Lewis River Bull Trout

Habitat Restoration Project Identification Assessment

Final Report

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Submitted by:

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EXECUTIVE SUMMARY

The primary goal of this project is to identify locations in the upper Lewis River basin to implement habitat restoration actions intended to increase the quality and quantity of suitable spawning and/or rearing habitat for bull trout (see Appendix D – Project Proposal). The agencies and organizations associated with the project proposal (i.e., US Forest Service, US Fish and Wildlife Service, WA Department of Fish and Wildlife, PacifiCorp, Cowlitz Indian Tribe, Lower Columbia Fish Recovery Board, and Mount St. Helens Institute) agreed to focus on spawning habitat and designed a two-phase study to accomplish the project goal (see Appendix E – Study Plan). The objective of the first phase of the study was to characterize suitable spawning habitat within the basin. To do this, we modeled the occurrence of bull trout redds as a function of in-stream habitat using field data (i.e., habitat surveys and redd surveys). By necessity, the data used to develop this model were collected in streams known to support bull trout spawning (i.e., the Pine and Rush creek basins). The objective of the second phase of the study was to identify areas within the basin that lacked the suitable spawning habitat characteristics identified in the first phase of the study. In-stream habitat data were collected from select reaches throughout the basin that were outside of known spawning locations, were most likely to be used by migratory bull trout (i.e., physically accessible and thermally suitable) and had some degree of restoration potential based on local knowledge and federal administrative constraints (i.e., habitat restoration cannot occur in the Mount Saint Helens Volcanic National Monument).

Model results showed that bull trout redds in the Pine Creek basin in 2014 were 4 times more likely to occur in reaches with complex channels (i.e., more than one channel with flowing water during base flow conditions) than reaches with only one main channel, and redd occurrence was negatively related to stream depth. Data from Rush Creek were not included in the model because only one redd was observed in 2014. The result from an independent habitat selection analysis suggested bull trout moderately selected side channel habitat for spawning. Taken together, these results suggest that habitat complexity and depth at the reach scale are important factors influencing bull trout spawning site selection within thermally suitable habitat. Areas throughout the study area that lacked these habitat features were mapped. Additional factors that should be considered for any restorations project is the thermal environment and the

proximity of the proposed site to currently occupied habitats. Evidence from multiple studies suggests cold water is an essential component of suitable spawning and early rearing habitat for bull trout and cannot be discounted. The source populations that would colonize any restored habitat will come from the Pine and Rush Creek basins; the closer the restoration site is to these populations the more likely a colonization event will occur. Overall, this study recommends restoration actions that increase channel complexity in the coldest accessible stream reaches within the basin.

METHODS

Field Surveys

<u>Stream Reach Selection</u>

In order to model associations between stream habitat and bull trout redd locations, habitat and redd surveys were conducted in all known spawning tributaries in the Lewis River basin above Swift Reservoir: Pine Creek, P8 (tributary to Pine Creek), and Rush Creek (Figure 1). Additional habitat surveys were conducted in areas outside of known spawning locations to expand the assessment of potential habitat restoration sites. These reaches were selected using several criteria including habitat accessibility, restoration potential, and thermal suitability.

The migratory life history type is the only life history type of bull trout known to inhabit the Lewis River basin so any habitat restoration actions need to take place in reaches accessible to migratory fish. Due to this limitation, reach selection was limited to areas downstream of migration passage barriers. The one exception was in Drift Creek. Local biologists suggested extending the survey reach above the passage barrier. Migration passage barriers in the basin include impassable waterfalls and dewatered channels above stream sources of emerging groundwater.

Restoration potential was considered when selecting reaches outside of known spawning locations. Reaches with little or no restoration potential were trimmed from the basin and included Crab Creek, Little Creek, the upper portion of Smith Creek, Muddy River upstream of the Smith Creek confluence, and all tributaries to Swift Reservoir except Drift Creek. Little Creek was excluded because there are existing plans for restoration actions in this basin. The upper portion of Smith Creek and the Muddy River upstream of the Smith Creek confluence were excluded because these reaches are located with the Mount Saint Helens National Volcanic Monument where federal law prohibits modifications to the landscape. The remaining reaches were excluded because they were determined by local biologists to be unsuitable for bull trout based on previous work funded by PacifiCorp Energy (Meridian Environmental 2007).

The thermal environment was included as a factor in identifying potential restoration sites because bull trout are among the most thermally sensitive species of North American salmonids (Selong et al. 2001) and stream temperature has been shown to be the most important component of suitable spawning and rearing habitat (Dunham et al. 2003; Isaak et al. 2010). We elected to use maximum daily temperature to determine thermal suitability as it is among the best temperature predictors (Dunham et al. 2003). To ensure we included a sufficient amount of habitat to assess, we chose to include reaches with ≥ 25% probability of juvenile bull trout occurrence in Washington streams which corresponds to a maximum daily temperature of ≤ 17.5 °C (Dunham et al. 2003). The presence of juvenile bull trout is assumed to indicate spawning and early rearing habitat (Dunham et al. 2003)

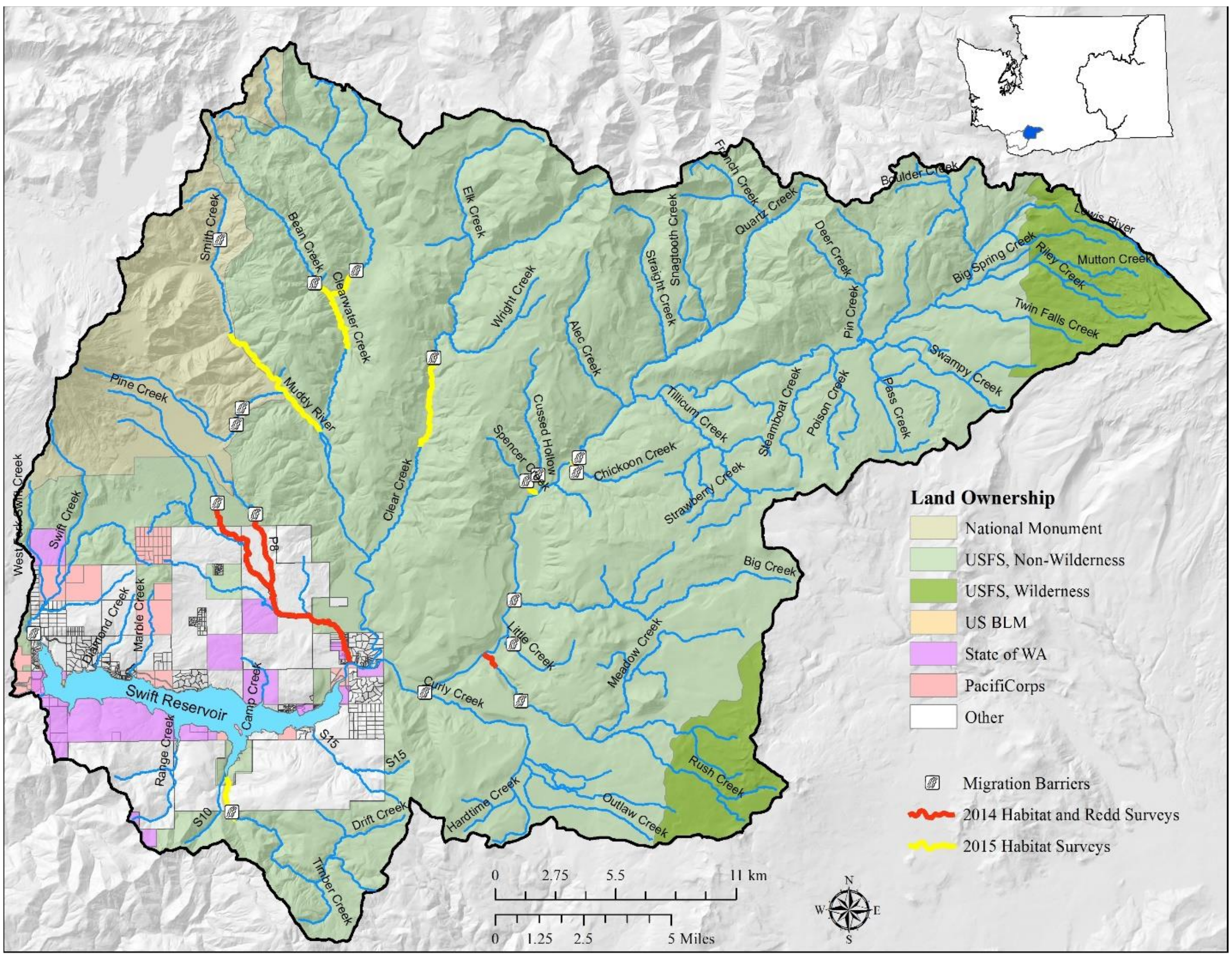

Figure 1. Map showing the reaches surveyed for this project. Red lines indicate reaches that were surveyed to develop a bull trout redd occupancy model. Yellow lines show reaches that were outside of known spawning locations and met specific selection criteria based on habitat accessibility, restoration potential, and thermal suitability.

To identify thermally suitable reaches in the basin, temperature data loggers (HOBO Pendant, Onset Computer Corporation, Pocasset, MA; accuracy ± 0.53°C) were deployed during the summer months of 2013 and 2014 to measure maximum daily temperatures (Figure 2). In addition to the data loggers deployed specifically for this project, temperature data were used from loggers deployed at monitoring sites for the Mount Saint Helens Water Quality Monitoring Program and the USFS Aquatic and Riparian Effectiveness Monitoring Program (Appendix A). In general, temperature sites were selected to capture thermal gradients related to elevation within the individual streams of interest. With this approach we could take advantage of the strong association between elevation and temperature (Dunham and Chandler 2001; Isaak and Hubert 2001) and model maximum temperature as a function of elevation using linear regression. Multiple data loggers were deployed in streams with extensive habitat availability (e.g., Clear and Clearwater creeks) with at least one each near the upper and lower bounds of the available habitat. Only one data logger was deployed in streams with little accessible habitat (e.g., Cussed Hollow and Spencer Creek) as temperature gradients were assumed to be negligible owing to the minimal elevation differences between the upper and lower bounds of the accessible habitat.

Only temperature data collected in 2013 were used to identify thermally suitable reaches because stream temperatures were cooler in 2013 compared to 2014 thereby increasing the amount of suitable habitat to assess and 2014 data were not available from several of the key sites (e.g. Muddy River above Clear Creek).

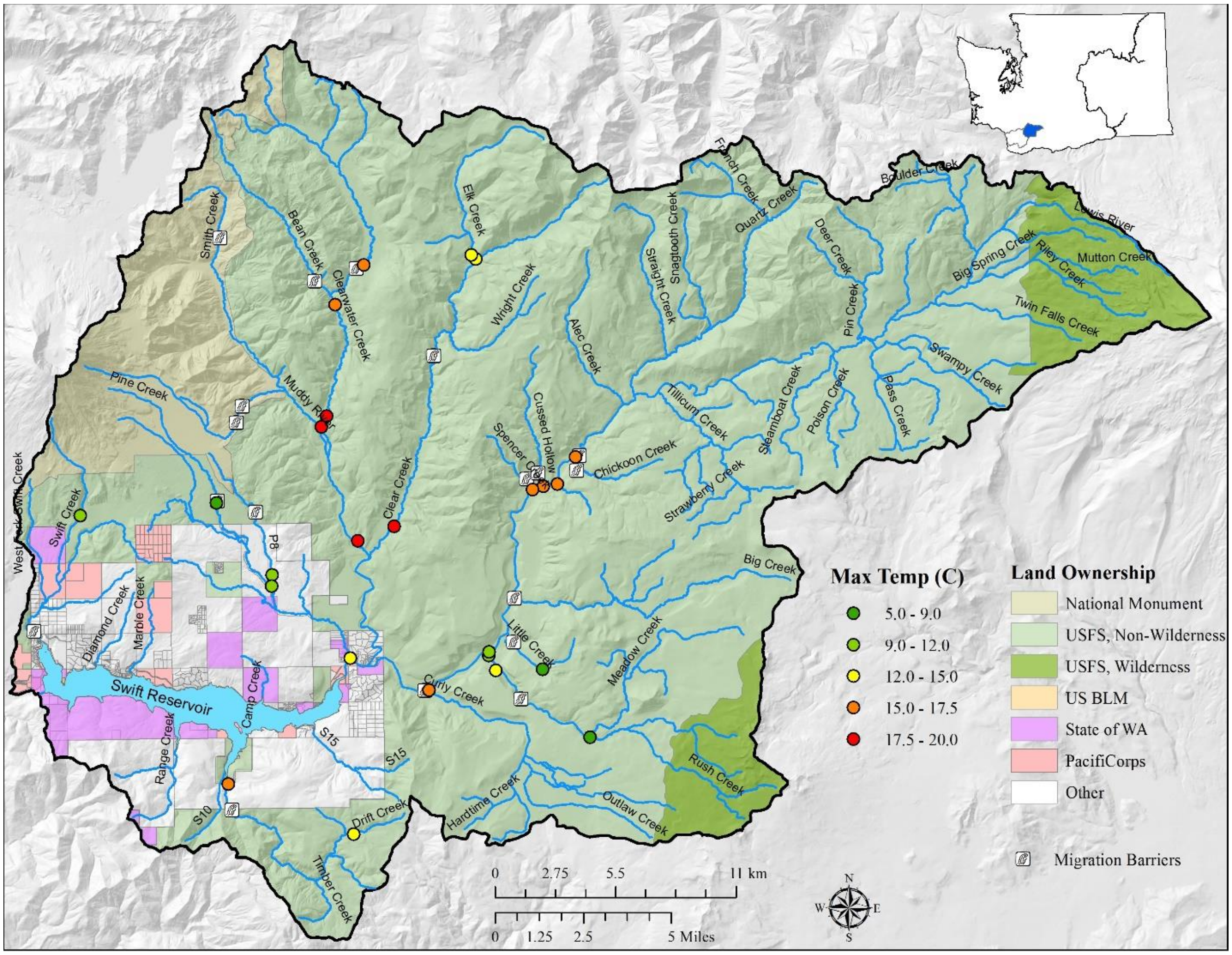

Figure 2. Map showing 2013 maximum daily stream temperatures in the upper Lewis River basin.

Of all the stream reaches that met the passage barrier and restoration potential criteria, only three were limited by our thermal suitability criterion (see Appendix A). These reaches were in Clear Creek, Clearwater Creek, and the Muddy River. Linear regression was used to model the lower bound of thermally suitable habitat in these reaches (Table 1). For Clear and Clearwater creeks, two temperatures were used as the inputs, one each near the upper and lower extent of available habitat. The lower bound of thermally suitable habitat was modeled at 1361 feet elevation in Clear Creek and 1528 feet elevation in Clearwater Creek. For the Muddy River, data were only available from one site (Muddy River Above Clear Creek) and that site was downstream of the temperature limit (>17.5 ^{o}C) so additional data inputs were needed from higher elevation sites to model Muddy River temperature. Clear Creek and Clearwater Creek temperature sites were considered as options and the Clearwater Creek sites were selected because the temperature at the Muddy River site was warmer than would be expected based on the Clear Creek regression but it was a reasonable value when compared to the Clearwater Creek regression. Therefore, Clearwater Creek and Muddy River data were pooled (3 sites) and the lower bound of thermally suitable habitat was modeled at 1498 feet elevation. This elevation is located 0.33 km above Clearwater Creek; however, the extent of the reach for survey purposes was extended downstream to the Clearwater Creek confluence based on recommendations by local biologists.

The reaches that met the selection criteria based on habitat accessibility, restoration potential, and thermal suitability are presented in Table 2 and Figure 1.

Table 1. Stream-specific linear regression equations relating maximum daily temperature (°C) to elevation (feet).

Stream	Linear Regression Equation
Clear Creek	MaxTemp = - 0.0048 * (Elevation) + 24.03
Clearwater Creek	MaxTemp = - 0.0139 * (Elevation) + 38.74
Muddy River	MaxTemp = - 0.0093 * (Elevation) + 31.43

Table 2. Stream reaches that were selected to model bull trout redd occurrence and to assess for potential habitat restoration sites.

Stream	Upper Bound	Lower Bound	Bull Trout Spawning Status
P8	Passage Barrier	Mouth	Known - Yes
Pine Creek	Passage Barrier	Mouth	Known - Yes
Rush Creek	Safety	Mouth	Known - Yes
Bean Creek	Passage Barrier	Mouth	Unknown
Big Creek	Passage Barrier	Mouth	Unknown
Chickoon Creek	Passage Barrier	Mouth	Unknown
Clear Creek	Passage Barrier	Thermal Threshold	Unknown
Clearwater Creek	Passage Barrier	Thermal Threshold	Unknown
Cussed Hollow	Passage Barrier	Mouth	Unknown
Drift Creek	Above Passage Barrier	Mouth	Unknown
Muddy River	MSHNVM	Thermal Threshold	Unknown
Smith Creek	MSHNVM	Mouth	Unknown
Spencer Creek	Passage Barrier	Mouth	Unknown

Note: MSHNVM, Mount Saint Helens National Volcanic Monument

In-stream Habitat Surveys

Spatially continuous habitat surveys were conducted during base flow conditions from July 28 to September 3, 2014 (known spawning areas) and from July 20 to September 15, 2015 (outside of known spawning areas) by a two-person field crew. The surveys were designed to quantify the habitat available to spawning bull trout and included metrics likely to influence salmonid spawning habitat use and likely to be altered by habitat restoration efforts. Attributes of in-stream habitat that have been shown to influence spawning habitat use and were quantified in the surveys included stream channel type (Wissmar and Craig 2004), large woody debris (LWD; Senter and Pasternack 2011; Shellberg et al. 2010), instream hiding cover (Bjornn and Reiser 1991; Wissmar and Craig 2004; Braun and Reynolds 2011; Nika et al. 2011), and potential spawning patches (PSP; Lamperth 2012). PSPs are defined below. Additionally, data were collected to characterize channel morphology (i.e., wetted width, depth, maximum depth) and surface substrate type.

Habitat surveys were conducted in a downstream direction and covered the entire spatial extent identified during the reach selection process. Typically the surveys started at a passage barrier and ended at the mouth of the stream or at the thermal threshold. Select habitat metrics were collected within each habitat unit, in other words, habitat data were organized by habitat unit. Habitat units were visually classified as a pool, riffle, or glide (Bisson et al. 1982). Pools were classified as a habitat unit if the length was greater than the wetted width of the channel. The upper extent of the habitat unit was georeferenced with a handheld global positioning system (GPS; Garmin etrex, Garmin, Olathe, KS) and the accuracy of the waypoint was recorded. The length of each habitat unit was measured with a hand-held range finder. Habitat units longer than 100 m (i.e., riffles) were subdivided into shorter distances with the maximum length set at 100 m due to the spatial resolution of the analysis approach (i.e., the habitat variables were summarized at 100 m reaches; see Data Analysis section).

Habitat units were classified as being part of one of three stream channel types: main channel, side channel, or braided channel. Main channels were defined as the channel with the majority of the flow; side channels were channels separated from the main channel by an island with well-established vegetation and carrying at least 10% of the stream flow; and braided channels were channels separated by islands of river bed material (i.e., substrate) without well-established vegetation and carrying at least 10% of the stream flow.

Wetted width was measured perpendicular to the flow at five evenly-spaced transects (including one at the upstream and one at the downstream extent of the unit) to the nearest 0.1 m. Depth was measured to the nearest 0.01 m at one-quarter, one-half, and three-quarter distance along each width transect and at the deepest location within the entire habitat unit (maximum depth). In cases where the channel could not be safely crossed, depth measurements were estimated. Pieces of channel-forming LWD (both > 5.0 m length and > 30 cm diameter) within the active stream channel were counted. Isolated pools that were not large enough to be classified as a habitat unit were counted. The percentage of dominant and subdominant surface substrate types were visually estimated to the nearest 10% within each habitat unit. The substrate type had to make up at least 20% of the habitat unit to be included. Substrate types were categorized by intermediate axis length and included fines (< 2 mm), gravel (2–64 mm), cobble (64–256 mm), boulder (> 256 mm), and bedrock (Cummins 1962).

Hiding cover was defined as a slow water velocity area that had some type of shelter associated with it. Aquatic and riparian habitat features that were considered hiding cover included wood (both > 1.0 m length and > 10 cm diameter), overhanging vegetation touching the stream surface, and undercut banks with horizontal depths > 50 cm. Turbulence was also considered cover if the samplers could not clearly delineate substrate particles through the water surface. In addition to these criteria, the habitat features needed to include a surface water area of at least 0.5 m^2 with no point shallower than 45 cm. Depths greater than 80 cm with a minimum area of 0.5 m^2 were considered cover even if no cover features were associated with them. Hiding cover was quantified as the surface water area associated with each cover feature.

Three important microhabitat components of suitable spawning habitat – gravel, water depth, and water velocity (Bjornn and Reiser 1991; Kondolf and Wolman 1993; Crisp 2000; Armstrong et al. 2003; Barlaup et al. 2008) – were quantified as a composite variable, PSP (*sensu* Isaak et al. 2007). PSPs were identified as areas at least 0.5 m^2 with gravel as the dominant substrate (intermediate axis length 2–64 mm), water depth 10–35 cm, and water velocities at least 10 cm/s (visually estimated). These criteria are based on research describing microhabitat characteristics of bull trout redds (Kitano et al. 1994; Hagen and Taylor 2001; Wissmar and Craig 2004; for a review see McPhail and Baxter 1996). Dominant surface substrate size for PSP was determined visually by comparing the surface substrate to a 64 mm reference stone. Similar to hiding cover, PSP was quantified as the area of the water surface where these criteria were met.

<u>Redd Locations and Microhabitat Characteristics</u>

Spatially continuous bull trout redd surveys were conducted in all of the known spawning tributaries from September 10 to October 30, 2014, after the habitat surveys were completed. The redd surveys covered, at minimum, the spatial extent of the habitat surveys. Surveys were conducted on a total of 33 days and each stream was generally surveyed on a weekly basis. The surveys were designed to document accumulation of redds, redd location, the type of channel used (i.e., main, side, or braided channel), and to quantify select microhabitat characteristics.

Surveyors were trained on redd identification prior to the conducting the redd surveys. Redds were identified as disturbed areas of the streambed with clean substrate and a well-defined substrate excavation site (i.e., pit or pot) and substrate deposition site (i.e., pillow and tailspill). Surveyors took care to exclude redd-like features that were created hydraulic forces. Redds were classified as either “definite” or “possible” based on how well defined the stream feature was. If the surveyor was uncertain whether the feature was created by a spawning bull trout, the redd was classified as “possible”. “Definite” and “possible” redds were georeferenced and the accuracy of the waypoint was recorded. Redds were also visually marked by securing surveyor’s flagging to stream side structures (e.g., vegetation or LWD). The date of the observation, the number of bull trout observed in the vicinity of the redd, and the type of stream channel used were recorded.

Microhabitat data were collected to characterize the location of the redd across the stream channel and the water depth of various features of the redd. At each “definite” redd, surveyors measured the wetted width of the channel (to the nearest 0.1 m), the distance from the center of the redd to the nearest stream margin (to the nearest 0.1 m), and the relative location of the redd (i.e., river right or river left). Depth measurements (to the nearest 0.01 m) were taken at the pit, the pillow, the tailspill, and from one undisturbed location on each side of the redd.

Data Analysis

There were four analysis objectives: 1) model bull trout redd occurrence as a function of in-stream habitat data, 2) use an electivity index to further understand spawning habitat selection, 3) describe the microhabitat of redds, and 4) identify areas lacking suitable spawning habitat based on the redd occurrence model.

Developing the redd occurrence model was a complex process so it is briefly summarized here. Logistic regression was used to model redd occurrence, or the present-absence of redds, in 100 m reaches. The model did not take into account the absolute number of redds in a reach, simply whether the number of redds was 0 or greater than 0. Several steps were taken to develop the model and included summarizing and organizing the field habitat data into 100 m reaches, linking redd and reach locations using GIS, selecting variables that contained information about redd occurrence but were not correlated with other variables (variable selection), and selecting the best model among several candidate models. The following sections provide more detail about this analysis process.

Logistic Regression

Logistic regression was used as a resource selection function to model the probability of bull trout redd occurrence as a function of select habitat variables. In general, logistic regression is a linear model that predicts the probability of an event occurring (e.g., redd occurrence) with a binary response variable (e.g., redd presence/absence) (Hosmer and Lemeshow 1989). Logistic regression is a popular analysis approach in habitat selection studies (Johnson et al. 2006) and is often used to predict the occurrence of stream fishes as a function of various biotic and abiotic factors (e.g., Dunham et al. 2003; Rich et al. 2003; Al-Chokhachy and Budy 2007; Isaak et al. 2007; Muhlfeld et al. 2009).

The following is the logistic regression equation used to model the probability of redd occurrence:

$$\theta = \frac{e^{g(x)}}{1 + e^{g(x)}}$$

Where θ is the probability of redd presence, e is the base of natural logarithms, and $g(x)$ is a linear model of the explanatory variables (i.e., $\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i$).

Summarizing Field Data

In-stream habitat survey data were first summarized at the habitat unit scale. Mean and coefficient of variation (CV; a measure of habitat diversity) values were calculated for depth, width, and width-to-depth ratio (W/D). Mean depth was calculated by summing all measurements, including 0.00 m depths at each stream margin, and dividing by the total number of measurements. Mean width was calculated by summing all transect measurements and dividing by the total number of transects. Mean W/D was calculated by summing the W/D values for each transect (the transect width measurement divided by the mean depth of the transect) and dividing by the number of transects. Coefficient of variation for each of these variables was calculated by dividing the standard deviation by the mean and multiplying by 100, thus it is represented as a percentage. Maximum depth was collected as a single measurement in the field and that value was used as the summary value. Cover, PSP, LWD, and the number of pools were summed. Habitat area was calculated by multiplying mean width by unit length. Dominant and subdominant substrate data were converted to areas (m^2) of each substrate type (fines, gravel, cobble, boulder, and bedrock). This was done by multiplying the proportion of each substrate type by the habitat area.

After summarizing the habitat data at the habitat unit scale, the data were summarized at 100 m reaches using an R script developed for binning longitudinal stream survey data (Welty et al. 2015). To achieve this, the script aggregated the habitat data based on location using the lengths of the habitat units as weighting factors. For each 100 m reach, the script calculated mean values for depth, width, W/D and the CVs for these variables; calculated summed values for cover, PSP, LWD, the number of pools, the area of each substrate type, the area of each habitat unit type (pools and riffles); and identified maximum depth. By using this approach, the more detailed information collected at the habitat unit scale was preserved while creating equally-sized analysis units. Expanding the spatial extent of the analysis unit also helped reduce inaccurate links (due to GPS inaccuracies) between redd and habitat locations.

A geographical information system was used to include an additional habitat variable, complex channel, for each 100 m reach and to link reaches with redd locations. Complex channels were populated into the data matrix as a binary dummy variable (i.e., 1 or 0) where the reach was given a value of 1 if more than one channel with flowing water existed in the reach or a value of 0 if only one channel was present. This was achieved by identifying reaches where side or braided channels were present. A reach was classified as occupied, if at least one redd was present within the reach, or unoccupied, if 0 redds were present in the reach.

Habitat Variable Selection

A multistep process was used to select the habitat variables that would be included in the model. In the first step, individual variables were tested to determine whether they could predict redd occurrence better than a model with no variables. In other words, the variables were tested to determine whether they contained information about redd occurrence. This was done by comparing single variable models to the intercept-only model using Akaike's information criterion corrected for small sample sizes (AIC_c; Burnham and Anderson 2002). Smaller AIC_c scores indicate models that contain more information. Variables that contained less information (had a larger AIC_c score) than a model with no variables were removed from the variable list. For the continuous variables (all variables except complex channel), this step was performed for both raw and log-transformed ($\log_e$ (x+1)) variables (two structural forms).

In the second step of variable selection, the two structure forms of each variable were compared using AIC_c. General guidelines for using AIC_c state that models within 2 points of each other contain similar amounts of information. Therefore, if the AIC_c score for one form of the variable was 2 points greater than the other form of the variable it was removed from the variable list. In cases where the difference in AIC_c score between two variable forms was less than or equal to 2, the raw form was retained.

In the final step of variable selection, correlations among variables were tested using Spearman's rank correlation coefficient (r) because habitat variables often covary and highly correlated variables in a model can lead to unreliable results (Hosmer and Lemeshow 1989). Variable pairs with $r > 0.65$ were considered highly correlated and the variable of the offending pair that had a higher AIC_c score was removed.

The variables that remained after this selection process were retained for the model selection process.

Model Selection

The first step in the model selection process was to test model assumptions. The assumptions were tested with the global model, or the model that related redd occurrence to all variables retained through the variable selection process. Model goodness-of fit was tested with the Hosmer-Lemeshow test (Hosmer and Lemeshow 1989). This test evaluated whether the logistic model was a good model to use with the given data. Spatial autocorrelation, or a systematic pattern in the spatial distribution of a variable, was evaluated with Mantel's test. Spatial autocorrelation violates the assumption of independent observations for parametric analyses (Legendre 1993). If the global model met these assumptions ($P > 0.05$), then all possible subsets of the global model were evaluated to identify the best models predicting redd occurrence.

Information theory was used to identify the best approximating models among all possible model subsets (i.e., 2^p models where p is the number of variables in the model). All possible model subsets were generated with the R package *glmulti* (Calcagno 2013) and ranked using AIC_c. The difference between the AIC_c of a candidate model and the one with the lowest AIC_c (Δ AIC_c) was used to identify models that had strong support for being the best approximating model (Δ $AIC_c \leq 2$) (Burnham and Anderson 2002).

Once the best models were identified, measures appropriate for logistic regression models were used to evaluate model accuracy and predictive power. Model accuracy was evaluated using the area under the curve (AUC) of the receiver-operator characteristic plots. In general, AUC values of 0.5 – 0.7 indicate low accuracy, values of 0.7 – 0.9 indicate medium accuracy, and values of > 0.9 indicate high accuracy (Manel et al. 2001). Predictive power was evaluated using max-rescaled R^2 values, a measure that ranges between 0 and 1 with larger values indicating stronger predictive power (Chen et al. 2008).

Odds ratios were used to determine the influence of each variable on redd occurrence. The odds ratio is the change in the odds of redd occurrence with a one unit increase in the variable and was calculated by raising e to the parameter estimate of the variable (i.e., e^{β}). The

95% confidence interval of the odds ratio was calculated as $e^{\beta \pm SE(\beta)*1.96}$. In cases where one unit increase did not make sense ecologically, scaling factors were included in the odds ratio calculation to provide more meaningful results. If the scaling factor is defined as *c*, then the scaled odds ratio is $e^{c*\beta}$ and the scaled 95% confidence interval is $e^{c*\beta \pm c*SE(\beta)*1.96}$.

Electivity Index

An electivity index (Baltz 1990) was used to evaluate habitat selection or avoidance by female bull trout. The analysis was limited to selection or avoidance of side and braided channel habitats combined. The following equation was used to calculate the electivity index (D):

$$D = (r - p) / (r + p) - 2rp$$

where r is the proportion of redds that occurred in side or braided channels and p is the proportion of side and braided channel habitat available to female bull trout.

Values of D range from -1.00 to 1.00 where values from -1.00 to -0.50 indicate strong avoidance, values from -0.49 to -0.26 indicate moderate avoidance, values from -0.25 to 0.25 indicate neutral selection, values from 0.26 to 0.49 indicate moderate selection, and values from 0.50 to 1.00 indicate strong selection (Matthews 1996).

Redd Microhabitat Characteristics

Redd microhabitat characteristics were summarized by measures of central tendency and variability (e.g., mean and standard deviation). Relative redd location across the stream channel was converted to an index, termed Cross-Channel Location Index, before summarizing the data. Cross-Channel Location Index was calculated by dividing the distance from the center of the redd to the stream margin by the wetted width. Cross-Channel Location Index values range from 0.00 to 0.50 with 0.00 being the stream margin and 0.50 being the center of the channel.

RESULTS

Model Results

Habitat and redd survey data collected in Pine Creek and P8 were used to generate the redd occupancy model. Rush Creek data were excluded from the occupancy model because only one "possible" redd was observed when it is likely several redds were present. Data from Pine Creek and P8 were summarized into a total of 163, 100-m reaches; 123 reaches in Pine Creek and 40 reaches in P8 (Appendix B-1 and B-2). Reaches that had more than one channel with flowing water (complex channels) made up 33.3% and 32.5% of the reaches in Pine Creek and P8, respectively.

The redd surveys documented a patchy distribution of 66 redds, 20 in Pine Creek and 46 in P8 (Figure 3). Of the total observed, 59 were classified as "definite" and 7 were classified as "possible". Both "definite" and "possible" redds were used to identify occupied reaches. Although the data are not presented here, redd life information (the length of time a redd remained visible) was collected during the redd surveys and all "possible" redds became non-visible at some point during the survey timeframe. This information suggests that the features identified as possible redds were not persistent features created by stream hydraulic forces. Furthermore, only 2 of the 7 "possible" redds were in reaches without "definite" redds. Therefore, the inclusion of these redds likely did not affect model results. Of the 163 reaches, 17.8% or 29 reaches (14 reaches in Pine Creek and 15 reaches in P8) were occupied by at least one redd.

A single redd survey was conducted above the P8 passage barrier, outside the spatial extent of the occupancy model, on October 13, 2014 to determine whether bull trout negotiated the passage barrier and spawned. No bull trout or redds were observed.

A total of 9 habitat variables were retained through the variable selection process. The retained variables included the only categorical variable (i.e., Complex Channel) and 8 of the possible 18 continuous variables. Table 3 (Complex Channel) and Table 4 (continuous variables) compare the variables between reaches with and without redds. Three of the continuous variables that were retained were of the log-transformed structural form (Pool (m^2), Fines (m^2), and

Bedrock (m^2)). The global model relating redd occurrence to these 9 variables adequately fit the data (Hosmer-Lemeshow, P = 0.50) and the residuals of the model lacked spatial autocorrelation (Mantel's test, P = 0.996).

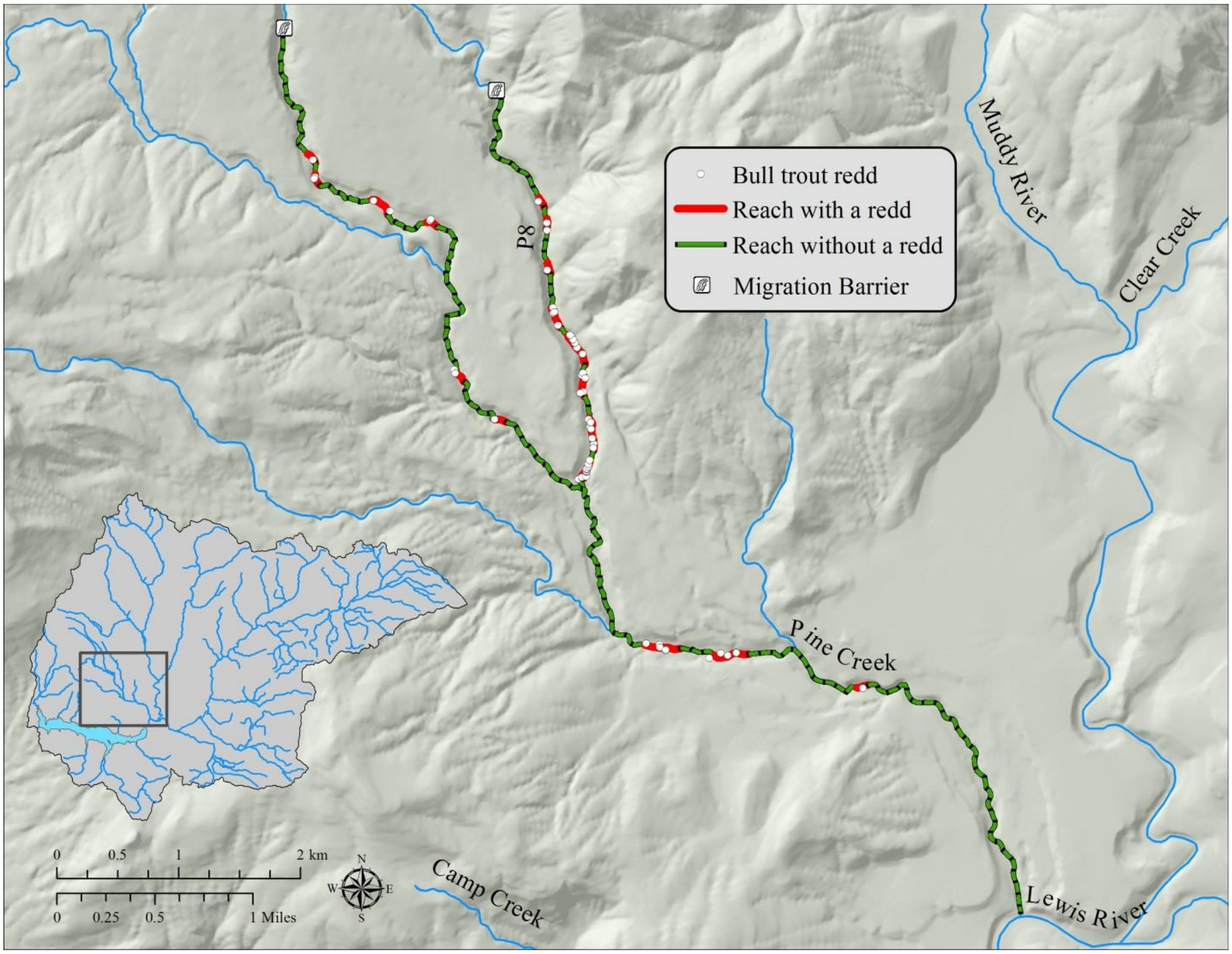

Figure 3. Locations of bull trout redds observed in the Pine Creek basin, WA in 2014 and the location of 100 m reaches by level of bull trout redd occurrence.

Table 3. Counts of redd occupancy in 100 m reaches with complex and simple channels. Numbers in parentheses are expected counts for each cell.

	Redd Present	Redd Absent	Total
Complex Channel	17 (9.6)	37 (44.4)	54
Simple Channel	12 (19.4)	97 (89.6)	109

Total	29	134	**163**

Table 4. Descriptive statistics of 100 m reaches by level of bull trout redd occurrence in Pine Creek and P8 combined. Variables that were retained through the variable selection process to model bull trout redd occurrence are in bold type. Statistics for each variable are derived from non-transformed values.

	Redd Present (n = 29)					Redd Absent (n = 134)				
Variable	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max
Depth (m)	**0.218**	**0.047**	**0.200**	**0.155**	**0.304**	**0.259**	**0.054**	**0.265**	**0.138**	**0.447**
Width (m)	**7.4**	**3.0**	**5.8**	**4.1**	**14.0**	**8.8**	**2.5**	**9.3**	**4.1**	**14.5**
W/D	36.1	9.9	33.6	22.5	61.8	37.2	8.9	37.0	18.3	69.8
CV depth (%)	96.1	5.1	95.6	90.3	115.3	97.1	5.1	96.8	88.5	110.7
CV width (%)	**19.3**	**6.9**	**18.2**	**10.1**	**35.9**	**22.2**	**7.7**	**22.5**	**6.2**	**47.6**
CV W/D (%)	35.0	12.1	34.4	9.4	61.4	40.2	14.1	38.2	9.3	79.5
Max Depth (m)	0.749	0.254	0.700	0.400	1.500	0.906	0.279	0.825	0.450	1.500
Cover (m^2)	3.8	6.6	1.4	0.0	31.5	3.0	5.1	1.5	0.0	40.7
PSP (m^2)	**4.3**	**4.7**	**2.1**	**0.0**	**15.0**	**2.5**	**3.6**	**1.5**	**0.0**	**26.3**
LWD (no./100m)	**5.7**	**4.6**	**5.6**	**0.2**	**14.3**	**4.0**	**4.1**	**3.0**	**0.0**	**19.0**
Pools (no./100m)	1.1	1.0	1.0	0.0	3.7	0.9	0.9	0.8	0.0	4.2
Pool (m^2)	**6.4**	**15.1**	**0.0**	**0.0**	**51.1**	**3.2**	**14.6**	**0.0**	**0.0**	**123.2**
Riffle (m^2)	737.0	301.9	569.3	388.4	1399.7	872.4	255.7	895.3	369.2	1457.2
Fines (m^2)	**14.5**	**31.4**	**0.0**	**0.0**	**125.3**	**7.4**	**35.7**	**0.0**	**0.0**	**267.2**
Gravel (m^2)	80.7	90.0	71.9	0.0	284.5	64.9	93.7	0.0	0.0	364.0
Cobble (m^2)	282.4	154.1	234.1	0.0	699.8	323.8	173.1	312.1	0.0	818.0
Boulder (m^2)	**138.3**	**154.6**	**61.3**	**0.0**	**439.9**	**182.5**	**139.5**	**197.3**	**0.0**	**495.6**
Bedrock (m^2)	0.0	0.0	0.0	0.0	0.0	34.4	114.2	0.0	0.0	666.2

Note: PSP is potential spawning patches; LWD is large woody debris; CV is coefficient of variation; W/D is width-to-depth ratio; SD is standard deviation; min is minimum; and max is maximum.

A total of 512 models were generated that included unique combinations of the 9 retained habitat variables. Of all the possible model subsets, 11 had strong support for being the best approximating model ($\Delta AIC_c \leq 2$; Table 5). The variables Complex Channel and Depth were present in all top models. Various combinations of CV Width (%), Fines (m^2), Boulder (m^2), LWD (no./100 m), Width (m), and PSP (m^2) appeared with Complex Channel and Depth in 10 of the models. Pool (m^2) was not included in any of the top models. This information suggests Complex Channel and Depth contained the most information about redd occupancy with minor contributions from the other variables. Indeed, Complex Channel and Depth were the only significant variables ($P < 0.05$) in all of the top models and the global model (Appendix C). Model accuracy and predictive performance were similar among all the top models. AUC values ranged from 0.76 to 0.78 indicating the models had medium accuracy, and max-rescaled R^2 values ranged from 0.23 to 0.25 indicating moderate predictive performance.

Table 5. The best supported models out of all possible model subsets predicting bull trout redd occurrence as a function of select habitat variables in the upper Lewis River basin, WA. Log-transformed ($\log_e(x+1)$) values of Pool (m^2), Fines (m^2), and Boulder (m^2) were used in the models.

Model Variables	K	AIC_c	ΔAIC_c	AUC	max-rescaled R^2
Complex Channel, Depth	3	134.46	0.00	0.76	0.23
Complex Channel, Depth, CV Width	4	134.59	0.13	0.77	0.25
Complex Channel, Depth, Fines	4	135.93	1.47	0.78	0.23
Complex Channel, Depth, Boulder	4	136.00	1.54	0.76	0.23
Complex Channel, Depth, Boulder, CV Width	5	136.23	1.77	0.77	0.25
Complex Channel, Depth, LWD	4	136.24	1.78	0.76	0.23
Complex Channel, Depth, LWD, CV Width	5	136.34	1.89	0.78	0.25
Complex Channel, Depth, Width, CV Width	5	136.38	1.92	0.78	0.25
Complex Channel, Depth, Width	4	136.41	1.95	0.76	0.23
Complex Channel, Depth, Fines, CV Width	5	136.43	1.97	0.78	0.25
Complex Channel, Depth, PSP	4	136.45	1.99	0.76	0.23
Complex Channel, Depth, Width, Boulder, Fines, PSP, LWD, CV Width, Pool [a]	10	145.80	11.34	0.78	0.26
NONE[b]	1	156.66	20.20	0.50	0.00

Note: K, the number of estimated parameters including the intercept; AIC_c, Akaike's information criterion corrected for small sample sizes; ΔAIC_c, AIC_c difference between model i and the model with the lowest AIC_c score; AUC, area under the curve of the receiver-operator characteristic plot; CV, coefficient of variation; LWD, large woody debris; PSP, potential spawning patches.

[a] Global model, shown for comparison.

[b] Null model, shown for comparison.

Parameter estimates and odds ratios for the two most important variables, Complex Channel and Depth, were very similar among all the best supported models ($\Delta AIC_c \leq 2$) and the global model (see Appendix C for global model results), therefore inferences about the relationship between these variables and redd occurrence are the same no matter which model is used. For simplicity, the parameter estimates and odds ratios for the model with the lowest AICc score are used to understand the relationship between these variables and redd occurrence (Table 6).

Table 6. Parameter estimates and odds ratios for the bull trout redd occupancy model with the lowest AICc score.

Variable	Parameter Estimate	Standard Error	Scaling factor	Scaled odds ratio	95% CI for scaled odds ratio	*P*-value
Intercept	1.871	1.086				0.085
Complex Channel	1.378	0.453	1.00	3.96	1.63 - 9.64	0.002
Depth (m)	-16.830	4.739	0.05	0.43	0.27 - 0.69	< 0.001

The model suggests bull trout redd occurrence was positively associated with the presence of complex channels and negatively associated with stream depth (Table 6). The odds of a bull trout redd occurring in a reach were four times greater if more than one channel (e.g., one main and one side channel) was present in the reach (odds ratio = 3.96). At minimum, indicated by the lower bound of the 95% confidence interval, there was a 63% increase in the predicted odds of redd occurrence in the presence of complex channels (1.63/1). Figure 4 shows the locations of redd occurrence in relation to channel complexity across the study area.

For stream depth, a scaling factor of 0.05 was used to compute the odds ratio. This converts the interpretation of the odds ratio from a 1 m unit to a 5 cm unit, a more meaningful unit of measure based of the difference in depth between reaches with and without redds (see Table 3). With a 5 cm increase in stream depth, the odds of a redd occurring in a reach decreased by more than two times (2.3 = 1/0.43). At minimum, indicated by the upper bound of the 95% confidence interval, the predicted odds of redd presence decreased by 1.6 times with a 5 cm increase in stream depth (1/0.69). This result is displayed graphically in Figure 5 by plotting a habitat preference index at various depth bins. The habitat preference index is the ratio of the proportion of habitat used to the proportion of habitat not used. For instance, 51.7% of reaches with redds (habitat used) had a mean depth between 15.1 cm and 20.0 cm while only 14.9% of reaches without redds (habitat not used) had a mean depth between 15.1 cm and 20.0 cm. At this depth range, the proportion of habitat used to the proportion of habitat not used was 3.47

(0.517/0.149). This ratio, and therefore habitat preference, decreased with increasing stream depth at the 100 m reach scale.

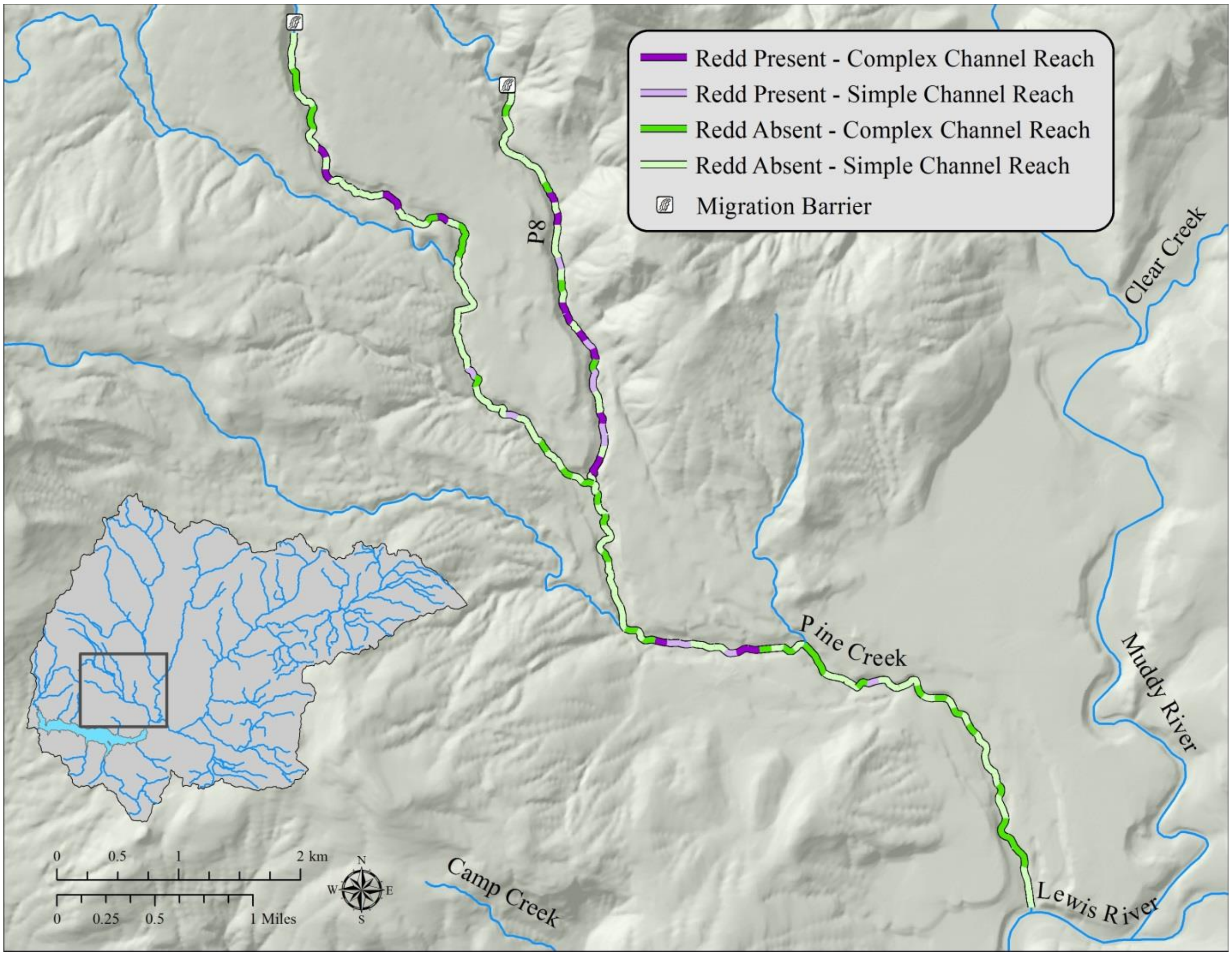

Figure 4. A map showing 100 m reaches by levels of bull trout redd occurrence and channel complexity in the Pine Creek basin, WA.

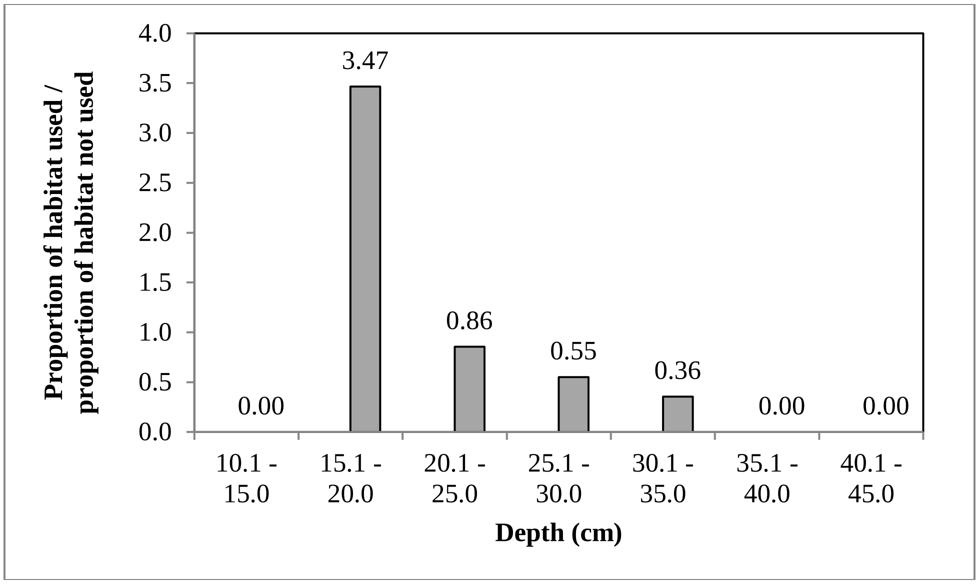

Figure 5. Stream depth preference by spawning bull trout in the Pine Creek basin, WA. Depth is the mean depth of 100 m reaches. The preference index values (proportion of habitat used/proportion of habitat not used) are indicated for each stream depth bin.

Electivity Index

The combination of side and braided channel habitat is referred to as side channel habitat in the following statements. Bull trout disproportionately used side channel habitat compared to mainstem habitat to construct redds. While only 9.2% of the available habitat was side channel habitat (14,064 m^2 of 152,960 m^2), 24.2% of the redds (16 of 66 redds) were constructed in side channel habitat (Table 7). This information resulted in an electivity index of 0.405, indicating moderate selection for side channel habitat.

Table 7. Habitat selection of side channel habitats by spawning bull trout as indicated by an electivity index (*D*) where *r* is the proportion of redds constructed in side channel habitat and *p* is the proportion of side channel habitat available to spawning bull trout.

Stream	*D*	*r*	*p*
Pine Creek	0.467	0.300	0.094
P8	0.429	0.217	0.080
Pooled Data	***0.405***	***0.242***	***0.092***

Redd Microhabitat Characteristics

Microhabitat data were collected from 53 of the 66 observed redds. The data suggest bull trout tend to spawn closer to the margin than towards the center of the channel (Mean Cross-Channel Location Index = 0.20; Table 8). In addition to depth measurements collected at various redd features, measurements were taken from undisturbed areas adjacent to redds. These measurements can be used as estimates of stream depths used by spawning bull trout. Mean ± SD depth adjacent to the redd and away from the stream margin was 0.21 ± 0.08 m while the stream depth toward the margin was 0.16 ± 0.09 m.

Table 8. Descriptive statistics of select microhabitat variables associated with bull trout redds.

		Depth (m)				
	Cross-Channel Location Index	Redd Pit	Redd Pillow	Redd Tailspill	Channel Away From Margin	Channel Toward Margin
n	53	53	53	53	53	53
Mean	0.20	0.28	0.15	0.20	0.21	0.16
Standard Deviation	0.08	0.07	0.07	0.08	0.08	0.09
Median	0.20	0.27	0.14	0.19	0.20	0.15
Minimum	0.05	0.13	0.05	0.02	0.05	0.00
Maximum	0.43	0.45	0.37	0.36	0.45	0.34

Habitat Outside of Known Spawning Locations

Habitat surveys outside of known spawning tributaries covered a total of 22.2 stream kilometers. The descriptive statistics of each stream are in Appendix B. In this section of the report the habitat is characterized in terms of the channel complexity and stream depth, the most important factors based on the model results. The figures below show the proportion of 100 m reaches with complex channels (Figure 6), suitable stream depths (Figure 7), and both complex channels and suitable stream depths (Figure 8). Rush Creek, P8, and Pine Creek are included in the graphs for comparison purposes as bull trout are known to spawn in these streams. Suitable stream depths are categorized into 5 cm bins to reflect the preference index bins displayed in Figure 5.

The streams with the highest proportion of reaches with both important variables (about 33% of the reaches per stream) are the streams where bull trout are known to spawn (Figure 8). Outside of known spawning streams, the streams with the highest proportion of reaches with both important variables are Muddy River (27%), Smith Creek (22%), Clearwater Creek (21%), Clear Creek (17%), and Cussed Hollow (17%). Based on the data collected in this study, bull trout have the highest preference for reach stream depths of 15 – 20 cm. Excluding the known spawning tributaries, the streams with the highest proportion of reaches with complex channels and the most preferred stream depth (15 – 20 cm) are Drift Creek and Smith Creek, both with 13% of the reaches. Reaches with both complex channels and suitable stream depths are not present in Big, Chickoon, and Spencer creeks.

The spatial distribution of reaches with both important variables is displayed in Figure 9. The map shows a patchy network of potentially suitable spawning habitat throughout the study area. For example, although Clearwater Creek has one of the highest proportions of reaches with both complex channels and suitable depths, it has long stretches of habitat lacking these attributes.

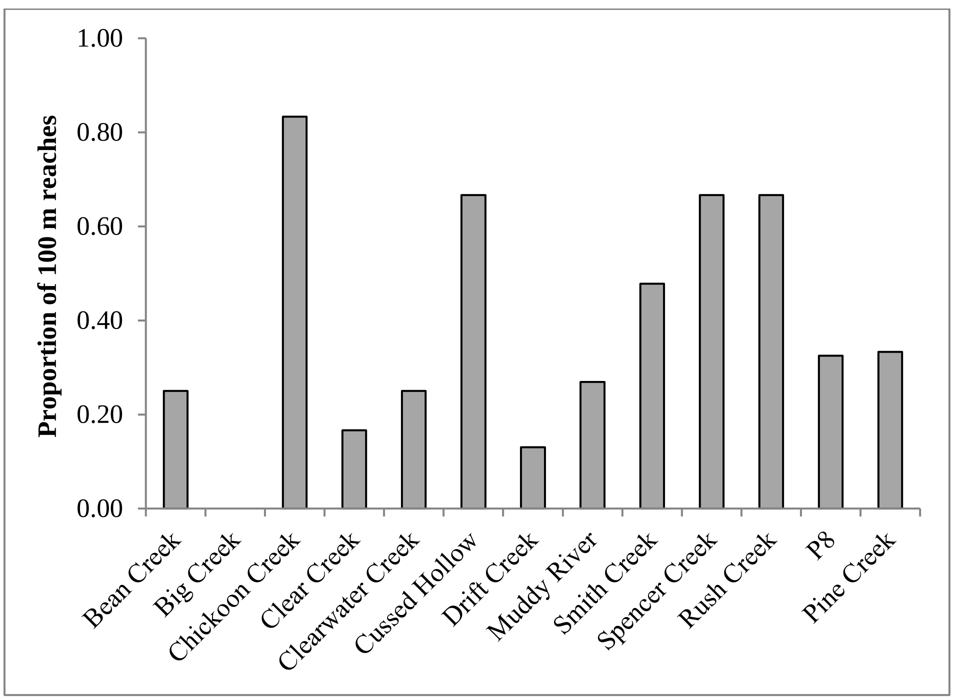

Figure 6. Proportion of 100 m reaches with a complex channel by stream in the upper Lewis River basin, WA. Bull trout are known to spawn in Rush Creek, P8, and Pine Creek.

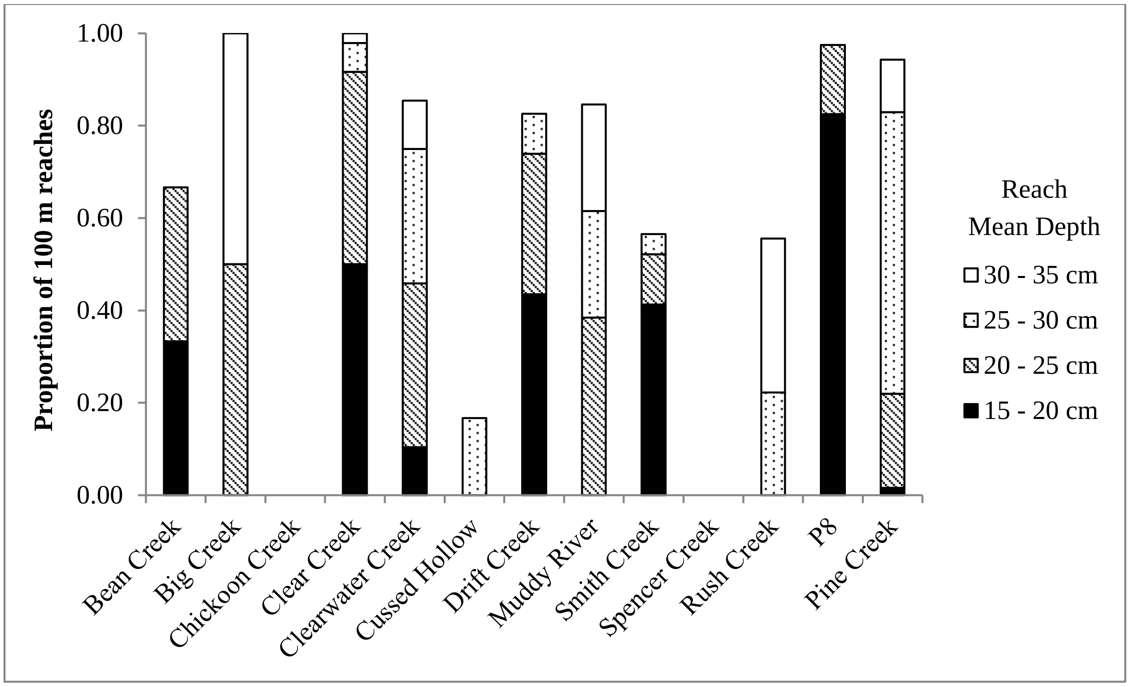

Figure 7. Proportion of 100 m reaches with suitable stream reach depth for spawning bull trout by stream in the upper Lewis River basin, WA. The most preferred depth is 15-20 cm. Habitat preference decreases with increasing depth. Bull trout are known to spawn in Rush Creek, P8, and Pine Creek.

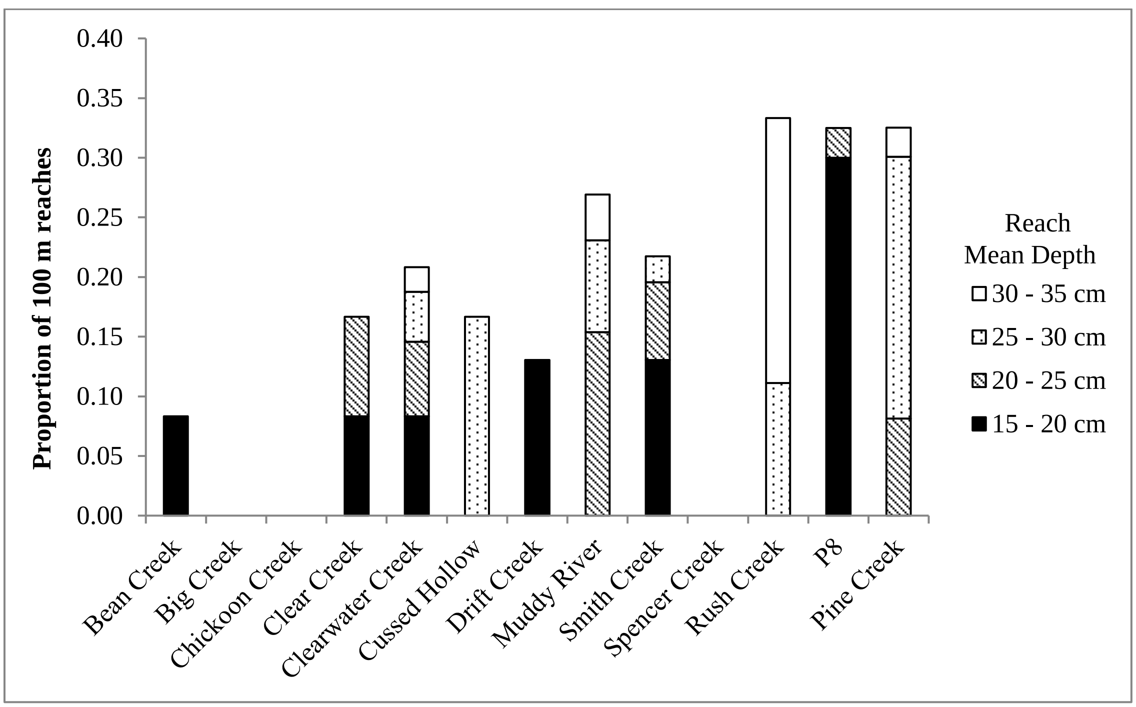

Figure 8. Proportion of 100 m reaches with both a complex channel and a suitable stream reach depth for spawning bull trout by stream in the upper Lewis River basin, WA. The most preferred depth is 15-20 cm. Habitat preference decreases with increasing depth. Bull trout are known to spawn in Rush Creek, P8, and Pine Creek.

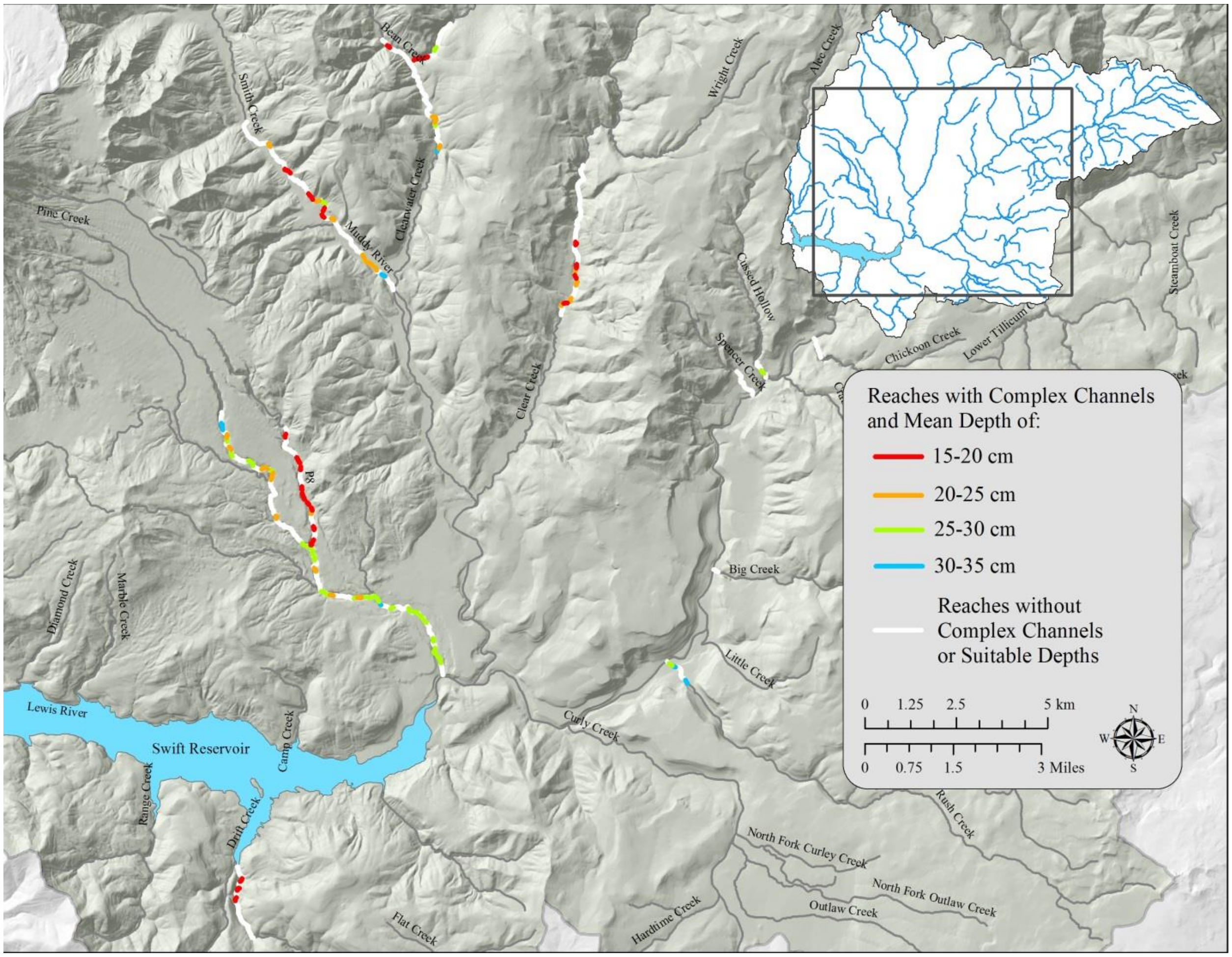

Figure 9. Location of 100 m reaches with both a complex channel and a suitable stream depth for spawning bull trout in the upper Lewis River basin, WA. The most preferred depth is 15-20 cm. Habitat preference decreases with increasing depth

DISCUSSION AND RECOMMENDATIONS

Stream temperature is the most important component of suitable spawning and rearing habitat for bull trout (Dunham et al. 2003; Isaak et al. 2010) as this species is one of the most cold water-adapted salmonid species in North America (Selong et al. 2001). Indeed, the current distribution of spawning in the Lewis River basin above Swift Reservoir is restricted to the coldest available habitat (see Figure 2 and Appendix A). The data used to model bull trout redd occurrence was collected within these cold-water habitats, so the results tell us what habitat characteristics are important in addition to cold water, or what habitat characteristics are important within cold-water habitats. We incorporated temperature when considering potential restoration sites (habitat outside of known spawning tributaries) by limiting potential restoration reaches to those that had ≥ 25% probability of juvenile bull trout occurrence based on maximum daily temperature (maximum daily temperature ≤ 17.5 °C). Again, we assume the presence of juvenile bull trout is indicative of suitable spawning and early rearing habitat. This liberal thermal suitability threshold resulted in ~ 22 km of habitat available for potential restoration actions. However, if we use a more conservative threshold and limit the study area to habitat that has ≥50% probability of occurrence (maximum daily temperature ≤ 15.0°C), the length of stream available for restoration actions is reduced to ~ 3 km. This habitat is in the Clearwater Creek basin and includes Bean Creek and the upper 2 km of Clearwater Creek below the passage barrier. This information suggests thermal suitability may be limited in the basin and the thermal environment must be considered when selecting potential restoration sites.

Within cold-water habitats of the upper Lewis Basin, bull trout redds were associated with complex channels and stream depths between 15 and 35 cm, and redds were generally constructed closer to the stream margin than the middle of the channel. Multiple lines of evidence suggest stream channel complexity is an important factor influencing the presence of bull trout redds in cold-water habitats of the upper Lewis River basin. Both the model results and electivity index indicate bull trout are more likely to build redds in reaches with multiple channels. This result is consistent with a habitat selection study on the east side of the Washington Cascades where spawning bull trout were also shown to select side channel habitats (Wissmar and Craig 2004). This result is also consistent with the general understanding that habitat complexity is considered an important attribute of quality bull trout habitat (Al-Chokhachy et al. 2010). As for depth, mean depth at the reach scale of the reaches with redds was similar to microhabitat depths of individual redds. The observed redd depths in this study are within the range of redd depths observed for other populations of bull trout (see Baxter and McPhail 1996 for a review; Lamperth 2012). Redds were observed closer to the stream margin than the center of the channel, similar to other Washington populations (Shellberg et al. 2010)

Proximity to existing populations is an additional factor that should be considered when selecting potential restoration sites. Any restored habitat in unoccupied areas of the basin will be used by colonizing bull trout or when a stochastic event occurs in current spawning tributaries (i.e., Pine or Rush basin) forcing adults to spawn elsewhere. In either event, the closer the restoration site is to existing spawning tributaries the more likely the restored habitat will be used.

Based on the results of this study, habitat restoration actions should be designed to increase habitat complexity and create stream depths between 15 and 35 cm during the spawning time frame in the coldest accessible stream reaches within the basin. If possible, actions also should consider reducing stream temperature adjacent to the coldest accessible habitat in order to increase the connectivity and spatial extent of cold water areas. Although the measures of gravel in this study (area of gravel and PSPs) did not come out as important variables, it is widely known and accepted that gravel-sized particles are an important component of suitable spawning habitat (Bjornn and Reiser 1991; Kondolf and Wolman 1993). Hence, it is also recommended that habitat actions be designed to promote gravel deposition and accumulation near stream margins of the project areas.

HABITAT RESTORATION CONCEPTUAL SCOPING DESIGNS

The primary objective of this project is to develop a list of habitat restoration recommendations that will increase the stability and viability of the Lewis River bull trout population. The ultimate goal of this project is to develop concept scoping designs for habitat restoration projects in areas outside of existing spawning and rearing locations to expand the range of available bull trout spawning and rearing habitat. Conceptual scoping designs identify habitat conditions to be targeted, but do not identify specific actions to address these habitat conditions. Subsequent project proposals will describe how the projects will benefit the habitat conditions in that specific location.

The key findings and recommendations of the project study were used to develop a habitat suitability matrix (Table 9) which in turn was used to guide the selection of potential restoration streams and to develop conceptual scoping designs of habitat restoration projects, the ultimate goal of this project. The habitat suitability matrix was developed by MSHI, WDFW, CIT, and USFS personnel and incorporates stream temperature, stream depth, channel complexity (as defined in the project study), and distance to a known population.

Table 9. Habitat attributes of streams considered for habitat restoration scoping designs.

Stream	Temperature (°C) [1]	Proximity to Pine (km)	Proximity to Rush (km)	Channel Complexity (proportions of 100 reaches)	Depth at 15-20 (cm) (proportions of 100 reaches)	Depth at 20-25 cm (proportion of 100 reaches)	Proportions of reaches with both important values (Complex channels and depth 15 - 25 cm)
Clearwater	15.0-17.5	19.6	25.7	25%	10%	35%	15%
Clear	16.2-17.5	14.8	21.0	17%	50%	42%	17%
Rush Side Channels	≤12.0	8.6	0.5	0%	33%	0%	0%
Drift	15.9-16.3	9.3	17.4	13%	43%	30%	13%
Muddy	≤17.5	15.3	21.5	27%	0%	38%	15%
Little	9.9	9.1	1.0	ND	ND	ND	ND

[1] Range of maximum daily temperature within the survey reach. A single value indicates that either there is not enough information to determine the temperature range (Muddy) or there is minimal temperature variation within the survey reach (Little Creek).

Each stream was examined for temperature, proximity to thermally suitable temperatures and the potential to enhance existing habitat or improve reaches without complex channels and suitable depths. Project partners conducted site reconnaissance to verify conditions and develop scoping designs for the selected streams. Potential stream restoration activities are prioritized below.

Little Creek

Little Creek was not identified in the original study because of active restoration activities; however, it was considered for habitat restoration actions because 1) stream temperature in Little Creek is colder than all reaches outside of existing spawning reaches evaluated for this project and is very similar to Rush and Pine basins and 2) Little Creek is in close proximity (within 1.0 km) to the Rush Creek population increasing the likelihood of a bull trout using this habitat. The work that the Forest Service completed in Little Creek appears to have improved habitat conditions throughout the lower gradient reaches of the stream. The short, high gradient reach above an old temporary road crossing may provide spotty bull trout spawning habitat, but additional work seems unlikely to provide benefits commensurate with the cost involved. For the time being, Little Creek habitat appears functional. One option discussed is to install a PIT tag array at the mouth of Little Creek to determine bull trout usage (PacifiCorps PIT-tags adult bull trout for population monitoring purposes). If bull trout use Little Creek, the project partners propose to re-evaluate existing habitat characteristics to identify restoration proposals to enhance or create suitable habitat.

Rush Creek Side Channels

Rush Creek Side Channels were selected as a potential restoration site as they 1) are in close proximity to Rush Creek proper where spawning and early rearing currently occurs and 2) share a similar thermal regime as Rush creek and thus are thermally suitable (≤12°C). Additionally, the habitat consists of complex channels, suitable spawning substrate, and 33% of reaches have an ideal depth (15-20 cm). Rush Creek Side Channels are easily accessible thereby reducing restoration implementation costs. However, the 2015 flood event changed lower Rush Creek below the USFS 90 Road bridge and has reactivated numerous braided channels. The channels appear to be processing large volumes of coarse sediment and wood, and seem likely to adjust vertically and horizontally during modest flood events. Restoration actions are not recommended at this time due to the active and disruptive stream processes currently occurring; however, once the area stabilizes, habitat actions would likely benefit the bull trout population by providing additional spawning and early rearing habitat within the basin. Project partners agree that Rush Creek Side Channels should be monitored and restoration potential re-evaluated on a regular basis.

Drift Creek

Drift Creek was considered for habitat actions because it is 1) in relatively close proximity to Pine Creek (9.3 km), 2) has a temperature range of 15.9-16.3 °C, and 3) has a high proportion of suitable stream depths (Figure 7). Restoration activities could include projects that improve channel complexity as this is a liming factor in the basin (Figure 6). Such actions include placement of large woody debris, increasing channel complexity, increasing spawning gravel and retaining wood transporting through the system before it's flushed into Swift Reservoir. An instream project focused on creating full length log jams would create deep pools with overhanging cover, narrower channels would likely benefit bull trout and other species. Full length log jams will increase stream bed load and help activate old side channels.

Clear Creek

Upper Clear Creek is thermally suitable (16.2-17.5°C), has reaches with complex channels (17%) and appropriate depths (50% at 15-20 cm) as indicated in Table 9. Clear Creek is in reasonable proximity to Pine Creek (14.8 km). Additionally, there are anecdotal and PIT tag data identifying occupancy by bull trout during the spawning time frame (September and October).

Restoration efforts to improve habitat in the upper Clear would focus on decreasing depth and increasing complexity; however, projects in the upper Clear could require helicopter activities and could be costly. Therefore, project partners agree that Lower Clear Creek seems to have the best potential for improving foraging, migratory and overwintering habitat. Although foraging, migratory and overwintering habitat were not the focus of this study, project partners suggest improving connectivity to spawning and rearing habitat. An instream project focused on creating deep pools with overhanging cover, narrower channels, and more complex channel forms would likely benefit bull trout and other species.

Clearwater Creek

Clearwater Creek has some of the colder stream temperatures in the survey area but also is the furthest from existing populations (~ 20 km to Pine Creek). Restoration efforts could include increasing the amount of habitat with ideal stream depths (15-20 cm) and increasing channel complexity. However, Clearwater Creek has challenging access issues which would make restoration activities reliant on helicopter and would significantly increase project costs. Additionally, there is little evidence of bull trout currently using Clearwater Creek thereby decreasing the potential benefit of restoration. More cost-effective projects could be designed in the lower end of the basin, specifically aimed to decrease stream temperature which would provide thermal connectivity to the suitable habitat in the upper basin (below the confluence with Bean Creek).

Muddy River

Muddy River has high but thermally suitable temperatures (≤17.5°C) and these thermally suitable temperatures are 15.3 km from Pine and 21.5 km from Rush Creek. Muddy River has 27% reaches with complex channels and no reaches with ideal spawning depth (15-20 cm). Restoration activities would focus on improving stream depths (to 15-35 cm). However, Muddy River is an evolving river with an unstable floodplain and high sediment load. Therefore, restoration investments may be compromised by channel stabilization events since the 1980 eruption of the Mount St. Helens.

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APPENDIX A.

Maximum daily temperature in the upper Lewis River basin, 2013 and 2014.

Appendix A. Maximum daily temperatures in the upper Lewis River basin, 2013 and 2014.

Year	Stream	Site Name	Elevation (ft)	Latitude	Longitude	Deployed	Removed	Max Temp (°C)	Max Temp Date
2013	Clear Creek	Near confluence with Muddy[a]	1229	46.126660	-121.989920	6/27/2013	10/29/2013	18.1	8/5/2013
2013	Clear Creek	Upper[c]	2161	46.235920	-121.939610	7/30/2013	10/28/2013	13.6	8/6/2013
2013	Clearwater Creek	Just above Muddy[b]	1474	46.167815	-122.032235	1/2/2013	8/1/2013	18.3	7/2/2013
2013	Clearwater Creek	Lower[c]	1495	46.172310	-122.029030	7/8/2013	10/31/2013	18.0	7/20/2013
2013	Clearwater Creek	8 miles above Muddy River[a]	1668	46.217950	-122.023180	7/3/2013	10/31/2013	15.6	7/24/2013
2013	Clearwater Creek	Above Barrier[b]	2201	46.234123	-122.005966	8/2/2013	10/2/2014	16.2	8/6/2013
2013	Crab Creek	Upper[c]	1563	46.143170	-121.893110	6/25/2013	10/28/2013	17.4	7/2/2013
2013	Drift Creek	Lower[c]	1034	46.021610	-122.089670	6/26/2013	10/30/2013	16.3	7/2/2013
2013	Drift Creek	Upper[c]	2723	46.000440	-122.015970	7/11/2013	10/28/2013	13.5	9/11/2013
2013	Elk Creek	Lower[c]	2159	46.237580	-121.942220	7/30/2013	10/28/2013	14.5	8/6/2013
2013	Lewis River	Above Curly Creek[a]	1102	46.059310	-121.970490	7/2/2013	11/3/2013	15.9	7/24/2013
2013	Lewis River	Below Cussed Hollow[a]	1400	46.142280	-121.901440	6/28/2013	10/4/2013	17.2	7/24/2013
2013	Lewis River	Above Chickoon[b]	1443	46.154164	-121.882225	1/2/2013	11/19/2014	16.5	7/24/2013
2013	Little Creek	Upper[c]	2413	46.067140	-121.903440	6/25/2013	10/27/2013	5.0	see NOTE
2013	Muddy River	Above Clear Creek[a]	1248	46.120830	-122.011390	7/3/2013	11/3/2013	19.6	7/2/2013
2013	P-8	Lower[c]	1640	46.107280	-122.062250	6/24/2013	10/29/2013	10.7	7/2/2013
2013	Pine Creek	0.5 mile above Lewis River[a]	1037	46.072720	-122.016720	6/27/2013	11/3/2013	14.3	7/2/2013
2013	Pine Creek	BLW P-8 Confluence[c]	1594	46.102670	-122.062750	7/11/2013	10/29/2013	9.8	7/24/2013
2013	Pine Creek	Upper[c]	2414	46.137060	-122.094690	6/24/2013	10/2/2013	8.0	10/2/2013
2013	Rush Creek	Side Channel[c]	1169	46.074610	-121.934830	7/12/2013	10/27/2013	10.3	7/24/2013
2013	Rush Creek	Nursery[c]	1189	46.073080	-121.935000	7/12/2013	10/28/2013	10.1	7/23/2013
2013	Rush Creek	Below 90 Rd Bridge[c]	1318	46.066940	-121.931080	6/27/2013	10/29/2013	12.4	7/1/2013

Year	Stream	Site Name	Elevation (ft)	Latitude	Longitude	Deployed	Removed	Max Temp (ºC)	Max Temp Date
2013	Rush Creek	Upper[c]	2866	46.038970	-121.875860	7/3/2013	10/27/2013	8.6	9/28/2013
2013	Spencer Creek	Lower[c]	1452	46.140970	-121.907810	7/3/2013	10/28/2013	15.9	9/14/2013
2013	Swift Creek	Upper[c]	2568	46.132470	-122.175280	7/10/2013	10/28/2013	9.6	9/28/2013
2014	Bean Creek	Lower[c]	1709	46.221494	-122.026119	7/23/2014	10/20/2014	12.8	8/4/2014
2014	Clear Creek	Near confluence with Muddy[a]	1229	46.126658	-121.989919	6/25/2014	10/27/2014	18.9	8/4/2014
2014	Clear Creek	Upper[c]	2161	46.235917	-121.939611	7/16/2014	11/3/2014	14.7	7/16/2014
2014	Clearwater Creek	8 miles above Muddy River[a]	1668	46.217953	-122.023175	6/23/2014	10/20/2014	16.5	7/16/2014
2014	Clearwater Creek	Above Barrier[b]	2201	46.234123	-122.005966	8/2/2013	10/2/2014	17.3	7/16/2014
2014	Crab Creek	Lower[c]	1429	46.143833	-121.895056	6/27/2014	11/2/2014	16.7	8/4/2014
2014	Lewis River	Above Curly Creek[a]	1102	46.059306	-121.970494	6/25/2014	10/28/2014	16.6	7/16/2014
2014	Lewis River	Below Cussed Hollow[a]	1400	46.142278	-121.901444	7/10/2014	9/25/2014	17.7	7/16/2014
2014	Lewis River	Above Chickoon[b]	1443	46.154164	-121.882225	1/2/2013	11/19/2014	17.1	8/4/2014
2014	Little Creek	Lower[c]	1275	46.078750	-121.921111	7/1/2014	11/3/2014	9.9	7/15/2014
2014	Little Creek	Upper[c]	2413	46.067139	-121.903444	6/27/2014	10/29/2014	5.0	see NOTE
2014	P-8	Lower[c]	1640	46.107278	-122.062250	7/12/2014	11/2/2014	11.3	7/16/2014
2014	Pine Creek	0.5 mile above Lewis River[a]	1037	46.072722	-122.016717	6/25/2014	10/27/2014	13.4	7/16/2014
2014	Pine Creek	BLW P-8 Confluence[c]	1594	46.102667	-122.062750	7/12/2014	11/2/2014	9.8	7/16/2014
2014	Pine Creek	Upper[c]	2414	46.137056	-122.094694	7/10/2014	10/30/2014	6.2	10/22/2014
2014	Rush Creek	Side Channel[c]	1169	46.074611	-121.934833	7/1/2014	11/3/2014	11.3	7/16/2014
2014	Rush Creek	Below 90 Rd Bridge[c]	1318	46.066939	-121.931081	6/25/2014	10/27/2014	10.7	7/16/2014
2014	Rush Creek	Upper[c]	2866	46.038972	-121.875861	6/27/2014	11/2/2014	9.4	7/1/2014
2014	Spencer Creek	Lower[c]	1452	46.140972	-121.907806	6/27/2014	10/29/2014	17.0	8/4/2014
2014	Swift Creek	Upper[c]	2568	46.132472	-122.175278	7/10/2014	10/30/2014	9.3	8/27/2014

Note: Only two temperatures were recorded at the Little Creek – Upper site, 4.9 ºC and 5.0 ºC.

[a] Annual monitoring site for the Mount Saint Helens Water Quality Monitoring Program

[b] Annual monitoring site for the USFS Aquatic and Riparian Effectiveness Monitoring Program (AREMP)

[c] Monitoring site specifically for this project

APPENDIX B.

Descriptive Statistics of 100 m reaches by Stream

APPENDIX B-1. Descriptive statistics of 100 m reaches in Pine Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	123	0.275	0.040	0.270	0.177	0.447
Width (m)	123	9.8	1.8	9.8	5.1	14.5
W/D	123	39.5	8.8	38.8	20.1	69.8
CV depth (%)	123	97.2	5.4	96.9	88.5	115.3
CV width (%)	123	22.7	7.8	22.6	6.2	47.6
CV W/D (%)	123	40.7	14.4	39.4	9.3	79.5
Max Depth	123	0.944	0.281	0.840	0.460	1.500
Cover (m^2)	123	2.2	3.0	1.4	0.0	15.4
PSP (m^2)	123	2.1	3.5	0.9	0.0	26.3
LWD (no./100m)	123	3.2	3.6	2.0	0.0	17.7
Pools (no./100m)	123	0.8	0.7	0.8	0.0	3.0
Pool (m^2)	123	2.0	13.8	0.0	0.0	123.2
Riffle (m^2)	123	969.2	187.1	969.3	494.5	1457.2
Fines (m^2)	123	5.5	35.3	0.0	0.0	267.2
Gravel (m^2)	123	53.3	94.1	0.0	0.0	364.0
Cobble (m^2)	123	364.4	165.6	360.0	0.0	818.0
Boulder (m^2)	123	213.0	138.0	232.2	0.0	495.6
Bedrock (m^2)	123	37.4	118.8	0.0	0.0	666.2

APPENDIX B-2. Descriptive statistics of 100 m reaches in P8.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	40	0.179	0.021	0.176	0.138	0.244
Width (m)	40	4.9	0.5	4.9	4.1	6.0
W/D	40	29.6	4.9	29.5	18.3	40.5
CV depth (%)	40	96.0	3.8	95.8	89.6	106.8
CV width (%)	40	18.5	5.9	17.4	7.9	35.8
CV W/D (%)	40	34.9	10.9	34.9	18.9	67.8
Max Depth	40	0.675	0.154	0.635	0.400	1.100
Cover (m^2)	40	5.9	9.0	1.9	0.0	40.7
PSP (m^2)	40	5.2	3.7	4.5	0.0	15.0
LWD (no./100m)	40	7.5	4.4	6.6	0.0	19.0
Pools (no./100m)	40	1.6	1.3	1.3	0.0	4.2
Pool (m^2)	40	9.2	16.3	0.0	0.0	51.1
Riffle (m^2)	40	476.8	50.1	470.2	369.2	597.7
Fines (m^2)	40	18.5	32.3	0.0	0.0	125.3
Gravel (m^2)	40	112.2	73.9	128.7	0.0	284.5
Cobble (m^2)	40	169.2	71.1	182.2	0.0	298.8
Boulder (m^2)	40	56.8	79.1	8.3	0.0	294.6
Bedrock (m^2)	40	0.2	1.1	0.0	0.0	7.0

APPENDIX B-3. Descriptive statistics of 100 m reaches in Bean Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	12	0.177	0.035	0.169	0.136	0.239
Width (m)	12	5.6	0.8	5.6	4.3	7.0
W/D	12	42.9	19.6	38.5	25.9	98.4
CV depth (%)	12	105.0	13.2	105.3	85.7	137.5
CV width (%)	12	36.6	9.4	32.8	23.9	54.0
CV W/D (%)	12	54.8	15.4	54.0	33.6	80.2
Max Depth	12	0.881	0.424	0.820	0.360	2.000
Cover (m^2)	12	2.3	3.8	0.6	0.0	12.7
PSP (m^2)	12	0.2	0.5	0.0	0.0	1.8
LWD (no./100m)	12	1.0	0.7	0.9	0.0	2.3
Pools (no./100m)	12	2.3	1.8	1.9	0.0	5.4
Pool (m^2)	12	92.3	88.1	75.5	0.0	289.5
Riffle (m^2)	12	432.5	165.6	483.6	60.5	597.3
Fines (m^2)	12	23.5	32.8	6.1	0.0	94.7
Gravel (m^2)	12	1.6	5.5	0.0	0.0	19.2
Cobble (m^2)	12	67.4	71.5	45.2	0.0	206.9
Boulder (m^2)	12	154.5	71.0	184.3	30.2	229.6
Bedrock (m^2)	12	50.1	94.0	0.0	0.0	293.2

APPENDIX B-4. Descriptive statistics of 100 m reaches in Big Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	2	0.285	0.064	0.285	0.240	0.330
Width (m)	2	9.8	1.6	9.8	8.7	10.9
W/D	2	41.8	14.0	41.8	31.9	51.7
CV depth (%)	2	106.0	5.5	106.0	102.1	109.9
CV width (%)	2	31.1	1.2	31.1	30.2	31.9
CV W/D (%)	2	50.9	4.1	50.9	48.1	53.8
Max Depth	2	2.005	1.407	2.005	1.010	3.000
Cover (m^2)	2	25.8	36.1	25.8	0.3	51.3
PSP (m^2)	2	0.7	0.4	0.7	0.4	1.0
LWD (no./100m)	2	4.5	6.4	4.5	0.0	9.0
Pools (no./100m)	2	1.5	1.4	1.5	0.5	2.5
Pool (m^2)	2	130.3	184.3	130.3	0.0	260.6
Riffle (m^2)	2	501.7	153.0	501.7	393.5	609.9
Fines (m^2)	2	0.0	0.0	0.0	0.0	0.0
Gravel (m^2)	2	9.9	14.0	9.9	0.0	19.8
Cobble (m^2)	2	0.0	0.0	0.0	0.0	0.0
Boulder (m^2)	2	370.7	134.7	370.7	275.4	465.9
Bedrock (m^2)	2	39.0	55.1	39.0	0.0	77.9

APPENDIX B-5. Descriptive statistics of 100 m reaches in Chickoon Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	6	0.122	0.017	0.125	0.094	0.146
Width (m)	6	3.9	0.2	4.0	3.6	4.2
W/D	6	46.2	10.6	43.8	33.7	63.3
CV depth (%)	6	117.1	7.3	118.0	107.2	126.8
CV width (%)	6	41.3	7.4	42.4	32.3	51.0
CV W/D (%)	6	62.8	12.5	63.7	46.6	81.0
Max Depth	6	0.767	0.258	0.750	0.400	1.100
Cover (m^2)	6	2.0	2.6	1.3	0.0	6.6
PSP (m^2)	6	0.5	1.2	0.0	0.0	3.1
LWD (no./100m)	6	9.3	14.3	4.5	0.5	38.0
Pools (no./100m)	6	3.7	1.8	4.0	0.5	5.4
Pool (m^2)	6	86.7	49.4	94.9	0.0	137.8
Riffle (m^2)	6	283.9	89.8	296.2	120.0	371.7
Fines (m^2)	6	4.4	8.7	0.0	0.0	21.9
Gravel (m^2)	6	2.8	6.7	0.0	0.0	16.5
Cobble (m^2)	6	82.2	28.0	75.1	45.8	118.7
Boulder (m^2)	6	62.9	36.8	56.2	12.4	111.6
Bedrock (m^2)	6	89.6	98.4	86.2	0.0	190.8

APPENDIX B-6. Descriptive statistics of 100 m reaches in Clear Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	48	0.202	0.036	0.202	0.156	0.332
Width (m)	48	11.5	2.8	12.3	5.7	17.3
W/D	48	71.7	23.7	68.0	27.7	126.4
CV depth (%)	48	103.5	10.1	101.8	90.5	136.4
CV width (%)	48	24.6	8.2	23.5	10.7	44.0
CV W/D (%)	48	45.9	16.1	46.8	9.7	92.8
Max Depth	48	0.891	0.312	0.910	0.380	2.000
Cover (m^2)	48	7.3	7.3	4.9	0.0	29.1
PSP (m^2)	48	1.4	3.8	0.0	0.0	20.3
LWD (no./100m)	48	6.3	6.7	4.6	0.0	28.7
Pools (no./100m)	48	1.4	1.0	1.4	0.0	5.8
Pool (m^2)	48	451.9	379.5	420.8	0.0	1380.6
Riffle (m^2)	48	682.4	458.2	635.0	0.0	1732.8
Fines (m^2)	48	21.9	52.7	0.0	0.0	222.6
Gravel (m^2)	48	85.7	116.7	0.0	0.0	402.6
Cobble (m^2)	48	458.0	192.2	456.4	0.0	809.3
Boulder (m^2)	48	146.8	189.1	53.2	0.0	613.1
Bedrock (m^2)	48	20.3	73.0	0.0	0.0	426.7

APPENDIX B-7. Descriptive statistics of 100 m reaches in Clearwater Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	48	0.270	0.069	0.257	0.170	0.460
Width (m)	48	9.1	1.5	9.0	6.4	14.7
W/D	48	40.7	8.0	40.8	24.4	61.1
CV depth (%)	48	103.9	19.4	99.2	87.8	187.7
CV width (%)	48	25.0	8.0	24.9	11.3	46.8
CV W/D (%)	48	43.0	14.5	40.4	16.9	76.4
Max Depth	48	1.235	0.640	1.000	0.490	3.000
Cover (m^2)	48	9.8	15.2	6.0	0.0	90.4
PSP (m^2)	48	1.7	3.2	0.8	0.0	20.1
LWD (no./100m)	48	4.5	5.7	2.6	0.0	26.4
Pools (no./100m)	48	1.5	1.1	1.3	0.0	4.5
Pool (m^2)	48	202.0	217.1	168.5	0.0	968.7
Riffle (m^2)	48	702.1	238.6	721.9	0.0	1345.3
Fines (m^2)	48	15.6	40.0	0.0	0.0	211.5
Gravel (m^2)	48	32.4	62.1	0.0	0.0	233.8
Cobble (m^2)	48	138.4	163.3	0.0	0.0	473.1
Boulder (m^2)	48	255.2	145.2	284.9	0.0	670.0
Bedrock (m^2)	48	29.8	78.7	0.0	0.0	377.5

APPENDIX B-8. Descriptive statistics of 100 m reaches in Cussed Hollow.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	6	0.138	0.081	0.118	0.072	0.300
Width (m)	6	4.4	0.6	4.5	3.4	5.1
W/D	6	51.7	9.0	51.6	38.6	66.7
CV depth (%)	6	124.6	20.5	120.9	102.2	162.4
CV width (%)	6	40.1	12.1	39.0	26.0	53.6
CV W/D (%)	6	67.6	23.3	71.7	35.2	99.9
Max Depth	6	1.018	0.987	0.725	0.310	3.000
Cover (m^2)	6	5.9	13.7	0.0	0.0	33.8
PSP (m^2)	6	0.5	0.5	0.5	0.0	1.2
LWD (no./100m)	6	3.2	3.3	1.8	0.0	7.6
Pools (no./100m)	6	4.2	1.5	4.6	1.4	5.5
Pool (m^2)	6	62.9	66.2	51.0	0.0	138.5
Riffle (m^2)	6	335.5	115.8	324.4	170.8	504.5
Fines (m^2)	6	4.2	8.2	0.0	0.0	20.6
Gravel (m^2)	6	0.0	0.0	0.0	0.0	0.0
Cobble (m^2)	6	74.2	76.5	46.7	0.0	177.3
Boulder (m^2)	6	148.8	82.1	129.7	51.2	254.3
Bedrock (m^2)	6	32.8	51.3	5.6	0.0	126.2

APPENDIX B-9. Descriptive statistics of 100 m reaches in Drift Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	23	0.195	0.046	0.185	0.130	0.294
Width (m)	23	8.5	1.9	8.3	6.1	15.6
W/D	23	56.2	16.6	53.5	34.8	99.4
CV depth (%)	23	104.5	8.2	104.6	92.7	119.1
CV width (%)	23	32.9	13.0	31.1	17.9	79.3
CV W/D (%)	23	57.8	18.6	55.6	18.2	101.5
Max Depth	23	0.763	0.261	0.720	0.410	1.170
Cover (m^2)	23	3.3	5.4	0.6	0.0	19.0
PSP (m^2)	23	1.5	2.1	0.8	0.0	7.6
LWD (no./100m)	23	4.0	3.9	3.2	0.0	14.9
Pools (no./100m)	23	1.3	1.2	1.2	0.0	4.1
Pool (m^2)	23	134.2	152.8	102.0	0.0	491.4
Riffle (m^2)	23	701.9	250.4	693.5	315.2	1447.3
Fines (m^2)	23	13.3	45.2	0.0	0.0	186.7
Gravel (m^2)	23	30.2	41.9	8.6	0.0	157.5
Cobble (m^2)	23	182.5	97.8	201.3	0.0	303.5
Boulder (m^2)	23	247.3	109.6	237.0	82.3	596.9
Bedrock (m^2)	23	11.5	45.2	0.0	0.0	216.5

APPENDIX B-10. Descriptive statistics of 100 m reaches in Muddy River.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	26	0.283	0.049	0.272	0.214	0.380
Width (m)	26	12.4	1.7	13.1	9.2	14.9
W/D	26	52.4	19.7	53.7	26.2	111.8
CV depth (%)	26	98.0	6.4	95.3	87.8	111.0
CV width (%)	26	23.5	10.2	22.6	9.2	52.0
CV W/D (%)	26	41.1	18.9	39.2	15.9	94.0
Max Depth	26	0.885	0.230	0.880	0.500	1.500
Cover (m^2)	26	0.6	1.3	0.0	0.0	4.9
PSP (m^2)	26	0.4	1.7	0.0	0.0	8.5
LWD (no./100m)	26	0.8	1.3	0.0	0.0	5.3
Pools (no./100m)	26	0.3	0.5	0.0	0.0	1.9
Pool (m^2)	26	40.1	98.0	0.0	0.0	434.5
Riffle (m^2)	26	1183.1	223.2	1240.9	656.9	1494.2
Fines (m^2)	26	222.7	231.4	95.1	0.0	631.0
Gravel (m^2)	26	0.0	0.0	0.0	0.0	0.0
Cobble (m^2)	26	264.3	197.1	294.5	0.0	740.5
Boulder (m^2)	26	246.8	198.8	277.0	0.0	576.7
Bedrock (m^2)	26	12.0	52.8	0.0	0.0	267.1

APPENDIX B-11. Descriptive statistics of 100 m reaches in Rush Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	9	0.349	0.057	0.326	0.281	0.442
Width (m)	9	11.0	2.0	10.2	7.6	13.8
W/D	9	34.9	7.9	36.1	19.2	46.6
CV depth (%)	9	100.6	6.8	100.3	91.9	110.4
CV width (%)	9	33.4	12.4	34.5	17.2	53.8
CV W/D (%)	9	47.7	16.1	43.8	23.8	75.2
Max Depth	9	1.423	0.394	1.500	0.800	1.900
Cover (m^2)	9	12.6	19.4	7.6	0.0	61.9
PSP (m^2)	9	2.9	5.1	1.0	0.0	15.9
LWD (no./100m)	9	10.8	9.6	8.2	3.9	35.2
Pools (no./100m)	9	1.6	1.8	0.9	0.0	5.5
Pool (m^2)	9	27.8	55.1	0.0	0.0	126.3
Riffle (m^2)	9	1035.6	246.2	1019.4	697.4	1382.0
Fines (m^2)	9	0.0	0.0	0.0	0.0	0.0
Gravel (m^2)	9	6.9	14.1	0.0	0.0	37.1
Cobble (m^2)	9	213.8	152.2	230.5	0.0	396.0
Boulder (m^2)	9	557.1	311.8	693.2	162.0	882.0
Bedrock (m^2)	9	0.0	0.0	0.0	0.0	0.0

APPENDIX B-12. Descriptive statistics of habitat units in the Rush Creek “side channels”. Data were not summarized at 100 m reaches for these waterways.

Variable	n	Mean	SD	Median	Min	Max
Length	18	36.1	35.5	19.0	7.7	105.0
Depth (m)	18	0.209	0.146	0.158	0.100	0.694
Width (m)	18	6.4	3.1	5.2	3.1	12.8
W/D	18	38.1	12.9	40.8	12.9	60.5
CV depth (%)	18	100.9	9.4	101.3	86.6	116.9
CV width (%)	18	20.8	13.1	18.8	5.1	51.0
CV W/D (%)	18	42.3	25.0	36.0	10.4	95.8
Max Depth	18	0.571	0.304	0.455	0.270	1.500
Cover (m^2)	18	1.5	2.8	0.6	0.0	12.0
PSP (m^2)	18	1.7	4.7	0.0	0.0	16.1
LWD (no./100m)	18	2.3	2.6	1.5	0.0	7.0
Pools (no./100m)	18	0.8	0.7	1.0	0.0	3.0
Pool (m^2)	18	50.8	82.1	0.0	0.0	230.0
Riffle (m^2)	18	149.2	194.2	88.6	0.0	582.8
Fines (m^2)	18	18.8	28.1	0.0	0.0	92.0
Gravel (m^2)	18	18.3	35.9	0.0	0.0	136.5
Cobble (m^2)	18	50.3	61.9	27.8	0.0	182.0
Boulder (m^2)	18	66.5	114.9	0.0	0.0	374.9
Bedrock (m^2)	18	0.0	0.0	0.0	0.0	0.0

APPENDIX B-13. Descriptive statistics of 100 m reaches in Smith Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	46	0.164	0.036	0.154	0.103	0.272
Width (m)	46	11.8	5.1	10.3	7.2	33.7
W/D	46	101.4	61.9	76.6	48.1	338.6
CV depth (%)	46	110.1	15.4	105.5	89.3	164.7
CV width (%)	46	30.0	8.8	29.2	14.1	53.2
CV W/D (%)	46	58.4	19.2	59.9	24.4	101.8
Max Depth	46	0.710	0.254	0.630	0.290	1.000
Cover (m^2)	46	5.0	7.6	1.0	0.0	35.7
PSP (m^2)	46	0.1	0.7	0.0	0.0	4.9
LWD (no./100m)	46	3.9	3.7	2.7	0.0	15.8
Pools (no./100m)	46	0.8	0.8	0.8	0.0	3.7
Pool (m^2)	46	177.8	233.6	93.6	0.0	882.4
Riffle (m^2)	46	975.6	570.1	890.8	11.8	3323.5
Fines (m^2)	46	180.7	182.9	141.6	0.0	766.5
Gravel (m^2)	46	107.2	193.7	0.0	0.0	997.1
Cobble (m^2)	46	391.0	292.6	372.7	0.0	1471.5
Boulder (m^2)	46	67.2	130.9	0.0	0.0	449.1
Bedrock (m^2)	46	4.5	25.0	0.0	0.0	165.5

APPENDIX B-14. Descriptive statistics of 100 m reaches in Spencer Creek.

Variable	n	Mean	SD	Median	Min	Max
Depth (m)	9	0.091	0.012	0.087	0.073	0.115
Width (m)	9	3.0	0.6	3.2	2.1	4.0
W/D	9	46.1	12.2	41.9	31.4	67.1
CV depth (%)	9	123.7	10.0	123.3	106.6	138.6
CV width (%)	9	45.3	13.2	43.3	22.7	64.8
CV W/D (%)	9	64.8	17.2	59.3	35.1	88.0
Max Depth	9	0.572	0.109	0.580	0.380	0.680
Cover (m^2)	9	0.1	0.3	0.0	0.0	0.7
PSP (m^2)	9	0.2	0.3	0.0	0.0	0.7
LWD (no./100m)	9	4.0	0.9	4.5	2.0	4.8
Pools (no./100m)	9	3.8	1.4	3.8	1.3	5.6
Pool (m^2)	9	28.4	17.0	26.4	8.4	54.8
Riffle (m^2)	9	270.7	68.6	283.3	169.8	372.5
Fines (m^2)	9	4.8	5.4	4.4	0.0	15.5
Gravel (m^2)	9	12.9	18.8	4.6	0.0	51.0
Cobble (m^2)	9	79.9	22.2	86.7	42.1	111.7
Boulder (m^2)	9	94.1	47.8	106.3	0.0	156.8
Bedrock (m^2)	9	5.2	15.5	0.0	0.0	46.5

APPENDIX C.

Parameter estimates and scaled odds ratios for the global model relating bull trout redd occurrence to physical habitat variables

APPENDIX C. Parameter estimates and scaled odds ratios for the global model relating bull trout redd occurrence to physical habitat variables in the upper Lewis River basin, WA. Log-transformed ($log_e(x+1)$) values of Boulder (m^2), Fines (m^2), and Pool (m^2) were used in the model. See text for details.

Variable	Parameter Estimate	Standard Error	Scaling factor	Scaled odds ratio	95% CI for scaled odds ratio	*P*-value
Intercept	2.218	1.705				0.193
Complex Channel	1.389	0.486	1	4.01	1.55 - 10.41	0.004
Depth (m)	-18.802	7.999	0.05	0.39	0.18 - 0.86	0.019
CV Width (%)	-0.046	0.032	5	0.79	0.58 - 1.09	0.151
Width (m)	0.155	0.142	1	1.17	0.88 - 1.54	0.277
Boulder (m^2)	-0.092	0.126	1	0.91	0.71 - 1.17	0.464
LWD (no./100m)	0.040	0.067	1	1.04	0.91 - 1.19	0.546
PSP (m^2)	-0.032	0.069	1	0.97	0.85 - 1.11	0.644
Fines (m^2)	0.074	0.174	1	1.08	0.77 - 1.51	0.673
Pool (m^2)	0.043	0.196	1	1.04	0.71 - 1.53	0.827

APPENDIX D.

Project Proposal for the Bull Trout

Habitat Restoration Project Identification Assessment

PROPOSAL FORM -
Lewis River Aquatic Fund

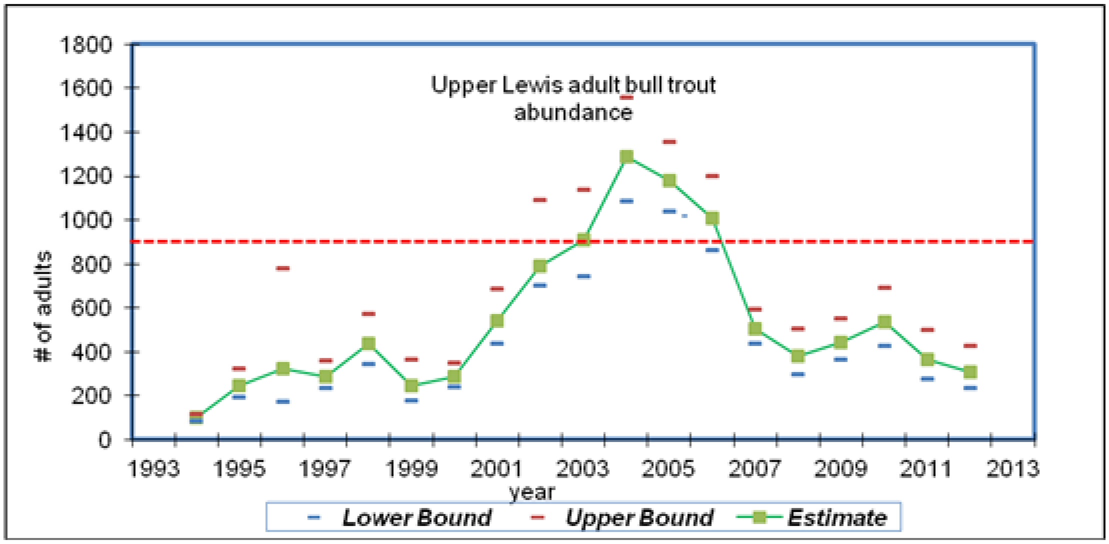
Due to unforeseen impacts associated with the federal budget during the fall of 2013 the USFS and MSHI were unable to conduct field tasks expected to be accomplished during that timeframe. These complications impacted the entire timeline of the project; therefore, the project was granted a 1-year extension by the ACC. Project timelines have been adjusted and changes to task completion dates are included in this document (highlighted in yellow).

1. Project Title
   Bull Trout Habitat Restoration Project Identification Assessment

2. Project Manager
   Adam Haspiel USFS
   Abi Groskopf Mount S. Helens Institute (MSHI)

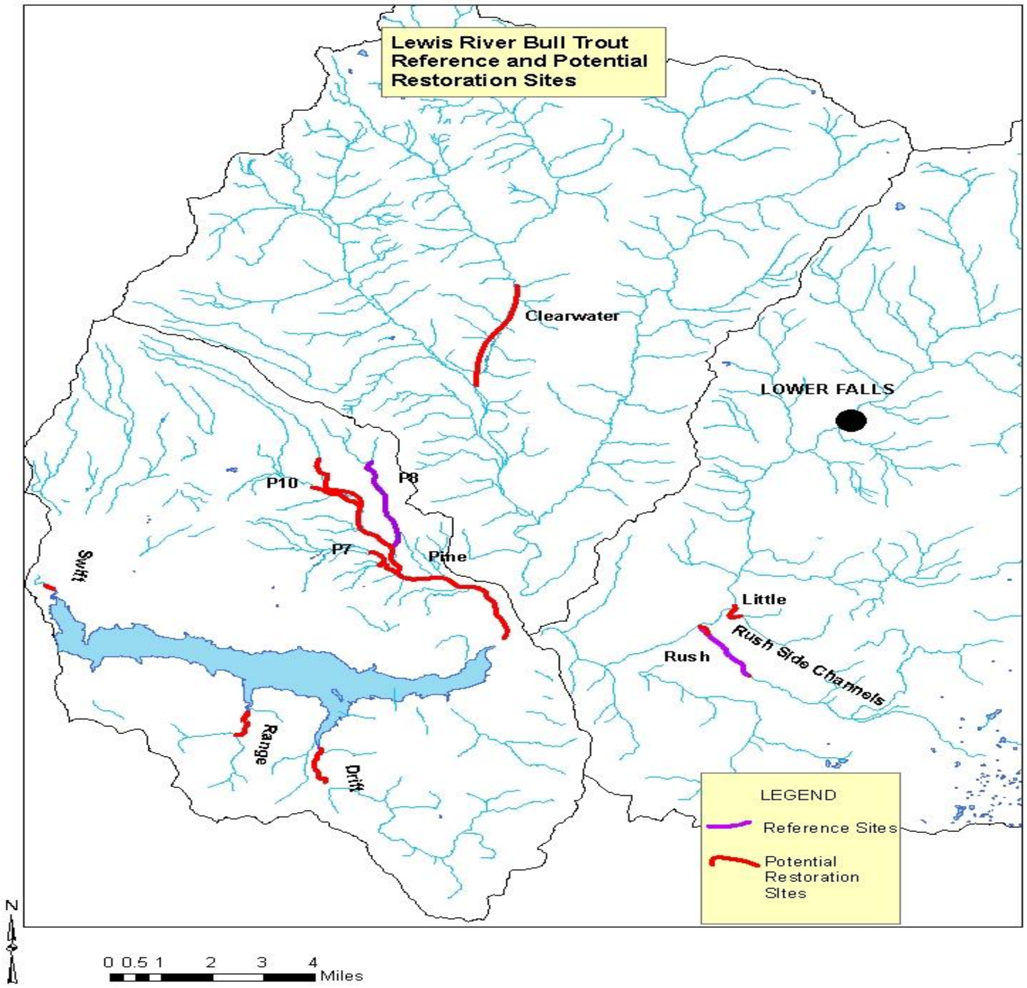
3. Identification of problem or opportunity to be addressed

   Bull trout adult abundance in the upper North Fork Lewis River Basin has been estimated annually since 1994. Based on annual abundance estimates of migratory adults the population has exhibited 3 distinct patterns of abundance; with lower abundance levels during 1994-2000 and 2007-present being separated by a period when abundance increased to and decreased from a peak of 1,300 migratory adults. The US Fish and Wildlife Service identified a minimum population target of 900 individuals to maintain population viability and this target has been exceeded only four times since 1994 (19 years). Recent population estimates (2005-2012) range from 250-500 migratory adults, which is 20%-40% of the peak abundance observed in 2004 and 25%-56% of the minimum population target (see figure below). While numerous factors are likely affecting the overall abundance estimates, many interested parties (e.g., WDFW, USFS, LCFRB, CIT, and MSHI) believe that spawning and/or rearing habitat could be limiting thus inhibiting the recovery and long-term stability of the bull trout population.



As part of the Lewis River Hydroelectric Projects Settlement Agreement (Settlement Agreement), PacifiCorp provides a dedicated source of funding for bull trout habitat restoration projects. This funding is stewarded by the Aquatics Coordinating Committee (ACC), members of which have been reluctant to recommend projects for funding in recent years because project scoping and prioritization has been impossible with existing bull trout habitat knowledge. Despite past and ongoing studies regarding bull trout spawning and rearing in the upper Lewis Basin, habitat characteristics that will direct successful restoration projects for the local subpopulations remains largely unknown.

This partner-driven project team proposes to fill the project scoping and prioritization void by initially using results of past or ongoing data collection efforts to characterize bull trout spawning and rearing habitat in Pine, P8, Rush, and Cougar Creeks. Subsequent portions of this project would conduct additional spawning and habitat surveys to collect habitat parameter data that would be used to site and scope specific restoration projects for future bull trout funding rounds (See Map Below for initial potential survey locations). The ultimate goal of this project is to develop concept scoping design of habitat restoration projects in areas outside of existing spawning and rearing locations to expand the range of available bull trout spawning and rearing habitat. The expected outcome of this project is improved long term stability of the bull trout population in the upper Lewis Basin.


Lewis River Bull Trout
Reference and Potential
Restoration Sites
Clearwater
LOWER FALLS
P10
P8
P7
Pine
Swift
Little
Rush
Rush Side Channels
Range
Drift
LEGEND
Reference Sites
Potential
Restoration
SItes
N
0 0.5 1 2 3 4
Miles

4. Background

Bull trout are confined to waters with exceptionally cool (<9˚ C for spawning and rearing through age 1+; <16 ˚ C for rearing age 2+ and older) water. In the upper Lewis watershed, bull trout routinely use the upper mainstem, Pine (especially P8), Rush, and Cougar Creeks for spawning and early rearing. Suitable bull trout spawning and rearing locations can be effectively predicted by water temperature in multiple basins, but other habitat conditions may limit bull trout usage of these locations. Based on information presented in Figure 1 status of the bull trout population in the upper Lewis Basin can be described as stable, but depressed. Current spawning habitat and/or juvenile rearing habitat may be limiting population productivity; however, habitat conditions limiting productivity have not been identified due to a lack of targeted studies concerning habitat quantity and quality. Recent studies have primarily focused on collecting data in areas currently being used by bull trout for spawning and/or rearing, as follows:

> USFWS has completed a patch analysis of likely bull trout habitats in the Lewis watershed based largely on water temperature. This analysis will be used to help focus this project on streams that exhibit habitat conditions that could potentially support bull trout spawning and/or rearing, but bull trout usage has not been confirmed based on recent study results.
>
> WDFW has conducted spawning surveys in several areas of the watershed, including lower Rush Creek, Pine, and P8. WDFW will continue to operate a PIT tag detector located in Rush Creek.
>
> USFS has conducted Level II habitat surveys in some of the drainages including Rush Creek in 2004, and Pine Creek, P8, and P7 in 2005.
>
> PacifiCorp will fund bull trout monitoring activities in the upper Lewis Basin. Activities funded include redd surveys in selected streams (i.e. P8 and Pine Creek) plus PIT tagging activities (i.e. annual netting) and subsequent snorkeling efforts to determine migratory adult bull trout abundance. PacifiCorp will operate PIT tag detectors in selected streams in the upper Lewis Basin.

Consistent with the purpose of this project – improve bull trout population status by expanding the quantity and quality of spawning and rearing habitat available for bull trout in the upper Lewis Basin - this proposal will focus on stream reaches that are known to be used by bull trout, but where physical habitat has been significantly degraded through natural (e.g., Mt. St. Helens’ 1980 eruption) or anthropogenic (e.g. riparian logging) factors. This project will build on the existing knowledge base (see descriptions below) by synthesizing existing spawning, tagging, and trapping data. Patch analysis completed by USFWS will also be critical for providing direction with regard where to implement habitat improvement projects in the upper Lewis Basin, and what habitat deficiencies should be addressed. However, existing information and plans have significant gaps that limit the direction provided with respect to on-the-ground projects that will result in improved population status for bull trout in the upper Lewis Basin. This project will implement additional spawning and physical habitat surveys to fill in the gaps not covered by existing efforts. Additionally, this project will take the next critical step by connecting habitat survey data with juvenile and adult presence/absence data to make recommendations for site-specific habitat improvements that will ultimately improve the status of the bull trout population in the upper Lewis Basin.

5. Project Objective(s)

The primary objective of this project is to develop a prioritized list of habitat restoration opportunities that will increase the stability and viability of the Lewis River bull trout population.

The prioritized list of habitat restoration projects will enable project sponsors to propose successful project proposals to access the bull trout fund for the purpose of implementing on-the-ground improvements to bull trout habitat. The project partners expect that the biological benefits of implemented projects will include improved spawning and rearing habitat for bull trout in suitable bull trout areas.

6. Tasks

Task 1: Collect and synthesize existing bull trout data
Time Frame: Summer-Fall 2013
Lead: MSHI
Contributing Partners: USFS and WDFW
Description: Bull trout population, survey, and tagging data exist in several organizations' databases and files. The Mt. St. Helens Institute and WDFW will work together to collect and synthesize existing data to highlight perennial high-use areas. The Forest Service (and potentially others) has existing Level II habitat survey information for many of the stream reaches. These data sets will be compared and analyzed for major gaps while preparing the final survey methodology.

Task 2 Collect temperature data and collect habitat parameter data in selected streams in the upper Lewis Basin
Time Frame: Summer-Fall 2013 & Summer-Fall 2014
Lead: USFS
Contributing Partner(s): MSHI
Description: MSHI will deploy temperature data loggers in suspected cold water streams from summer through October to capture peak temperatures and spawning temperatures. As part of their annual habitat survey efforts, the USFS will conduct Level II habitat surveys in key streams in the upper Lewis Basin.

Task 3: Conduct spawning surveys
Time Frame: Fall 2013
Lead: USFS
Contributing Partner(s): MSHI, CIT & WDFW
Description: MSHI survey teams trained by USFS and WDFW staff will conduct spawning surveys in streams that exhibit habitat conditions (primarily temperature) that are suitable for bull trout spawning but have not been recently surveyed. Presence/absence data obtained through these surveys will be used to assist in focusing habitat parameter surveys. Additional assistance in training staff will be provided by PacifiCorp staff and other experts in the region.

Task 4: Finalize field data collection study design
Time Frame: ~~Fall 2013-Winter 2014~~ Winter 2013-Spring 2014
Lead: WDFW
Contributing Partner(s): USFWS, USFS & MSHI

Description: WDFW, USFWS, USFS, and MSHI will collaboratively finalize survey method selection and refinement. The team will use past bull trout study designs and other habitat data collection protocols (see methods section) to guide development of the study design for this project. The team will refine existing protocols to include parameters that are specific to successful bull trout habitats in the upper Lewis Basin. The protocols will be detailed enough to form habitat suitability criteria that will apply to habitat project design in other reaches. Team members will establish quantitative analysis tools to measure redd and juvenile densities and correlate these densities to measured habitat parameters. Information collected from spawning surveys collected in Task 3 will be used to assist in determination of stream reaches to be surveyed to collect habitat parameter data.

Task 5: Implement Stage 1 of Study Design (Task 4) - Conduct habitat parameter and spawning surveys where bull trout presence is known
Time Frame: Summer-Fall 2014
Lead: MSHI
Contributing Partner(s): USFS & WDFW
Description: Candidate locations for habitat restoration will be identified using a two stage process. In the first stage, habitat structure and location, and redd location data will be collected to model the presence/absence of redds based on instream habitat features. Ideally, the model output will identify the quantity and type of habitat used by spawning bull trout in the Lewis River basin. MSHI survey teams (two to three-person crews) will conduct habitat and spawning surveys in streams with known bull trout occupancy. ~~Additional survey locations will include stream reaches that support little to no use by bull trout to identify habitat conditions that need to be improved to support bull trout spawning and/or rearing.~~

Task 6: Develop habitat selection model
Time Frame: Fall 2014-Winter 2015
Lead: WDFW
Contributing Partner(s): USFWS, USFS & MSHI
Description: A Lewis River-specific habitat selection model will be developed using data collected in Task 5. Ideally, the model output will identify the quantity and type of habitat used by spawning bull trout in the Lewis River basin. This will complete Stage 1 of the study design. Model results will guide habitat data collection protocols for Stage 2 of the study design (Task 7). Data analyses will be based on past similar studies (see methods section). MSHI and WDFW staff will develop a formalized habitat suitability matrix for Lewis River bull trout and habitat use maps as part of this task.

Task 7: Implement Stage 2 of Study Design (Task 4) - Conduct habitat parameter surveys where bull trout presence is undetermined
Time Frame: Summer-Fall ~~2014~~ 2015
Lead: MSHI
Contributing Partner(s): USFS & WDFW
Description: Candidate locations for habitat restoration will be identified using a two stage process. In the second stage, MSHI survey teams (two to three-person crews) will collect habitat data from randomly selected stream reaches that 1) are accessible by migratory bull trout , 2) are thermally suitable for spawning and rearing bull trout, and 3) support little to no use by bull trout. Data from these surveys, in conjunction with the habitat selection model, will guide the identification of areas that are lacking suitable spawning and/or rearing habitat.

Task ~~6~~8: Analyze and summarize Task 7 data
Time Frame: ~~Fall 2014-Winter 2015~~ Fall 2015-Winter 2016
Lead: WDFW
Contributing Partner(s): USFWS, USFS & MSHI
Description: Data collected during the Stage 2 habitat surveys will be entered into the Stage 1 model to determine the probability of redd occurrence as a function of the available habitat. Reaches that have a low probability of redd occurrence will be candidate locations for habitat restoration actions. These reaches will also be analyzed to determine the type and quantity of habitat that should be added to increase the probability of redd occurrence. Data analyses will be based on past similar studies (see methods section). MSHI and WDFW staff will develop a formalized habitat suitability matrix for Lewis River bull trout and habitat use maps as part of this task.

Task ~~7~~9: Develop conceptual project scoping designs
Time Frame: ~~Winter-Spring 2015~~ Winter-Spring 2016
Lead: ~~WDFW~~LCFRB
Contributing Partner(s): USFWS, USFS & MSHI
Description: LCFRB, MSHI, WDFW, CIT, and USFS personnel will develop a list of site-specific project conceptual scoping designs that could be implemented to improve bull trout habitat in lesser-used areas. The projects would be prioritized based on the likely benefit to bull trout, ease of access, certainty of achieving long-term habitat gains, and cost. The draft report will be presented to the ACC for review and comment for incorporation into the final draft. Conceptual scoping designs will identify habitat conditions to be targeted, but will not identify specific actions to address these habitat conditions. Subsequent project proposals will describe how the project will benefit the habitat conditions in that specific location.

7. Methods

This project relies heavily on the work previously completed by PacifiCorp, WDFW, and USFWS to direct field investigations. These data will be useful identifying suitable for spawning and early rearing habitat conditions for bull trout in the upper Lewis Basin. Study design and data analyses conducted as part of this proposal will rely on other similar studies conducted in other locations in the Pacific Northwest. Additionally, the USFWS 1998 document titled *A Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulation Watershed Scale* provides excellent guidance with respect to habitat elements and criteria to be assessed. This document, in conjunction with other documents listed below, will be used to develop study design and guide data analyses.

USFS Level II Stream Survey:
The level II stream survey methodology is the USFS standard used for stream inventory and monitoring. This protocol has been developed by USFS fish biologists and hydrologists over a 23 year time period so it is an excellent starting point to base our methodology on. Refinements need to be made to the protocol to adapt it for this project; these modifications may include refined inventory design and reach length. The Stream Inventory Handbook/Manual is approximately 125 pages in length. The following link will take you to the latest version of the Stream Inventory Handbook. .
http://www.fs.usda.gov/detailfull/r6/landmanagement/resourcemanagement/?cid=fsbdev2_026966&width=full

EPA Environmental Monitoring and Assessment Program (EMAP) physical habitat assessment protocols:

This quantitative assessment identifies seven general physical habitat attributes: stream size (channel dimensions), channel gradient, substrate size and type, habitat complexity and cover, riparian vegetation cover and structure, anthropogenic alterations and channel-riparian interactions. Sample reach length is determined as 40 times low flow wetted width and is divided into11 transects for channel dimension, substrate and riparian areas. Other attributes are measured throughout the reach length. Modifications to sampling design to target determinations of Task 2. Data analysis can be complex without the use of SAS. Protocol is available for wadable and non-wadable streams and can be found at the following link: http://water.epa.gov/type/rsl/monitoring/riverssurvey/upload/NRSA_Field_Manual_4_21_09.pdf)

Inventory and Monitoring of Salmon Habitat in the Pacific Northwest:

This document reflects an effort to establish a consistent format for the collection of salmonid habitat data across the Pacific Northwest. More specifically, our objectives were to: 1) provide a synthesis of the salmon habitat protocols applicable to the Pacific Northwest, 2) recommend a subset of these protocols for use by volunteers and management/research personnel across the region, 3) link these protocols with specific types of habitat projects, 4) establish a Quality Assurance/Quality Control framework for the data derived from the use of these protocols, and 5) to the degree possible, identify the format and destination where the data is routinely sent.

Following a detailed review of the protocols, we used selection criteria combined with a scientific peer-review process to recommend a subset of protocols for use across the Pacific Northwest. Protocols were evaluated in terms of: 1) a review of the protocol elements; 2) the accessibility and practicability to workers with diverse training; 3) applicability across the different environments of the region, so that data and analysis are comparable; 4) listing of tools and implements needed; and 5) kinds of data generated. We were not able to assess implementation costs, as budgetary information was seldom included in the protocols. We ultimately identified 68 protocols for use by volunteers, and 93 protocols for use by management/research personnel across the Pacific Northwest.

The following link will take you the website containing this document: http://wdfw.wa.gov/publications/00650/

Using a Spatially Explicit Approach to Evaluate Bull Trout Spawning Habitat Selection
Master of Science Doctorate Thesis by James S. Lamperth, Jr.

Understanding the relationship between habitat and fish populations is essential to recovering imperiled species such as bull trout *Salvelinus confluentus.* Most bull trout research has focused on juvenile or sub-adult rearing habitat leaving gaps in knowledge concerning bull trout spawning habitat. In this study, I used a resource selection function in the form of logistic regression to model the probability of bull trout redd occurrence in 100 m stream reaches. Aquatic habitat structure (23 predictors) and bull trout redd distribution data were collected from approximately 17 km in two headwater streams of the Yakima River basin, WA using spatially continuous surveys. I fit the logistic regression models to each stream separately and to the pooled data set (3 data sets total), ranked the models using Akaike's information criterion, and assessed model predictive performance and accuracy. Bull trout redds were non-uniformly distributed and present in approximately 58% of the reaches in each stream. The best logistic regression models for each stream contained different combinations of predictors possibly suggesting differences in habitat selection between streams. However, due to predictor selection methods, the same predictors were not used to fit the models of each stream making between-stream comparisons difficult. The best model fit with the pooled data set showed that redd occurrence was positively related to pool density and area of potential spawning patches. The range of habitat measures selected by bull trout differed between streams which caused relatively poor predictive ability; however, the predictive ability increased and was relatively good when the models were fit with standardized (mean = 0, SD = 1) habitat measures. This suggests bull trout were selecting spawning locations relative to stream-specific habitat availability. In a separate analysis, I evaluated patterns between bull trout redd distribution and the thermal environment using data collected from spatially-fixed temperature data loggers, and longitudinal thermal profile surveys. Both streams displayed thermal heterogeneity; however, there were only weak associations between bull trout redd distribution and reaches that were coldest during spawning and warmest during egg incubation. This is the first study to model bull trout spawning habitat and demonstrate that typical measures of aquatic physical habitat can be used to predict the occurrence of bull trout redds. These results increase our knowledge of bull trout – spawning habitat relationships and can be used to help restore imperiled populations.

Additional similar type studies that will help guide the completion of the final study plan are listed below. The list below is not and exhaustive list but does provide some examples of other similar effort to connect fish abundance and habitat characteristics

A Review of Bull Trout Habitat Associations and Exploratory Analyses of Patterns across the Interior Columbia River Basin

Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (Salvelinus confluentus)

Influences of Temperature and Environmental Variables on the Distribution of Bull Trout within Streams at the Southern Margin of Its Range

Patch-based Models to Predict Species Occurrence: Lessons from Salmonid Fishes in Streams

Chinook Salmon use of Spawning Patches; Relative Roles of Habitat Quality, Size and connectivity

Seasonal Movement and Habitat Use by Subadult Bull Trout in
the Upper Flathead River System, Montana

Utility and Validation of Day and Night Snorkel Counts for Estimating Bull Trout Abundance in First- to Third-Order Streams

8. Specific Work Products

The team will deliver a final report highlighting a prioritized list of conceptual project scoping designs for habitat restoration projects that will benefit bull trout in the upper Lewis watershed. This list will form the foundation of a restoration short term action plan for future ACC and other bull trout funding streams. The report will also include the data and analyses used to support the decisions on restoration priorities. These data and analyses will constitute a compendium of available information on Lewis River bull trout to date.

This project will also support a long term restoration strategy to be developed through the implementation of the USFWS bull trout recovery plan. It is expected that additional studies and restoration activities will occur as part of the recovery plan implementation. Data and projects implemented through this project will assist in future efforts to implement the recovery plan and improve the status of bull trout in the upper Lewis Basin

9. Project Duration

This project will commence upon contract with PacifiCorp, expected in late summer 2013 (if funded). Literature review and collection of existing data will be completed by fall 2013. Field work will be completed during summer and fall 2014, and the prioritized list of restoration actions and the supporting report will be complete in summer 2015.

10. Permits

No ground-disturbing activities are included as part of this work. Planned survey techniques will not require permits. If the team elects to use survey techniques that have the potential to take bull trout (e.g. electro-fishing), the MSHI will acquire a scientific collection permit and incidental take permit for bull trout.

11. Matching Funds and In-kind Contributions

Several project partners have agreed to provide in-kind assistance to this effort, as follows:

The Washington Department of Fish and Wildlife (WDFW) will commit two months of Biologist staff time, including salary and benefits, to assist in training survey crews, participate in project planning, developing study design, completing data analyses and prioritizing habitat restoration actions.

The U.S. Forest Service (USFS) will commit one month combined time from of a Fish Biologist and a Fisheries Technician to assist in project development, project implementation and prioritization of habitat restoration actions.

The Cowlitz Indian Tribe (CIT) will contribute staff time, including fringe benefits, to participate in project identification/scoping, report writing, and group coordination.

The Mount St. Helens Institute (MSHI) will contribute staff time, including overhead, to conduct literature reviews, compile existing data, manage field crews and provide survey equipment.

The U.S Fish and Wildlife Service (USFWS) will contribute staff time to assist in developing study design, data collection protocol and data analyses methodologies.

The Lower Columbia Fish Recovery Board (LCFRB) will contributes staff time, including administrative staff and overhead, to prioritize habitat restoration actions, develop project conceptual scoping designs and assist in project development and implementation.

Details of funds committed though commitments of in-kind activities are presented in the budget section of this proposal.

12. Peer Review of Proposed Project

This proposal is the collaborative work of multiple personnel from six organizations interested in bull trout recovery in the Lewis River. All parties agree that this is a critical step in implementing on-the-ground recovery actions for bull trout.

13. Budget

Provide a **detailed** budget for the project stages (Final design, Permitting, Construction, Monitoring/Reporting) by work task. Include:

- Personnel costs
  - Labor and estimated hours for each project employee
- Operating expenses
  - Supplies and materials
  - Mileage
  - Administrative overhead

Budget: Personnel Costs				
Partner	**In Kind**	**In Kind Task**	**Requested ACC Funds**	**Requested ACC Funds Task**
LCFRB	$55,215.50	Recovery Plan Implementation and Project Oversight Habitat Restoration Project Development and Prioritization	$0	
USFS	$5,000	ACC Project Lead and Oversight, Field Survey Project Lead and Development/Training of Field Staff	$7,000	Field Training, Restoration Project Development, Project Oversight and Coordination
WDFW	$16,156	Train field Staff, Participate in Field Investigations, , Project Implementation and Study Design and Statistical Analyses	$19,406	Study Design and Statistical Analyses Research Scientist (2 mos.)
MSHI	$1000	ACC Project lead and Existing Data Collection and Gap Analysis	$10,000 $14,000 $4,000	Conduct spawning and habitat surveys Field Leader (2 mos.) Field Assistant (8 mos.) Spawning Assistants (2 mos.)
USFWS	$1,000	Study Design and Statistical Analysis		
CIT	$1,000	Field Survey Assistance and Restoration Project Development and Prioritization.		
Budget: Operating Expenses				
MSHI	$3000 $1000	Mileage Supplies and materials	$0 $2000	 Dry suits, Temp. data loggers
SUBTOTAL			$56,406	
TOTAL	$83,371.50		$59,226	Includes Grant Administration (5%)

If in-kind contributions have been acquired, please note contributions according to project stage within the budget.

14. Photo Documentation (Per National Marine Fisheries Service's Biological Opinion for Relicensing of the Lewis River Hydroelectric Projects):

    Since this project will not directly result in on-the-ground habitat improvements, photo documentation of the project is infeasible. Instead, photographs of high-use bull trout habitats and sites for proposed habitat restoration projects will be included as part of the prioritized project list.

Attachment 2

ACC Comments and Questions on Pre-Proposals
USDA Forest Service - Lewis River Side Channel Near Little Creek, Muddy River Tributary near Hoo Hoo Bridge, Little Creek Fish Habitat Restoration and Survey of Bull Trout stream habitat features to develop future habitat restoration projects

Note: Questions that follow are directly from emails and/or discussions by the ACC.

All projects: Proposals should demonstrate that the project is scientifically supported, has a clear nexus to the Lewis River hydroelectric projects, and clearly supports the Aquatic Fund objectives. Please prepare the document with the assumption that the reader is not familiar with the Lewis River basin, its issues, or its resources.

Lewis River Side Channel near Little Creek
WDFW: Need better breakdown of budget. How will the structures be anchored. Need additional information on how fish will use area in high and low flows. Please explain the need for helicopter.

LCFRB: To fully evaluate this project it is important to know if the side channels are currently functional and are they accessible year round or seasonally. In addition to providing greater habitat diversity, would large wood structures also enhance or maintain flows in the side channels? A diagram showing approximate structure locations and elaborating on the type, location and scale of expected habitat outcomes (sort gravel, provide juvenile rearing, etc...) should be included in a final proposal. A full description of existing habitat and the improvement resulting from this project would assist in evaluating this project.

USFS: Please expand on project need and current fish usage; Please explain why helicopter is needed (vs. ground based/use of current abandoned road); Please clarify what scenario is if SRFB helicopter costs are not received; Please show map of proposed structure locations (eg zoomed aerial map with asterisks or symbols where log placement); Please describe more on "opportunity to treat invasives"; Recommend describing how fits into and contributes to Forest restoration plans.

Muddy River Tributary near Hoo Hoo Bridge
WDFW: Would like additional information on the success or failure of the stage one work that occurred in 2011. Need diagram of where structures will be placed. Need explanation on how structures will be anchored.

LCFRB: It appears from the pre-proposal that habitat may be functioning as is; therefore, there needs to be a full description of the current habitat conditions and the improvements in these conditions that will result from implementation of this project. A more complete description of existing stream in the project reach as well as watershed conditions is needed. The final proposal should explain the rationale for the number of structures and provide a diagram showing approximate structure locations and elaborating on the type, location and scale of expected habitat outcomes.

USFS: Please expand on project need and current fish usage; Please show map of proposed structure locations (eg. zoomed aerial map with asterisks or symbols where log placement); Like the invasive plant treatment elements and consider as an appropriate riparian treatment; Recommend describing how fits into and contributes to Forest restoration plans.

PacifiCorp: Is there any known spawning or rearing in this section?

Little Creek Fish Habitat Restoration
WDFW: Is helicopter service funded with this project or is it dependent on funding project #1 through aquatics funds or SRFB funding. Need explanation of how structures will be anchored.

LCFRB: A diagram showing approximate structure locations and elaborating on the type, location and scale of expected habitat outcomes should be included in a final proposal.

USFS: Please expand on project need and current fish usage; like the invasive treatment as part of appropriate stewardship; recommend describing how fits into and contributes to Forest restoration plans.

PacifiCorp: Need more specificity about weed control.

Survey of Bull Trout stream habitat features to develop future habitat restoration projects
WDFW: Final proposal needs to have a clear plan that identifies specific spawning and rearing habitats. What are the areas in Rush Cr. Pine Cr. and P-8 that BT actually use. What are the specifics attributes: depth, channel width, substrate, tree canopy, gradient, etc. WDFW supports this effort in having a more strategic planning effort with multiple partners that can provide information to the Bull Trout Technical Work Group.

LCFRB: A final proposal for this study needs to provide a clear plan to: 1) Identify and prioritize stream reaches; 2) Define Habitat Suitability Criteria; 3) Define the methodologies and protocols to be used in conducting the habitat surveys; and 4) Implement the survey and habitat strategy development, including identification of tasks, a schedule, management structure and partner responsibilities, needed skills and qualifications, and a detailed budget. The final proposal should provide additional information on which streams are being surveyed and what criteria was used to select these streams. Additionally, it will be important to describe how people conducting this work will be trained to collect the data necessary to guide future habitat restoration projects.

USFS: Please describe proposed inventory methodology…should incorporate a methodology for all habitat parameters.

APPENDIX E.

Study Plan for the Bull Trout Habitat Restoration

Project Identification Assessment

May 16, 2014

Bull Trout Habitat Restoration Project Identification Assessment, Study Plan

Introduction:

The primary goal of this study is to identify locations in the Lewis River basin to implement habitat restoration to increase the quality and quantity of suitable spawning and/or rearing habitat for bull trout. The group has agreed to focus on spawning habitat and to accomplish this effort in two phases. First, a study will be conducted to identify and quantify suitable spawning habitat for bull trout in the upper Lewis River basin. The expected results of this study will provide information about suitable spawning habitat and will aid in identifying locations in the basin that lack this habitat structure and can be improved (restored). The second stage of the study will quantify habitat in areas outside of existing spawning locations and areas that lack the habitat structure identified during the first stage of the study will be candidates for restoration. The following describes the details of each phase.

Phase 1: Identify suitable spawning habitat for bull trout

To understand suitable habitat for spawning, one needs to conduct a study in areas where bull trout spawn. In the upper Lewis River basin, the only known areas of spawning are in Pine Creek, P8 (tributary to Pine Creek), and Rush Creek. Spawning may occur in other watersheds but data are currently lacking.

Spatially continuous habitat mapping and redd surveys will be conducted in the three known spawning streams of the upper Lewis basin – Pine Creek, P8 (tributary to Pine Creek), and Rush Creek. The habitat surveys will be conducted during base flow conditions from July to September, 2014 (see Timeline). The habitat surveys are designed to quantify the habitat structure available to spawning bull trout and will incorporate metrics likely to aid habitat restoration efforts and likely to influence salmonid spawning habitat use. The habitat metrics will characterize channel morphology (i.e., wetted width, depth, maximum depth), and will quantify factors likely to influence salmonid spawning habitat use such as large woody debris (Senter and

Pasternack 2011; Shellberg et al. 2010) and instream cover (Bjornn and Reiser 1991; Wissmar and Craig 2004; Braun and Reynolds 2011; Nika et al. 2011). Potential spawning patches, based on gravel size, stream depth, and water velocity (*sensu* Isaak et al. 2007) will also be measured.

The habitat surveys will commence at upstream waterfall passage barriers and proceeded downstream to the mouth of each stream. The surveys in Pine Creek may only encompass the mid and upper portions of the creek due to safety reasons – unsafe sampling conditions due to high stream velocity in the lower portion of the creek. Samplers will visually delineated the stream into habitat units (i.e., pool, riffle, or glide; Bisson et al. 1982) measure the length of the habitat unit with a laser range finder, and georeference the upper extent of each habitat with a handheld global positioning system (GPS). Samplers will then quantify all habitat metrics within each habitat unit. Wetted width will be measured perpendicular to the flow at five spaced transects (including one at the upstream and one at the downstream extent of the unit), depth will be measured at one-quarter, one-half, and three-quarter distance along each width transect, and maximum depth within the entire habitat unit will be located and measured. Pieces of channel-forming LWD (both > 5.0 m length and > 30 cm diameter) within the active stream channel will be counted and the dominant and subdominant surface substrate types will be visually estimated. Substrate types will be categorized by intermediate axis length and include fines (< 2 mm), gravel (2–64 mm), cobble (64–256 mm), boulder (> 256 mm), and bedrock (Cummins 1962).

Instream hiding cover for adult bull trout will be quantified. Aquatic and riparian habitat features that will be considered hiding cover will include wood (both > 1.0 m length and > 10 cm diameter), overhanging vegetation that touches the stream surface, and undercut banks horizontal depths > 50 cm. Turbulence will also be considered cover if the samplers cannot clearly delineate substrate particles through the water surface. In addition to these criteria, these features need to include a surface water area of at least 0.5 m^2 with no point shallower than 45 cm. Depths greater than 80 cm with a minimum area of 0.5 m^2 will be considered cover even if no cover features are associated with them. Hiding cover will be quantified as the surface water area associated with each cover feature.

Gravel is an important component of suitable salmonid spawning habitat (Bjornn and Reiser 1991; Kondolf and Wolman 1993; Barlaup et al. 2008) and will be quantified as a composite variable termed potential spawning patches (PSP).   PSPs incorporate three important variables associated with suitable spawning habitat – substrate size, water depth, and water velocity (Crisp 2000; Armstrong et al. 2003). PSPs will be identified as areas with gravel as the dominant substrate (intermediate axis length 2–64 mm), water depths 10–35 cm, and water velocities at least 10 cm/s (visual estimate), and an area of at least 0.5 m^2. These criteria are based on research describing the microhabitat characteristics of bull trout redds (Kitano et al. 1994; Hagen and Taylor 2001; Wissmar and Craig 2004; for a review see Baxter and McPhail 1996). Dominant surface substrate size for PSP will be determined visually by comparing the surface substrate to a 64 mm reference stone. PSP will be quantified as areas.

Spatially continuous bull trout redd surveys will be conducted in each stream during September and October, 2014 (see Timeline). Each stream will be surveyed on weekly basis for 8 weeks to capture the spatial and temporal distribution of redds. Redds will be georeferenced and visually marked by securing surveyor's flagging to stream side structures (e.g., vegetation or LWD). The date the redd was first observed and the surveyor's initials will be written on each flag.

Instream habitat and redd location information will be linked using a geographical information system. The habitat structure data will be summarized at 100 m reaches using an R script developed for binning longitudinal stream survey data (E. Welty, University of Washington, unpublished script).

Logistic regression will be used as a resource selection function to model the probability of bull trout redd occurrence as a function of the habitat variables. In general, logistic regression predicts the probability of an event occurring (e.g., redd occurrence) with a binary response variable (e.g., redd presence/absence; Hosmer and Lemeshow 1989) Logistic regression is a popular analysis approach in habitat-selection studies (Johnson et al. 2006) and is often used to predict the occurrence of stream fishes as a function of various biotic and abiotic factors (e.g., Dunham et al. 2003; Rich et al. 2003; Al-Chokhachy and Budy 2007; Isaak et al. 2007; Muhlfeld et al. 2009). Several logistic regression models will be developed and the best model will be selected using an information theoretic approach (Burnham and Anderson 2002). This analysis approach will identify the habitat variables that best predict the occurrence of bull trout redds and thus contribute the most to suitable spawning habitat. The model will also provide information on the amount, or quantity, of the habitat variables needed to have a high probability of spawning habitat use.

Phase 2: Identify locations for habitat restoration

Habitat restoration location identification will take place in 2015 (see Timeline). Candidate locations will be identified by first filtering the upper Lewis basin based on maximum summer temperature, passage barriers, and areas outside of existing spawning locations. Maximum summer temperature has been successfully used to predict the occurrence of juvenile bull trout and is the best single predictor known to identify suitable spawning and rearing habitat for bull trout at the reach scale (Dunham et al. 2003). A maximum summer temperature of 17.5 ^{o}C will be used. This is a conservative value and corresponds to ~ 25% probability of occurrence in Washington streams. Temperature data from data loggers deployed in 2013 and 2014 will be used to model maximum temperatures in a GIS along the length of each stream. Habitat surveys will be conducted from a systematic sample of reaches that have a maximum summer temperature $\leq$ 17.5 ^{o}C, are below passage barriers, and are outside existing spawning locations. The habitat metrics measured during the surveys will be based on the model results from Phase 1. Data collected during the Phase 2 habitat surveys will be entered into the Phase 1 model to determine the probability of redd occurrence as a function of the available habitat. Reaches that have a low probability of redd occurrence will be candidate locations for habitat restoration. These reaches will also be analyzed to determine the type and quantity of habitat that should be added to increase the probability of redd occurrence.

Timeline:

2014 – Identify suitable spawning habitat

Dates	Activity	Stream	Miles	Days	Hours
Before June 15	Deploy Temp Loggers				
July 23 - 24	Paperwork/Training/Buffer			2	20
July 28 - August 7	Habitat Surveys	P8	2.4	8	80
August 18 - August 21	Habitat Surveys	Pine	7.5	4	40
September 2 - September 5	Habitat Surveys	Rush	1.8	4	40
September 8 - October 30	Redd Surveys*	All 3		32	320
November	Remove Temp Loggers				
November - December	Data Entry/Analysis				

* Survey each stream once a week. One day for P8, two days for Pine, one day for Rush. Eight passes total.

2015 - Identify locations for habitat restoration

Dates	Activity	Stream	Miles	Days	Hours
July - August	Habitat Surveys	TBA		32	320
September - October	Data Entry/Analysis				

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