ECOLOGY OF YELLOWSTONE CUTTHROAT TROUT AND AN EVALUATION OF POTENTIAL EFFECTS OF ANGLER WADING IN THE YELLOWSTONE RIVER

by

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VITA

Barbara Marie Kelly was born on June 19, 1963 to Robert Walsch and Audrey Marie Tschohl Kelly. She was raised with her sister and two brothers in Bayport, Minnesota. She attended and graduated from Stillwater High School, Minnesota in May 1981, and from University of Montana, Missoula in June 1986, with a Bachelor of Arts in Biology. She worked in fisheries for Montana Fish, Wildlife, and Parks from June 1986 to September 1989, when she began work on a Master of Science degree in Fish and Wildlife Management at Montana State University. She worked on science projects in Antarctica in 1991 and 1992.

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ABSTRACT

There has been concern that heavy angling pressure in the Yellowstone River between Yellowstone Lake and the Upper Falls may result in high wading-caused mortality of Yellowstone cutthroat trout embryo and pre-emergent fry. Effects of angler wading were evaluated for 1991. Factors considered included: number and distribution of redds; timing of spawning, embryonic development, and emergence; and amount and distribution of angler wading. In 1991, mortality from angler was estimated at 9.3% of the eggs laid. Estimated mortality was low because of the closure of 12 of 26 km of the river, which protected 60% of the redds, and the July 15 opening date which protected eggs for part of their development. Annual differences in the timing of embryonic development and emergence will change the amount of potential wading caused mortality. Cutthroat trout fry emergence was about 2 weeks earlier in 1990 than in 1991. Population level effects of reduced survival to emergence were evaluated by considering population limitations and regulations at several life stages. Based on visual estimation of surface substrate composition and amount of spawning in the river, spawning did not appear to be limiting. Recruitment of cutthroat trout from tributaries was insignificant. Trout fry were generally abundant along shorelines during peak emergence, but numbers declined by over 90% within 25 d in counting transects in 1990 and 1991, due to mortality and emigration. The adult cutthroat trout population appeared to be large. Population regulation probably occurs at stages other than the incubation period in the Yellowstone cutthroat trout population of the study area.

INTRODUCTION

Yellowstone cutthroat trout Oncorhynchus clarki bouvieri entered Yellowstone Lake and th
after the last ice age, 8,000 years agc
population is the largest concentration
cutthroat trout (Behnke 1992). The Upp
Falls of the Yellowstone River, downstr
Lake, have prevented upstream movement
into the system, and Federal legislatio
Service policies have also protected thi
current goal of the Yellowstone National
management program is to "... allow ecological processes to function as if uninfluenced by modern man, while providing for visitor use and education" (Jones et al. 1992)

The Yellowstone cutthroat trout population in the Yellowstone River between Yellowstone Lake and the Upper Falls may be the most intensively fished native trout stock in North America (Jones et al. 1990). Annual angler effort in the 14 km of stream open to angling has averaged 127,000 h/yr for the past 5 years, which is equivalent to 1,257 angler hours per hectare (Jones et al. 1992). Yellowstone cutthroat trout are vulnerable to angling, but hooking mortality in the Yellowstone River is low (Schill et al. 1986).

Cutthroat trout from both the river and the lake spawn in the Yellowstone River; allacustrine spawners comprise a discrete stock within the lake (Bowler 1975; Liebelt 1968; Raleigh and Chapman 1971; Varley and Gresswell 1988). The importance of the Yellowstone River tributaries for cutthroat trout reproduction and recruitment into the river is unknown.

Because of the heavy angling pressure within spawning areas, there has been concern that anglers wading on cutthroat trout redds in the Yellowstone River may reduce survival. Roberts (1988) and Roberts and White (1992) evaluated wading-caused mortality of embryo and pre-emergent trout fry in the laboratory. Embryo mortality rates varied with stage of development at the time of wading and with the frequency of wading. Eggs were most sensitive just prior to hatching, when a single wading event killed up to 46% of the embryos. Maximum mortality of up to 96% resulted from twice-daily wading throughout development.

The different mortality rates due to angler wading relate to trout embryonic development. When an egg enters the hypotonic medium, fluids fill the perivitelline space, hardening the chorion (Knight 1963; Blaxter 1969). Lipid droplets buoy the embryo in a dorsal position within the chorion (Knight 1963). During this pre-eyed period the egg is very resistant to crushing (Hayes 1949), and wading mortality is low (Roberts 1988; Roberts and White 1992). The embryo is sensitive to physical disturbance during blastopore closure, which occurs about mid-way between fertilization and eye-up (Johnson et al. 1983; Dwyer et al. in press). Wading-caused mortality of pre-eyed eggs during blastopore closure ranged from 4-10%, compared to 76-94% mortality from handling, perhaps due to relatively little physical disturbance within the substrate (Roberts 1988; Roberts and White 1992). Half-way between eye-up and hatch, enzymes are excreted into the perivitelline space to soften the chorion for hatching (Blaxter 1969; Knight 1963). Wading mortality is highest between the start of chorion softening and hatch (Roberts 1988; Roberts and White 1992); less than 1 kg pressure is required to burst eggs at this stage (Hayes 1949). After hatch, the pre-emergent fry's fragile body parts are vulnerable to crushing and wading mortality is high, although less than during the period of chorion softening (Roberts 1988; Roberts and White 1992). Indirect mortality from wading can result from the spread of <u>Saprolegnia</u> spp. from dead eggs (Smith et al. 1985).

The goal of this study was to evaluate the potential effects of angler wading on the Yellowstone cutthroat trout population between Yellowstone Lake and Upper Falls and to gather information about this Yellowstone cutthroat trout population and its habitat.

Specific objectives of the study were to:

1. Describe the physical and chemical characteristics of the Yellowstone River and tributaries.

2. Evaluate the distribution and availability of spawning habitat in the Yellowstone River and tributaries, and to evaluate the potential for recruitment of cutthroat trout from the tributaries to the Yellowstone River.

3. Quantify the number and distribution of redds.

4. Document the timing of cutthroat trout spawning, embryonic developmental stages, hatching, and emergence, and to relate this to the timing of wading.

5. Monitor the abundance, growth, and distribution of cutthroat trout fry.

6. Characterize the adult cutthroat trout population and examine their movements.

7. Document the amount and distribution of wading by anglers.

8. Estimate wading-caused mortality of trout eggs and pre-emergent fry.

STUDY AREA

The study area is in the central part of Yellowstone National Park, located in northwest Wyoming. The study was conducted on the Yellowstone River between Yellowstone Lake and the Upper Falls, 26 km downstream, and on the tributaries to the river within this reach: Thistle, Elk Antler, Trout, Cottongrass, Sour, Alum, and Otter creeks (Figure 1).

The Yellowstone River drains Yellowstone Lake at its northern end. Several characteristics of the river are influenced by the lake. Yellowstone Lake is a large, oligotrophic lake with a watershed of 261,590 ha, a surface area of 354 km^2 and a mean depth of 42 m (Benson 1961). Ice covers the lake from mid-December through May or June and the lake temperatures rarely exceed 18°C (Jones et al. 1992), and water temperatures in the river are moderated by those in the lake. Inflow to the river is relatively constant, and mean annual flow, measured 0.6 km downstream of the lake outlet, during the period of record, 1927-1991, was 37.64 m^3/s (U.S. Geological Survey 1991).

From Yellowstone Lake to Upper Falls the Yellowstone River drops from an elevation of 2357 m to 2326 m, an average gradient of 1.2 m/km. The river pattern is

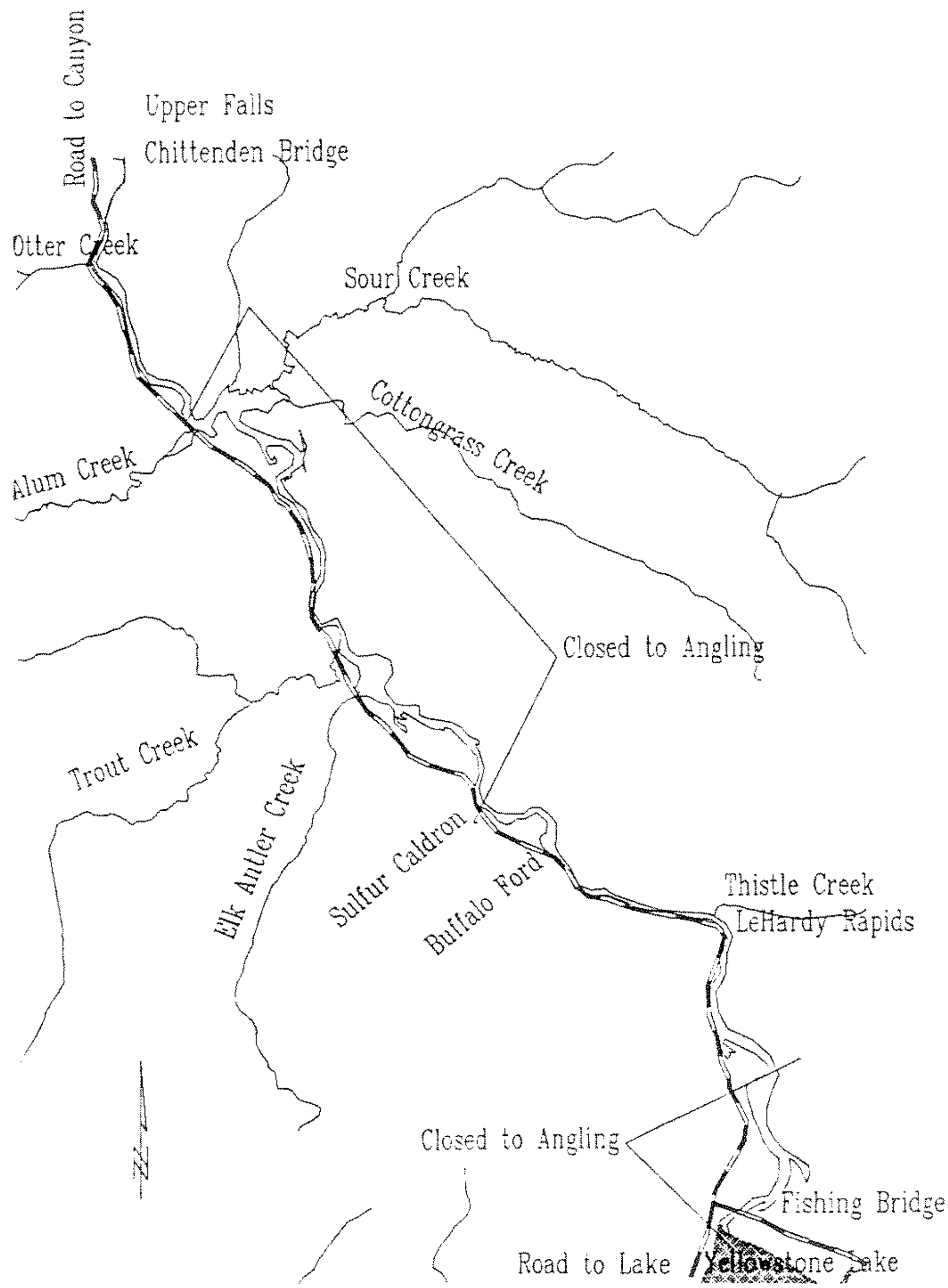

Figure 1. Yellowstone River, Yellowstone National Park, Wyoming, from Yellowstone Lake to the Upper Falls.

generally meandering and relatively stable. Relatively clear water and fine sediments allow good growth of macrophytes, over a substantial portion of the river bottom during the summer, limiting bed material transport (Skinner 1977). Aquatic plant species include: Carex aquatilis, C. rostrata, Elodea canadensis, Potamageton richardsonii, Ranunculus aquatilis, Myriopayllum exalbescens (Bergersen and McConnell 1973).

The study area was divided into three segments based on differences in channel morphology. The upper segment extended 6 km from the lake outlet to LeHardy Rapids, the middle segment included the next 5 km to Sulphur Caldron, and the 15-km lower segment terminated at the Upper Falls. The river was further divided into 84 study sections separated by distinct landmarks or marked differences in river substrate (Figures 2, 3; Table 1).

In the upper segment, sediments from Yellowstone Lake have been deposited downstream from Fishing Bridge as middle bars and have been filling the outside of bends, straightening the channel (Skinner 1977). From here the river is deep, slow moving, and the elevation of the bottom increased by 1.5 m from the lake outlet to LeHardy Rapids in 1987 (ref). LeHardy Rapids is an active tectonic fault, and its rise and fall in recent years probably caused the changes in morphology and sedimentology in the upper segment (Hamilton 1987; Skinner 1977).

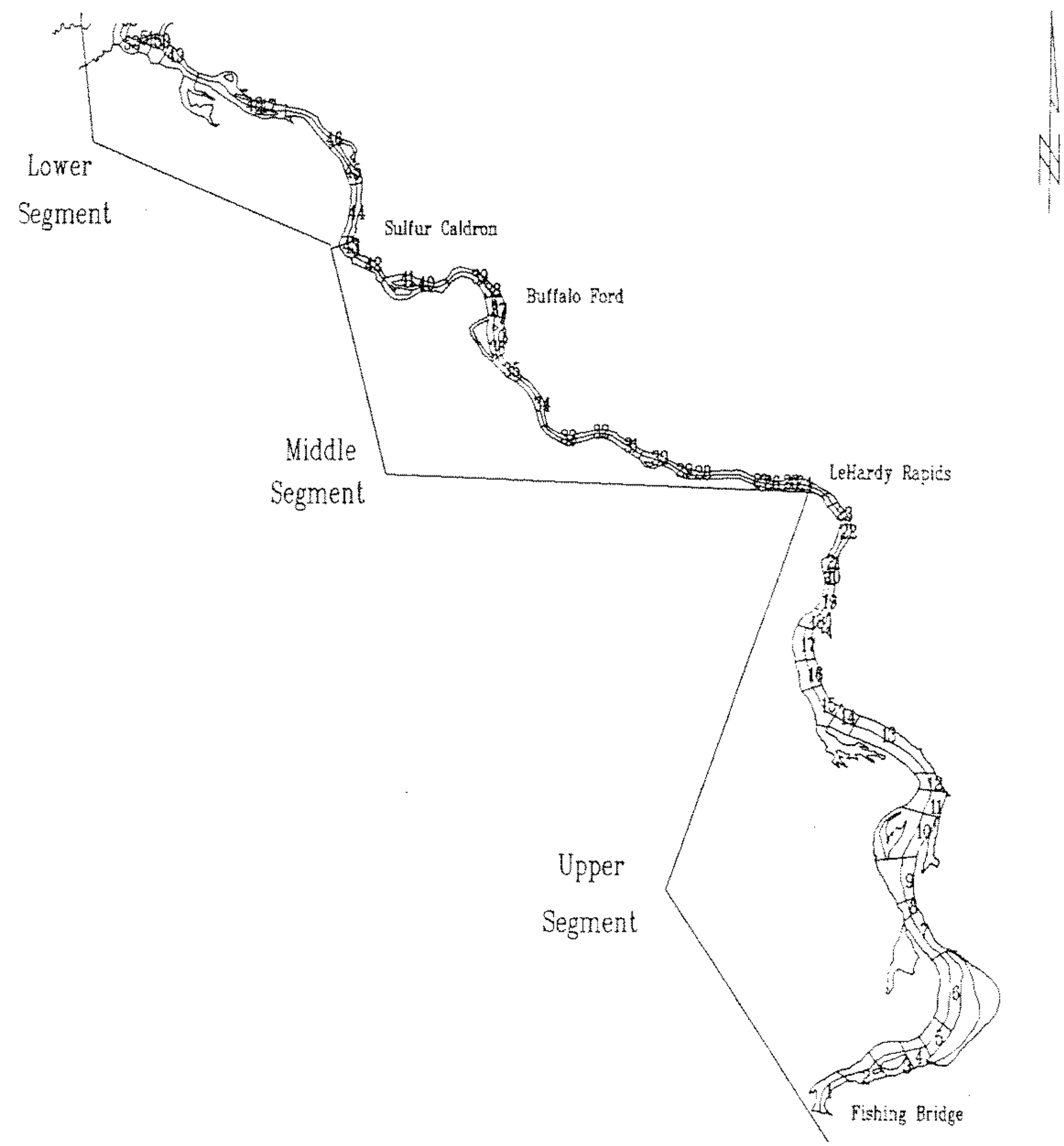

Figure 2. Sections 1-52 in the upper, middle, and lower segments of the Yellowstone River from Yellowstone Lake to mid Hayden Valley.

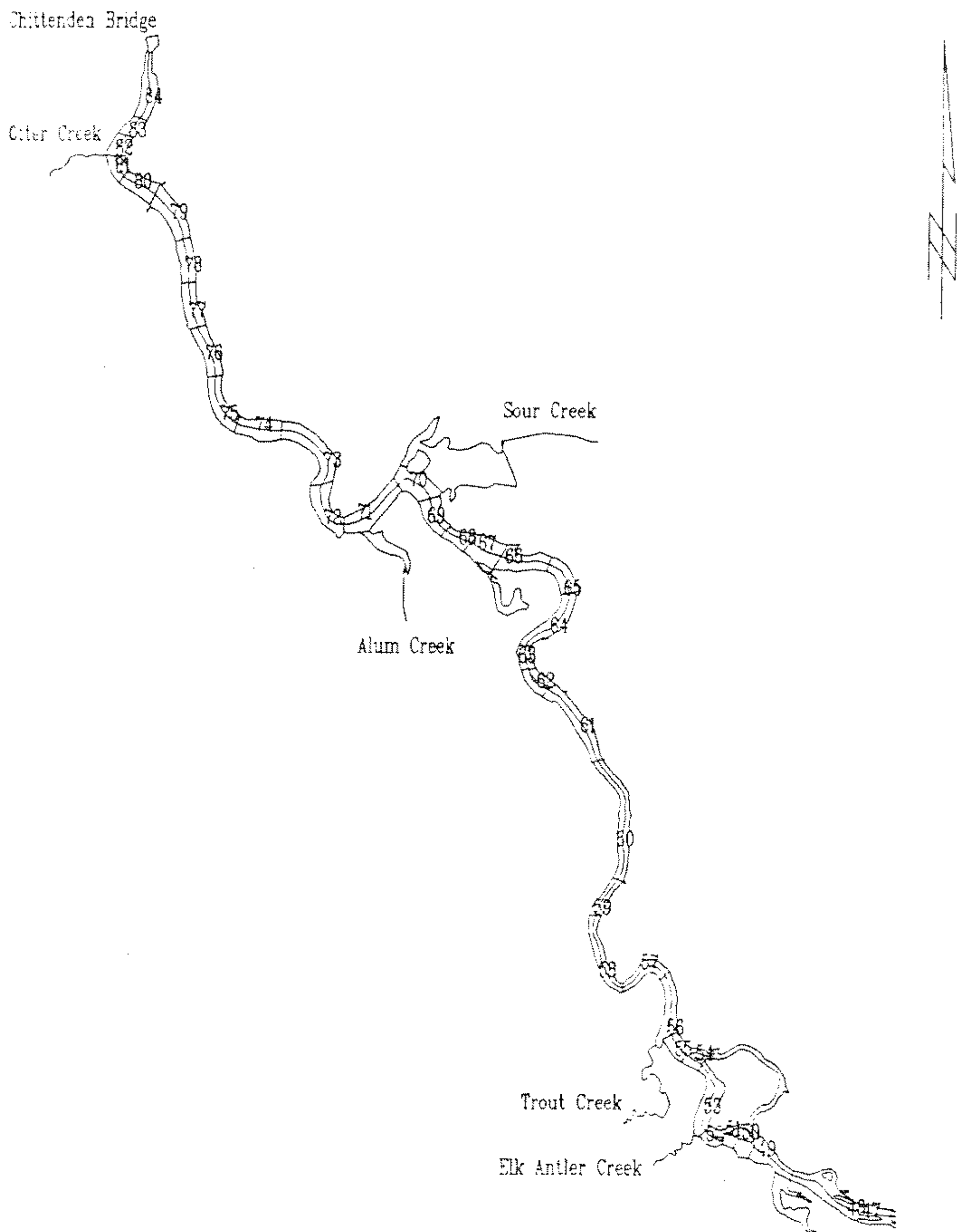

Figure 3. Sections 47-84 in the lower segment of the Yellowstone River from mid Hayden Valley to Upper Falls.

Table 1. Description of the locations of the three study segments and groups of sections, Yellowstone River between Yellowstone Lake and Upper Falls.

Segment	Section	Open or closed to angling	Description
Upper	1 - 23	Both	Yellowstone Lake to LeHardy Rapids
	1 - 7	Closed	Yellowstone Lake to 0.6 km below Fishing Bridge
	8 - 14	Open	0.6 km below Fishing Bridge to where the river first comes close to the road
	15 - 23	Open	Where river runs along road and down to LeHardy Rapids
Middle	24 - 42	Open	LeHardy Rapids to Sulphur Caldron
	24 - 34	Open	LeHardy Rapids to section just above Buffalo Ford side-channel
	35 - 42	Open	Buffalo Ford area and Sulphur Caldron area
Lower	43 - 84	Both	Sulphur Caldron to Upper Falls
	43 - 71	Closed	From Sulphur Caldron, through Hayden Valley, to Alum Creek
	72 - 84	Open	Alum Creek to Chittenden Bridge

Between LeHardy Rapids and Sulphur Caldron, numerous faults result in increased velocities associated with a mean gradient of 3.2 m/km (Skinner 1977). The river moves coarser sediments that deposit in the Buffalo Ford area, thus forming several intra-river gravel bars (Skinner 1977). The river at Buffalo Ford is relatively wide and shallow, and is usually the only place where anglers can wade across the river during low-flow periods. The side-channel at Buffalo Ford has substrate comprised mostly of gravel, and it was closed to angling during the study period for experimental purposes. From the lake outlet to Sulphur Caldron, the river flows through a lodgepole pine _Pinus contorta_ forest.

The lower segment meanders at a gradient of 0.4 m/km through the old lake-bed deposits of Hayden Valley, a broad valley dominated by sagebrush and grasses. The five tributaries in this reach (Elk Antler, Trout, Alum, Cottongrass, and Sour creeks) have transported large quantities of sediment into the river, forming large deltaic deposits (Skinner 1977). Below Alum Creek, the river again enters a lodgepole pine forest, where it flows at a gradient of 2 m/km for about 5 km before plunging over the Upper Falls (33 m).

Three areas of the river between Yellowstone Lake and Upper Falls, totaling 12 km, are closed to angling; Yellowstone Lake to 1.6 km below Fishing Bridge (sections

1-7), 100 m above and below LeHardy Rapids (part of sections 23-24), and 10 km in the Hayden Valley (sections 43-71) have been closed since 1973, 1949, and 1965, respectively (Figure 1). The remaining 14 km are open to fishing from 15 July to the first Sunday in November, and angling has been catch-and-release since 1973. Boats are not allowed on the river, so anglers must wade or fish from shore.

In addition to the native Yellowstone cutthroat trout, the Yellowstone River supports small numbers of native longnose dace *Rhinichthys cataractae* and two introduced species: redside shiner *Richardsonius balteatus* and longnose sucker *Catostomus catostomus*.

Tributaries

Thistle Creek

Thistle Creek enters the right side (looking downstream) of the Yellowstone River just below LeHardy Rapids. The creek is 3.2 km long, and has an average width of 1.34 m and an average depth of 0.19 m; mid-July flow in 1982 was 0.094 m^3/s (Jones et al. 1983). The upper 2.6 km flows through lodgepole pine and several small meadows at a moderate gradient averaging 19 m/km. The lower 0.7 km cuts through a small valley, and has a gradient of 47 m/km (Jones et al. 1983).

Elk Antler Creek

Elk Antler Creek flows 9.1 km through the southern end of Hayden Valley. This study was confined to the lower 3.5 km. Average physical parameters in this reach on 6 July 1982 were: width, 1.58 m; depth, 0.20 m; flow, 0.084 m^3/s; and gradient, 5 m/km (Jones et al. 1983).

Trout Creek

The lower 2.5 km of the 16.0 km long Trout Creek were surveyed in 1990 and 1991. This low gradient (5.5 m/km) reach meanders through the grassy meadows of Hayden Valley. It has a mean width of 3.9 m, mean depth of 0.35 m, and in early July 1982 a flow of 0.33 m^3/s (Jones et al. 1983).

Cottongrass Creek

Cottongrass Creek parallels Sour Creek, and both enter the Yellowstone River in a marshy area on the river's right side in Hayden Valley. Mud and silt cover the bottom of Cottongrass Creek, and runoff from several thermal areas enter the creek. Jones et al. (1983) measured iron levels toxic to aquatic life (18 mg/L) (ref), and warm (14.4°C) and acidic (pH = 4.5) water, with no instream vascular plants or macroinvertebrates. Since it was concluded that Cottongrass Creek is unlikely to support fish, it was not surveyed during this study.

Sour Creek

Only the lower 1.5 km of Sour Creek is accessible to Yellowstone River fish due to a 3-4 m waterfall. This area had an average width of 0.41 m, average depth of 0.30 m, and flow of 1.36 m^3/s (July 1982) (Jones et al. 1983).

Alum Creek

Alum Creek enters the Yellowstone River from the left side just downstream from Cottongrass and Sour creeks. Alum Creek is 25 km long, although only the lower 3 km were surveyed. In this reach, the creek is wide (average, 6.99 m), shallow (average, 0.23 m), and low gradient (1 m/km). Outlet flow in late July 1982 was 0.884 m^3/s (Jones et al. 1983).

Otter Creek

Otter Creek enters the Yellowstone River 2 km above the Upper Falls. A 3-4.5 m waterfall about 4 km from the mouth of Otter Creek forms a barrier to upstream fish movement. The study section below the falls runs through bedrock, boulders, and cobble in a hilly lodgepole pine area at a gradient of 30 m/km. In the lower 1.9 km, Otter Creek winds through small lodgepole-lined meadows at a gradient of 11 m/km, has a mean depth of 0.59 m, and mean width of 2.79 m. Flow on 2 July 1982 was 0.181 m^3/s (Jones et al. 1983).

METHODS

Discharge and Water Quality

Water chemistry characteristics were measured periodically in each of the three river segments and in six tributaries (except Cottongrass Creek) in 1991. Dissolved oxygen was measured with a Hach OX-2P field kit and alkalinity with a Hach AL-AP field kit. A Hellige color comparator was used to estimate pH, and conductivity was determined with a Beckman Solu-bridge meter (model no. Rb-5). Single water samples from the Buffalo Ford side-channel (section 36) and below Alum Creek (section 75) (Figures 2, 3), collected in late June or early July, were analyzed by Orlando Laboratories, Orlando, Florida.

Ryan Tempmentors recorded temperatures hourly during the field seasons. In 1990 temperatures were measured in the middle segment (section 39), and in 1991 temperatures were recorded in each of the three river segments (sections 2, 39, 63) (Figures 2, 3). A hand-held thermometer was used to periodically measure temperatures in the river and tributaries. Yellowstone River discharge has been measured since 1927 at a U.S. Geological Survey gaging station, 0.5 km downstream of the Yellowstone Lake outlet.

Substrate Composition

Substrate composition of the Yellowstone River was mapped by visually estimating the particle size composition to the nearest 25% of surface coverage; substrate were classified using a modified Wentworth scale presented in Welch (1948) (Table 2). Observations were made from a rowboat and the river banks in May and September, 1991.

Table 2. Substrate size classification modified from the Wentworth classification (Welch 1948).

Substrate class	Particle size range (mm)
Fines	<2.0
Gravel	2.0 - 64.0
Cobble	64.0 - 250.0
Boulder	>250.0

To evaluate availability of spawning substrate, single values representing the median particle sizes of a visual observation were calculated, using a method described by Spoon (1985). Substrate compositions were mapped in geographical information systems (GIS) using GRASS software for area calculations.

Spawning Areas and Redds

Trout redds were counted and mapped in the 84 river sections, right and left bank (looking downstream). Redds were visually counted from a rowboat, river banks, or hillsides every week from 10 June to 12 July 1991.

Redds were identified by the presence of cleaned, mounded gravels. Presence of trout on redds or eggs in the gravels confirmed some spawning areas. Where redds were not discrete, the number of redds was estimated, by visually assessing the size of the spawning area and assuming that one redd occupied approximately 1 m^2. Poor visibility prevented redd enumeration in a few areas. Because of differences in weekly redd counts and difficulties in identifying some redds, counts were considered estimates.

Timing of Spawning

The timing of the 1990 spawning period was estimated based on the stage of maturity of 1,313 trout captured by electrofishing in May and June 1990 in the three study segments. To characterize the spawning population, length to the nearest millimeter, weight to the nearest 2 g, sex, and stage of maturity (non-spawning juvenile ($\leq$350 mm) or adult (>350 mm), pre-spawner, ripe, or post-spawner) were recorded for all fish.

Estimated spawning period in 1991 was based on weekly visual counts of trout. Adult trout were counted in the 84 sections from a rowboat, river banks, or hillsides. Trout were counted weekly along the right and left banks from 10 June to 12 July 1991 and along the right bank on 25 and 31 July. Counts were not made from 15 to 25 July to avoid disturbing anglers.

Embryonic Development

To monitor embryonic development, trout were collected at LeHardy Rapids on 5 June, 20 June, and 12 July 1991, representing early, peak, and late spawning. Eggs were stripped, fertilized, water hardened, and then incubated in Astroturf substrate in two modified Porter (1973) boxes located in the side-channel at Buffalo Ford. Embryos and pre-emergent fry developing in the Porter boxes and in redds in the river were examined periodically to categorize the stage of development as pre-eyed, eyed, or hatched. A Ryan Tempmentor placed near the Porter boxes recorded water temperatures and allowed calculation of celsius temperature units (CTU), the sum of mean daily temperatures above 0°C.

Cutthroat Trout Fry

In 1990, to document the timing of emergence, fry were counted in 12 longitudinal transects in the Buffalo Ford side-channel and along the left bank in the Buffalo Ford area. Counts were made on 15 d between 15 July and 27 August 1990. Samples averaging 55 fry were hand-netted on 11 d and measured to the nearest millimeter total length.

In 1991, timing of emergence was documented by counting fry in nine, 25-m longitudinal transects along the left river bank (three transects in each river segment). Fry were counted on 18 d between 23 July and 5 September 1991.

The right river bank was floated weekly from 25 July to 21 August 1991 to monitor fry distribution. Fry were counted all 5 weeks along 11, 25-m longitudinal transects on the right bank between Fishing Bridge and LeHardy Rapids. In right bank sections below LeHardy Rapids, fry were counted in 25-m longitudinal transects or fry densities were estimated by counting fry within an estimated distance, greater than 25 m long.

Between 26 July and 5 September 1991, fry were hand-netted from slower waters along the right and left banks. Fry collected were measured to the nearest millimeter total length to evaluate length frequencies and growth of fry.

Adult Trout and Movements

To document movement patterns, 1,288 of the trout electrofished in May and June 1990 were tagged with colored, numbered floy tags. Segment-specific tag colors were used for trout from the upper, middle, and lower river segments. Tag-return information was obtained from anglers, weekly dip-net sampling of 100 trout at LeHardy Rapids during the spawning run, electrofishing in 1990, 6 d of snorkeling in 1990, and observations while floating the river in 1991.

Angler Use

Because the amount of wading-caused mortality of embryos and pre-emergent fry mortality depends wading frequency (Roberts 1988; Roberts and White 1992), several methods were utilized to estimate wading frequency in different locations. A roving creel survey was conducted at Buffalo Ford in 1990. A creel clerk asked anglers how many hours they had fished, how many fish they had caught and if any were tagged, if they were wading, and if they were finished fishing that day.

In 1991, angler distribution by section was estimated. Angler locations and numbers were surveyed on 37 d between 15 July and 30 August; all weekdays and the weekend days of 20 and 21 July were sampled. For each census, the surveyor counted anglers, wading or wearing waders, or not wading, for the right and left side of all 43 sections open to angling.

Tributaries

The lower reaches of Thistle, Elk Antler, Trout, Sour, Alum, and Otter creeks were surveyed at least four times each to evaluate their potential for cutthroat trout reproduction and recruitment to the Yellowstone River. In

1990, Trout and Elk Antler creeks were surveyed, and in 1991 all six creeks were surveyed.

During the 1990 surveys of Elk Antler and Trout creeks, dominant substrates were identified. Trout densities were estimated by counting fry in sections measured by pacing. Fry were counted in 1.27 km of the lower 3.5 km of Elk Antler Creek and in 0.69 km of the lower 2.5 km of Trout Creek.

In 1991, predominant substrates, and the presence and abundance of redds, adult, juvenile, and young-of-the-year cutthroat trout were documented. Trout fry were counted along 25-m transects, and samples of fry were hand-netted and measured to the nearest millimeter total length. For each tributary, one water sample was collected for analysis by Orlando Laboratories, Orlando, Florida. Alkalinity, pH, conductivity, and dissolved oxygen were measured once or twice in the field. Temperatures were measured periodically with a hand-held thermometer.

Geographic Information Systems (GIS) Analysis

A geographic information system was used to store and analyze spatial information. Aerial photos of the river taken on 24 June 1987 (approximately 1:7,200 scale) were digitized to provide a base map of the river. The river boundaries, substrate compositions and section boundaries were mapped using GRASS software, and section boundaries, substrate compositions, and spawning area and redd locations were mapped with ARC/INFO software. Polygon areas were calculated in ARC/INFO, and maps were printed for visual presentation. GIS maps were produced and are stored at Yellowstone National Park Geographic Information Systems Laboratory.

Estimate of Angler Wading Mortality of Cutthroat Trout Embryos and Pre-Emergent Fry

Estimating wading-caused mortality of eggs and pre-emergent fry in the study area was difficult to predict without knowing how frequently individual redds were waded on or the stage of embryonic development when wading occurred. To estimate the number of eggs killed by angler wading in each river section for 1991, a model was developed that included several components and assumptions.

Temporal considerations of the model included the estimated amount of pre-eyed and eyed eggs, and pre-emergent fry present in the gravel during the angling season (15 July - 1st Sunday in November) in the three river segments. The amount of angler wading also changed over time. Spatial factors included the number of redds in each section and the amount of angler wading in each section, from which an estimate was made of the wading frequency on those redds. The methods used for calculations of component numbers and explanations for the inclusion of the assumptions are in Appendix 1.

Model components included:

1. Estimated number of redds in each section.

2. Estimated wading hours per hectare by section for the months of July and August.

3. Estimated relative proportions of embryonic developmental stages present in the gravel during the angling season for each of the three river segments.

4. Wading-caused mortality rates for Yellowstone cutthroat trout eggs and pre-emergent fry measured in the laboratory in Roberts (1988).

Model assumptions included:

1. The redd of each Yellowstone cutthroat trout contained 1320 eggs.

2. 20% of eggs deposited in the substrate died of natural causes.

3. It takes 100 wading hours to wade on all substrates in one hectare.

4. Mortality rates for redds stepped on more or less than once only or twice daily were more or less than mortality rates in Roberts (1988).

The number of eggs killed each month in 1991 by section was estimated using the following equation:

((number of redds in section * 1320 eggs) - (0.20 * number of eggs in section)) * (estimated monthly mortality rates by section for redds waded on once only or twice daily given the estimated number of pre-eyed and eyed eggs and pre-emergent fry in the gravel) * (correction factor if wading frequency was much less or more than once only or twice daily).

Worst-Case-Scenario Wading-Caused Mortality Rates

Two worst-case-scenario mortality rates were estimated. All of the same components and assumptions were used except, in the first case, the twice-daily angler wading mortality rates for estimated developmental stages in the gravels on 15 July 1991 to complete fry emergence were used. In the second case, twice-daily mortality rates from fertilization to emergence (82.8% mortality) were applied to all redds in areas open to angling.

RESULTS

Discharge and Water Quality

Water chemistry characteristics of the Yellowstone River were within the suitable range for cutthroat trout (Tables 3, 4) (Hickman and Raleigh 1982; Alabaster and Lloyd 1982; U.S. Environmental Protection Agency 1986). Total dissolved solids, turbidity, hardness, and concentrations of carbon dioxide, chloride sulfate, fluoride, silica, sodium, potassium, calcium, and magnesium increased between the middle and lower segments. Inflow from the tributaries between the sampling sites (Trout, Elk Antler, Sour and Cottongrass creeks), and runoff from Sulphur Caldron (Rowe et al. 1973) may have contributed to these increases. Iron decreased from 0.56 mg/L at the middle segment to 0.17 mg/L at the lower segment. From the middle to lower segment, total alkalinity increased from 26.4 mg/L to 34.5 mg/L, and pH decreased from 8.01 to 7.38.

Temperature patterns measured in the Buffalo Ford area (section 39) in 1990 and 1991 were similar, although temperatures increased more rapidly and were usually warmer in 1990 (Figure 4). In 1991, ice on Yellowstone Lake kept temperatures in the upper segment cooler than the middle and lower segments until just after ice-off on 8 June.

Table 3. Chemical characteristics of the middle and lower segments of the Yellowstone River (YSR), 1991. Turbidity expressed in nephelometric turbidity units (NTU's), color in platinum color units (PCU's), other values (except pH, stability index, and saturation index) expressed in mg/L.

	Middle YSR	Lower YSR
Date (1991)	06-28	07-02
Total dissolved solids	46.0	78.0
Phenolphtalein alkalinity	<2.0	<2.0
Total alkalinity	26.4	34.5
Carbonate alkalinity	<2.0	<2.0
Bicarbonates as $CaCO_3$	26.4	34.5
Carbonates	<2.0	<2.0
Bicarbonates as HCO_3	26.4	34.5
Hydroxides	<0.50	<0.50
Carbon dioxide	<1.0	2.80
Chloride	2.98	6.95
Sulfate	4.96	10.2
Fluoride	0.41	0.77
pH (laboratory)	8.01	7.38
Stability index	10.5	10.8
Saturation index	-1.23	-1.70
Color (estimated)	<5	5
Turbidity	1.66	2.30
Silica	11.1	16.8
Hydrogen sulfide	<0.10	<0.10
Sodium	7.30	14.0
Potassium	1.40	3.10
Calcium	5.20	6.20
Magnesium	1.90	2.70
Iron	0.56	0.17
Manganese	<0.03	<0.03
Copper	<0.01	<0.01
Total hardness	21.0	27.0
Magnesium hardness	7.90	11.0
Calcium hardness	13.0	16.0

Table 4. Field measurements of dissolved oxygen (D.O.), alkalinity (ALK.), pH, and conductivity (COND.) in the upper, middle and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Segment and section	Date	D.O. (mg/L)	ALK. (mg/L)	pH (pH Units)	COND. (μmhos/cm)
Upper	8-23	7	35	8.2	95
16					
Middle	6-28	-	21	7.4	85
36	8-23	7	35	8.0	100
Lower	7-02	-	65	7.2	65
76	8-22	9	34	7.4	100

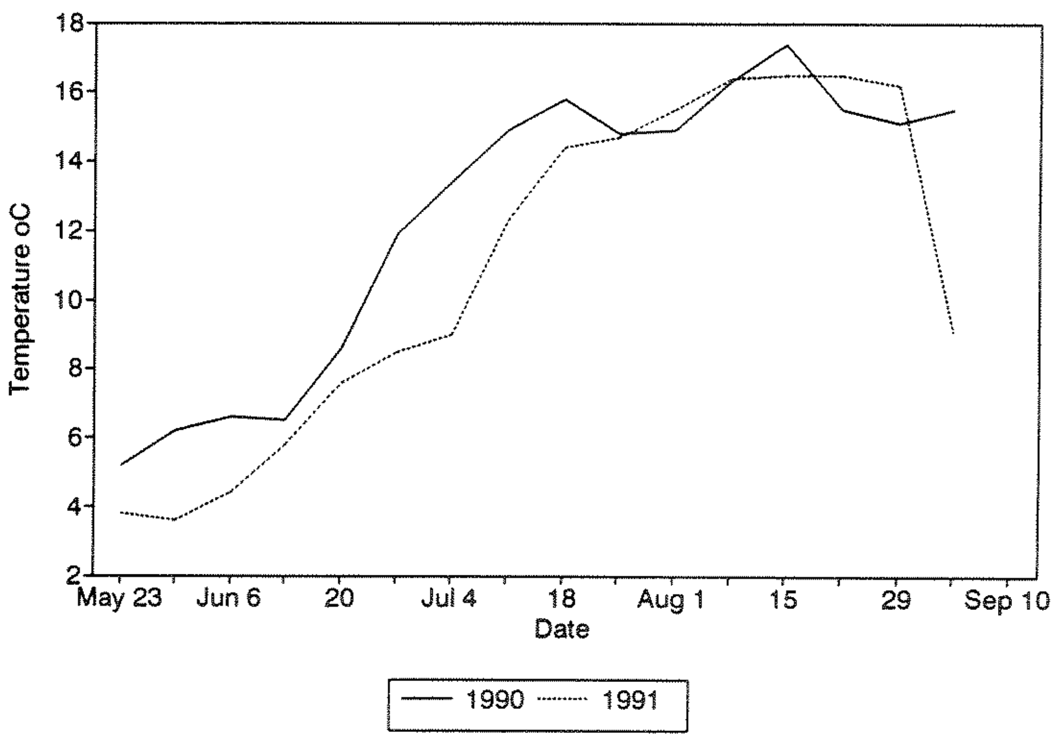

Figure 4. Mean weekly water temperatures (°C) measured in the Buffalo Ford area (section 39) of the Yellowstone River, 20 May - 8 September 1990 and 12 May - 8 September 1991.

Also, because of the stabilizing effect of lake temperatures, the mean-daily temperature fluctuation was lowest at the upper site and greatest at the lower site (Table 5).

Table 5. Monthly minimum, maximum, and mean water temperature (°C), and monthly mean daily temperature fluctuation (MDTF) of the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 22 May 22 - 14 September 1990 and 1991.

Parameter	Month	Middle 1990	Upper 1991	Middle 1991	Lower 1991
Minimum temperature	May	1.9	0.2	0.3	3.6
	Jun	3.3	0.8	0.8	6.6
	Jul	10.8	6.1	5.8	13.0
	Aug	12.0	13.8	13.0	16.3
	Sep	12.1	0.7	0.7	14.6
Maximum temperature	May	10.3	4.5	7.8	7.4
	Jun	15.0	10.5	10.5	10.3
	Jul	18.1	16.8	17.3	17.3
	Aug	20.3	18.8	19.1	18.9
	Sep	18.2	18.0	18.6	18.0
Mean temperature	May	6.0	2.3	3.5	3.6
	Jun	8.6	6.2	6.4	6.6
	Jul	14.7	12.7	12.9	13.0
	Aug	16.0	16.4	16.3	16.3
	Sep	15.4	12.8	12.6	14.6
MDTF	May	3.8	2.1	3.8	3.6
	Jun	3.6	2.3	2.7	2.7
	Jul	2.6	2.6	3.1	3.0
	Aug	4.0	2.3	3.4	3.0
	Sep	4.6	4.2	4.5	2.4

Discharge patterns differed between 1990 and 1991 (Figure 5). Peak discharge was 32% greater and occurred 12 d earlier in 1991 than in 1990. Flow was reduced by over 60% from mid-July to the end of August in both years (U.S. Geological Survey 1991).

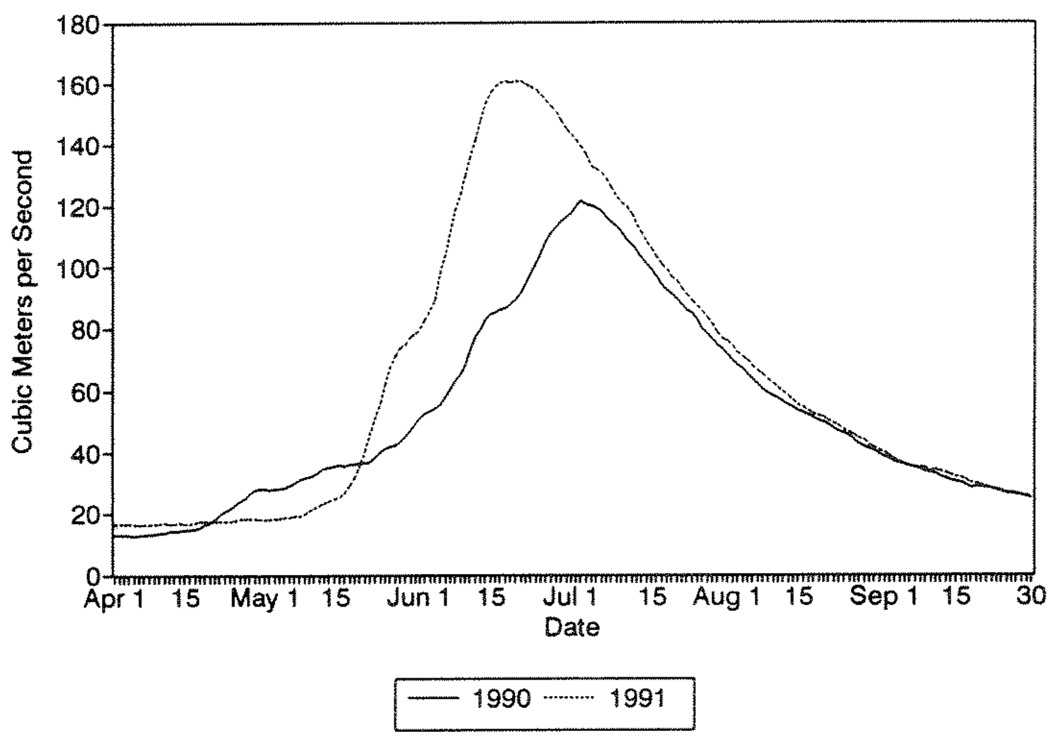

Figure 5. Mean daily discharge, in cubic meters per second, measured at a U.S.G.S. (1991) staff gauge located in the Yellowstone River 0.5 km below Yellowstone Lake, April - September, 1990 and 1991.

Substrate Composition

Substrate composition in the Yellowstone River varied spatially. Maximum estimated available river-bottom area suitable for spawning was 1,699,636 m^2 (51%), assuming that trout will utilize substrates with a mean diameter between 12 and 85 mm (Varley and Gresswell 1988), or 1,348,493 m^2 (40%) assuming use of mean substrate composition of 20-60 mm (Hickman and Raleigh 1982) (Table 6). A more conservative estimate, considering only those areas comprised of 75-100% gravel, was 671,740 m^2 (20%) of the river bottom.

Redd Distribution

Trout spawned in all study segments, but the estimated 2,151 redds were not evenly distributed among the sections (Figures 6, 7 and Appendix 2). Fifty-eight sections had no redds on at least one side of the river and six sections had over 100 redds. Redd concentrations were largest near Fishing Bridge, in the Buffalo Ford area, and in sections above Alum Creek.

An estimated 60% (1,298) of the redds were in areas closed to angling (Table 7). In sections open to angling, 352 redds (17%) were along the left bank and 501 (23%) were along the right bank.

Table 6. Estimated area in the Yellowstone River (YSR) between Yellowstone Lake and Upper Falls, 1991, comprised of fines, gravel, cobble, and boulder estimated to the nearest 25%, listed in ascending order of mean substrate diameter.

Substrate composition by percentage					
Fines (<2mm)	Gravel (2-64 mm)	Cobble (64-250mm)	Boulder (>250 mm)	Mean substrate diameter (mm)	Estimated area in YSR (m^2)
100				1.00	337,584
75	25			9.00	433,463
50	50			17.00	218,407
33	67			21.00	234,473
25	75			25.00	533,381
13	87			29.00	13,632
	100			33.00	13,933
75		25		40.00	0
50	25	25		48.00	94,907
25	50	25		56.75	458,167
	75	25		64.75	110,794
75			25	75.75	4,023
50		50		80.50	3,856
50	25		25	83.75	14,063
25	25	50		88.50	142,409
25	50		25	91.75	0
	50	50		96.50	0
	75		25	99.75	0
50		25	25	115.50	0
	25	75		120.25	31,049
25	25	25	25	123.50	2,373
	25	75		128.25	17,666
	50	25	25	131.50	12,507
50			50	150.50	0
25		50	25	155.25	0
25	25		50	158.50	0
		100		160.00	61,939
	25	50	25	163.25	55,075
	50		50	166.50	19,527
25		25	50	190.25	0
		75	25	195.00	0
	25	25	50	198.25	23,333
25			75	225.25	0
		50	50	230.00	10,616
	25		75	233.25	0
		25	75	265.00	0
			100	300.00	1,338
Back-waters:					466,251
Bedrock:					14,261

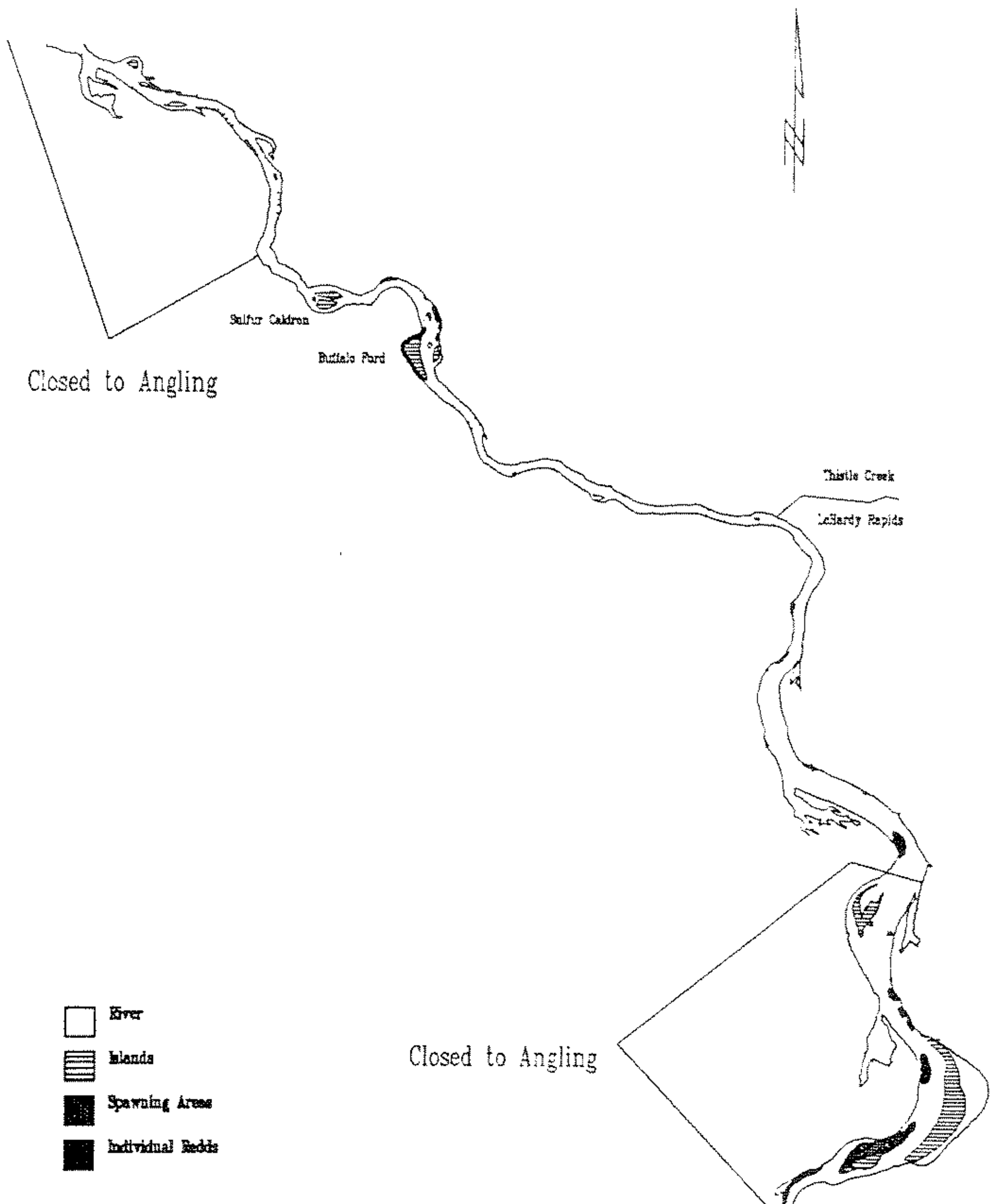

Figure 6. Spawning areas and redds in the Yellowstone River from Yellowstone Lake to mid Hayden Valley, 1991.

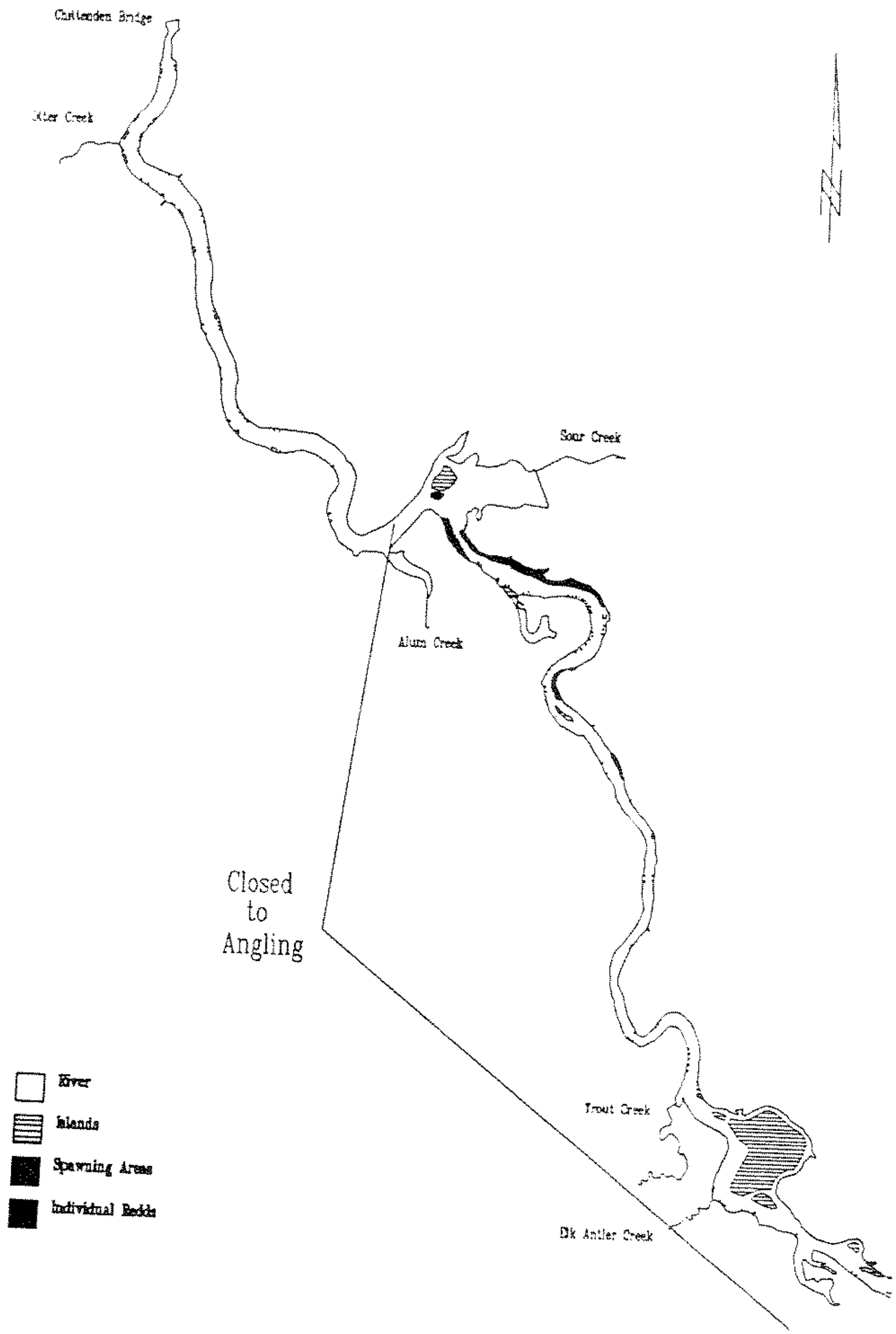

Figure 7. Spawning areas and redds in the Yellowstone River from mid Hayden Valley to Upper Falls, 1991.

Table 7. Estimated number of redds in groups of sections on right and left river-sides, Yellowstone River between Yellowstone Lake and Chittenden Bridge, 1991.

		Estimated number of redds		
Sections	Open or closed to angling	Right riverbank	Left riverbank	Right and left riverbank
1 - 7	Closed	225	525	750
8 - 14	Open	191	191	382
15 - 23	Open	20	49	69
24 - 34	Open	7	49	56
35 - 42	Open	97	143	240
43 - 71	Closed	363	185	548
72 - 84	Open	37	69	106
Total	-	940	1211	2151

Spawning

In 1990, spawning began in mid- to late May, peaked in early to mid-June, and was mostly complete by late June. Spawning began approximately 3 weeks later in 1991, in early to mid-June, peaking early July, and was mostly complete by mid-July.

On 23 and 24 May 1990, 56% of the trout collected in the middle segment were pre-spawners, 36% were ripe, and only 8% were post-spawners (Table 8). One week later, on 29 and 30 May, 34% of the trout collected were pre-spawners, 28% were ripe, and 38% were post-spawners. On 19 June, 70% were post-spawners and only 29% were ripe.

Table 8. Stage of sexual maturity and male:female ratio of adult cutthroat trout electrofished in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1990.

Date	Segment	Number of trout	Male: female	Percent pre-spawner	% Ripe	% Post-spawner
5-23,24	Middle	211	1:1.45	56	36	8
5-29,30	Middle	264	1:1.75	34	28	38
6-5,6	Upper	448	1:1.09	15	83	2
6-14	Lower	112	1:0.87	19	54	27
6-19	Middle	95	1:0.86	1	29	70
6-26	Lower	81	1:1.31	20	23	57

In 1991, most trout counted were in pairs and near spawning areas. Few trout were observed early in June (Figure 8). During the week of 17-21 June, 2,292 trout were counted. The next week's count was lower at 1,105, but visibility, measured with a Secchi disk at Fishing Bridge was 2.1 m compared to 2.7 m for 17-21 June and greater than 3 m for July 1-12. Peak numbers of trout, 3,581, were counted the week of 1-5 July. A total of 2,564 trout was counted between 8 and 12 July, and peak numbers were counted in some sections at that time. On 25 and 31 July, few trout were observed.

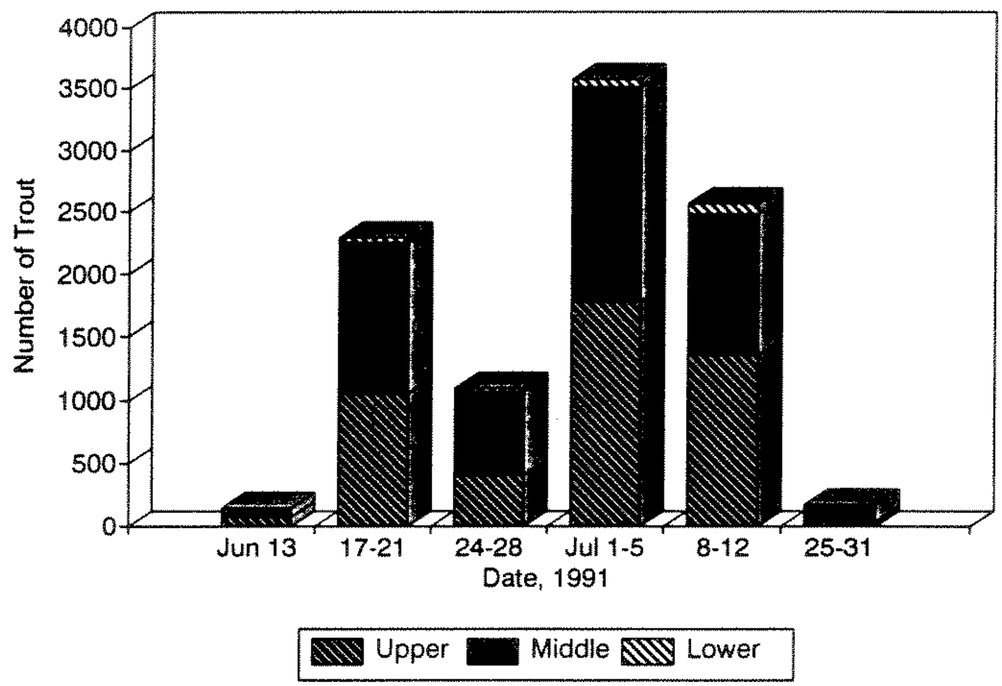

Figure 8. The number of trout counted by week during the spawning season in all sections of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Embryonic Development

Eggs incubating in Porter boxes in 1991 eyed between 171 and 207 CTU's (18-28 d) and hatched between 278 and 365 CTU's (26-41 d) (Table 9). In 1990, based on time of initial and peak spawning and emergence, I estimated that incubation to emergence required 506 to 525 CTU's (46-58 d). In 1991, trout spawned 25-30 d later and emerged 11-15 d later than in 1990, and CTU's to emergence were estimated at between 458 and 492 (Table 10).

On 12 July 1991, pre-eyed and eyed eggs were excavated in the upper segment, and eyed eggs were excavated in the middle segment. On 25 July, pre-emergent fry were found in the gravel in all three segments, and emerged fry were seen in the lower segment.

Cutthroat Trout Fry

Time of Emergence

In the middle segment, fry were first observed on 12 July 1990. Fry numbers peaked the week of 21-27 July, and abundance of fry in all 12 counting sections was highest or second highest on 23 or 24 July (Figure 9). It appeared that cutthroat trout fry were $\leq$25 mm at emergence. On 16 and 18 July, more than 69% of the captured fry were 25 mm or less, and then after 23 July, 35% or fewer of the fry were 25 mm or less (Table 11). Emergence was near

Table 9. Embryonic development of cutthroat trout eggs in Porter boxes placed in the Buffalo Ford side-channel in 1991. Celsius temperature units (CTU) = sum of mean daily temperatures above 0°C.

Stage of development	CTU'S	Days	Date eggs fertilized	Date eggs checked
Pre-Eyed	55	9	Jun 5	Jun 14
Pre-Eyed	78	8	Jun 20	Jun 28
Pre-Eyed	95	15	Jun 5	Jun 20
Pre-Eyed	118	10	Jul 8	Jul 18
Pre-Eyed	120	13	Jun 20	Jul 3
Pre-Eyed	165	23	Jun 5	Jun 28
Pre-Eyed	171	18	Jun 20	Jul 8
Eyed	207	18	Jun 5	Jul 3
Eyed	258	33	Jun 5	Jul 8
Eyed	278	26	Jun 20	Jul 16
Hatched	365	41	Jun 5	Jul 16

Table 10. Number of days and celsius temperature units (CTU's) between beginning and peak of spawning and fry emergence for cutthroat trout in the Yellowstone River between Yellowstone Lake and Upper Falls, 1990 and 1991.

	Dates			
Year	Initial spawning	Initial emergence	Number of days	CTU's
1990	May 15	Jul 12	58	506
1991	Jun 1	Jul 22	52	458
	Peak spawning	Peak emergence		
1990	Jun 8	Jul 22	46	525
1991	Jul 1	Aug 6	37	492

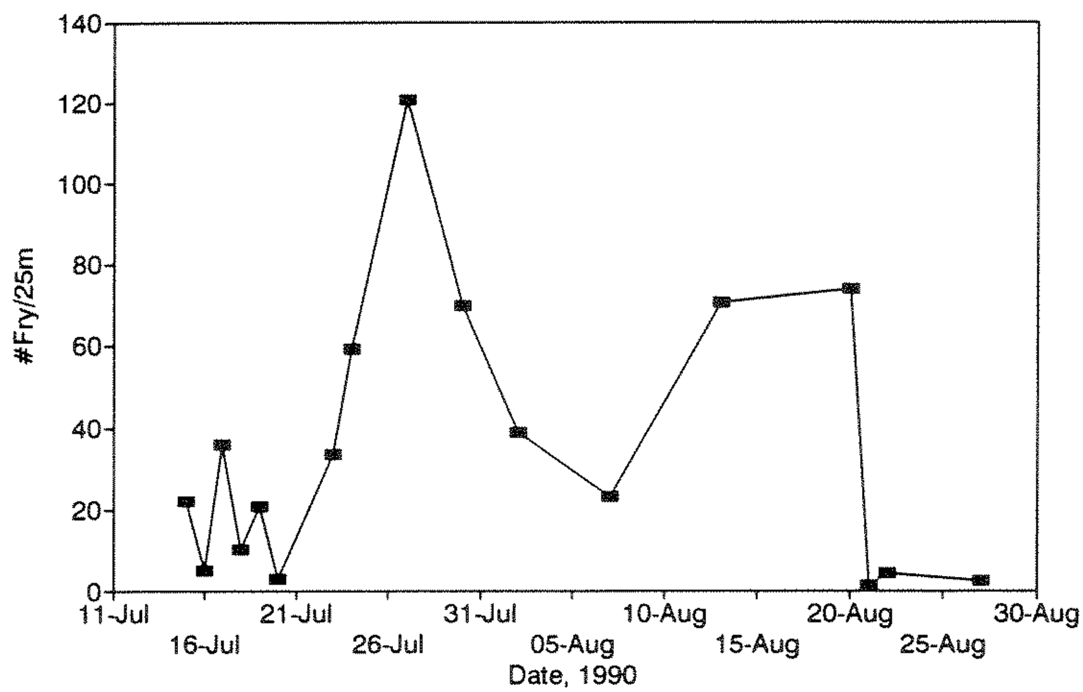

Figure 9. The mean number of cutthroat trout fry per 25 m in the Buffalo Ford area of the Yellowstone River, 1990.

Table 11. Mean lengths and length ranges of cutthroat trout fry and percentages of trout ≤25 mm total length captured by hand-netting in the Yellowstone River between LeHardy Rapids and Sulphur Caldron (middle segment), 1990.

Date	Number measured	Mean length (mm)	Standard deviation (mm)	Length range (mm)	Percent fry ≤25 mm
7-16	62	25	1	22-27	69
7-18	52	24	4	22-30	78
7-20	54	26	2	22-30	36
7-21	60	27	2	23-30	58
7-23	60	27	2	23-32	15
7-24	60	28	3	22-31	28
7-27	69	27	2	24-35	33
8-2	68	30	5	22-42	15
8-3	57	35	5	22-43	3
8-7	13	27	9	25-35	16
8-8	46	30	7	24-49	35

completion by the end of July, because few fry less than 25 mm were captured or observed in August.

Cutthroat trout fry were first observed during shoreline surveys on 22 July 1991 near the Otter Creek outlet, but few fry were seen in the upper and middle segments before 29 July. There appeared to be differences in the time of peak fry abundances in the three segments (Figure 10). Peak in the lower segment was earliest, occurring between 29 July and 2 August. Cutthroat trout fry were most abundant in the middle segment on 5 and 7 August. In the upper segment, fry numbers peaked latest, between 7 and 13 August, and emergence continued the longest.

In the upper segment, the percentage of fry sampled that were ≤25 mm was greater than 20% through the end of sampling on 7 September. In the middle and lower segment, less than 15% of the fry were 25 mm or less after 18 August (Table 12). Also, the mean length of fry captured in the upper segment remained under 30 mm through August, but in the middle and lower segment was greater than 30 mm beginning August 18. Counts in the 11 right-bank transects in the upper segment reinforced these findings. No fry were seen in the upper segment on 25 July, but fry were common by 31 July, and abundance peaked between 7 and 14 August (Table 13).

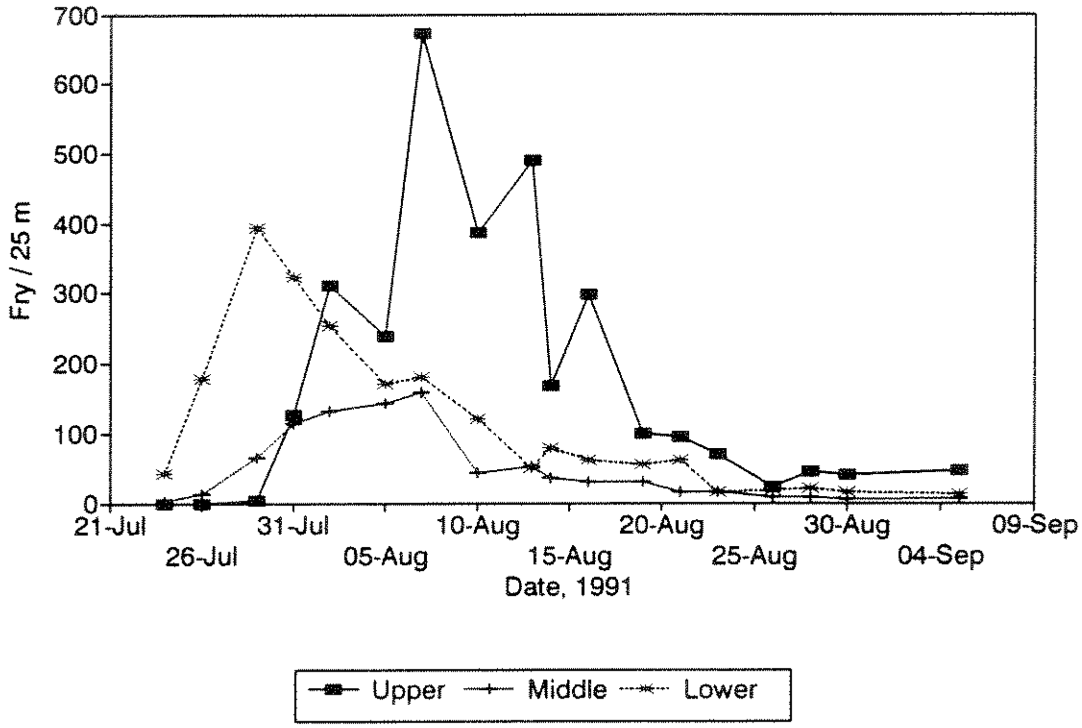

Figure 10. The mean number of cutthroat trout fry per 25 m in the nine 25 m counting transects in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Table 12. Weekly mean lengths and length ranges of cutthroat trout fry, and percentages of trout ≤25 mm captured by hand-netting in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Segment and sampling period	N	Mean length (mm)	SD (mm)	Length range (mm)	% fry ≤25 mm
Upper					
Jul 28-Aug 3	30	24	2	21-30	77
Aug 4-10	136	25	2	21-38	76
Aug 11-17	182	26	4	21-47	57
Aug 18-24	60	29	5	22-48	23
Aug 25-31	65	28	3	22-38	31
Sep 1-7	24	32	7	22-44	24
Middle					
Jul 28-Aug 3	80	26	1	23-29	43
Aug 4-10	111	27	3	22-33	37
Aug 11-17	83	27	3	23-34	25
Aug 18-24	72	33	6	23-50	10
Aug 25-31	77	33	5	25-45	3
Sep 1-7	26	41	6	30-53	0
Lower					
Jul 26	20	24	2	21-27	85
Jul 28-Aug 3	50	26	2	22-29	48
Aug 4-10	60	27	3	21-36	32
Aug 11-17	65	29	5	23-46	25
Aug 18-24	74	31	5	22-50	12
Aug 25-31	70	34	7	25-54	3
Sep 1-7	22	37	5	28-50	0

Table 13. Right bank counts of cutthroat trout fry along 11 25-m longitudinal transects, Yellowstone River between Yellowstone Lake and LeHardy Rapids (upper segment), 1991.

Date	Mean number of fry / 25 m	SE
Jul 25	0	0
Jul 31	42	18
Aug 7	96	53
Aug 14	51	23
Aug 21	6	2

Distribution

Fry were distributed all along the right bank in varying abundances (Figure 11). Fry abundances in a section were not correlated with redd numbers in the section (r^2=0.02).

Lengths of Fry

The size distribution of fry captured changed over time in a similar pattern for both years and in all segments. Near the beginning of emergence most fry were less than 27 mm, but with time the size range broadened (Figures 12-13), and the mean total length of fry captured increased by about 2 mm per week.

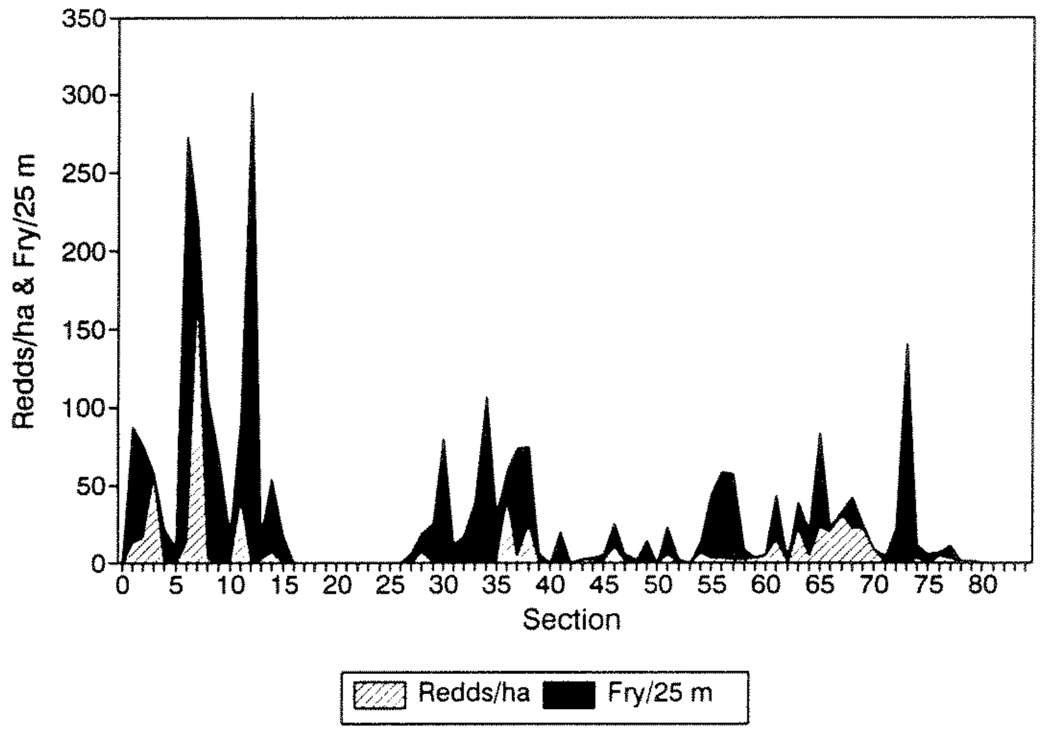

Figure 11. Maximum cutthroat trout fry densities in fry per 25 m and redd densities in redds per ha for the 84 sections along the right bank of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

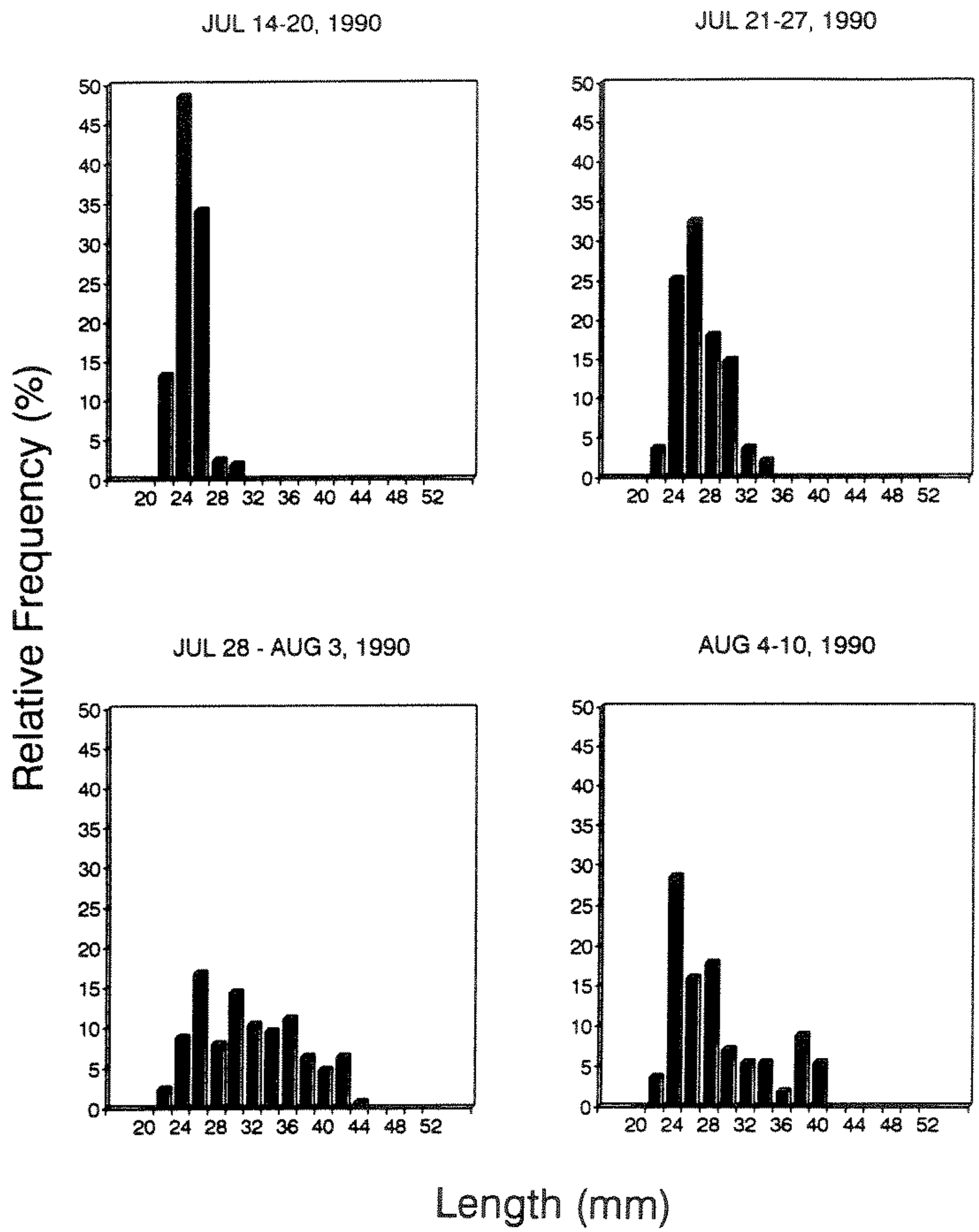

Figure 12. Length frequency distributions by week of cutthroat trout fry collected in the Buffalo Ford area of the Yellowstone River, 1990.

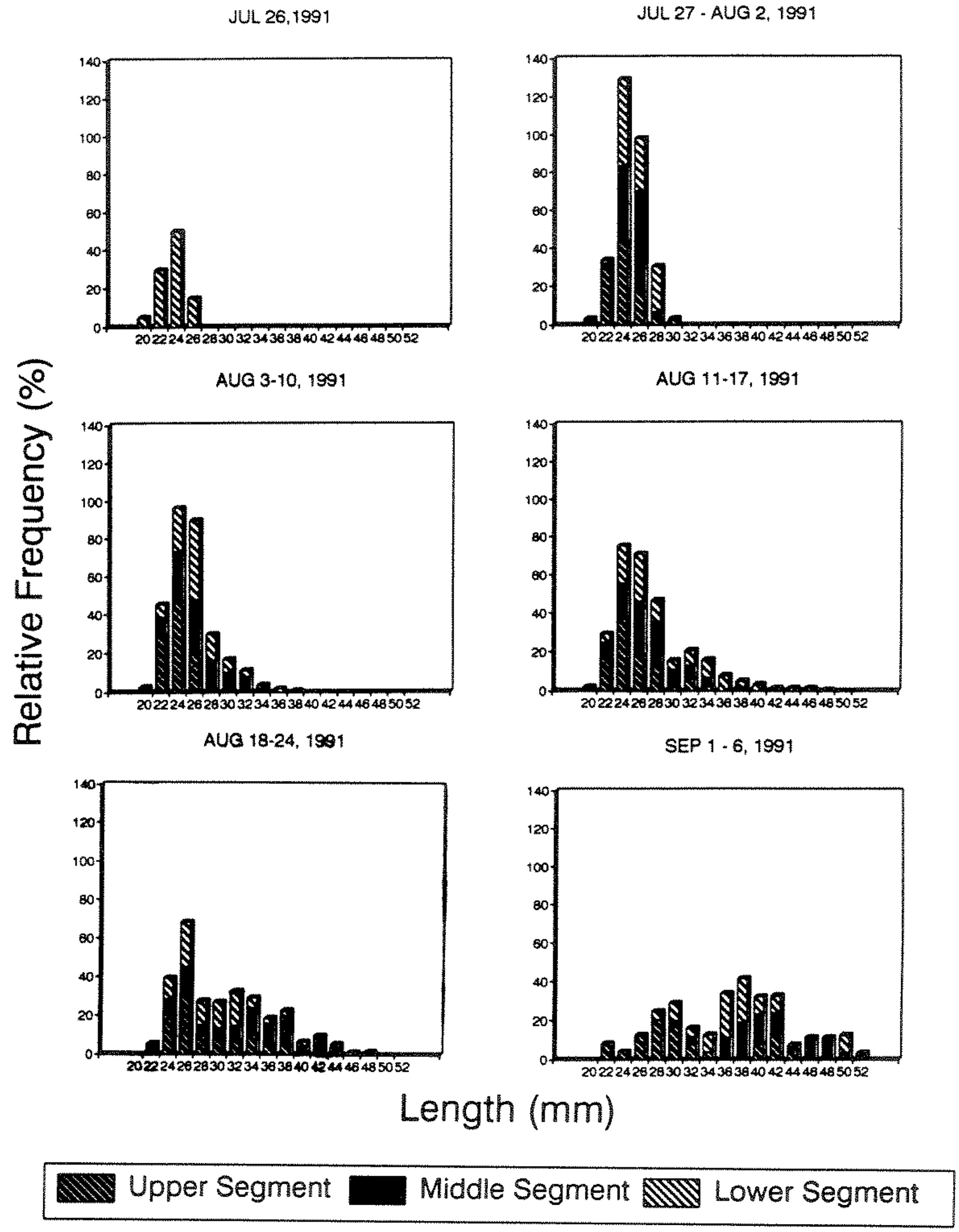

Figure 13. Length frequency distributions by week of cutthroat trout fry collected in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Overall size distribution of fry captured in 1990 and 1991 was similar (Figure 14). Few fry captured were less than 24 mm. Fry captured were predominantly between 24 mm and 27 mm (57% in 1990 and 49% in 1991). The number of fry captured decreased with increasing length, and only 9% and 16% of fry captured were over 35 mm in 1990 and 1991, respectively.

Spawning Trout and Redds

Characteristics of the Spawning Trout Population

Mean length of female and male spawners sampled was 395 mm (n=663) and 406 mm (n=546), respectively (Table 14). The mean condition factor for all spawners was 0.93, though condition of females varied more because of weight differences with stage of maturity. Spawners from the three segments were similar in size (Figure 15). Less than 2% of the fish captured in the upper and middle segments were non-spawning juveniles, but juveniles comprised 22.3% of the fish in the lower segment (Table 15).

Adult Trout Movement

Movement information was obtained on 92 of the 1,288 trout tagged (Appendix 3). Only one trout was reported more than once; one angler caught the same trout on two consecutive days. Anglers reported catching 48 (3.6%) of the trout tagged, which accounted for 52% of all recapture

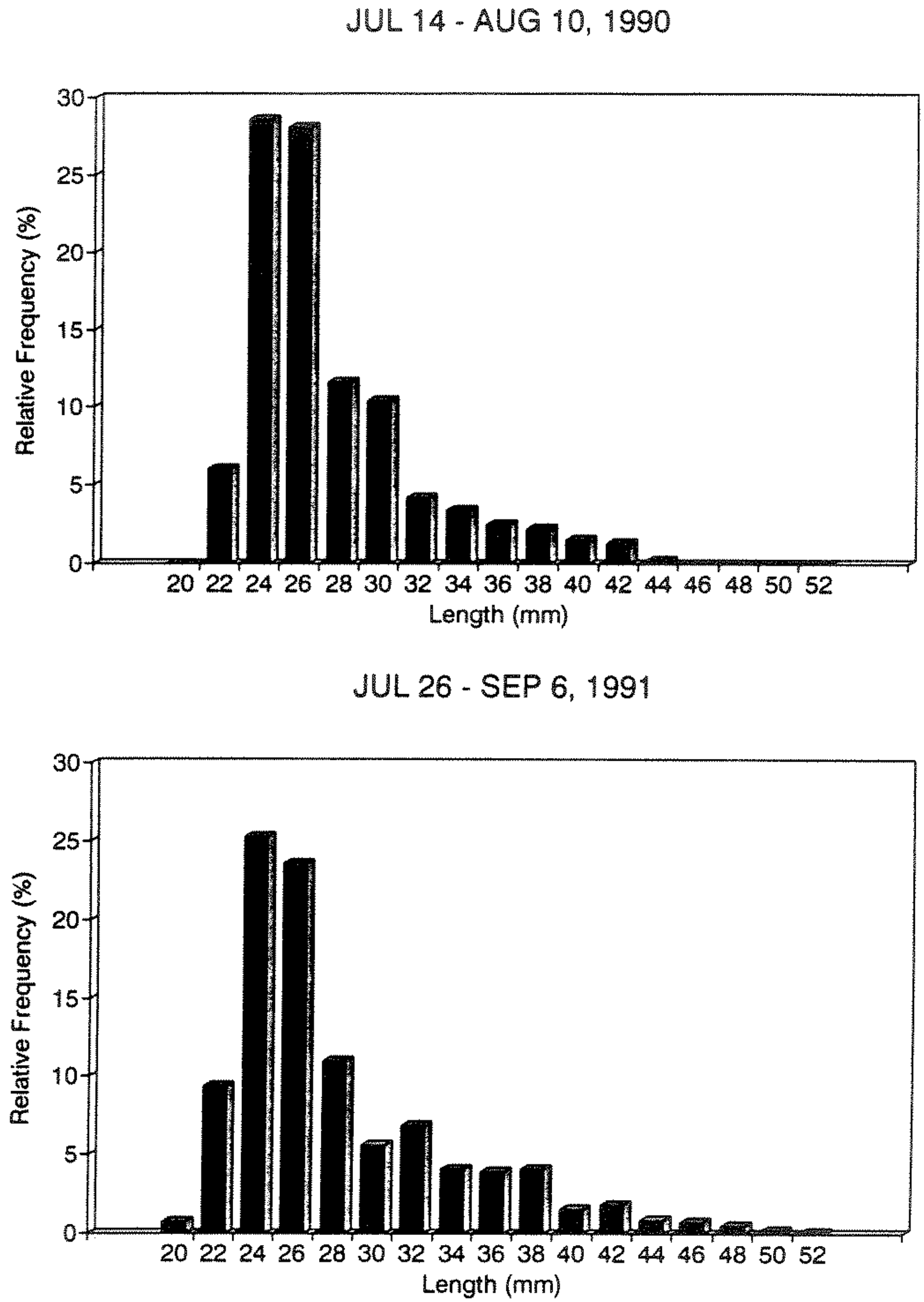

Figure 14. Length frequency distributions of all cutthroat trout fry collected in the Yellowstone River in 1990 and 1991.

Table 14. Mean, standard deviation, and range of total lengths, weights, and condition factors (K) of spawning males, females, and juvenile Yellowstone cutthroat trout (non-spawning trout <350 mm) captured by electrofishing in the Yellowstone River between Yellowstone Lake and Upper Falls in May and June, 1990.

	Male spawners	Female spawners	Juvenile non-spawners
Length			
Number	546	663	71
Range	310 - 515	320 - 492	107 - 348
Mean (SD)	406 (29)	395 (27)	281 (65)
Weight			
Number	282	301	71
Range	260 - 1247	316 - 1361	6 - 490
Mean (SD)	629 (161)	575 (155)	240 (124)
Condition Factor			
Number	282	301	71
Range	0.469 - 1.77	0.484 - 1.55	0.439 - 1.16
Mean (SD)	0.93 (0.11)	0.93 (0.48)	0.94 (0.17)

Table 15. Number and percentage of juvenile trout (non-spawning trout <350 mm) and number of adult trout captured by electrofishing in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls in May and June, 1990.

	Segment		
	Upper	Middle	Lower
Number of juveniles	5	6	60
Number of adults	450	583	209
Total	455	589	269
Percentage of juveniles	1.1	1.0	22.3

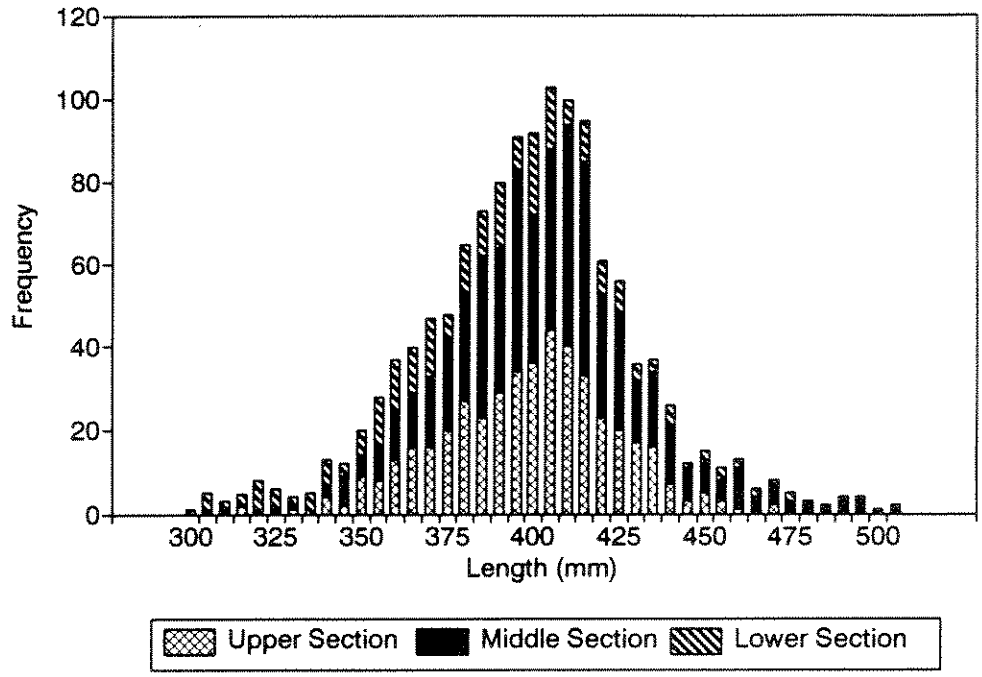

Figure 15. Length frequency distribution of 1282 Yellowstone cutthroat trout 350-515 mm electrofished in the Yellowstone River between Yellowstone Lake and Upper Falls, May and June 1990.

reports (Table 16). Most recaptures were at LeHardy Rapids (20) and the middle segment (64), where recapture effort was greatest. Unequal recapture effort between segments of the river and the low number of recaptures, prevented meaningful statistical analysis of movement patterns.

There was considerable movement during the spawning season. Fifty-two percent of the recaptured trout were in their original tagging segment, 41% had moved upstream and 7% had moved downstream (Appendix 3). Upstream and downstream movements between the upper and middle segments and the middle and lower segments were documented (Table 17 and Appendix 3). Trout from the lower segment recaptured at LeHardy Rapids were probably moving up to the upper segment. Two trout tagged in the upper segment were recaptured in Yellowstone Lake near the outlet, and one trout from the middle segment was recaptured at Plover Point in the Flat Mountain Arm of the lake.

Stage of sexual maturity was examined for 24 recaptured adult trout. Six of 24 (25%) trout recaptured upstream were pre-spawners or ripe when tagged and post-spawners when recaptured. Two trout that moved downstream were pre-spawners when tagged and when recaptured. Of the trout recaptured in the area where tagged, 8 of 11 (73%) had not changed stage of maturity, and 3 spawned between tagging and recapture. Five juveniles from the lower segment were recaptured in the middle segment within 43 d of tagging.

Table 16. Number of tagged trout recaptured by various methods, Yellowstone River between Yellowstone Lake and Upper Falls, 1990 - 1992.

	Number of trout recaptured				
Recapture method	1990	1991	1992	Total	%
Electrofishing	11	0	0	11	12
LeHardy Rapids sampling	13	2	0	15	16
Angler reports	35	11	2	48	52
Observations	1	6	0	18	20

Table 17. Movement of adult cutthroat trout tagged in 1990 in the Yellowstone River between Yellowstone Lake and Upper Falls based on recaptures in 1990, 1991, and 1992.

	Number of recaptures and direction moved*				
	Segment tagged				
Area recaptured	Upper	Middle	Lower	Total	%
Yellowstone Lake	2 ↑	1 ↑	0	3	3
Upper Segment	1 ↔	2 ↑	0	3	3
LeHardy Rapids	2 ↓	14 ↑	4 ↑	20	22
Middle Segment	4 ↓	45 ↔	15 ↑	64	70
Lower Segment	0	0	2 ↔	2	2

*Direction moved

↑ Upstream
↔ No movement out of segment tagged
↓ Downstream

Angler Use

The anglers interviewed in 1990 at Buffalo Ford Access had fished an average of 2.9 h per day (SE = 0.13), and landed 1.7 trout per hour (n=490). In 1991, anglers used some sections of the river more than others. Ninety-three percent of the anglers were along the left bank, where the road is, and 70% of these were in sections 15-42 (near the road through Sulphur Caldron). Sections 8-14 (away from the road) and 72-84 (below Alum Creek) only received 3% and 13% of the angler use, respectively (Table 18). No anglers were observed in the sections closed to angling.

In 1991 the pattern of angler use changed over time. Use on the right bank was 6.3-6.9% of the total use through 14 August, and then use on the right bank almost doubled to 12.5% for 15-31 August, mostly because of an increase in anglers on the right side in the middle segment (sections 24-42) (Table 18). By this time anglers easily crossed the river at Buffalo Ford. Use in the Alum Creek to Chittenden Bridge section decreased by about half from July to August.

Seventy-two percent of the anglers (n=7,030) observed in 1991 were wading or wearing waders. Only 41% of the 870 anglers in the Alum Creek to Chittenden Bridge waded (sections 72-84), and 84% of the anglers between Buffalo Ford and Sulphur Caldron waded (sections 34-42).

Table 18. The mean number of anglers counted and the percentage of the total number of anglers in groups of sections along the left bank (L) and right bank (R), summarized bimonthly for 15 July - 31 August 1991, Yellowstone River from 0.6 km below Fishing Bridge to Chittenden Bridge.

		Mean number of anglers (#) per survey and the percent of anglers (%) in a group of sections			
Section and bank-side		Jul 15-Aug 31	Jul 15-31	Aug 1-14	Aug 15-31
8-14	#	1.71	1.85	1.75	1.29
L	%	1.94	1.69	2.86	2.11
8-14	#	0.91	1.50	0.48	0.29
R	%	1.03	1.37	0.78	0.47
15-23	#	16.70	20.34	14.50	11.87
L	%	18.95	18.55	23.67	19.39
15-23	#	1.34	1.48	1.02	1.65
R	%	1.52	1.35	1.67	2.70
24-34	#	24.70	29.71	21.58	18.19
L	%	28.03	27.10	35.23	29.71
24-34	#	1.55	1.79	0.86	2.35
R	%	1.76	1.63	1.40	3.84
35-42	#	28.62	36.94	23.52	17.71
L	%	32.47	33.70	38.40	28.93
35-42	#	1.85	1.52	1.50	3.39
R	%	2.10	1.39	2.45	5.54
72-84	#	10.31	13.84	8.70	4.48
L	%	11.70	12.63	14.20	7.32
72-84	#	0.44	0.65	0.39	0.0
R	%	0.50	0.59	0.64	0.0
Sum L	#	82.04	102.68	57.00	53.54
(8-84)	%	93.1	93.7	93.1	87.5
Sum R	#	6.09	6.94	4.25	7.68
(8-84)	%	6.9	6.3	6.9	12.5
Sum L & R	#	88.13	109.62	61.25	61.22

Estimated Mortality of Cutthroat Trout Embryos and Pre-Emergent Fry Resulting from Angler Wading, 1991

No fry had emerged by 15 July 1991, opening of the angling season. Development was earliest in the lower segment and latest in the upper segment (Figure 16). It was estimated that few pre-eyed eggs were in the gravel on July 15, and by the week of 28 July - 3 August, few eyed eggs remained in the gravel. More than 90% of the fry had emerged by the week of 11-7 August in the lower and middle segment, and by 18-25 August in the upper segment.

Using the model (Appendix 1), estimates of wading-caused mortality for July and August 1991 were 8.1% and 1.2%, respectively, totaling 9.3% or 264,057 embryos and pre-emergent fry.

Of the total estimated wading-caused mortality, 57.4%, 38.0%, and 4.6% occurred in the upper, middle segment, and lower segments, respectively (Table 19). Estimated mortality was highest in the upper segment because this segment contained the largest number of redds, emergence occurred later, and wading pressure was high (383 wading hours per hectare for the season) (Appendix 2). The middle segment received 68.3% of the wading hours, but this segment contained fewer redds, reducing wading-caused mortality. Emergence was earliest in the lower segment, and this segment contained the fewest number of redds and received the least wading pressure (7.1%).

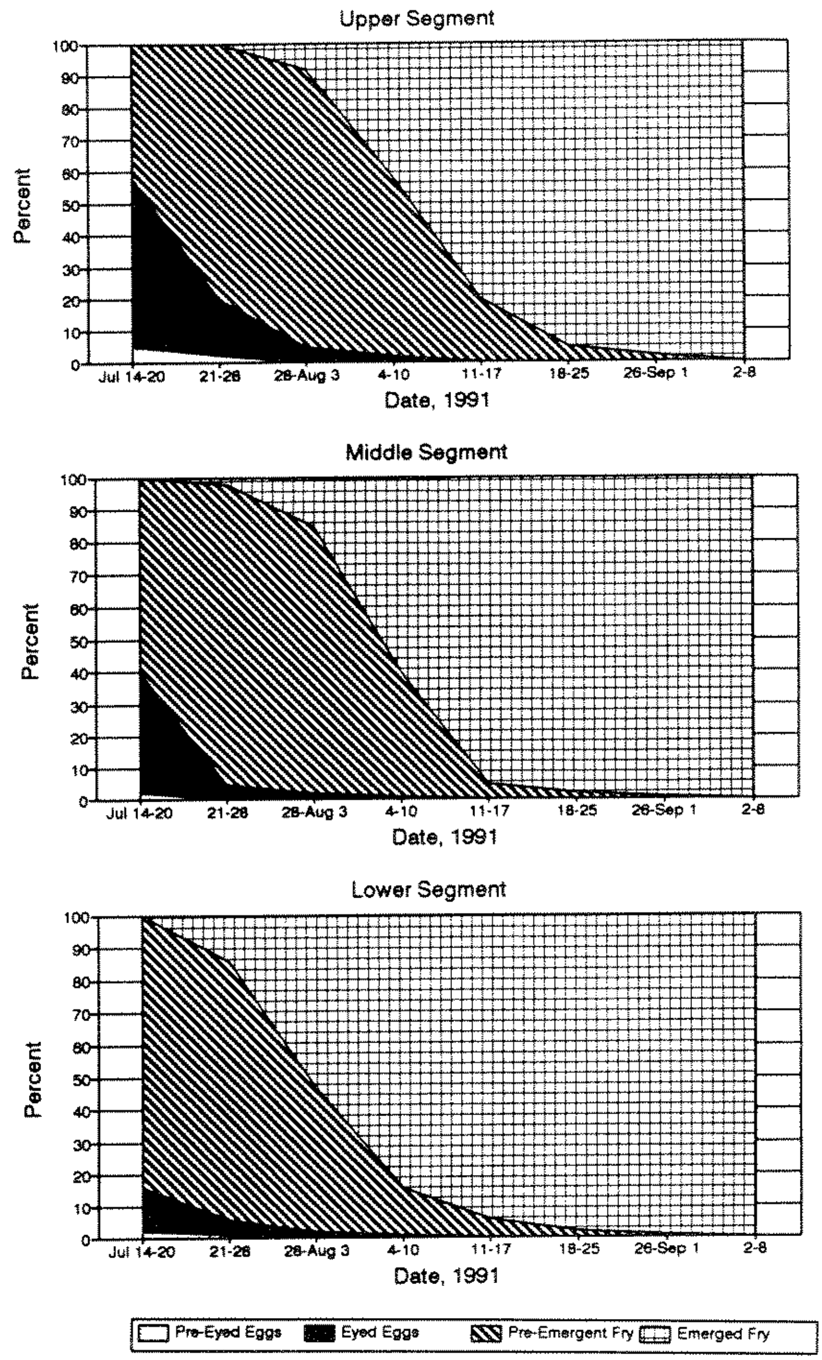

Figure 16. Estimated percentages of developing cutthroat trout at the pre-eyed egg, eyed egg, pre-emergent fry, and emerged fry stage in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 15 July - 8 September 1991.

Table 19. Percent of all redds, angler hours, anglers wading, angler wading-caused mortality for July, August, and season for the areas open to angling in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

	Segment and sections		
	Upper (8-23)	Middle (24-42)	Lower (72-84)
% All redds (n=2151)	21.0	13.8	4.9
% Angler hours among three sections	24.1	63.6	12.3
% Anglers wading within each section	71.6	75.6	41.0
% Wading hours among three sections	24.6	68.3	7.1
% July mortality among three sections	56.3	38.9	4.8
% August mortality among three sections	65.1	31.6	3.3
% Total mortality	57.4	38.0	4.6

Worst-Case-Scenario Wading-Caused Mortality Rates

With an assumed wading frequency of twice-daily during the angling season in 1991, 15.6% of all eggs in the study area would be killed by angler wading. Applying the 82.8% mortality rate for eggs waded on twice-daily from fertilization to emergence (Roberts 1988) to the 854 redds in areas open to angling (39.7% of all redds), and assuming

20% natural inter-gravel mortality, 26.3% of all eggs would be killed by angler wading.

Tributaries

Thistle Creek

Water quality in Thistle Creek was suitable for trout, with pH 7.35 and low total dissolved solids (72 mg/L) (Tables 20-22). Substrate was primarily comprised of gravel and cobble with boulders in some higher-gradient reaches. Several areas appeared suitable for spawning, and a pair of adult cutthroat trout was observed digging a redd on 19 June 1991.

Trout of all life stages were observed in Thistle Creek; five 100-150 mm fish and eight 250-400 mm fish were observed in June 1991 surveys. On 14 August 1991, cutthroat fry were counted in four 25-m sections, yielding 115, 19, 3, and 0 fry per 25 m; a sample of 12 fry had a mean length of 28 mm and a range of 25-30 mm. For most of the stream, few or no fry were seen.

Elk Antler Creek

Elk Antler Creek had slightly alkaline water; pH was 7.6-7.82 and total alkalinity was 57.8 mg/L. Total dissolved solids were high at 190 mg/L, but water analysis revealed no water chemistry problems for cutthroat trout (Tables 20-22).

Table 20. Chemical characteristics of Thistle, Elk Antler, and Trout creeks, 1991. Turbidity expressed in nephelometric turbidity units (NTU's), color in platinum color units (PCU's), other values (except pH, stability index, and saturation index) expressed in mg/L.

	Thistle Creek	Elk Antler Creek	Trout Creek
Date (1991)	07-01	07-02	07-02
Total dissolved solids	72.0	190	160
Phenolphtalein alkalinity	<2.0	<2.0	<2.0
Total alkalinity	26.4	57.8	30.4
Carbonate alkalinity	<2.0	<2.0	<2.0
Bicarbonates as $CaCO_3$	26.4	57.8	30.4
Carbonates	<2.0	<2.0	<2.0
Bicarbonates as HCO_3	26.4	57.8	30.4
Hydroxides	<0.50	<0.50	<0.50
Carbon dioxide	2.2	1.7	7.3
Chloride	<1.0	14.9	3.97
Sulfate	2.24	24.8	40.9
Fluoride	1.14	3.10	2.87
pH (laboratory)	7.35	7.82	6.91
Stability index	15.7	9.16	10.9
Saturation index	-4.15	-0.67	-1.98
Color (estimated)	10	20	40
Turbidity	0.56	3.00	5.90
Silica	37.3	61.2	52.8
Hydrogen sulfide	<0.10	<0.10	<0.10
Sodium	4.80	25.0	17.0
Potassium	2.40	6.40	4.90
Calcium	7.20	16.0	12.0
Magnesium	2.00	5.70	4.40
Iron	0.12	0.38	1.10
Manganese	<0.03	0.09	0.06
Copper	<0.01	<0.01	<0.01
Total hardness	26.0	65.0	48.0
Magnesium hardness	8.30	24.0	18.0
Calcium hardness	18.0	41.0	30.0

Table 21. Water temperatures (°C) measured in Thistle, Elk Antler, and Trout creeks, 1991.

Thistle Creek			Elk Antler Creek			Trout Creek		
Date	Time	Temp (°C)	Date	Time	Temp (°C)	Date	Time	Temp (°C)
6-14	0940	5	6-03		12	6-18	1450	13
6-19	0945	7	6-18	1610	12	6-25	1610	13
6-26	1030	7	6-25	1515	11	7-02	1110	13
7-01	1030	6	7-02	1140	9	8-01	1400	15
8-14	1000	8	8-08	1400	14	8-01	1530	18

Table 22. Field measurements of dissolved oxygen (D.O.), alkalinity (ALK.), pH, and conductivity (COND.) in Thistle, Elk Antler, Trout, Alum, Sour, and Otter creeks, 1991.

Creek	Date	D.O. (mg/L)	ALK. (mg/L)	pH (pH Units)	COND. (μmhos/cm)
Thistle	6-26	-	-	7.4	40
	7-01	-	20	7.3	60
Elk Antler	6-25	8	-	7.6	-
	7-02	-	27	7.6	200
Trout	6-25	9	-	7.0	-
	7-02	-	21	7.0	110
Alum	7-02	-	102	8.5	300
	8-30	9	224	8.4	>500
Sour	7-01	-	<6.8	3.0	300
	8-22	10	109	3.0	510
Otter	6-25	7.5	-	6.4	-
	7-02	-	<6.8	5.5	140

The substrate in lower Elk Antler was primarily silt and gravel, and numerous gravel deposits in the creek appeared suitable for spawning. Several adult and juvenile cutthroat were observed in 1990 and 1991.

On 9 August 1990, 528 cutthroat trout fry were counted within an estimated 1.27 km of the lower 3 km of the creek, a mean of 10.4 fry per 25 m. On 1 and 8 August 1991, cutthroat fry in 10 25-m sections were counted, and the mean was 13.2 fry per 25 m. Ten fry were measured on 8 August, and the length range was 28 to 35 mm and the mean length was 33.2 mm.

<u>Trout Creek</u>

Water chemistry of Trout Creek revealed no major problems for fish. Minor problems included high total dissolved solids, turbidity, sulfate, and iron. The iron concentration of 1.10 mg/L exceeded the U.S. Environmental Protection Agency (1986) criteria of 1.00 mg/L (Tables 20-22).

Sand and silt composed most of the substrate, but there were numerous gravel deposits that appeared suitable for spawning. On 8 August 1990, 1,499 cutthroat fry were counted in approximately 0.69 km within the lower 2 km of the creek, a mean of 54.3 fry per 25 m. Nine 25-m sections were counted on 1 August 1991 and the mean fry density was 28.8 per 25 m. Twenty-five fry between 25 and 47 mm had a mean length of 30.7 m. Several 70 to 250-mm cutthroat were observed in the creek.

Alum Creek

Numerous redside shiner and longnose dace inhabited Alum Creek, but no cutthroat trout were observed in the lower 4 km. Gravels that appeared suitable for trout spawning were present in several areas, but water quality may restrict trout. Stream pH was alkaline, 8.28-8.5, and total alkalinities ranged from 102 to 224 mg/L (Tables 20-22). Total dissolved solids were high, 708 mg/L, as were chloride, 101 mg/L; sulfate, 96.3 mg/L; fluoride, 8.41 mg/L; silica, 146 mg/L: sodium, 160 mg/L; potassium, 33.0 mg/L; and magnesium 3.90 mg/L, but these levels are not toxic to aquatic life (U.S. Environmental Protection Agency 1986). However, temperatures occasionally exceeded 22°C, the maximum suitable temperature for cutthroat trout (Hickman and Raleigh 1982). The maximum temperature recorded in the lower reach of Alum Creek in 1991 was 23 °C at 1445 on 21 June.

Sour Creek

Water quality in lower Sour Creek precluded its use by cutthroat trout. Iron was 1.70 mg/L, pH was 3-3.39, and alkalinity was less than 2.0 mg/L. On 22 August 1991 alkalinity measured 109 mg/L (Tables 22-24).

Table 23. Chemical characteristics of Sour, Alum, and Otter creeks, 1991. Turbidity expressed in nephelometric turbidity units (NTU's), color in platinum color units (PCU's), other values (except pH, stability index, and saturation index) expressed in mg/L.

	Sour Creek	Alum Creek	Otter Creek
Date (1991)	07-01	07-02	06-25
Total dissolved solids	192	708	126
Phenolphtalein alkalinity	<2.0	<2.0	<2.0
Total alkalinity	<2.0	184	<2.0
Carbonate alkalinity	<2.0	<2.0	<2.0
Bicarbonates as $CaCO_3$	<2.0	184	<2.0
Carbonates	<2.0	<2.0	<2.0
Bicarbonates as HCO_3	<2.0	184	<2.0
Hydroxides	<0.50	<0.50	<0.50
Carbon dioxide	*	1.80	*
Chloride	4.96	101	12.9
Sulfate	82.7	96.3	30.9
Fluoride	0.67	8.41	1.17
pH (laboratory)	3.39	8.28	4.38
Stability index	18.1	7.76	17.2
Saturation index	-7.37	0.26	-6.42
Color (estimated)	20	10	50
Turbidity	2.20	1.34	1.48
Silica	61.0	146	40.4
Hydrogen sulfide	<0.10	<0.10	<0.10
Sodium	17.0	160.0	15.0
Potassium	6.60	33.0	4.40
Calcium	5.30	17.0	4.50
Magnesium	1.20	3.90	<1.00
Iron	1.70	0.38	0.48
Manganese	0.06	0.04	0.08
Copper	<0.01	<0.01	<0.01
Total hardness	18.0	58.0	11.0
Magnesium hardness	4.80	16.0	<4.10
Calcium hardness	13.0	42.0	11.0

* Note: Carbon Dioxide could not be calculated using EPA SM406C, because the sample pH was less than 5.5.

Table 24. Water temperatures (°C) measured in Sour, Alum, and Otter creeks, 1991.

Sour Creek			Alum Creek			Otter Creek		
Date	Time	Temp (°C)	Date	Time	Temp (°C)	Date	Time	Temp (°C)
6-13	1430	12	6-05	1210	16	6-05	0930	6
6-19	1500	14	6-05	1310	17	6-05	1015	8
7-01	1615	16	6-18	1400	17	6-18	1140	9
8-22	1030	11	6-21	1430	21	6-18	1252	10
			6-21	1445	23	7-02	0900	8
			7-02	1000	18	8-08	1138	11
			8-30	1045	17	8-08	1255	12

Otter Creek

Otter Creek habitat appeared suitable for all life stages of cutthroat trout, but no fish were seen. On 25 June 1991, pH was 6, but in August when flows had decreased the pH was 3. Otter Creek has little buffering capacity; total alkalinity was less than 2.0 mg/L (Tables 22-24).

DISCUSSION

Population-level impacts of reduced survival of Yellowstone cutthroat trout embryos and pre-emergent fry resulting from angler wading depend on the extent of mortality and at what life stage population limitation occurs. Based on my research, I concluded that embryo and pre-emergent fry mortality associated with the present timing of emergence, distribution of redds, and amount of angler wading does not limit the Yellowstone cutthroat trout population in the Yellowstone River between Yellowstone Lake and Upper Falls.

Annual wading-related mortality rates depend on the stages of embryonic development present in the gravel during the angling season, which begins 15 July. The timing of spawning, embryonic development, and emergence varies annually and in different river segments due to differences in water temperatures. The onset of spawning is water temperature and light dependent (Kwain 1975). Cutthroat trout spawn when daily maximum temperatures reach 6-9°C (Behnke 1992) and up to 17°C (Hickman and Raleigh 1982).

In both years the trout spawned when mean weekly temperatures were between 5 and 12°C, which was 3 weeks later in 1991 than in 1990. The long term variation in timing of cutthroat trout spawning in the Yellowstone River has not been documented, although in tributaries to Yellowstone Lake in the Grant Village area, the onset and completion of spawning varied by 1 month, from early May to early June and from late June to late July, between 1986 and 1991 (Jones et al. 1992).

Water temperatures were warmer earlier in 1991. Fewer thermal units are required for embryonic development at warmer temperatures (Beacham and Murray 1990; Murray and McPhail 1988; Timoshina 1972). Most of the reported celsius temperature units (CTU) and days for development of Yellowstone cutthroat trout fell within my predicted ranges for development (Table 25).

Timing of fry emergence varied between years and river segments. In 1990 and 1991, these differences correlated with the differences in water temperatures. Emergence began 12 July 1990, and 22, 23, 29 July 1991 in the lower, middle, and upper segment, respectively. On 8 July 1992, I saw several fry in the lower segment and a few fry in the middle and upper segments, indicating emergence had recently begun. Griffith and Schill (1982) first saw fry on 10 July 1980 and 8 July 1981. In 1972, it appeared that fry began emerging in late July or early August in the Fishing Bridge, LeHardy Rapids, and Buffalo Ford areas

Table 25. Days and celsius temperature units (CTU) for Yellowstone cutthroat trout embryonic development.

Reference	Developmental period	Days	Temp. (°C)	CTU's
Roberts (1988)	Fert.[a] - Eye-up	14		158
	Fert. - Hatch	26		294
	Fert. - Emergence	47		478
D. Hodges (Pers. comm.) Big Timber Hatchery, Mont.	Fert. - Eye-up	18	11	198
	Fert. - Hatch	28	11	308
Varley and Gresswell (1988)	Fert. - Hatch	25-30		310
Scott and Crossman (1973)	Fert. - Hatch	42-49		
Cope (1957)	Fert. - Hatch	28-40		
Zubik (1983)	Fert. - Emergence	74-80		545-626
This study	Fert. - Eye-up	18-28		171-207
	Fert. - Hatch	26-41		278-365
	Fert. - Emergence	37-58		458-525

[a]Fert. = Fertilization

(Dean and Varley 1973). These studies suggest that in most years emergence begins before 15 July.

The 15 July opening for angling season reduces potential wading-related mortality, because eggs and pre-emergent fry are protected for all or part of their development. Variation in timing of embryo development will affect amount of wading mortality in the Yellowstone

River. Emergence in 1991 was later than in 4 of 5 years previously reported (Dean and Varley 1973; Griffith and Schill 1982; this study). In years where emergence occurs earlier than in 1991, wading-related mortality would probably be less than 10%.

Because 12 km of the river are closed to angling, 60% of the redds were protected. Redd and angler distribution within areas open to fishing also affect potential wading-caused mortality. Low angler use in many river sections, including most of the right bank, where 17% of the redds were observed, resulted in low estimated wading-related mortality in those areas.

Annual angler effort in the Yellowstone River has increased since 1974 (Jones et al. 1992), and will likely continue to increase. But, even if angler effort increased to where all redds in areas open to angling were waded on twice daily, mortality would only increase by 6.3% given the timing of development in 1991. However, educating anglers about stepping on redds (Roberts 1993) could decrease the impact of wading.

Wading-caused mortality would be of most concern where population regulation occurs during embryo and pre-emergent fry developmental periods. This would occur if spawning area was limiting. Results of this study suggest that spawning area is not limiting in Yellowstone River study area, and that the present amount of angler-wading would not limit this population.

Cutthroat trout in the Yellowstone River are not limited by water chemistry parameters or temperatures, because those measured were all within the suitable range for cutthroat trout (Alabaster and Lloyd 1982; Hickman and Raleigh 1982; U.S. Environmental Protection Agency 1986). Decreased flows in late summer and into the winter reduce space available and could limit the population. Spawning habitat rarely limits stream resident trout populations, but often limit migratory populations (McFadden 1969). An unknown portion of the Yellowstone Lake population spawns in the Yellowstone River, increasing the amount of spawning habitat needed. The large number and wide distribution of redds in the river suggested that suitable spawning area was not limiting. Also, the estimate that 20% of surface substrate appeared suitable for spawning exceeds the estimated 5% of the bottom area that a resident trout population needs for spawning (Hickman and Raleigh 1982). However, surface evaluation of spawning substrate may overestimate suitable spawning habitat. Substrate at the depth of egg deposition may differ from surface substrate (Everest et al. 1981), and the substrate in the egg pocket differs from surrounding substrate (Chapman 1988; Young et al. 1989).

Large reductions in cutthroat trout fry numbers over time suggested that there was high natural mortality or emigration of trout fry. In both years, cutthroat trout fry were generally abundant around the peak of fry emergence, but numbers declined by over 90% within 25 d in counting transects in both 1990 and 1991. Few cutthroat trout fry over 35 mm were captured or seen. Many of the larger fry may have moved into deeper water away from shore where they would not be sampled. Also, decreasing water levels reduced the areas of slow water near cover where fry tended to congregate.

When conducted consistently and under favorable visibility conditions, visual counts are a good method to monitor fry abundance (Bozek and Rahel 1991; Hankin and Reeves 1988; Moore and Gregory 1988a); however, larger fry ($\geq$35 mm) were under-sampled in the study area using hand-netting and visual counts. Larger fry were more difficult to net, and they fry may have moved away from shore to faster water (Chapman and Bjornn 1969).

Cutthroat trout fry mortality can be high during their first summer (Moore and Gregory 1988a; Scarnecchia and Bergersen 1986). Ball and Cope (1961) and Benson (1960) estimated mortality of 99.6% for cutthroat trout in tributaries of Yellowstone Lake between the time of egg deposition and the time fingerlings entered the lake. Upon emergence, trout fry are territorial (Latta 1969; McFadden

1969; Moore and Gregory 1988a and 1988b). Territoriality in salmonid fry leads to starvation or emigration of displaced fry and results in density-dependent population reduction (Allen 1969; McFadden 1969). Bowler (1975) and Raleigh and Chapman (1971) have shown that many cutthroat trout fry from the Fishing Bridge area migrate upstream into the lake. Young-of-the-year cutthroat trout from 50 to 150 mm long have been captured in the upper 5 km of the Yellowstone River in the fall, but not in the spring, which indicates that these fry move into Yellowstone Lake during their first year (Raleigh and Chapman 1971). Some young may be cannibalized by the adult cutthroat trout (Behnke 1992; Benson 1960; Dean and Mills 1971).

The Yellowstone River from Yellowstone Lake to Upper Falls is primarily occupied by adult cutthroat trout. Few juveniles were sampled or seen in 1990 and 1991, except in the lower segment, and Schill and Griffith (1984) saw few trout <250 mm. Fry from the upper segment may move into the lake to rear. It is not known if most fry or juveniles originating downstream of the Fishing Bridge area migrate to the lake or perish. Five tagged juveniles from the lower segment did move upstream to the middle segment in May and June 1990.

Angling pressure in the Yellowstone River between Yellowstone Lake and Upper Falls has increased from mean-annual effort of 57,200 h in 1973 and 1974 (Jones et al.

1992) to an annual mean of 127,000 h for 1987 to 1991. The mean-annual landing rate increased after the implementation of catch-and-release fishing in 1973 to a high of 2.3 trout/h in 1974, then declined to 1.2 trout/h in 1978, and averaged 0.8 trout/h for 1987 to 1991 (Jones et al. 1991). Decreased landing rates do not necessarily indicate population decline. However, total numbers of trout may have declined as the biomass shifted to larger fish. Since 1974 there has been no apparent reduction of the adult cutthroat trout population with increased angling pressure (catch-and-release), and associated angler wading (Jones et al. 1992). The adult cutthroat trout in the Yellowstone River appeared to be numerous during the study period. Long-term records from volunteer angler reports and LeHardy Rapids sampling indicate a relatively stable adult population. The relative abundance of larger and older trout collected at LeHardy Rapids increased from 1974 to the mid-80's, and has remained relatively constant since then (Jones et al. 1992). It does not appear that angling has an important impact on the adult trout population; hooking mortality was estimated at less than 1% by Schill et al. (1986). Predators such as pelicans remove some of the cutthroat trout from the Yellowstone River (Davenport 1974).

While no definitive movement patterns were evident, tagged trout did move between river segments and between the Yellowstone River and Yellowstone Lake. Other studies have reported similar movement (Ball and Cope 1961, Musser 1967; Schill and Griffith 1984). Trout from both the lake and the river spawn in the Fishing Bridge area, and subsequently move into the lake or remain in the river (Ball and Cope 1961). Ball and Cope (1961) presented evidence that trout moving through LeHardy Rapids were moving upstream to spawn in the Fishing Bridge area, and some of the trout tagged at LeHardy Rapids were captured in the lake 1 or 2 years later. In 1990, eight ripe trout recaptured at LeHardy Rapids had been tagged in the middle and lower segments and may have been moving to the upper segment to spawn. In addition to the abundance of spawning substrate in the Fishing Bridge area, its proximity to the lake, where juvenile survival has been estimated at 35% (Ball and Cope 1961), may also make this a particularly important spawning area. There is also evidence that some adult trout from the Fishing Bridge area winter in the lake; Laakso and Cope (1956) found that scales from only 9 of 1,300 trout from the Fishing Bridge and West Thumb areas (1951 to 1953) had scale patterns typical of trout that over-winter in the river. In 1967, 28 of 2,847 trout tagged in the river were recaptured in the lake (Musser 1967), and 3 trout of the 1288 tagged in 1990 were recaptured in the lake.

Cutthroat trout only reproduce in three of the tributaries in the study area, and probably few of these trout are recruited to the Yellowstone River. Unsuitable water quality in Sour, Cottongrass, and Otter creeks and warm temperatures in Alum Creek preclude their habitation by cutthroat trout. In 1982, Sour Creek pH ranged between 4.25 and 6.5 (Jones et al. 1983); in 1991 a low of 3.39 was measured. In lower Otter Creek, pH measured in 1982 (Jones et al. 1983) and 1991 fluctuated between 2.5 and 6.8. Drainage of thermal areas contribute to the acidity of these waters (Jones et al. 1983), and then the wide fluctuations in pH result from buffering capacities of less than 2.0 mg/L total alkalinity. Iron in Sour Creek was 1.70 mg/L. Fish cannot survive in these waters, because pH below 4.0 is lethal to salmonids (Alabaster and Lloyd 1982), and water quality criteria for aquatic life include: pH between 6.5 and 9, alkalinity of at least 20 mg/L as $CaCO_3$, and iron less than 1.0 mg/L (U.S. Environmental Protection Agency 1986). Temperatures exceeding 22°C, the maximum suitable temperature for cutthroat trout (Hickman and Raleigh 1982), have been measured in Alum Creek. The water temperature was 27.8°C in late July 1982 (Jones et al. 1983) and 23°C on 21 June 1991.

Thistle, Trout, and Elk Antler creeks support cutthroat trout reproduction. The presence of juvenile cutthroat trout in these creeks indicates that these are resident populations and/or that juveniles rear in the tributaries before moving into the mainstem. Twenty-four trout captured in Elk Antler Creek in 1982 were thought to be residents based on size and markings, and of 18 trout examined in Trout Creek in 1982, four spawners were believed to be Yellowstone River resident trout (Jones et al. 1983). Because many of the trout in these tributaries may be resident, and relatively little reproduction occurs here, tributary streams are not thought to be an important source of recruitment to the Yellowstone River study area.

In the Yellowstone River between Yellowstone Lake and Upper Falls, it did not appear that spawning areas were limited, fry mortality appeared high, and the adult population was large and stable. It appears that population regulation occurs at stages other than the incubation period in the Yellowstone cutthroat trout population of the study area. Territoriality of cutthroat trout at both the fry (Latta 1969; McFadden 1969; Moore and Gregory 1988a and 1988b) and the adult stage (Miller 1957), will lead to density-dependent regulation of the population. Because of mortality between fertilization and spawning age, there often is not a correlation between the adult cutthroat trout population size and the number of their progeny becoming adults (Benson 1960; Latta 1969).

In most years, predicted wading-related mortality of Yellowstone cutthroat trout embryos and pre-emergent fry in the Yellowstone River would be less than 10%, with a maximum of 26%. Considering mortality between the egg stage and adult spawning stages, which is over 99% in stable populations of salmonids, estimated wading-related mortality would not be expected to have a population-level effect. Wading caused mortality would probably be compensated by reduced density-dependent mortality during other life stages.

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APPENDICES

APPENDIX A

MODEL FOR ESTIMATING WADING-CAUSED MORTALITY

Methods used for calculations of component numbers and explanations for the inclusion of the assumptions for the model to estimate the amount of angler wading related mortality of embryo and pre-emergent fry in the Yellowstone River study area.

Component calculations and associated estimates and assumptions:

1. Estimated number of Yellowstone cutthroat trout redds in each section

Methods and estimates are in this thesis.

2. Estimated wading hours per hectare by section for the months of July and August.

I calculated the number of wading hours per hectare by month for each study section as follows:

(% total angler use in section[a]) * (% anglers wading in section[b]) * (144,008 angler hours[c]) * (0.413 for July use of 0.398 for August use[d]) / (area of section in hectares[e]) = wading hours by month per hectare for the section

[a] From distribution data from the 171 angler counts taken between 15 July and 30 August (see methods).

[b] From angler surveys, the observed percentage of anglers wading in each of the 47 sections.

[c] The estimated angler hours for 1991 for the Yellowstone River between 0.6 km below Fishing Bridge to Chittenden Bridge was 144,008 hours (Jones et al. 1991).

[d] The estimated percentages of use for July and August for the 1991 fishing season for the Yellowstone River between 0.6 km below Fishing Bridge to Chittenden Bridge were 0.413 and 0.398 for July and August, respectively.

[e] The area of each river section in hectares was calculated from digitizing using GRASS and ArcInfo (see methods).

3. Estimated stages of embryonic development present in the gravel during the angling season for each of the three river segments.

To estimate the percentages of the eggs at the pre-eyed, eyed, pre-emerged fry, and emerged fry stage by week for each of the three river segments, I took the following steps:

(a) Estimated the percentage of fry emerging by week.

Divided the weekly mean number of fry $\leq$25 mm per 25 m by the sum for all weeks of the mean number of fry $\leq$25 mm per 25 m.

(b) Made the estimate of the percentage of fry emerging by week more conservative by:

Averaging the percentage of fry emerging for the week and the percentage of fry emerging in the previous week.

c) Calculated the percentage by week that were pre-eyed eggs, eyed eggs and pre-emergent fry.

Using the conservative estimate of the percentage of fry emerging by week, I back-calculated the percentages at the other stages, assuming 2 weeks from eye-up to hatch and 3 weeks from hatch to emergence. For cutthroat trout incubation, Roberts (1988) reported 14 days from eye-up to hatch and 26 days from hatch to emergence (158 and 294 CTU's), which are close to the assumed 2 and 3 weeks.

(d) Calculated the mean percentage by month, July 15-31 and August 1-31, that were pre-eyed eggs, eyed eggs, pre-emergent fry and emerged fry, so that I could calculate monthly mortalities.

Calculated the mean of the percentages at each stage of development by week for the month.

4. Mortality rates estimated by Roberts (1988) were applied to the estimated mean number of pre-eyed and eyed eggs and pre-emergent fry in the gravel by month to calculate mean mortality rates for once only wading and twice daily wading on redds in the three segments (Table 26).

Table 26. Mean percent of pre-eyed eggs, eyed eggs, pre-emerged (pre-em.) fry, and emerged fry by month and the mortality rate used for the month for redds waded on once only (once only mort.) or twice daily (twice daily mort.) for the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Seg- ment	Month	Pre- eyed eggs	Eyed eggs	Pre- em. fry	Emer- ged fry	Once only mort.	Twice daily mort.
Upper	Jul	2.8	29.4	66.2	1.6	0.1529	0.4768
Middle	Jul	0.4	17.6	77.8	3.8	0.1431	0.4108
Lower	Jul	1.2	8.0	74.6	16.2	0.1194	0.3317
Upper	Aug	0	1.0	28.1	70.9	0.0403	0.1056
Middle	Aug	0	0.4	19.7	79.9	0.0272	0.0700
Lower	Aug	0	0.5	10.3	89.2	0.0158	0.0426
All	Sep	0	0	0	100	0	0

MODEL ASSUMPTIONS:

1. The redd of each Yellowstone cutthroat trout contained 1320 eggs.

This assumption is based on an estimated fecundity of 1381 for Yellowstone cutthroat trout with a mean length of 390 mm (Jones et al. 1983). Mean length of 663 females in 1990 was 395 mm. If each female had 1390 eggs but retained 5%, then she would deposit 1320 eggs.

2. 20% of eggs deposited in the substrate died of natural causes.

Roberts (1986) also assumed 20% natural mortality, based on egg mortality in the laboratory, and there was 20% mortality of non-handled control Yellowstone cutthroat trout eggs used by Dwyer et. al. (in press) .

Other studies have shown a wide variance in embryonic mortality, from less than 5% to 100%.

3. 100 wading hours to wade on all surfaces in one hectare.

If the bottom surface of one angler boot measured 0.42-m * 0.2-m which equals 0.084 m^2, and the angler took 1,200 steps in one hour, then it would take 100 hours to step on all surfaces in 1 hectare.
$(0.084\ m^2)\ (1{,}200)\ (100) = 10{,}080\ m^2 = \sim 1$ hectare
From observations it did not appear that anglers wade around much in the river, so this is probably an over estimate of the area waded on.

4. Estimated mortality rates for redds stepped on more or less than once only or twice daily.

Since mortality rates are only given for instances where redds are waded on once only or twice daily (Roberts 1988 and Roberts and White 1992), and the relationship of wading frequency to mortality is not known, I assumed that I could apply these mortality rates to the full range of my wading frequencies as follows:

(a) One time only wading mortality rates were used where there were 1-399 wading hours per hectare for the month. To correct for areas where it was estimated that each area was stepped on less or more than one time for the month, the mortality estimate was multiplied by the wading hours per hectare divided by 100, for those with 1-200 wading hours, and multiplied by 2 for those with 200-399 wading hours (twice the one time only wading estimate).

(b) The twice daily mortality rate was used for those areas with 400 or more wading hours per hectare. If each area received more than twice daily wading, > 3400 wading hours per hectare for July and > 6200 wading hours per hectare for August, then the mortality estimate was multiplied by (wading hours/hectare)/(100)/(#days in month)/(2).
Example: 4000 wading hours per hectare in July:
$(4000)/(100)/(17)/(2) = 1.18$

APPENDIX B

DATA USED FOR CALCULATIONS OF WADING-CAUSED MORTALITY

Table 27. Data used for calculations of wading-caused mortality. By section and river-side: area in hectares, estimated number of redds, number of trout eggs (number of redds * 1320), estimated number of angler hours for the season, the percent anglers wading by section, estimated number of times each redd waded on in the section for July and August - expressed as wading hours per hectare divided by 100, estimated number (#) of eggs killed by angler wading for July and August, given 20% natural egg mortality, for the Yellowstone River between Yellowstone Lake and Upper Falls, 1991.

Section and side	Ha	Esti- mated redds	Number of eggs	Angler hours/ season	Percent anglers wading	Wading hours/ Ha/100 July	Wading hours/ Ha/100 August	July mort- ality, # of eggs	August mort- ality, # of eggs
1-7 R	18.60	225	297,000	0	0	0	0	0	0
1-7 L	16.84	525	693,000	0	0	0	0	0	0
8 R	0.68	125	165,000	455	71	1.96	1.89	40,366	7,366
8 L	0.88	0	0	341	71	1.14	1.10	0	0
9 R	3.11	10	13,200	374	63	0.31	0.30	502	119
9 L	4.91	0	0	423	63	0.22	0.22	0	0
10 R	3.63	0	0	163	94	0.17	0.17	0	0
10 L	8.31	8	10,560	146	94	0.07	0.07	92	26
11 R	2.44	0	0	276	71	0.33	0.32	0	0
11 L	2.25	3	3,960	325	71	0.42	0.41	211	53
12 R	1.22	50	66,000	228	90	0.69	0.67	5,570	1,267
12 L	1.12	180	237,600	1,040	90	3.45	3.33	58,133	10,613
13 R	5.76	3	3,960	406	83	0.24	0.23	119	26
13 L	5.25	0	0	33	83	0.02	0.02	0	0
14 R	1.57	3	3,960	33	59	0.05	0.05	26	13
14 L	1.61	0	0	406	59	0.61	0.59	0	0
15 R	2.01	14	18,480	98	49	0.10	0.10	224	53

Table 27. Continued.

Section and side		Ha	Estimated redds	Number of eggs	Angler hours/ season	Percent anglers wading	Wading hours/ Ha/100 July	Wading hours/ Ha/100 August	July mortality, # of eggs	August mortality, # of eggs
16	R	1.67	0	0	97	43	0.10	0.10	0	0
16	L	2.05	0	0	3,414	43	2.96	2.85	0	0
17	R	1.17	0	0	33	52	0.06	0.06	0	0
17	L	2.26	4	5,280	2,926	52	2.78	2.68	1,294	238
18	R	1.01	0	0	341	76	1.06	1.02	0	0
18	L	1.14	0	0	6,714	76	18.49	17.41	0	0
19	R	1.05	6	7,920	764	87	2.61	2.52	1,927	343
19	L	0.98	15	19,800	5,055	87	18.53	17.86	7,550	871
20	R	0.36	0	0	309	78	2.77	2.66	0	0
20	R	0.34	0	0	2,065	78	19.57	18.85	0	0
21	R	0.55	0	0	228	91	1.56	1.50	0	0
21	L	0.77	25	33,000	4,113	91	20.08	19.35	12,593	1,452
22	R	1.16	0	0	228	91	0.74	0.71	0	0
22	L	1.18	2	2,640	1,349	91	4.30	4.14	1,003	119
23	R	0.74	0	0	81	41	0.19	0.18	0	0
23	L	0.75	0	0	569	41	1.28	1.24	0	0
24	R	0.84	0	0	309	58	0.88	0.85	0	0
24	L	0.67	5	6,600	1,853	58	6.62	6.38	2,165	224
25	R	0.61	0	0	81	55	0.30	0.29	0	0
25	L	0.58	2	2,640	1,577	55	6.18	5.95	871	92
26	R	0.28	0	0	130	54	1.04	1.00	0	0
26	L	0.32	4	5,280	3,934	54	27.42	26.42	1,729	172
27	R	0.21	0	0	98	58	1.12	1.08	0	0
27	L	0.24	2	2,640	3,219	58	32.13	30.96	937	79

Table 27. Continued.

Section and side	Ha	Esti-mated redds	Number of eggs	Angler hours/ season	Percent anglers wading	Wading hours/ Ha/100 July	Wading hours/ Ha/100 August	July mort-ality, # of eggs	August mort-ality, # of eggs
28 R	1.60	0	0	293	73	0.55	0.53	0	0
28 L	1.60	0	0	4,795	73	9.04	8.71	0	0
29 R	0.61	4	5,280	374	80	2.03	1.95	1,228	158
29 L	0.68	0	0	1,918	81	9.32	8.98	0	0
30 R	0.77	0	0	49	86	0.23	0.22	0	0
30 L	1.01	0	0	618	86	2.17	2.09	0	0
31 R	1.09	0	0	49	65	0.12	0.12	0	0
31 L	1.18	4	5,280	667	65	1.51	1.46	924	132
32 R	0.80	0	0	146	84	0.63	0.61	0	0
32 L	0.82	30	39,600	5,251	84	22.22	21.41	13,015	1,307
33 R	0.70	1	3,200	406	64	1.53	1.48	224	40
33 L	0.89	0	0	6,193	64	18.39	17.72	0	0
34 R	1.42	2	2,640	585	60	1.02	0.98	304	53
34 L	1.49	2	2,640	8,583	60	14.27	13.76	871	92
35 R	0.83	2	2,640	894	81	3.60	3.47	607	79
35 L	1.10	2	2,640	10,387	81	31.59	30.44	871	92
36 R	1.93	135	2,640	163	96	0.33	0.33	106	13
36 L	2.69	60	178,200	1,414	96	2.08	2.01	42,623	5,465
37 R	1.48	4	79,200	1,235	92	3.17	3.06	18,137	2,455
37 L	0.77	3	5,280	9,786	92	48.29	46.54	2,416	132
38 R	0.72	2	3,960	293	90	1.51	1.46	673	92
38 L	0.69	30	2,640	5,738	90	30.91	29.79	871	92
39 R	1.21	0	39,600	130	71	0.32	0.30	1,399	251
39 L	1.01	0	0	3,853	71	11.19	10.78	0	0

Table 27. Continued.

Section and side		Ha	Estimated redds	Number of eggs	Angler hours/ season	Percent anglers wading	Wading hours/ Ha/100 July	Wading hours/ Ha/100 August	July mortality, # of eggs	August mortality, # of eggs
40	R	0.68	0	0	33	78	0.16	0.15	0	0
40	L	0.92	0	0	3,771	78	13.20	12.72	0	0
41	R	2.05	0	0	179	86	0.31	0.30	0	0
41	L	1.53	0	0	5,982	86	13.89	13.38	0	0
42	R	1.00	0	0	81	79	0.26	0.25	0	0
42	L	1.22	0	0	6,535	79	17.48	16.84	0	0
71	R	2.60	2	0	0	81	0	0	0	0
71	L	3.20	0	0	0	81	0	0	0	0
72	R	1.95	0	0	0	41	0	0	0	0
72	L	2.67	2	2,640	1,479	41	1.85	1.79	462	53
73	R	3.48	0	0	0	41	0	0	0	0
73	L	3.21	1	1,320	293	41	0.15	0.15	26	0
74	R	1.92	2	2,640	0	41	0	0	0	0
74	L	2.28	5	6,600	325	41	0.24	0.23	158	13
75	R	1.74	5	6,600	0	41	0	0	0	0
75	L	2.35	5	6,600	1089	41	0.78	0.76	488	66
76	R	1.86	0	0	0	41	0	0	0	0
76	L	1.98	2	2,640	488	41	0.42	0.40	106	13
77	R	1.63	6	7,920	33	53	0.04	0.04	40	0
77	L	1.82	2	2,640	488	53	0.59	0.57	145	13
78	R	1.56	4	5,280	49	41	0.05	0.05	26	0
78	L	1.64	7	9,240	2,146	41	2.22	2.14	1,769	185

Table 27. Continued.

Section and side		Ha	Estimated redds	Number of eggs	Angler hours/ season	Percent anglers wading	Wading hours/ Ha/100 July	Wading hours/ Ha/100 August	July mortality, # of eggs	August mortality, # of eggs
79	R	2.48	3	3,960	0	32	0	0	0	0
79	L	2.41	10	13,200	536	32	0.29	0.28	370	40
80	R	1.48	2	2,640	16	38	0.02	0.02	0	0
80	L	1.75	5	6,600	2,178	38	1.95	1.88	1,241	119
81	R	0.77	3	3,960	0	27	0	0	0	0
81	L	1.04	7	9,240	3,397	27	3.64	3.51	1,769	185
82	R	0.86	5	6,600	33	33	0.05	0.05	26	0
82	L	0.95	10	13,200	2,487	33	3.57	3.44	2,534	264
83	R	0.80	3	3,960	65	30	0.10	0.10	40	0
83	L	0.74	5	6,600	1,642	30	2.75	2.65	1,267	132
84	R	2.08	4	5,280	504	39	0.39	0.38	198	26
84	L	2.04	8	10,560	520	39	0.41	0.40	409	53

APPENDIX C

TAG RETURN DATA

Table 28. Individual tag returns of cutthroat trout tagged in 1990 in the upper, middle, and lower segments of the Yellowstone River between Yellowstone Lake and Upper Falls and recaptured in 1990 and 1991. (1) = tag location by river segment; (2) = sex: male, female, or immature; (3) = sexual maturity when tagged; (4) date tagged; (5) = recapture location; (6) = sexual maturity when recaptured; (7) = recapture date; (8) = days from time tagged to time recaptured; YSL = Yellowstone Lake; UP = upper segment; LEH = LeHardy Rapids; MID = middle segment; LOW = lower segment; PRE = pre-spawner; RIPE = ripe spawner; POST = post-spawner; and IMM = immature non-spawner.

(1) Tag loc	(2) Sex	(3) Tag mat.	(4) Tag date	(5) Rec loc.	(6) Rec mat.	(7) Recap. date	(8) Days
UP	M	5	06/05/90	YSL	.	06/26/90	21
UP	.	.	.	YSL	.	06/27/90	.
UP	F	RIPE	06/06/90	UP	.	09/20/92	833
UP	.	.	.	LEH	.	06/11/91	.
UP	.	.	.	LEH	.	07/21/90	.
UP	.	.	.	MID	.	07/12/90	.
UP	.	.	.	MID	.	07/15/90	.
UP	M	PRE	06/05/90	MID	.	07/15/90	40
UP	F	PRE	06/05/90	MID	.	07/19/90	44
MID	M	RIPE	06/24/90	YSL	.	07/02/90	8
MID	F	PRE	05/29/90	UP	.	07/30/91	427
MID	F	POST	05/30/90	UP	.	09/08/90	101
MID	.	.	.	LEH	.	06/23/90	.
MID	.	.	.	LEH	.	07/08/91	.
MID	M	PRE	05/29/90	LEH	RIPE	06/04/90	6
MID	M	PRE	05/30/90	LEH	RIPE	06/11/90	12
MID	F	PRE	05/29/90	LEH	RIPE	06/18/90	20
MID	F	PRE	05/30/90	LEH	RIPE	06/25/90	26
MID	F	PRE	05/30/90	LEH	RIPE	06/25/90	26
MID	F	PRE	05/24/90	LEH	POST	06/11/90	18
MID	F	RIPE	05/23/90	LEH	RIPE	06/04/90	12
MID	M	RIPE	05/29/90	LEH	POST	07/02/90	34
MID	M	RIPE	05/24/90	LEH	LEH	06/24/91	396
MID	F	POST	05/30/90	LEH	POST	06/04/90	5
MID	F	POST	05/29/90	LEH	POST	06/18/90	20
MID	F	POST	05/30/90	LEH	POST	07/09/90	40
MID	.	.	.	MID	.	06/30/90	.
MID	.	.	.	MID	.	07/05/90	.
MID	.	.	.	MID	.	07/05/90	.
MID	.	.	.	MID	.	07/05/90	.