EFFECTS OF FINE SEDIMENT ON FISH POPULATIONS

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ABSTRACT

To describe conditions in natural redds of steelhead trout (Oncorhynchus mykiss), we evaluated the particle size distribution of egg pockets, redd pits and tailspills, artificially constructed redds, and undisturbed substrate outside redds. Egg pockets were located in upper strata an average of 14.9 cm below the substrate surface. Egg pockets contained fewer fines (<6.35 mm) than other sites, except in artificial redds. As substrate depth increased, percent fines tended to increase at all sampling sites and variability in percent fines among sites was reduced. We observed no change in percent fines sampled from May to July, except in cleaned intrusion sites where free interstitial areas rapidly accumulated sediments. Dissolved oxygen levels declined in redds during incubation. Limitations of the data are discussed.

INTRODUCTION

Increased sediment production within watersheds can amplify the transport and deposition of sediment in stream channels. Fishery biologists have been concerned about the effects of fine sediment on salmonids for more than 60 years (Grost 1989). A large body of research suggests that deposition of fine sediments in streams is detrimental to the spawning and incubation of salmonids (Cordone and Kelly 1961, Everest et al. 1987). To determine the consequences of sediment deposition in spawning areas, researchers have linked models that predict sediment delivery with sediment-based predictions of survival to emergence (Young et al. 1989).

Much of the past research on sediment-based estimates of survival has consisted of laboratory studies that may not accurately reflect conditions in the natural environment (Everest et al. 1987, Chapman 1988). Few data are available to characterize conditions including particle size distributions, dissolved oxygen concentrations, water temperatures, and intragravel velocities in natural redds, especially at the site of egg deposition, the "egg pocket." As Chapman (1988) observed, quantitative predictors depend upon careful definition of egg pocket structure and on intensive study of egg pocket conditions. An understanding of conditions in natural redds can aid in determining the location and method of sampling to assess sediment effects (Grost 1989). Conditions outside egg pockets may not be related to conditions within egg pockets (Young et al. 1989). Knowledge of the structure and composition of the egg pocket can be applied to laboratory conditions, making better analogs of natural conditions (Chapman 1988). Knowledge of spatial differences can aid in determining the location and timing of sampling to assess sediment effects.

We incorporated an interdisciplinary approach involving biologists and hydrologists to describe conditions in natural redds of steelhead trout (Oncorhynchus mykiss). We also compared conditions in egg pockets to those in the surrounding substrate, both within the redd environment and exterior to it. We further describe temporal changes in egg pockets and the surrounding substrate as incubation progressed. Finally, we compared conditions in natural egg pockets and artificially constructed redds. The Idaho Department of Health and Welfare-

Division of Environmental Quality (DEQ) has proposed artificial redd monitoring as a technique to measure the effects of fine sediment on beneficial uses (Burton et al. 1990). The validity of this method depends on an understanding of conditions in natural redds.

METHODS

Study sites were selected in a 1.6 km reach of the mainstem Salmon River approximately 19 km upstream from Stanley, Idaho. The river flows north through a broad valley composed of alluvium and glacial deposits and drains over 500 km^2 of the White Cloud and Sawtooth mountains in the Sawtooth National Forest. The area is mostly underlain with granitic rock with a small area of Paleozoic sedimentary rock in the southeast portion of the basin. Elevations range from 3050 m at the divides to 1950 m in the study reach. Peak stream discharge typically occurs during 6 weeks in May and June during snowmelt. Base flows occur from September through January.

Steelhead trout are indigenous to and formerly spawned in the study reach. As a result of severe declines in wild fish escapements, hatchery-reared steelhead trout have been introduced in the drainage (IDFG 1984). We obtained 30 pairs of hatchery-reared steelhead trout, ranging from 60 to 80 cm in length, from the Idaho Department of Fish and Game's Pahsimeroi Hatchery. The fish were released in the mainstem Salmon River near the confluence of Hell Roaring Creek on April 20, 1990. Within 4 days we identified redds and randomly selected 26, 10 in a diversion channel adjacent to the river and 0.8 km downstream from the release site and 16 near the confluence of Hell Roaring Creek. Subsequently, these two locations will be referred to as the Hell Roaring (HR) and Diversion (DV) reach.

We applied terminology described by Grost (1989) as follows: redd, an area of the substrate modified by a salmonid during reproduction, usually elliptical and composed of a pit and tailspill. Pit, the deeper, concave, upstream portion of the redd. Tailspill, the shallower, convex, downstream portion of the redd. Egg pocket, a concentration of eggs within the redd.

On April 24, 1990, we inserted probes into redds from the downstream end of the pit and at the boundary of the undisturbed substrate and tailspill. We attempted to insert the probes adjacent to the egg pockets within the redds. Probes were designed to allow extraction of water from the interior of the redd for measuring dissolved oxygen (D.O.), temperature, and apparent velocity. Probes were constructed of continuous coil slot well-screen (30.5 cm by 3.2 cm diameter) capped on both ends with PVC fittings. An inner perforated rigid tube was attached to a 152 cm length of 6.3 mm (inside diameter) flexible tubing (Burton et al. 1990). The flexible tubing was left exposed on the substrate.

Adjacent to each natural redd, we established three additional sampling sites for: (1) construction of an artificial redd, (2) sampling natural substrate (undisturbed substrate outside of redds), and (3) measuring the intrusion rate of fine sediments into "cleaned" substrate. We selected the locations of the three sites by establishing four 3 x 3 m quadrants around each natural redd and randomly selected a quadrant for each site. Within the selected quadrant we randomly selected a location that met the following criteria: water depth of 0.37 to 0.6 m, velocity of 0.5 to 0.65 m/s, and surface substrate with diameters of 0.3 to 7 cm and 10 to 25% cobble (Cochnauer and Elms 1986). Occasionally, multiple sites were located in a single quadrant. Sampling sites were located to minimize disturbance of natural redds.

Artificial redds were constructed on April 24 with assistance from experienced DEQ personnel. An egg basket and monitoring probe were placed in each artificial redd. Burton et al. (1990) describe the specific techniques of artifical redd construction and the construction and installation of egg baskets. We obtained water-hardened hatchery steelhead trout eggs from the Idaho Department of Fish and Game's Sawtooth Hatchery and inserted 100 in each egg basket. Eggs were distributed throughout the lower portion of the baskets.

Natural substrate sites were marked with surveyors stakes. We excavated a 30 cm by 38 cm diameter depression at the sediment intrusion sites. The excavated substrate was sieved and material smaller than 6.35 mm diameter was discarded. We placed a 40 cm by 30.5 cm diameter nylon bucket (T. Lisle, USDA-Forest Service, personal communication) in a collapsed position in the depression and filled it with the material larger than 6.35 mm.

We collected substrate samples to describe the particle size distribution in the sampling sites. At monthly intervals, we randomly selected two natural redds (and the associated two artificial redds and two natural substrate sites) each in the HR and DV reaches for freeze coring. Additionally, four intrusion sites were chosen at the HR site for extraction of collapsable buckets. A tri-tube freeze coring procedure using liquid CO_2 (Everest et al. 1980) was used to extract a substrate sample approximately 30 cm long and 15 cm in diameter from the tailspill and pit in natural redds, the egg baskets in the artificial redds, and the natural substrate sites. Using definitions proposed by Young et al. (1989), we labeled cores as egg pocket samples if we observed eggs or alevins in the core.

Core samples from each site were stratified by 10 cm depths. The sediment core samples were air dried and sieved for 5 minutes on a mechanical shaker through the following mesh sizes: 128, 64, 32, 16, 9.5, 8, 6.35, 4, 2, 1, 0.85, 0.5, 0.25, 0.125, and 0.063 mm. We weighed the material retained on each sieve.

The bias associated with very large particles has been recognized and many workers have excluded them from analysis (Adams and Beschta 1980, Tappel and Bjornn 1983). We observed larger particles being lost as our cores were extracted. To avoid bias, we excluded particles larger than 64 mm from our analysis. As Kondolf (1988) observed, where the percentage of fine sediment is to be compared among sites or sampling times, the sample can be computed based on the truncated distribution. Stowell et al. (1983) defined fines as particles smaller than 6.35 mm and used the percent fines as an index of gravel quality in the Idaho batholith. We adopted their definition.

We sampled the D.O. concentration of water within the natural and artificial redds at 2 week intervals. We used a hand activated vacuum pump to extract water samples from the monitoring probes. Approximately 250 ml of water was initially extracted to flush the probe and measure water temperature. A second extraction was used to fill a 300 ml BOD bottle. Water samples were fixed and titrated in the field using a modified Winkler procedure to estimate D.O. (Standard Methods 1989). We estimated percent saturation by correcting for water temperature and elevation.

We compared the percentage of the substrate less than 6.35 mm for each location by strata using a two-way ANOVA. We performed multiple comparisons using the Tukey-Kramer procedure for unequal sample sizes (Sokal and Rohlf 1981). We examined differences between the vertical strata, differences between reaches, and temporal changes in sediment composition. We compared conditions in natural and artificial redds by examining differences in substrate composition and dissolved oxygen. We accepted P=0.05 as the level of significance.

RESULTS

Egg pockets in steelhead trout redds were located in upper strata. The mid point of egg pockets averaged 14.5 and 15.2 cm below the surface, respectively, in the HR and DV reaches. Egg pocket depth ranged from 7.6 to 21.2 cm. Egg pockets in artificially constructed redds were deeper, averaging 22.5 and 19.9 cm below the surface, respectively, in the HR and DV reaches and ranging from 15 to 27.5 cm.

We observed differences in the percent fines (<6.35 mm) between sites in the upper 10 cm strata. Within the HR reach, comparisons revealed significantly less fines in natural redd egg pockets than in pit and tailspill sites within the redd but outside the egg pocket (Figure 1). Within the DV reach, natural redd egg pockets also exhibited less fines than other sites within the redd, but differences were not significant. There was no significant difference in the percent fines in natural substrate outside the redds as compared to pit and tailspill sites in the upper strata samples from either reach. Artificial redds in both reaches exhibited significantly less fines than sites outside the redd or outside the egg pocket. There was no significant difference between the percent fines in egg pockets and artificial redds.

Percent fines were similar for the same types of sampling sites in the HR and DV reaches (Figure 1). This trend was similar for sites in natural redd tailspills and egg pockets, natural substrate, and artificial redds.

As the depth of strata increased, differences in the percent fines tended to be reduced. Within the HR reach, there were no significant differences in the percent fines between sites in the 10-20, 20-30, or 0-30 cm strata. Within the DV reach, artificial redds retained significantly fewer fines than other sites across all three strata.

Percent fines generally increased in deeper strata, particularly below egg pockets. The percent fines at egg pocket sites in the HR reach increased from 12.9% at 0-10 cm to 33.6% at 10-20 cm, and 33.1% at 20-30 cm. In the DV reach, the percent fines at egg pocket sites increased from 17.5% at 10-20 cm to 32.2% at 10-20 cm to 51% at 20-30 cm. Percent fines also increased at other sites from the 0-10 to 10-20 cm strata and remained similar at strata below 20 cm.

With the exception of the intrusion sites, there were no consistent temporal changes in percent fines. Within redd pits and tailspills, undisturbed natural substrate, and artificial redds, there was no significant change in the percent fines sampled in May as compared to July. Figure 2 illustrates the data by reach for pooled 0-30 cm strata. Similarly, no significant temporal change was detectable in the 0-10, 10-20, or 20-30 cm strata. We did not locate sufficient egg pockets to compare temporal changes in them. Within the intrusion sites, substrate cleaned to remove fines less than 6.35 mm rapidly accumulated fines between May and July. This suggests that sediment was moving through the reach and was deposited where free interstitial areas existed.

D.O. levels (expressed as percent saturation) declined in both natural and artificial redds during the sampling period. During the first two sampling dates, D.O. levels in natural and artificial redds were close to 100% saturation in both reaches (Figure 3). D.O. levels declined significantly after May 15 and averaged less than 80% saturation on July 11. With the exception of the July 11 sample

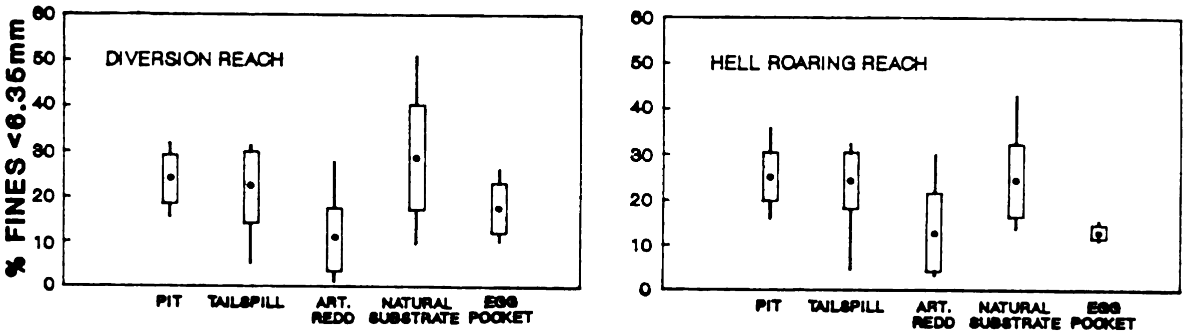

Figure 1. Percent of the substrate less than 6.35mm by sample site and reach, 0-10cm strata, Salmon River. Points, boxes, and vertical lines represent the mean, standard deviation, and range, respectively.

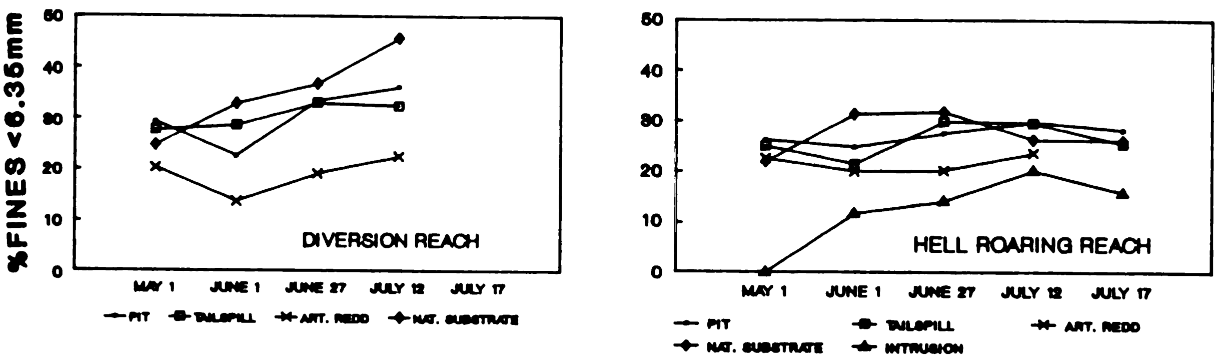

Figure 2. Comparison of the mean percent substrate less than 6.35mm by date, sample site, and reach, 0-30cm strata, Salmon River.

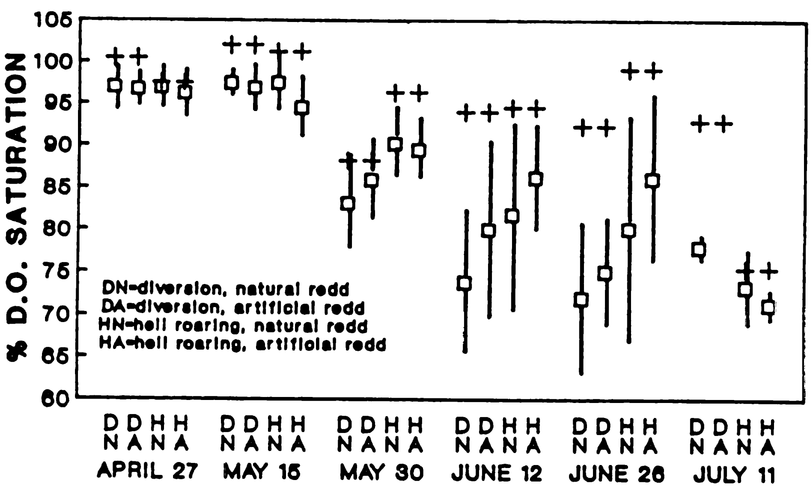

Figure 3. Means (boxes) and standard deviations (lines) of the dissolved oxygen percent saturation of water extracted from natural and artificial redds, by reach and date, Salmon River. Pluses represent the mean percent dissolved oxygen saturation of the river water column.

at the HR reach, D.O. levels in the river water column exceeded 90% saturation throughout the sampling period. The average D.O. saturation was higher at the Hell Roaring site on 5/30, 6/12, and 6/26. The difference was significant on 5/30.

The D.O. decline over the sampling period was most prevalent in natural egg pockets. We measured D.O. levels in three natural egg pockets from April 27 to June 26. D.O. levels averaged 94% saturation on 4/27, 97.3% on 5/15, 85% on 5/30, 76.9% on 6/12, and 65.1% on 6/26. We measured D.O. levels in six pits where we did not locate eggs or alevins. D.O. levels averaged 96.8% on 4/27, 96% on 5/15, 88.3% on 5/30, 80.1% on 6/12, and 81.7% on 6/26. Artificial redds maintained the largest average D.O. saturation during the sampling period, although not significantly larger than the natural redds. The D.O. levels in nine artificial redds averaged 95.5% saturation on 4/27, 94.7% on 5/15, 88.2% on 5/30, 82.6% on 6/12, and 82.7% on 6/26.

Temperatures within natural and artificial redds were generally within 1 ^{o}C of the temperature of the river water column. Water temperatures in the water column and in natural and artificial redds increased during the sampling period. Temperatures in natural and artificial redds in the HR reach averaged 3.9 ^{o}C and 3.9 ^{o}C, respectively on 4/27, and 12.2 ^{o}C and 12.3 ^{o}C, respectively on 7/11. Within the DV reach, temperatures in natural and artificial redds averaged 4.8 ^{o}C and 4.6 ^{o}C, respectively on 4/27, and 14 ^{o}C and 13.7 ^{o}C, respectively on 6/26. The HR reach maintained colder temperatures than the DV reach, probably as a result of tributary inflow.

DISCUSSION

Steelhead trout spawning in the Salmon River were apparently able to remove fine sediments less than 6.35 mm from the upper strata of the egg pocket. As Everest et al. (1987) observed, salmonids are not passive spawners, and redd building activities remove fine sediment. Our data suggest that the substrate in the egg pocket contains less fines than other sites, either inside or outside the redd. These results confirm the unique substrate composition of the egg pocket (Young et al. 1989) and tend to support the conclusions of Chapman (1988) who recommended sampling of natural egg pockets as being essential to quantitatively predicting effects of fines on salmonids.

Our inability to detect differences in the percent fines in lower strata suggests that it is critical to preserve the vertical stratification of substrate samples. Everest et.al. (1980) and Young et. al. (1989) reached similar conclusions.

The rapid increase in percent fines in the intrusion sites suggests that, where interstitial areas were free of fines, these areas retained available fines moving as bedload. Because the egg pockets also contain free substrate, sands and fine gravels could also be expected to intrude into the relatively clean gravel. We were unable to test this hypothesis as a result of an insufficient sample of egg pockets. It is also possible that a seal of fine particles, as Chapman (1988) describes, formed over the egg pocket or that hydraulic conditions above the redd in concert with a seal prevent deeper intrusion over the egg pocket. Our inability to detect differences in percent fines over time at sites outside the egg pocket suggests that interstices were filled.

Accelerated temporal depression of D.O. in egg pockets, compared to pits without eggs, suggests that developing embryos created an oxygen demand. Chapman (1988) reported that the rate of oxygen uptake increases steadily from fertilization to hatching. We observed the lowest D.O. levels in egg pockets where we observed decaying eggs and levels declined to an average of 5.2 mg/L at 65% saturation. Davis (1975) suggested a mean threshold of 8.1 mg/L and 76% saturation for successful hatching and incubation of salmonids. The presence of decaying eggs in artificial redds that did not display accelerated D.O. depression suggests that water samples from some artificial redds did not accurately reflect conditions in the redd. This may have been caused by placement of the probes, which are exterior to the egg baskets.

Several important uncertainties exist in our data. Sites in streams are not homogeneous, and conditions in individual redds vary. As a result, the wide natural variability in particle sizes within the same types of sites (i.e., across redd tailspills) makes comparison of conditions between sites difficult. A larger sample size would increase the reliability of comparisons. Also, our inability to core sample the same sites over time (as a result of destructive sampling) caused us to assume that temporal changes would be reflected in sites of the same type. This may not be a correct assumption.

We found it extremely difficult to precisely locate egg pockets in natural redds and sampled only nine. Further, placement of the probes inside the redd may have altered the structure of the egg pocket and precluded collection of accurate data describing particle size and D.O. (Young et al. 1989).

Our analysis of substrate composition applied a single index of gravel quality, percent fines less than 6.35 mm. Everest et al. (1987) and Kondolf (1988) have questioned using a single criterion to describe gravel quality. Our analysis is incomplete until we examine the distribution of other particle sizes. In addition, the geometric mean diameter (Platts et al. 1983) and Fredle index (Lotspeich and Everest 1981) have been proposed as more suitable indices of gravel quality. As Kondolf (1988) observed, geometric mean diameter and Fredle index are both heavily influenced by mean gravel size. To adequately evaluate differences in particle size distribution, several indices should be calculated for the sites by individual vertical substrata and for the composite (pooled) core. Our analysis is also incomplete until we examine the relationship between particle size, D.O., and apparent velocity.

An ultimate goal of this research is to contribute to the development of relationships between: stream sediment transport, sediment movement into redds, and the effects of sediment on egg and alevin survival. Additional research is in progress to describe the egg pocket environment of chinook salmon (Oncorhynchus tshawytscha) in the Salmon River. Our initial experiences with steelhead trout and chinook salmon illustrate that this research has many constraints and is labor intensive. As Chapman (1988) observed, the alternative to investigating natural redds is to use data of unknown accuracy and to extrapolate inappropriate data to natural redd environments.

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