

A Permeability Study on Salmonid Spawning Areas in Northern Humboldt County, California¹

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Abstract

This research was conducted to determine if local salmonid, specifically coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*O. tshawytscha*), and the steelhead trout (*O. mykiss*), redd location is dependent upon the permeability of the streambed. The study took place at four study sites in two coastal drainages in northern Humboldt County, California over a 16 month period (June 2004 to October 2005). This period covered pre and post spawning conditions, as well as changes in seasonal flow conditions. Sampling grids were established at each site to allow for repeatable permeability measurements which ranged in number from 37 to 105. Permeability measurements were taken using a battery operated pump to draw water through a perforated standpipe driven into the streambed at a depth of approximately 25 cm. Study results showed that permeability was not significant in predicting redd location. In addition, results showed that permeability measurements varied in orders of magnitude within as little as 30 cm. Graphic representations of the spawning areas were created using GIS and clearly display the heterogeneity of the streambed. The results of this study support the need for further investigation of spawning gravel assessment methods which can account for extreme spatial variation while minimizing disturbance to the streambed.

Key words: fine sediment, monitoring, permeability, redd, salmon, spawning habitat

Introduction

Increased fine sediment levels in rivers and streams are a concern for many land managers due to possible detrimental effects on salmonid habitat. The need to quantify sediment levels in watercourses serves as a driving force of research and monitoring for both private and public resource managers in California's north coast region. While all life stages of salmonids benefit from cool clean water, embryos and alevins require adequate flow of oxygenated water through the spawning gravel. Permeability, defined as the rate of flow through the substrate, is one parameter that has been used as an indicator of spawning gravel quality.

Excess fine sediment can fill the spaces between gravel in the streambed, or bury it entirely, thereby decreasing permeability, impeding the delivery of oxygen, and reducing the removal of waste from the redd (Cordone and Kelley 1961). Chapman (1988) summarized prior studies showing that the survival of salmonid embryos is positively correlated to permeability ($r^2 = 0.85$). Coble (1961) found that there was no relationship between permeability and survival, but rather a relationship between apparent velocity and survival. The difference is that permeability describes the physical capacity of the substrate to transmit water whereas apparent velocity

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describes the rate of flow of water through a unit area of substrate. While literature shows that redd placement is highly correlated with depth, velocity and bed material (Bjornn and Reiser 1991), there is continued research investigating the complexity of spawning site selection. Ongoing research provides reasons such as stream reach sinuosity, population densities and behavior as to why certain areas are more heavily utilized for spawning.

Sampling methods to determine particle size distribution, such as bulk sampling (McNeil and Ahnell 1960), or freeze coring (Walkotten 1976), are frequently used to quantify substrate composition; however, both methods are destructive to the streambed and are more labor intensive than permeability measurements. Additionally, while bulk sampling measurements can adequately determine the particle size distribution, they do not provide a clear picture of how those particles are arranged in the streambed itself.

The objectives of this study were to determine if streambed permeability explains why certain local salmonids, specifically coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*) create redds in specific locations in the streambed and to create graphic representations which depict the spatial variation of permeability within a spawning area. Permeability measurements for this study were conducted at sites where historic spawning activity has been documented. The hypothesis was that the redd locations and areas of high permeability would be positively correlated.

Methods

Study area

Streambed permeability measurements were conducted at four study sites between June 2004 and October 2005. Study sites were located in two major river drainages, the Mad River and Little River, in northern Humboldt County (*fig. 1*). All study sites were on Green Diamond Resource Company property within commercially managed forests of coast redwood (*Sequoia sempervirens*) and Douglas fir (*Pseudotsuga menziesii*). The estimated total annual precipitation (Rantz 1972) is 165 cm for the Cañon Creek (CC) site in the Mad River drainage and 178 cm for the three Little River sites: mainstem Little River (MLR), Upper South Fork Little River (USFLR), and Lower South Fork Little River (LSFLR). During the study period (June 2004 to October 2005), the rainfall totals from the nearest rain gauges to each of the study sites indicate that the study period had slightly lower than average annual precipitation.

The four sample areas were selected in areas known to have high spawning activity based on results of historical spawning surveys. These watersheds are all known to have spawning coho, Chinook, and steelhead. These sites were also chosen because of similar geology, gradient and substrate. All four sites are low gradient, depositional reaches located within watersheds dominated by formations that consist largely of sandstone.

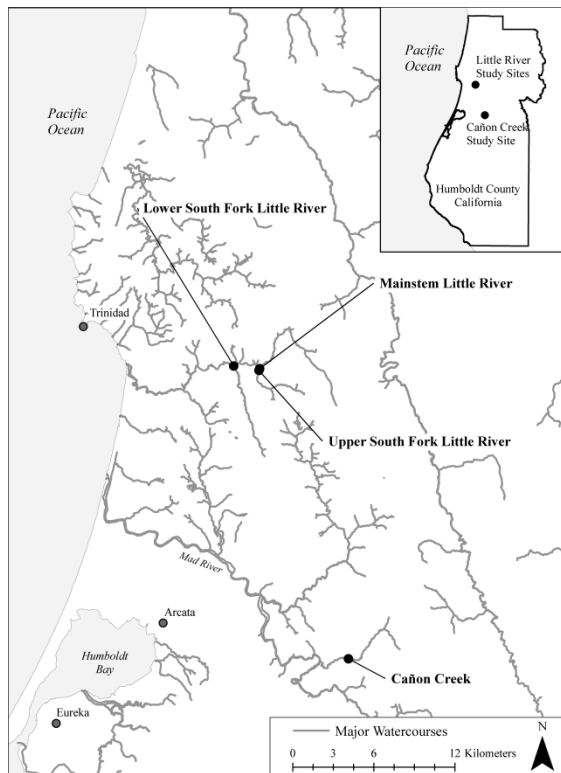


Figure 1—Locations of study sites within Humboldt County, California.

Study design

The method used to measure permeability in this study was based on those developed by Barnard and McBain (1994) and the Mark VI permeability standpipe (Terhune 1958). The sample design varied from the original protocol (McBain and Trush 2000) by greatly increasing the number of points sampled. Rather than using an average of five points at the riffle crest to determine the permeability at a site, a 1.2 m grid was established across the pool tail/riffle crest area. The number of grid points sampled ranged from 37 to 105 depending on the wetted width and total length of the riffle at each site and sampling period in which it was sampled.

Pre-spawning permeability measurements were recorded during summer 2004 at multiple stations throughout the grid, within the wetted width. Each permeability measurement location was marked with a survey flag. Streambed elevation, data point locations, and the wetted perimeters of the study areas were surveyed using a Leica TC307 total station.

Spawning surveys were conducted during the fall/winter 2004 to 2005 run of steelhead, Chinook, and coho. Redd locations were marked with bricks and flags and later surveyed with the total station. Post-spawning permeability measurements were made at grid points and redd locations during early summer 2005. A second post-spawning season measurement of permeability at grid points and redd locations was made in October 2005 at two of the four study sites: MLR and USFLR. These measurements had to occur prior to the onset of rain since increased flows could

potentially mobilize deposited sediments. This second measurement (October 2005) was to provide a comparison of seasonal variation at a site and to allow for repeatable measurements in exact locations. In addition, 13 grid points per site were selected at random and designated to have a 30 cm offset permeability measurement point during the October 2005 survey. These offsets were measured in an attempt to determine if permeability varies within very short distances across the study area.

Data analysis

Due to the number of near zero permeability values, a natural log transformation of the data was used to attempt to create a normally distributed data set. Even with the transformation, the data failed normality tests. Logistic regression was used to determine if presence or absence of a redd could be predicted based on the measured variables. The variables used in the regression models were permeability (cm/hr), distance from the riffle crest (m), and distance from the thalweg (m).

Spatial analysis of the data was performed using ArcGIS Spatial Analyst to interpolate permeability values between measured points at each of the study sites. This analysis was done using an inverse distance weighted method (IDW). One analysis used the transformed permeability values, and another used ranked categories. Permeability ranks were used to relate the data back to its biological significance: positive correlation between permeability and survival to emergence (Chapman 1988). The ranks represent three categories, defined as Low (L) (<1,000 cm/hr), Medium (M) (1,000 -10,000 cm/hr) and High (H) (>10,000 cm/hr). Spatial patterns were analyzed to determine if salmonids select areas of high permeability to create redds.

The analysis also investigated the within site and between site variation, the difference between years, seasonal differences, and offset differences. T-tests were used to determine if there were significant differences in permeability between pre and post spawning activity, early and late season measurements and original sampling locations compared to their corresponding offset points.

Results

The mapped interpolated surface (*fig. 2*), shows the location of permeability measurements with their corresponding rates (cm/hr) and the location of redds observed between January and May 2005. The total number of redds marked at each site was (7) CC, (1) LSFLR, (14) MLR, and (9) USFLR. The placement of the redd markers on the map are for comparison only as they were not present during the pre-spawning sampling period.

Logistic regression models were applied to the data set in order to determine if redd location could be predicted based on prior season permeability, distance from the thalweg or distance from the riffle crest. The models indicated that permeability, distance from the riffle crest and distance from the thalweg were not significant predictors in redd placement location. LSLFR was excluded from the models because of the occurrence of only one redd and the presence of an area of very high permeability created by a half-buried log.

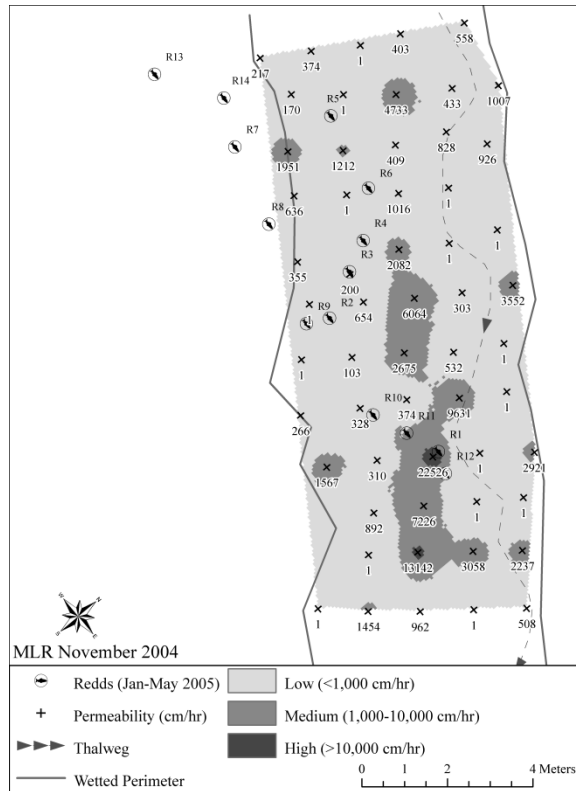


Figure 2—IDW interpolation of pre-spawning substrate permeability at Mainstem Little River study site showing sampling locations and permeability rates in cm/hr.

The models were initially run with the exclusion of low permeability values (<1,000 cm/hr) in an effort to create a normal distribution of the data. This was based on the assumption that fish would not spawn in areas of low permeability due to the limited success of their redds in these areas. Upon further analysis of the data, it was shown that 61 percent of all redds among all sites were built in areas of low permeability; hence it did not seem valid or justified to remove the low permeability values from the analysis.

Although none of the measured variables proved to be significant predictors of redd location, models were developed to provide insight to weak trends in the data. Multiple versions of the logistic regression model indicated that distance from the riffle crest was the most significant factor in predicting the presence of a redd and provided a better result than permeability alone. The prediction model showed that, for this study, the probability of a redd occurrence is more likely as distance from the riffle crest increases. The best fit model, which used categories of permeability, still only explained 52 percent of the variation of the data. The logistic regression models indicate almost no relationship between likelihood of redd presence and permeability.

Spatial analysis of the study sites showed that all three sites were dominated by areas of low permeability prior to the spawning season. There appeared to be no statistically significant change to the site permeability after spawning, or as the flows continued to drop into October. The relationship between the available area of each previously defined category (L, M, H) of permeability and the number of redds

present within that category are highly correlated. This distribution further demonstrates the lack of correlation between areas of high permeability and occurrence of redds.

The data were then analyzed to investigate if the fish were able to create their own permeable areas that would persist into the following sampling period. A paired t-test was performed to determine if a change in permeability could be detected between pre-spawning activity and post-spawning activity at individual redd locations. Although the data do show a small difference in the means before and after spawning, there was not a statistically significant difference between pre-spawning and post-spawning permeability ($p = 0.70$, $\alpha = 0.05$). While pre- vs. post-spawning did not show a clear trend, the comparison of early to late summer median values did suggest that permeability decreased between May 2005 and October 2005, though not statistically significant. The difference in permeability values between the original point and the 30 cm offset point measured at MLR and USFLR sites in October differed by category (L, M, H) approximately 50 percent of the time. While the statistical analysis did not detect a difference in the median values, it is clear from the data that there was variation in permeability values within 30 cm.

Discussion

This study used the following assumptions based on literature and established protocols. The first assumption was that the spatial heterogeneity of the gravel in the study sites was low enough that a 1.2 m grid was sufficient to capture the variation in permeability. Another was that the measurements were independent of flow and season. It was evident from the results of this study that the timing of data collection has significant effects on both the ability to actually collect the data and its biological significance. This study also demonstrated that if permeability sampling occurs during times of low flow conditions, then critical spawning locations may be excluded from the data set. The permeability testing for this study was not done while the redds were active to avoid harming incubating eggs. The redd locations were marked as soon as possible and sampled after the fry emerged from the gravel. Because of this, it was impossible to know the conditions while the eggs were buried in the substrate. The monitoring efforts of many governmental agencies and private landowners occur during summer months when weather and work schedules allow. While it is important to monitor organisms in natural conditions, it is difficult to weigh the importance of data collection and the possible impacts that certain methods and timing can have on the organism being studied. It is also important to consider the timing and methods of data collection that will provide scientifically sound and biologically significant data.

In addition to timing or seasonality of data collection, the nature of spawning adds greater uncertainty in analysis of the data. Redd locations were surveyed as a single point, and therefore there are some problems in interpretation of the actual influence of the permeability on redd location. The point at which the redd was marked and surveyed is at best an estimation of the actual location of egg burial. The area of influence of fish activity on or around a redd varies depending on both fish and substrate size (Bjornn and Reiser 1991). Based on estimated measurements from this study, the average area of fish disturbance of the substrate at a redd was approximately 0.88 square meters, but a summary of studies show that redds can

average up to 10 square meters (Bjornn and Reiser 1991). Salmonids have the ability to clean the gravel by removing the fine particles while digging their redds. Chinook and steelhead have the ability to reduce the amount of fines within a spawning area by a range of 7 to 23 percent (Everest et al. 1987). It is unknown if the sites that were marked as redds were actually used for spawning, as fish were not present when the redds were marked. Fish can dig “test redds” and can also superimpose redds. While every effort was made to mark each and every redd location, there may have been some that were missed, or were not actual redds, but rather a test redd. Every location marked was assumed to be a single true redd. The sites were visited on a regular basis and redds were marked as soon as they were visible. Due to low visibility in the water during higher flows and the necessity to not disturb the fish during active spawning, the redds were marked as soon as it was feasible. In future studies, redd measurements such as total surface area, pot dimensions, and tailspill dimensions should be observed and recorded.

There were questions that arose with the method and predetermined protocol as the field investigation continued. One issue was the depth at which the measurements were taken. In some cases, the depth that the permeability measurement was made may not necessarily be the depth at which the eggs are buried. The depth in the protocol comes from an average depth of salmonid species; therefore, due to differing geology of the underlying sediments, particle size of the streambed and fish size, the depth of measurement may not accurately represent the permeability of the egg pocket.

The two study sites, MLR and USFLR, in which 30 cm offsets and late summer measurements were taken showed a decrease in permeability between early and late season measurements. The lower permeability in late summer may be attributed to infiltration of fines and organic matter as both surface flow and hyporheic flow decrease. The data also indicated that large variations of permeability can occur within a short distance. Coble (1961) found that permeability values varied at sites only 15 cm apart. Based on results from Kondolf et al. (2008) the zone of influence for each standpipe was less than a 20 cm radius. Because of this variation, and lack of potential spatial dependence, IDW may not have been the appropriate approach to analyze these data, though it appeared to be the best available method, and did provide insight into the complex distribution of the streambed matrix.

Another issue encountered with the data is determining the source of variability, as shown in the permeability maps. The streambed is a very dynamic system and is constantly undergoing change. The spatial variation could be due to hyporheic flow, bed movement, surface flow, fish disturbance, or disturbance due to the sampling method. The variation in fine sediment in streambeds is so large that distinguishing between background and land-use augmented amounts is difficult (Adams and Beschta 1980). It is also hard to determine if the variation is an artifact of the method itself. Kondolf et al. (2008), using the same method, found that up to 68 percent of water that entered the standpipe may actually be surface water leakage along the edge of the pipe. They found that this was common in coarse gravel installations. Installation of the standpipe into the streambed often opened up pockets free of material allowing for excess water to move along the edge of the pipe.

Conclusion

The results of this study suggest that redd location is not correlated with prior season substrate permeability as determined from a 1.2 m grid. The variation shown within study sites suggests that results are dependent upon where the standpipe is placed within a study area. The large variation suggests that many more sample points would be required to account for, or at least minimize, the variation between measurements. If more sample points are required, other issues arise. The measurements would no longer be independent due to influence of one point on another in close proximity. More sample points would also negate the major benefit of this method in that it is assumed to be a rapid sampling technique. If a large number of samples would be required in order to address variation, then the method is no longer a rapid and inexpensive approach.

This study provides graphic representations of the heterogeneity of the streambed and indicates that redd location is not correlated with permeability. Regardless of the imperfections of the method, study results show the recorded permeability measurements indicate great variation in subsurface conditions. While monitoring permeability rates can describe general bed conditions in specific locations, individual or even average permeability values from individual sites should not be used to characterize spawning gravel conditions for watersheds or even smaller stream reaches.

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