# Determination of Physical and Hydraulic Attributes of Spawning Sites of Finespotted Snake River Cutthroat Trout on Three Channel Spring Creek, Wyoming

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Abstract. I characterized spawning sites of a fluvial population finespotted Snake River cutthroat trout, described how redd morphology influences water movement over the redd, determined if preferences existed for depth, velocity, and substrate, and conducted a habitat enhancement project based on results of sampling data on Three Channel Spring Creek, Wyoming. Finespotted Snake River cutthroat trout commenced spawning in June after minimum water temperatures exceeded 7 C and mean daily temperatures exceeded 9 C. Water depths taken immediately upstream from redds averaged 32 cm, while mean water velocities averaged 48 cm/s. About 75% of the redds were constructed at depths between 27 and 36 cm and velocities between 34 and 64 cm/s. Cutthroat trout spawned in substrate less than 64 mm, with most of the substrate less than 32 mm. The geometric mean particle size of the spawning gravel averaged 13.9 mm and the fredle index averaged 9.2. Cutthroat trout altered water depths and velocities within completed redds. Pits averaged 9.3 cm deeper, and 33.4 cm/s slower, while tailspill crests averaged 8.2 cm shallower, and 17.7 cm/s faster than undisturbed sites upstream from redds. Although a particular depth or velocity class predominated along cross channel transects, cutthroat trout selected spawning sites outside the prevalent class, thus, exhibiting preference. The habitat enhancement project produced a significant increase in use by spawning finespotted Snake River cutthroat trout. The total number of redds increased 205% for all newly enhanced locations.

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# INTRODUCTION

The importance of wild trout fisheries is well documented (Mesa 1991, Behnke 1992, Taylor 1992, White 1992) and include such things as the resilience and stability of wild populations as opposed to the rather short-lived and relatively unstable populations of hatchery trout. Increasingly, fisheries managers have recognized the drawbacks of hatcheries, while at the same time recognized the value of wild trout as a natural resource. The presence of wild trout not only indicate the health of streams and lakes as ecosystems, but also offer an angler a priceless relief from the pressures of society. Management objectives from many states, provinces, and national parks across North America are now emphasizing the importance of wild trout populations (White 1992).

In the mid-1950's, as a response to declining numbers of native cutthroat trout in western Wyoming, the Jackson District of the Wyoming Game and Fish Department committed itself to better understand and perpetuate the native cutthroat trout of the upper Snake River drainage. Presently, this drainage holds the distinction of being one of the few remaining areas left in North America that sustains a thriving population of native cutthroat trout on a large scale.

The upper Snake River in Wyoming is managed to sustain a naturally reproducing wild trout population and to provide anglers with the opportunity to catch finespotted Snake River cutthroat trout *Oncorhynchus clarki subsp.*. Distinguished by its unique spotting pattern, this indigenous subspecies is adapted to the large riverine environment of the upper Snake River (Kiefling 1978). The present range of the subspecies includes the Snake River drainage from below Jackson Lake downstream to Palisades Reservoir, encompassing all tributaries from the

Gross Ventre River to the Salt River (Behnke 1992). A combination of factors including habitat degradation, genetic introgression, urban development, and exploitation have contributed to the decline of indigenous cutthroat trout populations (Thurow et al. 1988). Understanding critical habitat requirements of finespotted Snake River cutthroat trout could assist efforts to maintain this wild trout fishery.

The objectives of this study were to: (1) develop spawning criteria for finespotted Snake River cutthroat trout; (2) determine the physical and hydraulic characteristics of the spawning habitat; (3) determine if differences in preference exist between pre- and post-treatment spawning locations, and (4) develop a basis for future artificial improvements.

## LITERATURE REVIEW

This paper characterizes spawning sites used by a fluvial population of finespotted Snake River cutthroat trout found in Three Channel Spring Creek (a tributary of the Snake River). Early studies of cutthroat trout spawning habits included timing, homing, and behavior (Cramer 1940; Smith 1941; Ball 1955; Hayden 1967; LaBar 1971). More recently, Thompson (1972), Kiefling (1978), and Varley and Gresswell (1988) have provided general descriptions of spawning habitat including gravel sizes and water temperatures preferred by spawning cutthroat trout. In fact, the work by Hayden (1967), Kiefling (1978, 1984), and Erickson (1980) specifically addressed general spawning requirements of Snake River cutthroat trout. There are only a few detailed studies of other cutthroat trout subspecies, however, and they include the work of Thurow and King (1994), who described the microhabitat of completed redds and characterized spawning sites of Yellowstone cutthroat trout *O. c. bouvieri* and the work of Hunter (1973) who characterized spawning sites of resident and sea-run coastal cutthroat trout *O. c. clarki*. I found no detailed studies of spawning criteria or description of redds of Snake River cutthroat trout in the literature. Although, spawning habitat suitability indices do exist for cutthroat trout (see Bovee 1978 and Hickman and Raleigh 1982), spawning criteria for different populations may vary, mainly due to the size of spawners. I present data specific to finespotted Snake River cutthroat trout and describe depths, velocities, and substrates found within spawning sites and completed redds.

A general knowledge of spawning behavior of salmonids will aid an understanding of their spawning requirements. Salmonids use similar types of habitat for spawning and egg incubation. Preference is for cold, well oxygenated, gravel-bottom instream areas since incubating eggs require constant water flow for the delivery of oxygen to eggs and removal of waste products. Burner (1951) described a redd as an area of streambed dug out by a female trout before spawning and in which she buries her eggs after spawning. By turning on her side and rapidly flexing her caudal fin, she loosens the substrate, which is subsequently carried downstream by the water current. Disturbed gravel collects into a pile, called a tailspill, downstream of the excavated depression, called a pit, which eventually reaches substrate (cobble) too large to be moved. Following egg deposition and fertilization, the female will swim just upstream of the pit and repeat this process which effectively covers the eggs just deposited and constructs an additional pit in which to spawn again, if she is not spent. The tailspill which is higher than the surrounding channel, increases water velocity running over the tailspill, thus keeping the fine sediments from accumulating (Reiser and Wesche 1977). These authors further concluded that the convex nature of the tailspill associated with redd construction causes downwelling of water into the substrate creating a current past the egg deposition site.

McNeil and Ahnell (1964) have shown that permeability through the tailspill substrate is related to the size composition of bottom materials that influences the rate of downwelling and subsequently influences egg survival. Permeability is a measure of the ability of a substrate to pass water per unit of time (Platts et al. 1983). Platts et al. (1979) showed that permeability is a function of the geometric mean diameter ($D_g$), discussed later, which is related to survival in salmonid redds. Typically, the higher the permeability, the higher the survival. Coble (1961) observed that when comparing two different redds with similar concentrations of dissolved oxygen, conditions for embryonic development may be better in the area with the higher exchange rate of water.

Many man-made and natural conditions may reduce or eliminate existing spawning areas. In fact, suitable spawning habitat has become limiting in many stream ecosystems as a result of flood control structures, abusive land use, urban development, or a combination of impacts. For many years the Wyoming Game and Fish Department has managed the Snake River as a self-sustaining native fishery and has been particularly interested in protecting and enhancing spawning success of the finespotted Snake River cutthroat trout. High volume flows, particularly during spring run-off, produce large sediment bed loads and turbitity that inhibit successful spawning within the main channel of the Snake River. The spawning opportunities and recruitment essential to sustain a wild trout population are restricted to the tributary spring-fed streams. Adfluvial migration of finespotted Snake River cutthroat trout into these spring creeks occurs during March, April, or May, with the spawning occurring primarily between March and June, depending upon location and the associated water temperature. Fry emerge throughout late-spring and early-summer and reside in these same creeks during their first year. Few young of the year fish can be found in the main channel of the Snake River during the summer. Most juveniles migrate to the river during January and February of the folling year (Kiefling 1978). Therefore, spring creeks used for spawning function not only as important reproductive habitat but also important nursery habitat. Additionally, they represent the majority of spawning habitatupon which the main river fishery depends.

Prior to the construction of the Snake River flood protection levee system, the spring-fed creeks provided an abundance of suitable spawning areas. Annual floods associated with spring run-off would clean the spring creek system of deposited sediments, making available suitable gravel for spawning. Following construction of the levees, the Snake River became more channelized. Annual floods were no longer able to flush out the system and spawning habitat began to degrade as sediments associated with both natural and anthropogenic sources accumulated. This habitat degradation has reduced carrying capacity and suitability of spawning areas and has resulted in an overall decline in the quality of these spring creeks for spawnig (Kiefling 1978).

The Wyoming Game and Fish Department in the 1960's began to evaluate the ecology of the finespotted Snake River cutthroat trout, Hayden's (1967) initial investigation of spawning tributaries suggested a low density of spawning cutthroat trout which, prompted a fingerling stocking program to supplement natural reproduction. This program however failed because fingerlings were not imprinted with characteristics of the tributary stream. It has been shown that the homing behavior of the Snake River cutthroat trout is comparable to that of salmon (Erickson 1980). He obtained data from one spring-fed creek indicating that tagged trout were subsequently caught up to 30 miles above the mouth of the spring creek in which they spawned.

In 1970, eyed-eggs were planted in another attempt to sustain a spawning run. Three Channel Spring Creek was one of several creeks investigated for potential eyed-egg plant sites. Redds were mapped to determine use. It was found that trout were using all gravel riffles and, in many cases, redds were superimposed (Erickson 1980). Planting eyed-eggs would, therefore, not solve the problem since use of available gravel was already saturated. Instead, it seemed obvious that the limiting factor was the availability of suitable gravel and as a result, artificial gravel was placed at various locations along Three Channel Spring Creek to provide additional spawning habitat.

The number of spawning cutthroat trout in Three Channel Spring Creek increased over 426% between 1970 and 1980 attributed to these man-made modifications to increase suitable substrate (Erickson 1980). Potentially contributing to increases in the overall recruitment and stock density levels of the Snake River have increased as well.

## SITE DESCRIPTION

All measurements were taken in Three Channel Spring Creek, a spring-fed tributary of the Snake River in northwestern Wyoming (Fig. 1.). The creek enters the Snake River from the east and its confluence lies immediately upstream from that of the Gros Ventre River. It is

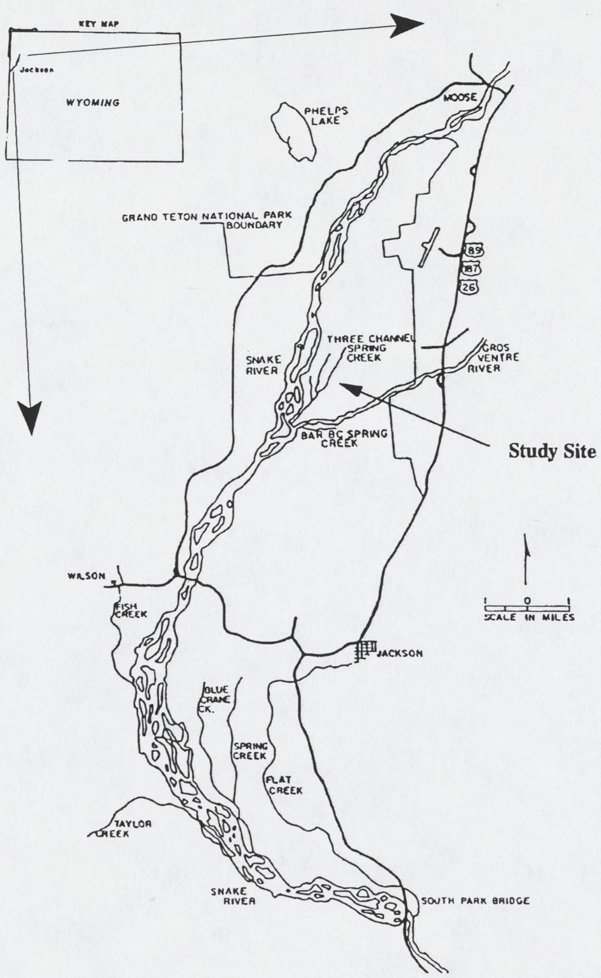


Figure 1. Study site of spawnng area of finespotted Snake River cutthroat trout sampled in Three Channel Spring Creek, Wyoming, 1993-1994.

located about five miles north of Jackson, in Teton County, Wyoming (T42N R116W S32 SE 1/4 of NE 1/4).

Three Channel Spring Creek is surrounded by private property. The riparian habitat has a history of heavy livestock use, but recent subdivisions have eliminated such land use. It has a gradient of about 3 meters per kilometer and an average riffle velocity of 27 to 76 cm/s. The flow is 12 $m^3$/s throughout spring, summer and early fall. As this is a spring-fed creek there are no true peak discharges associated with snowmelt, however, average flow does decline to about 8 $m^3$/s from October through April. Riparian vegetation is dominated by cottonwoods *Populus* ssp., willow *Salix* spp., and sedge *Carex* spp.. Besides Snake River cutthroat trout, the native fish fauna in Three Channel Spring Creek may include mountain whitefish *Prosopium williamsoni*, longnose dace *Rhinichthys cataractae*, speckled dace *Rhinichthys osculus*, mottled sculpin *Cottus bairdi*, and Paiute sculpin *Cottus beldingi* along with the introduced brook trout *Salvelinus fontinalis*.

The study reach expands throughout a large portion of the creek that receives the majority of spawning pressure. The reach encompasses a 3 km section of stream beginning approximately 0.5 km upstream from the confluence of the Snake River.

# METHODS

Spawning by finespotted Snake River cutthroat trout in Three Channel Spring Creek begins in June and proceeds through the first weeks of July. In early June, 1993, I made a preliminary reconnaissance of spawning activity and selected ten gravel beds to be studied in the reach. Between June 13 and 20, 1993, I placed three cross-channel transects across each gravel bed to be sampled. The transects were placed perpendicular to the stream bank and extended from one side of the stream bank to the other (Figs. 2, 3, 4, and 5). Primary attributes of spawning habitat consisting of a combination of physical and hydraulic parameters, explained later, were sampled at six randomly selected points on the three transects (two points per transect). This sampling was done to acquire a representative sample of those locations available to Snake River cutthroat trout for spawning and to compare areas chosen for spawning with those not selected. Sampling was performed during peak spawning activity.

During the preliminary reconnaissance, I also mapped the location of spawning fish and redds. By observing fish on the redds, locations could be accurately determined and mapped. I mapped a total of 14 redds and defined them as completed if they were both abandoned by the fish after spawning activity was observed and

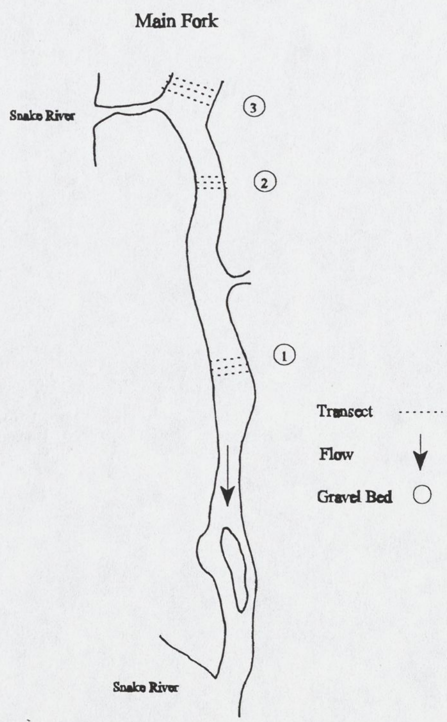

Figure 2. Main Fork of Three Channel Spring Creek showing gravel bed locations and transects.

the redd exhibited the characteristic pit and tailspill as described earlier. After fish abandonment, I sampled the primary attributes of the redd immediately upstream and adjacent to the redd (this is believed to be typical of conditions encountered by fish prior to redd construction). Reiser and Wesche (1977) and Grost (1989) reported that depth and velocity measured immediately upstream from redd pits most closely represented those conditions present prior to redd construction.

After the 1993 sampling was completed, a spawning habitat enhancement project was conducted in the Fall of 1993 on gravel beds 10, 11, 12, 13, and 14 of the Middle Fork (Figs. 4 and 5) to determine if artificial enhancements would increase use of these locations compared to unimproved control gravel beds. The project consisted of the rejuvenation of existing and/or the construction of new spawning gravel beds based on the spawning criteria found during pre-treatment sampling. Approximately 100 tons of washed, commercial gravel with a size range of 10 to 50 mm in diameter were used for enhancement of gravel beds. These enhanced gravel bed locations were constructed by excavating about 25 cm of silt, sand, and gravel from the old beds and replacement with the washed gravel. The new gravel was then raked by hand to acquire the proper depths and velocities for spawning.

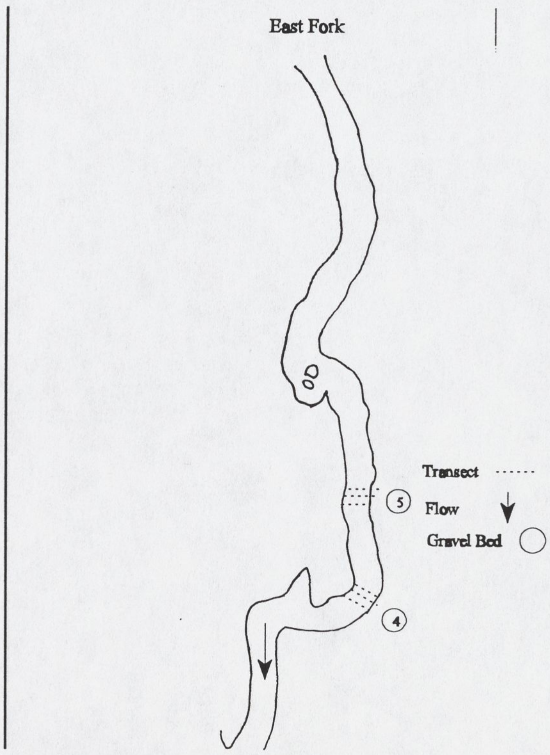

Figure 3. East Fork of Three Channel Spring Creek showing gravel bed locations and transects.

To determine spawning preferences, field measurements of the primary attributes of spawning habitat must be taken. Those primary attributes include;

1) Physical Parameters:

Temperature and substrate are the most important physical parameters. A continuously recording thermograph was installed and recorded temperatures from June 1 to June 30. I collected substrate samples from the sites adjacent to redds to describe the particle size distribution in spawning gravels. Thurow and King (1994) concluded that gravel samples taken adjacent to redds were typical of gravels selected by fish. Fourteen samples were taken towards the end of the incubation period on August 28, 1993, to avoid disturbing the incubating eggs. Substrate samples were taken using a core sampler designed by McNeil and Ahnell (1964). The sampler consisted of a steel tube 45 cm long by 30 cm in diameter connected to a tube 23 cm long by 15 cm in

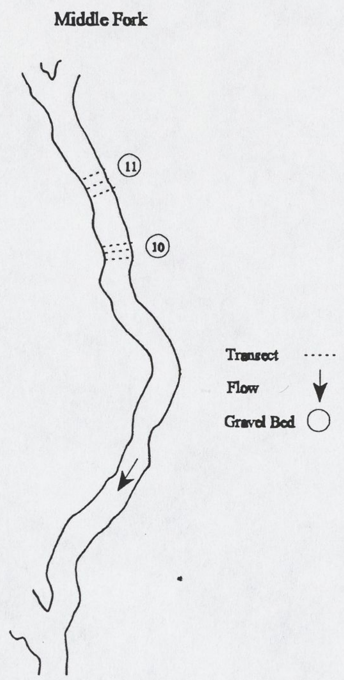


Figure 4. Middle Fork of Three Channel Spring Creek showing gravel bed locations and transects.

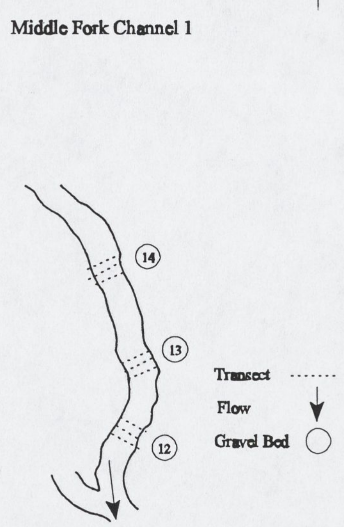


Figure 5. Middle Fork Channel 1 of Three Channel Spring Creek showing gravel bed locations and transects.

diameter. The 15 cm tube was imbedded into the substrate and the sample was scooped out of the tube into a collection basin to extract verticle substrate samples from a depth of 10 cm. Samples were dried in a forced air oven at 150 C for 4 hours and sieved through mesh sizes of 64, 32, 16, 8, 4, 2, 1, 0.5, 0.25, 0.125, and 0.063 mm. I weighed the material retained on each sieve and calculated the percent of the sample passing through each sieve size.

For each sample, two measures of central tendency were calculated: the geometric mean ($D_g$) and the fredle index ($F_i$). Formulas used to calculate $D_g$ and $F_i$ are described by Lotspeich and Everest (1981). They concluded that the measure of $F_i$ indicates the quality of riffle gravels for salmonid reproduction and has been used to predict embryo survival to emergence (Irving and Bjornn 1984). The measures of central tendency were used to indicate the quality of gravels for spawning because methods that use percentage of fines has been criticized (Platts et al. 1979).

2) Hydraulic Parameters:

To characterize the undisturbed sites selected by spawning cutthroat trout, I measured depth and velocity at a site immediately upstream from (within 5 cm) the redd with a wading rod and a Swoffer 1200 current meter, accurate to about 2 cm/s. Velocities were measured at sixth tenths of the depth to acquire a mean water velocity. Velocity at this depth approximates nose level velocities of most spawning salmonids. I did not attempt to sample sites before fish began spawning because I could not predict specific locations where fish would construct redds. To describe microhabitat conditions in redds, I measured depths and point velocities of 14 completed redds. I measured depths and point velocities at three locations in each redd: The upstream edge of the pit, the bottom of the pit, and the leading edge of the tailspill crest. Salmonid egg pockets are typically found under the leading edge of the tailspill (Grost 1989; Young et al. 1989).

I described the distributions of water depths, velocities, and substrate used by spawning Snake River cutthroat trout. The distribution of all microhabitat variables were checked for normality with normal probability plots. I used frequency analysis to describe and compare the ranges of depth, velocity, and substrate. Measures of central tendency ($F_i$ and $D_g$) were regressed against each other. I used *t*-tests to determine if the slopes of the regression lines were significantly different from zero. Statistical analyses were preformed using the SAS statistical package.

## RESULTS

Finespotted Snake River cutthroat trout commenced spawning after minimum Three Channel Spring Creek temperatures constantly exceeded 7 C and mean daily temperatures exceeded 9 C, which occurred in the first week of June. Maximum daily water temperatures ranged from 10 to 13 C, mean temperatures ranged from 9 to 11 C, and minimum temperatures ranged from 7 to 9 C (Fig. 6). Temperatures fluctuated as much as 5 C within a day during the spawning period.

Two hundred ninety two spawning cutthroat trout were trapped in Three Channel Spring

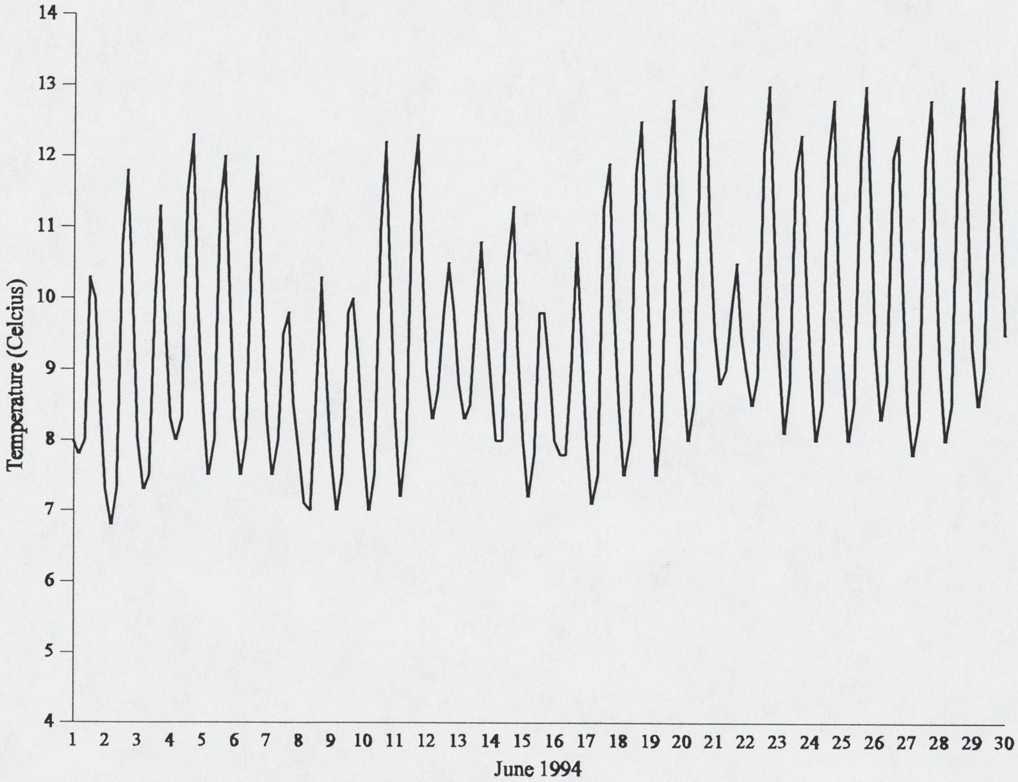


Figure 6. Water temperatures recorded from a continuously recording thermograph, Three Channel Spring Creek, 1994.

Creek in 1993 during the spawning run by the Wyoming Game and Fish Department. Their unpublished data show the length of trapped trout ranged from 208 mm to 513 mm, The average female was 409 mm in total length, and the average male was 410 mm in total length.

*Attributes of Snake River Cutthroat Trout Redds*

Finespotted Snake River cutthroat trout of Three Channel Spring Creek spawned in water 21 to 41 cm deep. Depths taken immediately upstream from completed redds averaged about 32 cm (Table 1). The trout constructed 75% of the redds at depths between 27 and 36 cm (Fig. 7).

**Table 1**. Substrate particle characteristics taken immediately upstream from (within 5cm) 14 sites selected by finespotted Snake River cutthroat trout for spawning in Three Channel Spring Creek, 1993. Sites immediately upstream from redds were assumed to be typical of the site before redd construction.

| Characteristic | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Water Depth (cm) | | | | | |
| Upstream from pit | 14 | 32.7 | 5.8 | 21.3 | 41.2 |
| Water Velocity (cm/s) | | | | | |
| Upstream from pit | 14 | 64.4 | 16.2 | 42.7 | 90.5 |
| Substrate (0-12cm depth) particle size distribution. | | | | | |
| Percent less than: | | | | | |
| 64.00 mm | 14 | 100.0 | 0.0 | 100.0 | 100.0 |
| 32.00 mm | 14 | 96.1 | 6.8 | 76.7 | 100.0 |
| 16.00 mm | 14 | 50.2 | 15.3 | 20.0 | 84.7 |
| 8.00 mm | 14 | 16.7 | 13.1 | 2.4 | 36.2 |
| 4.00 mm | 14 | 7.7 | 8.7 | 0.1 | 24.0 |
| 2.00 mm | 14 | 5.0 | 5.7 | 0.1 | 14.8 |
| 1.00 mm | 14 | 3.4 | 3.9 | 0.1 | 9.0 |
| 0.50 mm | 14 | 2.4 | 3.0 | 0.1 | 8.6 |
| 0.25 mm | 14 | 1.5 | 2.1 | 0.1 | 6.9 |
| 0.12 mm | 14 | 0.5 | 0.7 | 0.1 | 2.1 |
| 0.06 mm | 14 | 0.1 | 0.1 | 0.0 | 0.3 |
| Geometric Mean $D_g$ (mm) | 14 | 13.9 | 3.9 | 9.0 | 19.8 |
| Fredle Index $F_i$ | 14 | 9.2 | 3.7 | 3.8 | 15.7 |

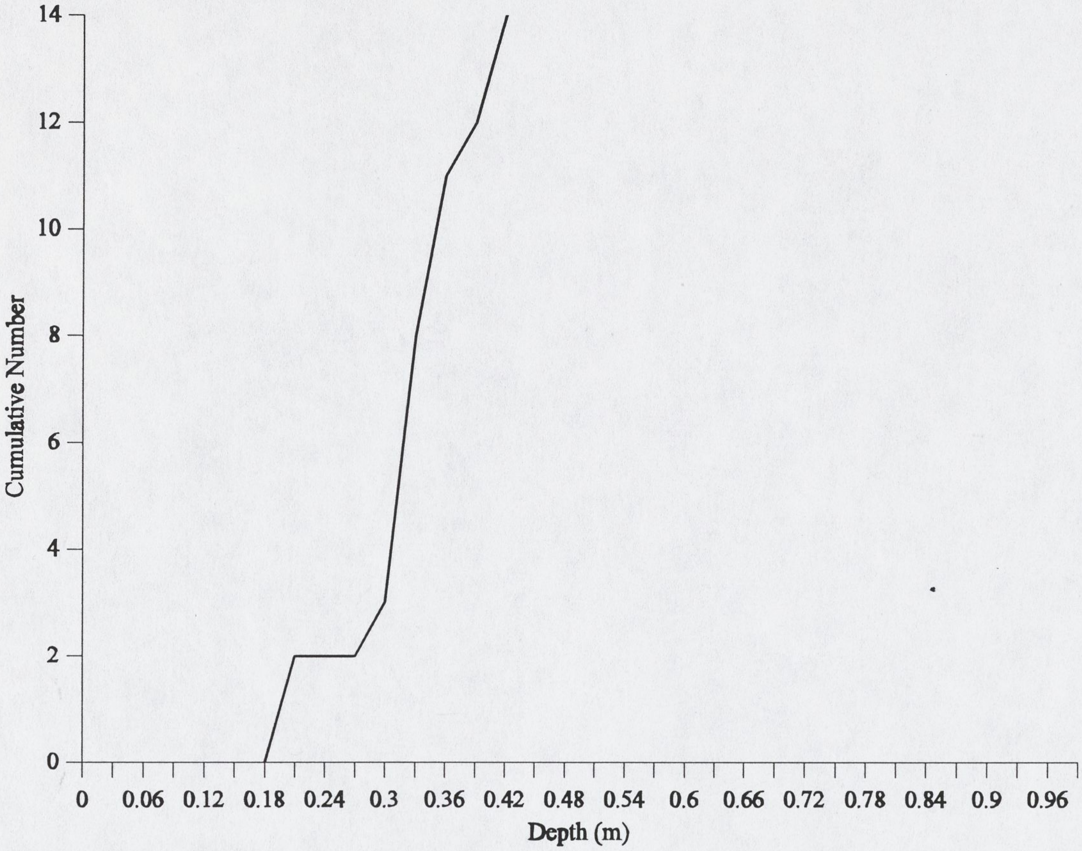


Figure 7. Cumulative frequency distribution of water depths upstream from finespotted Snake River cutthroat trout redds, Three Channel Spring Creek, 1993.

Water velocities taken at sixth-tenth depths immediately upstream from completed redds ranged from 23 to 73 cm/sec, averaging 48 cm/s (Table 1). Water velocities encountered by trout prior to redd construction ranged from 36 to 64 cm/s at more than 75% of the sites (Fig. 8).

All cutthroat trout in this study spawned in substrate less than 64mm in diameter. A mean of 4% of the substrate taken immediately upstream from 14 sites selected by trout for spawning ranged from 32 to 64 mm, with half of the substrate less than 32 mm in diameter (Fig. 9). The geometric mean particle size was positively correlated with the fredle index and the slope of the

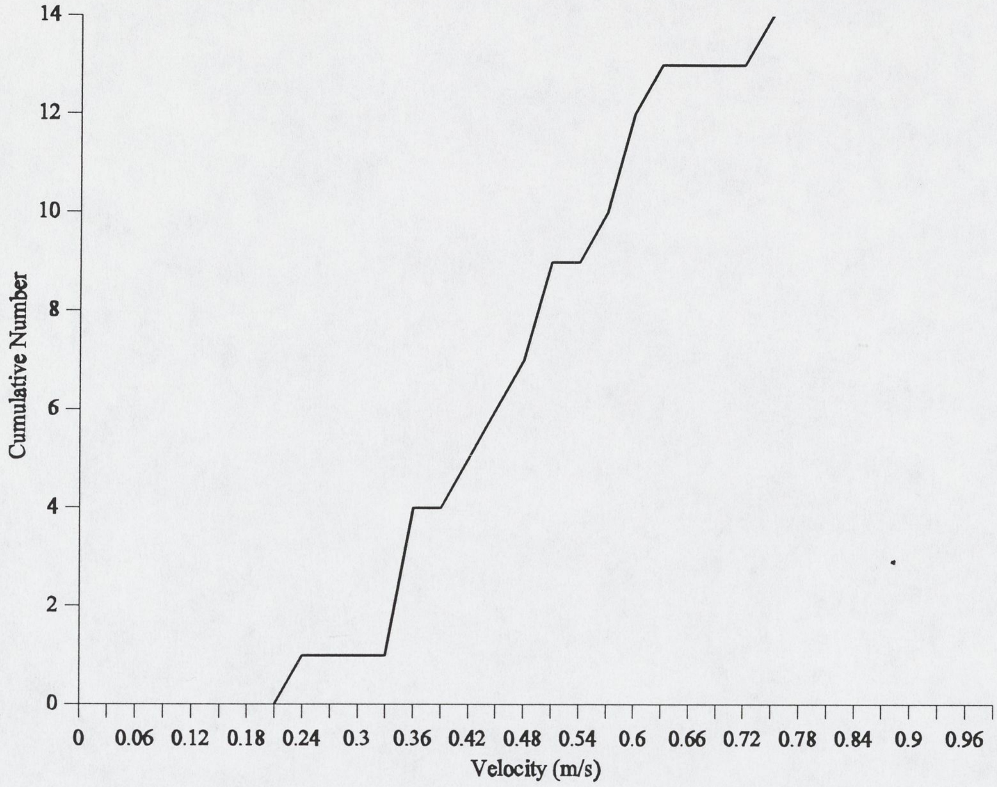


Figure 8. Cumulative frequency distribution of mean water velocities upstream from finespotted Snake River cutthroat trout redds, Three Channel Spring Creek, 1993.

regression line was significantly larger than zero ($P < 0.0001$, $r^2 = 0.94$). Both $D_g$ and $F_i$ were inversely correlated with the percentage of particles less than 8 mm. The mean $D_g$ of all substrate samples was 13.9 mm (Table 1), with 70% of all values falling between 9 and 16. The mean $F_i$ of all substrate samples taken was 9.2 mm (Table 1), with 70% of all calculated values falling between 5 and 12. Predicted cutthroat trout embryo survival to emergence was predicted using the equation described by Irving and Bjornn (1984). Predicted survival to emergence ranged from 61.0 to 82.6%, with a mean of 73.2 % for substrate samples taken immediately upstream from the 14 sites.

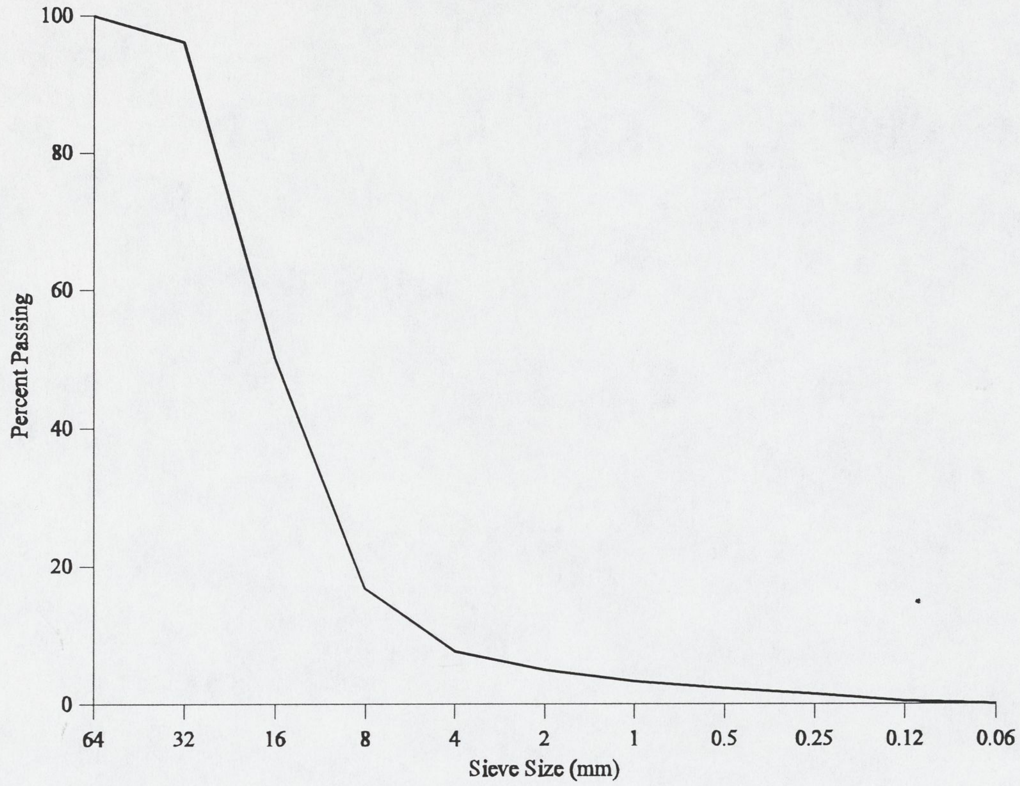


Figure 9. Particle size distribution of finespotted Snake River cutthroat trout spawning gravels in Three Channel Spring Creek, 1993.

Assuming that sites immediately upstream from redds represent pre-redd construction conditions, it can be concluded that cutthroat trout alter water depths and velocities by constructing redds. Pits averaged 9.3 cm deeper (SD, 4.9), and tailspill crests averaged 8.2 cm shallower (SD, 2.2) than the undisturbed sites upstream from redds (Tables 1 and 2). Similar comparisons can be made with water point velocities. Point velocities in pits averaged 33.4 cm/s slower (SD, 16.1) and point velocities at tailspill crests averaged 17.7 cm/s faster (SD, 12.1) than the undisturbed sites upstream from redds.

Comparison of point velocities at the upper edge, pit, and tailspill locations for cutthroat trout redds can represent the change in velocity in relation to the location upon the redd and can explain how trout alter water movement over a redd by its shape (Fig. 10). The majority of the water passes over the pit, strikes the tailspill, and passes up and downstream over it. The pit forms an eddie on the stream floor creating a slow upstream flow along the bottom of the pit. The convex shape of the tailspill causes downwelling of water into the substrate. The slower current in the pit allows eggs to be deposited and lodge among the substrate, without being swept downstream. Milt can also be deposited and retained in the pit for successful fertilization.

Table 2. Attributes of 14 redds constructed by finespotted Snake River cutthroat trout in Three Channel Spring Creek, 1993.

| Attribute | Location in redd | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Depth (cm) | Pit | 41.9 | 7.5 | 27.4 | 54.9 |
| | Edge | 32.7 | 5.8 | 21.3 | 41.2 |
| | Tailspill | 24.5 | 5.0 | 16.8 | 33.5 |
| Point Velocity (cm/sec) | Pit | 14.3 | 9.2 | 3.96 | 29.6 |
| | Edge | 47.7 | 13.8 | 23.2 | 73.5 |
| | Tailspill | 65.5 | 15.8 | 47.6 | 99.1 |

*Preferences exhibited for Depth, Velocity, and Substrate*

To determine if preferences were exhibited for a particular depth, velocity, and substrate, attributes of sites upstream from redds were plotted against available depths, velocities, and substrate types taken along the cross channel transects (Figs. 11, 12, and 13). The depth and velocity intervals most often used by spawning finespotted Snake River cutthroat trout may be compared by percent to the availability of the same intervals in the cross channel transects. The trout constructed 75% of the redds at depths between 27 and 36 cm, and 40% of the cross

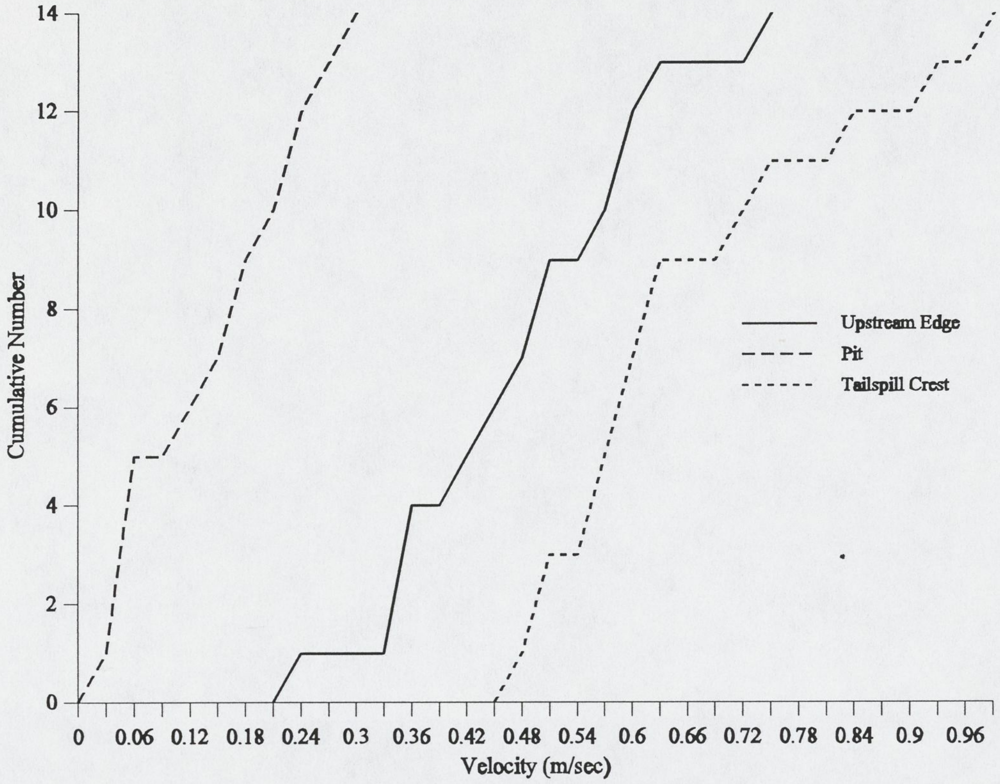


Figure 10. Distribution of water point velocities at three locations within finespotted Snake River cutthroat trout redds, Three Channel Spring Creek, 1993.

channel transect depth measurements were in this interval. The velocity most often used by cutthroat trout (75%) was in the range of 36 to 64 cm/s, and 50% of the measurements of available velocity were in this range. Figure 12 compares the substrate size classes found along the cross channel transects with those found on sites sampled upstream from trout redds. Eighty percent of the substrate sizes chosen by cutthroat trout were in the interval from 8 to 32 mm, which was identical to cross channel transect samples.

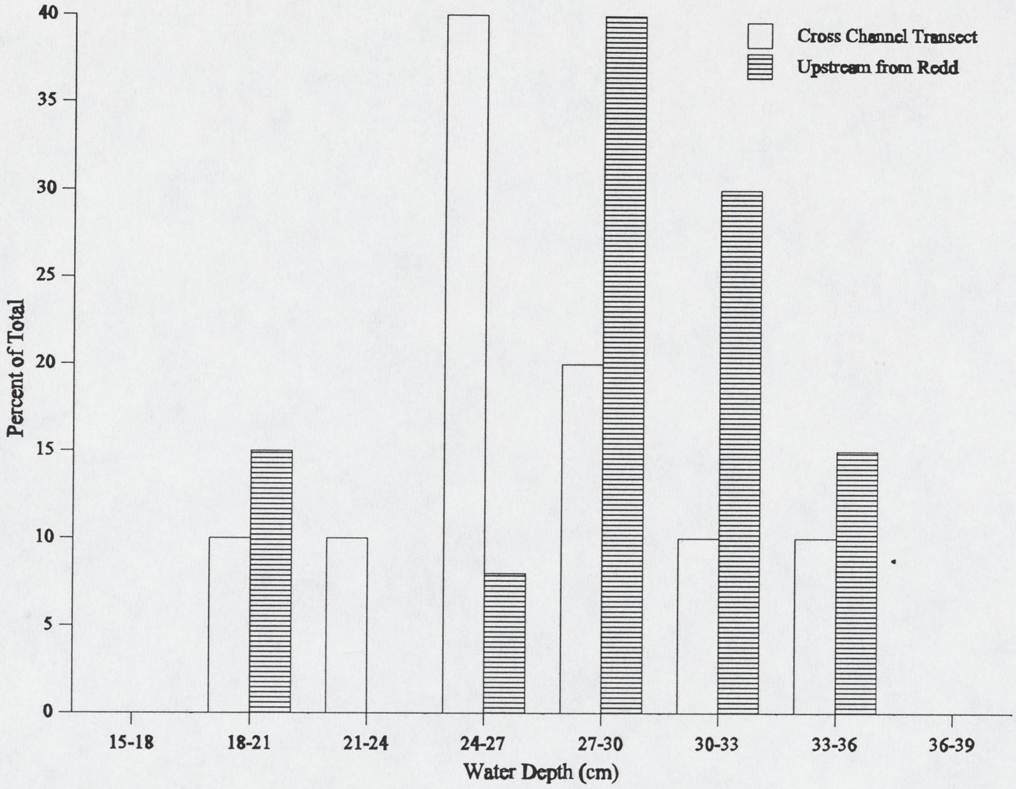


Figure 11. Comparison of water depths taken upstream from redds with those taken along cross channel transects on Three Channel Spring Creek, 1993.

Although a particular depth or velocity class predominated along the cross channel transects, finespotted Snake River cutthroat trout selected spawning sites with depths and velocities outside the prevalent class, thus, exhibiting preference. The trout chose substrate size classes that were most predominant along the cross channel transects, or in other words, they chose the substrate that was available to them and showed no real preference. Cross channel transects were laid across gravel beds that were assumed adequate for spawning *a priori*. Substrate samples consisted primarily of gravel that showed little variability relative to the other

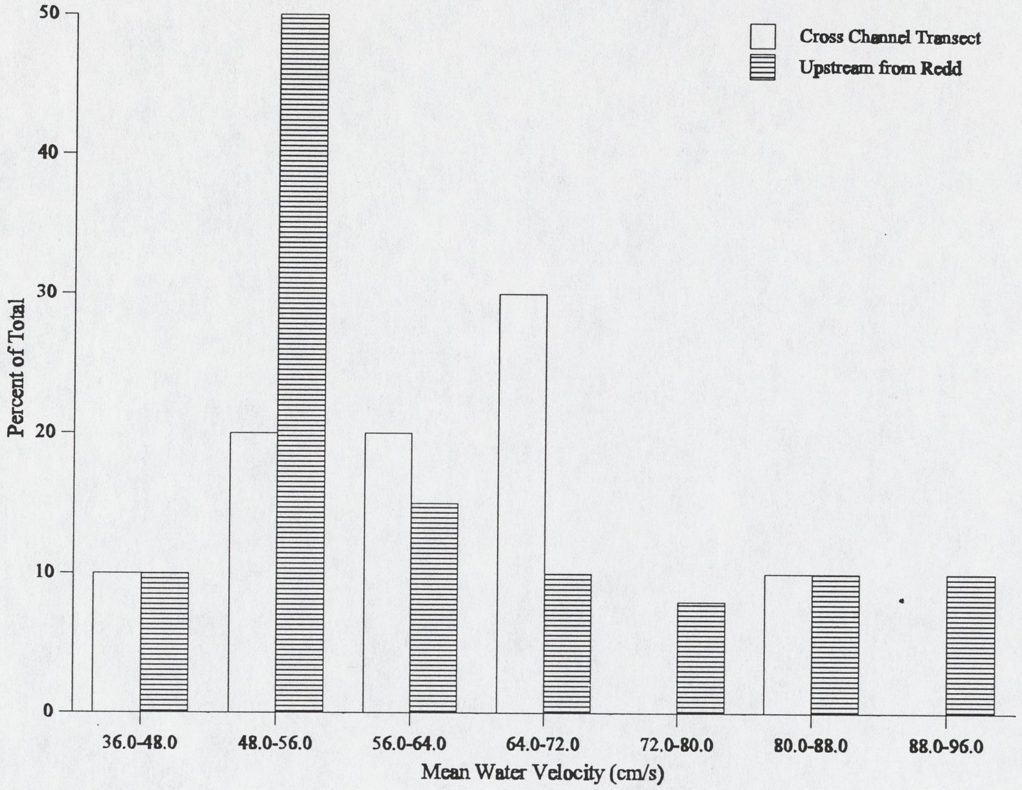


Figure 12. Comparison of mean water velocities taken upstream from redds with those taken along cross channel transects on Three Channel Spring Creek, 1993.

redd attributes. Visual observation showed no spawning activity on cobble, silt, or sand, therefore, trout do show a preference for "gravel".

*Spawning Habitat Enhancement Project*

The habitat enhancement project produced a significant increase in use by spawning finespotted Snake River cutthroat trout. The total number of redds (or pairs of fish) increased from 17 to 35 (205%) for all newly enhanced locations 10, 11, 12, 13, and 14. No site effect existed when comparing pre-treatment and control gravel beds in 1993. There was no between

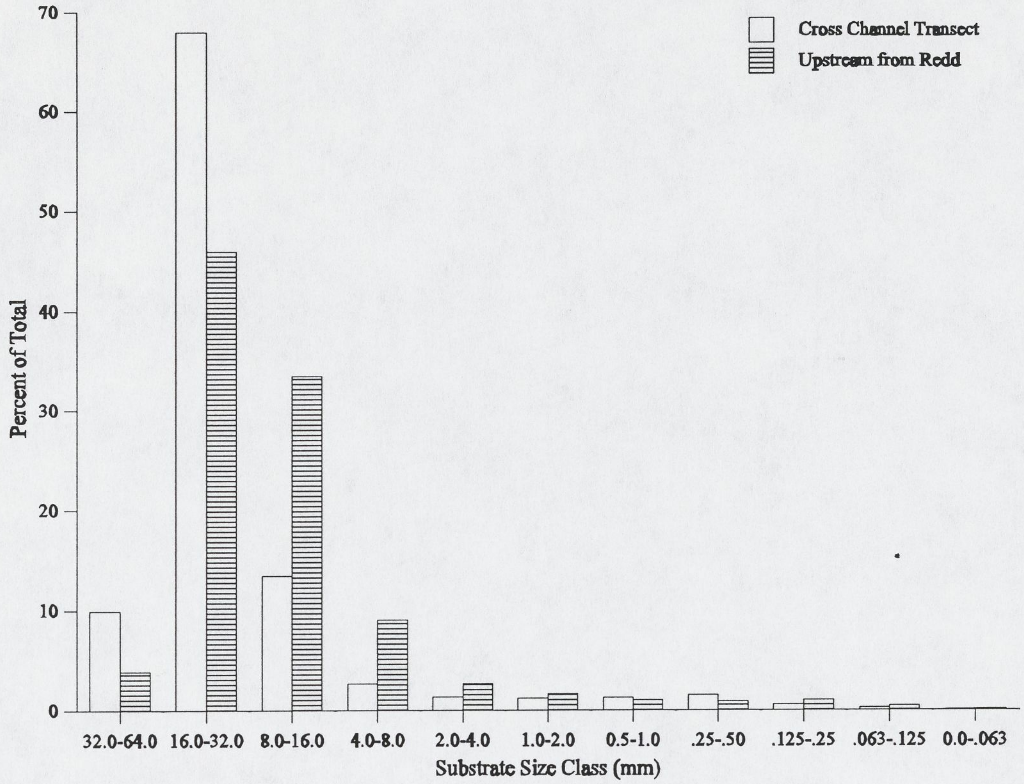


Figure 13. Comparison of substrate size classes taken upstream from redds with those taken along cross channel transects on Three Channel Spring Creek, 1993.

year difference in the number of redds on control gravel beds 1, 2, 3, 4, and 5 from the 1993 to 1994 spawning runs. In fact, the total number of potential spawning cutthroat trout trapped by the Wyoming Game and Fish Department decreased almost 50% from 1993 to 1994 (unpublished data). In conclusion the evidence provided suggests the increase in use of post-treatment gravel beds to be a result of improved spawning conditions provided by the artificial enhancements.

Table 3. Total number of redds (or pairs of fish) for pre- and post treatment gravel beds on Three Channel Spring Creek, 1993 and 1994.

| Gravel Bed | Number of Pairs, 1993 | Number of Pairs, 1994 |
|---|---|---|
| | **Control** | |
| 1 | 17 | 16 |
| 2 | 3 | 2 |
| 3 | 15 | 17 |
| 4 | 10 | 10 |
| 5 | 2 | 2 |
| | **Treatment** | |
| 10 | 2 | 7 |
| 11 | 6 | 12 |
| 12 | 1 | 2 |
| 13 | 5 | 6 |
| 14 | 3 | 8 |

## DISCUSSION

The concept of defining spawning requirements for salmonids is not new. This study has attempted to develop spawning criteria for finespotted Snake River cutthroat trout and to: (1) form a basis for man-made spawning habitat enhancements and (2) to aid in general trout habitat surveys. I have incorporated measurements of depth, velocity, and substrate size into attributes of finespotted Snake River cutthroat trout redds.

Since Three Channel Spring Creek is a spring-fed tributary of the Snake River, cutthroat trout in this creek do not spawn over a broad range of temperatures. The trout spawned in temperatures (7-13 C) that were similar to published ranges. Bell (1973) showed preferred cutthroat trout spawning temperature ranges of 6 - 17 C, and Varley and Gresswell (1988) suggested ranges of 5.5 - 15.5 C.

Finespotted Snake River cutthroat trout of Three Channel Spring Creek spawned in water depths slightly deeper than reported in the published data. Depths averaged about 32 cm upstream from completed redds, and trout constructed 75% of the redds at depths between 27 and 36 cm. Thurow and King (1994) observed Yellowstone cutthroat trout spawning at depths averaging 21.8 cm, with a range of 9.2 to 54.9 cm. The depth suitability curve of cutthroat trout prepared by Bovee (1978), indicates suitable depths ranging from 16.8 to 30.4 cm. This discrepancy in depths preferred by cutthroat trout may be explained by the larger average mature size of finespotted Snake River cutthroat trout relative to other inland species. According to Hunter (1973), interspecies spawning preferences for salmonids of the same size will be closer than intraspecies requirements for fish of varying size.

In Three Channel Spring Creek, velocities in spawning areas were similar to published data. Velocities averaged about 48 cm/s, and 75% of the redds were constructed in water moving between 34 to 62 cm/s. Thurow and King (1994) reported Yellowstone cutthroat trout spawning where velocities averaged 46 cm/sec and ranged from 18 to 73 cm/s. Hickman and Raligh (1982) put forth an optimal spawning velocity for cutthroat trout ranging from 30 to 60 cm/s.

Finespotted Snake River cutthroat trout of Three Channel Spring Creek spawned over substrate similar to the initial investigations of substrate preferred by Snake River cutthroat trout (78 to 6 mm; from Hayden 1967). However, most earlier published accounts of cutthroat trout spawning substrate listed general gravel sizes used by fish and do not include particle size distributions. Recently, Thurow and King (1994) presented a comprehensive report of Yellowstone cutthroat trout spawning substrate. They observed trout using substrate of which 60% consisted of gravel 16 to 64 mm in diameter, 15% was in the 6.4-16 mm size-class, and 20% was less than 6.4mm. all observations of spawning in this study occurred in substrate less than 64 mm in diameter, with about 80% of the spawning occurring in substrate in the 8-32mm size-class, and about 17% in substrate less than 8 mm.

Platts et al. (1979) proposed the use of geometric mean particle size ($D_g$) as an associate measurement to percent fine sediment for a more complete analysis of spawning substrates. However, Lotspeich and Everest (1981) concluded the usefulness of $D_g$ alone is limited since gravel mixtures with the same measure of central tendency can have different particle size compositions. The fredle index ($F_i$) uses the measure of central tendency of the distribution, and a measure of permeability to characterize the suitability of gravels for salmonid reproduction. Chapman and McLeod (1987) state that in the absence of field corroboration and correlation of embryo survival to emergence, it appears premature to asses utility of the fredle index. This index can, therefore, only be used as an apparent measure of gravel quality for embryo survival.

The initiation of redd construction and spawning may be controlled by physical cues, including water temperature, depth, velocity, and substrate particle size. Simon (1946) stated that finespotted Snake River cutthroat trout usually begin to spawn in the spring-fed tributaries to the Snake River in mid-March, and the time of spawning is dependent upon elevation above mean sea level and water temperature. The importance of each factor in spawning site selection is not well understood. For finespotted Snake River cutthroat trout, both depth and velocity appear to be equally important in the redd selection process. Obviously, an optimum spawning site is that which provides suitable depth and velocity over the most suitable substrate. Although, even the best conditions will not suffice if the flow is reduced and the redd exposed or the flow increases and the redd is destroyed. Thurow and King (1994) suggest that Yellowstone cutthroat trout of Pine Creek in Idaho did not spawn wherever suitable gravel was found, rather, spawning sites changed from one year to the next according to yearly hydrologic regimes. Grost et al (1990) observed that spawning brown trout *Salmo trutta* selected new spawning locations from year to year but used consistent depths and velocities during different flow conditions. In addition, Vaux (1962) reported that the stream bottom at the lower end of a pool gradually assumes a convex shape as the riffle area is approached, causing an acceleration in velocity and a downwelling of the current into the substrate. These stream features could also determine the choice of spawning site selection.

My observations of the attributes of redds constructed by finespotted Snake River cutthroat trout explain the unique morphology of salmonid redds and how water movement is manipulated to enhance fertilization and egg incubation. The convex nature and increased permeability of the tailspill causes a downwelling of water into the substrate, thereby carrying oxygen to the eggs and effectively removing metabolic wastes (Coble 1961). Hoppe and Finnell (1970) observed that the downwelling of water is dependent on velocity and that a velocity of 46 cm/s was recommended to ensure salmonid egg survival.

The use and effectiveness of artificial spawning areas has been described for many salmonids. Hourston and MacKinnon (1957) described use by Pacific salmon, Webster (1962) described how effective enhancement of spawning areas were for brook trout in a New York stream, and Kiefling (1984) described the effectiveness of enhancements used by finespotted Snake River cutthroat trout. Each study observed significant increases in use on some enhancements with little or no use on others, pointing out that factors involved in the redd selection process is fundamental to any habitat enhancement project. Spawning criteria developed in this study are based on these factors and should provide a basis for artificial spawning habitat enhancement projects.

The spawning habitat enhancement project on the Middle Fork of Three Channel Spring Creek in the Fall of 1993 provided a significant increase in use by finespotted Snake River cutthroat trout in the first year following its completion. The total number of redds increased from 17 to 35 (205%) for all newly enhanced gravel beds from 1993 to 1994 in spite of a poor overall cutthroat trout spawning run in 1994 relative to 1993. The increased number of redds was believed to be indicative of improved spawning conditions provided by artificial enhancements. Kiefling (1984) suggested that improved distribution of spawners over rejuvenated areas should decrease the superimposition of redds resulting in decreased hatching mortality and increased recruitment of cutthroat trout fry to the Snake River. Hopefully, as a result of this project the increased availability of improved gravels for spawning will result in increased numbers of spawners returning to Three Channel Spring Creek and a corresponding increase in stock density levels on the Snake River in the future.

My analysis has some important limitations. First, one of the problems associated with sampling one stream is that differences may exist between minimum and maximum depths, velocities, and substrates between streams indicating differences in the availability of certain depths, velocities, and substrates within different streams. Depths, velocities, and substrates used for spawning in this study may only reflect what was available and not what the trout may have selected if a greater range of depths and velocities were present. Second, I assumed that samples taken immediately upstream from redds represented the conditions that fish encountered when they began spawning. The actual conditions are unknown because I was not able to sample sites before fish began spawning. Third, there were no true replicates when determining if differences in preference existed between pre- and post-treatment spawning gravel beds. Therefore, the inferences and conclusions drawn from these results are limited to site specific conditions.

Many cutthroat trout stocks are at risk of decline. The upper Snake River drainage between Jackson Lake and Palisades Reservoir holds the distinction of being one of the few remaining areas left in North America that sustains a thriving population of native cutthroat trout. Where site specific data are not available, spawning criteria established in this study could assist in the instream flow recommendation process.

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