A basin approach to characterizing spawning and fry rearing habitats for westslope cutthroat trout in a sediment-rich basin, Montana

by James Patrick Magee

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:

This study used a basin-wide scale to identify and characterize critical spawning and fry rearing habitats for westslope cutthroat trout (Oncorhvnchus clarki lewisi) in a sediment-rich basin. Strong spatial and temporal patchiness occurred within the basin. Cache Creek and Wapiti Creek subbasins produced 99% of the redds and fry for the entire basin. The percentage of available spawning substrate was the only habitat variable significantly correlated with redd densities. However, elevation, temperature and gradient were important variables identifying critical spawning and fry rearing areas on a basin level. Availability of suitable spawning gravel, stream size, and gradient were important variables at a reach level. Spawning gravels were highly sedimented (40% of spawning substrate was <6.35 mm). High adult densities in Cache and Wapiti Creek subbasins indicate spawning and fry rearing habitats are not limiting recruitment, but low survival to emergence (mean = 18%, range 9-28%) suggests the amount of sediment may be close to a limiting threshold. Strong spatial patchiness and physical variation over short distances indicate that all scales are important to identify critical habitats, and that none are singularly sufficient.

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF FIGURES

LIST OF FIGURES--Continued

ABSTRACT

This study used a basin-wide scale to identify and characterize critical spawning and fry rearing habitats for westslope cutthroat trout (<u>Oncorhynchus</u> <u>clarki</u> <u>lewisi</u>) in a sediment-rich basin. Strong spatial and temporal patchiness occurred within the basin. Cache Creek and Wapiti Creek subbasins produced 99% of the redds and fry for the entire basin. The percentage of available spawning substrate was the only habitat variable significantly correlated with redd densities. However, elevation, temperature and gradient were important variables identifying critical spawning and fry rearing areas on a basin level. Availability of suitable spawning gravel, stream size, and gradient were important variables at a reach level. Spawning gravels were highly sedimented (40% of spawning substrate was <6.35 mm). High adult densities in Cache and Wapiti Creek subbasins indicate spawning and fry rearing habitats are not limiting recruitment, but low survival to emergence (mean = 18%, range 9-28%) suggests the amount of sediment may be close to a limiting threshold. Strong spatial patchiness and physical variation over short distances indicate that all scales are important to identify critical habitats, and that none are singularly sufficient.

INTRODUCTION

Westslope cutthroat trout Oncorhynchus clarki lewisi were historically abundant in western Montana, northern and central Idaho, northwestern Wyoming, southern Alberta, southeastern British Columbia and southwest Saskatchewan (Liknes and Graham 1988). Populations have declined dramatically in the past 100 years and shrinking distribution is attributed to habitat loss, hybridization, and overfishing (Liknes 1984; Rieman and Apperson 1989). In Montana, populations now exist in only 27% of their historical range, and genetically pure populations occur in only 2.5% of their original range (Liknes 1984; Liknes and Graham 1988). To protect and enhance this now rare species, the state of Montana has designated westslope cutthroat trout as a species of special concern (Holton 1990). Recent efforts of state and federal agencies are aimed at identifying remaining westslope cutthroat trout populations, increasing the distribution of pure populations, and evaluating habitat requirements and sensitivity to land use.

Variation of physical characteristics and use of critical spawning and rearing habitats for westslope cutthroat trout may depend on life stage, life history form (adfluvial, fluvial, or resident forms), and season (Rieman and Apperson 1989). Identifying where (spatial) and when (temporal) spawning and rearing habitats are used is essential to protect and enhance existing populations. This study focuses on identifying habitats required for spawning and early fry rearing life stages. Although all life history forms of cutthroat trout are known to use small headwater tributaries for spawning (Rieman and Apperson 1989), there is little information regarding the timing of use of these sites and the habitat characteristics that determine their relative suitability. Because spawning and rearing streams are small, they are often overlooked in research or management plans (Rieman and Apperson 1989). However, small headwater tributaries are particularly sensitive to land use disturbances (Platts and Megahan 1975; Everest et al. 1987).

Numerous studies of the effects of fine sediment in spawning substrate have demonstrated that egg-fry survival in salmonids is negatively correlated to the percentage of fine sediment in spawning gravel (Chapman 1988). Fines may decrease permeability and porosity of gravel, thereby reducing the amount of dissolved oxygen and removal of metabolic wastes, and thus increasing mortality during the incubation period (Chapman 1988). Sedimentation may also cause entombment of fry during the emergence stage (Koski 1966; Phillips et al. 1975; Weaver and Fraley 1991) or premature emergence (Everest et al. 1987).

Newly emerged fry utilize lateral habitats along stream margins and backwater areas with suitable velocities, cover, and food sources (Moore and Gregory 1988). Sedimentation of these habitats may reduce available rearing space, thereby limiting production (Everest et al. 1987). Spatial and temporal variability of sediment infiltration into spawning substrate or rearing habitats may cause survival to vary from year to year, depending on sediment transport regime and runoff events (Lisle and Lewis 1992) and from site to site, depending on land type and land use intensity.

Geological characteristics of a drainage basin are likely to have a strong influence on sedimentation and sensitivity to land use disturbance (Snyder et al. 1978). Much of the knowledge of sediment effects on cutthroat trout is based on research of geological formations of the Idaho batholith. These formations are granitic in nature, producing copious amounts of sand-sized fine particles (Bjornn et al. 1977; Rieman and Apperson 1989). Other dominant geological formations in the range of westslope cutthroat trout include the belt series and soft sediment formations. There have been few studies examining sediment effects on westslope cutthroat trout in these geological types.

The site of this study, the Taylor Fork drainage in the upper Gallatin River basin in southwest Montana, is comprised predominantly of soft sedimentary rock. This material is highly erosive and produces large amounts of fine sediment during runoff events and is very sensitive to land use disturbances (Snyder et al. 1978). Variation in land use intensities in the Taylor Fork basin have resulted in conditions ranging from pristine to highly disturbed. The Taylor Fork also contains one of the last strongholds of westslope cutthroat trout in the Gallatin River basin (Liknes 1984), and thus provides an ideal setting to study sedimentation and land use effects on cutthroat trout spawning and early rearing stages.

Recently, fisheries biologists have shown the importance of defining critical habitat requirements and of evaluating effects of land management over entire drainage basins (Bisson 1985). Previously, most studies have derived habitat use information from representative reaches or sections of streams, and extrapolated these findings to the entire watershed. However, Bisson (1985) illustrated that such an approach can lead to large sources of error when attempting to identify areas of critical habitat or limiting habitat factors for a population. In this study, I characterized critical habitats for spawning and fry-rearing of westslope cutthroat trout at the basin, subbasin and reach scale. The overall working hypothesis was that all three scales are important in defining habitat requirements and sensitivity to land use disturbance.

Specific objectives of the study were to determine:

1) location of spawning redds throughout a drainage.
2) the physical factors accounting for variation in redd densities on a basin, subbasin, and reach scale.

3) the effects of land use on sedimentation of redds.

4) the timing of spawning movements and characteristics of spawners.

5) the distribution and relative production of early fry stages throughout the basin.

STUDY AREA

The Taylor Fork River originates on the east slope of the Madison-Hilgard Range in southwest Gallatin County, Montana, and flows east approximately 27 km before entering the upper Gallatin River (Figure 1). Elevations range from 2804 m at the headwaters to 2012 m at the mouth. The basin encompasses approximately 161 km^2 of sagebrush/grasslands, forested slopes, and steep alpine ridges. Cache, Wapiti, and Lightning creeks are the major third-order tributaries in the basin; the mainstem Taylor Fork is a fourth-order stream. Major fish species include westslope cutthroat trout, rainbow trout Oncorhynchus mykiss, brown trout Salmo trutta, mountain whitefish Prosopium williamsoni, and mottled sculpin Cottus bairdi. Over 300,000 rainbow trout were stocked in the Taylor Fork River from 1928 through the late 1980's (N. Hetrick, Fisheries Biologist, Montana Department of Fish Wildlife and Parks, personal communication) resulting in hybridization with native cutthroat trout. Hybridization has also occurred between westslope cutthroat trout and Yellowstone cutthroat trout Oncorhynchus clarki bouvieri in upper Wapiti Creek (B. May, Gallatin National Forest Fishery Biologist, personal communication). Previous electrophoretic analysis indicate that westslope cutthroat trout in Cache Creek are approximately 87% genetically pure, one of the highest purities remaining in the Gallatin River drainage (Liknes 1984).

The geology of the basin is primarily soft, sedimentary rock (88%) with a small amount of bedrock (12%) (Snyder et al. 1978). The drainage is naturally highly erosive with a high potential for landslides and yields a large amount of fine sediments (Snyder et al. 1978). The combination of unstable geological conditions and high land use disturbance in the Taylor Fork basin have resulted in highly unstable channels and banks (Snyder et al. 1978). Land use disturbance ranges from very low in the upper Wapiti Creek subbasin to moderate to high in the Cache Creek and mainstem Taylor Fork River subbasins. Predominant past and present land uses include logging, livestock grazing, channelization, and splash damming (Snyder et al. 1978). Two grazing allotments (220 cow-calf pairs each) are present along Cache Creek, middle Taylor Fork and middle Wapiti Creeks. Recent clearcuts are present along Cache Creek and the upper Taylor Fork River. The Taylor Fork basin is also a popular recreational area for dude ranching, hunting, and fishing.

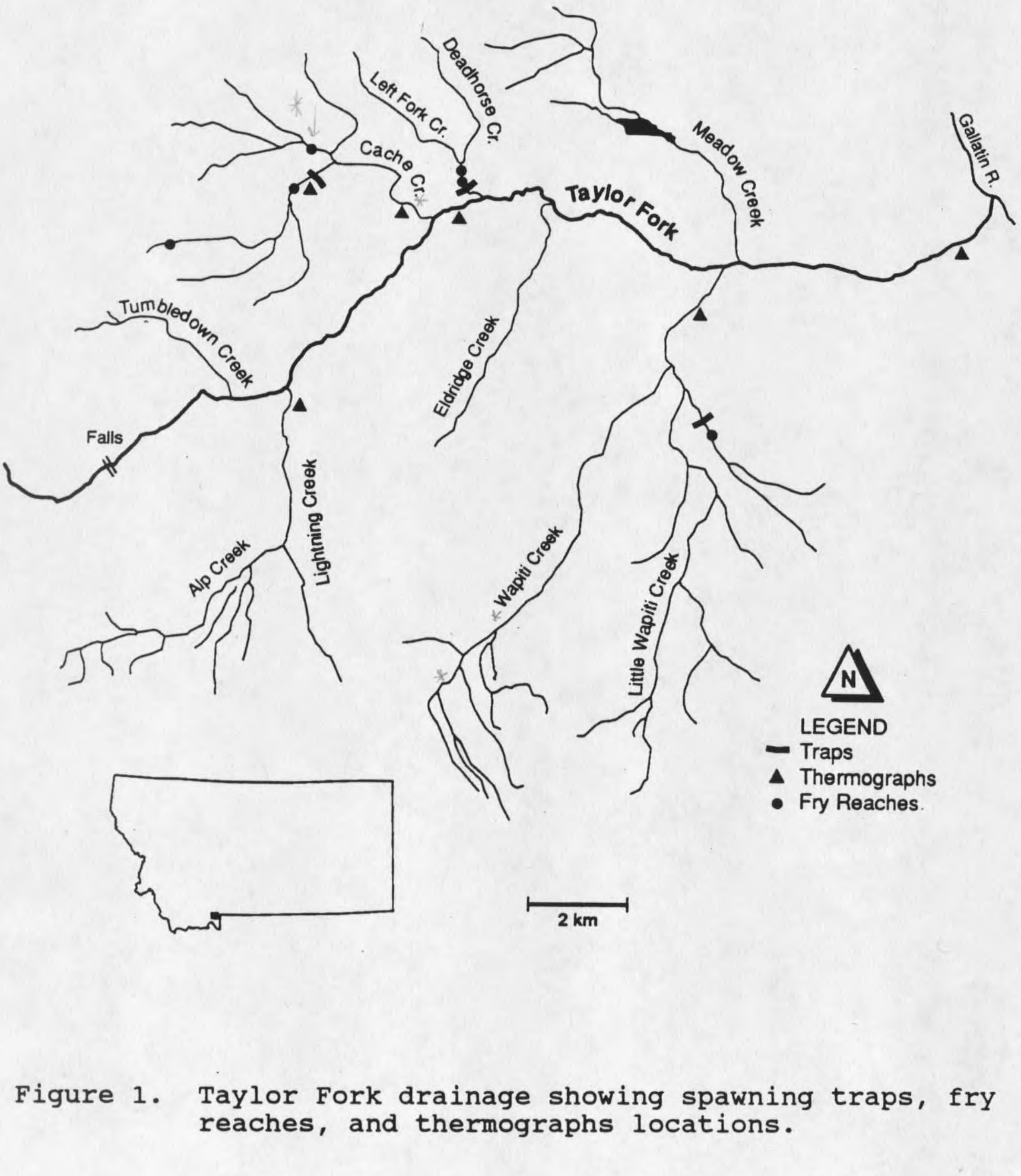


Figure 1. Taylor Fork drainage showing spawning traps, fry reaches, and thermographs locations.

METHODS

Timing of Spawning and Redd Distribution

To determine the timing and magnitude of spawning, and characteristics of spawning westslope cutthroat trout, traps were installed in three headwater tributaries located in the upper, middle and lower parts of the basin (Figure 1). Traps consisted of 1.1 cm plastic mesh fence supported by metal stakes driven into the substrate and anchored with sandbags. Upstream and downstream traps were attached to fences to capture migrants. Fences were installed on 19 May when weather, road, and runoff conditions permitted. Fences were dissembled on 19 June, 1992, as daily catch rate declined and it appeared most migration had occurred. Traps were checked twice daily, weather permitting. All fish captured were anesthetized with MS222, weighed, measured (fork length (FL)), and marked with an adipose fin clip. Fish were tagged with individually numbered visible implant tags in the adipose tissue behind the left eye. Sex and spawning condition were determined by the presence of milt or eggs. Duration of spawning and weight loss were calculated from spawners tagged in the upstream trap and recaptured in the downstream trap. An adipose fin clip was used to identify tag loss on recaptured fish. Species were classified as westslope cutthroat trout, rainbow trout, or hybrids. Hybrids were identified as fish with a spotting pattern similar to rainbow trout but also had characteristic orange slashes on the lower jaw (Holton 1990).

To determine potential spawning sites, I surveyed most of the watershed in 1991 for the presence of spawning substrate (0.2-3.5 cm) or newly emerged fry. Suitable areas were included in more detailed redd counts in 1992. I divided potential spawning areas into 18 reaches according to gradient, topography, stream order, tributary junctions, or road crossings (Cache Creek reaches are referred to as CC and Wapiti Creek as WC) (Figure 8). In 1992, redd counts were made in each reach every 3-4 days from 25 May to 19 June. Salmonid redds consist of a depression or pit in the upstream portion of the redd and mound of substrate or tailspill downstream, which contain the centrums or egg pockets (Chapman 1988; Young et al. 1989; Grost et al. 1991). In previous studies, salmonid redds have been counted by identifying clean gravel sites with the pit-tailspill configuration (Grost et al. 1991). In the Taylor Fork, redds were counted only by the presence of spawning fish as substrate disturbance was relatively minimal and could not be used as a reliable indicator of redd building. Probable redd locations were marked with numbered wooden stakes and maps were drawn for each redd. Spawning activity at a particular redd was noted during subsequent surveys to determine if multiple redds were constructed at each site.

Temperature and water levels were measured to determine potential effects of these factors on the timing of spawning. Hourly temperatures were recorded from thermographs placed in the upper and lower Taylor Fork, Wapiti Creek, Lightning Creek, and upper and lower Cache Creek (Figure 1). Stream water level was measured on the mainstem Taylor Fork, Deadhorse Creek, Wapiti Creek, and Cache Creek. Missing measurements in Cache Creek were supplemented through use of a regression between Deadhorse Creek and Cache Creek water levels (Appendix 1).

Substrate Composition of Redds

To determine substrate composition of redds, McNeil core samples were taken from 21 redds in Cache Creek and 15 redds in Wapiti Creek following the techniques of Shepard and Graham (1983). Core samples were taken from 23 July - 6 August 1992 to represent conditions in the redd at the time of emergence (emerging fry were first observed on 22 July). Cores were taken in the front third of the tailspill to a depth of 10 cm based on the depth of egg pockets from previous sampling of westslope cutthroat trout redds (B. May, Fisheries Biologist, Gallatin National Forest, personal communication). Redd maps were used to position core samples near egg pockets. Egg pockets were verified by the presence of eggs in the core sampler or by digging in the substrate to expose eggs in areas adjacent to core samples.

Core samples were dried and passed through a series of sieves of sizes: 50.8, 25.4, 12.4, 9.5, 6.3, 2.36, 0.85, and 0.074 mm. Volume of fines <0.074 mm which remained in suspension in the corer were sampled via an Imhoff Cone (Shepard and Graham 1983). Conversion of volume to dry weight was calculated using a gravel density of 2.2 g/cm^3, the estimated density of the sediment type present in the Taylor Fork drainage (S.Custer, Hydrologist, Montana State University, personal communication). The fredle index (Lotspeich and Everest 1981) and percentage of fine sediment <6.35, 2.36, and 0.85 mm in diameter were calculated for each core sample. The fredle index is a quality index used as an indicator of sediment permeability and pore size to characterize the suitability of substrate for incubation and emergence (Platts et al. 1983). The percentage of fine sediment <6.35, 2.36, and 0.85 mm in diameter were used because of their inverse relationship with the survival of salmonid fry (Everest et al. 1987; Chapman 1988) and to compare with other salmonid studies in the Rocky Mountain region.

To determine how well the more labor-intensive core sampling techniques compared to less labor-intensive measurements of fine sediments, I related the percentage of fine sediment <2.36 mm from McNeil core samples to percent surface fines <2.0 mm as determined via Wolman pebble counts (Wolman 1954) and via percent surface fine grid (Kramer and Swanson 1990). Wolman pebble counts consisted of categorizing substrate particles by size via the Wentworth scale (Table 1) for 50 points taken across the redd. Points were measured at 5 cm intervals along transects across the redd. The surface fines measurements were calculated by counting the number of intersections with substrate < 2.0 mm on a 7x7 grid drawn on a clear plexiglass sheet. The percent surface fines for each redd was calculated as the average of the ratio of intersections with fines (< 2.0 mm) to the total number intersections (49) for five random grid tosses on each redd.

A Mann-Whitney, two-sample analysis was used to test for the differences in substrate composition of core samples containing egg pockets with those without egg pockets. Substrate composition of redds in subbasins of high (Cache Creek) and low (Wapiti Creek) land use disturbance were also tested with a Mann-Whitney, two-sample analysis.

A one-way analysis (ANOVA) and a Fisher's Least Significant Difference (LSD) multiple range test was used to compare substrate composition between reaches. A significance level of $P \leq 0.05$ was used for all tests. Regression analysis was used to compare percentage of fines obtained from McNeil Core samples with that obtained from Wolman pebble counts and from the surface fines grid.

Table 1. Wentworth system used to classify substrate size classes (Welch 1948).

Substrate Class	Particle Diameter (mm)
Sand/Silt	<2.0
Peagravel	2-6
Gravel	6-7.5
Rubble	7.5-15
Cobble	15-30
Boulder	>30
Bedrock	

Spawning Habitat Characteristics

To describe factors that may account for variation in redd densities, habitat surveys were conducted in Deadhorse Creek and the Cache and Wapiti Creek subbasins. Surveys were completed in 11 of the 18 spawning reaches before freeze-over in mid-October. Characteristics of spawning habitat were determined using the INT/R1/R4 Standard Watershed Inventory System developed by USDA Forest Service Intermountain Research Station, Boise, Idaho. Length, wetted width, maximum depth, habitat type (Bisson et al. 1982) and potential spawning substrate were determined for each consecutive channel unit (pool, riffle, glide) moving upstream. Potential spawning substrate was estimated as the percent surface area having substrate sizes similar to those seen in redds (0.2 - 3.5 cm).

Additional measurements of dominant and subdominant substrate, bankfull width, average depth, bank stability, embeddedness, and riparian composition were determined at every tenth channel unit. Bank stability (Table 2) and embeddedness (Table 3) were estimated using the visual rating systems developed by Platts et al. (1983). Riparian composition was determined as the percentage of each bank consisting of bare soil, grass, shrubs or trees.

Table 2. Streambank stability rating based on percentage of protected streambank from Platts et al. (1983).

Rating	Percent	Description
4 (Excellent)	75-100	>75% of the streambank surfaces are covered by vigorous vegetation or by boulders and rubble. If not covered by vegetation the streambank is protected by materials that do not allow bank erosion.
3 (Good)	50-75	50-75% of the streambank surfaces are covered by vegetation or by gravel or larger materials. Those areas not covered by vegetation are protected by materials that allow only minor erosion.
2 (Fair)	24-49	25-49% of streambank surfaces are covered by vegetation or by gravel or larger materials. Those areas not covered by vegetation are covered by materials that give limited protection.
1 (Poor)	0-24	<25% of the streambank surfaces are covered by vegetation or larger materials. That area not covered by vegetation provides little or no control over erosion and banks are usually eroded each year by high water flows.

Table 3. Substrate embeddedness rating based on the percentage of substrate particles covered by fine sediment from Platts et al. (1983).

Rating	Description
5	Gravel, rubble, and boulder particles have <5% of their surfaces covered by fine sediment.
4	Gravel, rubble, and boulder particles have 5-25% of their surfaces covered by fine sediment.
3	Gravel, rubble, and boulder particles have 25-50% of their surfaces covered by fine sediment.
2	Gravel, rubble, and boulder particles have 50-75% of their surfaces covered by fine sediment.
1	Gravel, rubble, and boulder particles have >75% of their surfaces covered by fine sediment.

Substrate composition was measured via Wolman pebble counts and the surface fines grid technique on pool tailouts and riffles. Wolman pebble counts were based on 100 points (50 points in streams <1 m width). Wolman points were taken at equal distances (5 cm intervals in streams < 1 m width, and 10 cm intervals in streams > 1 m width) along a transect from bank to bank across the stream . Percent surface fines were based on 5 random grid tosses in small streams (<1.0 m width) and 10 grid tosses in larger streams (>1.0 m width).

A non-parametric Spearman rank correlation analysis was used to test for associations between redd density and specific habitat features. A Mann-Whitney two sample analysis was used to test for differences in habitat variables between high (>3 redds/100 m) and low (<3 redds/100 m) redd densities.

Fry Distribution and Production

Visual counts of fry in various sections of the basin were used to identify important fry rearing areas. Preliminary surveys of fry locations were conducted throughout the basin in 1991. In 1992, weekly fry counts began 1 week after the first observed fry, and were conducted from 1 August - 1 October in six reaches located in various parts of the basin (Figure 1). An observer crawled along the one bank and counted fry for each 6 m segment of a reach following the methods of Bozek and Rahel (1991). After each segment was surveyed, the observer waited 90 seconds to allow fry to recover from disturbance before beginning the next segment count. Visual counts were compared with two-pass electrofishing depletion population estimates (Everhart and Youngs 1981) on 10 occasions at four different reach sites to estimate accuracy of visual counts. Regression analysis was used to compare visual counts with two-pass electrofishing depletion estimates.

Habitat features measured during detailed spawning habitat surveys (see previous section) were used to identify variables that could account for differences in fry densities.

Fry counts were standardized as densities per m² based on the highest number of fry counted. Regression analysis was used to compare fry densities with redd densities. A Mann-Whitney two sample analysis was used to test for differences in habitat variables between high (>0.15 fry/100 m) and low fry density reaches (<0.15fry/100m).

I compared changes in mean lengths of fry over time to determine relative growth rates of fry in different reaches. Fry were captured in a small hand net during visual surveys and electrofishing removals, and lengths were measured to the nearest millimeter.

I estimated dates of peak hatching and peak emergence to describe temporal differences in fry incubation rates between sites and to compare incubation times in the Taylor Fork with other cutthroat trout studies. Incubation time in centigrade temperature units (CTU's) was determined for peak emergence as the time of peak spawning (from redd surveys) to the time of emergence (visual observation of newly emerged free swimming fry) in reach CCB. Time of peak hatching (from egg to alevin stage) was calculated using 310 CTU's from peak spawning (Rieman and Apperson 1989). A CTU is defined as the sum of the mean daily temperatures over 0°C (Rieman and Apperson 1989).

Fry production for 10 reaches was estimated by the following equation:

$$F = R \times E \times STE$$

where F = fry production per reach, R = number of redds per reach, E = egg deposition per female, STE = survival to emergence. Egg deposition was calculated from a westslope cutthroat trout fecundity-length relationship equation ($E = 3x10^{-4} \times L^{2.57}$), ($R^2=0.88$), (Rieman and Apperson 1989). The following equation was used to estimate egg deposition per reach: E_r= redds/reach x percent size class of the total catch x mean fecundity of the size class. A length-frequency distribution for females captured in the Cache Creek trap was used to estimate the percentage of total spawners within 25 mm size classes. Fecundity was estimated for each size class from the average fecundity of all fish within the class.

Survival to emergence was estimated based on the average substrate composition of redds in a given reach (average percent fines <6.35 mm from core samples) and the relationship between substrate composition and STE for westslope cutthroat trout as determined by Weaver and Fraley (1991) (STE = -0.654812 (% fines <6.35 mm) + 35.6749).

RESULTS

Spawning Migration and Timing

There were large differences in the numbers of spawning fish caught in the three traps. A total of 579 fish were captured in Cache Creek, compared to only 18 in Deadhorse Creek, and 10 in Little Wapiti Creek (Table 4). Because spawning movements appear to have initiated prior to trap installation and some migrants may have avoided capture, trap catch represents a subsample of the total number of spawners.

Fish size, sex ratio, and species composition also differed between sites (Table 4). Migrating females as small as 159 mm were sexually mature. Historical length-frequency data from the Taylor Fork basin indicate that a 150-mm fish is approximately 3 years old (N. Hetrick, Fisheries Biologist, Montana Department of Fish, Wildlife, and Parks, personal communication). Thus, I considered 3-year-old fish as the earliest age of spawners. Of the potential spawners in Cache Creek, females averaged 191 mm, slightly larger than the average size for males (189 mm) (Figure 2). We found an abundance (34 % of the total trap catch) of small males <200 mm, and few (5% of the total trap catch) large fish >250 mm, of either sex.

Sex could be identified for 438 fish, with 282 males and 156 females (1.8:1 ratio). Sex could not be identified in 141 of the potential spawners caught in the trap, which may account for a higher sex ratio in Cache Creek than either Deadhorse (1.2:1) or Wapiti Creeks (1:1). I did not test for differences of sex ratios between tributaries due to small sample sizes in Deadhorse and Wapiti Creeks and the large number of unidentified fish in Cache Creek. There were also 259 fish <150 mm captured in the Cache Creek trap in which sex could not be identified.

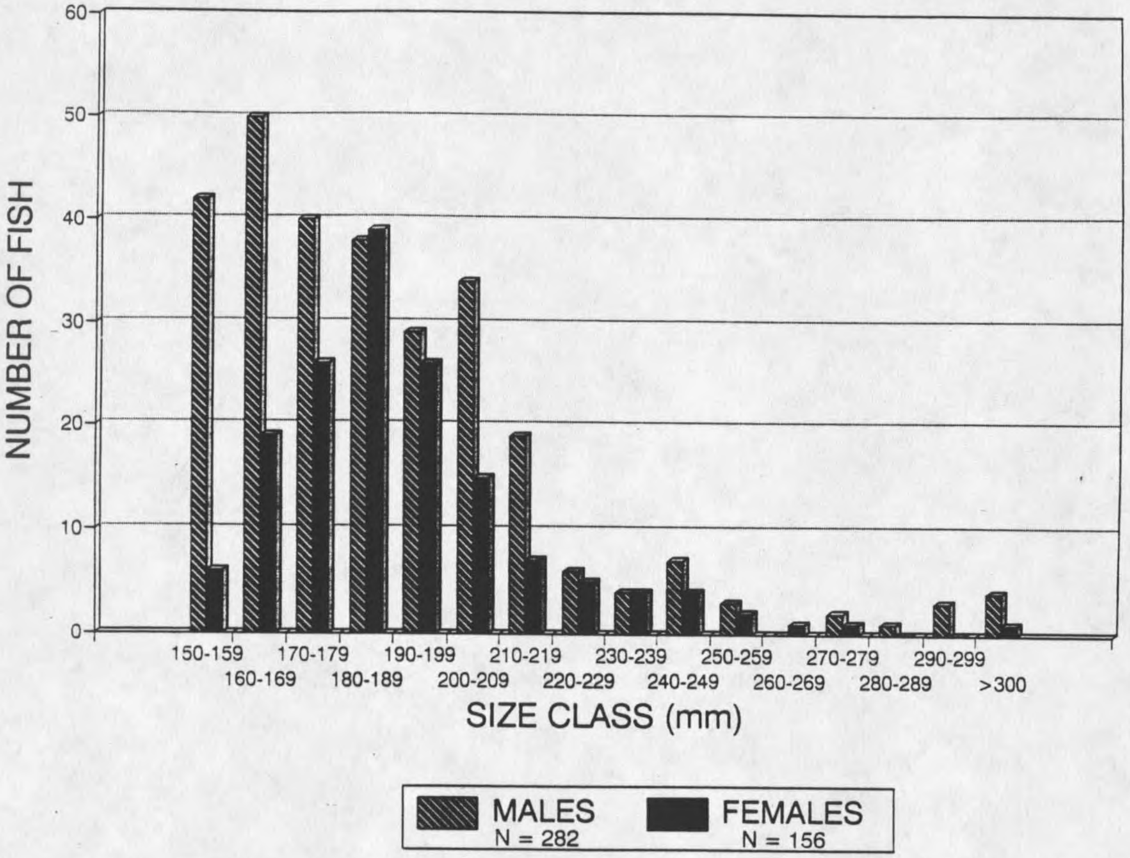


Figure 2. Length-frequency distribution for all fish >150 mm caught in the Cache Creek trap.

Table 4. Characteristics of trap catch for Cache, Deadhorse and Little Wapiti Creeks for potential spawning fish >150 mm. (STD = standard deviation.)

TRAP	CACHE	DEADHORSE	WAPITI
TOTAL CATCH:	579	18	10
MEAN LENGTH: (mm)			
MALES (STD)	189 (39)	185 (15)	262 (71)
FEMALES (STD)	191 (30)	252 (32)	297 (29)
MALES	282	6	5
FEMALES	156	5	5
UNKNOWN	141	7	0
SEX RATIO	1.8:1	1.2:1	1:1
SPECIES COMPOSITION (%)			
WSCTT (%)[a]	99.6	72.0	0.0
RBT (%)[b]	0.4	6.0	70.0
HYBRIDS (%)	0.0	22.0	30.0
RECAPTURES			
MALES	96	1	0
FEMALES	74	0	1
SPAWNING DURATION (DAYS)			
MALES (RANGE)	9.21 (0-26)	14	-
FEMALES (RANGE)	11.36 (0-30)	-	18
WEIGHT LOSS (g)			
MALES (STD)	4.88 (9.74)	4.0	-
FEMALES (STD)	10.29 (8.14)	-	46.0

[a] WSCTT (westslope cutthroat trout)
[b] RBT (rainbow trout)

Species composition differed between tributaries and was affected by elevation. Cache Creek had the highest elevation and also was comprised mostly of westslope cutthroat trout (99.6%). Species composition in Deadhorse Creek was also dominated by cutthroat trout (72%), but westslope cutthroat x rainbow trout hybrids comprised most of the remaining spawners. By contrast, in the lowest elevation tributary of Little Wapiti Creek, spawning fish were comprised primarily of rainbow trout (70%), with the remainder (30%) cutthroat x rainbow trout hybrids. The predominance of rainbow trout in Little Wapiti Creek may account for the greater size of spawners than in either the Cache or Deadhorse traps (Table 4).

The timing of upstream migration was similar for all three streams; however, downstream migration showed more variation (Figure 3). In Cache Creek, 79% of the upstream migration occurred between 19 May and 4 June. Most downstream movement occurred between 1 June and 17 June. The pattern of upstream spawning movement suggests that some upstream migration had occurred prior to trap installation.

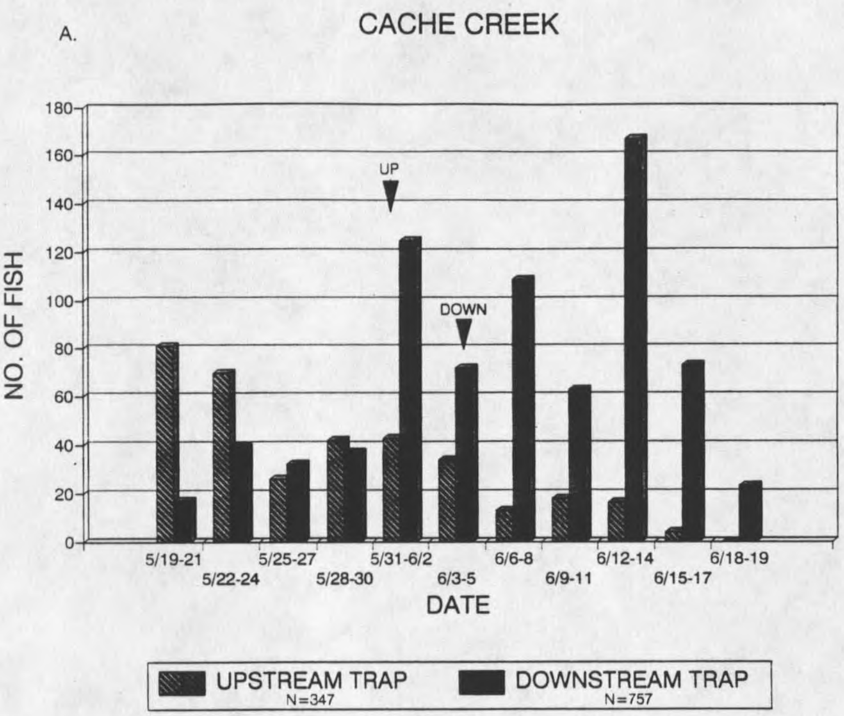


Figure 3. Upstream and downstream trap catch for spawners in Cache Creek (A), Deadhorse Creek (B) and Little Wapiti Creek (C). Arrow indicates median dates for upstream and downstream migration.

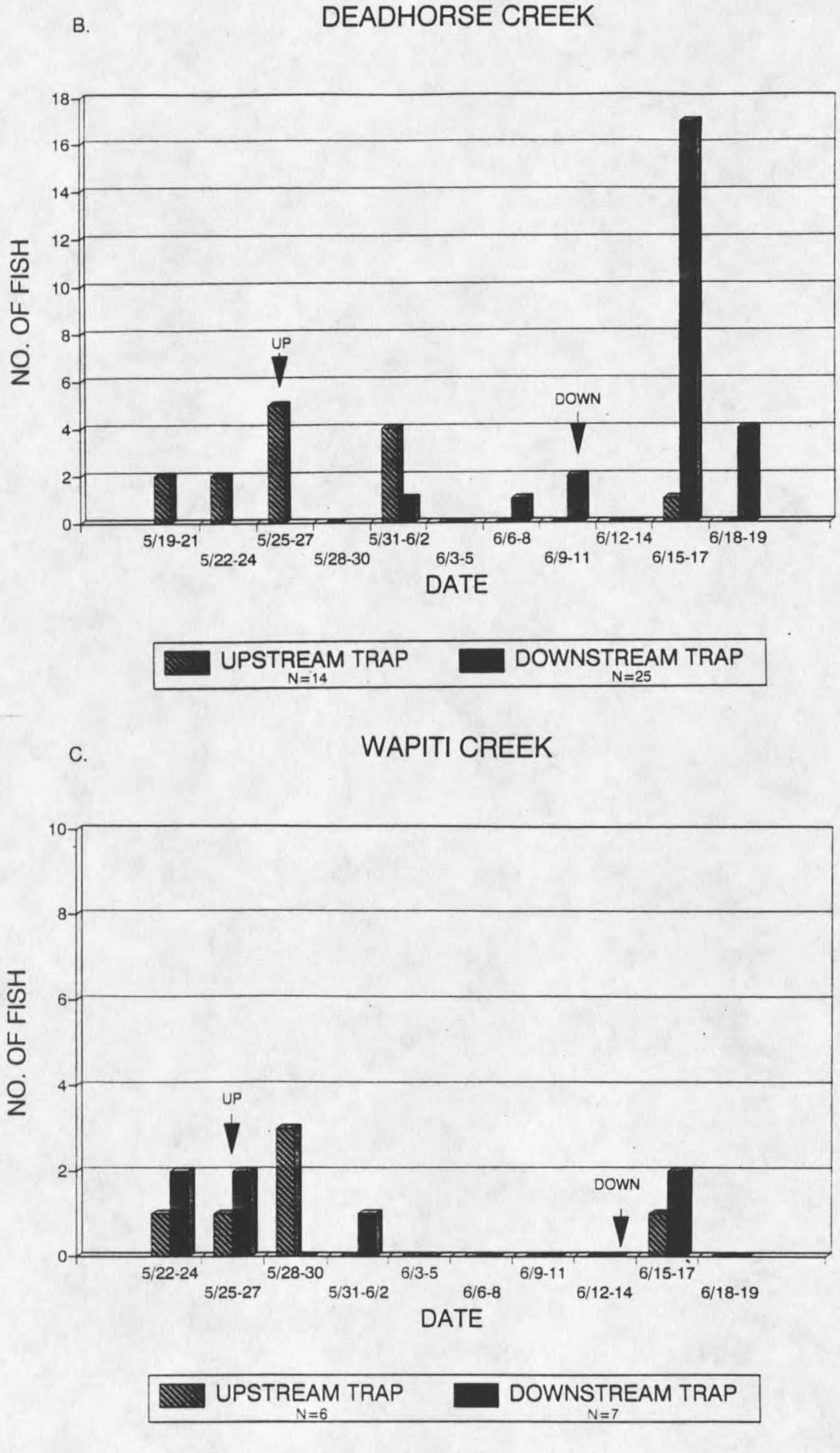


Figure 3 Continued.

In Cache Creek, 73% (n=207) of the fish tagged in the upstream trap were recaptured moving downstream. Females remained in spawning tributaries an average of 11 days, 2 days longer than males (Table 4). The average spawning female weight loss was 10.29 g, or about 12.25% of body weight. Males lost an average of 4.88 g or 6.17% of their body weight, about half that of the females. Only one fish was recaptured in each of the Deadhorse and Little Wapiti Creek traps. Of the recaptured spawners, 8.5% had lost tags during the 2-3 week period between upstream and downstream migrations.

Temperature and Flow during Spawning

The Taylor Fork Basin is characterized by long cold winters with freeze over from mid-October to April (Figure 4). Mean daily temperatures in lower Cache Creek and the lower Taylor Fork River averaged 10-13°C from mid-June to the first week in September (Figure 4A and B). Temperatures in Wapiti Creek were slightly cooler, and a mean daily temperature of 10°C did not occur until the first week in July (Figure 4C). Mean daily temperatures in Lightning Creek were >10°C only during 3 weeks in August (Figure 4D).

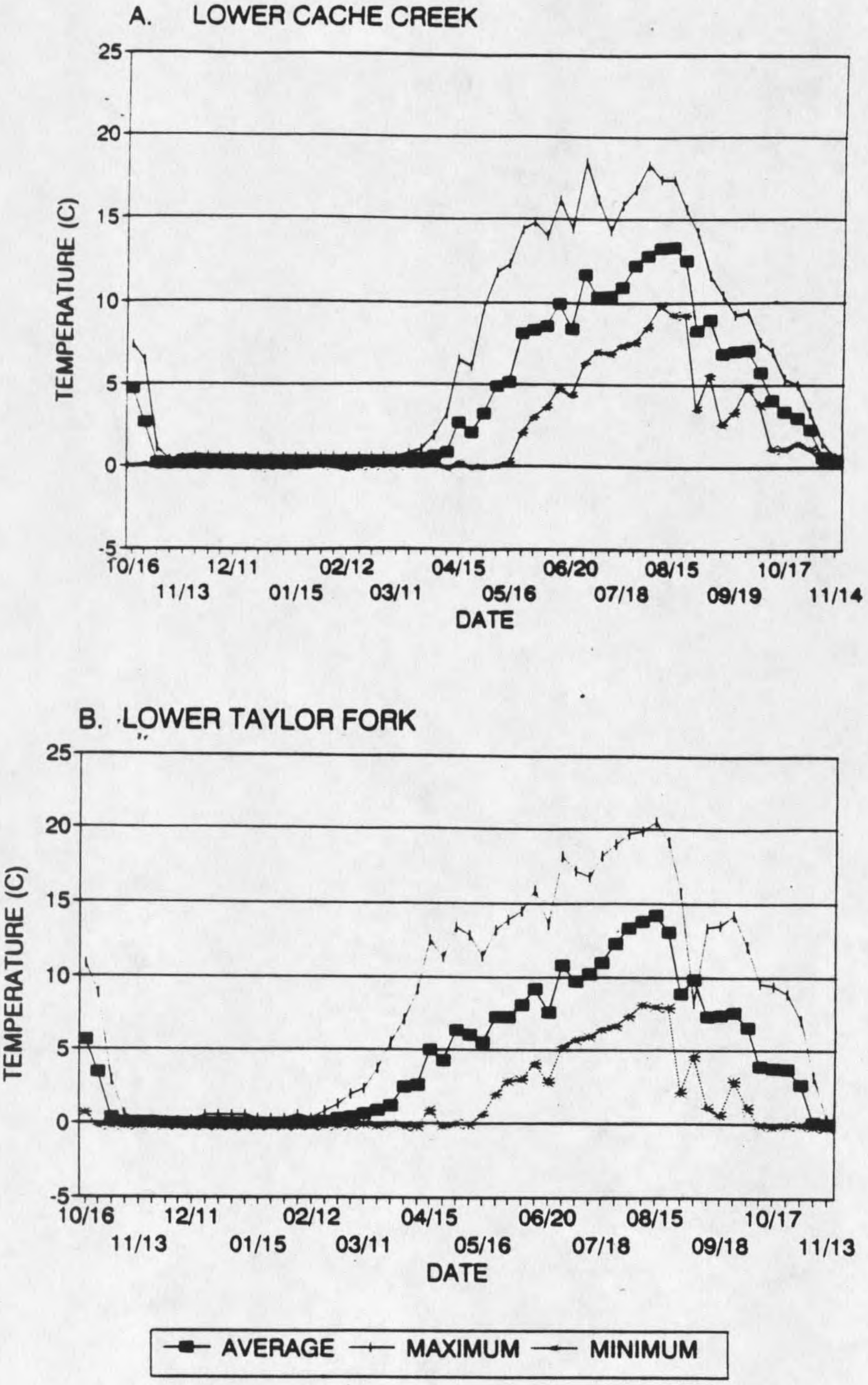


Figure 4. Weekly mean, maximum, and minimum temperatures for lower Cache Creek (A), the lower Taylor Fork River(B), Wapiti Creek (C), and Lightning Creek (D) from 10/91 - 11/92.

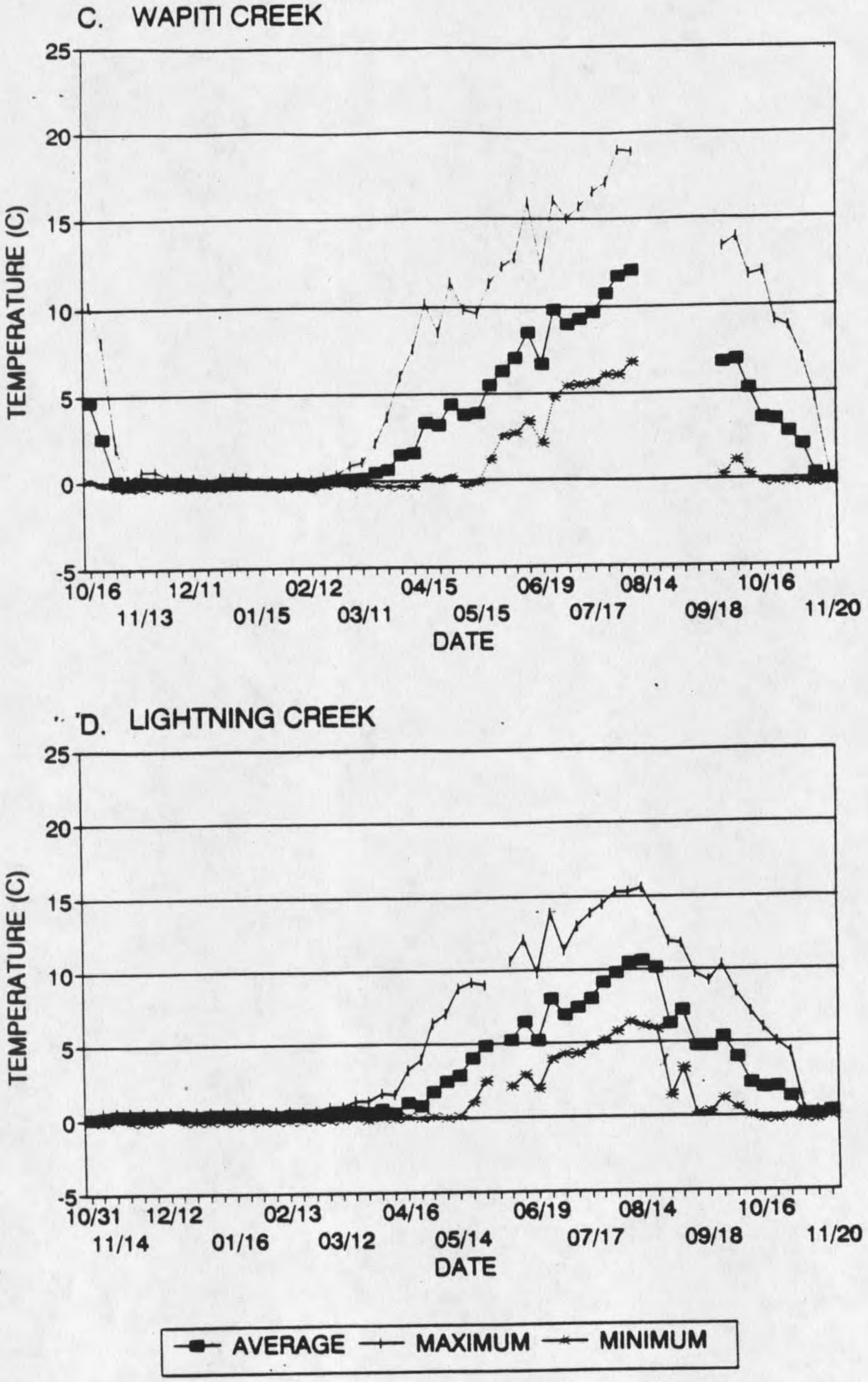


Figure 4 continued.

Most spawning migration (90.2%) in Cache Creek occurred between temperatures of 7-9°C, although spawning migrations likely began before trap installation and may have been initiated at slightly lower temperatures (Figure 5). However, neither upstream ($r^2=0.02$, $P=0.68$) or downstream ($r^2=0.01$, $P=0.80$) migrations were correlated with changes in water temperatures on a daily basis. Highest redd counts in Cache and Wapiti Creeks occurred at temperatures >7°C (Figure 6). Mean daily temperatures in both creeks remained above 7°C throughout spawning except for a storm event on 16 June that decreased temperatures dramatically (Figure 6). Temperatures in Lightning Creek were colder and did not reach 7-9°C until late June - early July.

There was no apparent relationship between water levels and number of upstream migrants ($r^2=0.00$, $P=0.99$) (Figure 7). During a storm on 27 May, both upstream and downstream catch was reduced; however, high flows scoured around the outside of the traps and some fish may have avoided capture. A greater number of migrants captured moving downstream than upstream indicates movement upstream was initiated before traps were installed. Generally, downstream migration increased as water levels decreased (Figure 7); however, downstream migration increased during rising flows during a storm on 13 June. During this period, 209 fish (28% of the total) were caught moving downstream. Peak flows the following day scoured and rose over the top of the trap and resulted in a decline in numbers of fish caught in traps.

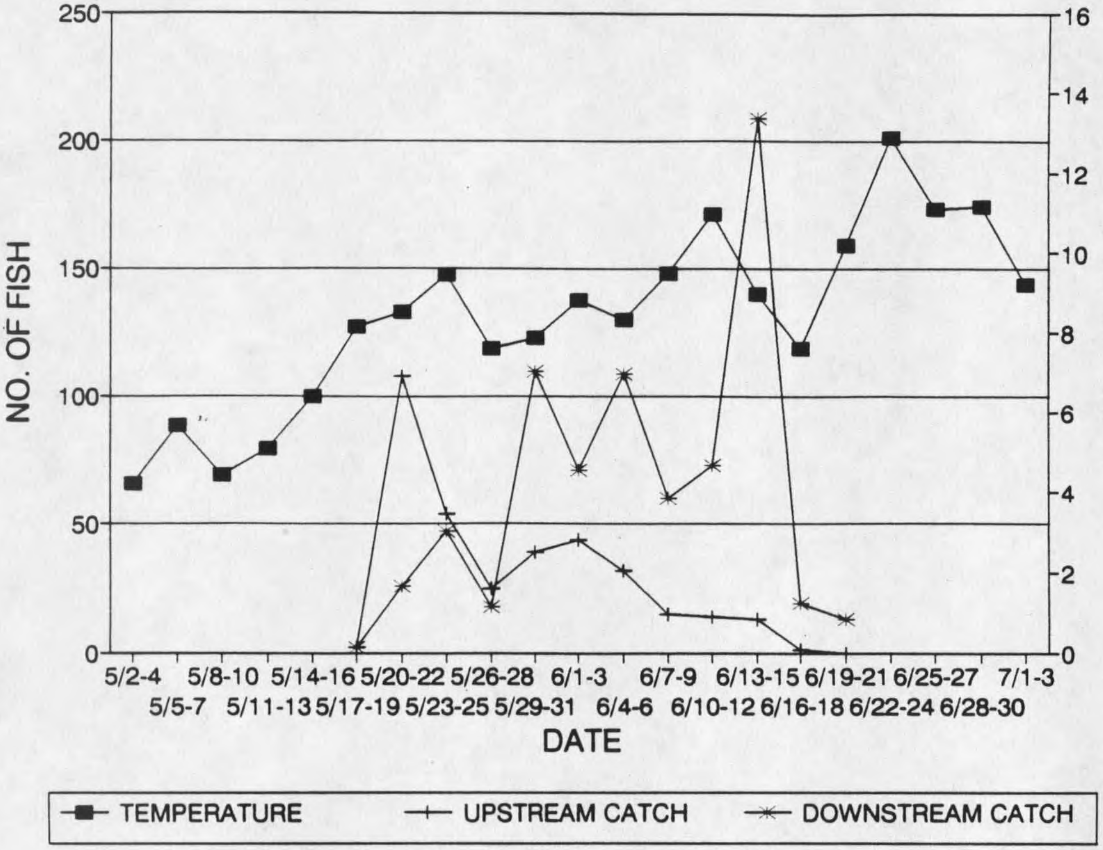


Figure 5. Mean daily temperatures and trap catch from Cache Creek, (based on 3 day averages).

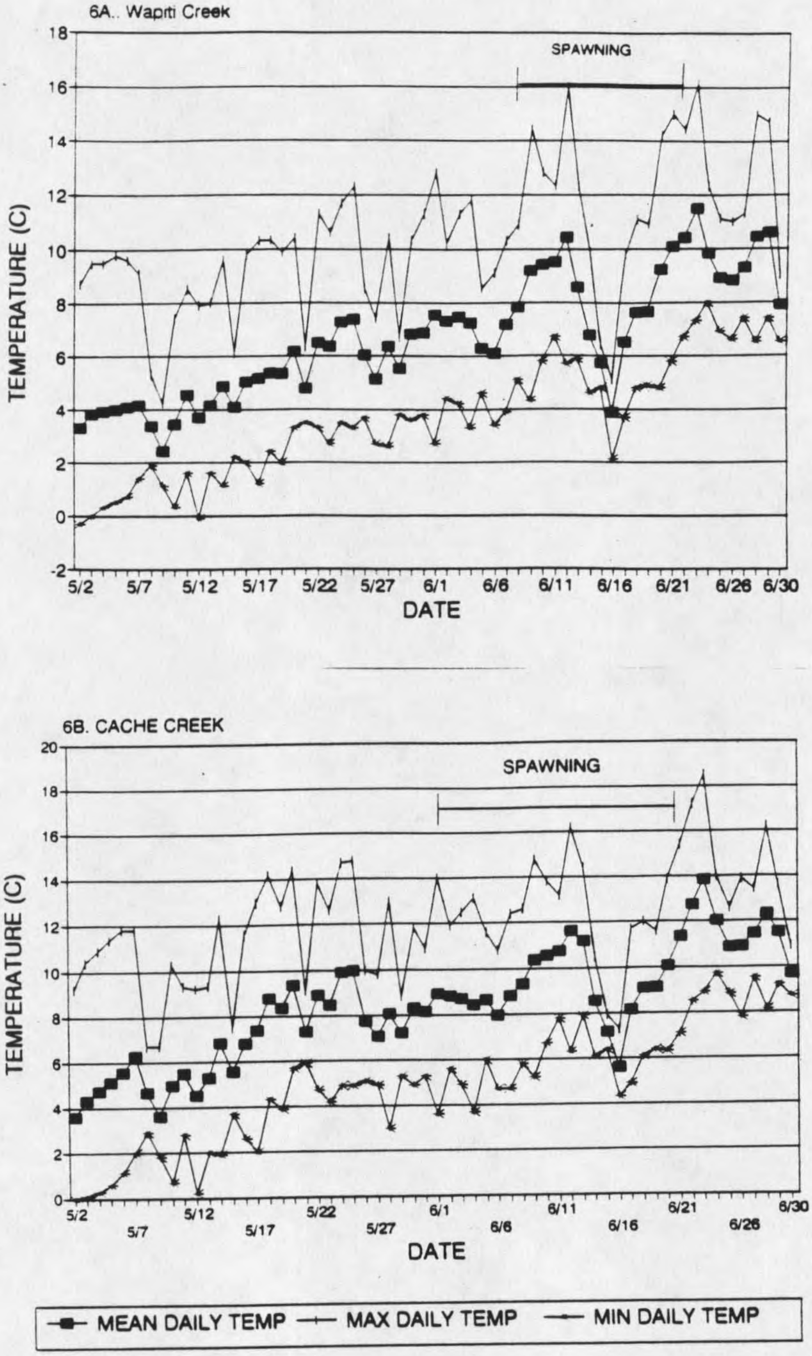


Figure 6. Mean, maximum and minimum daily temperatures for spawning in Wapiti Creek (A) and Cache Creek (B) during redd surveys.

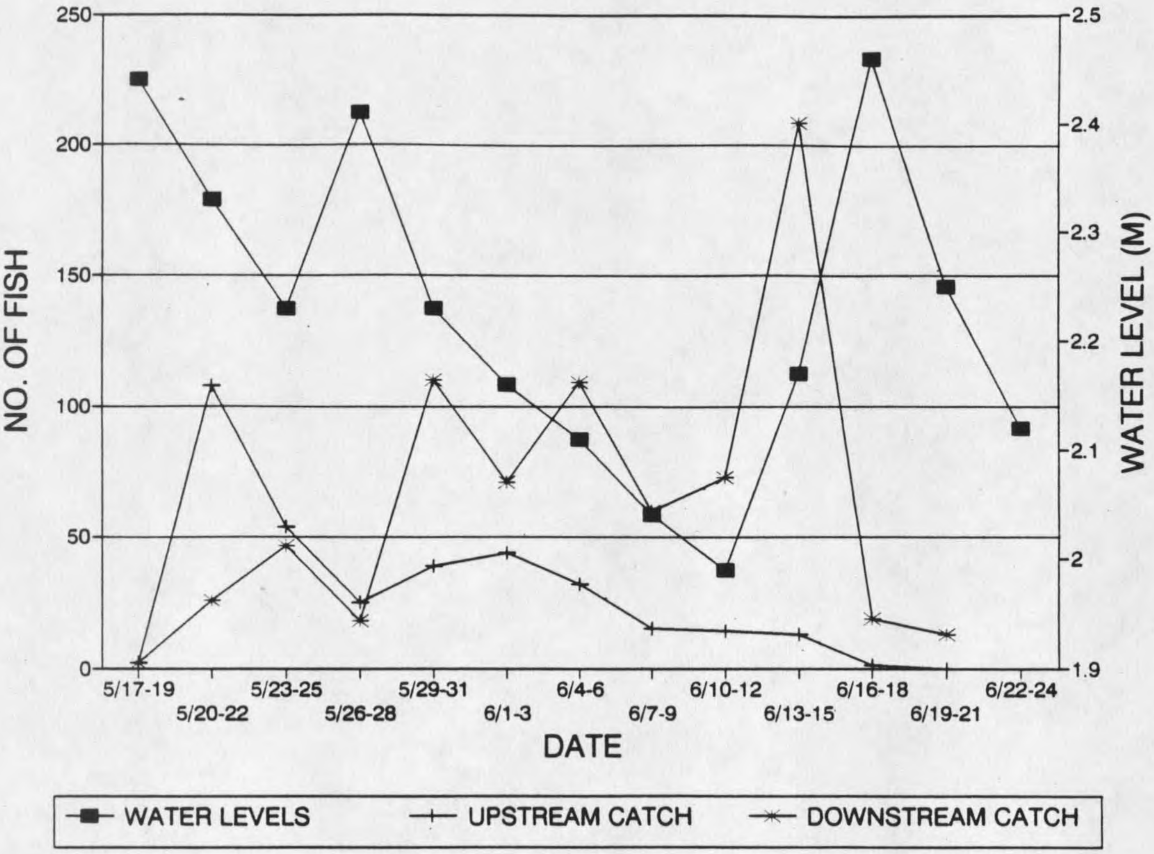


Figure 7. Mean stream water level and trap catch from Cache Creek (based on 3 day averages).

Redd Distribution

I observed no spawning activity or fry in the mainstem Taylor Fork, Eldridge Creek, Meadow Creek, Left Fork Creek or Alp Creek (Figure 8). The presence of small numbers of fry in lower Wapiti Creek, Little Wapiti Creek and Lightning Creek indicated there were other low density spawning areas; however, I located the majority of redds in the basin, and all major spawning areas were identified.

Nearly all (99%) of the 362 redds counted in the Taylor Fork basin occurred in only 15% of the total area sampled. Specifically, upper Cache Creek produced 70% and upper Wapiti Creek 29% of the total redds (Figure 8). Deadhorse Creek had only three redds (1%) and the Little Wapiti Creek tributary had only one redd. Redd densities also varied within subbasins (Figure 9). In Cache Creek, redd densities ranged from 0.9-5.0 redds/100 m, in Wapiti Creek 2.5-3.5 redds/100 m.

Redd counts probably underestimated actual redd numbers. Stream surveys on 3-4 day rotations did not identify all redds, and storm events decreased the visibility of redds and spawning activities. For example, high flows on 27 May prevented clear viewing of reach CCA until 2 June when peak spawning was occurring.

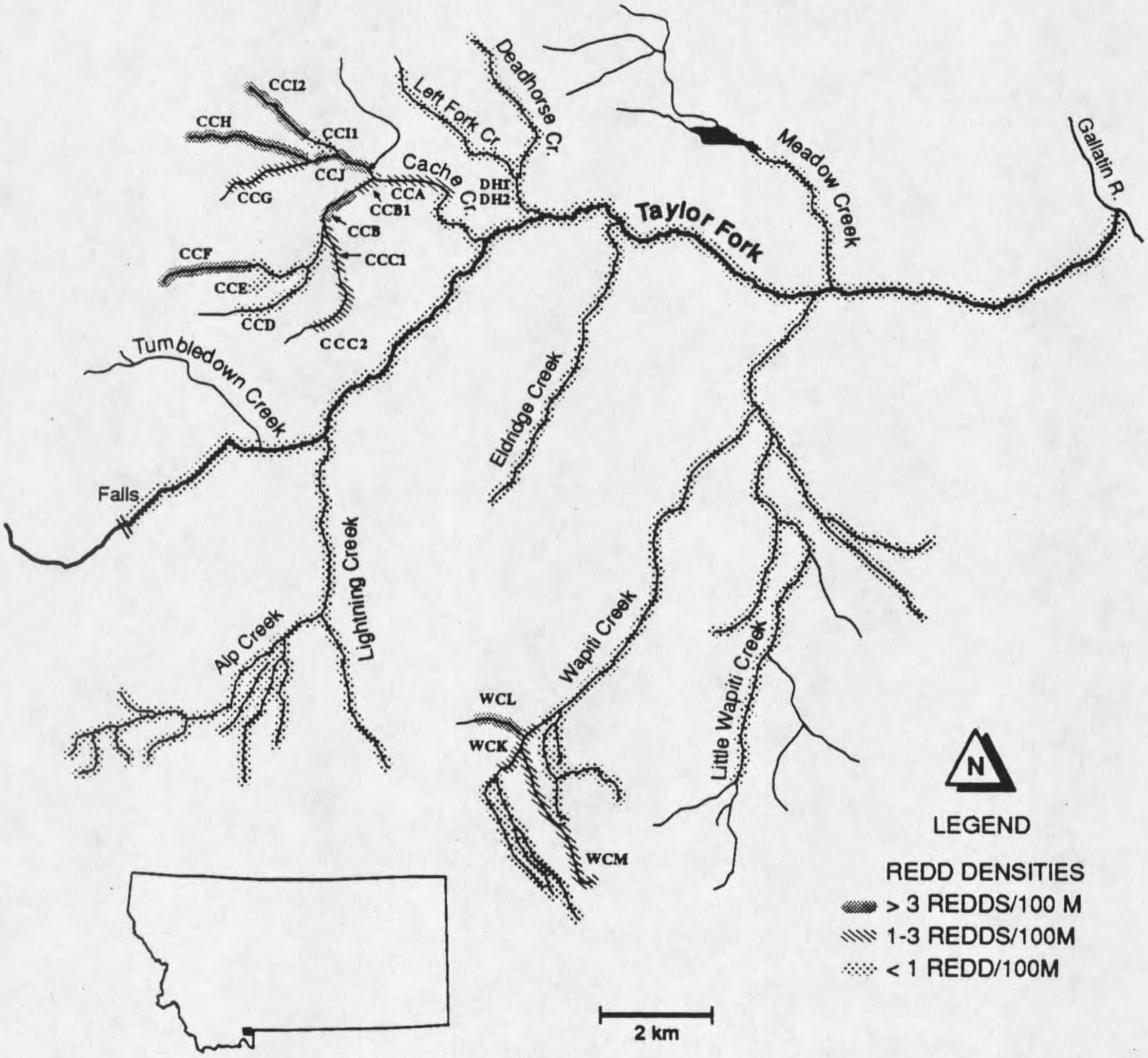


Figure 8. Redd distribution and densities for the Taylor Fork drainage, 1991-1992.

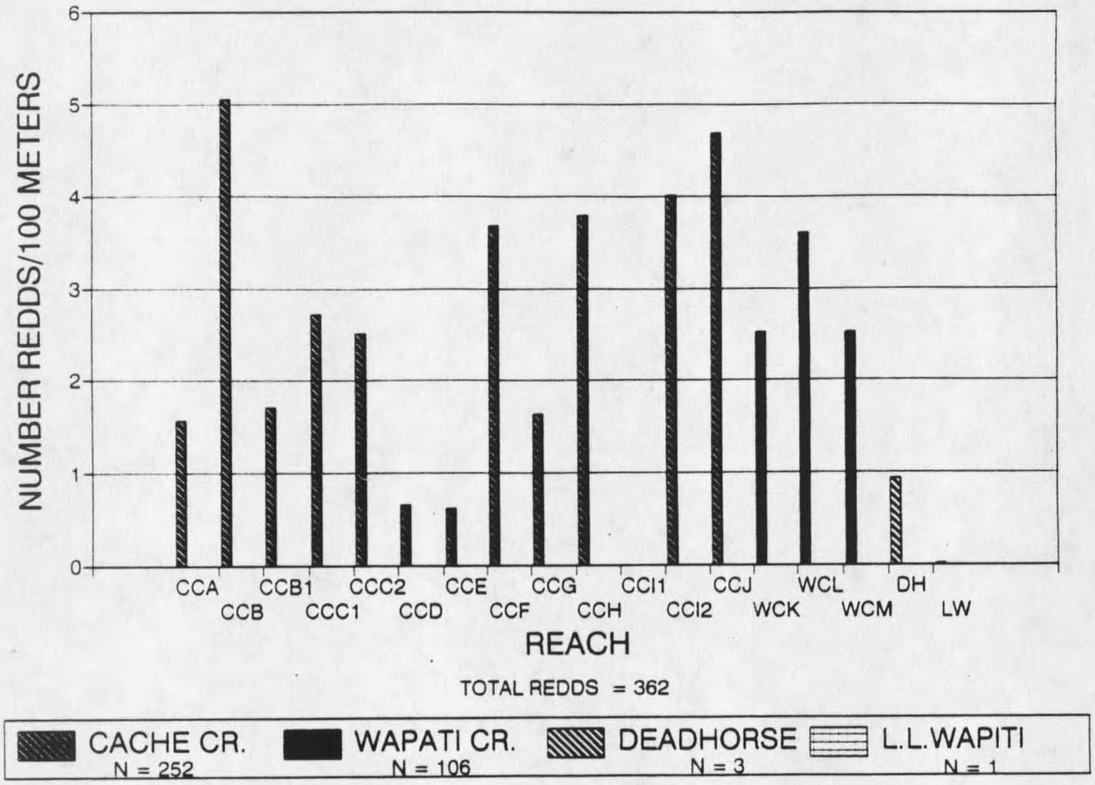


Figure 9. Redd densities by reach and total redd counts by stream for the Taylor Fork basin, 25 May-19 June 1992.

In Cache Creek, active redds were observed from 25 May - 19 June. Peak spawning occurred from 3-5 June, when 77 of 193 (40%) redds were observed (Figure 10). Peak spawning in Wapiti Creek occurred approximately 1 week later than Cache Creek (Figure 10). Later peak spawning in Wapiti Creek may be a reflection of lower temperatures (Figure 4A and 4C) due to higher elevation (Wapiti Creek is 286 m higher in elevation than Cache Creek).

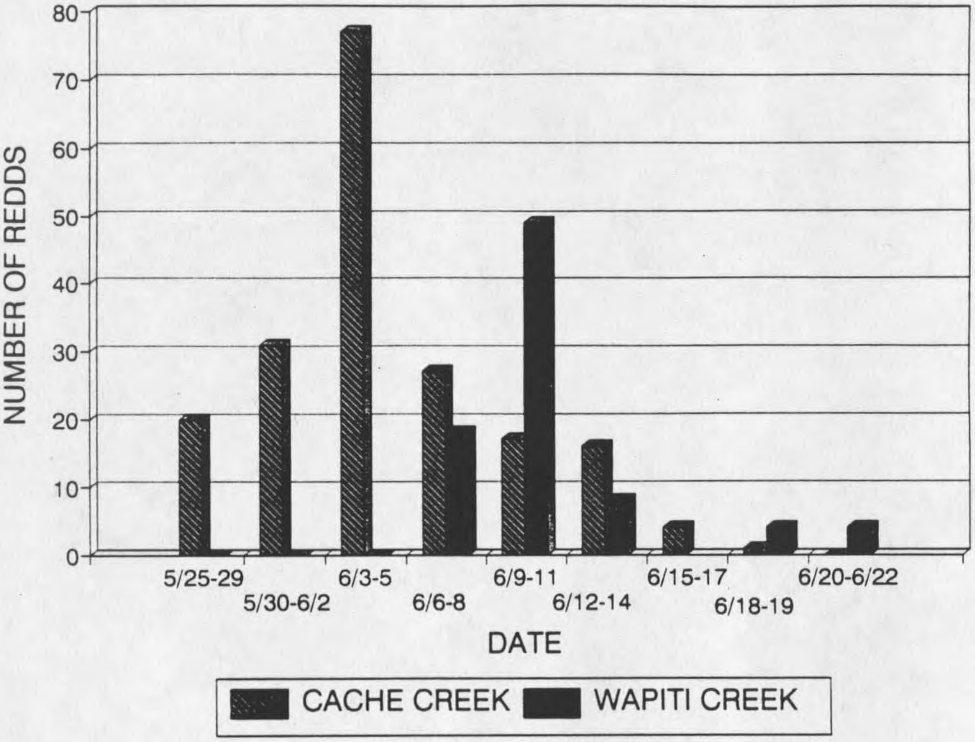


Figure 10. Number of redds counted by 3 day periods for Cache Creek and Wapiti Creek, 25 May-19 June 1992.

Habitat Characteristics Of Spawning Areas

Spawning areas were generally characterized by shallow (<0.2m), narrow (<1.8 m), low-gradient (<4.0%) headwater reaches (Table 5). Of the habitat variables measured, only percent available spawning substrate showed a significant positive correlation with redd density (r_s=0.84, P=0.008) (Table 6). Spawning substrate availability ranged from 3% (reach CCI1) to 25% (reach CCF), and averaged 13% for all reaches.

Habitat features that differed significantly between reaches with high (>3 redds/100 m) and low redd densities (<3 redds/100 m) included gradient, wetted width, average depth, embeddedness, and the percent available spawning substrate. Higher redd densities occurred at significantly higher gradients, with smaller wetted widths and average depths, contained significantly more spawning gravels, and had lower embeddedness than reaches with low redd densities (Table 5). There were no significant differences in streambank condition between high and low redd density reaches (Table 5). The average streambank condition for all reaches was fair (25-50% stable), and no streambanks were classified as over 75% stable. There were no significant differences in habitat type percentages (pool, riffle, glides) between high and low redd density reaches, indicating spawners were not keyed into specific habitat units but where suitable substrate was available.

Substrate Composition of Redds

Eggs were found in, or adjacent to, 11 of the 36 core samples. Fry were seen in the vicinity of six core sites indicating some emergence had occurred at the time of core sampling. I found no significant difference of the percentage of fines <6.35, 2.36, 0.85 mm or the fredle index between core samples with egg pockets and those without (Appendix C). I therefore used all core samples to characterize sediment composition of redds. Due to a small number of core samples in some reaches, I combined Cache Creek South Fork (CCSF) reaches (CCC1, CCC2, CCD, CCE, and CCF; Figure 8) and Cache Creek North Fork (CCNF) reaches (CCG, CCH, CCI, and CCI1) in the analysis.

Both Cache and Wapiti Creeks had high levels of fine sediments, with fines <6.35 mm comprising 33-47% of the total substrate (Table 7). Redds from the relatively undisturbed Wapiti Creek had significantly lower percent surface fines (measured with surface fines grid) and significantly lower percent fines <0.85 mm (measured with McNeil core samples) than did Cache Creek redds.

Table 5. Mean values for habitat variables ranked by redd density (> or < 3 redds/100 m) for the Taylor Fork basin, and significant differences (*) from a Mann-Whitney Wilcoxon test (P≤0.05).

	> 3 REDDS/100 M						< 3 REDDS/100 M							
HABITAT VARIABLE	CCB	CCJ	CC12	CCH	CCF	AVERAGE	CCC1	WCK	CCC2	CCA	DH	CC11	AVERAGE	P-VALUE
REDDS/100M	5.05	4.68	4.01	3.79	3.68	4.24	2.7	2.52	2.5	1.56	0.93	0	1.70	-
GRADIENT	0.50	0.50	2.50	3.00	1.50	1.7	1.00	1.2	3.83	0.50	0.50	4.00	1.20	0.01*
WETWIDTH (m)	1.80	1.44	1.13	1.23	1.04	1.33	1.11	3.05	1.18	3.23	1.31	1.09	1.83	0.01*
BANKFULL WIDTH (m)	13.70	2.38	5.26	2.26	4.07	5.53	1.60	4.92	3.61	3.74	4.75	4.95	3.93	0.53
AVG DEPTH (m)	0.09	0.19	0.08	0.07	0.07	0.1	0.12	0.25	0.07	0.27	0.15	0.06	0.15	0.01*
EMBEDDEDNESS %	50-75	25-50	25-50	5-25	25-50	25-50	50-75	50-75	25-50	50-75	50-75	25-50	50-75	0.01*
BANKSTABILITY %	25-50	25-50	25-50	50-75	25-50	25-50	25-50	0-25	50-75	50-75	25-50	25-50	25-50	0.73
%AVL SPAWN SUBS.	18.02	17.32	16.15	13.93	25.41	18.78	13.27	14.13	3.67	8.45	9.93	3.24	8.78	0.01*
RIPARIAN TYPE														
%SOIL-ROCK	71	26	41	23	47	41.6	24	49	39	18	40	56	37.7	0.28
%GRASS	17	34	48	56	33	37.6	60	43	48	34	38	43	44.3	0.9
%SAGE	2	3	3	0	0	1.6	0	0	0	0	0	2	0.3	-
%WILLOW	10	37	5	7	20	15.8	17	8	8	49	22	0	17.3	0.05
%CONIFER	0	0	3	15	0	3.6	0	0	5	0	0	0	0.8	-
HABITAT TYPE (%)														
LOW GRAD RIFFLE	44	38	42	46	45	43	43	39	45	34	42	50	42.0	0.78
GLIDES	33	27	11	13	28	21	9	16	14	21	20	33	19.0	0.78
POOLS	23	35	48	41	27	35	48	44	41	46	38	17	39.0	0.52
%SURFACE FINES	20	15	12	14	16	15	23	10	17	16	15	13	16.0	0.5
%SILT	22	16	20	19	25	20	24	17	16	18	20	23	20.0	0.41
%PEAGRAVEL	16	22	14	18	18	18	24	24	8	14	9	11	15.0	0.09
%GRAVEL	50	58	46	40	54	50	42	52	37	46	59	44	47.0	0.58
%RUBBLE	10	3	11	15	4	9	4	8	28	16	7	15	13.0	0.1
%COBBLE	2	1	8	9	0	4	6	0	11	4	4	7	5.0	0.96
%BOULDER	0	1	0	0	0	0	0	0	0	1	0	0	0.0	-
%BEDROCK	0	0	0	0	0	0	0	0	0	0	1	1	0.0	-

Table 6. Spearman's coefficient of rank correlation (r_s) and significance (*) ($P \leq 0.05$) of habitat variables with redd densities in the Taylor Fork basin.

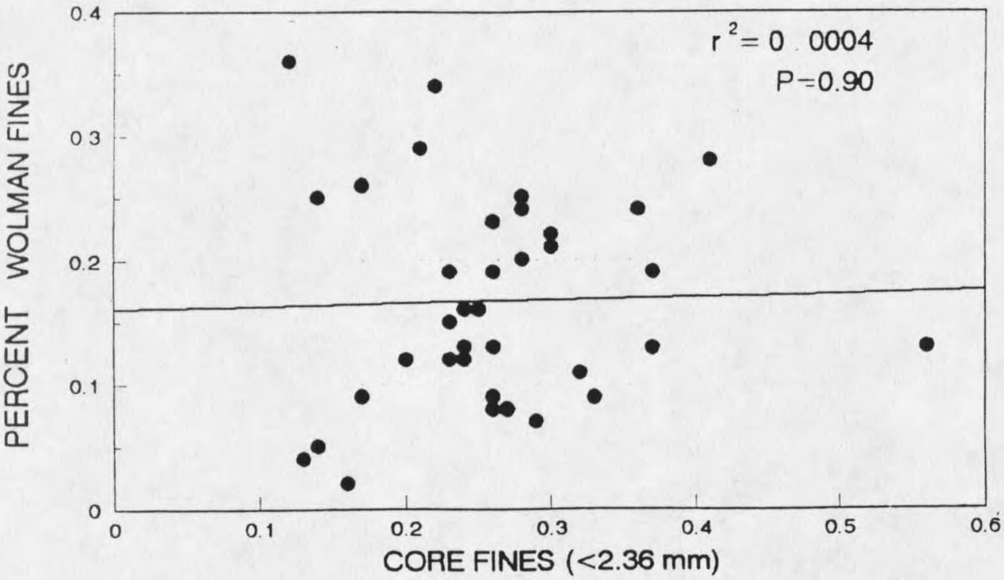
HABITAT VARIABLE	r_s	P
WET WIDTH	0.1	0.75
GRADIENT	-0.25	0.43
AVERAGE DEPTH	0.07	0.81
EMBEDDEDNESS	0.12	0.71
BANK STABILITY	-0.05	0.88
% AVAILABLE SPAWN SUBSTRATE	0.84	0.008*
RIPARIAN TYPE:		
SOIL-ROCK (%)	0.07	0.81
GRASS (%)	-0.18	0.56
SAGE (%)	0.48	0.12
WILLOW (%)	0.03	0.94
CONIFER (%)	0.18	0.57
HABITAT TYPE:		
LOW GRADIENT RIFFLE (%)	-0.10	0.75
GLIDES (%)	-0.13	0.68
POOLS (%)	0.005	0.99
SUBSTRATE TYPE:		
SURFACE FINES (%)	0.14	0.66
SILT (%)	-0.02	0.95
PEAGRAVEL (%)	0.51	0.11
GRAVEL (%)	0.15	0.62
RUBBLE (%)	-0.38	0.23
COBBLE (%)	-0.2	0.53
BOULDER (%)	0.07	0.81
BEDROCK (%)	–	–

Variation in redd substrate composition also occurred between spawning reaches located only a short distance apart. For example, the fredle index for reach WCL was significantly lower than adjacent reaches WCK and WCM (Table 7). Similarly, reach CCSF had significantly lower fredle index than nearby reach CCB (Figure 8) indicating that redd substrate composition can vary significantly over a small distance.

I found no apparent relationship between surface fines measurements (Wolman pebble counts and surface fines grid) and subsurface fines (McNeil core samples) (Figure 11). Surface fines consistently underestimated subsurface fines (Table 7). In contrast, Wolman fines and percent surface fines were positively correlated (Figure 12).

Table 7. Mean values of substrate characteristics for reaches, and Cache and Wapiti subbasins (Figure 8). Significant differences for reaches are based on one way ANOVA and LSD multiple range test. Significant differences for subbasins are based on a Mann-Whitney U test (P≤0.05). Values with a letter in common are not significantly different.

REACH	N	% <6.35mm	% <2.36mm	% <0.85mm	%SURFACE FINES <2.0mm	%WOLMAN FINES <2.0mm	FI
WCL	3	47.78z	30.00z	20.20z	14.35z	18.51z	1.33z
CCSF	4	41.23z	29.51z	21.76z	21.43z	17.95z	1.42zy
CCNF	6	42.43z	28.73z	21.19z	15.37z	12.36z	1.70zyx
CCJ	3	42.78z	28.02z	19.78z	14.29z	18.84z	1.79zyx
CCA	4	38.29z	25.05z	18.46z	19.59z	18.72z	1.93zyx
CCB	4	34.22z	22.42z	14.16z	13.27z	18.06z	2.56zyxv
WCK	5	45.94z	29.90z	19.76z	8.90z	14.90z	3.12z xv
WCM	7	32.78z	18.65z	11.85z	14.93z	17.08z	3.58 v
CACHE	21	39.90z	26.87z	19.24z	16.77z	16.65z	1.87z
WAPITI	15	40.18z	24.67z	16.15y	12.80y	16.64z	2.98z



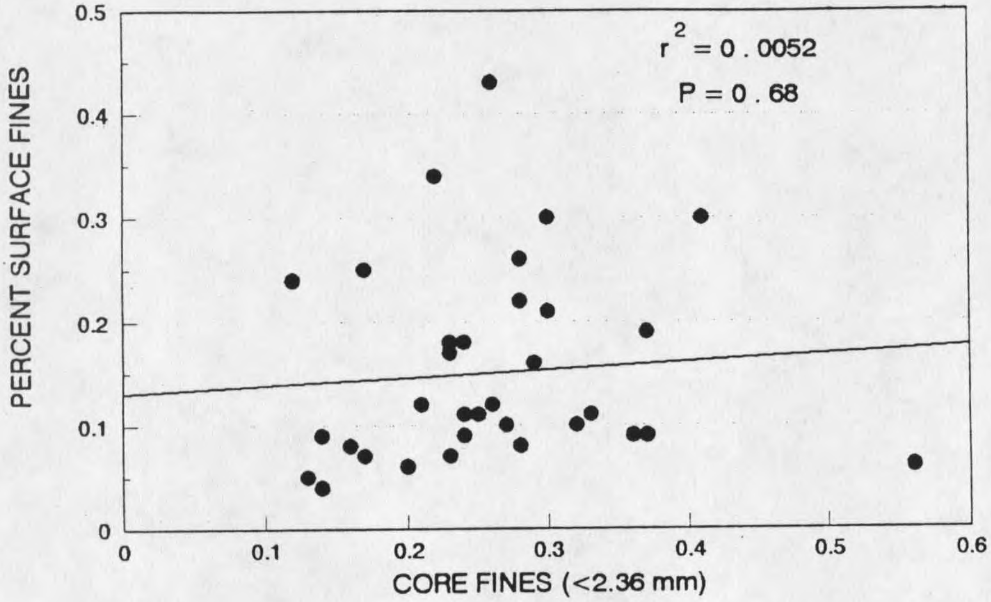


Figure 11. Comparison of percent fines <2.0 mm from the Wolman pebble count (A) and percent surface fines <2.0 mm from surface fine grid technique (B) with subsurface fines <2.36 mm from McNeil core samples at redd sites (N=36).

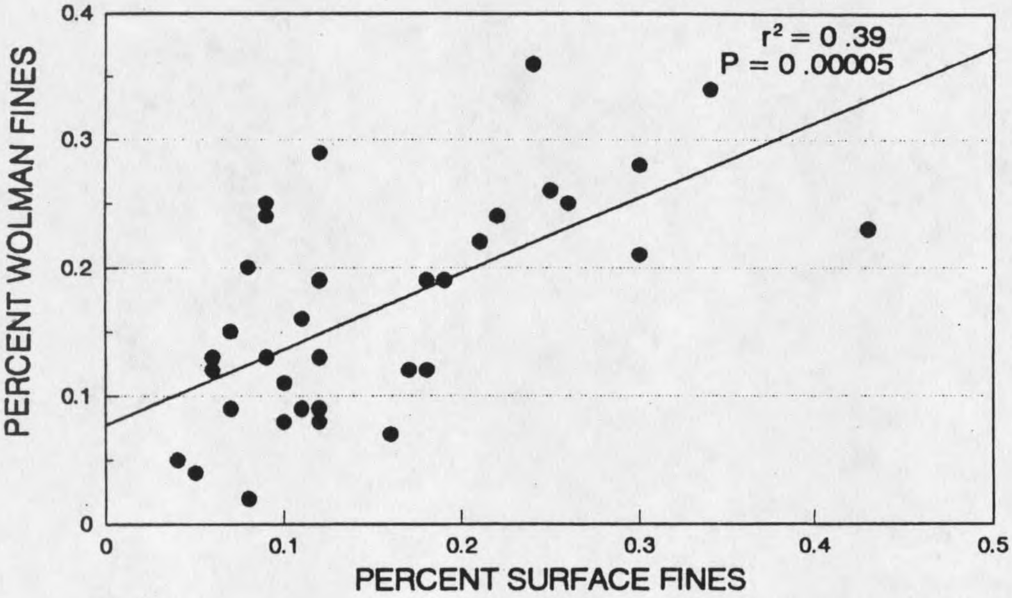


Figure 12. Comparison of percent fines <2.0 mm from Wolman pebble counts to percent fines <2.0 mm from surface fines grid technique at redd sites (N=36).

Fry Distribution

Fry densities varied considerably between reaches (Figure 13) ranging from 0-0.96 fry/m². Visual counts generally declined after 1 September. On a basin scale fry densities were highest in the Cache and Wapiti Creek subbasins, where the majority of the redds were located; however, in comparison of reaches within subbasins, fry densities were not significantly correlated with redd densities ($r^2=0.02$, $P=0.79$), suggesting that productive spawning areas are not necessarily productive fry rearing habitats. For example, reach CCJ had a high redd density (4.68 redds/100m) but a low fry density (0.08fry/m²) (Table 8), suggesting either low survival to emergence, or fry movement out spawning reaches to more suitable rearing habitats.

Although data were available for only four reaches, fry rearing areas can be described as small (<2 m width), low gradient (<1.5%), shallow streams (<0.20 m), with a mixture of riffle, pool and glide habitats (Table 8). Reaches used by fry had moderate embeddedness and streambank stability rated as fair (25-50% stable). Correlations are based on a small sample size, and much of the variation for fry densities in this study cannot be explained.

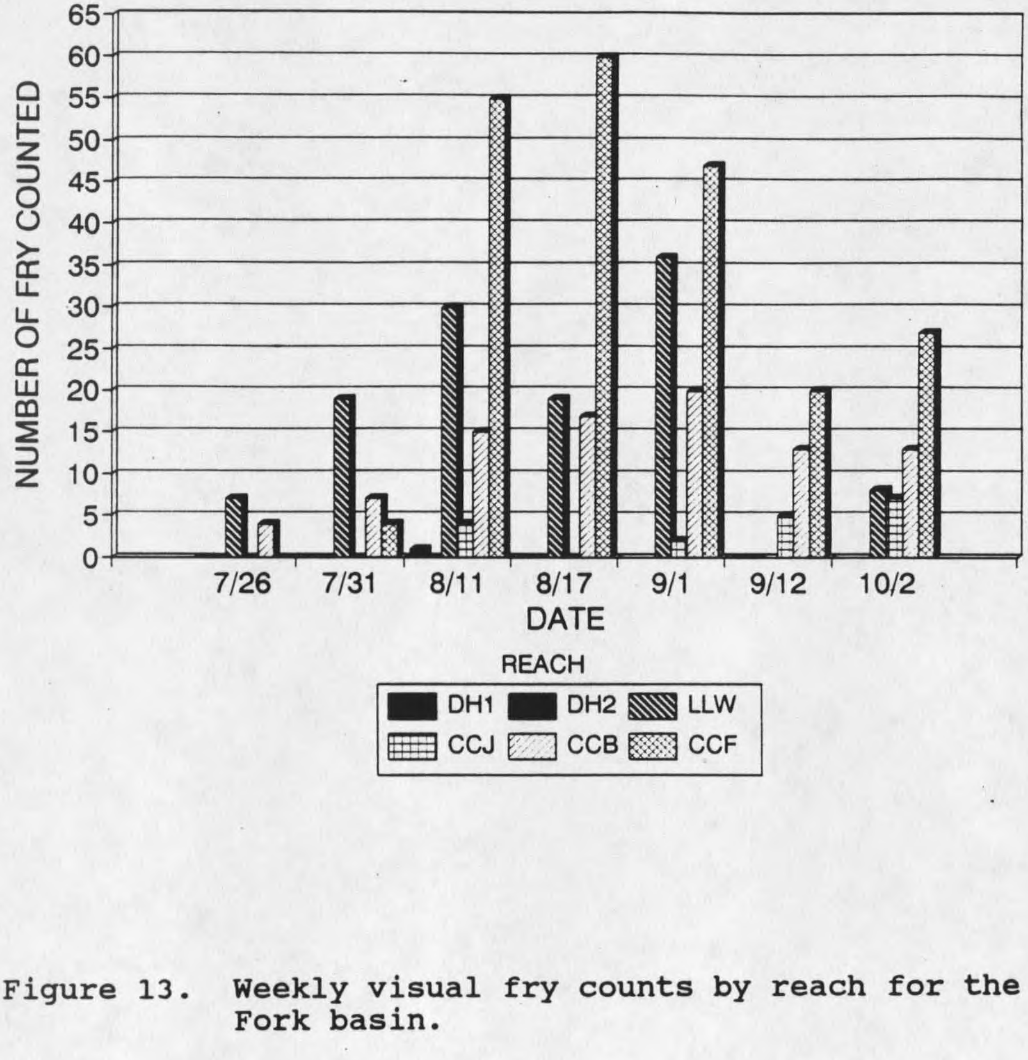


Figure 13. Weekly visual fry counts by reach for the Taylor Fork basin.

I tested habitat variables for the two highest fry density reaches (>0.15 fry/m^2) with those in the two lowest fry density reaches (< 0.15 fry/m^2). Among the 17 habitat variables measured only gradient, average depth, and bankfull width were significantly different between high and low fry densities (Table 8). The high density reaches were characterized by a slightly higher gradient, shallower depth, and narrower channel than lower density units.

Visual fry counts generally underestimated electrofishing removal estimates by about 60% (Figure 14). Differences between visual counts and electrofishing were highest when fry densities were low (<2 fry/m) and high (>15 fry/m).

Table 8. Mean values of habitat variables for fry reaches, and significant differences (*) ($P \le 0.05$) from a Mann-Whitney U test between reaches with fry densities > 0.15 fry/m^2 and < 0.15 fry/m^2.

HABITAT VARIABLE	CCF	CCB	AVERAGE	CCJ	DH	AVERAGE	P-VALUE	N
FRY/M^2	0.96	0.19	0.58	0.08	0.01	0.05	-	-
REDDS/M2	0.04	0.03	0.03	0.03	0.01	0.02	0.7	4
GRADIENT	1.50	0.50	1.00	0.50	0.50	0.50	0.01*	36
WETWIDTH (m)	1.04	1.80	1.42	1.44	1.31	1.38	0.82	36
BANKFULL WIDTH (m)	4.07	13.70	8.89	2.38	4.75	3.56	0.02*	36
AVG DEPTH (m)	0.07	0.09	0.08	0.19	0.15	0.17	0.01*	36
EMBEDDEDNESS	3.22	2.83	3.03	3.10	2.64	2.87	0.41	36
BANKSTABILITY	2.50	2.08	2.29	2.70	2.50	2.60	0.28	36
%AVL SPAWN SUBS.	25.41	18.02	21.72	17.32	9.93	13.63	0.25	4
RIPARIAN TYPE:								
%SOIL-ROCK	47	71	59.00	26	40	33.00	-	36
%GRASS	33	17	25.00	34	38	36.00	0.06	36
%SAGE	0	2	1.00	3	0	1.50	0.34	36
%WILLOW	20	10	15.00	37	22	29.50	0.13	36
%CONIFER	0	0	0.00	0	0	0.00	0.32	36
HABITAT TYPE:								
% LOW GRAD RIFFLE	45	44	44.50	38	42	40.00	0.25	4
% GLIDES	28	33	30.50	27	20	23.50	0.25	4
% POOLS	27	23	25.00	35	38	36.50	0.25	4
SUBSTRATE TYPE:								
%SURFACE FINES	16	20	0.00	15	15	15.00	0.47	34
% SILT	25	22	23.50	16	20	18.00	0.06	34
% PEAGRAVEL	18	16	17.00	22	9	15.50	0.86	34
% GRAVEL	54	50	52.00	58	59	58.50	0.07	34
% RUBBLE	4	10	7.00	3	7	5.00	0.58	34
% COBBLE	0	2	1.00	1	4	2.50	0.65	34
% BOULDER	0	0	0.00	1	0	0.50	0.16	34
% BEDROCK	0	0	0.00	0	1	0.50	0.97	33

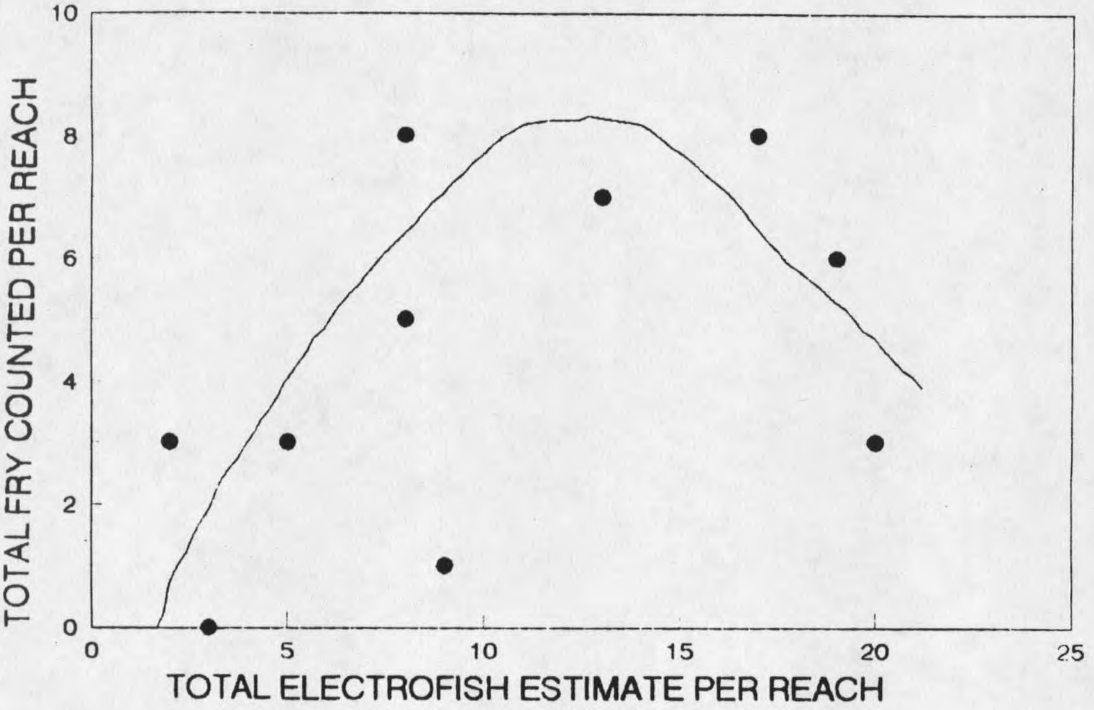


Figure 14. Comparison of visual fry counts and a two-pass electrofishing depletion estimate for 6 meter reach segments.

Fry Emergence and Growth

Peak hatching in Cache Creek was estimated to occur on 6 July, and peak emergence on 28 July (Table 9). In Wapiti Creek, peak spawning was 6 days later than Cache Creek, resulting in a predicted peak hatch 9 days, and peak emergence 10 days later than in Cache Creek redds (Table 9). Mean daily temperatures in Cache Creek were approximately 1°C warmer between fertilization and peak hatch, and almost 2°C warmer between fertilization and peak emergence than Wapiti Creek.

Table 9. Centigrade temperature units (CTU's) for embryonic development in Cache Creek and Wapiti Creek.

STREAM	DEVELOPMENTAL STAGE	DAYS/DATE	MEAN TEMP (°C)	CTU'S
CACHE CR.	FERT-HATCH	33/6 JULY	9.45	312
PEAK SPAWN	FERT-EMERG	55/28 JULY	11.2	559
(4 JUNE)				
WAPITI CR.	FERT-HATCH	36/15 JULY	8.5	307
PEAK SPAWN	FERT-EMERG	60/8 AUGUST	9.4	566
(10 JUNE)				

Mean lengths of fry at the end of the sampling period varied between reaches. Reaches where fish spawned earlier had higher growth rates and typically greater lengths at the end of the sampling period (Figure 15). Mean lengths ranged from 41 mm in reach CCF which had a relatively late spawning date (8 June) to 53 mm in CCB which had an early spawning date (25 May). Higher growth rates appear to result from earlier spawning time (and thus emergence time), and associated longer growing period. Although I did not measure temperature regimes for individual tributaries, variation in water temperatures between reaches may affect redd location, spawning and emergence times and thus growth rates.

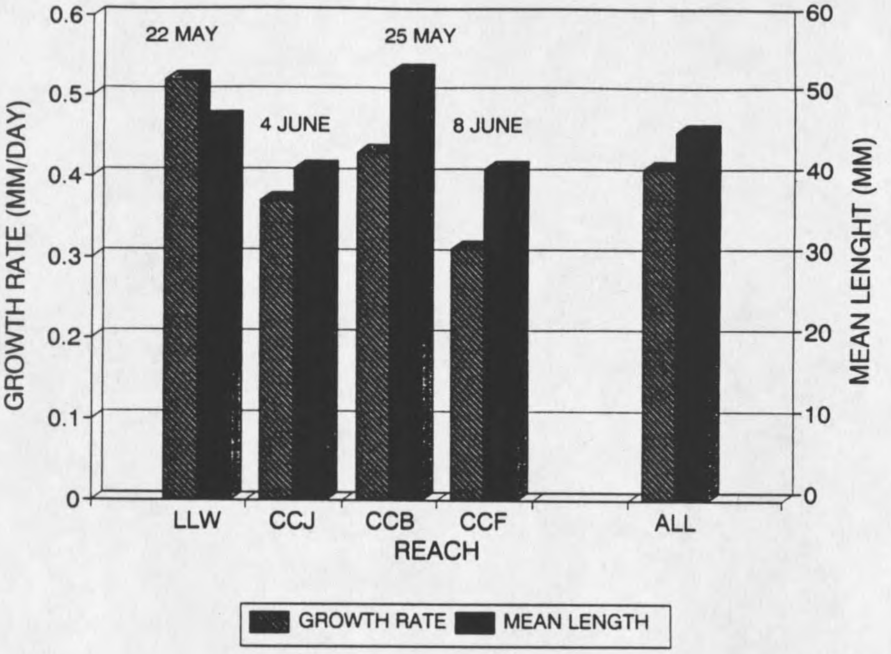


Figure 15. Fry mean daily growth rates, spawning dates, and mean lengths at the end of the sampling period, by reach, in the Taylor Fork basin.

Fry Production

The length-frequency distribution of females caught in the Cache Creek trap (Figure 2) indicates that fish ranging from 175-200 mm dominated (50.6%) the spawning population, and larger females (>225 mm) comprised only 9% of the spawning females. Estimates for fecundity by size class are given in Table 10.

Table 10. Number of females, percentage of females by size class, and mean fecundity for all females >150 mm captured in the Cache Creek trap in May-June 1992.

LENGTH	NUMBER FEMALES	PERCENT SIZE CLASS OF TOTAL CATCH	MEAN FECUNDITY
150-175	37	23.7	152
176-200	79	50.6	208
201-225	26	16.6	282
226-250	9	5.7	387
>250	5	3.2	614
TOTAL	156	100	-

Table 11 illustrates variation in redd densities, survival to emergence (STE), and the predicted fry production per reach and per redd. I estimated the 362 redds identified would produce 15,714 fry. Cache Creek contained 69.6% of the redds and 67.8% of the fry. Wapiti Creek produced 29.3% of the redds and 31.1% of the fry. Deadhorse and Little Wapiti had less than 1% of both redd and fry production.

Table 11. Number of redds and predicted number of fry produced by reach based on percentage of survival to emergence, calculated from an equation from Weaver and Fraley (1991), based on fines <6.35 mm. Range of fry produced per redd is based on range of fecundity per reach.

REACH	# of REDDS	% TOTAL REDDS	AVG % FINES <6.35mm	% STE	# FRY PRODUCED	RANGE # FRY/ REDD	% TOTAL FRY
CCA	39	10.8	38.3	21.2	1899	32-130	12.1
CCB	33	9.1	34.2	26.5	2014	40-163	12.8
CCSF	67	18.5	41.2	17.4	2678	26-107	17.1
CCNF	74	20.4	42.4	15.8	2690	24-97	17.1
CCJ	39	10.8	42.8	15.3	1371	23-94	8.7
WCK	32	8.8	45.9	11.2	826	17-69	5.2
WCL	17	4.7	47.8	8.8	342	13-54	2.2
WCM	57	15.7	32.8	28.4	3719	43-174	23.7
DH*	3	0.8	40.0	19.0	131	29-117	0.8
LW*	1	0.3	40.0	19.0	44	29-117	0.3
TOTAL	362	100.0	40.5	18.3	15714	13-174	100.0

* Estimated with 40% fines

Survival to emergence ranged from approximately 9% in reach WCL to 28% in WCM, and averaged 18% for all reaches. Fry produced per redd ranged from 13 to 174 depending on STE and fecundity. The average size spawning female (191 mm, egg deposition = 218) would produce 39 fry based on the average STE (18%). I predicted reaches CCSF, CCNF, CCJ, WCK, and WCL produced a smaller percentage of the total fry than redds. Reaches CCA, CCB, and WCM produced higher percentage of fry than redds. For example, reach WCM produced 16% of the total redds and 24% of the total fry which can be attributed to a higher than average survival to emergence (28.4%). Fry production in three small first-order tributaries, CCSF (17.%), CCNF (17%), and WCM (24%) accounted for 58% of the total fry produced in the entire basin. Production in second-order streams, CCB (13%), CCJ (9%), WCL (2%), WCK (5%), and DH (1%), accounted for 30% of the total, and a third-order stream, CCA, accounted for only 12% of the total fry production.

DISCUSSION

Spawning Migration

The westslope cutthroat trout in the Taylor Fork basin are resident fish completing their entire life cycle within one stream or river. In 1992, fish migrated to spawning areas in upper tributaries of the basin in late May-early June when temperatures were 7-9°C. Spawners remained in these streams for a short period (9-11 days), and after spawning moved downstream for summer and winter rearing in Cache and Wapiti Creeks (Ireland 1993). Recaptures of spawning fish the following summer and winter provided no evidence of a fluvial life history form, whereby fish moved back to the mainstem Taylor Fork or Gallatin River after spawning. I sampled only a few larger spawners (>250 mm) that are more characteristic of fluvial populations (Liknes and Graham 1988). Further, Ireland (1993) via tag recaptures found no mixing between Cache and Wapiti Creek spawning fish throughout the year, and it thus appears there may be two distinct subpopulations of cutthroat trout in the Taylor Fork basin.

Temperature appeared to be the most important factor affecting the timing of spawning and length of incubation. Generally, spawning peaked during the first 2 weeks of June, fry hatched during the first 2 weeks of July, and then emerged from the gravel from late July-early August. Lower temperatures in Wapiti Creek appeared to delay spawning and lengthen incubation times resulting in later emergence than Cache Creek. Colder temperatures in Lightning Creek may have delayed spawning as temperatures 7-9°C did not occur until late June or early July. Our incubation times were slightly higher than studies done by Roberts (1988) and Kelly (1993) for Yellowstone cutthroat trout, but similar to Zubick (1983) for McBride cutthroat trout (Appendix 2). Differences in incubation periods may be attributed to elevation and temperature differences between systems and years, and between subspecies. Differences in spawning and emergence times illustrate the variation of temporal use of small headwater streams for spawning and early life history phases.

Redd Distribution

I observed high spatial variability in spawning by westslope cutthroat trout within the Taylor Fork basin. Nearly all (99%) redds were concentrated in the upper tributaries of Cache and Wapiti Creeks (Figure 8). These areas produced respectively 70% and 29% of the total redds observed in the entire basin yet comprising only 15% of the total available habitat.

Of the nine habitat variables examined, the availability of spawning substrate was the only factor significantly correlated with redd densities. Cope (1957) also found that the availability of spawning gravel was the most significant variable affecting the distribution of spawning redds for Yellowstone cutthroat trout in Yellowstone National Park. He also reported that gradient, temperature and physical barriers affect redd distribution. Similarly, a combination of factors influenced redd distribution and use of available spawning substrate at different scales in the Taylor Fork basin. Specifically, on a basin scale, elevation, temperature and gradient influenced redd densities, whereas on a reach scale suitable spawning substrate, stream size, and gradient affected redd density.

High elevation tributaries (Cache and Wapiti Creeks) had greater redd densities than lower elevation tributaries (Deadhorse Creek, Little Wapiti Creek, Meadow Creek, Eldridge Creek). I found 88% of the total redds in first-order and second-order streams of high elevation subbasins of Cache and Wapiti Creeks. Other studies have documented the use of headwater tributaries as important spawning habitat for westslope cutthroat trout (Rieman and Apperson 1989).

Although lower elevation tributaries (Deadhorse Creek and Little Wapiti Creek) contained some suitable spawning substrate, they were not used as extensively for spawning. This is likely due to differences in species composition. Higher elevation reaches were dominated by westslope cutthroat trout while lower reaches were comprised primarily of rainbow trout and hybrids. Rainbow trout have been introduced extensively throughout the native range of westslope cutthroat (Liknes and Graham 1988). Typically, westslope cutthroat trout and rainbow trout exhibit habitat segregation where rainbow trout inhabit lower reaches and westslope cutthroat trout use headwater reaches (Rieman and Apperson 1989). Westslope cutthroat trout inhabit and are adapted to high elevation, cold, unproductive systems (Rieman and Apperson 1989), which may function to limit interactions and reduce overlap between westslope cutthroat trout and rainbow trout.

Variation in temperature regimes between and within tributaries may also influence spawning distribution and fry production of westslope cutthroat trout. In Lightning Creek, no spawning fish and few fry were observed despite the presence of some suitable spawning substrate and a similar elevation to Cache and Wapiti Creeks. Fry observed in Lightning Creek in the first week of September had recently emerged (20-22 mm), approximately 1 month later than fry in Cache and Wapiti Creeks. Temperatures in Lightning Creek do not reach the 7-9°C threshold for spawning until late June or early July, resulting in emergence in late August or early September. Such late-emerging fry likely have poor survival due to a limited growth period before winter (Holtby 1988; Hartman and Scrivener 1990). Low redd density throughout Lightning Creek appears to be a result of a combination of cold temperatures, limited spawning substrate, and high gradients.

In the Taylor Fork basin, gradient appeared to be an important geomorphic variable useful in identifying potential spawning areas. Redds were rare in the steeper gradient sections (> 4.0%) of the mainstem Taylor Fork and Cache, Lightning, and Wapiti Creeks. Gradients in spawning areas ranged from 0.5 to 3.8% where spawning substrate 0.2 to 3.5 cm in diameter was available. Thus, spawning fish selecting for specific substrate sizes are restricted to suitable gradient reaches within the basin.

Variation of redd densities between adjacent reaches illustrates that tributaries were not equal as suitable spawning habitat for westslope cutthroat trout. Specifically, higher redd densities occurred at slightly higher gradients (1.7% vs. 1.2%) that were smaller in width and depth and contained significantly more spawning substrate (range 0-22%, mean = 10%). Suitable spawning substrate may be a function of the streams transporting ability which is proportional to the discharge and gradient (Dunn and Leopold 1978). Spawning reaches with higher gradients such as reach CCH (3%) and reach CCI2 (2.5%) usually followed a step-run profile (Bisson et al. 1982) in which steep sections dominated by boulders and cobble were followed by lower gradient sections that contained smaller gravel and peagravel suitable for spawning substrate.

The quality of spawning substrate in lower gradient spawning reaches was possibly reduced due to high embeddedness. These lower gradient reaches may act as depositional areas for fine sediment reducing the suitability of substrate for spawning.

Substrate Composition

The erosive geology of the Taylor Fork basin produces large amounts of fine sediment (Snyder et al. 1978). I compared the percent fines <6.35 and <0.85 mm from the Taylor Fork basin to that reported in studies of substrate composition in egg pockets of salmonids in other streams in the Rocky Mountain region (Table 12). Streams in the Taylor Fork basin have higher percentages of fines in egg pockets than reported in any other locality. Some differences may be attributed to the time of sampling. The Taylor Fork samples were obtained at the time of emergence where fines may have accumulated into the egg pocket through incubation. In contrast, samples in other studies were obtained right after spawning or earlier in the incubation stage, where less fines may have accumulated.

Fredle indices were also the lowest reported in the literature. Thus cutthroat trout egg pockets in the Taylor Fork basin are of a substrate size and quality lower than reported elsewhere in the region.

Table 12. Percentage of fines <0.85 mm and <6.35 mm and the fredle index (FI) in egg pockets of salmonids redds in the Rocky Mountain Region.

STREAM	SPECIES	% <0.85mm	% <6.35mm	FI	N	REFERENCE
PINE CR., ID.	YCT[a]	6.5	24.4	7.6	13	R.THUROW @ J.KING UNPUBLISHED
UPPER SALMON, ID.	STLHEAD[b]	10.2	32.8	3.9	9	R.THUROW @ J.KING UNPUBLISHED
TELEPHONE CR., WY.	BROOK TROUT	6.4	12.1	-	31	YOUNG ET AL. 1989
DOUGLASS CR., WY	BROWN TROUT	3.0	15	-	69	GROST ET AL. 1991
HUNGRY HORSE CR., MT.	WSCTT[c]	5.9	27.4	4.9	3	WEAVER AND FRALEY 1991
TAYLOR FORK, MT.	WSCTT[c]	16.8	39.0	2.7	11	THIS STUDY

[a] YCT (Yellowstone cutthroat trout)
[b] STLHEAD (steelhead)
[c] WSCTT (westslope cutthroat trout)

Salmonid females clean the spawning substrate of fines during redd construction to increase porosity and permeability in the redd (Chapman 1988). Infiltration of fine sediment does occur during incubation (Grost et al. 1991). However, egg pockets usually contain less fine sediment than the surrounding substrate in the redd (Young et al. 1989; Grost et al. 1991). I found no significant differences in percentages of fine sediment between core samples in redds with egg pockets and without egg pockets. It appears in the Taylor Fork drainage high levels sediment may saturate the entire redd, including the egg pockets.

Substrate composition below egg pockets may contain more fine sediment than upper strata (R.Thurow, Fisheries Biologist, USFS Intermountain Research Station, unpublished data). Core samples in the Taylor Fork drainage were taken to a depth of 10 cm based on depth of egg pockets from previous sampling of cutthroat redds (B.May, Fisheries Biologist, Gallatin National Forest, personal communication). However, previous samples were from redds of larger size spawners (≥300 mm) than in the Taylor Fork drainage. Smaller spawners in the Taylor Fork (mean=191 mm) may excavate shallower redds, and core samples may have overestimated the percentage of fines within redds. Future research should address depth of egg pockets for small spawners of resident populations.

Although, as a whole, the quality of spawning substrate was low in the Taylor Fork basin, variation of quality occurred over small areas. However, spawners apparently did not select for substrate quality but rather utilized suitable substrate size (0.2-3.5 cm) when it was available throughout the basin. In Cache Creek, land use practices appear to have increased sedimentation, resulting in significantly more fines <0.85 mm and percent surface fines than Wapiti Creek. However, 70% of the total spawning occurred within Cache Creek, indicating spawners select redd sites based on substrate availability despite the amount of fines. Furthermore, availability of spawning substrate was also very important on a reach level. For example, reach WCM contained high quality spawning gravel (FI=3.58) but had a lower redd density than adjacent reach WCL (FI=1.33). Reach WCM contained more total redds because they were distributed over a large area indicating substrate was used when it was available. In contrast, redd distribution in reach WCL was concentrated in a small area where suitable spawning substrate was available.

Measuring sedimentation either from natural causes or land use is an on-going problem for managers. McNeil and freeze core sampling techniques provide accurate data but are labor and cost intensive, and thus limit the number of samples. Surface measurements have been used as an alternative method to describe the relative degree of sedimentation because they are easier to obtain, cost less, and cover larger areas than core samples. Our surface fine measurements consistently underestimated core sample results. C. Clancy (Fisheries Biologist, Bitteroot National Forest, personal communication) also found little correlation between pebble counts, percent surface fines, and McNeil core samples for both westslope cutthroat trout and bull trout <u>Salvelinus confluentus</u> spawning areas in the Bitteroot River, Montana. Surface measurements may be useful for describing sedimentation if compared to other surface measurements; I found a significant correlation between surface fines measured by the grid technique and Wolman pebble counts. However, the data suggest that surface fine measurements are not an accurate estimator of subsurface fines for the soft sedimentary geology of the Taylor Fork Basin.

Habitat Use and Production of Fry

Presence of spawning gravel and high densities of redds did not ensure the presence of fry. In the Taylor Fork I found higher fry densities in reaches that had high availability of spawning substrate, in combination with shallow stream depths (<10 cm). Bozek and Rahel (1991) studied early life stages of Colorado River cutthroat trout (Oncorhynchus clarki pleuriticus) and found that presence of suitable fry rearing habitat (characterized by small shallow streams (3-20 cm) with slow velocities (<0.06 m/s)), did not guarantee fry were present unless it was adjacent to spawning gravel. Likewise, the presence of spawning gravel did not ensure the presence of fry if suitable fry rearing habitats were not available.

Newly-emerged fry establish territories in lateral habitats of low velocities and move into deeper, faster areas as they grow (Moore and Gregory 1988; Bozek and Rahel 1991). Moore and Gregory (1988) found fry densities were proportional to the area of lateral habitats for coastal cutthroat trout (Oncorhynchus clarki clarki). I observed the use of lateral habitats adjacent to redds in the two shallowest reaches, but I was unable to determine locations of fry in the other two deeper reaches. In reach CCJ, which contained high redd densities, but low fry densities, redds were severely trampled by cattle and I could not determine if low densities were a result of high mortality or if fry migrated to other areas.

Fry densities ranged from 0 fry/m² to 0.96 fry/m² and were within the range of densities reported in other cutthroat trout studies. Irving (1987) (as cited in Rieman and Apperson 1989) summarized fry rearing habitat studies for westslope cutthroat trout and estimated productive fry habitat could support up to 2 fry/m². Bozek and Rahel (1991) found variation of fry densities between reaches of <0.0001 to 0.96 fry/m² for Colorado River cutthroat and Moore and Gregory (1988) found densities of 0.13 to 0.16 fry/m² for coastal cutthroat trout. My reach densities were low to moderate in reference to Irving and were similar to those of Bozek and Rahel and Moore and Gregory. Fry counts generally declined after September 1 indicating either fry movement out of tributaries, an increase in the use of cover habitat, or an increase in mortality. However, sample size was limited. Improved estimates of fry production and habitat use could be obtained through the use of emergence traps and more extensive reach surveys.

Visual fry counts generally underestimated electrofishing depletion estimates. Because water turbulence, vegetation, shade, and fry movement often inhibited visibility, counts probably could have been improved by using an additional observer. Bozek and Rahel (1991) used two observers (one on each bank) for visual counts of Colorado River cutthroat trout and found a strong correlation (R=0.92) with electrofishing estimates. In addition, they used a five-minute waiting period between counts to allow disturbed fry to recover and used a clear plastic sled to reduce water turbulence. Traps or nets can also be used to verify fry movement to other habitats. These techniques may increase accuracy of visual counts in future studies.

Higher stream temperatures resulted in earlier-emerging fry which had longer growing periods before winter. Increased temperatures may cause higher active metabolism (Dwyer and Kramer 1975) in which energy may be used for growth rather than maintenance (Moore and Gregory 1988). Variation in emergence times and thus growth rates of fry in different areas within the basin may ultimately affect fry survival. Overwinter survival for age 0 fish generally increases with fish size in the autumn (Hartman and Scrivener 1990). Holtby (1988) found a positive relationship between stream temperatures and first year winter survival for coho salmon (Oncorhynchus kisutch) and concluded that higher temperatures resulted in shorter incubation periods and longer growing seasons resulting in larger fry in the autumn and subsequent higher winter survival. In Wapiti Creek, peak emergence was 10 days later than Cache Creek. Although we did not measure fry lengths in Wapiti Creek, colder temperatures may cause higher winter fry mortality than in Cache Creek. Colder temperatures in Lightning Creek could result in later emergence and higher winter fry mortality than either Cache or Wapiti Creeks.

My estimation of fry production for the Taylor Fork basin illustrates that much of the total fry production occurred within a relatively small portion of the basin. Furthermore, there was considerable variation in fry production at a reach scale, varying from <1% to 24% of the total fry produced. Variation of production is due both to differences in availability and quality of spawning substrate. The availability of suitable spawning substrate is limited to specific areas within the basin. The quality (percent fines) of spawning substrate resulted in STE ranging from 9-28% and varied drastically over small distances. My data illustrate that extrapolating data from a representative sample of potential spawning tributaries could easily under- or over-estimate total fry production throughout an entire drainage basin.

Effects of Disturbance

Land use activities (logging, roads and grazing) may increase sedimentation in spawning areas and decrease fry production (Platts and Megahan 1975; Everest et al. 1987). However, even with a multitude of studies and research, the effects of fines in salmonid redds is not clearly understood. Chapman (1988) pointed out that failure to standardize fines measurements has led to inconsistent results and confusion. Young et al. (1991) tested the proficiency of 15 different fines measurements for determining variation in STE or changes in spawning substrate composition. They found fines <0.85 mm were the most sensitive measure to known changes of substrate composition in field studies.

The erosive geology and land use activities in the Taylor Fork have resulted in unstable channels and banks, and high sediment levels in the spawning substrate. The two most productive subbasins in the Taylor Fork drainage had similar percentage of fine sediments <6.35 and <2.36 mm; however, Cache Creek had a higher level of fine sediment <0.85 mm than Wapiti Creek. In Cache Creek, sedimentation from land use activities appear to have increased fine sediments <0.85 mm which supports Young's conclusions that fine sediments <0.85 mm are more sensitive to land use disturbances. Although sedimentation of redds is high in both Cache and Wapiti Creeks, 99% of the total fry are produced in these subbasins, indicating westslope cutthroat trout in the Taylor Fork basin may have a high tolerance to high sediment levels.

Salmonids have adapted numerous mechanisms that allow successful reproduction under high sediment conditions. Mechanisms may include physiological adaptions. Studying coho salmon van den Berghe and Gross (1989) found survival was negatively correlated with egg size in poor quality substrate. They attributed higher mortality of large eggs to an increased requirement of oxygen. Large amounts of sediment in the Taylor Fork basin may result in a greater fitness for a smaller egg size. Fecundity and egg size increase with adult body size (van den Berghe and Gross 1989). In poor quality substrate smaller females may produce eggs with a higher survival rate than larger females. The small spawning females (mean=191 mm) of the Taylor Fork drainage may partially compensate for high levels of sediment with higher survival of smaller eggs. Future studies should address fish size, fecundity, and egg size under high sediment conditions.

Everest et al. (1987) gave examples of salmonid behavioral adaptations to mitigate the effects of sedimentation in spawning gravel. For example, the salmonid redd is constructed to minimize fine sediment deposition. Spawning females initially clean the spawning gravel to reduce fines and increase porosity and permeability in the redd (Chapman 1988). The redd pit contains lower velocities and may act as a depositional area for fine sediment. The tailspill, which contains the eggs, has accelerated velocities that keep fine sediment in suspension, resulting in transport downstream. In addition to behavioral adaptations, mitigation may also include temporal or spatial use of habitats.

In the Taylor Fork, spatial diversity of redd sites compensates for the variation of sediment transport, infiltration, and runoff events to ensure fry recruitment. However, spatial change of spawning habitats may not be possible if spawning gravel is limited.

For resident populations, spawning habitat is generally not thought to limit populations (McFadden 1969). However, Beard and Carline (1991) found that recruitment was limited for resident brown trout, and juvenile and adult densities were a function of the available spawning habitat. Similarly, on a basin scale, I found recruitment is limited to Cache and Wapiti Creek subbasins and is also a function of available spawning substrate. However, within these subbasins, despite high levels of fine sediment, Cache and Wapiti Creeks support high adult densities (Ireland 1993) and do not appear to be limited by spawning or fry rearing habitats.

High mortality generally occurs in the first year for resident salmonid species (Benson 1960; McFadden 1969; Scarnecchia and Bergersen 1986). Salmonids establish territories and dominance hierarchies that act as a density dependent regulator in both the rearing and adult stages (Chapman 1966; McFadden 1969; Bachman 1984; Moore and Gregory

1988). Low fry densities may result in decreased competition and higher yearling survival. Specifically, in the Taylor Fork, low survival to emergence may result in less competition in the fry rearing stage and a higher survival rate for yearling fish. This is supported by low to moderate fry densities and moderate to high adult densities (Ireland 1993).

However, there may be a low threshold of STE that limits recruitment. Although most research has described STE in laboratory situations, STE in the Taylor Fork is low compared to field studies of other salmonids. Cederholm et al.(1981) found with 20% fines <0.85mm, STE in natural coho redds was 20% in the Clearwater River, Washington. In contrast, Koski (1966) found considerably higher STE (45%) for 20% fines <0.85mm for coho redds in Alsea River Oregon. Scrivener and Brownlee (1989) found a decline in STE from 29.1 to 16.4% for coho salmon and 22.2 to 11.5% for chum salmon (Oncorhynchus keta) after logging in Carnation Creek, British Columbia.

Variation of STE (9-28%) between reaches in the Taylor Fork indicate some reaches may be limited by recruitment, and the basin as a whole (with a low mean STE of 18%) may be close to limiting recruitment. In the Taylor Fork, if percent fines <6.35 mm in spawning gravels increased from 40% to 50%, STE would decrease from 18% to 6%, and fry survival per redd would decrease from 39 to 13.

Sedimentation of spawning and fry rearing habitats in Cache and Wapiti Creeks does not appear to be limiting adult densities, however, it may be on the threshold of limiting spawning success and fry production. With a low average survival to emergence for westslope cutthroat eggs in the Taylor Fork basin, populations may be more vulnerable to catastrophic events or further disturbances. Management objectives should include protection for these limited spawning habitats.

Protecting spawning and rearing habitats is important to ensure recruitment into a population. Spawning fish and developing fry are vulnerable in small tributaries. Spawning fish are vulnerable to angling as they migrate toward headwater streams. In Cache Creek, I observed anglers harvesting larger fish as they migrated into spawning tributaries. Angling restrictions or closures is an effective method to protect spawning fish (Johnson and Bjornn 1978), but may be ineffective in protecting incubating eggs.

Disturbances during incubation may cause premature emergence or physical destruction of eyed-eggs resulting in higher mortality (Post et al. 1974; Blaxter 1969; Roberts and White 1992). Johnson et al. (1983) found that from midway between fertilization and the eyed-egg stage, embryos become more sensitive to physical disturbances. Roberts and White (1992) described the effects of angler wading on developing embryos and found that twice-daily angler wading on redds from hatching to emergence resulted in 35-69% mortality of fry for rainbow trout, brown trout (<u>Salmo</u> <u>trutta</u>), and Yellowstone cutthroat (Oncorhynchus clarki bouvieri). However, Kelly (1993) concluded that wading had little effect on Yellowstone cutthroat trout populations partially because angling closures were in effect during the development of eggs and pre-emergent fry.

In Cache Creek, peak hatch occurred on 6 July and peak emergence on 28 July. Cattle were introduced into the Cache Creek Basin on 2 July, 5 days before peak hatching. I noticed severe trampling of redds in several reaches of Cache Creek. For example, reach CCJ, which had a high redd density, was severely trampled and also had low fry densities. Although this reach had relatively poor gravel quality (FI=1.79), trampling may have resulted in additional fry mortality. Evidence from Roberts and White (1992) suggests that cattle-induced trampling of redds may also increase mortality of eggs and pre-emergent fry.

By identifying vulnerable spawning and incubation periods a manager has the opportunity to protect these critical life stages. If reproduction is a limiting factor, angling closures in Cache Creek during spawning may increase adult escapement and delaying the introduction of cattle into the subbasin until after peak emergence may decrease fry mortality.

CONCLUSION

Bisson (1985) gave an example of estimating smolt yield for entire streams or basins by extrapolating densities from representative reaches. He concluded that such extrapolations to the total population size or limiting factors could be deceptive. In the Taylor Fork basin, I found strong patchiness of locations of critical spawning and fry rearing habitats. These habitats were restricted to two high elevation subbasins with suitable gradients, temperatures and spawning gravels for productive spawning and fry rearing habitats. Management based on data from other subbasins or entirely from Cache and Wapiti Creeks would result in a high degree of error. By using a large scale approach I identified the most important spawning and rearing habitats within the entire basin, and defined variables at each scale that identified these critical habitats. However, more intensive reach evaluations were also necessary to identify which factors account for why certain areas are more critical spawning and fry rearing habitats than others.

Variation in redd densities and habitat characteristics within and between these habitat scales illustrates the importance of utilizing all scales to describe critical habitats. Managers can use each scale to provide different information important in identifying critical habitats for different life history stages. Identifying where and why "hotspots" for fish production occur is essential before protection and enhancement can begin.

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APPENDICES

APPENDIX A

Regression model for Cache and Deadhorse Creek water levels.

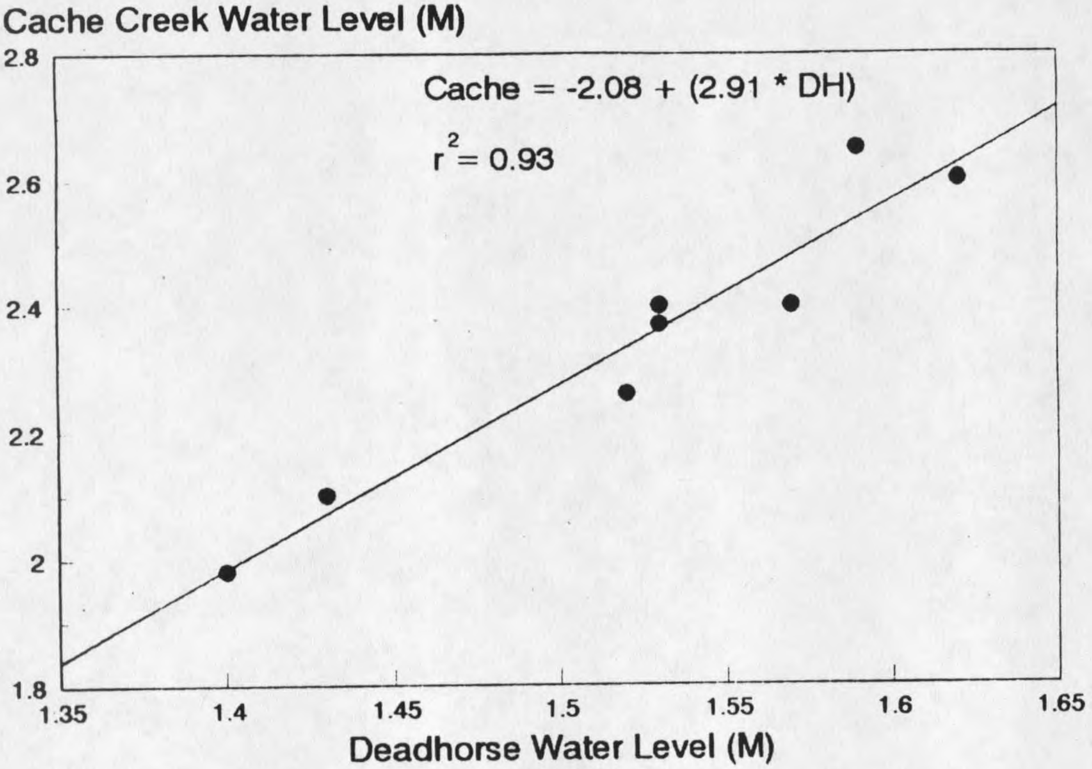

Figure 16. Regression for Cache and Deadhorse Creek water levels, and equation for estimating Cache Creek water levels.

APPENDIX B

Embryonic incubation times for cutthroat trout.

Table 13. Centigrade temperature units for embryonic development for cutthroat trout.

REFERENCE	DEVELOPMENTAL STAGE	DAYS	CTU'S
ROBERTS (1988)	FERTILIZATION -HATCH	26	294
	FERTILIZATION -EMERGENCE	47	478
ZUBICK (1983)	FERTILIZATION -EMERGENCE	74-80	545-626
KELLY (1993)	FERTILIZATION -HATCH	26-41	278-365
	FERTILIZATION -EMERGENCE	37-58	458-525

APPENDIX C

Mean values of substrate characteristics between egg pockets and redds.

Table 14. Mean values of substrate characteristics between egg pockets and redds, and P-values based on a Mann-Whitney U test.

FINES	EGG POCKETS (N=11)	REDDS (N=25)	P-VALUE
<6.35 mm	0.39	0.40	0.65
<2.36 mm	0.25	0.26	0.71
<0.85 mm	0.17	0.18	0.55
PSF[a] (<2.0 mm)	0.16	0.15	0.99
WOLMAN[b] (<2.0 mm)	0.18	0.16	0.27
FREDLE INDEX	2.7	2.2	0.47

[a] PSF (percent surface fines grid technique)
[b] Wolman (Wolman pebble counts)