Abundance, distribution, and habitat use by trout and other fishes in the North Fork Snoqualmie River, WA
FERC No. 14110

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1) Introduction

Black Canyon Hydro, LLC has proposed the construction of a low impact run-of-the-river hydropower facility on the North Fork Snoqualmie River near North Bend, WA. Initial plans indicate that the facility would divert streamflow from a roughly 3.5 km reach of the North Fork. The bypass reach encompasses the entire length of the Black Canyon (canyon) river segment (BCH 2012). Field studies of fish, wildlife, and habitat, among others, are being planned and conducted in the vicinity of the facility in response to concerns raised by public agencies and organizations with jurisdiction over land and natural resources.

The purpose of this field study was to quantify mid-summer abundance, distribution, and habitat use by trout and other non-benthic fishes throughout selected river segments in the North Fork Snoqualmie River near North Bend, WA. Results from this study are intended to fill information gaps for fish and aquatic habitat inventories in the vicinity of the facility, and will accommodate temporal comparisons with previous fish and aquatic habitat surveys conducted by the WDFW during summer 2009 (Thompson et al. 2011). Agency personnel or other parties interested in the project may review this document to guide the further development of long term fish, wildlife, and habitat studies in the vicinity of the project.

2) Study Area

A general description of the North Fork Snoqualmie River sub-basin and the 3 levels of sampling stratification used in this study can be found in Thompson et al. (2011). More specific to the location of the facility, the canyon is a difficult-to-access, deeply incised, high gradient river segment of the North Fork Snoqualmie River. It loses about 150 meters in elevation over 3.5 river-kilometers. Previous fish surveys in the canyon indicated that all life stages of both rainbow and cutthroat trout inhabit the canyon in relatively low densities (Beck and Associates 1985). More recent fish and habitat studies did not include surveys in the canyon. However, surveys and sampling showed that rainbow trout were the predominant species of game fish in the North Fork, and were relatively densely populated just upstream and downstream of the canyon (Thompson et al. 2011).

3) Methods

To quantify habitat variables and abundance of trout and other fishes during mid-summer, continuous daytime snorkeling was conducted in river segments proximate to, and throughout the canyon. For field crew safety, target streamflows were set prior to surveys at < 60 cubic feet per second as reported at the USGS gaging station 12142000. Very cold (< 10°) or warm water temperatures (> 18°) can influence the positioning behavior and thus detection of salmonids by snorkelers during daylight. Therefore, target temperatures for surveys ranged between 10° and 18° Celsius (Dolloff et al. 1993).

Up to 3 snorkelers and 1 data recorder surveyed each habitat unit (pool, riffle, glide, or cascade) continuously between the active real-time USGS gage site (N 47.6152 W 121.71303, river kilometer [rkm] 15.32) and the confluence between the North and Middle forks of the Snoqualmie River (rkm 0). The data recorder used a laser range finder to visually estimate habitat unit dimensions, and substrate sizes and number large woody debris (LWD) for the wetted portion of each habitat unit. Snorkelers visually estimated mean and maximum depths and counted fish by species (Onxx: pacific trout species, MWF: mountain whitefish, and LS: largescale sucker) and length class (total length in mm: 0-49 or YOY, 50-99, 100-149, 150-229, 230-299, 300-379, and 380+) in each unit.

Surveys were conducted in a passive, downstream direction and were designed for continuous data collection. However, snorkelers did not estimate depth or count fish in habitat units where highly consequential hazards or excessive turbulence prohibited accurate, safe depth estimates or fish counts.

Where braided channels were encountered, the longer channel represented the distance upstream measurement. However, because braided channels located at the same distance upstream often represented different habitat unit types, lengths snorkeled, habitat unit dimensions, and fish counts were segregated into discrete units. Natural fish passage limitations or barriers and other geomorphic features were documented and pictures were taken throughout surveys.

Data Analysis: Data smoothing

To provide a cohesive framework for the synthesis of statistical and graphic analyses within the context of the North Fork sub-basin, habitat and fish count data were plotted as a function of rkm and smoothed using the LOWESS function (Sigma Plot 11.0). This function scales localized polynomial regressions along a specified x-axis period interval. A second-degree polynomial and sampling proportion (period) of 0.30 were used for this study. If the period and polynomial match the desired scale for viewing trends in the data, meaningful trends will emerge for the total length of river surveyed. While smoothed quantitative data are imprecise and show only relatively large-scale interactions, smoothed plots of habitat variables and fish counts catalyze more focused questions regarding fish, habitat and interactions between biological and physical variables.

Habitat

The main stem of the North Fork Snoqualmie River was segregated by one of four habitat unit types (pool, riffle, glide, or cascade). Proportion by length of each habitat type was calculated for each river segment. As indicators of geomorphic functionality, LWD count, mean substrate size rank, and active channel width were compared to determine the strength of their relationships.

Fish

Trout densities were calculated for each habitat unit and river segment as the mean number of fish per 10 linear meters, and were compared across habitat unit types within and among river segments. Kruskall-Wallis ANOVA on ranks was paired with Dunn's post hoc pairwise comparisons to establish where differences in habitat use were statistically significant within and among river segments.

Trout density was used to estimate total abundance by combining observed counts with length of habitat not snorkeled*trout density per unit type for each non-surveyed unit per segment.

Barriers and limitations were defined as any habitat characteristic that could impede upstream movement by fish, including height of vertical drop, steepness of the unit, turbulence, or shallowness. Barriers were characterized as perennial impediments to upstream fish movement due to a combination of height of vertical drop, presence of boulder substrates at bottom of drop, confinement of active channel, and extended, sheer high velocity flow over bedrock or boulders (i.e., chute), whereas seasonal or perennial limitations were characterized by steep (> 10% gradient), turbulent, or shallow (< 0.01 m deep) units. To assess the influence of base flows conditions and channel morphology on habitat use by fish, fish densities in habitat units bordered immediately by upstream limitations or barriers were compared with densities in units without limitations or barriers immediately upstream using Mann-Whitney rank sum test.

4) Results

Snorkel surveys were conducted during August 22 – 27 in 2012. Streamflow at time of surveys ranged from 60 cfs on the 22nd to 48 cfs on the 27th. Water temperatures taken at the beginning of each survey ranged from 13° - 14° C. Except for some cascades in the Black Canyon, Calligan, and Moon Valley segments, a majority of all habitat units were snorkeled during surveys. Lengths and lineal ranges of river segments, percentages of each habitat type snorkeled, and total surface area by habitat type per segment are provided in Table 1.

Habitat and Fish longitudinal profiles

For reference, longitudinal profiles of elevation, habitat variables, and fish counts were plotted for the North Fork between 0 and 15.316 rkm. Trendlines for non-benthic fish and Onxx functional size group counts did not indicate there were obvious strong interactions among fish abundance and habitat variables. However, trout appeared more highly concentrated in locations with larger substrates. Relative abundance was highest at the Three Forks-Moon Valley interface and in the lower portion of the Black Canyon segment, which is downstream of the highest concentration of limitations and barriers (Figure 1).

Data analysis: Habitat functionality

Spearman rank order correlation indicated that mean substrate size rank tended to decrease with increasing linear density of LWD ($P = 0.0023$) and increasing active channel width ($P < 0.001$). Spearman correlation also indicated that number of LWD and active channel width correlated positively, though the relationship was not significant ($P = 0.186$).

Habitat throughout the upper and lower portions of the canyon segment was highly segregated due to numerous boulder or bedrock cascades and chutes with vertical drops ranging between approximately 2/0 and 5/4 meters (rise/run). The locations of 31 seasonal limitations and 7 probable perennial barriers to upstream fish movement were mapped (Figure 2), and 3 of the perennial barriers were photographed (Figure 3).

Habitat composition varied among the river segments. By length, pools constituted a vast majority of the available habitat in the Three Forks segment. The Moon Valley segment was nearly evenly composed of pools, riffles, and glides, with very little cascade habitat. The Black Canyon contained the greatest proportion of cascades, and the second greatest proportion of pools following Three Forks. The Hancock and Calligan segments were composed predominately of riffle habitat, and contained a relatively small proportion of pools (Figure 4).

Data analysis: Fish

There were significant differences in the density of trout (#/10 meters) within habitat types when compared among river segments ($P < 0.001$). Pairwise comparisons indicated that trout were more densely populated in Moon Valley pools than in Calligan riffles, glides and cascades, and Hancock and Three Forks riffles, and glides. Trout were also more densely populated in Moon Valley glides than in Calligan riffles, glides and cascades, and Hancock and Three Forks riffles and glides (Figure 4).

The Black Canyon contained the greatest estimated total number of trout, followed by Moon Valley, Calligan, Hancock, and Three Forks (Table 2). Abundance in the Hancock reach was the most variable, with cascades contributing more variability than any other habitat unit type among river segments. The Three Forks segment contained the fewest numbers, lowest variability among units, and lowest overall density of trout among all segments (Table 2).

Habitat units bordered immediately upstream by limitations or barriers contained significantly higher densities of fish than in units without limitations or barriers immediately upstream (limited unit median, n=45: 5.6 fish/10 m, non-limited unit median, n=212: 1.7 fish/10 m, $U = 1{,}901$, $P < 0.001$).

Comparison with 2009 data

Substantial differences in mean values of habitat variables were observed between surveys conducted in 2009 and 2012. Most of the Black Canyon was not surveyed in 2009; therefore comparisons of habitat were not made. On average, mean wetted width was approximately 6 m greater in the Calligan and Moon Valley segments during 2012. Mean active width was also about 14 m greater in the Moon Valley segment and 43 m greater in the Three Forks segment during 2012. In 2012, mean depth in the Hancock segment decreased by 0.2 m, and maximum depth decreased by 0.3 m. Black Canyon depths increased. Width-to-depth ratios increased dramatically in the Calligan and Moon Valley segments in 2012. This difference corresponded with increased wetted width values in both segments in 2012. Number of pieces of LWD also increased in 2012, especially in the Three Forks segment where they increased fourfold (Table 3).

Because a majority of the Black Canyon segment was not surveyed during 2009, comparisons were not made with 2012 fish density values. The most notable difference in Pacific trout linear density was an increase of 1.6 trout per 10 meters in the Calligan segment and approximately 2 trout per 10 meters in the Hancock segment in 2012. Largescale suckers also increased in density in 2012 by 2.4 fish per 10 meters in the Moon Valley segment (Table 3).

5) Conclusions

From a river segment perspective, trout densities were greatest in areas with increased gradients, numerous limitations or barriers, and in units where boulders were the predominant substrate type. Corresponding individual habitat units included deep pools or glides, with ample cover (mostly large substrates or deep interstitial 'pockets'), and downstream of vertical cascades, bedrock chutes, or falls. Adult and large adult trout in the Black Canyon were most densely populated in pools. This is probably due to the aquatic functionality of these habitats, as drifting food items are conveyed to a deeply scoured or incised cascade-pool interface, and turbulence provides added cover and aerated water. Although not statistically significant, substrate size was positively related to fish density. Substrate in the Black Canyon is composed primarily of boulders, which create interstitial space for cover, increase the habitable surface area, and accommodate groundwater exchange, which buffers water temperature fluctuations. Increased pool depth and channel confinement also results in lower width-to-depth ratios and might further buffer water temperatures during the warmest and coolest periods.

Upstream movement by trout inhabiting the Black Canyon segment is highly limited regardless of the volume of water passing through the channel at any given time. Vertical cascades, bedrock chutes, and falls correspond with a confined active channel resulting in numerous seasonal limitations and perennial barriers to upstream movement by trout. A bedrock-boulder cascade, known as 'Crash Test Dummy' rapids, limited the upstream distribution of mountain whitefish and largescale suckers. Based on the combination of height of vertical drop, active channel confinement, and the large substrates onto which the water falls, we believe it serves to limit the upstream distribution of all fishes inhabiting the lower North Fork during all times of the year. At least 4 barrier features similar or greater in magnitude are located upstream in the canyon, and numerous other lower magnitude cascades and falls also severely limit movement by trout perennially throughout this segment.

Fish were highly concentrated in habitat units bordered by upstream limitations or barriers. Many units below limitations contained very high densities of fish (maximum: 15 fish/m), and most of the largest trout (up to 22" TL) were observed in these units. These observations provide evidence that fish populations adapt to annual extreme climatic conditions (end of summer and possibly mid-winter base flows), and natural environmental conditions set annual limits on abundance and distribution of trout and other fishes in the North Fork. However, we suspect that not all life stages of trout utilize these habitat types in the same way. For example, feeding lanes proximate to structure in large pools and glides would not be optimal for smaller juveniles because they would be territorially outcompeted by adults and larger juveniles. As a result, and as was observed during surveys, most small juveniles occupy off-channel and isolated pools and margins along riffles.

In general, in the canyon there appeared to be ample volumes of the various habitats needed to sustain all life stages of trout at the densities observed. While we did not quantify off-channel or spawning habitat explicitly, we did note shallow side-pools and riffle margins containing 10's of young-of-year trout, and a number of pool tail-outs, glides, and riffles that contained abundant beds of gravel that could be used for spawning. We therefore hypothesize that most of the trout observed during surveys result from intra-segment canyon production within discrete, isolated units, with a minor amount of fry being seeded from upstream habitats by juveniles either moving or being flushed involuntarily downstream into the canyon during higher flows.

A comparison between 2012 and 2009 surveys suggests that Pacific trout populations have increased in density. The one exception occurred in the Three Forks segment. During 2012 surveys in the Three Forks segment, we noted the lack of quantity of deeper habitats with ample flow that would otherwise convey food items while also providing cover. For example, trout density correlated positively with substrate size, and although the relationship was not significant, smoothed trendlines showed that trout numbers declined in relation to substrate size from the Moon Valley-Three Forks interface downstream to the confluence with the Middle Fork. This spatial pattern of fish abundance during summer low-flows might be expected in most small to medium rivers in the Pacific Northwest, as delta regions are generally depositional by nature and lack larger substrates that might create deeper riffles and cascades. However, the pattern of diminishing density may be exaggerated during summer low flow periods in the Three Forks segment, where some very expansive yet shallow, stagnant glides and pools increase the surface area, but do not provide adequate 3-dimensional habitat for large numbers of trout by volume for each unit.

The mainstem channel in the Moon Valley and Three Forks segments has been diked extensively in places, causing channelization where the stream would otherwise braid dynamically throughout a broad valley-bottom floodplain. Channelization and subsequent land development is a problem in river systems as flow is constricted and not allowed to enter the valley bottom laterally, having a deleterious effect on mainstem and off-channel habitats, groundwater exchange, and water retention capacities that would otherwise buffer flood events. Fish populations also suffer as habitat is simplified and off-channel spawning and rearing habitat is lost or rendered inaccessible. However, there is an extensive floodplain channel-beaver pond network in the lower portion of the Three Forks segment, but use by mainstem trout populations is unknown. It is also noteworthy that Tate Creek, the only major tributary to the lower North Fork, is vulnerable to degradation as it flows through numerous residential lots and a channelized floodplain before it enters the North Fork through a diked bank.

While it is difficult to account for differences in most habitat variables between 2009 and 2012 surveys, changes in active widths are probably a result of a slight adjustment in methods in 2012, where satellite imaging and a digital elevation model was used to measure active channel width as opposed to using only ground-based data. This was changed to improve our ability to estimate the natural active width, which greatly influences channel morphology and thus corresponds with habitat type and availability. When native active channel widths are compared to current widths, which are often diminished as a result of diking and residential development, channel functionality can be viewed from its potential state and then compared with its current state. This information can help guide restoration or mitigation efforts. An increase in wetted width estimations probably drove the increased width-to-depth ratios in 2012. Disparities in wetted widths were probably due to observer error in the field, either in 2009 or 2012. Overall number of LWD at least doubled in all segments in 2012, but a striking fourfold increase was observed in the Three Forks segment in 2012. It is possible that LWD recruitment and accumulation increased in this segment between 2009 and 2012. In an apparent effort to lessen bank erosion at a private residence just upstream of the 428th bridge abutment, approximately 15 large mature trees had been cabled to the left bank.

The reason for the increase in trout densities between 2009 and 2012 in the Calligan and Hancock river segments cannot be confirmed. However, it is noteworthy that the last major flood occurred in January 2009, and the 2009 snorkel surveys were conducted in August of that year. The upper Snoqualmie River watershed was highly impacted by that flood event, and channel confinement and lack of off-channel refuge suggests that trout upstream of 'Crash Test Dummy' rapids may be vulnerable to permanent, involuntary downstream transport during extended high flow or flood events. If this is the case, many trout might have been flushed downstream from above the Black Canyon where they would have either found new unoccupied habitat, or competed with other trout for new habitat. Considering the confined nature of habitat in the North Fork upstream of the Moon Valley segment, the high concentration of fish near the base of the Black Canyon, and the inadequacy of habitats in the Three Forks segment, those fish that were flushed downstream and survived may have sought habitats in other sub-basins in the upper Snoqualmie River watershed (e.g., mainstem Snoqualmie, lower Middle Fork, or lower South Fork).

6) Literature Cited

Black Canyon Hydro, LLC. 2012. Black Canyon hydroelectric project FERC No. 14110, pre-application document. March 2012. 102 pgs.

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Thompson, J.N., J.L. Whitney, and R.E. Lamb. 2011. Snoqualmie River Game Fish Enhancement Plan – final report of research. Washington Department of Fish and
Wildlife. Submitted to Puget Sound Energy in partial fulfillment of the Snoqualmie Falls Hydroelectric Project FERC No. 2493.

Table 1. Lengths and lineal ranges of river segments, total length of surveys and percentage of each habitat type snorkeled per river segment, and total surface area by habitat type per river segment in the North Fork Snoqualmie River.

	River kilometer (rkm)			*Length surveyed (km)*					*Length snorkeled (km)*						*Surface area surveyed (ha)*				
River Segment	***Segment length (km)***	***From***	***To***	***Pool***	***Riffle***	***Glide***	***Casc.***	***Total***	***Pool***	***Riffle***	***Glide***	***Casc.***	***Total***	***% Snorkeled***	***Pool***	***Riffle***	***Glide***	***Casc.***	***Total***
Calligan	4.228	***11.143***	***15.371***	1.36	1.75	0.98	0.17	**4.26**	1.25	1.45	0.87	0.07	**3.64**	**86%**	2.25	3.97	2.07	0.36	**8.65**
Hancock	3.450	***7.693***	***11.143***	0.72	1.58	0.93	0.27	**3.49**	0.66	1.33	0.76	0.17	**2.92**	**84%**	1.47	4.00	2.23	0.68	**8.38**
Black Canyon	3.610	***4.083***	***7.693***	1.74	0.65	0.35	0.92	**3.66**	1.46	0.56	0.31	0.21	**2.54**	**70%**	2.54	2.04	0.61	1.30	**6.49**
Moon Valley	1.721	***2.362***	***4.083***	0.50	0.57	0.62	0.03	**1.72**	0.48	0.37	0.56	0.00	**1.41**	**82%**	1.10	1.38	1.32	0.06	**3.86**
Three Forks	2.362	***0.000***	***2.362***	1.47	0.20	0.86	0.00	**2.53**	1.37	0.16	0.82	0.00	**2.35**	**93%**	3.76	0.16	0.71	0.00	**4.64**
Total	**15.371**			**5.78**	**4.76**	**3.73**	**1.39**	**15.65**	**5.22**	**3.87**	**3.32**	**0.45**	**12.86**	82%	**11.12**	**11.56**	**6.93**	**2.39**	**32.01**

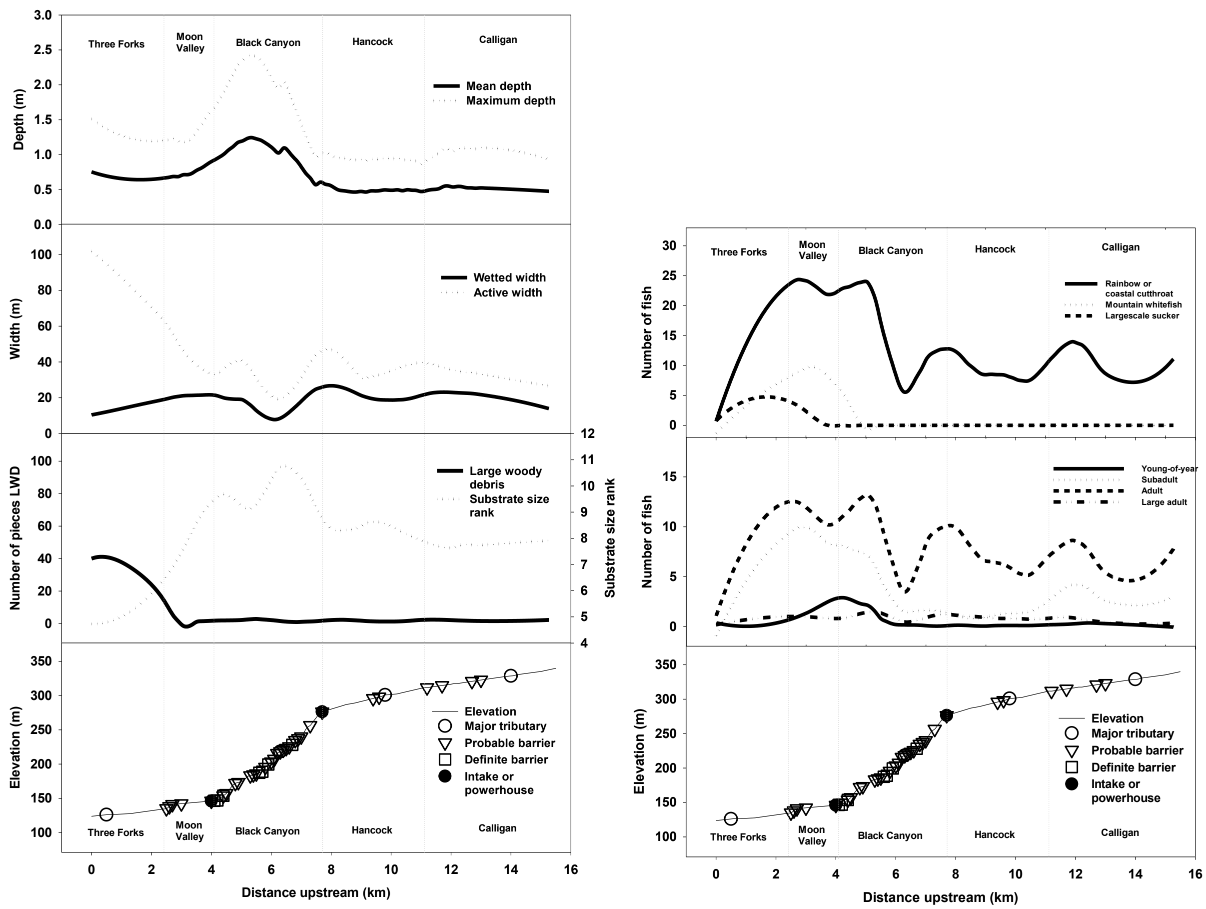

Figure 1. Longitudinal profiles of elevation, habitat variables, and fish counts in river segments of the North Fork Snoqualmie River. Definite barriers include perennial impediments to upstream fish movement due to a combination of height of vertical drop, presence of boulder substrates at bottom of drop, confinement of active channel, and extended, sheer high velocity flow over bedrock or boulders (i.e., chute). Probable barriers represent seasonal or perennial impediments to upstream fish movement due to habitat steepness (> 10% gradient), turbulence, or shallowness (< 0.01 m deep).

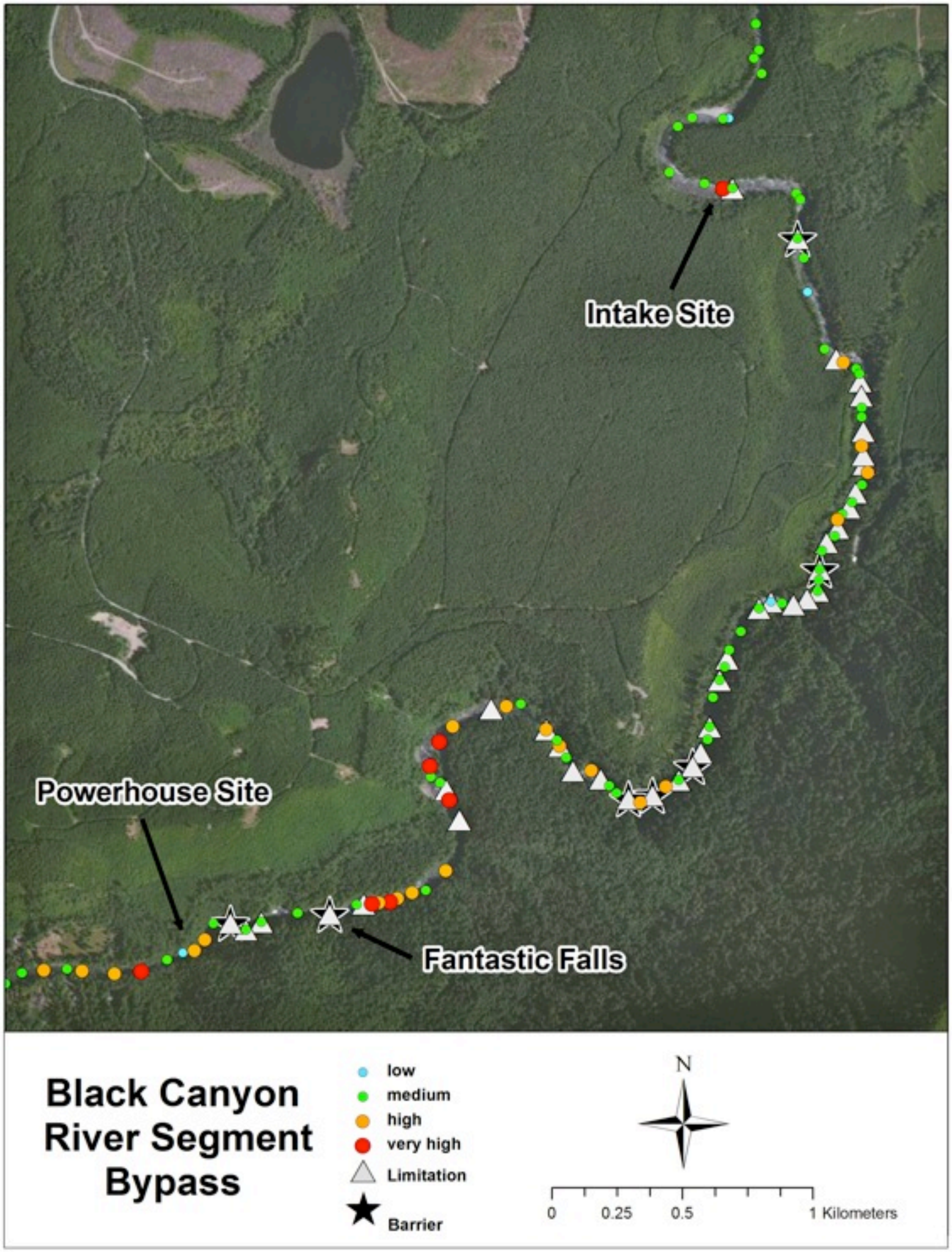

Figure 2. Map of most perennial barriers and limitations, and all trout densities in habitat units where trout were observed (#trout/10 m/unit) in the Black Canyon river segment during summer base flows in 2012. Density categories are as follows, low: 0.01-1; medium: 1-5; high: 5-10; and very high: >10.

Figure 3. Portions of some perennial barriers to upstream fish passage (**top left**: looking upstream into 'Big Nasty' rapids; **top right**: looking upstream at 'Split Falls' rapids; **bottom left**: looking upstream at final drop of 'Toilet Bowl' rapids; **bottom right**: looking downstream over the main drop of 'Crash Test Dummy' rapids). No mountain whitefish or suckers were observed upstream of the main drop of 'Crash Test Dummy' rapids, an approximate 2 m vertical drop onto boulders over about 2 m length. This was considered the downstream-most perennial barrier to upstream fish passage in the North Fork Snoqualmie River.

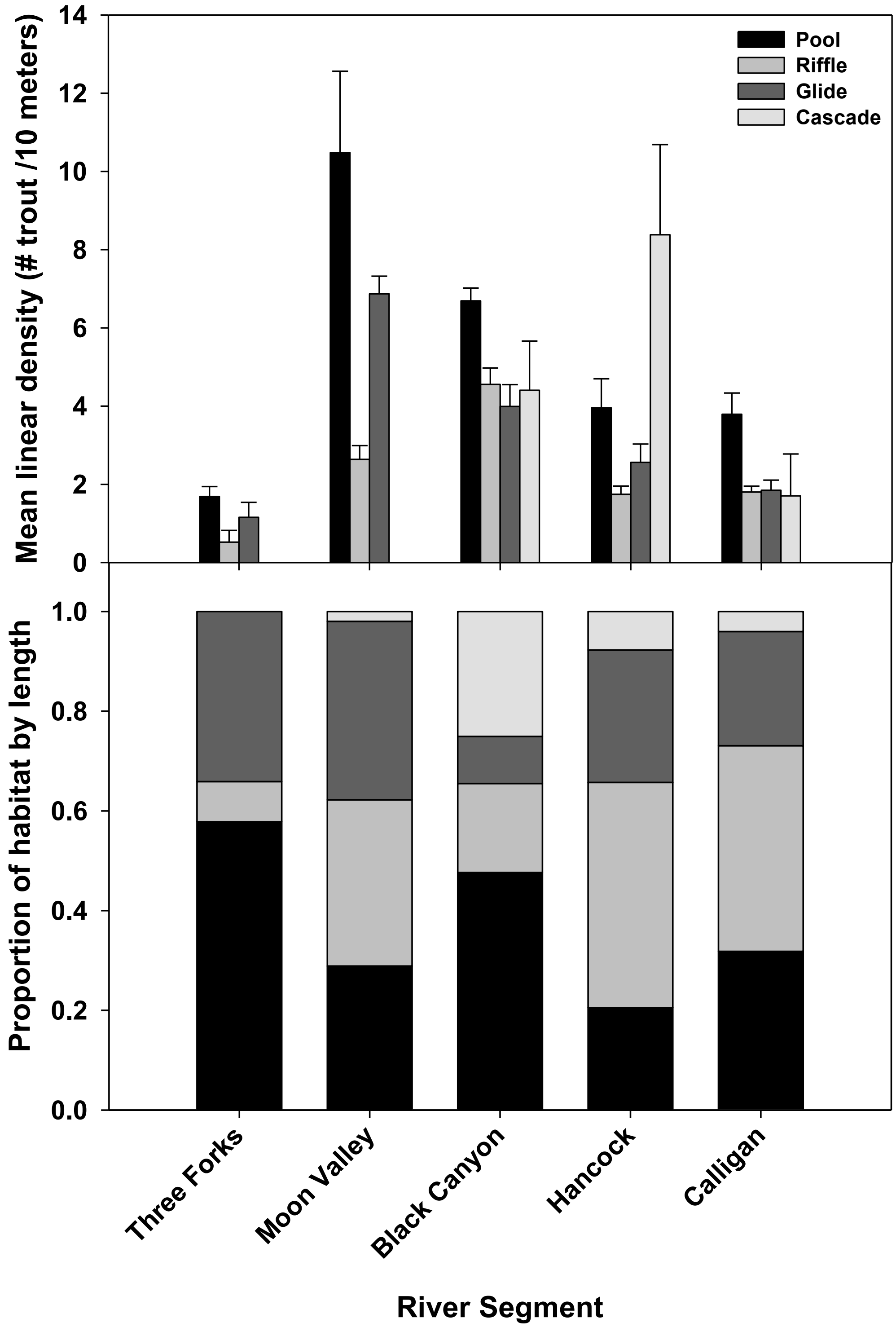

Figure 4. Habitat composition by length and trout densities (2SE) for each habitat unit type by river segment.

Table 2. Abundance estimates (2SE) for trout (Onxx) among habitat types and river segments.

River Segment	Pool		Riffle		Glide		Cascade		Total	
Calligan	388	0.54	262	0.15	156	0.26	30	1.07	**836**	**0.51**
Hancock	169	0.74	245	0.21	187	0.47	164	2.30	**765**	**0.93**
Black Canyon	980	0.33	287	0.42	120	0.56	386	1.25	**1,773**	**0.64**
Moon Valley	433	2.08	159	0.35	417	0.45	0		**1,010**	**0.96**
Three Forks	178	0.25	8	0.30	85	0.38	0		**271**	**0.31**
Total	**2,148**	**0.79**	**962**	**0.29**	**965**	**0.42**	**580**	**1.54**	**4,655**	**0.67**

Table 3. Comparisons of habitat variable means (***a***) and mean fish densities (#fish/10 meters) (***b***) between years 2009 and 2012. The same survey methods were used among years. Mean habitat variable and fish density values were calculated for each habitat unit and then by river segment. *Only 133 meters of the Black Canyon river segment were surveyed in 2009 compared to 3,606 meters in 2012, therefore pooled means in the bottom row do not include these values.

a)

	2009						**2012**					
River Segment	**Wetted Width**	**Active Width**	**Avg Depth**	**Max Depth**	**W:D**	**LWD**	**Wetted Width**	**Active Width**	**Avg Depth**	**Max Depth**	**W:D**	**LWD**
Calligan	13.8	25.0	0.5	1.0	32.8	0.4	19.8	31.4	0.5	1.0	58.5	2
Hancock	23.1	33.3	0.6	1.3	41.6	0.4	21.2	38.0	0.5	0.9	52.5	2
Black Canyon	**10.5***	**17.1***	**1.0***	**1.7***	**10.4***	**0***	14.7	30.0	1.1	2.0	22.1	2
Moon Valley	15.8	29.5	0.7	1.1	29.7	0.0	21.6	44.0	0.7	1.2	45.0	1
Three Forks	17.1	37.6	0.8	1.6	31.2	5.8	15.4	81.0	0.8	1.7	22.5	24
All units	**17.4**	**31.4**	**0.6**	**1.2**	**33.8**	**1.6**	**18.6**	**44.9**	**0.7**	**1.4**	**40.1**	**6.0**

b)

	2009				**2012**			
River Segment	**Pacific trout**	**Mountain Whitefish**	**Largescale Sucker**	**All non-benthic**	**Pacific trout**	**Mountain Whitefish**	**Largescale Sucker**	**All non-benthic**
Calligan	0.7	0.0	0.0	0.7	2.3	0.0	0.0	2.3
Hancock	1.4	0.0	0.0	1.4	3.3	0.0	0.0	3.3
Black Canyon	**23.6***	**7.2***	**0.0***	**15.4***	5.8	2.0	0.0	5.8
Moon Valley	6.2	2.2	0.0	4.5	6.4	2.8	2.4	4.6
Three Forks	1.5	0.7	0.9	1.3	1.3	0.3	0.6	1.1
All non-benthic	**2.5**	**0.7**	**0.2**	**2.0**	**3.8**	**1.0**	**0.6**	**3.4**