fewer cross channel bars and fewer pieces of sound large wood due to reduced recruitment; influences of large wood and jams are a prevalent influence on channel morphology where channel gradient and flow allow such influences.	Few pieces of large wood and their lengths are reduced and decay classes older; small debris jams poorly anchored in place; large wood habitat and channel features of large wood origin are uncommon where channel gradient and flow allow such influences.	No pieces of large wood and the natural function of wood pieces limited due to diminished quantities, sizes, decay classes and the capacity of the riparian streambank vegetation to retain pieces where channel gradient and flow allow such influences.	No wood present.

Appendix 2 --Table 2. *Level 3 Survival Factors*. These factors are defined as the relative survival or productivity of the focal species by life stage. These factors act as "umbrella attributes", combining the effects of Level 2 correlates on the species..

Factor	Definition
Channel stability	The effect of stream channel stability (within reach) on the relative survival or performance of the focus species; the extent of channel stability is with respect to its streambed, banks, and its channel shape and location.
Chemicals	The effect of toxic substances or toxic conditions on the relative survival or performance of the focus species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Competition (with hatchery fish)	The effect of competition with hatchery produced animals on the relative survival or performance of the focus species; competition might be for food or space within the stream reach.
Competition (with other species)	The effect of competition with other species on the relative survival or performance of the focus species; competition might be for food or space.
Flow	The effect of the amount of stream flow, or the pattern and extent of flow fluctuations, within the stream reach on the relative survival or performance of the focus species. Effects of flow reductions or dewatering due to water withdrawals are to be included as part of this correlate.
Food	The effect of the amount, diversity, and availability of food that can support the focus species on the its relative survival or performance.
Habitat diversity	The effect of the extent of habitat complexity within a stream reach on the relative survival or performance of the focus species.
Harassment	The effect of harassment, poaching, or non-directed harvest (i.e., as can occur through hook and release) on the relative survival or performance of the focus species.
Key habitat	The relative quantity of the primary habitat type(s) utilized by the focus species during a life stage; quantity is expressed as percent of wetted surface area of the stream channel.
Obstructions	The effect of physical structures impeding movement of the focus species on its relative survival or performance within a stream reach; structures include dams and waterfalls.
Oxygen	The effect of the concentration of dissolved oxygen within the stream reach on the relative survival or performance of the focus species.
Pathogens	The effect of pathogens within the stream reach on the relative survival or performance of the focus species. The life stage when infection occurs is when this effect is accounted for.
Predation	The effect of the relative abundance of predators species on the relative survival or performance of the focus species, apart from the influence of the amount of cover habitat used by the focus species.
Salinity	The effect of the concentration of salts within the reach on the relative survival or performance of the focus species.
Sediment load	The effect of the amount of the amount of fine sediment present in, or passing through, the stream reach on the relative survival or performance of the focus species.
Temperature	The effect of water temperature with the stream reach on the relative survival or performance of the focus species.
Withdrawals (or entrainment)	The effect of entrainment (or injury by screens) at water withdrawal structures within the stream reach on the relative survival or performance of the focus species. This effect does not include dewatering due to water withdrawals, which is covered by the flow correlate.

Appendix 3

Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Appendix 3 -- Table 1. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
Spawning	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - Intra daily (diel) variation						
	Food	no effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood		
	Harvest	Harassment	Habitat type - primary pools	Riparian function	Turbidity	Wood		
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Flow - changes in interannual variability in low					

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
			flows					
	Sediment load	Turbidity	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Incubation	Channel stability	Bed scour	Icing	Riparian function	Wood	Confinement – Hydro-modifications	Flow - change in interannual variability in high flows	Flow - intra-annual flow pattern
	Chemicals	Miscellaneous toxic pollutants - water column	Metals/ Pollutants - in sediments/soils	Metals - in water column	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - Intra daily (diel) variation						
	Food	no effects						
	Harvest	Harassment						
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Sediment load	Fine sediment						
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Fry colonization	Channel stability	Bed scour	Icing	Riparian function	Wood	Confinement – Hydro-modifications	Flow - change in interannual variability in high flows	Flow - intra-annual flow pattern
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/-Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Flow	Flow - change in interannual variability in high flows	Confinement - natural	Confinement – Hydro-modifications	Gradient		Riparian function	Wood
	Food	Benthos diversity and production	Alkalinity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood	Icing	
	Harvest	no effects						

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Turbidity	Embeddedness					
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
0-age resident rearing	Channel stability	Bed scour	Icing	Riparian function	Wood			
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Competition (with other species)	Fish community richness	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Flow	Flow - changes in interannual variability in low flows	Embeddedness	Habitat type - backwater pools	Habitat type - beaver ponds	Habitat type - primary pools	Confinement - natural	Confinement – Hydro-modifications

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	**Modifying**	**Modifying**	**Modifying**	**Modifying**	**Modifying**	**Modifying**
	Food	Benthos diversity and production	Alkalinity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood	Icing	
	Harvest	Harassment	Habitat type - primary pools	Riparian function	Turbidity	Wood		
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Turbidity	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
0-age transient rearing	Channel stability	Bed scour	Icing	Riparian function	Wood			
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Competition (with hatchery fish)	Hatchery fish outplants	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Competition (with other species)	Fish community richness	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Flow	Flow - changes in interannual variability in low flows	Embeddedness	Habitat type - backwater pools	Habitat type - beaver ponds	Habitat type - primary pools	Confinement - natural	Confinement – Hydro-modifications
	Food	Benthos diversity and production	Alkalinity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood	Icing	
	Harvest	Harassment	Habitat type - primary pools	Riparian function	Turbidity	Wood		
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Turbidity	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Withdrawals	Water withdrawals						
0-age migrant	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - changes in interannual variability in low flows						
	Food	no effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood		
	Harvest	Harassment						
	KeyHabitat	<all habitat types applied equally>						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	**Modifying**	**Modifying**	**Modifying**	**Modifying**	**Modifying**	**Modifying**
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Turbidity	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Inactive	Channel stability	Bed scour	Icing	Riparian function	Wood	Confinement – Hydro-modifications	Flow - change in interannual variability in high flows	Flow - intra-annual flow pattern
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - change in interannual variability in high flows	Confinement - natural	Confinement – Hydro-modifications	Gradient		Riparian function	Wood
	Food	Benthos diversity and production	Alkalinity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood	Icing	
	Harvest	Harassment						

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily minimum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Embeddedness	Turbidity					
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
1-age resident rearing	Channel stability	Bed scour	Icing	Riparian function	Wood			
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Competition (with other species)	Fish community richness	Alkalinity	Benthos diversity and production	Riparian function	Salmon Carcasses		
	Flow	Flow - change in interannual variability in high flows	Confinement - natural	Confinement – Hydro-modifications	Gradient		Riparian function	Wood

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	**Modifying**	**Modifying**	**Modifying**	**Modifying**	**Modifying**	**Modifying**
	Food	Benthos diversity and production	Alkalinity	Riparian function	Salmon Carcasses			
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood	Icing	
	Harvest	Harassment	Habitat type - primary pools	Riparian function	Turbidity	Wood		
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Turbidity	Temperature - daily maximum (by month)					
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
1-age migrant	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/ Pollutants - in sediments/soils	Nutrient enrichment			

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - changes in interannual variability in low flows						
	Food	no effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood	Icing	
	Harvest	Harassment						
	KeyHabitat	<all habitat types applied equally>						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Fish community richness	Fish species introductions	Temperature - daily maximum (by month)	Flow - changes in interannual variability in low flows	Hatchery fish outplants	
	Sediment load	Turbidity	Flow - changes in interannual variability in low flows	Temperature - daily maximum (by month)				

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Temperature	Temperature - daily minimum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Prespawning migrant	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/-Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - changes in interannual variability in low flows						
	Food	no effects						
	Habitat diversity	Gradient	Confinement - natural	Confinement – Hydro-modifications	Riparian function	Wood		
	Harvest	Harassment	Habitat type - primary pools	Riparian function	Turbidity	Wood		
	KeyHabitat	<all habitat types applied equally>						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum	Nutrient enrichment			

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
				(by month)				
	Predation	Predation risk	Flow - changes in interannual variability in low flows					
	Sediment load	Turbidity	Flow - changes in interannual variability in low flows	Temperature - daily maximum (by month)				
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						
Prespawning holding	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals - in water column	Metals/-Pollutants - in sediments/soils	Nutrient enrichment			
	Competition (with hatchery fish)	Hatchery fish outplants						
	Competition (with other species)	Fish community richness						
	Flow	Flow - changes in interannual variability in low flows	Embeddedness	Habitat type - backwater pools	Habitat type - beaver ponds	Habitat type - primary pools	Confinement - natural	Confinement – Hydro-modifications
	Food	no effects						
	Habitat diversity	Gradient	Confinement – Hydro-modifications	Riparian function	Wood			

Appendix 3 -- Table 1 continued. Primary and Modifying Environmental Correlates (Level 2's) used in the development of the "Bio-rules" for each Chinook Survival Factor (Level 3) by Life Stage.

Life stage	Survival Factor (Level 3)	Environmental Correlates (Level 2)						
		Primary	Modifying	Modifying	Modifying	Modifying	Modifying	Modifying
	Harvest	Harassment	Habitat type - primary pools	Riparian function	Turbidity	Wood		
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	Fish pathogens	Fish species introductions	Temperature - daily maximum (by month)	Nutrient enrichment			
	Predation	Predation risk	Flow - changes in interannual variability in low flows					
	Sediment load	Turbidity	Flow - changes in interannual variability in low flows	Temperature - daily maximum (by month)				
	Temperature	Temperature - daily maximum (by month)	Temperature - spatial variation					
	Withdrawals	Water withdrawals						