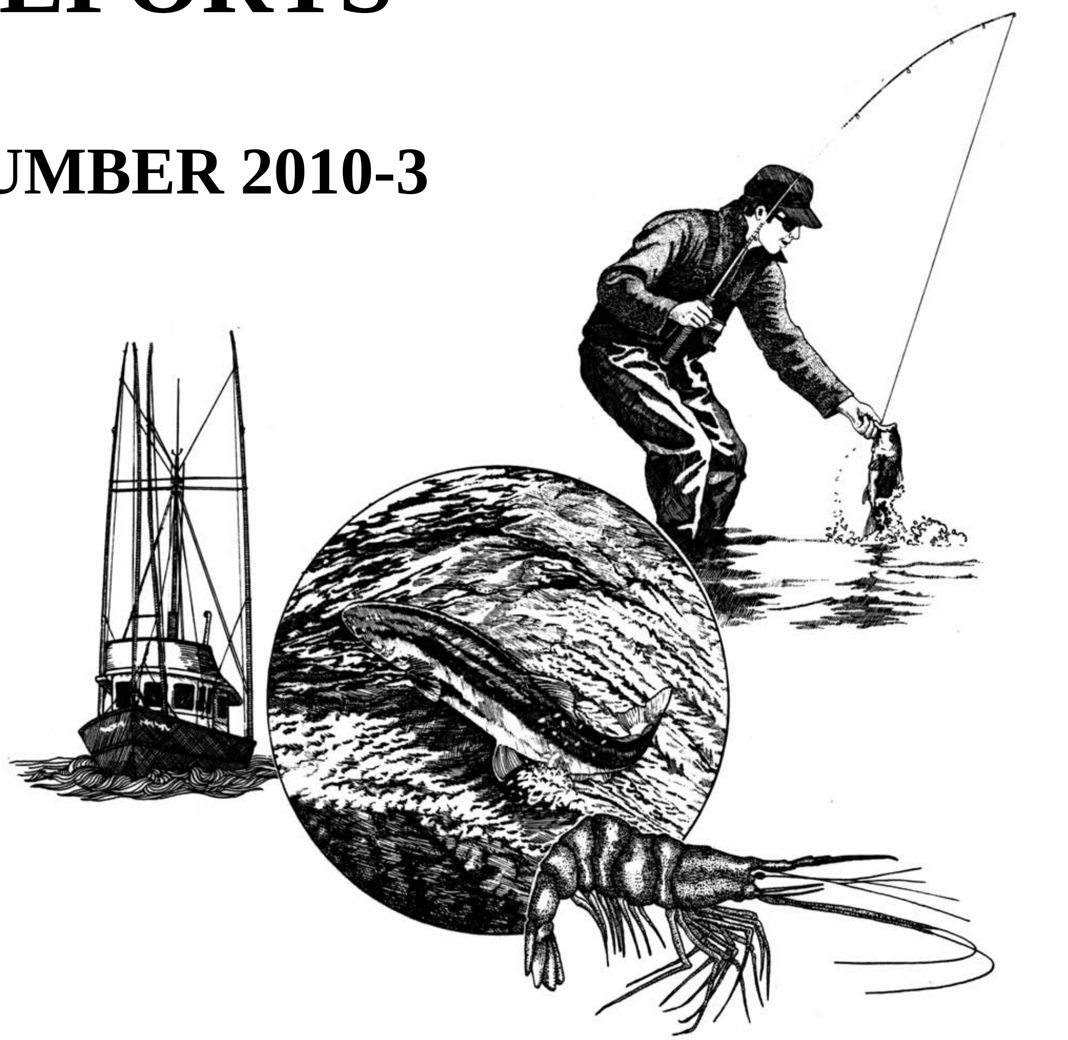
INFORMATION REPORTS

NUMBER 2010-3



FISH DIVISION

Oregon Department of Fish and Wildlife

HabRate: A Limiting Factors Model for Assessing Stream Habitat Quality for Salmon and Steelhead in the Deschutes River Basin

HabRate: A Limiting Factors Model for Assessing Stream Habitat Quality for Salmon and Steelhead in the Deschutes River Basin

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Citation: Burke, J. L, K. K. Jones, and J. M. Dambacher. 2010. HabRate: A Limiting Factors Model for Assessing Stream Habitat Quality for Salmon and Steelhead in the Deschutes River Basin. Information Report 2010-03, Oregon Department of Fish and Wildlife, Corvallis.

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ABSTRACT

Fishery managers are commonly tasked with the basic question "Will the contemporary habitat above a barrier support the fish populations that historically resided in the watershed?" Managers in central Oregon were confronted with that question in an effort to reestablish fish populations in 375 kilometers of stream above the Round Butte-Pelton Dam complex (Rkm 161) on the Deschutes River. Stream surveys had been conducted in most of the available stream habitat, but had not been synthesized in a form that allowed managers to view the quality and complexity of stream habitat in an easily-understandable fashion. In response, we developed a limiting factors model (HabRate) that assessed the potential quality of stream habitat using stream survey data for each juvenile life stage of salmon and steelhead. The model was developed for a specific application to the middle Deschutes River basin in Oregon, but was intended for general application to Pacific Northwest basins. To paramatize the model, we summarized available literature on salmonid habitat requirements. Habitat criteria were developed for discrete life history stages (i.e. spawning, egg survival, emergence, summer rearing, and winter rearing) and used to rate the quality of stream 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 data were entered into MS Excel, and interpreted by a series of algorithms to provide a limiting factor assessment of potential egg-to-fry and fry-to-parr survival for each reach. Model output lists habitat quality by species and life stage for each reach of stream. The model is a decision making tool that is intended to provide a qualitative assessment of the habitat potential of stream reaches within a basin context. Design criteria for the model were simplicity, flexibility, and transparency. While HabRate was based on our interpretations of the published literature, specific criteria for habitat quality were structured to be easily adjusted where interpretations differ from ours. Information not common to standard stream survey designs, such as seasonal flow or temperature extremes can be included as input from professional judgment. The results were integrated into a GIS coverage coupled with the stream network and habitat data to provide a comprehensive map-based perspective of habitat quality in a watershed.

INTRODUCTION

The Deschutes River basin, located on the east flank of the north Oregon Cascades, formerly supported anadromous salmon and steelhead trout populations throughout the middle and upper reaches and tributaries. Salmon and trout populations first declined coincident with the degradation of river conditions and fish harvest pressure in the late 1800s. Deschutes River salmon and trout were subject to intense fishery harvest from the terminal fisheries on the lower Columbia River, and streams were dammed for irrigation withdrawal which blocked access to spawning and rearing habitat. Further habitat degradation resulted from the early transport of logs and associated activities along the Deschutes waterways. Construction of dams on the mainstem and tributary systems further restricted or reduced access to spawning and rearing areas. The construction of two small dams on Blue and Suttle lakes for recreational swimming extirpated the sockeye salmon populations in the lakes and in the Metolius River. The Crooked River basin, comprising two-thirds of the Deschutes River basin accessible to anadromous fish, was rendered inaccessible after the construction of Ochoco Dam in 1921 and Bowman Dam in 1961. Bonneville and Dalles dams on the mainstem Columbia River downstream of the Deschutes confluence, constructed in 1938 and 1960 respectively, decreased survival of outmigrant juveniles (Lichatowich et al. 1996). The final blow to anadromous fish in the Deschutes basin was the construction of the Pelton-Round Butte hydropower dam complex at RM 161 on the mainstem Deschutes River in 1958. Initial attempts to facilitate trout and salmon passage over the dams with fish ladders failed, leading to the removal of the ladder in 1968, a year marking the extinction of middle and upper Deschutes River salmon and trout populations (Nehlsen 1995).

In 1996, Portland General Electric (PGE) initiated the process to re-license the Pelton-Round Butte hydropower complex to continue operation in accordance with the Federal Energy Regulatory Commission guidelines (FERC). The application process required a plan for Protection, Mitigation and Enhancement Measures of environmental resources, particularly cultural resources and threatened and endangered species impacted by the complex. To comply with the license application guidelines, PGE committed to the reintroduction and establishment of Chinook and sockeye salmon and steelhead trout populations above the Pelton - Round Butte complex (Figure 1).

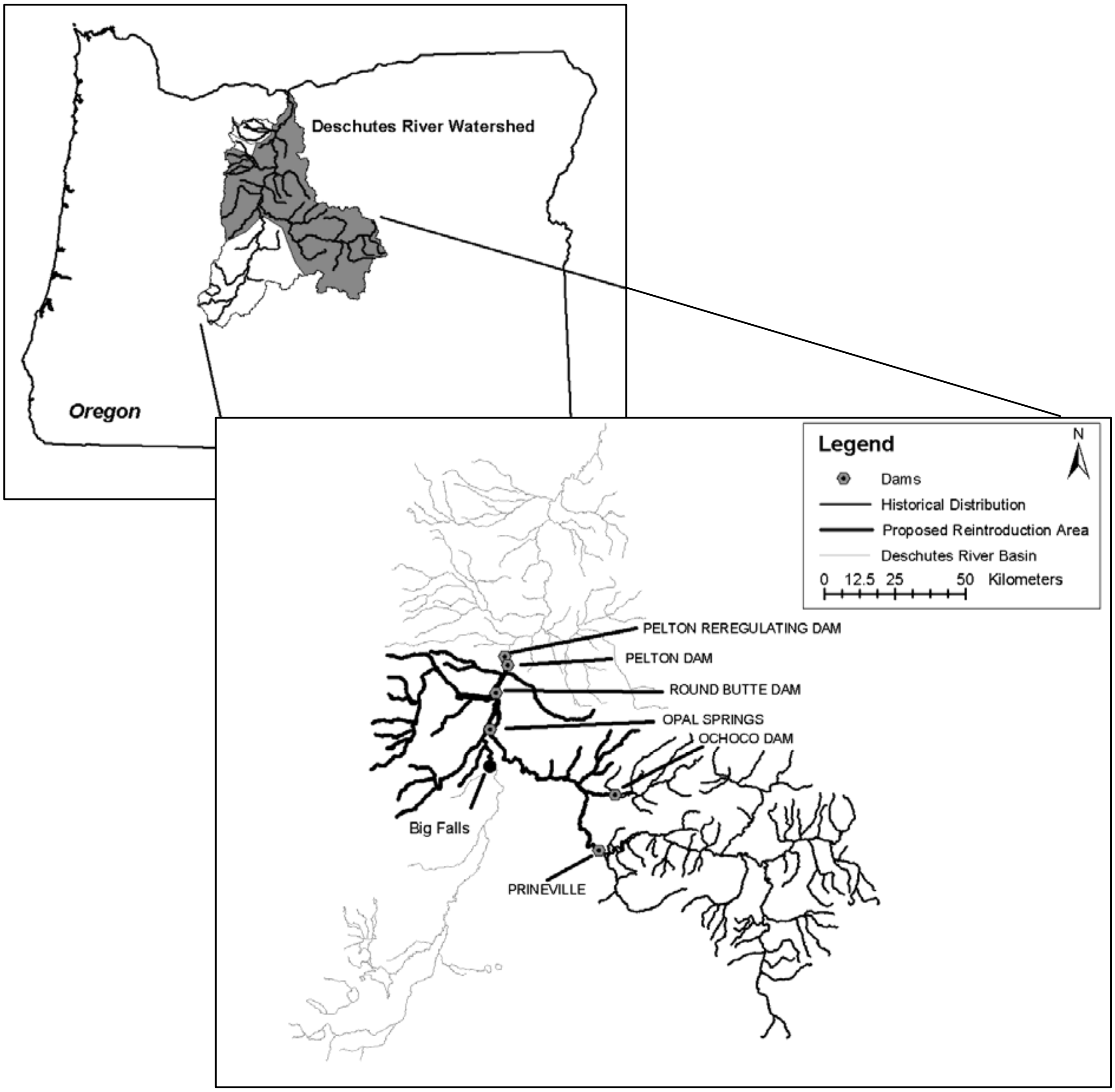

Figure 1. Historic distribution (thin dark lines) and proposed reintroduction areas (thick dark lines) of anadromous fish in the mid- and upper Deschutes River basin. Significant passage barriers are labeled and depicted by filled circles.

The reintroduction area covered a portion of the historic range of anadromous salmonids within the Crooked River, and all of the historic range within the Deschutes and Metolius Rivers (Figure 1). A feasibility study reviewed a number of biological and physical factors that may prevent the reestablishment of salmonids above the Round Butte-Pelton complex (Oosterhout 1999). One critical need was an evaluation of the suitability of aquatic habitat in each subbasin for each species and life stage of Chinook and sockeye salmon, and steelhead trout. The goal of the evaluation was to determine the likelihood that current aquatic conditions could support self-sustaining populations of anadromous salmonids, and if not, how and where restoration should occur. Our challenge, therefore, was to develop a comprehensive and spatially explicit view of aquatic habitat conditions relevant to salmonid life history requirements for the three species.

In light of the decline of salmon populations in the Northwest and elsewhere, fish biologists have attempted to quantify the relationship of salmon life history and ecology with measurable attributes of aquatic habitat to predict productivity and survival. The ecological responses to physical conditions occurs at multiple scales, from micro to landscape scale (e.g. Vannote 1980; Hicks et al. 1991; Rahel and Hubert 1991; Nelson et al. 1992; Murray and Bailey 1998.

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). 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. The coho salmon study was expanded to predict the viability of coho populations in three coastal basins in Oregon (Nickelson and Lawson 1998). However, a spatial or network component was not incorporated into the model.

Incorporating a life history approach to the relationship between habitat and biological response at a scale from channel habitat unit to river network adds another dimension to the interpretation (Lichatowich et al. 1995). The overall quality, connectivity, and relationships among habitats are crucial to the successful completion of a fish's life cycle. Modeling the survival of fish through the life cycle requires integrating spatial and temporal information. Kocik and Ferreri's (1998a) 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. 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 watershed. A life history perspective has the advantage of incorporating spatial structure and connectivity of the habitat with the survival of fish at each life stage.

However, 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 (R^2 < 30%) when applied elsewhere without recalibration. Limiting factor models are applied with the implicit assumption that included variables are of general importance. Where the status of a 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 (Hankin and Reeves 1988), significant effort has been dedicated toward basin-wide assessments of stream habitat. Specifically in Oregon, an extensive stream survey program by the Oregon

Department of Fish and Wildlife (ODFW), Aquatic Inventories Project (AIP), has inventories of over 16,000 km of streams statewide (http://oregonstate.edu/dept/ODFW/freshwater/inventory/basinwid.html). The challenge remains to interpret an increasingly large volume of stream survey data in a way that is meaningful for basin-wide management of salmonid populations. While AIP stream survey data has been used to describe bull trout *Salvelinus confluentus* rearing areas (Dambacher and Jones 1994), and predict carrying capacity of juvenile coho salmon (Nickelson and Lawson 1998, Jones and Moore 1999), applications for other salmonid species have yet to be developed or researched. We sought therefore to derive meaningful criteria from existing literature of spawning and rearing habitat conditions based on life history studies for steelhead trout, 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); however, our design is generally applicable to Pacific Northwest systems.

The model is a habitat rating system (HabRate) of aquatic conditions designed to link salmon with their environment and to provide a foundation for reach and watershed scale restoration programs. The conceptual basis for our modeling approach was to 1) capitalize on the wealth of existing field survey data (specifically basin survey data from ODFW), 2) describe habitat attributes at multiple scales, 3) be spatially explicit, 4) describe connectivity within a drainage, and, 5) build transparency and ease-of-use in the model to allow the user to adjust parameters and logic statements. HabRate describes habitat quality relative to each life stage of a salmonid species rather than numerically predict the carrying capacity of a habitat unit, reach, or stream. HabRate permits integration of survey and landscape data into a GIS format to display aquatic habitat within a watershed context and has incorporated flexibility of scale for comparisons between the reach, river, and basin level.

STUDY AREA

The Deschutes River basin lies adjacent to a major climate transition zone and within a geologically active landscape shaped by volcanism, tectonics, and glacial activity (Taylor and Hannan 1999). The Deschutes River system drains from the Eastern Cascade Mountain ecoregion in the west, the Blue Mountain ecoregion in the east, with the Northern Basin and Range ecoregion in the south and Columbia Plateau ecoregion in the north (Thorsen et al. 2003). The 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 more open and lower elevation (Thorsen et al 2003), but is also primarily of volcanic origin. The river basin in the Cascades and southern region of the Blue Mountain ecoregion (John Day/Clarno lowlands and uplands) are unique in that the river primarily flows through lava fields pocketed by prairies. The Eastern Cascade and Blue Mountain Ecoregions 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 (Taylor and Hannan 1999). These regions support temperate alpine forests and meadows. The Northern Basin and Range and Columbia Plateau are largely composed of basalt and ash-tuff that have been eroded over time. In the Deschutes River Valley of the Columbia Plateau, the rivers flow through imposing basaltic canyons and arid meadows. The southern Blue Mountain and

Deschutes-Columbia Plateau are cool desert and steppe lands that receive less than 15 inches per year of precipitation in the lower elevations (Thorsen et al 2003, Taylor and Hannan 1999). The unique nature of the geology and climate of the region maintains river flows throughout the year. River flow throughout the Blue Mountain and Deschutes-Columbia Plateau is maintained by recurrent, and sometimes large, cold springs originating from snowmelt and precipitation percolating through a vast network of permeable volcanic rock.

ANADROMOUS SALMONIDS IN DESCHUTES RIVER BASIN

Historical distribution

HabRate describes the quality of habitat in the streams that were historically occupied by each life history stage of spring and fall Chinook salmon, sockeye salmon, and summer steelhead trout in the Deschutes River above the Pelton-Round Butte complex. The historical extent of chinook salmon lacked full documentation, although we pieced together the probable location and timing of adult and juvenile migration in the middle Deschutes basin (Appendix A). It is believed that spring Chinook spawned throughout the basin and summer/fall Chinook run spawned in the mainstem Deschutes and lower Metolius River (Nehlsen 1995) Progeny of the adult Chinook salmon runs were comprised of subyearling (ocean-type) and yearling (stream-type) migrants based on timing of their migration past the Pelton-Round Butte site (Nehlsen 1995). The spawning distribution of steelhead was poorly documented in the upper Deschutes basin, although they were thought to spawn throughout the accessible portions of the basin. The steelhead juveniles typically remained in the Deschutes River basin for 1 to 2 years (King 1966, Nelsen 1995). Sockeye salmon were confined to the Metolius River drainage, with probable spawning areas in Lake Creek and rearing in Suttle Lake.

Three life stages of Chinook and sockeye salmon and steelhead trout were evaluated; 1) spawning, incubation and emergence, 2) summer rearing, and 3) winter rearing. Spawning, incubation, and emergence were combined into a single life stage in the evaluation due to the similar criteria values (Table 1). Migratory conditions for adult salmonids were considered optimal for temperature and river flow; therefore, adult life history attributes were not evaluated. However, temperature and flow information can be incorporated in the HabRate model if available.

Table 1. Early life histories evaluated in HabRate.

Life History	Chinook Salmon	Steelhead Trout	Sockeye Salmon
Spawning, incubation, and emergence	X	X	X
Subyearling (0+) summer rearing	X	X	X
Subyearling (0+) overwintering	X	X	X
Yearling (1+) summer rearing		X	
Yearling (1+) overwintering		X	

METHODOLGY

Literature review and habitat criteria

We performed an extensive literature review and compiled the habitat requirements of Chinook and sockeye salmon, and steelhead trout for each freshwater life history stage. Few juvenile salmonid life history studies were conducted in the Deschutes River basin. Consequently, the scope of the literature review for criteria values was expanded to included Alaska, Idaho, and the eastern regions of Oregon and Washington as necessary. We preferentially selected research from field studies over research in a laboratory setting. We evaluated three life history stages for chinook salmon. Spawning and 0+ summer rearing (limited duration) evaluation applied to both ocean-type and stream-type juveniles, while 0+ overwintering applied only to yearling (stream-type) juveniles. Five life stages of steelhead trout were evaluated that accounted for 1 to 2 years of freshwater rearing. Sockeye salmon had an abbreviated life history evaluation in HabRate, limited to spawning areas in streams with access to the expanded rearing potential in lakes.

The literature review is summarized by species: Chinook salmon (Appendix B), Steelhead trout (Appendix C), and sockeye salmon (Appendix D). Similarly, from these sources, we developed habitat rating criteria for each species, presented in Appendices E, F, and G, representing our interpretation of the various values presented in the literature.

Spreadsheet Components

HabRate is organized by four worksheet components; 1) HabData, 2) Evaluation, 3)Reach Rating, and 4) Input criteria. The elements that comprise each of the worksheets are discussed in the following sections. The model is available at http://oregonstate.edu/dept/ODFW/freshwater/inventory/habratereg.htm.

Habitat Data

Most of the streams and rivers in the Metolius, Deschutes and Crooked Rivers above the Round Butte complex available to anadromous salmonids have been surveyed (Figure 2). The analysis incorporated stream survey data from the Oregon Department of Fish and Wildlife (ODFW), Aquatic Inventories Project (Moore et al. 1997, 2007). Stream survey design followed the census approach described by 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 census survey design to efficiently collect information on aquatic habitat attributes continuously in a consistent format 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 and continuous record of geomorphic reaches, habitat units, and associated features. It provided information on stream size, channel structure, large wood debris, sediment throughout the watershed, all features that influence the distribution and productivity of anadromous, fluvial, and resident fishes.

Habitat surveys in the middle Deschutes River basin began in 1989 by the USFS, and in 1993 by ODFW. Both agencies continued surveying in the basin through 1997, when HabRate was developed. Both agencies conducted the stream surveys during summer flow levels. Since 1997, ODFW has continued to survey streams, and these data have been incorporated into HabRate, replacing the older data as streams were resurveyed.

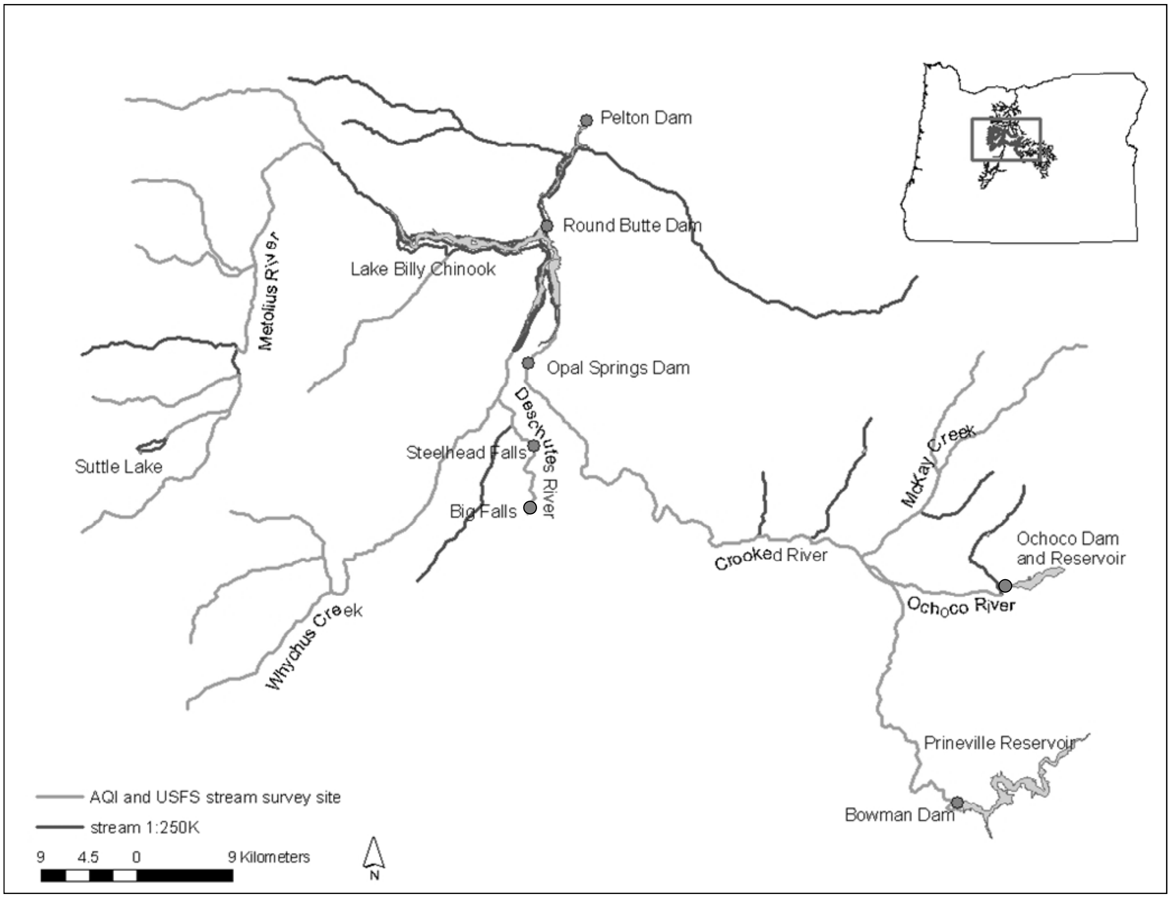

Figure 2. Survey reaches (light gray lines) in the reintroduction area of the mid- and upper Deschutes River basin.

Basin level stream surveys were completed in the Deschutes River from Lake Billy Chinook reservoir to Big Falls, the uppermost historic natural barrier. The Crooked River was surveyed from Lake Billy Chinook to Bowman Dam, and from the confluence with the Crooked River up Ochoco Creek to Ochoco Dam. Whychus Creek (Deschutes) and McKay Creek (Crooked) were also surveyed. In the Metolius watershed, the upper mainstem was surveyed as were most tributaries (Figure 2).

Reach level values consisted of total counts per reach, proportions (as a percentage) of the reach, averages, and counts per fixed length (100 meters or 1 km). The length of the reach was variable based on the geomorphology of the stream. The reach level values were compiled in MS Access and exported to a MS Excel worksheet, titled HabData on the worksheet tab, and served as the source data for the evaluation. The structure of HabRate is such that the scope of the evaluation is expandable at any time to include additional reaches or streams by adding in additional rows of data.

HabData included 4 classes of data: substrate, channel morphology, habitat unit features, and large woody debris. Individual attributes within each category are listed in Table 2. All of the attributes were compiled in HabData in metric units. Although not all attributes were used in the analysis, we retained them for reference. The habitat rating process evaluated stream habitat attributes collectively deemed important for productivity at each life stage (Table 3).

Table 2. Reach attributes (averaged values) included in HabData.

Substrate	Channel Morphology	Habitat	Wood
Percent fines	Reach length	Number of pools	Pieces of large woody debris (LWD)
Percent gravel	Channel area	Percent pools	Volume of LWD
Percent cobble	Gradient	Scour pool depth	Pieces of LWD per 100m
Percent boulders	Wetted width	Depth of riffles	Volume of LWD per 100m
Percent fines in riffles	Active channel width	Pools per km	Key pieces of LWD
Percent gravel in riffles	Large boulders	Pools greater than 1m depth per km	Key pieces of LWD per 100m
Average percent boulders per pool	Large boulders per 100m	Channel width (bankfull) pools	Average LWD per pool
	Percent Open sky	Number of Pools per 100m	Average key pieces of LWD per pool
	Width to depth ratio	Residual pool depth	
		Percent undercut	
		Average percent undercut per pool	

Rating Habitat

HabRate hierarchically rates and then evaluates the attributes at three levels (Figure 3, Table 3). At Level 1, a rating is generated for each individual attribute for each applicable life history of each species (Table 3). In Level 2, the rating summarized the attributes by category to represent the collective condition. In the final Level 3, the rating evaluates Level 2 rating values using a combination of individual and collective assessments. For instance, spawning, incubation, and emergence rating evaluates the substrate separately from the combined evaluation of pool area and residual pool depth ratings. The approach focuses the rating on conditions potentially inadequate in quality and survival, without compromising the value of equally important habitat features for an overall rating. The model retains each subcomponent for reference.

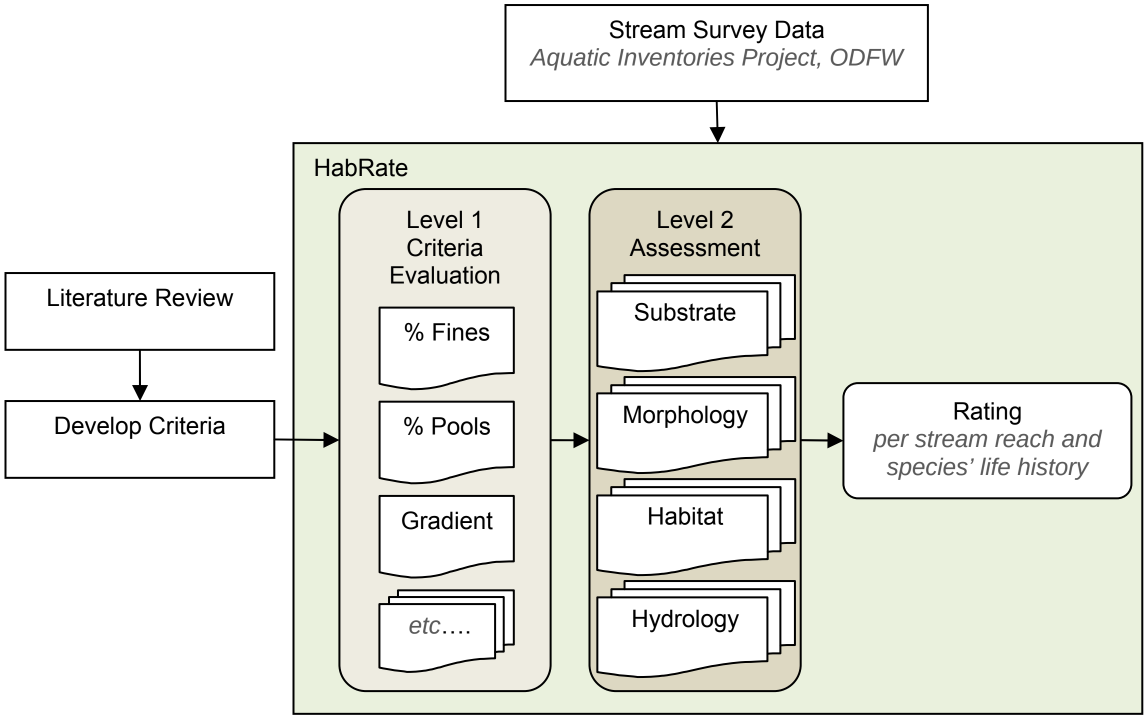

Figure 3. Schematic of the HabRate assessment process and its elements.

Table 3. Level 1 and 2 Reach attributes evaluated for Chinook and sockeye salmon and steelhead trout. *Excludes sockeye salmon. **Excludes steelhead trout.

Level 1			Level 2
Spawning, Incubation, Emergence	Percent fines		Substrate
	Percent gravel		
	Percent cobble		
	Pool area*		Morphology
	Residual pool depth		
	Gradient**		
Summer Rearing *(Chinook salmon and steelhead trout only)*	Percent fines		Substrate
	Percent gravel**		
	Percent cobble and boulders		
	Pool area		Pool area
	Average scour pool depth per pool**	Pool complexity**	Pool Complexity**
	Average large woody debris per pool**		
	Undercut		Cover
	Large woody debris per 100m		
	Large boulders per 100m		
	Gradient**		Gradient
Overwintering *(Chinook salmon and steelhead trout only)*	Percent fines		Interstices
	Percent cobble and boulders		
	Pool area		Pool habitat
	Average scour pool depth per pool**	Pool complexity**	
	Average large woody debris per pool**		
	Percent undercut		Cover
	Large woody debris per 100m		
	Large boulders per 100m		
	Gradient		Gradient
Summer rearing 1+ *(steelhead trout only)*	Percent fines		Interstices
	Percent cobble and boulders		
	Pool area		Pool Habitat
	Depth in fast water units		Hydrology
	Percent undercut		Cover
	Large woody debris per 100m		
	Large boulders per 100m		
Overwintering 1+ *(steelhead trout only)*	Percent fines		Interstices
	Percent cobble and boulders		
	Pool area		Pool Habitat
	Percent undercut		Cover
	Large woody debris per 100m		
	Large boulders per 100m		

Input Criteria

Each Level attribute is evaluated using a range of criteria and assigned a numerical value on a scale of 1 to 3, with 3 being the best condition. A rating of 1 equated to poor conditions (potential low survival) that are very detrimental to the eggs or juveniles. A rating of 2 reflected conditions favorable (fair) to survival or adequate for juvenile use. A rating of 3 indicated conditions were optimum for productivity or survival.

We constructed a criteria input table for each life history stage of each species that show the criteria and logic statements used to rate individual attributes for Level 1 (Table 4). The structure of the criteria input worksheet allows for easy adjustments of the critical values, denoted by white boxes, which link the criteria input worksheet to the HabData worksheet and rating worksheets. This permits the user to adjust the criteria ranges, if deemed necessary, which will automatically update the formulas and adjusts the resultant ratings in the subsequent rating worksheet. As structured, the rating process has a greater geographic range of application through the adjustment and refinement of criteria values according to ecological province. Please note the input page was not intended for use in a 'what if' scenario, which could lead to erroneous interpretations and results.

Table 4. Sample of input criteria section of worksheet for spawning, egg survival, and emergence of Chinook salmon. Non-shaded cells are adjustable and formulas throughout the worksheet update automatically through linked formulas.

	Criteria and Rating		
Attribute	**3**	**2**	**1**
Fines (%)	≤ 10	> 10 and ≤ 20	> 20
Gravel (%)	≥ 30	< 30 and > 15	≤ 15
Cobble (%)	≥ 20 and ≤ 40	< 20 and ≥ 10 > 40 and ≤ 70	< 10 or > 70
Pool Area (% pools)	≥ 40 and ≤ 60	< 40 and ≥ 20	< 20 or > 60
Residual Pool depth (m)	≥ 0.2		< 0.2
Gradient (%)	< 4		≥ 4

The scaled range (e.g. 1, 2, or 3) and minimum value rating methodology was preferred to mean values so as not to obscure potentially detrimental attributes, and to identify limiting factors in each reach. Because the rating process is adjustable and transparent, the analysis can identify individual attributes responsible for a low rating in a given reach for a species' life stage.

All habitat surveys were conducted during summer flows, levels that are typically the lowest for the Deschutes River basin. In the evaluation of the winter habitat component of chinook salmon and steelhead trout, the depth criteria was interpreted from winter flow studies. The summer data were extrapolated to represent base flow during winter conditions.

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 evaluating the effects of summer temperatures and flows on juvenile salmonids in the Deschutes River. Therefore, those variables were not included in the evaluation although the formulas in HabRate retained the variables for use in other basins where irrigation withdrawals or natural fluctuations in flow may create critical thresholds for flow or temperature.

Spatially-Explicit Output

HabRate is structured to link the components and the final output to a spatially-explicit GIS dataset to provide the rating results in a map-based view. The structure and model results integrate with a geospatial stream reach dataset using a unique identifier for each reach, i.e. LLID code and reach number (HABRCH). The habitat quality rating and habitat data for each reach, species, and life history can then be displayed in a Geographic Information System (GIS) on a digitized stream layer. Even though connectivity is not modeled between reaches, the map-based view of ratings and attributes permits additional analysis of the spatial connectivity and salmonid survival between reaches.

RESULTS

HabRate generated a rating of salmonid habitat quality and potential limiting factors in the Deschutes River basin for three species of salmonids and one to five life histories per species. While the focus was on the reintroduction area in the mid- and upper Deschutes basin, we also evaluated the streams in the lower Deschutes to provide a balance and perspective on conditions throughout the Deschutes basin. The average reach level rating per species and subbasin provide an initial assessment of average conditions of the surveyed reaches for each life history (Table 5). Ratings that are less than 2 were subbasins with substandard conditions for that particular life history. For example, Buckhollow Creek basin rated the lowest for spawning, incubation, and emergence for steelhead trout, while the remaining steelhead life histories rated predominately adequate to optimum. Here we will provide selected examples of how the model functions and selected examples of the output.

Figure 4 displays the cumulative counts of reach ratings (1, 2, or 3) for the spawning, incubation , and emergence life stage for chinook salmon in seven subbasins in the Deschutes River. For example the scores from 14 reaches in Bakeoven subbasin were summarized to display the frequency of scores for that life stage. Most of the habitat was good for spawning, incubation, and emergence. Table 6 provides an example of the level of detail that goes into each reach rating; in this case for the summer rearing of subyearling steelhead trout in the Metolius River subbasin. The survey variables were summarized at level 1, then combined by logic statements to level 2, and finally combined through logic statements to an overall rating for the reach for that life stage and species. The approach allows the rating to be dissected to their component indices or variables to gain a better understanding of the quality of habitat. In the same way, the component ratings, such as large wood or fine sediment, could be displayed in GIS to demonstrate areas of limited complexity or excessive sedimentation.

Table 5. Average HabRate ratings summarized by subbasins within the Deschutes River basin. Sockeye salmon spawn only in the Metolius.basin, and rear in Suttle Lake and Lake Billy Chinook, which were not evaluated in HabRate. A value of 1 = poor, 2 = fair, and 3 = good habitat quality.

Species	Spawn and Emergence	Summer Rearing	Overwintering	Summer Rearing 1+	Overwinter 1+
Bakeoven Creek					
Steelhead salmon	2.8	2.3	2.9	2.0	2.9
Chinook salmon	2.7	2.0	2.4	-	-
Sockeye salmon	-	-	-	-	-
Buckhollow Creek					
Steelhead salmon	1.3	2.3	2.5	1.8	2.5
Chinook salmon	2.3	2.0	2.2	-	
Sockeye salmon	-	-	-	-	-
Crooked River					
Steelhead salmon	1.7	2.2	2.2	1.9	2.6
Chinook salmon	1.9	1.6	2.0	-	
Sockeye salmon	-	-	-	-	-
Metolius River					
Steelhead salmon	1.7	2.2	2.2	1.9	2.6
Chinook salmon	1.7	1.6	2.0	-	
Sockeye salmon	2.0	-	-	-	-
Shitike Creek					
Steelhead salmon	1.5	2.4	2.1	1.8	2.3
Chinook salmon	1.5	1.8	2.0	-	
Sockeye salmon	-	-	-	-	-
Trout Creek					
Steelhead salmon	2.3	2.4	2.5	2.0	2.8
Chinook salmon	2.2	1.9	2.0	-	
Sockeye salmon	-	-	-	-	-
Upper Deschutes River					
Steelhead salmon	1.9	2.2	2.7	2.0	2.7
Chinook salmon	2.1	2.1	2.4	-	-
Sockeye salmon	-	-	-	-	-
Warm Springs River					
Steelhead salmon	1.8	2.6	2.4	2.0	2.7
Chinook salmon	2.0	1.8	2.0	-	-
Sockeye salmon	-	-	-	-	-

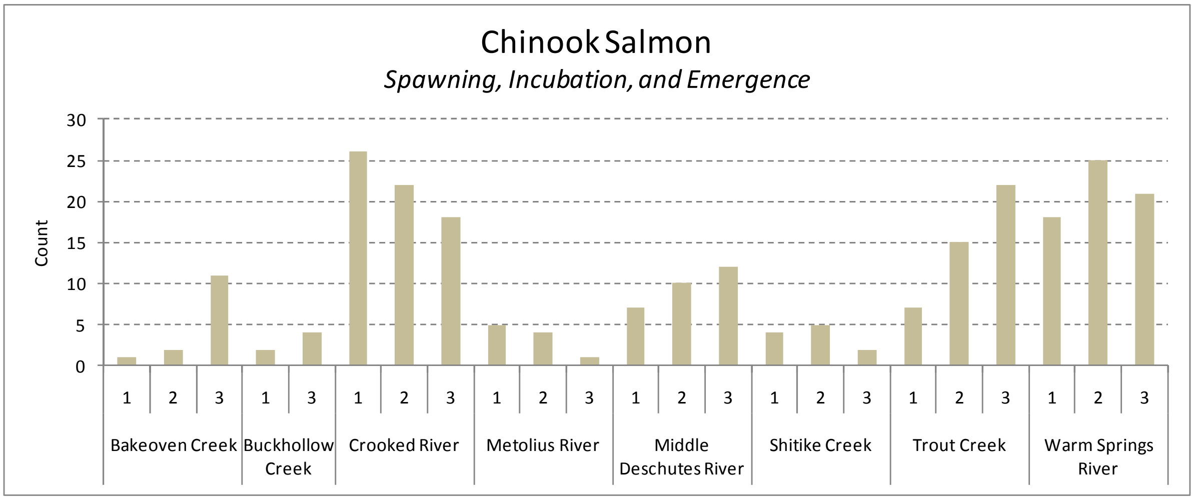

Figure 4. Cumulative summary of reach ratings in seven subbasins in the Deschutes River. Each reach was given a rating of 1, 2, or 3. The count represents the number of reaches of a given score in each subbasin. Larger subbasins usually had more reaches. A value of 1 = poor, 2 = fair, and 3 = good habitat quality.

Table 6. Sample of tiered results for Metolius River reaches evaluated for summer rearing life stage of subyearling steelhead trout. A value of 1 = poor, 2 = fair, and 3 = good habitat quality.

		Level 1					Level 2			Rating
				Cover						
Stream	Reach	Fines	Cobble and boulders	Undercut	Large woody debris per 100m	Boulders per 100m	Substrate	Pool Area	Cover	
Mariel Creek	1	2	2	2	3	1	2	1	2	2
Mariel Creek	2	3	3	1	2	3	3	1	2	2
Mariel Creek	3	1	2	1	1	1	2	1	1	2
Metolius River	1	2	3	3	1	1	3	2	2	3
Metolius River	2	2	2	3	1	1	2	1	2	2
Parker Creek	1	3	3	3	3	2	3	1	3	3
Parker Creek	2	3	3	1	1	3	3	1	2	2
Whitewater River	1	2	3	1	2	3	3	1	2	2
Whitewater River	2	1	3	1	3	3	2	1	3	2
Whitewater River	3	1	3	1	3	3	2	1	3	2

Spatial Display of Reach Level Ratings

Because the HabRate results are referenced to spatially-explicit hydrologic datasets, the results may be mapped at all levels. Reach level ratings provide the coarsest resolution to assess the spatial distribution of the HabRate evaluation (e.g. Figure 7). Individual metrics (e.g. complex pools, high quality spawning habitat) could also be mapped at a channel unit scale, on the order of tens of meters rather than kilometers. Figures 7, 8, and 9 display the distribution of habitat quality relative to spawning and emergence, summer rearing, and winter rearing, respectively. The variability in habitat quality is apparent within and between each subbasin. For example, the mainstem Crooked River has low quality habitat for spawning and emergence, and moderate quality for rearing through much of its length. However, McKay Creek, a tributary to the Crooked River has fair and good quality habitat for all life stages.

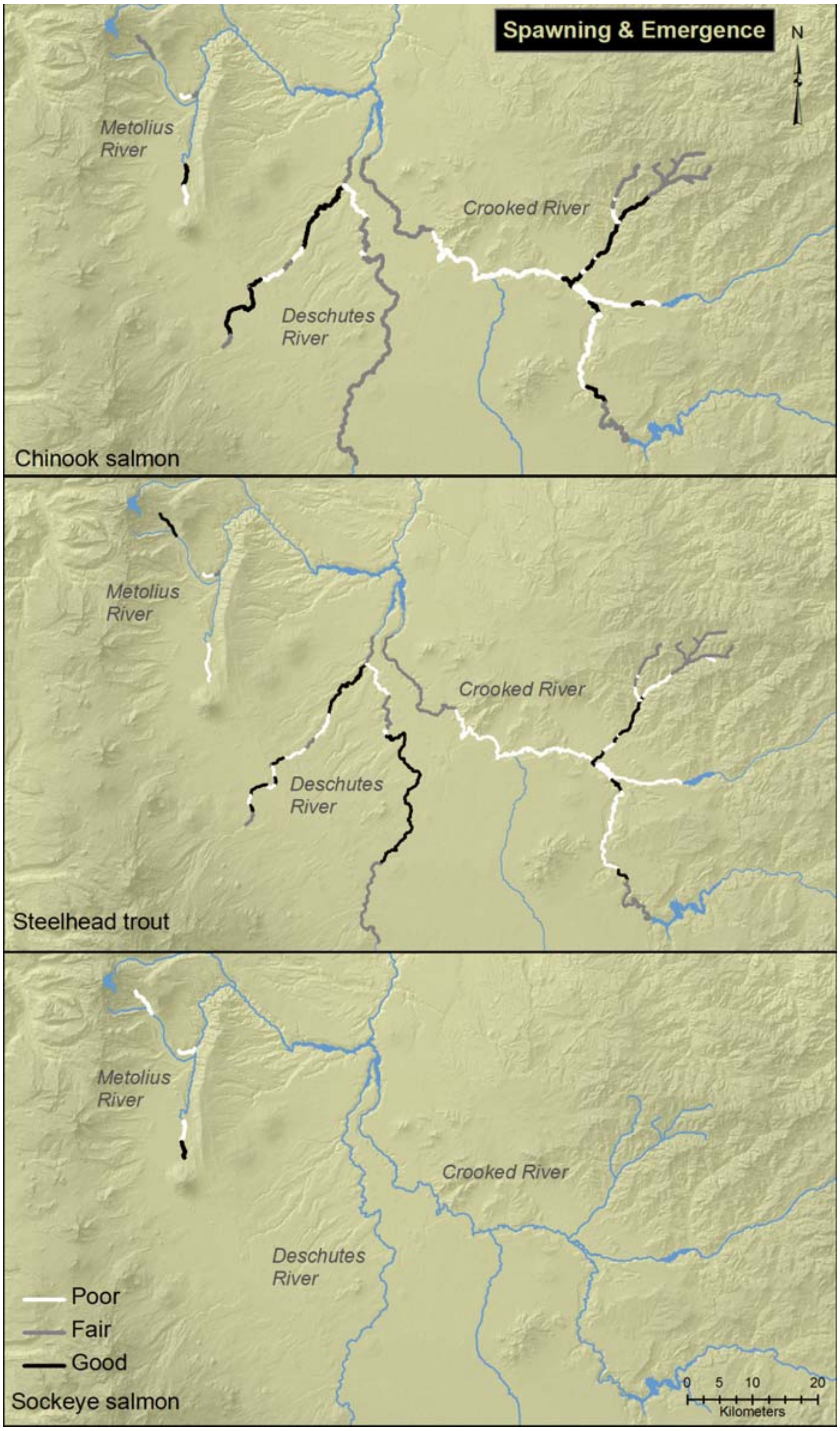

Figure 5. Reach level ratings of spawning, emergence and incubation habitat for steelhead, Chinook (top), steelhead (middle), and sockeye (bottom) in the Deschutes River basin above Lake Billy Chinook. Sockeye are only present in the Metolius drainage.

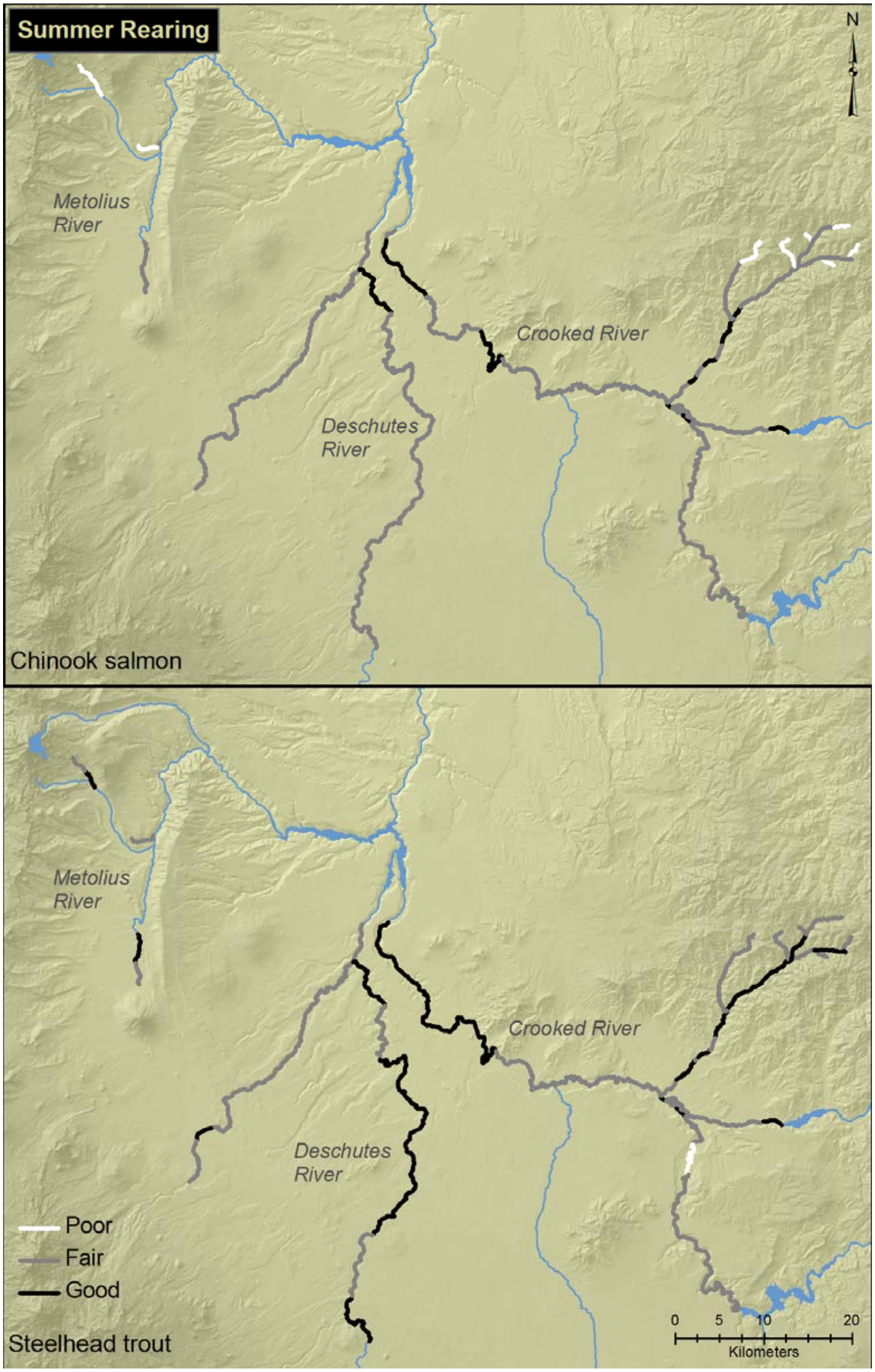

Figure 6. Reach level ratings of summer rearing habitat for chinook (top) and subyearling steelhead (bottom) in the Deschutes River basin above Lake Billy Chinook.

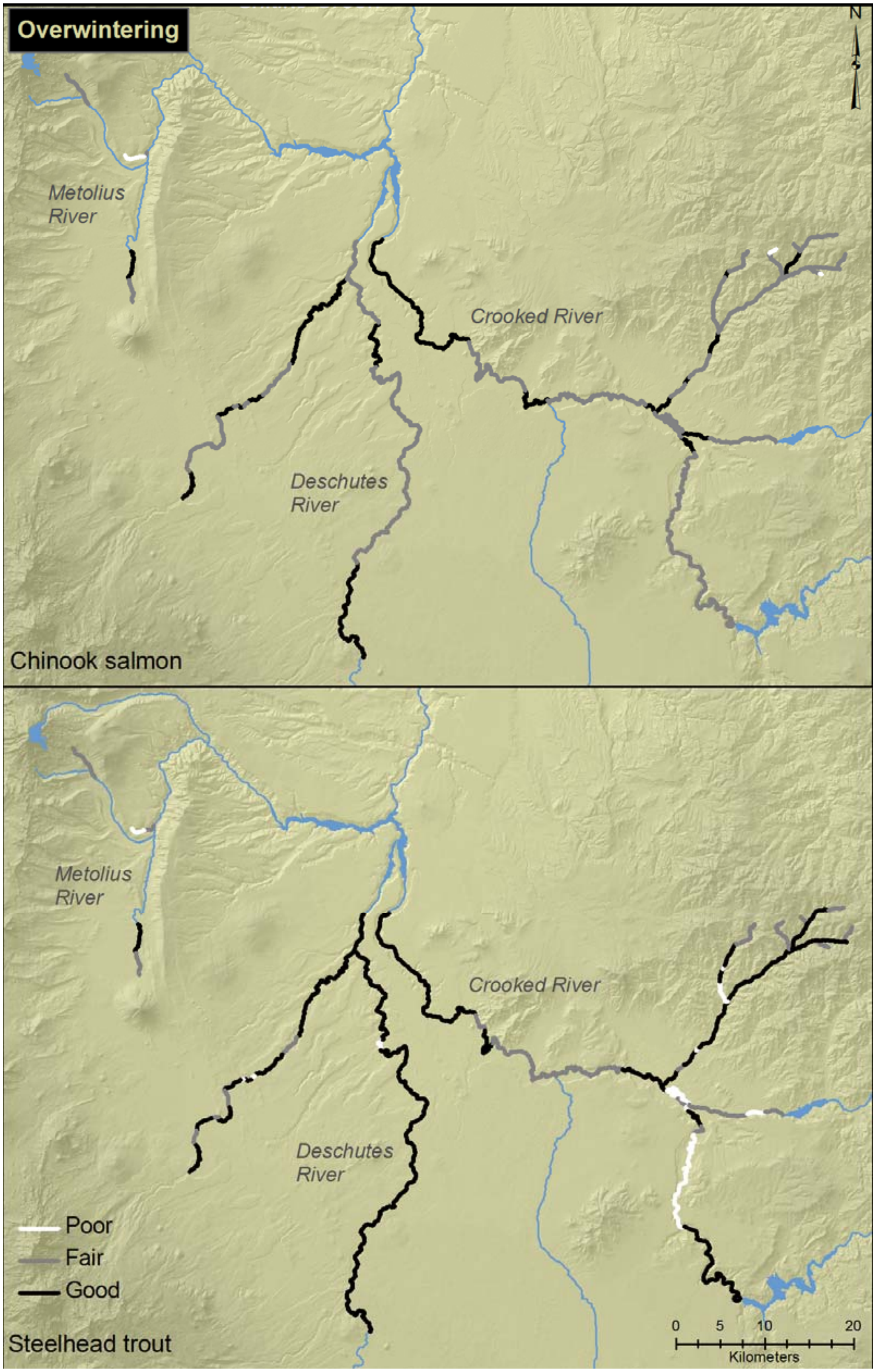

Figure 7. Reach level ratings of winter rearing habitat for chinook (top) steelhead (bottom) in the Deschutes River basin above Lake Billy Chinook.

DISCUSSION

HabRate, developed in 1997, is one of many models to evaluate suitability of salmonid habitat as part of conservation, restoration, and reintroduction efforts. Here we presented a model that permitted an examination of habitat features that influence productivity and capacity for different life history strategies and life stages of salmon and steelhead in the Deschutes basin. We built this model based on the availability of an extensive and spatial explicit data set of stream habitat conditions in the study area coupled with literature rich with information on habitat requirements of salmonids. Due to the limited availability of field-collected stream data in most areas, many salmonid habitat assessments employ best professional judgment in the rating procedure, often at the landscape-scale or watershed-scale using decision-supported logic models that may or may not included field-collected data. Examples include the widely used Ecosystem Diagnosis and Treatment (EDT) developed by Mobrand Biometrics Inc. (2003), and the Ecosystem Management Decision Support (EMDS) developed and used by Reynolds and Peets (2001) on the Chewaucan River basin in Southern Oregon. These habitat evaluation models are often not transparent or straightforward but are capable of complex assessments and analyses that may incorporate dozens of variables. This model, in contrast, was developed specifically to take advantage of the availability of documented field data, and to use literature-based relationships of habitat to fish.

Less complex, linear evaluations that utilize best professional judgment in the review of habitat criteria within a river basin are also widely used and closely resemble the structure of HabRate. An example includes Smith's (2005) Washington statewide stream-level assessment for the State of the Salmon report that included critical limiting factors ratings per stream and summarized at the watershed level.

Although HabRate is not novel in its objectives, it is unique in its compatibility with the Aquatic Inventories Project Steam Survey methods and results, transparency throughout the analysis, and direct link to GIS, including the original stream survey data at the unit, i.e. riffle, pool, etc., reach levels attribute data, and each rating level of the HabRate analysis. In addition, all HabRate criteria and logic statements are editable in a MS Excel spreadsheet for easy updates and application to basins outside of the Deschutes River. Furthermore, stream survey data can be continuously added and updated easily at any time, providing a unique monitoring tool that works readily with Microsoft Access, Microsoft Excel, and ArcGis. The model criteria can also readily updated as new research provides additional insight on the relationship of habitat attributes to survival at different life stages, and the model can be modified to provide habitat quality ratings for Chinook, steelhead, and sockeye in other provinces or adapted to other salmon species. Additional sources of information can be integrated or overlaid with the habitat data such as water quality (e.g. temperature), instream structures (e.g. passage barriers, diversion structures), or landscape features (e.g. geology, land use) to provide a more comprehensive perspective on the basin.

Different modeling methods inherently possess different strengths and limitations. We compiled a list identifying HabRate's strengths and limitations in Table 7.

Table 7. Strengths and limitations of HabRate, a spatially explicit physical and biological limiting factors model.

Strengths	Limitations
Uses quantitative and qualitative data	No modeled connectivity between reaches
Flexible scales	No empirical testing of results
Visual presentation (GIS)	No multiplicative effects or interactions
User 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	
Identifies potential limiting factors	
Spatial relationships	
Transparent evaluation process	

HabRate was developed as tool to evaluate the suitability of habitat for salmonids in the Deschutes River basin, but has a much broader application to other basins in the Pacific Northwest. Because HabRate provides a link between stream habitat conditions and life history requirements of salmon, it may be used as is or adapted to identify limiting factors in stream conditions for prioritizing habitat restoration and developing recovery plans for salmon and trout in other basins

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APPENDIX A

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+							

a) Shaded boxes represent residence or migration period, darker shaded cells are peaks in migration past Pelton Dam during evaluation period
b) Immigration is migration into the Deschutes River
c) Outmigration is at Pelton Dam (rkm 161)
d) Pelton signifies time at which passing the Pelton weir

APPENDIX B

Chinook salmon habitat requirements and references

Spawning	
Substrate	
Gravel = 3 - 15 cmmeasured in redd] 15 cm is upper useable limit Gravel = 62% [measured in redd] Cobble = 38% [measured in redd]	Chambers 1956 in Raleigh et al. 1986b
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] 59 - 86 % gravel 8 - 35% rubble	Burner 1951 in Raleigh et al. 1986b
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] 12 to 26% optimum level of fine sediments in spawning areas	Everest et al. 1987

Spawning (continued)	
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 et al. 1986b
≥ 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 et al. 1986b
Temp	
4.4 - 18 °C preferred for spawning	Mattson 1948, Burner 1951 in Raleigh et al. 1986b
low survival (egg + fry) if temp ≥ 16°C no embryo survival at 0°C initially >2 ≤ 3.5 weeks at ≥ 4.5 °C but ≤ 12.8 °C	Seymour 1956 in Raleigh et al. 1986b
10-12 °C favorable range for spawning	Bell 1986
≥ 15 °C may be lethal for embryo	Eddy 1972 in Raleigh et al. 1986b
Flow	Raleigh et al. 1986b
Habitat	
Pool tailouts	Vronskii 1972 in Raleigh et al. 1986b
Pool tailouts	Sullivan et al. 1987
40-60% pools is optimum for spawning and rearing	Raleigh et al. 1986b

Egg survival (incubation)	
surface fines	
≤ 5% silt (≤ 0.8 mm) is optimum ≤ 5% sand (≤ 30.0 mm) is optimum	Raleigh et al. 1986b
< 15% fines (<0.84 mm) is optimal, any greater = decreased survival	McNeil & Ahnell 1964 in Raleigh et al. 1986b
< 5% = high O2 permeability > 15% = low O2 permeability (<0.84mm)	McNeil & Ahnell 1964 in Bjornn & Reiser 1991, 1979
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 et al. 1983 in Bjornn & Reiser 1991
utilize 2cm size substrate for cover	Burger et al. 1982 in Raleigh et al. 1986b
20 - 25 % fines (> 75 % survival) (≤ 6.4 mm)	

Summer Rearing 0+ (Fry)	
Substrate Preference	
< 10% fines (< 3mm) in riffle runs > 30% fines, low probability of use as cover	Raleigh et al. 1986b
10 - 40 cm substrate ≥ 15% of area is adequate cover with < 5% fines	Raleigh et al. 1986b
found over silt to 20cm diameter [0+]	Everest & Chapman 1972
Habitat is marginal if fines ≥15% [Pink salmon]	McNeil & Ahnell 1964 in Raleigh et al. 1986b
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 et al. 1986b
Tendency towards less than 50% for higher densities	Platts 1974
59% chinook found in area with <20% pools	Platts and Partridge 1983
Habitat	
prefer pools	Platts and Partridge 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. 1995-1998
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 et al. 1986b
slow growth ≥19.5°C, preferred 9.4 – 13.8°C	Brett at al. 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 et al. 1986b
> 15% of 10 - 40 cm sized substrate for cover	Raleigh et al. 1986b
Highest pool complexity had highest densities	Platts 1974
Prefer overhead bank cover (provided 32% cover in trench) to no cover Undercut banks in addition to other cover	Brusven et al. 1986

Overwintering 0+	
Substrate	
< 5% fines optimum, > 30 % tends to prevent use enter gravel or migrate	Raleigh et al. 1986b
enter the substrate	Everest & Chapman 1972
emigrate if lack of substrate cover in cobble/bldrs sand-gravel to silt -cobble (fry size dependent) will not migrate if suitable cobble present	Hillman & Griffith 1987
Overwinter in the substrate	Everest & Chapman 1972
Substrate is major source of cover	Raleigh et al. 1986b
Pool Complexity	
≥ 20% area Class 1 & 2 pools (preferred)	Raleigh et al. 1986b
Habitat	
Pools, glides and RI's, abundant in pools ssoc. with cover	Jonasson et al. 1995-1998
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 LP and Glides	Bjornn & Reiser 1991
Cover	
> 15% cover including 10 -40 cm sized substrate, silt free	Raleigh et al. 1986b
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 et al. 1986b
0°C minimum	Bjornn & Reiser 1991; Raleigh et al. 1986b
≤ 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 C

Steelhead trout habitat requirements with references

Spawning	
Substrate	
< 5% fines in redd (optimal)	Raleigh et al. 1986a
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 et al. 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 et al. 1986a
Depth (reflects pre-spawning conditions)	
≥ 0.24 m	Smith 1973
Shallowest = 0.21m	Orcutt at al. 1968
Temperature	
10 - 15°C for spawning	Scott and Crossman 1973
≥ 4°C for upstream migration	Hanel 1971 in Raleigh et al. 1986a
3.9 - 9.4 °C preferred for spawning	Bell 1986
7 - 12°C optimum for embryo development	Raleigh et al. 1986a
<4°C and >16°C is low survival (HSI) for embryo	
Flows	adapted from Binns & Eiserman 1979, Wesche 1980 in Raleigh et al. 1986a

Egg Survival	
Substrate	
< 5% fines = high O2 permeability > 15% fines = lower O2 permeability (fines = 0.84mm)	McNeil & Ahnell 1968 in Bjornn & Reiser,1979 & 1991
0 - 25% fines (>80% survival) (fines<6.35mm) > 40% fines (~ 50% survival)	Tappel and Bjornn 1983 in Bjornn & Reiser 1991
>30-40% fines (1-3mm) resulted in <50% survival [lab]	Hall and Lantz 1968

Emergence	
Substrate	
< 15 % fines (> 90% emergence) >20-25% fines (<50% emergence) (fines < 6.4 mm) resulted in reduced survival + emergence	McCuddin 1977, Bjornn 1969 in Reiser & Bjornn 1979
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) >50% sand (<50% emerged)	Bjornn 1968

Summer Rearing 0+	
Substrate	
<10 % fines (interstices and production) 30% fines upper limit	Raleigh et al. 1986a
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 et al. 1986a
Tendency towards 50% ratio with riffles	Platts 1974
Cover	
10 - 40 cm substrate in 10% of habitat area (small juveniles) >15% cover including substrate (adequate)	Raleigh at al. 1986a
<10% rating: 0 (worst) 10 to 25% 1 26 to 40 2 41 to 55% 3 >55 4 (best)	Binns & Eiserman 1979 [Trout habitat rating model]
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
Temperature	
0-25°C (lower/upper limits)	Lagler 1956, McAfee 1966, Black 1953
optimal 12 - 18°C (rainbow trout)	Raleigh et al. 1986a
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 et al. 1986a
Larger substrate shift in winter	Sheppard and Johnson 1985
Rubble, primary cover assoc. with rocks 10 - 25 cm in diameter	Bustard and Narver 1975, cited in Raleigh et al. 1986a
Cover	
≥ 15% including substrate and other undercut banks and cover	Wesche 1980 in Raleigh et al. 1986a
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 low velocity, any habitat with rubble	Bustard & Narver 1975
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 et al. 1986a
found over larger rubble substrate (>40 cm)	Everest & Chapman 1972
occupy larger substrate as they grow	Sheppard & Johnson 1985
Habitat	
Riffles (runs areas)	Raleigh et al. 1986a
found in all habitat types	Platts & Partridge 1983 in Platts et al. 1989
prefer LP and PP, found in all avoided RI, GL, DP, and SC higher velocity and deeper water	Bisson et al. 1988
prefer LP,PP,TP w/ undercut banks and LWD found in RB and CB	Bisson et al. 1981
Depth	
0.6 - 0.75m preferred (I+)	Everest & Chapman 1972
deeper than 0+	Bisson et al. 1988
Cover	
≥ 15% (substrate and other)	Raleigh et al. 1986a
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 et al. 1986a
Class 1 pools	Lewis 1969 in Raleigh et al. 1986a
Rubble (15-45cm diameter) substrate [trough] Rubble or undercut banks [nature]	Bjornn 1971
Depth	
> 45cm	Bustard & Narver 1975
> 45 cm (otherwise, lower densities) 0.6 - 0.75 m preferred (I+)	Everest & Chapman 1972
Cover	
prefer > 40cm boulders	Everest & Chapman 1972
≥ 15% (substrate and other)	Raleigh et al. 1986a
highest density associated with pool depth undercut banks, large rock and brush as strong affinity to large rock as PD,UB and LR combined	Bjornn and Steward, unpublished in Bjornn & Reiser 1991
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), and rubble in rivers	Bustard & Narver 1975

Pool Complexity

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

Platts 1974

Platts and Partridge 1983

Rating	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

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 et al. 1986a: Pool classification

APPENDIX D

Sockeye salmon habitat requirements references

Spawning, egg survival, emergence	
Substrate	
salmonids can spawn in gravel w/ median diam ≤ 10% of their body length.	Kondolf 1993
< 5% fines in redd > 15% lower O2 permeability	McNeil & Ahnell 1964 in Bjornn & Reiser 1991
1.3-10.2cm	Bell 1986
medium to small gravel with no silt	Eiler 1992
<15% fines (<2mm) (PU) Typically spawning where there is upwelling, so substrate is highly variable	Lorenze and Eiler 1989
20% is harmful stage	Stowell et al. 1983; Bjornn & Reiser 1991
Habitat	
Areas of upwelling or subsurface flow preferred for spawning	Lister et al 1970, Wilson 1984, Vining et al 1985 in Bjornn & Reiser 1991
small streams of lakes, gravel shores with upwelling or tributaries of lake outlet	Meehan and Bjornn 1991
Lake shore or tributary riffle areas preferred Concentrate in areas of upwelling	Groot 1991
Depth	
enough to cover the fish (minimum)	Groot 1991
≥ 0.15m [estimated]	Bjornn & Reiser 1979, 1991
Temperature	
10.6 - 12.2°C preferred 4.4 - 13.3°C for incubation	Bell 1986
15.5°C moralities ensue 5.5-12.8°C preferred for spawning	Seeley & McCammon 1966

Summer Rearing 0+ and migration to lake	
Cover	
use undercut banks, overhanging vegetation, and gravel	Hartman et al. 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 usually in lakes	Meechan & Bjornn 1991
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 E

Chinook salmon habitat criteria.

Spawning, Egg Survival, and Emergence

prior to redd construction

	3	2	1
Substrate Fines (< 2mm) Gravel (2 – 64mm) Cobble (64-256mm)	 ≤ 10 % ≥ 30 % 20 - 40 %	 10 - 20 % 15 - 30 % 10-20,40-70 %	 >20 % <15 % < 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+

	3	2	1
Substrate Fines *(interstices and productivity)* Gravel *(cover)* Cobble and Boulder *(cover)*	 ≤ 10 % ≥ 15 % ≥ 15 %	 10 - 30 % 5 - 15 % 8 - 15 %	 > 30 % < 5 % < 8 %
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Pool Complexity	3	2	1
Additional Cover (*at least one true*) % Undercut LWD / 100m Boulders / 100m *(cobble and boulder from above)*	 ≥ 15 ≥ 20 ≥ 20	 10 –15 10 – 20 5 – 20	 < 10 < 10 < 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

Overwintering 0+

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

Spring 1+ and Emigration

	3	2	1
Substrate Fines *(interstices)* Cobble and Boulder *(cover)*	 ≤ 10 % ≥ 20 %	 10 - 30 % 10 - 20 %	 > 30 % < 10 %
Pool Area	40 - 60 %	20 - 40 %	< 20 % , > 60%
Pool Complexity	3	2	1
Additional Cover (*at least one true*) % Undercut LWD / 100m Boulders / 100m	 ≥ 15 ≥ 20 ≥ 20	 10 –15 10 – 20 5 – 20	 < 10 < 10 < 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

Pool Complexity

3	Deep with considerable cover
	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 %
2	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 %
1	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 F

Steelhead trout habitat criteria.

Spawning, egg survival, emergence

prior to redd construction

	3	2	1
Substrate Fines Gravel Cobble	 ≤ 10 % ≥ 30 % 10 - 30 %	 10 - 20 % 15 - 30 % 30 - 60 %	 > 20% < 15 % < 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+

	3	2	1
Substrate Fines *(interstices and productivity)* 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
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

Overwintering 0+

	3	2	1
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+

	3	2	1
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

Overwintering 1+ and Emigration

	3	**2**	**1**
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 G

Sockeye salmon habitat criteria.

Spawning, egg survival, fry emergence

prior to redd construction

	3	2	1
Substrate Fines Gravel Cobble	 ≤ 10 % ≥ 30 % 10 - 40 %	 10 - 30 % 15 - 30 % 40 - 60 %	 > 30% < 15 % < 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

	3	2	1
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

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