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Stream Habitat of Juvenile Bull Trout Populations in Oregon and Benchmarks for Habitat Quality

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Abstract. - Fish population and habitat surveys of Oregon streams containing bull trout (*Salvelinus confluentus*) were conducted by the Aquatic Inventories Project, Oregon Department of Fish and Wildlife from 1990 to 1994. This paper examined the association of juvenile (<170 mm fork length) bull trout populations with other fish species, and with habitat characteristics at the watershed, reach, and habitat unit level of organization. Juvenile bull trout were most commonly found with rainbow trout (*Oncorhynchus mykiss*), but were frequently found alone, or with sculpin (*Cottus* spp.), non-native brook trout (*S. fontinalis*), or cutthroat trout (*O. clarki*). Populations of juvenile bull trout were in watersheds that averaged 30 km^2 in size and on average ranged from 1,460 m to 2,320 m elevation. Populations were found nearly equally among hillslope constrained, terrace constrained, and unconstrained channel types. Stream channels had average gradients of 5.0% slope, wetted widths of 2.9 m, and were dominated by riffle and rapid habitat. Stream reaches supporting juvenile bull trout populations were compared, by multivariate analysis, to reaches without bull trout using 31 habitat variables. Seven habitat variables were significant ($P<0.0001$) descriptors of the presence of juvenile bull trout: high levels of shade, undercut banks, large woody debris volume, large woody debris pieces, and gravel in riffles, and low levels of fine sediment in riffles, and bank erosion. These variables describe important components of juvenile rearing habitat, and collectively characterize stream reaches with juvenile bull trout as having healthy riparian zones and relatively undisturbed stream channels. Habitat quality benchmarks were developed based upon habitat supporting extant juvenile bull trout populations in Oregon. Suggestions for their application are discussed.

The decline of bull trout (*Salvelinus confluentus*) populations throughout their range has been linked in part to habitat destruction, migration barriers, and introduced salmonids (Ratliff and Howell 1992; Rieman and McIntyre 1993; Goetz 1994). Water temperatures below 15° C are commonly cited as important for spawning, egg incubation, and early rearing (McPhail and Murry 1979; Shepard et al. 1984). Stream reaches with suitable thermal regimes for spawning and early rearing are typically located in the upper portions of watersheds, are geographically isolated, and account for only a small portion of available habitat in a basin (Rieman and McIntyre 1993 and 1995). Goetz (1994) found the elevation of historic and extant juvenile bull trout populations in Oregon and Washington to increase with decreasing latitude and longitude, and implicated groundwater temperature as an attendant factor. Graham et al. (1982) described spawning areas of large adfluvial bull trout in Montana using stream order, channel gradient and substrate, and the amount of undercut banks. These variables were thought to be linked to migration distance from a lower lake, and the quality of adult spawning and hiding habitat. Reduced juvenile rearing densities have been associated with fine sediments, which are thought to limit egg-to-fry emergence survival, and juvenile overwinter survival, by the filling of streambed interstices (Rieman and McIntyre 1993). Juvenile bull trout at the habitat unit level prefer pools, and utilize microhabitats of small pockets of slow water associated with coarse substrate, woody debris, bank undercuts, and channel margins (Dambacher et al. 1992; Bonneau 1994; Goetz 1994).

While available literature is replete with specific life history requirements, there is a lack of definition in the variation of habitat conditions across which bull trout populations persist (Rieman and McIntyre 1993). In this study an extensive database of habitat and fish population surveys of Oregon streams was used to describe typical juvenile bull trout habitat, and to develop habitat quality benchmarks for use in monitoring programs. This study does not address the habitat of fluvial adult bull trout, which range downstream of juvenile rearing areas.

Methods

Stream habitat and fish population surveys of Oregon streams have been conducted statewide since 1990, by the Oregon Department of Fish and Wildlife, Aquatic Inventories Project (AIP). Stream habitat surveys (Moore et al. 1993) quantified the amount and character of in-channel and riparian conditions, and described the valley and channel form. The surveys are similar in approach to that of Hankin and Reeves (1988). Habitat data from 103 reaches in 32 streams were summarized by ecoregion (Omernick and Gallant 1986), basin, stream, reach, and habitat unit levels of organization (Frissell et al. 1986). Fish distribution surveys were conducted with direct pulsed current backpack electroshockers. Each sample site consisted of six habitat units; three pools and three fastwater units. Units were electroshocked during a single-pass without blocknets. In one pool and one fastwater unit, a second pass was performed. Stunned fish were collected by dip-nets and placed in buckets with stream water. Fish were enumerated by species and fork length class and returned to the stream. Each sample site was described and located on a map.

AIP databases were queried for sites where bull trout <170 mm fork length were located. Presence of this size of fish was considered indicative of a juvenile population, and is so defined for this paper. Fish species occurring with juvenile bull trout were also summarized for individual streams. The relative abundance of fishes was not considered in this summary; a species represented by a single individual in sampling was treated the same as one more numerously and widely found throughout a stream.

Where distributional sampling was intensive, the downstream limit of juvenile fish was determined by their absence at lower sites. Map based watershed characteristics were compiled from 1:25,000 scale U.S. Geological Survey Maps to describe basin features above a confirmed lower limit of juvenile bull trout rearing.

Habitat data of stream reaches with juvenile bull trout were summarized with descriptive statistics. A separate summary was made of stream reaches without juvenile bull trout that were considered as potential or historic, but presently unoccupied, habitat for juvenile bull trout. These reaches were in the same basin, or basins adjacent to reaches with juvenile bull trout. They were also of similar valley form, as determined from field observations and 1:25,000 scale maps. Some of these reaches were known to historically contain juvenile bull trout populations, the absence of which has been attributed to a wide range of both physical and biological factors (Ratliff and Howell 1992).

Detrended correspondence analysis (Hill 1979; Gauch 1982), and discriminant function analysis (Dixon et al. 1988) were both used to identify the principle patterns of variation in the habitat of stream reaches with and without juvenile bull trout. These techniques array similar reaches closely and separate dissimilar reaches based on multiple attributes of stream habitat.

Detrended correspondence analysis maximizes the correlation between the habitat variables and reaches, while maximizing the difference among reaches. It arrays the habitat variables along each axis in a direction similar to the individual reaches, and prevents undesired systematic relations between successive axes. Each reach, with or without juvenile bull trout, is treated as an individual sample unit. As a result, the reaches are laid out along a continuum that represents the variability of habitat parameters among the reaches.

Discriminant function analysis relies upon a priori grouping, stream reaches with or without juvenile bull trout in this instance, and maximizes the dissimilarity between groups. Discriminant function analysis tests the cohesiveness of each a priori group based on the habitat variables that are most dissimilar between the groups.

Results

We examined the association of bull trout with other fish species, and with habitat characteristics at the watershed, reach, and habitat unit level of organization. Eight fish species occurred with juvenile bull trout in 72 sampled streams (Table 1). Rainbow trout (*Oncorhynchus mykiss*) occurred most frequently (67% of the streams), followed by sculpin (*Cottus* spp.) (38%), brook trout (*S. fontinalis*) (15%), and cutthroat trout (*O. clarki*) (15%). Less frequently occurring were chinook salmon (*O. tshawytscha*) (8%), brown trout (*Salmo trutta*) (6%), mountain whitefish (*Prosopium williamsoni*) (6%), and dace (*Rhinichthys* spp.) (4%). The most common association of fishes in bull trout streams besides juvenile bull trout alone (22% of the streams), was juvenile bull trout with rainbow trout and sculpin (21%), and with rainbow trout only (15%). The degree of association with anadromous salmonids was incompletely defined by this analysis, as resident rainbow

Table 1. Frequency and percent of presence and association, of fishes with juvenile bull trout in 72 Oregon streams.

	Association																					Frequency of presence	%[1]
Bull trout alone	x																					16	22
Bull trout not alone		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	56	78
Oncorhynchus mykiss		x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x		48	67
Cottus spp.		x						x		x	x	x	x	x	x	x	x	x	x			27	38
Salvelinus fontinalis					x				x	x				x	x	x			x			11	15
O. clarki				x			x	x		x				x								11	15
O. tshawytscha										x	x	x			x		x			x		6	8
Salmo trutta						x															x	4	6
Prosopium williamsoni										x	x		x			x						4	6
Rhinichthys spp.[2]												x	x					x				3	4
Frequency of association	16	15	11	4	4	3	3	2	2	1	1	1	1	1	1	1	1	1	1	1	1		
%[1]	22	21	15	6	6	4	4	3	3	1	1	1	1	1	1	1	1	1	1	1	1		

[1] Rounded values.
[2] Both *R. cataractie* and *R. osculus* were noted in one stream, and *Rhinichthys* spp. in two others.

Table 2. Descriptive statistics of 25 Oregon watersheds containing juvenile bull trout populations. Compiled from 1:25,000 scale United States Geological Survey maps, above a confirmed lower limit for summer rearing.

Watershed characteristic	Mean	Median	Mode	Standard deviation	Minimum	Maximum	Lower quartile	Upper quartile
Lower limit distance from divide (km)	10.1	8.7	11.6	4.4	4.0	21.2	7.1	13.0
Elevation of lower limit (m)	1,460	1,510	1,530	270	710	1,840	1,340	1,640
Maximum elevation (m)	2,320	2,400	2,450	230	1,660	2,550	2,320	2,470
Basin area (km^2)	30	23	18	26	4.3	89	10	38
Drainage density (km/km^2)	1.0	1.0	1.0	0.2	0.7	1.5	0.9	1.2

trout (*O. mykiss*) and anadromous steelhead trout (*Salmo gairdneri*) could not be distinguished.

Basins with a verified downstream limit of juvenile rearing had an average area of 30 km^2, and ranged between 4 km^2 and 89 km^2 (Table 2). Streams from this sample were first to fourth-order. The lower limit of juvenile rearing extended on average 10 km from the watershed divide (range 4.0-21 km), and had an average elevation of 1,460 m. The elevation of the lower limit in most of the basins analyzed (75%) was below 1,600 m. Maximum basin elevation averaged 2,320 m.

Channel form did not influence the distribution of juvenile bull trout; populations were found in roughly equal proportions among hillslope constrained, terrace constrained, and unconstrained channel types (Table 3). Stream channels had average gradients of 5.0% slope, and wetted widths of 2.9 m (Table 4). Stream habitat was dominated by riffles and rapids; pools were typically a minor feature of the channel. Stream channels typically were not hydraulically rough, total stream substrate was dominated by fine, gravel, and cobble sized sediment; boulder and bedrock substrates were generally minor components of the streambed. Large woody debris volume averaged 23 m^3/100 m, and stream shade averaged 75%.

A total of 103 reaches from 32 different streams were selected for comparison of habitat: 59 reaches with juvenile bull trout; and 44 reaches without. The channel form was similar among reaches with and without juvenile bull trout (Table 3). Of the 44 reaches selected without bull trout, 4 (9%) were upstream of existing populations of juvenile bull trout, 14 (32%) were downstream, and 26 (59%) were from adjacent basins. A total of 31 habitat variables were used in the comparison (Table 4, Appendix Table A). Selected reaches were primarily from ecoregions (Omernik and Gallant 1986) of the Blue Mountains (63 reaches), and Eastern Cascades Slopes and Foothills (36 reaches). Four reaches were from the Cascades ecoregion.

Detrended correspondence analysis yielded two axes (Figure 1) that were considered meaningful. A scatter plot of the ordination scores for habitat variables showed the first axis to represent high to low habitat quality. Variables defining high quality habitat were large woody debris volume, large woody debris pieces, shade, undercut banks, and the amount of gravel in riffles, while low quality habitat was defined by bank erosion, and the amount of fine sediment (silt and sand) in riffles. The amount of pool habitat appeared to be neutral along this first axis. The second axis represented low to high amounts of pool habitat, and was described oppositely by pool area, and pool frequency (number of active channel widths between pools). The other habitat variables appeared neutral within this second axis. A scatter plot of stream reach ordination scores showed a moderate separation of reaches with and without bull trout only along the first axis; no separation occurred along the second axis. Reaches with bull trout were clustered toward the end of the first ordination axis that was strongly associated with high quality habitat, particularly large woody debris volume. Visually placed borders around each group of reaches showed no overlap in 41% of the reaches with juvenile bull trout, and 45% of those without. Mean ordination scores of stream reaches with and without juvenile bull trout were significantly different along the first axis ($P=5.0x10^{-8}$), and not along the second ($P=0.71$). Ordination scores of reaches with different channel forms were evenly distributed across the first ordination axis, demonstrating equal importance of the habitat variables to each channel form.

A stepwise discriminant function analysis generated a single function with a highly significant Wilk's λ ($P<0.00001$), which is a measure of the functions discriminating power.

A jackknifed classification from the discriminant function correctly classed 78% of the stream reaches; 81% of the reaches with bull trout and 73% without were correctly classed. Mean discriminant scores of stream reaches with and without juvenile bull trout (Figure 2) were significantly different

Table 3. Channel form of 103 reaches with and without juvenile bull trout from 32 Oregon streams, percent in parentheses.

Channel form	Stream reaches with juvenile bull trout	Stream reaches without juvenile bull trout	Total
Hillslope constrained	23 (39)	20 (46)	43 (42)
Terrace constrained	17 (29)	12 (27)	29 (28)
Unconstrained	19 (32)	12 (27)	31 (30)
Total	59	44	103

Table 4. Stream reaches with juvenile bull trout in Oregon. Descriptive statistics of 31 habitat variables for 59 stream reaches. Percent refers to wetted area of entire stream reach unless otherwise noted. ACW-active channel width; LWD-large woody debris.

Habitat variable	Mean	Median	Mode	Standard deviation	Minimum	Maximum	Lower quartile	Upper quartile
Gradient[1]	5.0	4.4	2.7	2.9	1.2	18	3.3	6.0
Valley width index[2]	10	7	20	11	1	75	1	20
Wetted width (m)	2.9	2.4	2.0	1.6	1.4	9.5	2.0	3.2
ACW (m)	5.4	4.3	4.1	3.0	2.5	17.7	3.6	6.2
ACW per habitat unit[3]	3	3	3	4	1	30	1	4
Percent pool	12	9	6	10	0.1	40	4	17
Scour pool depth (m)	0.4	0.4	0.4	0.1	0.2	0.7	0.4	0.5
Riffle depth (m)	0.2	0.2	0.2	0.1	0.1	0.3	0.1	0.2
Percent riffle fines[4]	16	12	11	12	0	53	8	21
Percent riffle gravel[4]	53	53	48	11	24	78	48	60
Percent shade[5]	75	79	89	15	41	95	66	87
Percent bank erosion[6]	5	0	0	12	0	62	0	4
Percent undercut bank[6]	9	6	3	9	0	37	3	11
LWD pieces/100 m	19	18	15	10	2	45	10	25
LWD m^3/100 m	23	18	32	21	1	119	9	28
Residual pool depth (m)	0.3	0.3	0.2	0.1	0.1	0.5	0.2	0.4
Riffle width/depth ratio	18	17	20	7	7	45	13	22
ACW per pool[7]	18	10	2	21	2	100	5	23
Large boulders/100 m	20	15	14	18	0.3	79	5	33
Percent dam pool	2	0.8	0	5	0	39	0	3
Percent scour pool	9	7	7	8	0	39	3	14
Percent glide	1	0.3	0	2	0	9	0	2
Percent riffle	48	52	0	30	0	97	19	75
Percent rapid	24	18	0	23	0	79	4	44
Percent cascade	14	3	0	24	0	97	0	15
Percent step	2	1	1	1	0	6	0.5	2
Percent fines	30	31	43	15	2	61	18	43
Percent gravel	36	35	28	10	16	64	28	43
Percent cobble	24	24	27	9	2	48	18	29
Percent boulder	8	5	3	6	0	26	3	12
Percent bedrock	2	0	0	9	0	55	0	1

[1] Expressed as percent slope, i.e., 45 degrees equals 100 percent slope.
[2] Valley floor width divided by active channel width.
[3] Unit spacing by average number of active channel widths between habitat units.
[4] Percent wetted area of riffle habitat only.
[5] Measured with a clinometer; percent of 180° that topography or vegetation visually occludes the sky.
[6] Percent of lineal distance, left and right bank average.
[7] Pool spacing by number of active channel widths between pools.

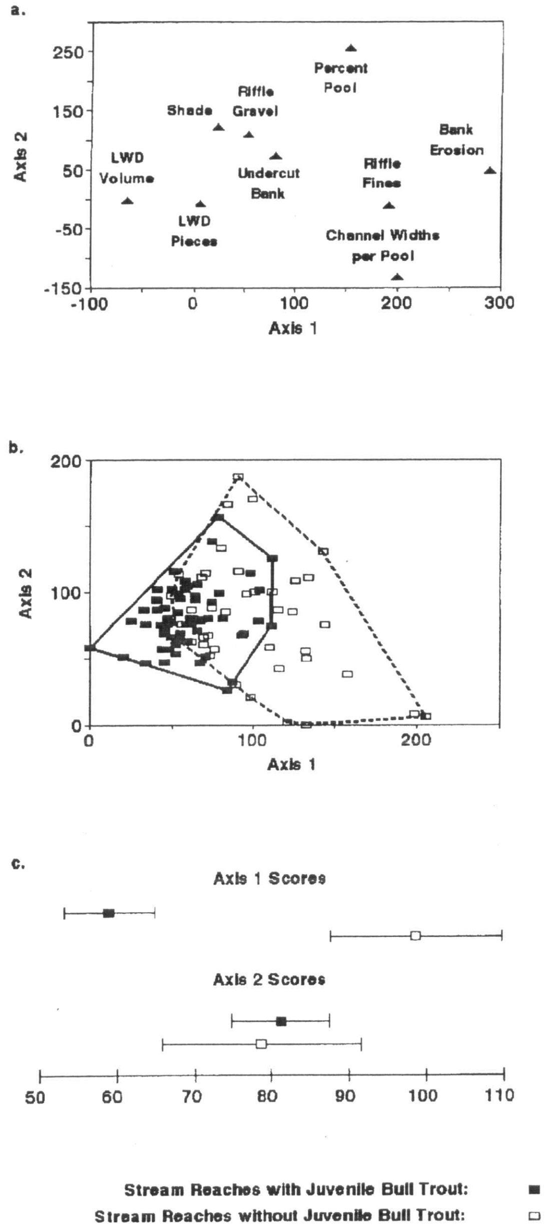

Figure 1. Detrended correspondence analysis ordination of habitat variables and 103 reaches from 32 Oregon streams. Bull trout occurred in 59 reaches, and were absent from the other 44. The first axis represents high to low habitat quality; the second axis represents low to high amounts of pool habitat. a). Ordination scores for habitat variables along the first and second axes. b). Scatter plot grouping of stream reaches along first and second axes. Lines visually drawn to define overlap. c). Mean ordination score and 95 percent confidence interval of stream reaches with and without juvenile bull trout along the first and second axes. Percent Pool: denotes percent pool area, Channel Widths per Pool: denotes pool frequency by active channel widths, LWD-large woody debris.

($P=2.0x10^{-7}$). Seven habitat variables were highly correlated

Table 5. Correlation between discriminant scores derived from a stepwise discriminant function analysis of juvenile bull trout presence and seven stream habitat variables. Stream habitat variables listed in the order they entered into the discriminant function. LWD-large woody debris.

Habitat variable	r	Significance
Shade	0.81	<0.0001
Riffle gravel	0.77	<0.0001
Bank erosion	-0.60	<0.0001
Undercut bank	0.39	<0.0001
Riffle fines	-0.52	<0.0001
LWD pieces	0.42	<0.0001
LWD volume	0.40	<0.0001

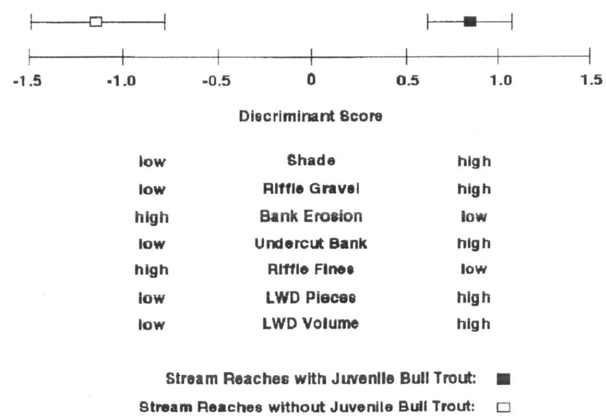

Figure 2. Mean discriminant score and 95 percent confidence interval for stream reaches with and without juvenile bull trout. Habitat variables were significantly correlated ($P<0.0001$) with the discriminant score, and are listed in the order they entered into the discriminant function. LWD - large woody debris.

($P<0.0001$) with the discriminant scores (Table 5). Shade, riffle gravel, undercut banks, and large woody debris volume, and large woody debris pieces were positively correlated with the presence of juvenile bull trout, while bank erosion and riffle fines were negatively correlated. Shade and riffle gravel were most strongly correlated with the discriminant score, suggesting that these variables were the most different between reaches with and without juvenile bull trout. Discriminant scores were similar among reaches with different channel forms, indicating equal importance of the function to each channel form.

Preliminary analysis found significant correlations ($P<0.05$) with the discriminant scores that were negative for channel gradient ($r = -0.54$) and valley width ($r = -0.20$), and positive for wetted ($r = 0.27$) and active channel width ($r = 0.37$). This reflects a bias in the data set that is related to channel size. Reaches without juvenile bull trout were often selected from stream channels that were downstream of reaches with juvenile bull trout, and hence were of greater size (+0.8 m wetted width) and lesser gradient (-2.2% slope). We believe these differences to be unimportant, as stream depth and the overall composition of substrate and habitat types were nearly identical between the two groups of channels (Table 4, Appendix Table A). These four variables were dropped from the discriminant function to remove the influence of stream size. This had no appreciable effect on the significance (Wilk's λ) of the discriminant function.

Benchmarks for habitat quality were developed for the seven habitat variables that were determined to be important descriptors of juvenile bull trout habitat (Table 6). Low, moderate, and high quality levels were derived from interquartile values of the habitat variables in Table 4.

Table 6. Benchmarks of habitat quality for juvenile bull trout, derived from 59 reaches of 19 Oregon streams. Percent bank erosion and percent riffle fines are negatively associated with habitat quality. LWD-large woody debris.

Habitat variable	Quality		
	Low	Moderate	High
Percent shade[1]	<66	66 - 87	>87
Percent riffle gravel[2]	<48	48 - 60	>60
Percent bank erosion[3]	>4	0 - 4	0
Percent undercut bank[3]	<3	3 - 11	>11
Percent riffle fines[2]	>21	8 - 21	<8
LWD pieces/100m	<10	10 - 25	>25
LWD m^3/100m	<9	9 - 28	>28

[1] Measured with a clinometer; percent of 180° that topography or vegetation visually occludes the sky.
[2] Percent wetted area of riffle habitat.
[3] Percent of lineal distance, left and right bank average.

Discussion

Populations of juvenile bull trout in Oregon were most commonly associated with rainbow trout, sculpin, brook trout, and cutthroat trout. Similar assemblages are found in other parts of the bull trout's range (Rieman and McIntyre 1993). Chinook salmon, common to large streams and wide valleys, seldom overlapped with juvenile bull trout. Accordingly, both species would require separate measures of habitat protection for their conservation.

The difference in elevation from the lower distribution limit to the watershed divide, may be an important factor in determining the relative vulnerability of juvenile populations, as the amount of useable habitat may be greater in basins reaching to higher elevations. We found the lower limit of most juvenile bull trout populations in Oregon to be less than 1,600 m elevation. At latitudes similar to Oregon, but at lower longitudes (approximately 2° east), Rieman and McIntyre (1995) found bull trout populations in the Northern Rockies ecoregion to range primarily above 1,600 m elevation. This is consistent with projections from Goetz's (1994) findings for populations at lower longitudes. However, juvenile bull trout populations in the Northern Rockies ecoregion also occur in basins with an even greater elevation and overall relief (B. Rieman, U.S. Forest Service, Intermountain Research Station, unpublished data). Compared to other portions of their range, bull trout in Oregon occur in mountains with relatively low relief, and may therefore persist in comparatively short distances of stream. This could contribute to low population size and a relatively higher risk of local extinction (Rieman and McIntyre 1995) for Oregon populations.

In this study we found seven variables to be important descriptors of juvenile bull trout habitat: high amounts of shade; undercut banks; large woody debris volume; large woody debris pieces; gravel in riffles; low amounts of bank erosion; and fines in riffles. While this study made no causal link between these variables and the presence of juvenile bull trout, we assert that they characterize important features of juvenile rearing habitat, and collectively describe stream reaches with juvenile bull trout as having healthy riparian zones and undisturbed stream channels. Large woody debris is an important component of channel structure and function (Bisson et al. 1987), and provides preferred cover for juvenile bull trout (Goetz 1994). Stream shade maintains cool water temperatures, and is correlated with the growth and maturation of the riparian canopy (Beschta et al. 1987). Having sufficient clean gravel is important for bull trout spawning, and egg-to-fry survival (Graham et al. 1982, Rieman and McIntyre 1993). The interstitial spaces of unembedded cobbles are an important component of summer, and especially winter habitat for juvenile bull trout (Bonneau 1994), and their use is diminished when filled with fine sediments. Undercut banks afford another important habitat for both juvenile fish (Goetz 1994), and adult spawners (Graham et al. 1982). And while bank erosion has obvious countering effects to undercut banks, it can also be a local source of fine sediment. Eroding stream banks can be caused by a loss of riparian vegetation, and by both local and upstream disturbances (Sullivan et al. 1987).

While juvenile bull trout prefer pools (Dambacher et al. 1992; Bonneau 1994; Goetz 1994), typical rearing streams in Oregon have gradients of 5.0%, and are dominated by riffles and rapids. Pool habitat was only a minor feature of bull trout streams, and not an important descriptor of juvenile bull trout presence. Monitoring or improvement projects for stream habitat should therefore not rely too heavily upon the sometimes popular pool-to-riffle ratio for setting desired future conditions.

Rieman and McIntyre (1993) propose a conservation approach for bull trout populations that is based upon protection of core areas that are "selected from the best available habitat or from habitat with the best opportunity to be restored to high quality". The benchmarks for habitat quality developed in this study would be useful for the ranking, selection, and monitoring of core areas, and are based upon common and easily obtained inventory data. Most of the benchmark variables have narrow ranges separating levels of low and high quality (i.e. riffle gravel, bank erosion, undercut bank, riffle fines, large woody debris pieces) (Table 6); a result of these variables having a narrow range of values in streams with juvenile bull trout. In application of these it may be practical to consider only the high quality level. Also, these benchmarks should be used in conjunction with the consideration of other important factors, such as temperature, barriers to migration, or the presence of introduced salmonids.

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Appendix Table A. Stream reaches without juvenile bull trout in Oregon. Descriptive statistics of 31 habitat variables for 44 stream reaches. Percent refers to wetted area of entire reach unless otherwise noted. ACW-active channel width; LWD-large woody debris.

Habitat variable	Mean	Median	Mode	Standard deviation	Minimum	Maximum	Lower quartile	Upper quartile
Gradient[1]	2.8	2.4	1.6	1.8	0.3	7.3	1.4	3.7
Valley width index[2]	7	4	20	7	1	20	2	12
Wetted width (m)	3.7	3.0	1.6	2.3	0.9	10.6	1.9	5.2
ACW (m)	8.0	5.9	5.5	6.4	1.6	34.7	4.1	8.7
ACW per habitat unit[3]	5	4	7	4	1	19	3	7
Percent pool	16	9	9	18	0.5	70	4	17
Scour pool depth (m)	0.6	0.5	0.5	0.2	0.1	1.0	0.4	0.7
Riffle depth (m)	0.2	0.2	0.2	0.1	0.1	0.3	0.2	0.2
Percent riffle fines[4]	27	27	3	17	0	75	16	36
Percent riffle gravel[4]	35	36	40	17	0	77	21	47
Percent shade[5]	53	54	56	18	19	93	42	62
Percent bank erosion[6]	22	13	0	24	0	100	2	35
Percent undercut bank[6]	4	3	0	5	0	23	0.6	6
LWD pieces/100 m	12	10	1	10	0.2	45	4	19
LWD m^3/100 m	12	9	2	11	0.6	35	3	19
Residual pool depth (m)	0.3	0.3	0.3	0.1	0.1	0.7	0.3	0.4
Riffle width/depth ratio	18	16	8	9	5	44	11	21
ACW per pool[7]	24	15	4	24	3	106	8	30
Large boulders/100 m	44	16	15	130	0.8	861	5	35
Percent dam pool	1	0.1	0	3	0	20	0	2
Percent scour pool	14	7	6	17	0	70	4	15
Percent glide	4	0	0	7	0	27	0	2
Percent riffle	39	34	0	28	0	96	13	62
Percent rapid	30	30	0	26	0	89	5	50
Percent cascade	11	0.7	0	21	0	88	0	12
Percent step	1	0.4	0	2	0	12	0.1	1
Percent fines	32	35	48	18	0	74	18	46
Percent gravel	26	28	33	11	1	48	16	33
Percent cobble	26	25	28	11	5	50	18	33
Percent boulder	15	10	4	16	0	77	4	22
Percent bedrock	1	0	0	1	0	6	0	1

[1] Expressed as percent slope, i.e., 45 degrees equals 100 percent slope.
[2] Valley floor width divided by active channel width.
[3] Unit spacing by average number of active channel widths between habitat units.
[4] Percent wetted area of riffle habitat only.
[5] Measured with a clinometer; percent of 180° that topography or vegetation visually occludes the sky.
[6] Percent of lineal distance, left and right bank average.
[7] Pool spacing by number of active channel widths between pools.