Ecology of Yellowstone cutthroat trout and an evaluation of potential effects of angler wading in the Yellowstone River
by Barbara Marie Kelly

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

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Barbara Marie Kelly

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This thesis has been read by each member of the graduate committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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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 the Yellowstone River after the last ice age, 8,000 years ago, and now this population is the largest concentration of native interior cutthroat trout (Behnke 1992). The Upper Falls and Lower Falls of the Yellowstone River, downstream from Yellowstone Lake, have prevented upstream movement of non-native fishes into the system, and Federal legislation and National Park Service policies have also protected this population. The current goal of the Yellowstone National Park aquatic 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 Saprolegnia 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

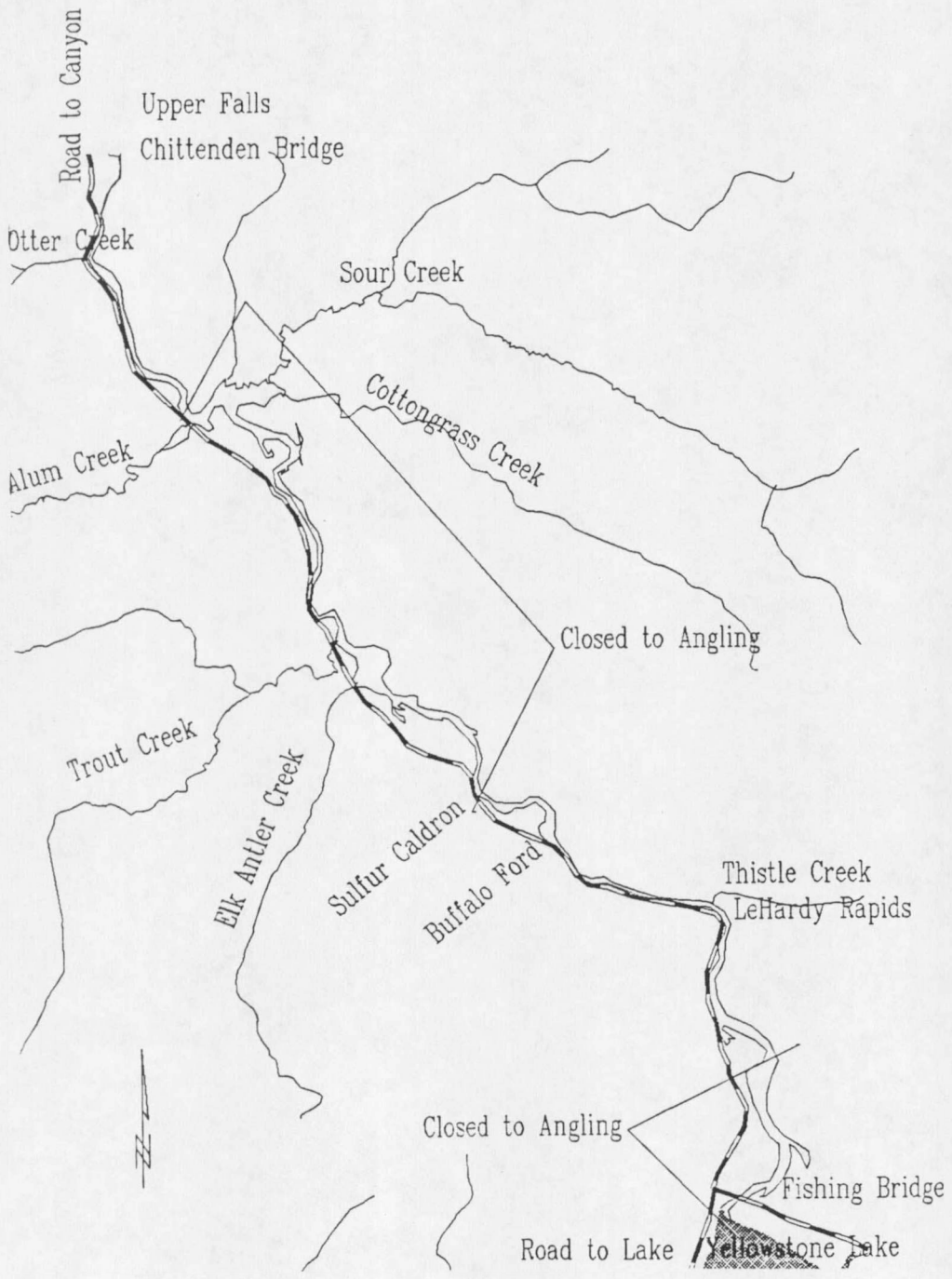

Figure 1. Yellowstone River, Yellowstone National Park, Wyoming, from Yellowstone Lake to the Upper Falls.

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).

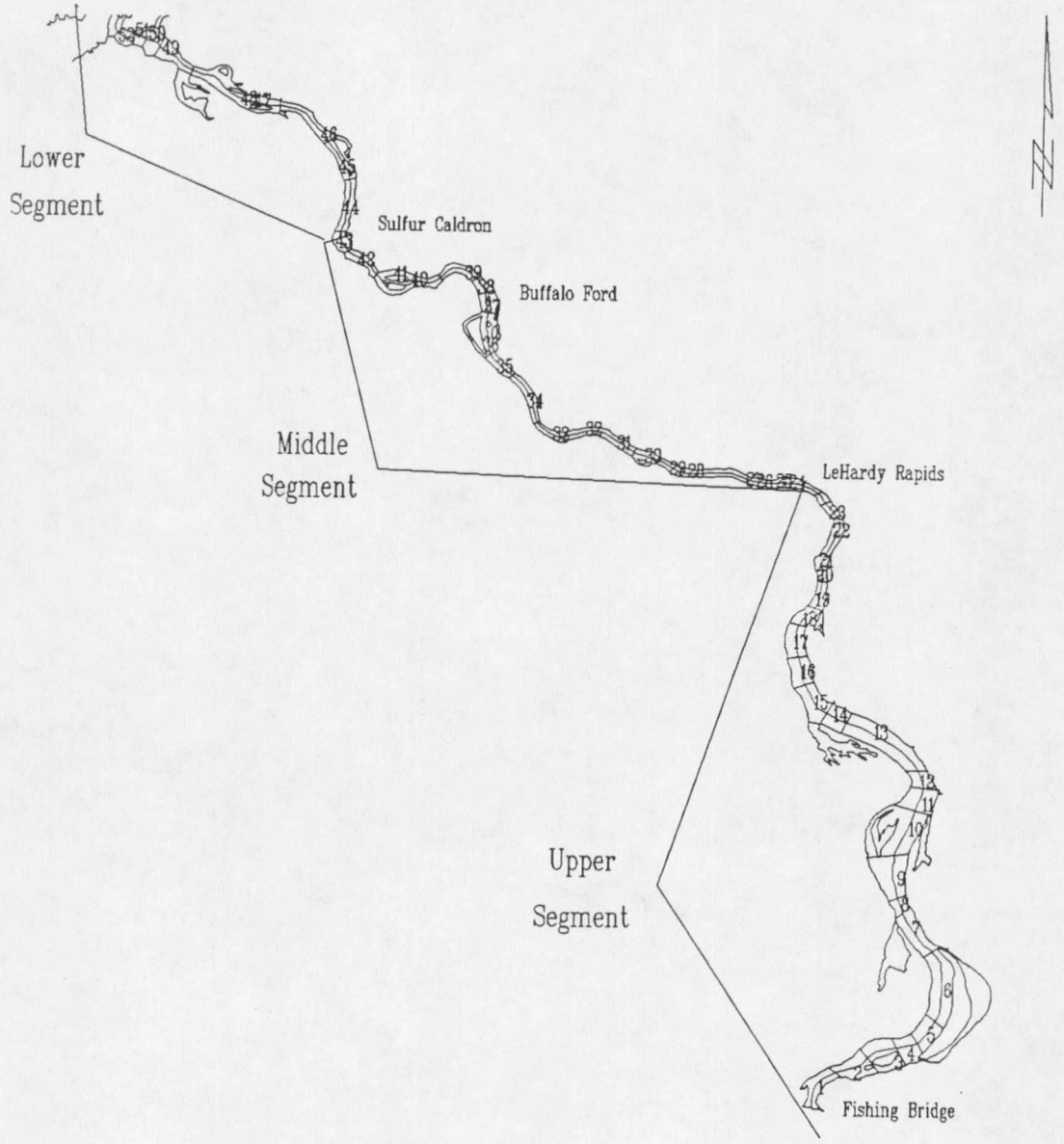

Figure 2. Sections 1-52 in the upper, middle, and lower segments of the Yellowstone River from Yellowstone Lake to mid Hayden Valley.

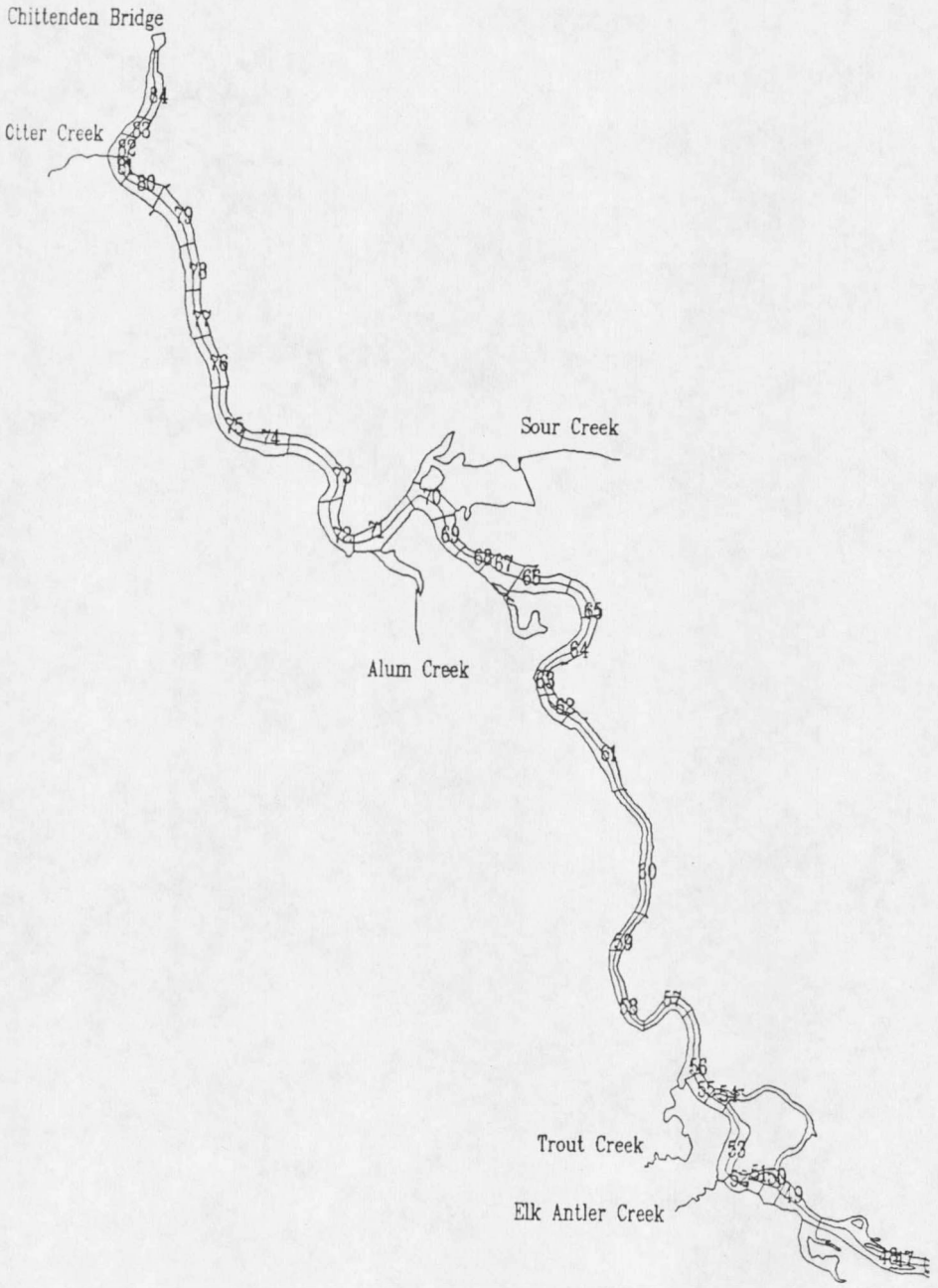

Figure 3. Sections 47-84 in the lower segment of the Yellowstone River from mid Hayden Valley to Upper Falls.

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

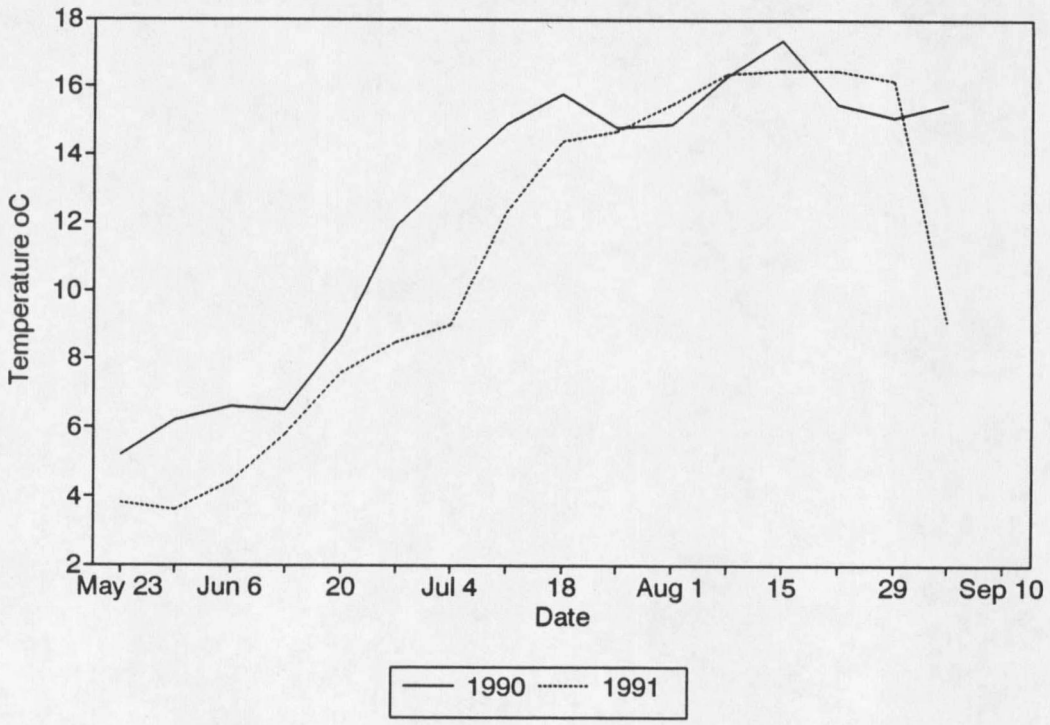

Figure 4. Mean weekly water temperatures (°C) measured in the Buffalo Ford area (section 39) of the Yellowstone River, 20 May - 8 September 1990 and 12 May - 8 September 1991.

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 temp- erature	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 temp- erature	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 temp- erature	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).

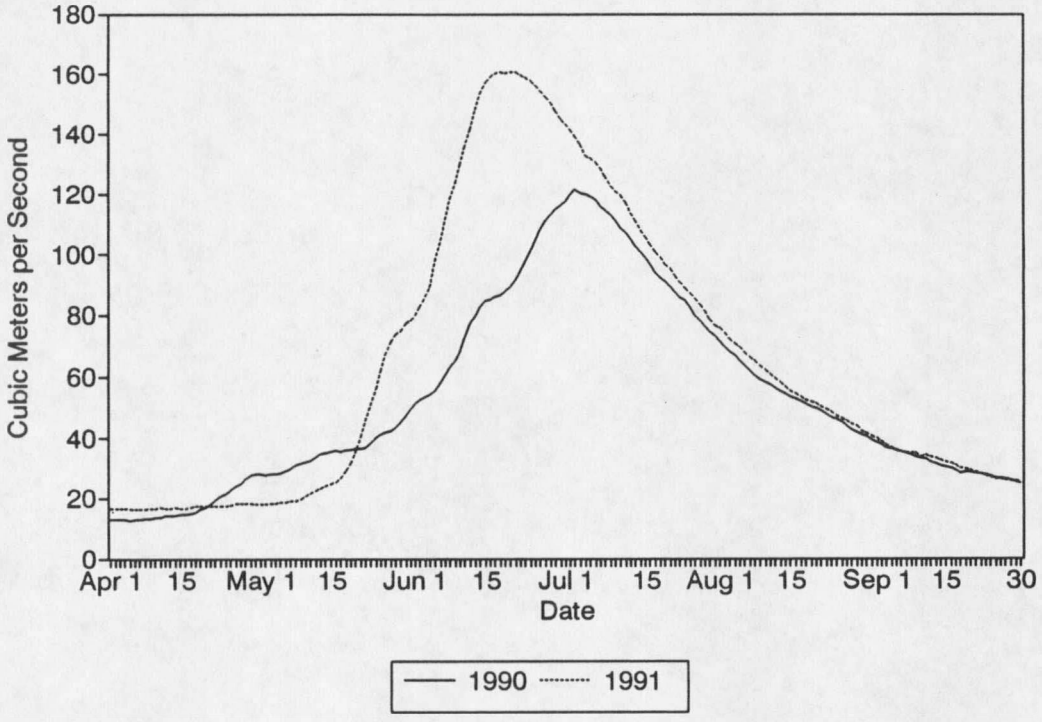

Figure 5. Mean daily discharge, in cubic meters per second, measured at a U.S.G.S. (1991) staff gauge located in the Yellowstone River 0.5 km below Yellowstone Lake, April - September, 1990 and 1991.

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

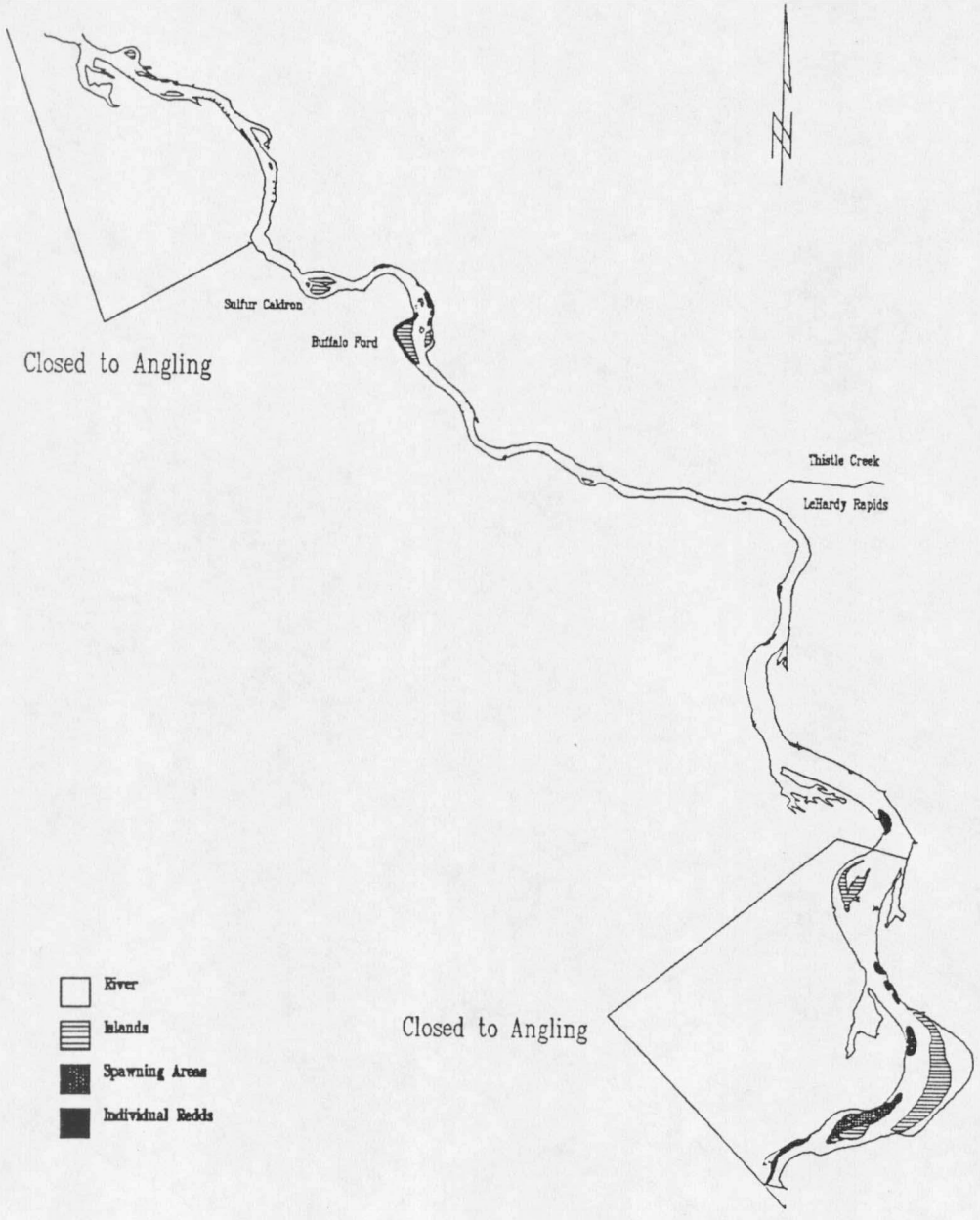

Figure 6. Spawning areas and redds in the Yellowstone River from Yellowstone Lake to mid Hayden Valley, 1991.