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The Effects of Sedimentation on the Reproductive Success of Rainbow Trout

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The Effects of Sedimentation on the Reproductive Success of Rainbow Trout

Submitted in partial fulfillment of the requirements for graduation with honors to the Department of Natural Sciences at Carroll College, Helena, MT

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April 09, 2001
SIGNATURE PAGE

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The effect of sedimentation on fish populations, especially the effect on reproduction, has been one of the most significant problems surrounding sedimentation pollution. Sedimentation has deleterious effects on the hatching and survival of trout eggs by reducing the egg's access to oxygen and nutrients. To test for the effects of sedimentation, five streams in the Townsend, Montana area were examined. The effects of total suspended solids (TSS) as well as the individual effects of different particle sizes (clay, silt, sand) on trout reproductive success were measured. The number of rainbow trout hatchlings was not significantly associated with sand (p=0.794), silt (p=0.815), or clay (p=0.140). However, there was a significant negative correlation between TSS and trout numbers (p=0.043). Collectively, all the particles contributed to the reduction in trout hatchling numbers. Despite testing of individual particles, the individual effects of different particle sizes could not be observed, possibly because they could not be sufficiently isolated from the other particles within the sediment. The TSS results show a strong correlation between the amount of fine sediment and reproductive success of rainbow trout, supporting previous studies. Sedimentation does indeed lower the survival rate of salmonid eggs.
INTRODUCTION

The effect of sedimentation on fish populations, especially the effect on reproduction, has been one of the most significant problems surrounding sedimentation pollution. Sedimentation has the most deleterious effect on the egg stage of a trout's life cycle. High amounts of sediment can reduce redd permeability and therefore reduce the nutrients the eggs need for survival. It is during this fragile stage that sedimentation has the potential to reduce trout populations. Although many studies have been performed on total suspended sediments (TSS), there have been only a few examining the effects of individual sediment types. My field study provides more conclusive study on the effects of TSS by adding the individual effects of sand, silt, and clay on trout reproduction.

Studies in Trout Reproduction:

Trout use redds, which are gravel-spawning grounds in flowing water, to lay their eggs. Redds begin as pockets from which the female fish has removed fine particles and small gravels by vigorous flexing of her body. Water currents take the lifted fine sediment downstream, while the small gravels are deposited as a ridge below the pocket. The female lays her first eggs in the excavated pocket, and the male immediately fertilizes them. The female then digs another pocket, further upstream from the first one. This process is repeated until the female has successfully deposited all of her eggs. Water current again carries fine particles downstream from later pockets and the particles are re-deposited into downstream egg pockets (Hobbs 1937, cited in Chapman 1988).
The redds are devoid of small sediment immediately following their construction; however, particles inevitably move back into their gravel spaces. The depth that fine particles can enter into gravel crevices is greater for smaller-diameter particles and less for larger ones (Beschta and Jackson 1979). The re­entry of fine particles into the redd lowers its permeability to water. The permeability, related to percentage of sediment, directly influences survival by controlling water movement past the embryo (Lotspeich and Everest 1981).

In the absence of high sedimentation, the permeability of the egg pockets is much greater than that of the area outside the pocket (Pollard 1955). The egg pocket needs greater permeability in order to get the nutrients and oxygen it needs for development. It has been shown that water velocities must be high enough within the redd to support oxygen requirements of the embryos and to transport enough oxygen to the chorion's surface (Silver et al. 1963). Shumway et al. (1964) also established that water velocity and dissolved oxygen concentration directly affect embryo survival.

High sedimentation levels decrease the amount of dissolved oxygen and nutrients available to egg pockets in redds; reducing the embryo survival rate. For example, Parkhill (1998) added clay to experimental streams to test stream productivity. The addition of clay resulted in decreased dissolved oxygen, light penetration, and whole-stream respiration. Hypoxia, the deficiency of oxygen, has also been correlated to a reduction in the size of fish embryos if they survive to hatching (Mason 1969). Smaller fish have less chance of surviving because of the competition with larger fish for resources.
In addition to lowering oxygen and nutrient flow past the embryos, high sedimentation also affects the fry's ability to leave the redd after hatching. Blockage of redd gravel pores by sedimentation impedes the ability of hatchlings to emerge from the redd. Peterson and Metcalfe (1981) found that fine sand (0.06-0.5 mm) reduced the emergence success of embryos more than coarse sand. In a study that examined the effects of fine sediments on survival of rainbow trout from eyed egg to emergence, survivals were 51-74% with 40-100% fines, and survivals were 87-92% with 0-20% fines (MacCrimmon and Gots 1986).

Other studies reveal similar sedimentation effects on trout reproductive success. Hauer (1996) found that sedimentation pollution has a particularly deleterious effect on the hatching and survival of trout eggs. Waters (1995) also found a strong correlation between increased sedimentation and a decline in fish numbers in both natural and artificial stream channels. Experimentally stocked trout eggs that were covered by sediment in artificial channels did not survive (Peters 1965). In the Rocky Mountain region, high fine-sediment levels in redds led to very low estimated embryo survival (Magee et al. 1996). Bjornn and Tappel (1983) found that fish embryo survival decreased as the amount of fine particles increased in experimental gravel mixtures. Smaller sediments (<0.84 mm) were confirmed to be the most detrimental to incubating eggs (Reiser and White 1988).

**TSS Testing:**

To test further the effects of sedimentation, I examined five streams in the Townsend, Montana area. I measured the effects of total suspended solids as well
as the individual effects of different particle sizes (clay, silt, and sand) on trout reproductive success. TSS sampling and analysis had not been conducted on Duck Creek, Dry Creek, or Magpie Creek. Total suspended solid (TSS) samples have been taken in the past on Deep Creek and Confederate Creek by the Department of Fish and Wildlife in Townsend. However, none of the sediment in these streams has been divided into particle size to determine the individual influence of particle size in the Townsend creeks. In addition, there have not been many previous studies involving the individual effects of sand, silt, and clay on trout reproduction. In light of these facts, my testing aimed to elaborate on past TSS studies breaking the sediment data into individual particle sizes.

I conducted TSS sampling on two unstudied streams and performed a particle size separation on all of the stream sites in order to supplement prior studies. Electro-fishing, the process by which fish are stunned and captured by a low voltage current, followed TSS sampling. Electro-fishing allowed me to count the number of trout hatchlings at each sampling site.

**Hypotheses:**

I expected that the total number of rainbow trout hatchlings would be inversely proportional to TSS at each collection site. Furthermore, in testing for a relationship between sites having a high component of finer sediment (clay) and hatchling numbers, I expected that streams with the highest amount of clay would also produce the lowest number of rainbow trout hatchlings.
MATERIALS AND METHODS

I surveyed five streams around Townsend, Montana: Deep Creek, Duck Creek, Dry Creek, Magpie Creek, and Confederate Creek (see Figure 1). Each stream had one sampling site with the exception of Deep Creek, which I sampled at three different sites. Deep Creek was sampled at three sites (Horse Pasture, Clopton, and MT Ditch) because its sedimentation varied considerably along its length, due to erosion, and because irrigation water is returned to it at midstream. The other streams did not vary as much in sedimentation along their length (pers. comm., R. Spoon), thus, I only sampled each at one site in the stream.

Suspended sedimentation samples were collected and flow measurements were taken at the headwaters, midstream, and at the mouth of Deep Creek. All other stream samples and measurements were obtained near the mouth of the stream. The collection sites were not at certain distances from the mouth, but rather at sites chosen because they were wadeable. Sample sites thus consisted of relatively straight and shallow channel reaches without large flow obstructions.

Suspended sediment was collected using the depth-integrated sampling method. I used a DH-48 sampler, a hand-held sampler with a container attached to a wading rod. The container is attached at an angle in which it always remains seven to eight inches above the streambed so that it only collects suspended sediment and excludes bedload sediment. I raised and lowered the DH-48 into the water column from the surface of the water to the streambed and repeated this step across the width of the channel until the container was full. This method
prevents biased sedimentation resulting from collecting at only one depth or site across the channel.

I obtained flow measurements with a flowmeter at the same sites of suspended sediment collection. A tape measure (at least 50 m) was tied above and across the collection channel and velocities were recorded at equal distances along the tape. The stream was divided so that at least twenty velocity measurements were recorded. These measurements were then averaged to find the flow of the stream at that particular location. I also measured temperature, time, and water depth at the collecting sites. Temperature was collected using a hand-held thermometer. Water depth was recorded from measuring meters permanently implanted by the Department of Fish and Wildlife.

Samples were collected and flow measurements were taken every Tuesday starting in May 2000, when the run-off starts to accumulate, and sampling was continued until the end of July 2000, when stream flow diminishes. Immediate TSS examination was not necessary because the samples can be preserved for up to a week under refrigeration at 4°C.

For each water sample, I measured TSS using Method 160.2 (Residue, Non-filterable) as stated by the Environmental Protection Agency (1983). The sediment was separated into sand, silt, and clay using the time it takes for each of them to settle after suspension. Sand settles after five minutes; silt settles after eight hours. Therefore, 200 mL of sample were filtered upon immediate suspension, 200 mL were filtered after 5 minutes, and after eight hours 200 mL were filtered. The sediment was then oven-dried and weighed.
Filtering upon immediate suspension measures TSS of all particles. The sediment filtered after five minutes measures the amount of clay and silt suspended. The eight-hour filtrate measures the amount of clay suspended. The amount of sand is calculated by subtracting the five-minute sediment weight from the immediate suspension weight. The amount of silt is calculated by subtracting the eight-hour filtrate weight from the weight of the five-minute filtrate. Clay is determined by subtracting the amounts of silt and sand from the TSS of the immediate suspension.

Electro-fishing was carried out at the end of July 2000/beginning of August 2000 on at least 100 ft of stream at each site. Fish are shocked, netted, counted, recorded, and released. Rainbow trout (Oncorhynchus mykiss) spawn in April and their eggs hatch around the first of July. Therefore, the rainbow trout were about four to six weeks old at the time of electro-fishing, which made them easier to handle than newly born hatchlings. Using a multi-factorial statistical analysis, the population of rainbow trout at each site and the TSS data obtained were compared with each other to observe any correlation.
RESULTS

MT Ditch, Dry Creek, and Duck Creek contained the highest amounts of suspended clay, while Horse Pasture, Clopton, Confederate, and Magpie had clay concentrations of less than 4 mg/L (Figure 2). MT Ditch had the highest suspension of silt, followed by Dry Creek and Duck Creek again. Confederate contained the highest concentrations of sand, followed by Duck Creek and MT Ditch. Dry Creek had the greatest number of rainbow trout per sq. foot, followed by Confederate Creek and Magpie Creek (Figure 3).

Using a multi-factorial statistical analysis, I found no correlation between rainbow trout numbers and any single type of sediment. The number of rainbow trout was not significantly associated with sand (p=0.794), silt (p=0.815), or clay (p=0.140). However, TSS was significantly correlated with trout numbers (p=0.043).
DISCUSSION

My first hypothesis stated that the TSS of each sampling site was expected to be inversely proportional to the number of rainbow hatchlings at that site. I found that TSS samples were indeed negatively associated with trout reproduction. My second hypothesis expected that the sites with the highest component of fine sediment (clay) would have the lowest reproductive success. However, the individual amounts of clay, silt, and sand showed no correlation to trout hatchling numbers.

Although my results did not support my second hypothesis, the hypothesis should not be rejected. Clay, silt, and sand are all considered fine sediment (under 0.84 mm) and therefore all contribute to lowering trout reproductive success when trapped in redds. My results do not rule out the possibility that clay and silt have a more deleterious effect than a coarser particle such as sand. However, all sites had a combination of clay, silt, and sand. Even though certain sites may have had more clay than others, the effects of lower clay concentration in some streams may have been compensated for with higher amounts of silt and/or sand. Thus, it is possible that, between two redds, if one was packed with only clay and the other with only sand (in equal quantities), the redd with clay would have a lower hatching success of trout eggs than the redd packed with sand.

There have not been many prior studies showing the effects of clay on stream ecosystems. Most studies have only dealt with the effects of fine sediment particles less than 0.84 mm in diameter. This classification includes clay, but
does not allow for individual effects of clay to be measured. However, it has been noted that the depth of intrusion into clean gravels tends to be greater for smaller-diameter particles and less for larger ones (Beschta and Jackson 1979). As the finest particle, clay should therefore penetrate redds more frequently and more deeply than larger particles, becoming more influential on the survival of egg pockets.

The individual effects of clay on dissolved oxygen have been recently studied. Parkhill (1998) examined the influences of inorganic sediment on productivity and light penetration in ecosystems. The study involved the use of outdoor experimental streams equipped with horizontal flow systems to simulate the flow velocity of actual streams. The streams were treated with clay in two sessions. In both sessions, the addition of clay significantly increased turbidity and sedimentation, and decreased light penetration. As a result, the amount of dissolved oxygen was decreased. Whole-stream respiration was also significantly decreased as the amount of added sediment increased. The effects of sand and silt were not tested.

Parkhill’s results correlate decreased dissolved oxygen levels with increased addition of clay (1998). Therefore, clay should indirectly decrease hatchling numbers, as oxygen deficit has been related to lower egg survival rate (Silver 1963). Shumway et al. (1964) and Tagart (1984) showed that dissolved oxygen was related inversely to the percentage of fines under 0.85 mm in diameter. This was due to the biochemical oxygen demand reducing oxygen levels where permeability was low. Exchange of surface water oxygen with redd
intergravel water may have been prevented by low permeability also. Low permeability, which is directly influenced by sediment texture, decreases survival by slowing water movement (and hence, dissolved oxygen) over the embryos (Lotspeich and Everest 1981).

Two factors that could have influenced my results include low water levels and unknown recruitment to fecundity ratios. For example, the MT Ditch site had a higher number of hatchlings than the Horse Pasture or Clopton sites on Deep Creek. This is due to the low water levels in the summer of 2000 and the number of beaver dams present in Deep Creek. The shallow water flow and beaver dams are physical barriers that prevent the fish from swimming further upstream.

Unknown recruitment to fecundity ratios could also have influenced my results. Fecundity is the total number of eggs deposited by a female, whereas recruitment is the number of eggs that survive to hatchlings. Some streams have a large number of trout hatchlings because they simply have more eggs even though recruitment may be lower than other streams. In my study, MT Ditch had more total suspended sediment than the Horse Pasture or Clopton Creek sites on Deep Creek, but had a higher number of trout hatchlings. It was also recorded that approximately 1,500,000 eggs were laid in MT Ditch (pers. comm., R. Spoon). Although the number of hatchlings recorded for MT Ditch was more than expected, the reproductive success was probably very low in proportion to the number of total eggs laid at MT Ditch. Vast numbers of eggs were laid at MT
Ditch because fish could not swim further upstream. These increased egg numbers contributed to the higher hatchling population at MT Ditch.

In retrospect, there are several factors not addressed in my study that should be incorporated into future projects. First, to test the effects of clay particles, it may help to experimentally manipulate the amount of clay in the streams. Second, I could examine the effects of clay further with the use of artificial stream channels. Third, I would extend the length of the study to several years to get more comprehensive results. Data should not be taken during a low water year because low water levels greatly influence where eggs are laid, suspended solids, and temperature. Fourth, I would collect data during normal water level years to obtain more accurate results. Fifth, I would incorporate recruitment and fecundity ratios into my study. Future studies may count the number of eggs and hatchlings to better assess survivorship to hatching.

My TSS effect on numbers of rainbow trout hatchlings supports previous fine sedimentation studies. In a study testing two sediment class sizes, fine sediment (<0.84 mm) and coarse sediment (0.84-4.6 mm), it was found that egg survival in both sediment types was inversely related to the percentage of sediment within incubation gravel (Reiser and White 1988). Reiser and White confirmed that it is the smaller sediments (<0.84 mm) that are most detrimental to incubating eggs. Waters (1995) correlated increased total sedimentation to the decline in fish numbers. Experimentally stocked trout eggs covered by sediment did not survive in a study by Peters (1996). Bjornn and Tappel (1983) placed experimental gravel into 40 incubation troughs at the University of Idaho. The
troughs tested various particle sizes: <0.85 mm, 1-3 mm, <3.3 mm, and <6.35 mm. As the amount of fine material increased in the experimental gravel mixtures, embryo survival decreased.

In conjunction with the above studies, my TSS results support a strong correlation between amount of fine sedimentation and the reproductive success of rainbow trout. Sedimentation does indeed lower the survival rate of salmonid eggs.
Figure 1. Map of the creeks studied in the Townsend, MT area (Deep Creek, Dry Creek, Duck Creek, Magpie Creek, Confederate Creek).
Figure 2. The amount of sand, silt, clay, and total suspended solids per sampled creek.
Figure 3. The number of rainbow trout hatchling electro-fished per sampling site.
REFERENCES


