HabRate: A Stream Habitat Evaluation Methodology for Assessing Potential Production of Salmon And Steelhead in the Middle Deschutes River Basin.

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Abstract

HabRate represents a simple spreadsheet model that rates the potential quality of stream habitat for the early life stage of salmon and steelhead based on common survey data. The model was developed for a specific application to the middle Deschutes River basin in Oregon, but was intended for general application to the Pacific Northwest Basins. We summarized available literature on salmonid habitat requirements. Habitat requirements for discrete early life history stages (i.e. spawning, egg survival, emergence, summer rearing, and winter rearing) were summarized and used to rate the quality of reaches as poor, fair, or good, based on attributes relating to stream substrate, habitat unit type, cover, gradient, temperature, and flow. Reach level summaries of stream habitat were entered into a computer spreadsheet, and interpreted by logical statements to provide a crude limiting factor assessment of potential egg-to-fry and fry-to-parr survival for each reach. The model is a decision making tool that is intended only to provide a qualitative assessment of the habitat potential of stream reaches within a basin context. Design criteria for the model was simplicity and flexibility. While HabRate was based on our interpretations of the published literature, specific criteria for habitat quality were structure to be easily adjusted where interpretations differ from ours. Information not common to standard stream survey designs, such as seasonal flow or temperature extremes are included as input from professional judgment. A graphic summary of the rating results was present as an example of the potential interpretation.

Introduction

Models that predict fish standing crop and production based on habitat parameters implicitly assume a deterministic relationship between fish and their physical environment.

Such models are typically based either on regression analyses, or a limiting factors approach (Shrivell 1989). While some regression-based models have been highly predictive (R^2 = 50 to 96%) in the areas from which they were developed, their generality appears limited (R2<30%) when applied elsewhere without recalibration. Limiting factor type models are applied with the implicit assumption that included variables are of general importance. Where the status of particular population is poorly predicted, it is implied that the population is limited by variables not include in the model.

With the widespread application of the Hankin-Reeves stream survey design, there has been significant effort dedicated toward basin-wide assessments of stream habitat. Specifically in Oregon, and extensive stream survey program by the Oregon Department of Fish and Wildlife (ODFW), Aquatic Inventories Project (AIP) has inventories over 7,000 km of streams. A need exists to interpret an increasingly large volume of stream survey data in a way that is meaningful for basin-wide management of juvenile salmonid populations. While AIP stream survey data has been used to describe juvenile bull trout rearing areas (Dambacher and Jones 1994), and predict survival of juvenile coho salmon (Nichelson and Lawson 1999), applications for other salmonid species have yet to be developed or researched. We sought therefore to derive meaningful criteria from existing literature of habitat based on life history requirements for steelhead, chinook, and sockeye salmon. This effort grew out of a specific request to provide habitat based stream production potential as input to a stochastic simulation of chinook and sockeye life history model for the Deschutes River basin (Oosterhoot 1999), our approach however, is general to Pacific Northwest systems.

Background

HabRate was initiated as part of a feasibility study to assess the reintroduction of salmon and steelhead above the Pelton-Round Butte dam hydropower complex on the Deschutes River (Figure 1). HabRate was developed for the automated assessment of basin-wide habitat conditions based on quantified habitat data. Salmon and steelhead formerly spawned and reared above the complex until the Pelton-Round Butte dam fish ladder was removed from operation in 1968. To assess the current viability of the habitat, HabRate evaluated reach-level habitat data for each early life history stage for chinook and sockeye salmon and steelhead trout using a developed set of criteria. The suitability of each subbasin for each species and life stages was reviewed. Life history stages that were not well supported by the conditions of the habitat were identified. Additional scrutiny of the results revealed the specific attributes limiting salmon productivity in the middle Deschutes River basin. These results provide stream characteristics that are applicable to planning restoration efforts. The ultimate goal of HabRate was to provide a more holistic watershed assessment by viewing the spatial connectivity of the habitat conditions across the basin.

Feasibility Study Background

Portland General Electric (PGE), owner and operator of the Pelton-Round Butte hydropower complex, funded the feasibility study in conjunction with submitting a re-licensing application to continue the operation of the hydropower complex. In accordance with the Federal Energy Regulatory Commission guidelines (FERC), the application process requires a plan for proposed Protection, Mitigation and Enhancement Measures of environmental resources, particularly cultural resources and threatened and endangered species impacted by the Project. To comply with the license application guidelines, PGE committed to the reintroduction and establishment of chinook salmon and steelhead trout populations above the Pelton - Round Butte complex.

The HabRate model

HabRate is a conceptual and numerical model that analyzes the spatial complexity of stream habitat features in the context of salmon survival and habitat usability at each early life history stage. Quantitative habitat criteria for each life history stage were derived from the literature review. Three life history stages were evaluated: spawning, incubation, emergence, summer rearing, and overwintering. Spawning, incubation, and emergence were combined into a single life stage in the evaluation due to the similar criteria values. Adult migration and holding habitat in the Deschutes River basin were decidedly optimal during the migration timing for temperature and flow conditions; therefore, adult life history attributes were not evaluated. The criteria parameters analyze the habitat quality based on salmon survival at each life history stage and create a rating of suitability.

Analysis can be conducted at the micro, macro, and meso-scale level within each reach or across the basin. The design of the model permits continual update and modification of the criterion and habitat data as new information becomes available.

The database structure integrates to a spatially explicit GIS coverage. HabRate' results link to a stream network GIS coverage using a unique identifier for each stream reach, i.e. LLID code. The display plots the habitat quality rating by reach and life stage or stream attribute for each species. The GIS map-based view of ratings and attributes permits analysis of the spatial connectivity and salmon survival between reaches.

Model Justification

In light of the decline of salmon populations, fish biologists have attempted to quantify the relationship of salmon production and survival to the aquatic habitat for an understanding of salmon life history ecology. HabRate may be utilized to understand the ecological relationships between salmon and their environment and to assess watershed and reach scale restoration programs. In addition, HabRate results and interpretations will affect biological and economic justification of restoration and recovery programs.

A variety of approaches have been used to assess habitat quality and quantity in order to determine the potential of a stream to support particular early life history stages of salmon and steelhead trout. Incorporating a life history approach to the relationship between habitat and biological response adds a critical dimension to the interpretation. The overall quality of habitat and the connectivity and relationship of habitats is crucial to the successful completion of a fish's life cycle. Seasonal use of specific habitat types by juvenile coho salmon has been used to predict potential carrying capacity of coastal streams for juvenile coho salmon in Oregon (Nickelson *et al*. 1992; Nickelson *et al*. 1993). The coho study was expanded to include extensive data on habitat quality in individual stream reaches to predict the viability of coho populations in three coastal basins in Oregon (Nickelson and Lawson 1998). Nickelson *et al*. (1992), Nickelson *et al*. (1993) and Nickelson and Lawson (1998) used channel habitat unit and reach level data coupled with temporal data (seasonal habitat use) to predict production and capacity at a stream and basin level. However, a spatial component was not incorporated into the model.

Modeling the survival of fish through the life cycle required integrating spatial and temporal information. A simulation model has been used to describe how the spatial structure of spawning and rearing habitat in a river system influenced the population dynamics of Atlantic salmon (Kocik and Ferreri 1998). Mobrand et al. (1997) developed a spatially and temporally descriptive numerical model of the productivity and capacity of a system by integrating survival of a salmonid species at each life stage. The model then used potential life history trajectories of a salmonid to define connectivity within a drainage. A life history approach had the advantage of incorporating spatial structure and connectivity of the habitat with the survival of fish at each life stage (Nickelson et al. 1992; Nickelson et al. 1993; Mobrand et al 1997; Kocik and Ferreri 1998; Nickelson and Lawson 1998). Each approach had limitations in terms of scale, spatial explicitness, or modeling connectivity within a drainage.

HabRate integrates survey and landscape data into a GIS format to display spatial patterns in aquatic habitat for further understand distribution, survival and production, and life history diversity of fish species. Lahontan cutthroat trout and brook trout have shown responses to geologic and geomorphic land classes as well as micro level environmental gradients in northeastern Nevada (Nelson et al. 1992). Environmental and biotic processes and conditions within a stream structure the biological communities along a longitudinal gradient (Vannote 1980; Rahel and Hubert 1991). Natural and anthropogenic disturbance of aquatic habitat further influences the survival and production of salmonids within these ecosystems along the longitudinal gradient (Hicks et al. 1991; Murray and Bailey 1998). Three components common to the previously mentioned efforts have been the examination of the relationship between spatial, temporal, and ecological parameters. The most important concept is that salmon life history is intertwined with habitat at a scale from channel unit to river network (Lichatowich et al. 1995). HabRate has the incorporated flexibility of scale for comparisons between the reach, river, and basin level.

Scope of the Project

The HabRate model was applied to the middle Deschutes River and its tributaries that were within the proposed reintroduction area. The Middle Deschutes River basin is situated between the Pelton-Round Butte dam complex and Big Falls (RKM 213), a natural barrier to salmon migration on the Deschutes River (Figure 1). Anadromous salmon and steelhead trout formerly spawned and reared in the mainstem Deschutes River and its principle tributary basins: Metolius River, Crooked River and Squaw Creek. If reintroduction were successful, only a portion of the former range would be accessible under existing conditions due to impassable barriers, i.e. Ochoco and Bowman Dams (Figure 1). The habitat data incorporated in the analysis included all stream and river segments that were within the former distribution of anadromous salmon and below Ochoco and Bowman Dams.

Deschutes River Basin Landscape

The Deschutes River basin lies adjacent to a major climate transition zone and within a geologically active landscape (Taylor and Hannan 1999). Volcanism, tectonics, and glacial activity have shaped the Deschutes River basin. The middle and upper Deschutes River system drains from the eastern High Cascade Mountain Province in the west, the Blue Mountain Province in the east, with the High Lava Plains Province in the south and Deschutes-Columbia Plateau in the north (DNF website). The High Cascades mountain range is volcanic in origin and historically contributed substantial amounts of lava and ash-tuff to the basin. The Blue Mountain Province is an uplifted plateau (DNF website). High elevation and forests characterize both regions. The High Lava Plains and Deschutes-Columbia Plateau are largely composed of basalt and ash-tuff that have been eroded over time. The river basin in the High Cascades and High Lava Plains region are unique in that the river primarily flows through lava fields pocketed by prairies. In the Deschutes-Columbia Plateau, the rivers flow through imposing basaltic canyons and arid meadows.

The four geologic regions of the middle and upper Deschutes River basin encompass a variety of ecosystems. The High Cascades marks the beginning of the rain shadow effect on the eastern side of the Cascade Mountain range. The High Cascade and Blue Mountain Provinces receive a considerable amount of snow (greater than 80 inches per year on average) from November to March, while the remainder of the year is predominantly dry (DNF website, Taylor and Hannan 1999). These regions support temperate alpine forests and meadows. The High Lava Plains and Deschutes-Columbia Plateau are cool desert and steppe lands that receive less than 15 inches per year of precipitation in the lower elevations (Deschutes NF website, Taylor and Hannan 1999).

The unique nature of the geology and climate of the region work in concert to maintain river flow throughout the year. River flow throughout the High Lava Plateau and Deschutes-Columbia Plateau is maintained by recurrent, and sometimes large, cold springs. The springs are sustained by snowmelt and precipitation that percolates through the permeable lava rock.

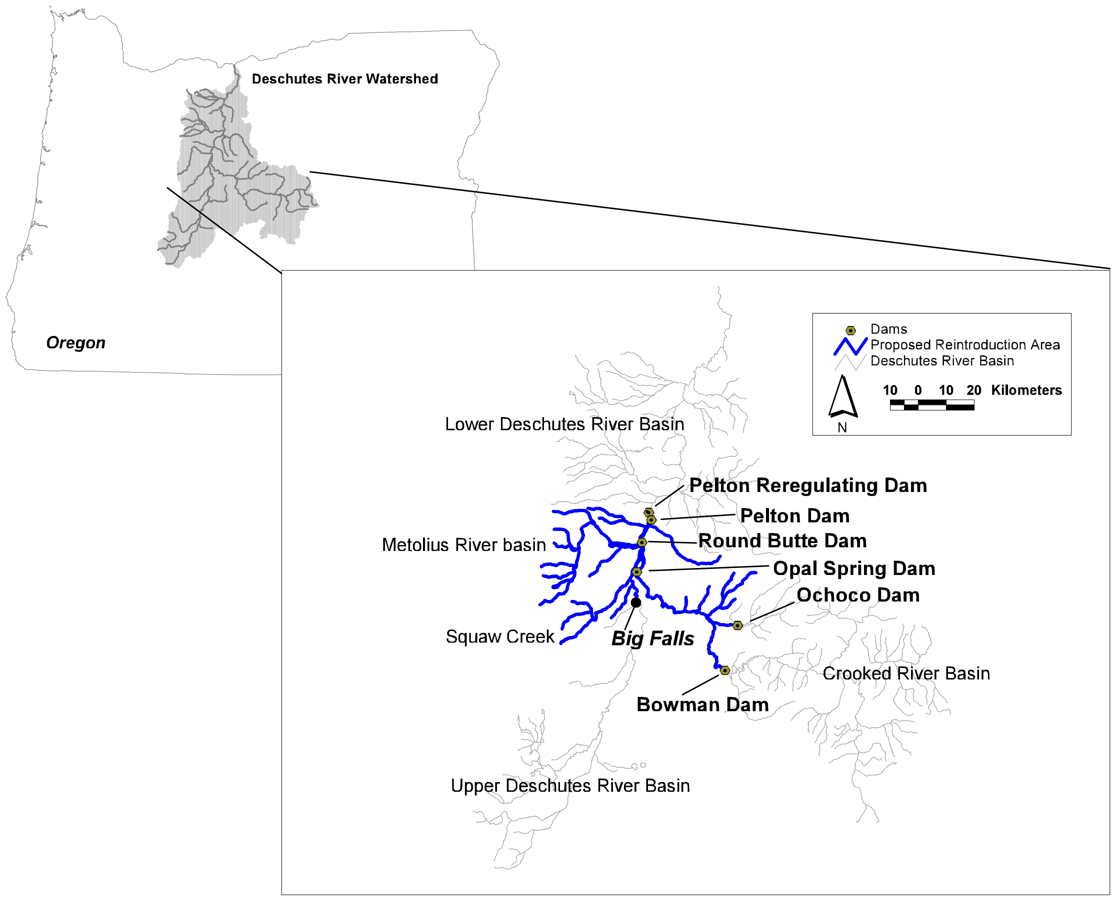


Figure 1. Proposed reintroduced distribution of anadromous salmon and steelhead trout in the Middle Deschutes River.

Life Stages, Former Distribution, and Habitat Criteria

The aim of the literature review was to establish the habitat requirements of spring chinook and sockeye salmon, and steelhead trout at each freshwater life history stage for the Deschutes River basin. Unfortunately, anthropogenic changes in and outside of the Deschutes River basin imparted a devastating effect on salmon populations prior to the complete documentation of their life history and distribution. Nehlsen (1995) compiled notes from biologists and ancillary sources to reconstruct as best as possible the historic range and life history of salmon and steelhead once observed in the Middle Deschutes River and its tributaries (Appendix II). The historical distribution primarily came from anecdotal information with the exception of observations just before completion of the dam, e.g. lower Squaw Creek. Few salmon life history studies occurred prior to the extinction of the runs. The location of rearing habitat, other than sockeye salmon rearing in Suttle Lake, was lacking. Consequently, the scope of the literature review for criteria values was expanded to included Alaska, Idaho, and the eastern regions of Oregon and Washington. We preferentially selected research from field studies that approximated a natural setting over research in a laboratory setting. The criteria values were developed from multiple sources listing habitat requirements (Appendices III, IV and V). Life stage evaluation included only spawning (inclusive of incubation and emergence), summer rearing, and overwintering.

History and current status of anadromous fish in the Deschutes River

Chinook and sockeye salmon and steelhead trout formerly spawned and reared in the Middle Deschutes River basin above the Pelton-Round Butte Dam complex (RKM 161) (Appendix I and II). Beginning in the late 1800s, habitat degradation, irrigation withdrawal and hydropower structures led to the precipitous decline of anadromous salmon and steelhead trout in the Deschutes River basin (Nehlsen 1995). Pressures outside the Deschutes River basin that were detrimental to salmon populations included intense harvesting in the Columbia River in the late 1800s and the establishment of Bonneville Dam (1938) and The Dalles Dam (1957) below the Deschutes River confluence (Lichatowich *et al.* 1996). Ecological changes in the Deschutes River basin were initiated in the early 1900s with the use of waterways for irrigation withdrawal and log transport, leading to severe habitat degradation in streams utilized by salmon and steelhead trout for spawning and rearing.

Baseline information pertaining to anadromous distribution and life history prior to severe disturbance in the late 1800s and early 1900s is not available.

Several anthropogenic events in our recent history have drastically altered the life history and distribution of salmon in the Deschutes River. Two dam structures place in the Metolius River system in the 1930s eradicated the Deschutes River sockeye population by preventing sockeye from reaching their only spawning and rearing habitat in the Deschutes River basin at that time. The sockeye run did not exist when the Pelton-Round Butte Complex was constructed. Steelhead trout and chinook salmon populations declined considerably with the construction of the Pelton–Round Butte Dam complex in 1958 on the Middle Deschutes River. Although a fish ladder was in place on the complex, the ladder was removed from operation in 1968 marking the eradication of the anadromous salmon and steelhead trout populations above the complex. Spring run, or yearling juveniles migrants, hypothetically dominated the run timing at the Pelton-Round Butte weir, but this included hatchery-reared juveniles (Nehlsen 1995).

The Pelton-Round Butte Dam complex is the current upper distribution limit of salmon and steelhead trout. If the populations are re-established, the actual salmon and steelhead distribution may or may not extend into the available habitat that was evaluated in this model.

Life stages and distribution of chinook salmon

HabRate evaluated three life history stages for chinook salmon (Figure 2) (Nehlsen 1995). Timing at weir counts documented the adult and juveniles run timings prior to the Pelton-Round Butte complex. Adult run timing suggested a spring, summer, and fall chinook run above the complex (Nehlsen 1995). Progeny of the adult runs were composed of yearling and subyearling migrants, were documented traveling downstream of the Pelton-Round Butte site (Nehlsen 1995). Spawning and 0+ summer rearing (limited duration) evaluation in HabRate applied to both subyearling and yearling juveniles, while 0+ overwintering applied only to yearling juveniles.

The extent of chinook salmon distribution lacked full documentation. Spring chinook spawned throughout the basin. The summer/fall run hypothetically spawned in the Deschutes and lower Metolius River (Appendix I).

Table 1. Early life history stages by species evaluation in HabRate.

Chinook Salmon	Steelhead Trout	Sockeye Salmon
Spawning	Spawning	Spawning
0+ Summer rearing	0+ Summer rearing	0+ Summer rearing
0+ Overwintering	0+ Overwintering	0+ Overwintering
	1+ Summer rearing	
	1+ Overwintering	

Life stages and distribution of steelhead trout

Weir counts just prior to the dam construction and anecdotal historical accounts in the region established a multiple run timings of adult and juvenile steelhead. Spawning count surveys were conducted in the early 1950s in Squaw Creek, but could not account for the large number of steelhead passing over a weir on the lower Deschutes River. Steelhead typically remained in the Deschutes River basin for 1 to 2 years (King 1966, Nelsen 1995). Therefore, five life stages of steelhead trout were evaluated in HabRate that accounted for 1 to 2 years of freshwater rearing (Figure 2). The uncertainty of the location of adult steelhead spawning grounds lead to a hypothesized historical distribution that covered most of the basin (Appendix I).

Life stages and distribution of sockeye salmon

Sockeye salmon historical distribution and rearing habitat comprised solely of the Metolius River, i.e. spawning in Lake Creek and rearing in Suttle Lake. Contemporary potential rearing habitat includes Suttle Lake, Blue Lake, and Lake Billy Chinook. Sockeye had a short life history evaluation in HabRate, limited to streams with access to the expanded rearing habitat potential: Metolius River and the lower portions of Squaw Creek and Deschutes River (Figure 2).

Data collection

Habitat survey field methods

Habitat surveys were conducted following the methodology described in Hankin (1984) and Hankin and Reeves (1988). While the primary objective of the Hankin (1984) and Hankin and Reeves (1988) methodology was to estimate the number of fish in a stream, it was adapted as a survey design to efficiently collect information on aquatic habitat throughout a stream or watershed. The methodology permitted surveyors to collect information continuously from the stream mouth to headwaters. This census survey design, frequently referred to as a basin survey, was a departure from the traditional representative reach survey for a basin (Dolloff et al. 1997). The major advantage to census surveys was the concurrent record of geomorphic reaches, habitat units, and associated features. It provided process information in addition to status, such as hydrologic processes, distribution of large wood debris or sediment, and features that influence the life history of anadromous, fluvial, or resident fishes in a stream or watershed.

Two sources of aquatic habitat survey data were used in the analysis: US Forest Service (USFS) Pacific Northwest Region 6 and Oregon Department of Fish and Wildlife (ODFW), Aquatic Inventories Project, Moore et al. (1998). The USFS and ODFW used different modified versions of the Hankin (1984) and Hankin and Reeves (1988) methodology in the Deschutes River basin. Habitat surveys in the middle Deschutes River basin began as early as 1989 by the USFS. ODFW began surveys in the area in 1993. Both agencies continued surveying in the basin through 1997, the year HabRate was created. USFS and ODFW data collection methodology differed slightly between years. Different USFS ranger districts in the Deschutes River used different tiers of collection methods. However, the different survey methods were consistent in the qualitative descriptors and quantitative measurements of the stream's physical attributes. Compensation for differences between the field data sources, between the years of collection, and lack of pertinent data was addressed in Appendix X.

Habitat data collection occurred primarily during summer flow levels. The advantage of collecting habitat attributes during decreased discharge is the documentation of limiting factors without compensation for increased discharge and habitat accessibility.

Scope of HabRate

We incorporated the habitat data sets into the model for streams and rivers that were within the former distribution of salmon and steelhead trout. Basin surveys were conducted on the Deschutes River above Lake Billy Chinook reservoir and below Big Falls, the uppermost historic natural barrier. Tributaries of the Deschutes River were also evaluated; the Metolius River and tributaries, Crooked River below Bowman Dam, Ochoco Creek, Squaw Creek, and McKay Creek. The streams surveyed were a small subset of the potential areas that reintroduced salmon and steelhead trout may populate (MAP).

Data compilation

Habitat data from the agencies was assimilated at the reach level from stream survey reports and electronic data files. Additional handling and analysis of the USFS data was required to conform the attribute values to a format similar to ODFW values (Appendix IX). Digital USFS data were acquired from the USFS Data General Smart system, translated to dBase format, converted to metric values and processed through an ODFW dBase application. The dBase application derived quantitative values from qualitative descriptors and compiled unit-level data to reach-level data.

Three methods of estimating surface substrate were utilized by the USFS: Wohlman Pebble Counts, ocular dominant and subdominant classification, or ocular estimates of unit percentages. The preferred methodology was percent surface substrate due to the estimates application in the evaluation of various habitat types. Dominant and subdominant surface substrate observations were converted to numerical values but were limited to two of five substrate types described. Wohlman Pebble Counts were not incorporated into the database because the substrate is restricted to riffles habitat types and includes the area outside of the wetted channel resulting in an overestimate of finer substrate material (Dachtler and Burke, unpublished report 1998). The upper reaches of McKay Creek and all of Little McKay Creek did not have adequate substrate measures for all habitat unit types and consequently were not incorporated into the analysis. An "X" in HabRate results noted reaches that were lacking pertinent data.

In the USFS protocol, unsurveyed and dry reaches were not reported. Length and gradient values for unsurveyed reaches were obtained from summary reports and/or topographic maps. Because no data existed for these reaches, an evaluation was not conducted on dry reach or unsurveyed reaches. However, the length of these reaches was needed to apply HabRate in a GIS.

Reach level habitat values were a combination of total counts per reach, proportions (as a percentage) of the reach, and counts per 100 meters. The length of the reach was variable based on the source agency's methodology and the geomorphology of the reach. The reach level stream data was compiled in an MS Excel worksheet, titled HabData, that served as the basis for the evaluation. Additional stream data could be easily appended at any time. In essence, the scope of the evaluation can be expanded at any time.

There were four categories of habitat information: substrate, channel morphology, habitat, and large woody debris. Individual attributes within each category were listed in Table 3. All of the attributes were compiled in HabData, but not all were used in the analysis. All values were compiled in metric units.

Table 3. Averaged reach attributes compiled in HabData spreadsheet. Selective attributes were used in the evaluation.

Substrate	Channel Morphology	Habitat	Wood
% Fines	Reach length	Number of pools	Pieces of large woody debris (LWD)
% Gravel	Channel area	% Pools	Volume of LWD**
% Cobble	Gradient	Scour pool depth	Pieces of LWD / 100m
% Boulders	Wetted width	Depth of riffles	Volume of LWD / 100m**
Riffle % fines	Active channel width	Pools / km	Key pieces of LWD
Riffle % gravel	Large boulders*	Pools > 1m depth / km	Key pieces of LWD / 100m
Average % boulders per pool	Large boulders / 100m*	Channel width (bankfull) pools	Average (LWD) per pool
	% Open sky**	Pools / 100m	Average key pieces of LWD per pool
	Width to depth ratio	Residual pool depth	
		% Undercut***	
		Average % undercut per pool**	

*Excluding USFS data except Squaw Creek
** Excluding all USFS data
*** Excluding USFS data except Link Creek

Rating the Habitat

The rating process was structured in a linear sequence whereby the individual attributes were rated and then combined for a category rating, and lastly grouped for a reach level rating result. Each level of the results had an individual worksheet so that the results could be evaluated at any of the levels.

Attribute – Level Rating

The reach rating process evaluated habitat attributes that were collectively deemed important for survival (Table 4). Each habitat attribute was evaluated independently, except for cover and pool complexity. These were derived from the interdependent coupling of several habitat attributes and were then evaluated in a manner similar to the individual attributes (Table 5). The selected attributes were processed through the evaluation using a set of criteria values.

Table 4. Reach attributes used in rating of life stages of spring chinook salmon and steelhead trout. Attributes absent in a row were not applied to that life stage.

Spawning, Incubation, Emergence	Summer Rearing	Overwintering
% Fines	% Fines	% Fines
% Gravel		
% Cobble	% Cobble and Boulders	% Cobble and Boulders
% Pools	% Pools	% Pools
Residual Pool Depth		
	Pool Complexity (chinook only)	Pool Complexity
	Cover	Cover
Gradient	Gradient	Gradient
Temperature	Temperature	
Flow	Flow	Flow

Table 5. Interdependent reach attributes and their dependencies. (* Not applicable to USFS data)

Reach Variable	Dependent Characteristics
Pool Complexity	Average Scour Pool Depth per pool Average Large Woody Debris per pool Average % Undercut per pool Average % Boulders per pool
Cover	% Cobble and boulders % Undercut * Large Woody Debris / 100m Boulders > 0.5m diameter / 100m*

A literature review provided the values for the criteria and was primarily focused on the Eastern region of the Columbia River basin. A set of criteria was derived from literature-based habitat requirements (Appendices III - IV). The criteria values for each freshwater life history stage were derived primarily from field research and secondarily from laboratory analysis of habitat usability and relative survival (Appendices III - IV). For attributes that lacked supporting research, criteria values were established from Deschutes River basin reaches that were considered adequate by professional opinion. The criteria used varied by species and life history stage. The criteria values derived were adjusted to include basin-wide application in the Columbia River system and the wetter, more temperate and forested coastal region of Oregon.

Quantifiable criteria ranges were developed to classify the stream attributes as poor, fair, or good for survival and potential use. The range of measured and opinion-based criteria values were assembled and reviewed for the most objective delineation of poor, fair, or good conditions. Poor conditions resulted in mass mortality or detriment to the eggs or juveniles. Fair conditions were favorable to survival or adequate for juvenile use. Good conditions were optimum for survival and usability. Fair conditions were sufficient in most cases since a good rating, or optimum conditions, was a superior standard to distinguish habitat conditions.

The parameters of the evaluation were structured in HabRate for easy adjustments. The habitat rating formulas in the worksheet hyperlink to a criteria Input page. A criteria input table for each species and life stage allows the user the adjust the criteria ranges that automatically update the formulas and adjusts the resultant rating (Table 6). The evaluation has a greater geographic range of application through the adjustment and refinement of criteria values. The input page was not intended for use in a 'what if' scenario, which could lead to erroneous interpretations and results.

Several levels of rating results provided different scales of analyses. A conditional formula assigned a base rating at the attribute-level for each reach according to species and life stage. The conditional formula contained hyperlinks with HabData and the criteria input page. Each attribute was evaluated independently for each species, life history stage, and reach segment, thereby removing spatial and temporal dependence within the evaluation.

Categorical- Level Rating

The attribute-level ratings were combined into stream feature categories: substrate, hydrology, and morphology (Table 7). The rating procedure for the broader-context

Table 6. Sample of input page for spawning, egg survival, and emergence of steelhead trout. Unshaded values are adjustable. Remaining boxes and conditional formulas throughout the worksheet update automatically.

	Good	Fair	Poor
Fines (%)	≤ 10	10 to 20	> 20
Gravel (%)	≥ 30	15 to 30	≤ 15
Cobble (%)	≥ 20 to ≤ 40	≥ 10 to 20 AND 40 to ≤ 70	< 10 > 70
Pool Area (% pools)	≥ 40 to ≤ 60	≥ 20 to 40	< 20 and > 60
Residual Pool depth (m)	≥ 0.2		< 0.2
Gradient (%)	< 4		≥ 4

categories involved assigning a numerical value to the base rating (good = 3, fair = 2, and poor = 1), summing those values within each category and applying another conditional range of criteria that permitted various combinations of suitable habitat attributes while highlighting potentially detrimental ones (Appendices???).

Table 7. An example of the combined rating of chinook salmon spawning, incubation, and emergence life stage for a particular reach.

Stream Feature Categories	
Reach Variable	**Dependent Characteristics**
Substrate	Fines Gravel Cobble
Morphology	% Pools Residual pool depth Gradient
Hydrology	Temperature Flow

Reach - Level Rating Results

In the final rating process, each reach was assigned an overall rating by life history stage based on the minimum value from the stream feature categories (Table 8). The life stage rating result identified reaches that were potentially inadequate in quality and survival. The entire process is summarized in Figure 3. The overall rating was a numerical value on a scale of 1 to 3, with 3 being the best condition.

The overall rating was later applied to indices of smolt capacity. The smolt indices and capacity was beyond the scope of this paper.

Table 8. The overall reach rating

Reach – Level Rating	
Reach Rating	= Minimum value (Substrate, Morphology, and Hydrology)

The scaled range and minimum value rating methodology was preferred to mean values so as not to obscure potentially detrimental attributes. The purpose of the exercise was to evaluate habitat capacity and identify inadequate reaches for future restoration projects, and was not to review the overall conditions.

Not all reaches were intended to provide fair to good conditions for all life history stages. The results should be examined as a continuum within the stream system to evaluate the adequacy of the system to function for proper life history development.

Is this paper limited to definition of habitat quality? - Kim

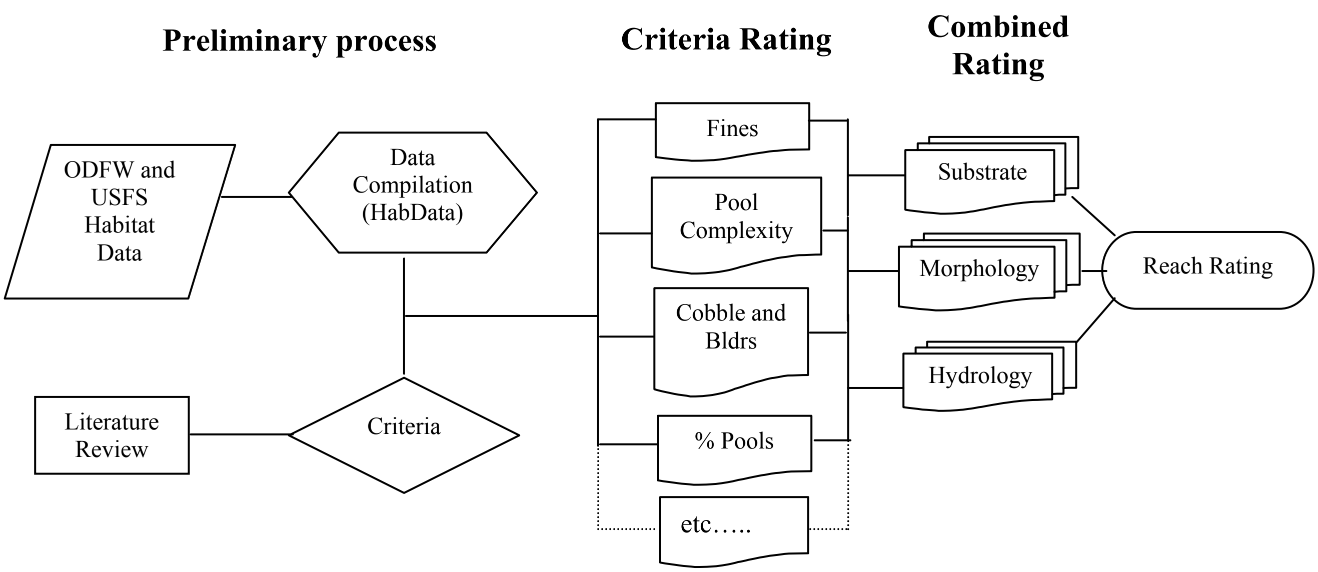


Figure 3. A flowchart depiction of habitat rating progression

All habitat surveys were conducted during summer flows, levels that are typically the lowest for this basin. In the evaluation of the winter habitat component of chinook salmon and steelhead trout, the criteria applied to *depth* in *pool complexity* evaluation was from winter flow studies but adjusted for application to summer flow values. A complete documentation of the data handling was provided in Appendices IX - X.

Temperature and flow conditions were included in the list of attributes. Due to the nature of the Deschutes River basin, winter temperature and discharge were not considered a limiting factor for early life history development. Very little data existed for summer temperatures and flows. Therefore, those variables were excluded from the evaluation although the formulas retained the variables in HabRate.

HabRate Limitations

Different modeling methods inherently possess different strengths and weaknesses. We compiled a list identifying HabRate's strengths and weaknesses in Table 2.

Table 2. Strengths and weaknesses of HabRate, a spatially explicit physical and biological model.

Strengths	Weaknesses
Quantitative and qualitative data	No spatial connectivity between reaches
Flexible scales	No empirical testing of results
Visual (GIS)	No multiplicative effects or interactions
Adjustable criteria	Static evaluation (discreet to life history stage)
Wide geographic range of application	Single species evaluation
Life history stage breakdown	Limited by the quality of data available
Simple - straightforward evaluation	Limited by the quantity of data available
Identifies bottleneck – limiting factors	
Spatial relationships	
Transparent evaluation process	

Rating Results

The rating results may be used to identify reaches in need of restoration after the appropriateness of that reach is assessed and the connectivity of the reaches are evaluated. A rating of fair (2) was considered sufficient. An reach rating of poor (1) for one life stage does not preclude that reach's importance at another life stage. Every reach should not be expected to receive a fair or good rating. Instead, the appropriateness of that reach to support each life stage should be an additional step in the analysis with consideration of the connectivity to the fair and good habitat.

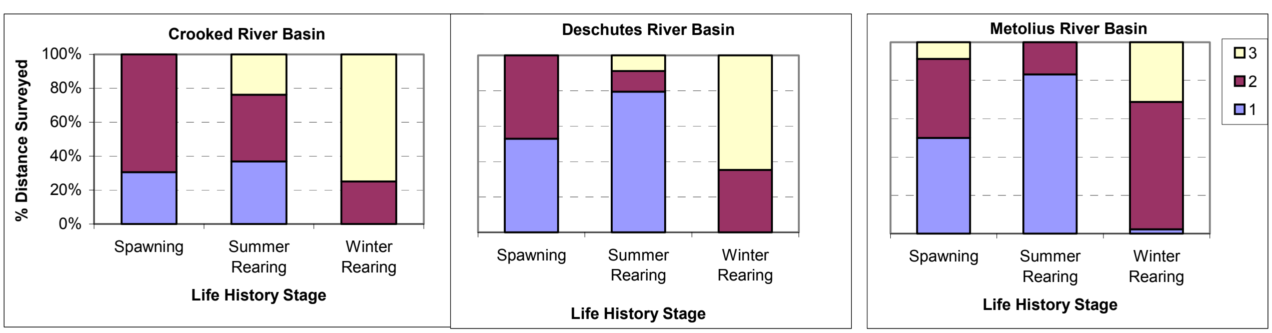
Methods

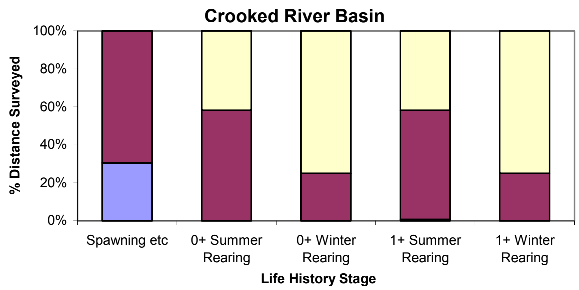
The Deschutes River habitat analysis results may be evaluated at a subbasin or stream level, and within the broad context of reach-level ratings or specific attribute-level results. The results can be applied only to those reaches for which habitat data was available. The rating results were summarized in MS Excel tables and graphs for a comparison of life stage conditions within the subbasin. The subbasin results were not summarized explicitly in HabRate, but were presented as an example of how one may use HabRate results.

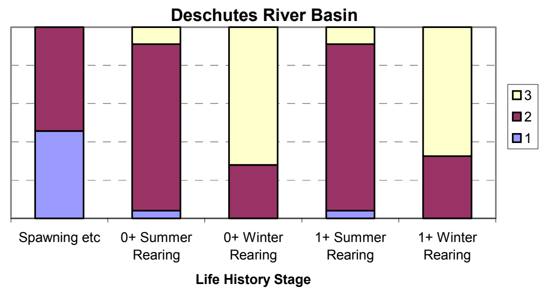
Subbasin Rating Results

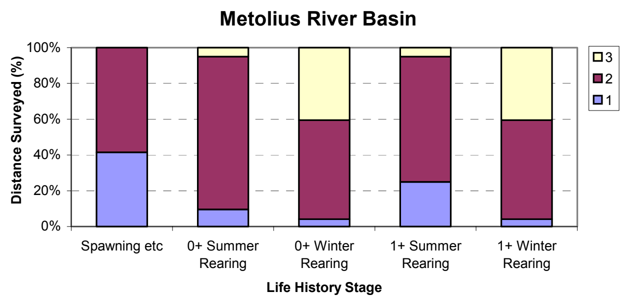
Within each individual basin (Crooked, Deschutes, and Metolius River) spawning and summer rearing habitat results were lower than overwintering habitat (Figure 4). In contrast, overwintering habitat was dominated by fair and good ratings. A finer level of analysis was needed to determine which attributes contributed to the ratings of concern. Therefore, the results were further scrutinized at the stream level for each basin.

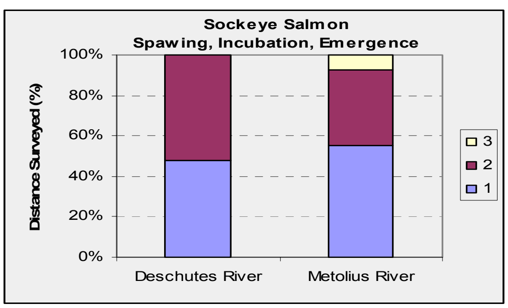
Figure 4. Chinook salmon results by subbasin.











No further investigation was needed for overwintering habitat. However, the first two early life stages were of concern and justified further scrutiny by life stage. The following evaluation highlights how HabRate can be used to discern specific stream attributes of concern.

Subbasin Rating Results for attribute-level and categorical level

Spawning, incubation, and emergence

Spawning, incubation, and emergence conditions for chinook and sockeye salmon and steelhead trout were consistently between poor to fair for all streams surveyed. Substrate was high in fines leading to the poor Substrate rating in each of the subbasins for all three species. Several reaches rated poor (3) in gravel coupled with a poor rating (3) for fines: Lake Creek reach 4 (chinook and sockeye salmon and steelhead), Deschutes River reach 2 (steelhead and chinook). The coupling of high level of fines and a low abundance of gravel will deter spawning and survival to the fry life stage. A situation as such should be reviewed to determine if those reaches were appropriate spawning areas, i.e. not dominated by rapids and cascades, and if restoration was an option.

Regions that were rated as good for spawning, incubation, and emergence were First Creek reach 2 (chinook salmon), Canyon Creek reach 1 (chinook and sockeye salmon), Link Creek reach 1 (sockeye salmon), and Metolius River reach 4 (sockeye salmon).

Age 0+ Summer Rearing

Rating results for 0+ chinook salmon and steelhead rearing varied by basin and species. The low percentage of pools in the Middle Deschutes River and Squaw Creek basin contributed to a less than fair rating for 0+ summer rearing chinook. Pole Creek and Reach 1 of Snow Creek, both tributaries to Squaw Creek, were high in fines and low in cobble and boulder, in addition to low percentage of pools. Interestingly, the reach below the Squaw Creek confluence with the Deschutes River was deem good, the highest rating possible. This would provide rearing habitat for juveniles that moved out of the Squaw Creek system.

Steelhead conditions in the Deschutes River system rated poor only for reach 1 of Pole Creek, where fines, cobble and boulders, and percent pools were limiting factors.

Summer rearing for chinook salmon rated less than fair in the Crooked River basin. Factors which contributed to the low rating were; the upper Crooked River (reaches 8 through 10) rated poor for 0+ summer rearing due to the lack of pools, and the middle reaches of McKay Creek had inadequate pool habitat coupled with an abundance of fines resulting in a poor rating. Summer rearing habitat for steelhead was above fair for the Crooked River basin.

In the Metolius River basin, all reaches that rated as poor for steelhead rearing conditions were high in fines, low in cobble, boulder, and percent pools. These reaches were Abbot Creek reach 2, Brush Creek reach 1, and Roaring Creek reach 1. Chinook rearing conditions rated low in the Metolius River system primarily due to the low percentage of pools for all reaches mentioned hereafter. Other attributes of concern were high percent fines and too low of cobble and boulders in all reaches of Abbott Creek, Jack Creek reach 2, Roaring Creek reach 1, and Brush Creek reaches 1 and 2. Percent fines were high (poor rating) in Middle Fork Lake Creek, North Fork Lake Creek, South Fork Lake Creek, and Lake Creek reach 4. Reach 1 of the Metolius River was low in percent gravel. Pool complexity was poor for Jack Creek reach 2, First Creek reach 3, and Abbott Creek reach 2.

Age 0+ Overwintering

Overwintering habitat for chinook age 0+ and steelhead trout (0+ and 1+) were midway between fair and good. All reaches below the Smith Rock Park footbridge on the Crooked River received a good (3) rating for overwintering habitat winter for both chinook salmon and steelhead trout. Two reaches received a poor rating for chinook 0+ overwintering habitat in the Metolius River basin. These reaches were Abbott Creek reach 2 and Roaring Creek reach 2. Attributes of concern were percent fines, percent cobble and boulder, and percent pools. Gradient and pool complexity were of additional concern for Abbott Creek reach 2.

Age 1+ Summer Rearing (Steelhead Trout)

The Metolius River basin was slightly below fair for steelhead at age 1+ summer rearing. The primary culprits were percent pools, percent fines, and percent cobble and boulders. Link Creek reach 1 had cover and percent cobble and boulders as limiting factors. In the Crooked River basin, McKay Creek reach 5 rated poor for percent fines and percent pools. In the Squaw Creek basin, reach 1 of Pole Creek and Roaring Creek were also limited by percent fines, percent cobble and boulders, and percent pools.

Table 10. Averaged reach results by subbasin.

Metolius River Basin	Spawning, incubation, and emergence	0+ Summer rearing	0+ Overwintering	1+ Summer rearing	1+ Overwintering
Chinook Salmon	1.4	1.2	2.1	--	--
Steelhead Trout	1.5	1.9	2.3	1.8	2.3
Sockeye Salmon	1.6	--	--	--	--
Mid-Deschutes and Squaw Creek Basin					
Chinook Salmon	1.5	1.2	2.6	--	--
Steelhead Trout	1.5	2.1	2.6	2.0	2.6
Sockeye Salmon	1.5	--	--	--	--
Crooked River Basin					
Chinook Salmon	1.5	1.8	2.5	--	--
Steelhead Trout	1.5	2.3	2.5	2.2	2.5
Sockeye Salmon	--	--	--	--	--

Discussion

Discuss other studies

This study provides a link between the habitat attributes, life history, and survival of salmon. Incorporating a life history approach and spatial analysis potential to describe the relationship between habitat and salmon adds an additional dimension to conventional analysis. The model provides a spatial context and display capability for restoration and recovery programs while retaining flexibility for application outside the Deschutes River basin.

A review of the Squaw Creek and lower Deschutes land use and potential impacts is recommended.

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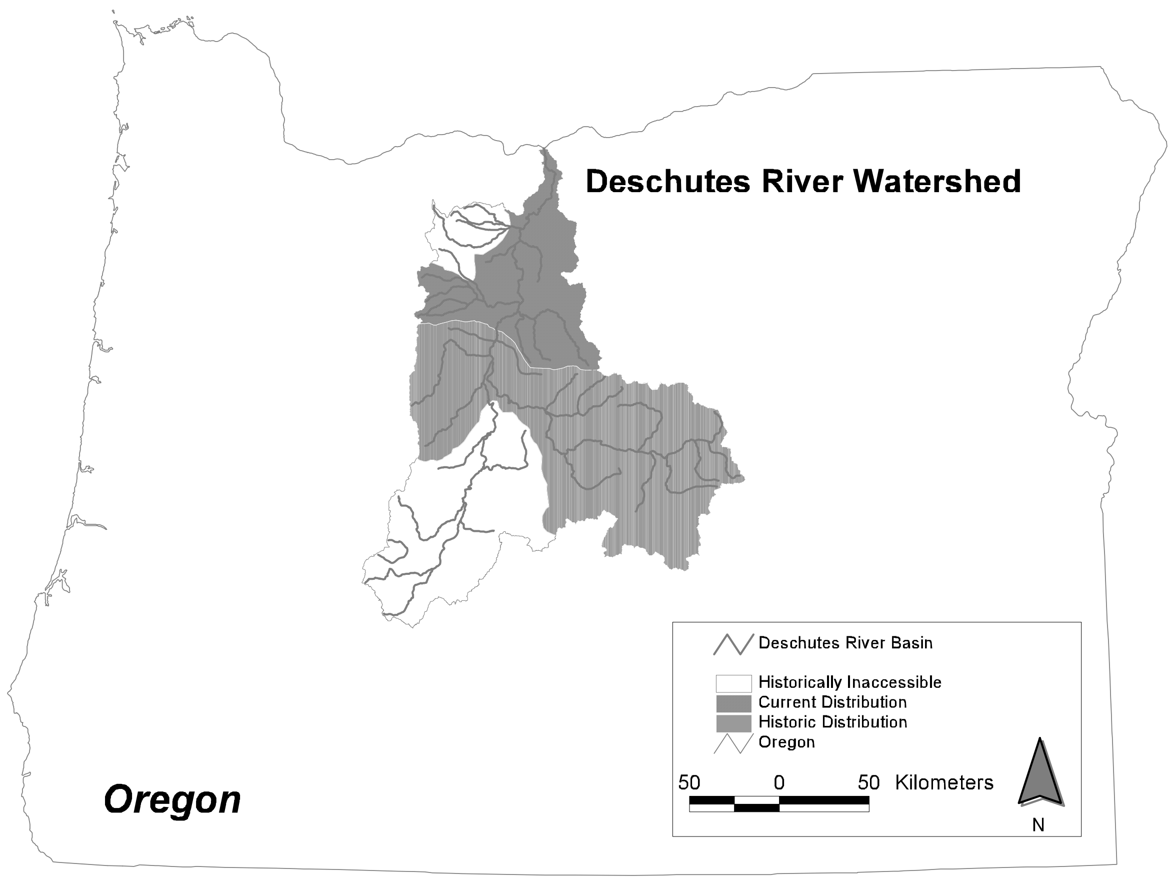
Appendix I. Historic range of anadromous salmonid in the Middle Deschutes River basin.



Appendix II. Life history timing of anadromous salmonids in the Middle Deschutes River basin.

	Life Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Chinook	Immigration						spring						
								summer					
	Spawning												
	Emergence												
	Outmigration				1+								
Steelhead	Immigration			*Pelton*				fall (summer)				*Pelton*	
					spring (winter)			*Pelton*					
	Spawning												
	Emergence												
	Outmigration					1+ and 2+							
							0+						
Sockeye	Immigration												
	Spawning									3 - 7 °C			
	Emergence												
	Outmigration					1+ and 2+							

Shaded boxes are the timing, darker shaded cells are peaks in abundance at Pelton Dam during evaluation period

Immigration is migration into the Deschutes River,

Outmigration is at Pelton Dam

Pelton signifies time at which passing the Pelton weir

Appendix III. Steelhead trout habitat requirements references

Spawning

Substrate	
< 5% fines in redd (*optimal*)	Raleigh 1986
Gravel/cobble *(1.5 - 10cm*) preference	
0.6 - 10.2 cm, criteria for spawning area	Hunter 1973 in Bjornn & Reiser 1979,1991
Favored 1.2 - 10 cm	Orcutt 1968
Pre spawning silt at 14.5% reduced to 7.5 post spawning	Everest et al. 1987
Salmonids can spawn in gravel w/ median diameter ≤ 10% of their body length.	Kondolf & Wolman 1993
0.64 - 7.62 cm [*probability of use*]	Huntington 1985
% Fines [*Spawning and rearing*]	Platt et al. 1983
5 < 5%	
4 5-25%	
3 25-50%	
2 50-75%	
1 >75%	
Habitat	
Pool tailouts	Greeley 1932 in Raleigh 1986
Depth (reflects pre-spawning conditions)	
≥ 0.24 m	Smith 1973
Shallowest = 0.21m	Orcutt 1968
Temperature	
10 - 15°C for spawning	Scott 1973
≥ 4°C for upstream migration	Hanel 1971 in Raleigh 1986
3.9 - 9.4 °C preferred for spawning	Bell 1986
7 - 12°C optimum for embryo development	Raleigh 1986
<4°C and >16°C is low survival (HSI) for embryo	
Flows	adapted from Binns & Eiserman 1979, Wesche 1980 in Raleigh 1986

Egg Survival

Substrate

< 5% fines = high O2 permeability McNeil & Ahnell 1968 in Bjornn & Reiser 1991,1979

> 15% fines = lower O2 permeability (*fines = 0.84mm*)

0 - 25% fines (>80% survival) (*fines <6.35mm)* Tappel and Bjornn 1983 in Bjornn & Reiser 1991

> 40% fines (~ 50% survival)

>30-40% fines (1-3mm) resulted in <50% survival [*lab*] Hall and Lantz 1968

Appendix III. (continued)

Emergence

Substrate

< 15 % fines (> 90% emergence) McCuddin 1977, Bjornn 1969 in Reiser & Bjornn 1979

>20-25% fines (<50% emergence) (*fines < 6.4 mm*) resulted in reduced survival + emergence

20% is harmful stage (<*6.4 mm*) Stowell et al. 1983 in Bjornn & Reiser 1991

inverse relationship with increased sand Phillips et al. 1975

> 20% fines (<50% fry emerge) McCuddin 1977 in Reiser & Bjornn 1979

0-17.5% sand (>80% emerged) Bjornn 1968

>50% sand (<50% emerged)

Summer Rearing 0+

Substrate

<10 % fines (*interstices and production)* Raleigh 1986

30% fines upper limit

RI's with boulders > 25cm preferred Hillman & Griffith 1987

Found over rubble substrate Everest & Chapman 1972

Closely assoc. with cover (*substrate and other*) Fausch 1993

Larger substrate than chinook of same length Chapman and Bjornn 1969

Depth

0.09 - 0.15m preference Sheppard & Johnson 1985

< 0.15m preference Everest & Chapman 1972

shallower than chinook of same length Chapman and Bjornn 1969

Pool Area

40 - 60% Raleigh 1986

Tendency towards 50% ratio with riffles Platts 1974

Cover

10 - 40 cm substrate in 10% of habitat area (*small juveniles*) Raleigh 1986

>15% cover including substrate (*adequate*)

<10% rating: 0 (worst) Binns & Eiserman 1979

10 to 25% 1 [*Trout habitat rating model*]

26 to 40 2

41 to 55% 3

>55 4 (best)

Habitat

all habitat types Platts & Partridge 1978

Pools margins, RB's Hillman & Griffith 1987

RI's, pools, abundant in BW, no preference Bisson et al. 1988

RI's with LWD, RB,CB Bisson et al. 1981

Pools, glides, and riffles Hicks 1990

Appendix III. (continued)

Temperature

0-25°C (*lower/upper limits*) Lagler 1956, McAfee 1966, Black 1953

optimal 12 - 18°C (*rainbow trout*) Raleigh 1986

10 - 13°C preferred, 0 - 23.9° (*lower/upper*) Bell 1986

0 to 23-25°C [*Salmonids*] Bjornn & Reiser 1991

Overwintering 0+

Substrate

10 - 40 cm substrate which is ≥ 10% of total habitat Raleigh 1986

Larger substrate shift in winter Sheppard and Johnson 1985

Rubble, primary cover Bustard 1975, cited in assoc. with rocks 10 - 25 cm in diameter Raleigh 1986

Cover

≥ 15% including substrate and other Wesche 1980 in Raleigh 1986

undercut banks and cover

Assoc. with rubble, will emigrate otherwise Bjornn 1971

Assoc. with cover - rubble primary source Bustard & Narver 1975

Assoc. with out of channel cover and submerged cover Bjornn & Reiser 1991

moved to pools and forest canopy in winter (*from clear cuts*) Johnson et al 1986

winter cover is important, correlated with substrate Chapman and Bjornn 1969

Habitat

pools Bustard & Narver 1975

low velocity, any habitat with rubble

lower velocity habitat Sheppard & Johnson 1985
deep pools and abundant cover Johnson et al. 1986

Summer Rearing 1+

Substrate
<10 % fines in riffle (*interstices and production*) Raleigh 1986
found over larger rubble substrate (>*40 cm*) Everest & Chapman 1972
occupy larger substrate as they grow Sheppard & Johnson 1985

Habitat
Riffles (*runs areas*) Raleigh1986
found in all habitat types Platts & Partridge 1983 in Platts et al. 1989
prefer LP and PP, found in all Bisson et al. 1988
avoided RI, GL, DP, and SC
higher velocity and deeper water
prefer LP,PP,TP w/ undercut banks and LWD Bisson et al. 1981
found in RB and CB

Appendix III. (continued)

Depth

0.6 - 0.75m preferred (I+) Everest & Chapman 1972

deeper than 0+ Bisson et al. 1988

Cover

≥ 15% (*substrate and other*) Raleigh 1986

associated with cover Fausch 1993

assoc. with cover Bisson et al. 1988

assoc. with cover undercut banks and LWD Bisson et al. 1981

Overwintering 1+ and Outmigration

Substrate

enter substrate - boulders and under logs Bustard & Narver 1975

10 - 40 cm substrate which is ≥ 10% of total habitat, silt-free Raleigh 1986

Class 1 pools Lewis 1969 in Raleigh 1986

Rubble (*15-45cm diameter*) substrate [*trough*] Bjornn 1971

Rubble or undercut banks [*nature*]

Depth

> 45cm Bustard & Narver 1975

> 45 cm (*otherwise, lower densities*) Everest & Chapman 1972

0.6 - 0.75 m preferred (I+)

Cover

prefer > 40cm boulders Everest & Chapman 1972

≥ 15% (*substrate and other*) Raleigh 1986

highest density associated with pool depth, Bjornn and Steward, unpublished

undercut banks, large rock and brush in Bjornn & Reiser 1991

as strong affinity to large rock as PD,UB and LR combined

moved to pools and forest canopy in winter (*from clear cut*) Johnson et al 1986

Deep pools with LWD in streams (w/o >40cm rubble), Bustard & Narver 1975

and rubble in rivers

Appendix III. (continued)

Pool Complexity

Hartman 1965, Lister and Genoe 1970, Everest and Chapman 1972, Edmundson et al 1968 in Raleigh 1986.

Platts 1974

Platts and Partridge 1983

Ratin g	Length or Width	Depth	Cover
1	> ACW	≥0.61 m	abundant
	< ACW	≥ 0.91m	absent
2	>ACW	≥0.61 m	Abundant
	>ACW	≥0.61 m	Intermediate
	>ACW	≥0.61 m	absent
3	= ACW	≥0.61 m	Abundant
	= ACW	≥0.61 m	intermediate
4	= ACW	~ equal to average stream depth	absent
	<ACW	~ equal to average stream depth	abundant
		~ equal to average stream depth	intermediate
		≥0.61 m	Intermediate
		≥0.61 m	abundant
5	< ACW	~ equal to average stream depth	absent

Source: Platts 1974: Pool quality rating
Cover: woody debris, boulders, vegetation (in channel or overhanging), and undercut banks.

Rating	Diameter	Depth	Cover
5	> average stream width	> 0.92m	Absent
		> 0.6m	Abundant
4	> average stream width	< 0.6m	absent
		0.6 to 0.91m	Absent
3	< average stream width	> 0.6m	Intermediate to abundant
2	< average stream width	< 0.6m	Intermediate to abundant
1	< average stream width	< 0.6m	absent

Source: Platts and Partridge 1983: Pool classification

Appendix III. (continued)

Rating	Width	Depth	Cover
First class	≤ 5.0m	≥ 1.5m	30%
	> 5.0m	> 2.0m	
Second class	Moderate	Moderate	5 – 30%
Third class	Small	Shallow	< 5%

Source: Raleigh 1986: Pool classification

Appendix IV. Chinook salmon habitat requirements references

Spawning

Substrate

Gravel = 3 - 15 cm [*measured in redd*] Chambers 1956 in Raleigh, 1986

15 cm is upper useable limit

Gravel = 62% [*measured in redd*]

Cobble = 38% [*measured in redd*]

1.3 - 3.8 cm (80%) and up to 10.2 cm (20%) [*salmon spawning channel recommendation*] Bell 1986

2 to 10 cm preferred [*spawning channel study*] Lucas 1959 in Reiser & Bjornn 1979

6% fines [*measured in the redd, Columbia spring chinook*] Burner 1951 in Raleigh 1986

59 - 86 % gravel

8 - 35% rubble

7.6 - 25.4 cm preference [*area prior to spawning*, *Deschutes chinook*] Huntington 1985

10 cm size limit Lotspeich & Everest 1981

Salmonids can spawn in gravel w/ median diam ≤ 10% of their body length. Kondolf & Wolman 1993

Avg. dg=24.4 mm, 12.9 % fines reduced to 8.3% Chambers et al 1954,1955 in Kondolf & Wolman 1993

Reduced fines,<1mm, from 30% to 7.2% [*during redd construction*] Everest et al. 1987

12 to 26% optimum level of fine sediments in spawning areas

Depth (reflect pre-spawning conditions)

≥ 0.18m (Willamette, n=270) Sams and Pearson 1963 in Reiser & Bjornn 1979

≥ 0.24m Thompson and Fortune 1968

≥ 0.2m Briggs 1953 in Raleigh 1986

≥ 0.24m spring chinook (Oregon, n=158) Thompson 1972 in Reiser & Bjornn 1979

≥ 0.24m Smith 1973

≥ 0.2m at optimum densities Divinin 1952 in Raleigh 1986

Temp

4.4 - 18 °C preferred for spawning Mattson 1948, Burner 1951 in Raleigh 1986

low survival (egg + fry) if temp ≥ 16°C Seymour 1956 in Raleigh 1986

no embryo survival at 0°C initially

>2 ≤ 3.5 weeks at ≥ 4.5 °C but ≤ 12.8 °C

10-12 °C favorable range for spawning Bell 1986

≥ 15 °C may be lethal for embryo Eddy 1972 in Raleigh 1986

Flow Raleigh 1986

Habitat

Pool tailouts Vronskii 1972 in Raleigh 1986

Pool tailouts Sullivan et al. 1987

40-60% pools is optimum for spawning and rearing Raleigh 1986

Appendix IV. (continued)

Egg survival (incubation)

surface fines

≤ 5% silt (≤ 0.8 mm) is optimum
Raleigh 1986

≤ 5% sand (≤ 30.0 mm) is optimum

< 15% fines (<0.84 mm) is optimal, McNeil & Ahnell 1964 in Raleigh 1986

any greater = decreased survival

< 5% = high O2 permeability McNeil & Ahnell 1964 in Bjornn & Reiser 1991, 1979

> 15% = low O2 permeability (<0.84mm)

0 - 30% fines <6.35mm resulted in > 80% survival Tappel and Bjornn 1983 in Bjornn & Reiser 1991

20% fines <0.83 mm in diameter is upper limit Everest et al. 1987

Emergence

Surface fines

> 25 % fines (< 50% survival) Bjornn 1969 in Reiser & Bjornn 1979

< 15% (> 75% survival) (*≤ 6.4 mm*)

>30-40% sand resulted in nearly no emergence Bjornn 1968

20% is harmful stage (*≤ 0.8mm*) Stowell 1983 in Bjornn & Reiser 1991

utilize 2cm size substrate for cover Burger 1982 et al. in Raleigh 1986

20 - 25 % fines (> 75 % survival) (*≤ 6.4 mm*)

Summer Rearing 0+ (*Fry*)

Substrate Preference

< 10% fines (< *3mm*) in riffle runs
Raleigh 1986

> 30% fines, low probability of use as cover

10 - 40 cm substrate ≥ 15% of area is adequate cover with < 5% fines
Raleigh 1986

found over silt to 20cm diameter [*0+*] Everest & Chapman 1972

Habitat is marginal if fines ≥15% [*Pink salmon*] McNeil & Ahnell 1964 in Raleigh 1986

boulders > 25 cm in riffle runs Hillman & Griffith 1987

sand and gravel substrate

as growth occurs, larger substrate

>~40% fines resulting in embeddedness reduced fish locally (<1fish/m^2) Bjornn et al 1977 in Bjornn & Reiser 1991

Utilize 2 to 5cm diameter substrate Bjornn & Reiser 1991

Pool Area

40 - 60% pool area Raleigh 1986

Tendency towards less than 50% for higher densities Platts 1974

59% chinook found in area with <20% pools Platts and Partridge 1983

Appendix IV. (continued)

Habitat

prefer pools Platts 1978

90% used pools & glides Hillman & Griffith 1987

preferred pools Murray and Rosenau 1989

all pool habitat esp. alcoves, BW, DP except high gradient Jonasson et al. 1994-1997

Pools with LWD and willow margins Johnson et al.1992

prefer pools with > 10 cm depth Konopacky 1984 in Bjornn & Reiser 1991

Pools and eddies had greatest densities Everest & Chapman 1972

Temperature

12-14°C preferred Brett 1952 in Bjornn & Reiser 1991

12 - 18°C Raleigh 1986

slow growth ≥19.5°C, preferred 9.4 – 13.8°C Brett 1982

24°C for 1h not harmful Bjornn 1978 in Bjornn & Reiser 1991

0 to 23-25°C (*Salmonids upper and lower lethal limits*) Bjornn & Reiser 1991

Depth

Enough to cover them Bjornn & Reiser 1991

Shift to deeper water with growth Chapman & Bjornn 1969

Correlated with growth Everest & Chapman 1972

Gradient

rear in stream reach gradients < 4 - 5% Lunetta et al. 1997

densities peaked at 4% Platts 1974

Cover

Depth : ≥15cm Everest & Chapman 1972
20 % of all types
Raleigh 1986
> 15% of 10 - 40 cm sized substrate for cover
Raleigh 1986
Highest pool complexity had highest densities
Platts 1974
Prefer overhead bank cover (*provided 32% cover in trench*) to no cover
Brusven et al 1986
Undercut banks in addition to other cover

Overwintering 0+

Substrate
< 5% fines optimum, > 30 % tends to prevent use
Raleigh 1986
enter gravel or migrate
enter the substrate Everest & Chapman 1972
emigrate if lack of substrate cover in cobble/bldrs Hillman & Griffith 1987
sand-gravel to silt -cobble (*fry size dependent*)
will not migrate if suitable cobble present
Overwinter in the substrate Everest & Chapman 1972
Substrate is major source of cover
Raleigh 1986

Appendix IV. (continued)

Pool Complexity

≥ 20% area Class 1 & 2 pools (*preferred*)
Raleigh 1986

Habitat

Pools, glides and RI's, abundant in pools Jonasson et al. 1994-1997
assoc. with cover
Pools, glides and RI's Hillman & Griffith 1987
Assoc. with cover overhanging brush + banks Steward and Bjornn 1987 in
Reiser & Bjornn 1979
Assoc. with cover, prefer pools, found in all types Bjornn & Reiser 1991
LP and Glides
rear in stream reach gradients < 4 - 5% Lunetta et al. 1997

Cover

> 15% cover including 10 -40 cm sized substrate, silt free
Raleigh 1986
Prefer overhead bank cover (*provided 32% cover in trench*)
Brusven et al 1986
Undercut banks with riparian overhanging Hillman & Griffith 1987

Temperature

12-14°C preferred Brett 1952 in Bjornn & Reiser 1991
12 - 18°C Raleigh 1986
0°C minimum Bjornn & Reiser 1991; Raleigh 1986
≤ 4°C resulting in hiding in substrate Chapman & Bjornn 1969

Spring 1+ Rearing and Outmigration

Substrate

Occupy larger substrate with growth Hillman & Griffith 1987
prefer rubble Everest and Chapman 1972

Depth	
≥ 0.6m	Everest and Chapman 1972
40-58cm	Steward & Bjornn 1987 in Bjornn & Reiser 1991
<61 cm	Stuehrenberg 1975 in Bjornn & Reiser 1991
55 - 60 cm	Konopacky 1984 in Bjornn & Reiser 1991
Cover	
1+ assoc. with cover in pools in winter	Steward & Bjornn, unpublished in
vegetation and undercut banks	Bjornn & Reiser 1991
Pool Complexity	*Same as steelhead*

Appendix V. Sockeye salmon habitat requirements references

Spawning, egg survival, emergence

Substrate

salmonids can spawn in gravel w/ median diam ≤ 10% Kondolf 1993
of their body length.
< 5% fines in redd McNeil & Ahnell 1964 in Bjornn & Reiser 1991
> 15% lower O2 permeability
1.3-10.2cm Bell 1986
medium to small gravel with no silt Eiler 1992
<15% fines (<2mm) (PU) Lorenze 1989
Typically spawning where there is upwelling, so substrate
is highly variable
20% is harmful stage Stowell 1983; Bjornn & Reiser 1991

Habitat

Areas of upwelling or subsurface flow preferred Lister et al 1980, Wilson 1984, Vining
for spawning et al 1985 in Bjornn & Reiser 1991
small streams of lakes, gravel shores with upwelling Meehan and Bjornn 1991
or tributaries of lake outlet
Lake shore or tributary Groot 1991
riffle areas preferred
Concentrate in areas of upwelling

Depth
enough to cover the fish (minimum) Groot 1991
≥ 0.15m [*estimated*] Bjornn & Reiser 1979, 1991

Temperature
10.6 - 12.2°C preferred Bell 1986

4.4 - 13.3°C for incubation
15.5°C moralities ensue Seeley & McCammon 1966
5.5-12.8°C preferred for spawning

Summer Rearing 0+ and migration to lake

Cover

use undercut banks, overhanging vegetation, and gravel Hartman 1962
Use gravel or above gravel when not migrating [*trough*]
McDonald 1960

Habitat

0+ rear in lakes, rivers, estuaries, and ocean Groot 1991
0+ rear in lakes, rivers, estuaries and ocean Meechan & Bjornn 1991
usually in lakes

Temperature

11.1 - 14.4°C preferred Bell 1986
12 - 14°C preferred,3.1 - 25.8°C (limits) Brett 1952 in Bjornn & Reiser 1991
0 to 23-25°C (salmonids) Bjornn & Reiser 1991

Appendix VI. Chinook salmon habitat criteria.

Spawning, Egg Survival, and Emergence

prior to redd construction

	Good	Fair	Poor
Substrate			
Fines (< 2mm)	≤ 10 %	10 - 20 %	>20 %
Gravel (2 – 64mm)	≥ 30 %	15 - 30 %	<15 %
Cobble (64-256mm)	20 - 40 %	10-20,40-70 %	< 10 %, > 70 %
Habitat (Pool Tailouts)	40 - 60 % pools	20 - 40 %	< 20 % , > 60%
Residual Pool Depth	≥ 0.2m		dry
Gradient	< 4 %		≥ 4 %
Temperature	6 - 14°C	4 - 6°C, 14-16°C	< 4°C, > 16°C
Flow	50-100 % base flow	25-50% base flow	< 25 % base flow > annual base flow

* lethal levels extending longer than 1 hour in 24 hour period

Summer Rearing 0+

	Good	Fair	Poor
Substrate			
Fines *(interstices and productivity)*	≤ 10 %	10 - 30 %	> 30 %
Gravel *(cover)*	≥ 15 %	5 - 15 %	< 5 %
Cobble and Boulder *(cover)*	≥ 15 %	8 - 15 %	< 8 %
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Pool Complexity	3	2	1
Additional Cover (*at least one true*)			
% Undercut	≥ 15	10 –15	< 10
LWD / 100m	≥ 20	10 – 20	< 10
Boulders / 100m *(cobble and boulder from above)*	≥ 20	5 – 20	< 5
Habitat (Gradient)	Prefer pools, (≤ 4%)		> Rapids (> 4%)
Temperature	9.5 - 14°C	4 – 9.5° , > 14°C	Lethal levels* (24°C)
Flow	50 - 100 % base flow	25-50% base flow	< 25 % base flow

* lethal levels extending longer than 1 hour in 24 hour period

Appendix VI. Chinook salmon habitat criteria (continued).

Overwintering 0+

	Good	Fair	Poor
Substrate			
Fines *(interstices)*	≤ 10 %	10 - 30 %	> 30 %
Cobble and Boulder *(cover)*	≥ 15 %	8 - 15 %	< 8 %
Pool Complexity	3	2	1
Habitat (Gradient)	Pools, GL, RI assoc. with cover (< 4%)		≥ Rapids (≥ 4%)
Additional Cover (*at least one true*)			
% Undercut	≥ 15	10 –15	< 10
LWD / 100m	≥ 20	10 – 20	< 10
Boulders / 100m	≥ 20	5 – 20	< 5
Flow	100 - 50% base flow	25 -50% base flow	< 25 % base flow

Spring 1+ and Emigration

	Good	Fair	Poor
Substrate			
Fines *(interstices)*	≤ 10 %	10 - 30 %	> 30 %
Cobble and Boulder *(cover)*	≥ 20 %	10 - 20 %	< 10 %
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Pool Complexity	3	2	1
Additional Cover (*at least one true*)			
% Undercut	≥ 15	10 –15	< 10
LWD / 100m	≥ 20	10 – 20	< 10
Boulders / 100m	≥ 20	5 – 20	< 5
Habitat (Gradient)	Prefer Poor gradient (≤ 4%)		> Rapids (> 4%)
Temperature	9.5 - 14°C	4 – 9.5° , > 14°C	Lethal levels* (24°C)
Flow	100 - 50 % base flow	25-50% base flow	< 25 % base flow

* lethal levels extending longer than 1 hour in 24 hour period

Appendix VI. Chinook salmon habitat criteria (continued)

Pool Complexity

Good Deep with considerable cover *At least one condition true

Depth > 0.6 m (≤ 10m wetted width stream)

Depth > 1 m (> 10m wetted width stream)

Criteria Conditions:*

Keypieces of LWD > 0.6 or Pieces of LWD ≥ 2.0

Undercut bank > 20 %

Boulders in pools > 15 %

Fair Moderate depth and cover

Depth ≥ 0.6 m (≤ 10m wetted width stream)

Depth ≥ 0.6 – 1.0 m (> 10m wetted width stream)

Criteria Conditions:*

LWD present

Undercut banks = 5 - 20 %

Boulders = 8 - 15 %

Poor Shallow and lacking cover

Depth < 0.6 m (≤ 10m wetted width stream)

Depth < 0.6 m (> 10m wetted width stream)

Criteria Conditions:*

No LWD

Undercut banks < 5 %

Boulders < 8 %

Appendix VII. Steelhead trout habitat criteria.

Spawning, egg survival, emergence
prior to redd construction

	Good	Fair	Poor
Substrate			
Fines	≤ 10 %	10 - 20 %	> 20%
Gravel	≥ 30 %	15 - 30 %	< 15 %
Cobble	10 - 30 %	30 - 60 %	< 10 %, > 60 %
Habitat (Pool Tailouts)	40 - 60 %	20 - 40 %	< 20 % , > 60%
Residual Pool Depth	≥ 0.2 m		No Pools
Temperature	6 - 12.5°C	4- 6°C, 12.5-16°C	< 4°C, > 16°C
Flows	100 - 50 % base flow	25-50% base flow	< 25 % base flow > annual base flow

Summer Rearing 0+

	Good	Fair	Poor
Substrate			
Fines *(interstices and productivity)*	≤ 10 %	10 - 30 %	> 30%
Cobble and Bldr *(cover)*	≥ 20 %	10 - 20 %	< 10 %
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Additional Cover (*at least one true*)			
% Undercut	≥ 15	10 –15	< 10
LWD / 100m	≥ 20	10 – 20	< 10
Boulders / 100m	≥ 20	5 – 20	< 5
Temperature	10 - 13°C	< 10, >13°C	Lethal levels* (24°C)
Flows	100 - 50 % base flow	25-50% base flow	< 25 % base flow

* lethal levels extending longer than 1 hour in 24 hour period

Appendix VII. Steelhead trout habitat criteria (continued)

Overwintering 0+

	Good	Fair	Poor
Substrate Fines *(interstices)* Cobble and Bldr *(cover)*	 ≤ 10 % ≥ 20 %	 10 - 30 % 10 -20%	 > 30% < 10%
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Additional Cover (*at least one true*) % Undercut LWD / 100m Boulders / 100m	 ≥ 15 ≥ 20 ≥ 20	 10 –15 10 – 20 5 – 20	 < 10 < 10 < 5
Pool Complexity	3	2	1
Habitat (Gradient)	Pools & RI with cover (< 4%)	all else (≥ 4 %)	
Flows	100 - 50 % base flow	25-50% base flow	< 25 % base flow

* lethal levels extending longer than 1 hour in 24 hour period

Summer Rearing 1+

	Good	Fair	Poor
Substrate Fines *(interstices & productivity)* Cobble and Boulder *(cover)*	 ≤ 10 % ≥ 20 %	 10 - 30 % 10 - 20 %	 > 30% < 10%
Depth (*in riffles*)	≥ 0.45 m		< 0.45 m
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Additional Cover (*at least one true*) % Undercut LWD / 100m Boulders / 100m	 ≥ 15 ≥ 20 ≥ 20	 10 –15 10 – 20 5 – 20	 < 10 < 10 < 5
Temperature	10 - 13°C	< 10, >13°C	Lethal levels* (24°C)
Flows	100- 50 % base flow	25-50% base flow	< 25 % base flow

* lethal levels extending longer than 1 hour in 24 hour period

Appendix VII. Steelhead trout habitat criteria (continued)

Overwintering 1+ and Emigration

	Good	*Fair*	*Poor*
Substrate			
Fines *(interstices)*	≤ 10 %	10 - 30 %	> 30%
Cobble and Boulder*(cover)*	≥ 25 %	10 - 25%	< 10%
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Additional Cover (*at least one true*)			
% Undercut	≥ 20	10 – 20	< 10
LWD / 100m	≥ 20	10 – 20	< 10
Boulders / 100m	≥ 20	5 – 20	< 5
Pool Complexity	3	2	1
Temperature	10 - 13°C	< 10, >13°C	Lethal levels* (0°C)
Smoltification	> 4°C, < 13°C		> 13°C
Flows	100 - 50 % base flow	25-50% base flow	< 25 % base flow

* lethal levels extending longer than 1 hour in 24 hour period

Pool complexity - refer to chinook criteria Appendix III, page 12.

Appendix VIII. Sockeye salmon habitat criteria.

Spawning, egg survival, fry emergence
prior to redd construction

	Good	Fair	Poor
Substrate			
Fines	≤ 10 %	10 - 30 %	> 30%
Gravel	≥ 30 %	15 - 30 %	< 15 %
Cobble	10 - 40 %	40 - 60 %	< 10 %, > 60 %
Habitat (gradient)	lakeshore or trib with upwelling		high gradient
Residual Pool Depth	≥ 0.15m		≤ 0.15m
Temperature	4.4 - 13.3 °C	< 4.4°C, > 13.3°C	< 1°C, > 20°C
Flows	100 - 50 % base flow	25-50% base flow	< 25 % base flow, > annual base flow

* lethal levels extending longer than 1 hour in 24 hour period

Summer Rearing 0+ including migration to lake habitat

	Good	Fair	Poor
Depth			no passage
Cover - undercut banks	≥ 30%	10 - 30%	≤ 10%
Habitat	Lakes		
Temperature	12 - 14°C	< 12, >14°C	Lethal levels* (25°C)
Flows	100 - 50 % base flow	25-50% base flow	< 25 % base flow, > annual base flow

* lethal levels extending longer than 1 hour in 24 hour period

Appendix IX. Data documentation.

Documentation of formulas	
Fines	independent
Gravel	dependent on condition of *Fines*
Cobble (Cbl)	dependent on condition of *Fines*
Boulders (Bldr)	dependent on condition of *Fines*
Residual Pool Depth	independent
Depth	Average depth of *riffles*
Gradient	independent
Temperature	independent
Flow	independent
% Pools	independent
Cover	dependent on *Cbl + Bldr*, *Undercut Banks*, *LWD/km*, and *Bldrs/100m*
	for USFS data, large *Bldrs/100m* and *undercut banks* are not applicable
Pool Complexity	dependent on *scour pool depth, LWD* or *Keypieces of LWD*, *Undercut* banks, and *% Boulders* in pools only.

Appendix X. Example of habitat attribute values manipulation

Metrics
USFS data was converted from feet to meters

Gradient
USFS % gradient is measured from a topographic map.
ODFW % gradient is measured in the field and calibrated

Substrate
USFS - no substrate data collected for culverts, falls, or side channels

Pools
ODFW glide habitat type was a considered fast water unit and not included in evaluation of pools
USFS pools > 3 ft deep = ODWF pools > 1m deep
USFS primary channel pool average max depth ~ ODFW scour pool average max depth
USFS pools per km includes secondary channels where measured.

Residual Pool Depth
ODFW residual pool depth pre-1997 surveys = unit pool depth - average riffle depth
ODFW residual pool depth 1997+ surveys = unit pool depth - unit depth at pool tail crest
USFS residual pool depth calculated =average (pool depth - depth at pool tail crest)

Large Woody Debris
USFS Large LWD~ ODFW key pieces
USFS wood per 100m calculated using primary channel length.

Width to Depth Ratio
USFS width: depth ratio is BFW/BFD
ODFW pre-1998 w:d ratio is average (riffles wetted width: depth ratio)
ODFW 1998+ w:d ratio is average (ACW/ACH)

Pool Complexity
LWD in pools is taken from scour pools (ODFW) and primary channel pools (USFS).

Stream-specific limitations
USFS riffle data includes all runs with the exception of Squaw Creek and Link Creek.
McKay Creek and Little McKay Creek lack habitat-unit substrate data.

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