ASSESSMENT OF TRIBUTARY POTENTIAL FOR WILD RAINBOW TROUT RECRUITMENT IN HEBGEN RESERVOIR, MONTANA

by

Darin Allen Watschke

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APPROVAL

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Darin Allen Watschke

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Dr. Thomas E. McMahon

Approved for the Department of Ecology

Dr. David W. Roberts

Approved for the College of Graduate Studies

Dr. Joseph J. Fedock

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Darin Allen Watschke

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ABSTRACT

Trout fisheries in Montana reservoirs are almost entirely maintained by stocking hatchery fish. An exception is Hebgen Reservoir, where wild rainbow trout *Oncorhynchus mykiss* were established in 1979. Continued, unexpectedly low gill net catch rates of rainbow trout led to the objective of this study, which was to assess tributary production of wild rainbow trout and identify potential limiting factors. A combination of redd surveys, adult, young-of-the-year (YOY; age-0), and juvenile (age-1 and age-2) trapping, and measurements of water temperature and spawning and rearing habitat was used to assess spawning use and habitat characteristics of 11 tributaries, comprising 170 stream kilometers, in 2002 and 2003. A total of 5,642 redds were counted, suggesting the number of spawners was not limiting. Redd occurrence within individual habitat units was positively associated with spawning gravel densities, and negatively associated with rearing habitat density. At the tributary scale, redd abundance was positively associated with availability of both spawning and rearing habitat. Temperature also appeared to influence spawning as most production occurred in tributaries with May to July temperature averaging 8 to 10 °C. The majority (80%) of spawning occurred in only two of the 11 tributaries (Duck Creek and the South Fork of the Madison River). These tributaries contained a combination of abundant spawning and rearing habitat. Rainbow trout YOY production estimates exceeded 4.7 million in 2002 and 2003 combined and abundant YOY and age-1 and age-2 juvenile rainbow trout were captured during spring and summer outmigrations in two lake tributaries. Estimates of available spawning (7.0 ha) and rearing habitat (1.1×10^6 m^3) suggest that tributary habitat does not limit the rainbow trout population of Hebgen Reservoir from reaching a self-sustaining level that would meet the recreational requirements of the sport fishery. However, high densities of YOY and juvenile brown trout *Salmo trutta* captured during outmigrant trapping of rainbow trout suggests that competition and predation may be affecting overwinter survival of rainbow trout in the tributaries. Protection and enhancement of tributary habitat in other reservoirs offers the potential for greater use of wild trout for maintenance of trout fisheries in lentic systems.

INTRODUCTION

Trout management in Montana has changed appreciably over the past 100 years. As in other western states, streams were widely stocked with nonnative trout species beginning around the turn of the 20th century (Behnke 1992). From the 1930s to the 1950s, stocking of subcatchable-size trout was a common management practice, followed by a shift to stocking primarily catchable-size trout from 1955 through 1972 (Vincent 1987). In 1973, the current era of self-sustaining wild trout management began with the cessation of stocking in nearly all streams in the state (Vincent 1987; Montana Outdoors 2004).

The conversion from trout stocking to self-sustaining wild trout fisheries has been a cornerstone of trout management in Montana streams for the past 30 years. The transition to wild trout management occurred largely as a result of studies conducted on the Madison River and O'Dell Creek from 1967 through 1972. This research revealed that stocking of catchable trout had apparently substantial negative effects on wild brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* populations (Vincent 1987; Montana Outdoors 2004).

Hatchery stocks can have negative effects on wild populations in several ways. The presence of hatchery stocks can lead to hybridization, genetic contamination, and increased competition for food and space (Hindar et al. 1991; Krueger and May 1991; Waples 1991). Stocking may also lead to increased predator attraction and disease transmission (White et al. 1995), displacement of wild fish (Mesa 1991; McMichael et al. 1999), and can result in declines in wild populations through competition for spawning and rearing habitat (Kostow et al. 2003). In addition, survival rates and, hence, cost effectiveness of stocking programs can vary widely and can generate further demand, resulting in increased public dependence on hatchery trout (Wiley et al. 1993).

In contrast, trout stocking can be a very effective management tool in lakes and reservoirs where reproduction is limited. Stocking can redirect and absorb consumptive effort, by decreasing fishing pressure on wild populations, and can help garner support for habitat management and wild trout policies in streams (Van Vooren 1995). Fisheries management of Montana lakes and reservoirs is based on maintaining wild fish populations where natural spawning occurs (MTFWP 1986). However, many Montana lakes and reservoirs have little wild trout recruitment because of inadequate spawning habitat, and are supplemented with hatchery-reared fish to maintain recreational fisheries (MTFWP 1986). Over half (11 of 18) of the large (1,200 ha and larger) reservoirs in Montana were stocked in 2003 (R. McFarland, Systems Analyst, Montana Department of Fish, Wildlife and Parks (MTFWP), personal communication; MTFWP 2004a). For example, one of the most valuable and popular recreational trout fisheries in the state of Montana, Canyon Ferry Reservoir of the Missouri River system, relies on annual stocking of rainbow trout to maintain a quality fishery because of a lack of tributary spawning habitat (McMahon 1992; MTFWP 2000).

Hebgen Reservoir in southwest Montana, however, appears unique among many reservoirs because of the presence of 10 apparently high quality spawning and rearing tributaries. Hebgen Reservoir has a good quality brown trout fishery, established in the 1930s, that has been self-sustaining since the last hatchery stocking in 1956 (Hetrick

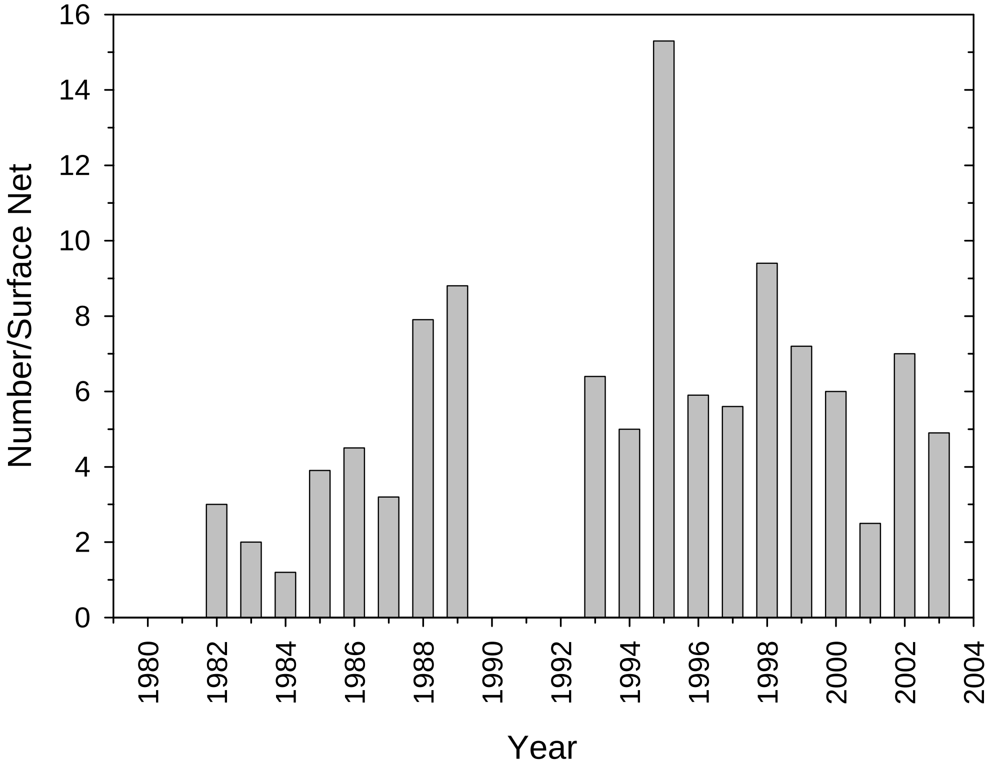
1994a). The current management goal for Hebgen Reservoir is to obtain a self-sustaining wild rainbow trout population that can support a high quality recreational fishery. A recreational fishery for rainbow trout was established in the mid 1950s in Hebgen Reservoir. Several strains of rainbow and cutthroat trout *Oncorhynchus clarki* have been stocked since the establishment of the fishery (Appendix A). Montana Department of Fish, Wildlife and Parks stocked catchable and subcatchable rainbow trout, primarily Arlee and Shasta strains, in Hebgen Reservoir from 1954-1979 (ERI and NWPS 2002). In most years, however, these hatchery stocks experienced poor survival, slow growth rates, and poor catch rates. As a result, MTFWP decided to manage Hebgen Reservoir as a wild trout fishery in 1979 and began stocking wild strains exclusively.

The intent of stocking wild-strain trout was to build a population that would reproduce naturally, thereby providing ample recruitment to sustain a productive fishery without the dependence and expense associated with annual stocking (Hetrick 1994b). Wild-strain McBride cutthroat trout were stocked from 1979 through 1986. The McBride cutthroat trout had high survival rates, but did not establish significant spawning runs in Hebgen Reservoir tributaries (Hetrick 1993a). Supplementation shifted to two wild strains of rainbow trout in 1987, the Eagle Lake and DeSmet (MTFWP 2004a). The system has been stocked annually with about 100,000 Eagle Lake rainbow trout fingerlings in recent years (1996 through 2004) (MTFWP 2004a). Wild rainbow trout spawning runs have since been established in several tributaries, but the extent of tributary recruitment is unknown (Oswald et al. 1990; Fredenberg 1991).

Although the stocking of wild rainbow trout strains has resulted in the successful establishment of wild spawning runs, previous investigations suggested that recruitment of wild rainbow trout to the reservoir has been inadequate to support a recreational fishery. Hetrick (1994a) considered the rainbow trout population in Hebgen Reservoir to be declining throughout the late 1980s and early 1990s. Similarly, the Ecosystems Research Institute and North West Power Services (ERI and NWPS) reported that rainbow trout gill net catch rates declined 50% from 1980 to 1994 in Hebgen Reservoir in both spring and autumn gill net surveys (ERI and NWPS 2002). Additionally, numerous complaints were filed with MTFWP by anglers and local businesses during this period (1980-1994) expressing dissatisfaction in the Hebgen Reservoir rainbow trout fishery (Hetrick 1994a; ERI and NWPS 2002).

Hebgen Reservoir annual spring gill net surveys have revealed wide fluctuations in rainbow trout abundances since wild trout management was initiated in 1979 (Figure 1). From 1982 to 2003, rainbow trout gill net catch rates have averaged less than 6 fish/net (Figure 1). In contrast, brown trout have established a strong, self-sustaining population in Hebgen Reservoir, with gill net catch rates 2 to 3 times higher than that of rainbow trout. In addition, Utah chub *Gila atraria* gill net catch rates have averaged over 50 fish/net since 1996. Area fisheries managers believe that the rainbow trout population level is lower than expected and the full potential for wild reproduction has not been met (P. Byorth, Fisheries Biologist, MTFWP, personal communication). A perplexing question is why wild rainbow trout recruitment to the adult population appears to be limited in Hebgen Reservoir, despite the presence of apparently high quality spawning tributaries.

Figure 1. Hebgen Reservoir spring surface gill net catch rates (average number of fish per surface net) for rainbow trout from initiation of wild trout management through 2003. No data were collected from 1979-1981 and from 1990-1992.



Previous studies conducted on Hebgen Reservoir tributaries suggested that spawning activity and young-of-the year (YOY; age-0) recruitment have been substantial in certain areas, but are much lower than anticipated in others. Efforts were made to document the timing, intensity, and duration of rainbow trout spawning and YOY recruitment in 1989 (Oswald et al. 1990). Rainbow trout redds and outmigrant YOY were observed in 8 tributaries (Oswald et al. 1990). Based on outmigrant YOY trapping, Fredenberg (1991) estimated that 590,000 rainbow trout YOY were recruited to Hebgen Reservoir upon emergence from tributary gravels. These findings indicated that newly emergent YOY were being recruited to Hebgen Reservoir, but the occurrence of juvenile (age-1 and age-2 wild rainbow trout that overwinter in tributary rearing habitats) recruitment was not detected. This investigation also revealed that a wide variation of thermal regimes existed across Hebgen Reservoir tributaries (Fredenberg 1991). Further investigation was recommended to more closely evaluate adult spawning and YOY outmigration levels in order to determine factors potentially limiting tributary recruitment (Fredenberg 1991).

Wild rainbow trout populations typically exhibit multiple juvenile life history forms that contribute to adult recruitment, the composition of which can vary among populations (Kwain 1971, 1981; Biette et al. 1981; Rosenau 1991; Northcote 1997). Natal stream-reared juveniles, of age-1 to age-3, are often the dominant life history forms recruited to adult populations (Stauffer 1972; Van Velson 1974; Munro 2004). For instance, over 80% of adult rainbow trout of the mainstem Missouri River, Montana, were recruited as yearling (age-1) juveniles, yet YOY comprised 65% of the total number of outmigrants (Munro 2004). The occurrence of multiple juvenile life history forms is suspected for the Hebgen Reservoir fishery also, but has not been documented in past studies and the relative contribution of each to overall adult recruitment is unknown.

Wild adfluvial trout populations in Montana reservoir systems are often limited by the availability of tributary spawning habitat (MTFWP 1986). Factors limiting salmonid production in lotic environments may include sub-optimal temperature, the quantity and quality of spawning and rearing habitat, and the inaccessibility to tributary habitat because of migration barriers (Bjornn and Reiser 1991). Inventories of physical habitat conditions of several Hebgen Reservoir tributaries suggested that a combination of these factors may be limiting rainbow trout recruitment (Oswald et al. 1990; Fredenberg 1991).

The primary goals of this study were to: 1) assess rainbow trout production levels among tributaries and; 2) determine if tributary habitat conditions limit rainbow trout recruitment to Hebgen Reservoir. The specific objectives of the study were to: 1) estimate the relative contribution of each tributary to wild rainbow trout production; 2) determine the quantity and quality of tributary habitat associated with wild reproduction and YOY (age-0) and juvenile (age-1 and age-2) rainbow trout recruitment to the reservoir; and 3) determine life history characteristics for spawning adult and juvenile outmigrant rainbow trout from a subset of the population. The working hypotheses of this study were: 1) a lack of spawning and rearing habitat or inaccessibility to spawning and rearing habitat limits tributary production and hence adult population size; and 2) tributary reared, juvenile (age-1 and age-2) rainbow trout contribute substantially to tributary recruitment to Hebgen Reservoir.

STUDY AREA

Hebgen Reservoir is a 5,140 ha impoundment on the upper Madison River, located in southern Gallatin County (Township 12 South, Range 4 East), Montana (Figure 2). The reservoir is formed behind a concrete and earth fill dam, completed in 1914 by the Montana Water and Irrigation Company (Martin 1967). The spillway is located about 29 km northwest of West Yellowstone (lat 44° 51' 50" long 111° 20' 05"), Montana, and 19 km west of the Yellowstone National Park west boundary.

Hebgen Dam is owned by Pennsylvania Power and Light (PPL) Montana and is operated for water storage under a permit issued by the Federal Energy Regulatory Commission (FERC 2000). Hebgen Reservoir is maintained at a normal, full pool elevation of between 1,990 and 1,992 m above sea level from 20 June through 1 October (PPL 2000). Throughout an annual cycle, the water level undergoes an average vertical fluctuation of 3.5 m, with a minimum elevation of 1988.5 m between 1 September and 31 March (PPL 2000). Maximum storage capacity of the reservoir is 46,560 hectare-meters (377,500 acre-feet), the total surface area at full pool is 52 km^2, and maximum depth is 26 m (Martin 1967).

The Hebgen basin drainage area encompasses over 2,000 km^2 (Table 1). Land ownership of the basin area includes private land (2%), Gallatin National Forest (38%), and Yellowstone National Park (60%). Ten major tributaries flow directly into Hebgen Reservoir, and an additional six minor tributaries flow into major tributaries (Figure 2; Table 1). All tributaries were identified as possessing potential for spawning salmonids (Oswald et al. 1990) and were included in this study.

Figure 2. Map of the Hebgen Reservoir basin.

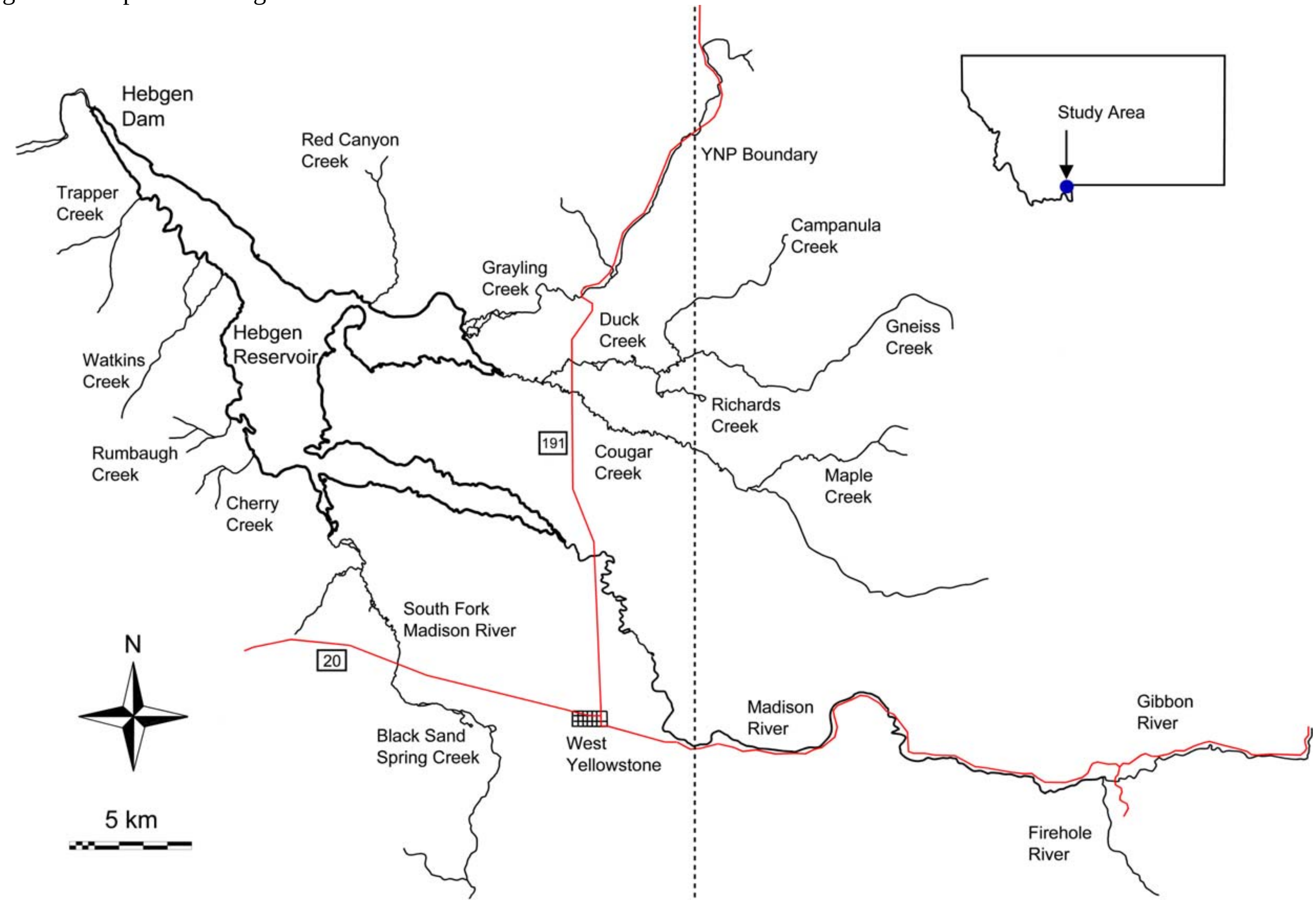


Table 1. Physical characteristics of the 10 major and 6 minor tributaries to Hebgen Reservoir. Major tributaries are listed by stream order and minor tributaries and parenthesized values are included in major tributary totals. Stream length is expressed as linear stream kilometers that are accessible to fishes of Hebgen Reservoir. Drainage area was estimated from USGS, 7.5 minute, topographical maps.

Major Tributary Minor Tributary	Stream Order	Drainage Area (km^2)	Stream Length (km)
Madison River	5	1,087	53.3
Firehole River	4	(510)	(2.1)
Gibbon River	4	(279)	(12.1)
South Fork Madison River	4	335	31.6
Black Sand Spring Creek	2	(3)	(1.8)
Grayling Creek	4	174	19.9
Duck Creek	3	127	29.1
Campanula Creek	2	(44)	(3.4)
Gneiss Creek	2	(36)	(11.8)
Richards Creek	1	(12)	(1.0)
Cougar Creek	3	212	27.5
Trapper Creek	3	18	1.6
Watkins Creek	3	35	4.9
Cherry Creek	2	7	0.7
Red Canyon Creek	2	22	0.5
Rumbaugh Creek	2	7	0.9
Total	--	2,024	170

Two major elevational land types are present in the Hebgen basin. Headwater sections (above 2,200 m), including first and second-order streams, occupy areas of dense conifer forests with scattered alpine meadows (Davis and Shovic 1996). Streams in these areas are moderately to highly entrenched and are characterized by low sinuosity and moderate to high gradients (2 to 10%). Lower sections (below 2,200 m), comprised primarily of third, fourth, and fifth-order streams, occupy terraced valley bottoms consisting of sparse conifer stands, mountain meadows, and riparian communities (Davis and Shovic 1996). They are associated with broad, well-defined flood plains, are moderately to highly sinuous, and are low gradient (< 2%).

Most of the Hebgen basin is covered by up to 30 m of obsidian gravel that lies between the extensive Bull Lake moraines and the smaller Pinedale moraines (Adams 1990). The Hebgen basin drainage area within Yellowstone National Park (60%) is associated with this large area of glacial outwash and alluvial deposition weathered from obsidian and rhyolite (Davis and Shovic 1996; O'Neil and Christiansen 2002). Area soils have high water-holding capabilities resulting in predominant upwelling in the form of springs (K. Pierce, Geologist, U.S. Geological Survey Northern Rocky Mountain Research Center, personal communication) and the potential for surface runoff is low (Davis and Shovic 1996). The geology of the remaining area of the Hebgen basin (40%) consists primarily of stratified alluvial deposits and interbedded layers of bedrock, sandstone, shale, welded tuff, rhyolite and diorite (Davis and Shovic 1996; O'Neil and Christiansen 2002). Soils in these areas have lower water-holding capacities and groundwater-fed springs are rare (Davis and Shovic 1996).

Hebgen Reservoir is a popular recreational trout fishery experiencing over 38,000 angler-days annually (7th in Montana for large reservoir fishing pressure) (MTFWP 2004a). The fish assemblage is comprised primarily of brown trout, rainbow trout, Utah chub, and mountain whitefish *Prosopium williamsoni* (MTFWP 2004a).

Limited numbers of cutthroat trout, brook trout *Salvelinus fontinalis*, Arctic grayling *Thymallus arcticus*, longnose sucker *Catostomus catostomus*, longnose dace *Rhinichthys cataractae*, and mottled sculpin *Cottus bairdi* have also been documented in the reservoir (Graham 1955).

METHODS

Redd Surveys

The relative contribution of each tributary to total spawning effort was assessed through basin wide redd counts conducted in 2002 and 2003. Surveys included all Hebgen Reservoir tributaries (Figure 2; Table 1) and encompassed about 170 stream kilometers. Preliminary field reconnaissance in May and June was conducted both years to determine the appropriate time for redd counts. Redd counts were performed following peak runoff in late June when the majority of redd construction was complete and few adults were present, yet redds were still visible. Each count comprised a total census of redds in each tributary. Crews of two began at the mouth of each tributary and continued upstream until likely barriers to upstream migration (ratio of height of falls to depth of pool below falls >1:1.25) were encountered (Stuart 1962). Passage barriers were photographed and their position recorded with a GPS unit.

Redds were visually identified by the presence of a pit or depression and associated tail area of "cleaned" gravel; each pit with a distinct tail was counted as a redd (Spalding 1997). Counts were conducted incorporating the degree of superimposition; redds that overlapped by one third or greater were counted as one. To assess the number of false redds and potential observer misidentification, 10% of redds in each tributary were randomly selected and partially excavated to check for the presence of ova (Witzel and MacCrimmon 1983; Knapp and Vredenburg 1996; Downing 2000). The rate of false redds was incorporated in tributary production estimates. Redd excavations also included a measurement of egg pocket depth to the nearest centimeter (DeVries 1997). Egg depth measurements were later used to determine the average depth of substrate material collected during redd substrate core sampling.

Adult Spawner and Outmigrant Trapping

Adults

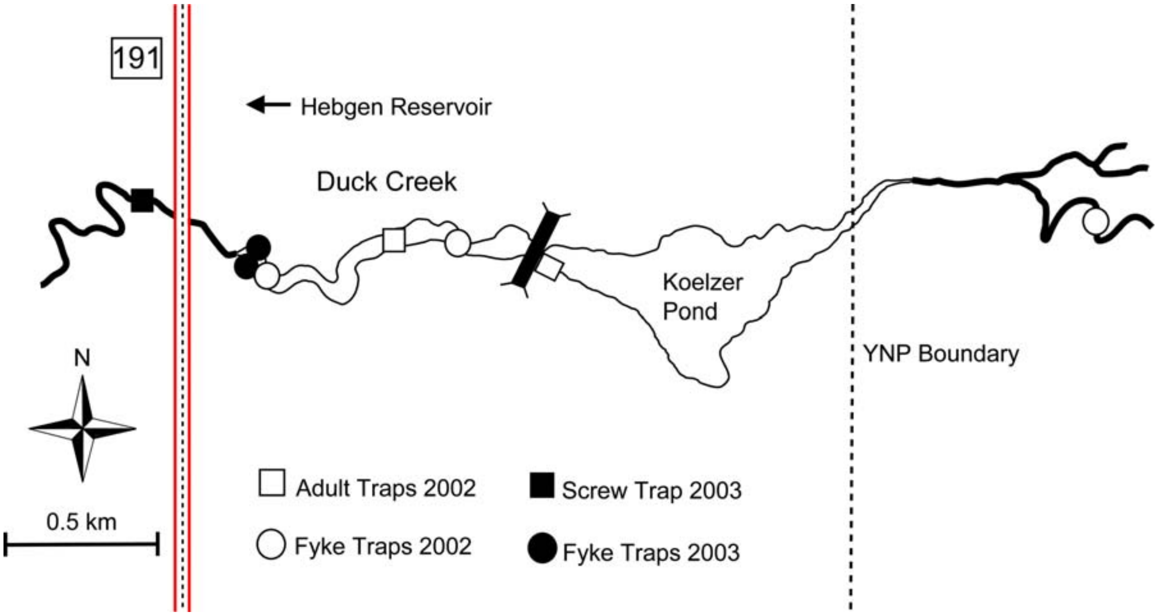
Fredenberg (1991) trapped over 1,200 upstream migrating adult rainbow trout in Duck Creek in May 1990 and identified Duck Creek as the largest producer of wild rainbow trout (estimated 590,000 YOY outmigrants) in the Hebgen basin. I trapped adult upstream migrants on Duck Creek to examine life history characteristics from a subset of the Hebgen Reservoir population and to determine abundance and timing of upstream migration in relation to the number of redds observed in Duck Creek 2002.

An upstream migrant trap was installed about 4.5 km from the mouth and 700 m downstream from the Yellowstone National Park boundary (Figure 3). The aluminum conduit weir and trap box was positioned directly above the Koelzer Pond fish ladder culvert, which provides upstream passage around the man-made dam (Fredenberg 1991). The trap was installed on 1 April and was operated until 19 June. The trap was checked at least every other day and several times each day during peak migration (mid-May through mid-June).

The adult trap generally remained operable throughout the trapping period. However, on 30 April 2002 the pond trap became inoperable when local landowners lowered the water level in Koelzer pond necessitating the addition of a second upstream migration trap (cross channel weir) positioned 75 m downstream of the pond trap (Figure

3). The downstream trap was in operation until flows and landowner cooperation permitted further use of the pond trap (30 April – 22 May). There was an initial "downtime" of 12 hours prior to the installation of the second trap on 30 April and on 13 May passage around the downstream trap site was allowed for 2 hours after bison *Bison bison* collapsed the left side of the weir. Apart from these occasions, trapping efforts were continuous from 1 April through 19 June.

Figure 3. Map of the locations of adult and juvenile trap sites on the Duck Creek drainage. The black bar indicates the location of the Koelzer Dam.



Upstream migrating adults were anesthetized, measured for length and weight, gender was recorded, and scale samples were collected for age determination. Deep anesthesia with a minimal recovery time was achieved with a dose of 30-40 mg/L of clove oil (Prince and Powell 2000). Scales were taken from an area posterior of the dorsal fin and above the lateral line (Mogen 1996).

Outmigrants

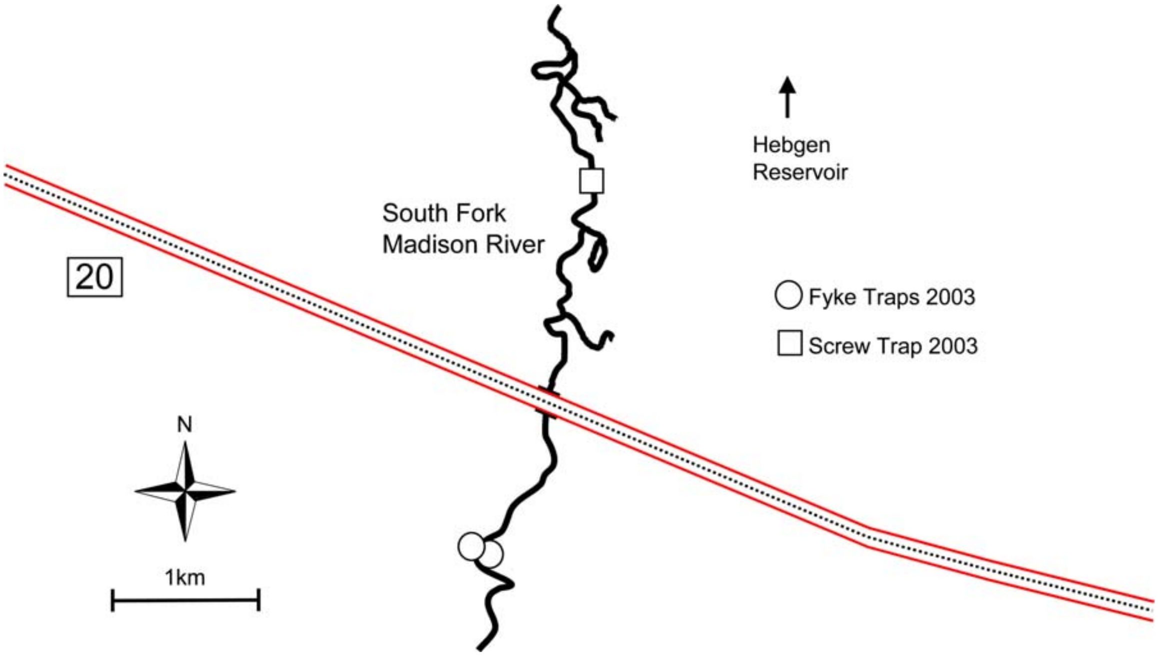
Enumeration and timing of emigration of outmigrant YOY (age-0) and juvenile (age-1 and age-2) rainbow trout from Duck Creek and the South Fork Madison River were estimated using a series of fyke and screw traps during spring and summer, 2002 and 2003. In 2002, fyke traps were operated from 20 June through 13 August on Duck Creek. In 2003, fyke traps were deployed from mid-March through the end of May, and screw traps were in operation from late May through mid-August on both Duck Creek and the South Fork of the Madison River. Fyke and screw traps were in operation for a four-day period each week.

Fyke traps were positioned in the thalweg in three locations on Duck Creek in 2002 to quantify outmigrant YOY rainbow trout production in relation to the number of upstream redds. Each fyke trap had a rectangular entrance (80 cm in width by 48 cm in height) framed of 5 mm diameter metal rod that was secured flush to the stream bed with two metal fence posts on either side of the trap entrance (Fredenberg 1991; Hennessey 1998). Mesh netting (1.6 mm mesh), 1.5 m in length, was sown around the frame in a conical shape that tapered to a 10 cm threaded PVC collar fastened to a plastic trap box (94 cm in length, 61 cm in width, and 46 cm in height) where captured fish were retained. Two trap "wings" (122 cm in width and 76 cm in height), constructed of 0.6 cm neoprene mesh panels overlaid with 1.6 mm mesh netting, were fastened at a 45° upstream angle to the trap entrance to extend the overall width of the trap to about 2.6 m, thereby diverting YOY into the trap entrance. The upstream end of the "wing" panels were secured to additional fence posts positioned about 60 cm upstream and 90 cm to each side of the trap entrance.

All three Duck Creek fyke traps were placed upstream of U. S. Highway 191 (Figure 3) because less than 10 redds were observed downstream of this point during 2002 redd surveys. The uppermost trap was positioned immediately inside the YNP boundary (upstream trap site), a mid-stream trap was installed directly below Koelzer Pond (midstream trap site), and a downstream trap was operated upstream of the U. S. Highway 191 culvert (downstream trap site) (Figure 3). Locations were chosen in these areas to estimate the number of YOY: 1) entering the Koelzer Pond upon emerging from redds constructed in YNP (upstream trap site), 2) exiting Koelzer Pond (midstream trap site), and 3) emigrating to Hebgen Reservoir (downstream trap site). In 2003, fyke traps were operated on Duck Creek and the South Fork of the Madison River. Two traps were located side-by-side at one site in each tributary (Figure 3, 4). Traps were located downstream of the majority of redds constructed the previous year.

Traps were checked and cleaned daily. Young-of-the-year (YOY) were identified, counted, and fork length (mm) was measured on a haphazard sample of 20 YOY each day to determine average length. Weekly trap efficiency estimates were calculated at all trap sites. Young-of-the-year captured during the first night of operation each week were marked with a 1:30,000 Bismarck Brown Y dye solution. Dye marks were distinguishable for at least 4 days (Ward and Verhoevon 1963; Lawler and Fitz-Earle 1968; Hennessey 1998). A concentration of 1:30,000 and a 1-hr immersion time was chosen for YOY marking because this combination yielded the best retention, shortest immersion time, and the lowest associated mortalities in recent laboratory trials (Hennessey 1998). I immersed YOY in solution for one hour in an aerated tank and then released them 200 m upstream into the nearest slow water habitat (Fraley and Clancey 1988). Efficiency trials were conducted once a week within 24 hrs following release of the dyed individuals. The number of fish recaptured divided by the number of dyed fish released was used as an estimate of trap efficiency (Kennen et al. 1994). Efficiencies were extrapolated to estimate total numbers outmigrating to Hebgen Reservoir weekly. Weekly efficiencies were pooled when data were similar (chi-square test; $P > 0.05$) (Thedinga et al. 1994) and ninety-five percent confidence intervals (CI) for trap efficiencies were calculated from the binomial distribution (Roper and Scarnecchia 1996; Zar 1999).

Figure 4. Map of the locations of juvenile trap sites on the South Fork of the Madison River.



Rotary screw traps (Kennen et al. 1994; Thedinga et al. 1994) were deployed in spring 2003 to enumerate outmigrant juvenile (age-1 and age-2) rainbow trout that had overwintered in tributaries. The screw trap design allowed for trapping during high flow conditions. The 1.5 m-diameter traps were operated on Duck Creek and the South Fork of the Madison River from mid-May through early August (Figure 3, 4) for 4 days weekly and were checked at least every other day for the 4-day period. Captured juveniles were weighed, fork length was measured to the nearest mm, and scales were randomly collected from 10 fish per week from the Duck Creek trap site. All juveniles captured on the first trap night each week were fin clipped and released 200 m upstream. Weekly efficiencies were calculated (as described above) at both trap sites to estimate total numbers recruited to Hebgen Reservoir.

Relationships between migration and stream discharge were evaluated during all trapping periods in 2002 and 2003. The velocity-area method was used to estimate discharge at the Duck Creek and South Fork of the Madison River trap sites (McMahon et al. 1996). Staff gauges were installed and laminar flow cross sections were chosen near trap sites in order to establish a staff-height x discharge relationship. Discharge was measured at four different flows. Velocity measurements were taken with a Marsh-McBirney Model 2000 Flo-Mate®.

Age and Growth

To compare life history forms among rainbow trout recruited to Hebgen Reservoir from Duck Creek, a stratified random sample (stratified by gender and length class) of adult scales (n = 512 of a total of 2,735) and all juvenile (age-1 and age-2) scales (n = 109) collected at the Duck Creek adult and screw trap sites were examined. Scale samples were pressed on acetate sheets and the impressions were viewed with a compound microscope under 40 to 100× magnification. Standard ageing criteria for rainbow trout were used to identify annuli and estimate age (Kwain 1971; Van Velson 1974; Rosenau 1991; DeVries and Frie 1996; Munro 2004). Age at outmigration was assessed through determination of migration checks on adult scales; migration checks were defined as zones of increased growth revealed in scale circuli spacing (Rosenau 1991; Munro 2004). Circuli formed during tributary rearing were assumed to be thinner and more closely spaced than circuli formed in Hebgen Reservoir. Scales obtained from outmigrant juveniles were analyzed to establish length-at-age and to relate age-at-migration to migration checks observed in adult scales.

Length frequency distributions were constructed for all juvenile rainbow trout captured at the Duck Creek and South Fork Madison trap sites. Average length-at-age, for age-1 and age-2 rainbow trout, was obtained from Duck Creek juvenile scales (n = 109). Composite length frequency distributions were then divided into age classes, with the use of a computer algorithm program (NORMSEP, FiSAT II 2004), based on mean length-at-age from scale samples. Estimates of the proportion of age-1 and age-2 juveniles outmigrating from each tributary were then made from the decomposed distributions.

A sample of 112 juvenile rainbow trout scales from the Missouri River with known age (age 1 through age 3) and migration history (see Munro 2004) was examined to test observer accuracy at ageing and identifying the presence and location of migration checks. The sample was read 3 times, in a random order, and 91% accuracy was achieved for ageing and for presence and location of migration checks. A sample of

100 adult Duck Creek scales were aged twice randomly and then read twice by a second, experienced scale reader for verification of age determination of older fish (86% agreement was achieved between readers). All Duck Creek scales (adults, n = 512; and juveniles, n = 109) were then read 3 times, in a random order by the same observer to determine age and presence and location of migration checks.

Tributary Characteristics Influencing Rainbow Trout Production

Temperature

Previous investigations indicated that water temperature may play a key role in determining which Hebgen tributaries support spawning runs and when spawning occurs (Oswald et al. 1990). Onset Stowaway Tidbit® thermographs were installed in riffle sections near the mouths of all mainstem tributaries during 2002 and 2003 (Figure 2). Thermographs were tested for accuracy (Chandler et al. 2002) and then programmed to record water temperatures at 2-hour intervals. Units were installed in mid-April and were retrieved in early October. The mean average daily temperature for the adult upstream migration and spawning period (1 April through 1 July) was evaluated in relation to the total number of redds constructed in each tributary.

Spawning and Rearing Habitat

Tributary habitat associated with wild rainbow trout reproduction and recruitment was assessed through basin-wide habitat inventories conducted in 2003. Habitat inventories encompassed all tributaries and the total linear stream distance (about 170 km) located downstream of identified passage barriers (Table 1). Spawning and rearing habitat measurements followed the terminology and methodology of the R1/R4 Fish and Fish Habitat Standard Inventory Procedures Handbook (Overton et al. 1997). Streams were subdivided into individual habitat units based on slow or fast water characteristics and by channel position (main, adjacent, or side channel). Fast water units included: cascades, high-gradient riffles, low-gradient riffles, runs, and glides. Slow water units included: backwaters, alcoves, ponds, and pools (dammed, plunge, and scour). Length and width of each habitat unit was measured to the nearest 0.1 m with a laser range finder, hip chain, or reel tape. Depth measurements were collected for slow water habitat units with a meter stick to estimate residual pool depth (difference between maximum depth and pool crest depth; Overton et al. 1997). Large woody debris (LWD) was counted as the numbers of LWD per habitat unit with dimensions of ≥ 3 m in length and ≥ 10 cm in diameter.

Percent stream gradient (RISE/RUN x 100; Overton et al. 1997) was calculated for each tributary. The difference in elevation between the mouth or lower end and the upper-most end of a tributary (RISE) was obtained with a GPS unit and United States Geological Survey 7.5 minute topographical maps. Tributary length (RUN) was calculated by adding the lengths of all main channel habitat units within the tributary.

The total area of spawning and rearing habitat per tributary was calculated to obtain basin-wide estimates of habitat availability (Bisson et al. 1982). Lengths and widths of all areas of potential spawning gravel (patches of substrate at least 0.25 m^2) containing substrate from 6-128 mm in diameter were measured with a meter stick (Bjornn and Reiser 1991; Schuett-Hames and Pleus 1995; Magee et al. 1996). Visual estimates of substrate size were made with the aid of a substrate-sampling quadrant (Hankin and Reeves 1988; Waite and Carpenter 1999; Mullner et al. 2000). Total available rearing habitat was estimated by summing the residual volumes of all pools and ponds. Residual volume (m^3) was expressed as the product of residual pool depth and surface area of each pool or pond unit. Spawning and rearing habitat density (available spawning habitat (m^2) or rearing habitat (m^3) divided by total surface area (m^2)) were calculated for individual habitat units. At the tributary scale, available spawning and rearing habitat were expressed as totals.

Habitat Analysis

Associations between habitat features and redd abundance were assessed at the habitat unit and tributary scale. Redd totals were converted to densities per m^2 for the unit-scale and total number of redds was used for the tributary-scale analysis. Habitat features included in the unit-scale analysis included available spawning habitat, available rearing habitat, and large woody debris frequency. As with redd counts, habitat features were converted to densities (per m^2) at the unit-scale and were expressed as totals (total m^2 or m^3 of each habitat feature present in each tributary) for tributary-scale analysis. Additional habitat features incorporated in the tributary-scale analysis included: gradient and average mean daily temperature for the upstream migration and spawning period (1 April – 1 July). Temperature data were square root transformed to achieve approximate normality. Because the number of redds per individual habitat unit were only recorded in 2003, unit scale analyses were limited to that year. However, tributary-scale analyses, incorporating habitat data from 2003, were conducted for both 2002 and 2003.

Unit Scale

For the unit-scale analyses, habitat data were first plotted to view the distributions of these data. Negatively skewed distributions were evident for all unit habitat variables. Transformations of these data were performed to normalize distributions, stabilize error variance, and alleviate the effects of highly influential points. One-half of the lowest reported nonzero value for each category density was added to all of the density values in that category. A constant (from 1,000 to 100,000), uniform within category, was then multiplied by each category density to produce values greater than one, while having no effect on the statistical analyses. Natural log transformations were then calculated for each habitat feature density. Box-Cox power transformations to normality were then performed on the dependent variable (redd density) for all regression models. Redd densities were natural log transformed based on power transformation results (where 95% confidence intervals for λ contained zero).

Logistic regression was applied at the unit-scale to assess associations among the presence or absence of redds in a unit and the main effects of habitat features in the unit (PROC LOGISTIC, SAS Institute 2000). Backward selection was used to determine which habitat feature variables were to be included in the logistic regression model. The fit of the model was evaluated using the Deviance chi-square statistic and the Hosmer-Lemeshow goodness-of-fit test (Cody and Smith 1997).

A stepwise multiple regression model (PROC REG, SAS Institute 2000), which included only those habitat units that contained redds, also was developed to determine associations between redd density and habitat features at the unit-scale (Zar 1999).

Tributary Scale

Due to substantially skewed distributions, Spearman's rank correlation was used to assess relations between redd abundance and habitat features at the tributary-scale (Zar 1999; ANALYST, SAS Institute 2000).

Redd Substrate Composition

A modified hollow-core sampler (Appendix B), based on the McNeil design (McNeil and Ahnell 1964), was used to sample redd substrate composition in 2003. The total number of redds counted in each tributary in 2003 was stratified into 10 sections, each containing 10 percent of the total. A random number generator was then used to determine which redd from each stratum would be sampled. Ten redd cores were then randomly sampled from each tributary inventoried that contained at least 10 redds. Cores were not collected from tributaries with less than 10 redds. Samples were taken from the front one third of the tailspill (Magee 1993) at the average egg depth measured during partial redd excavations (10-15 cm).

Core samples were processed in the field by the wet sieve method (Platts et al. 1983; McMahon et al. 1996). Samples were sifted through a series of sieves (50.8, 25.4, 12.4, 9.5, 6.35, 2.36, 0.85, and 0.074 mm) and the amount of suspended fine sediment (< 0.074 mm) retained in the corer was estimated with Imhoff settling cones (Shepard et al. 1984). A correction factor for wet sieved material (particle density of rhyolite, 2.6 g/cm^3; K. Pierce, Geologist, U.S. Geological Survey Northern Rocky Mountain Research Center, personal communication) was applied to all volumetric substrate data to convert water displacement to percent composition of dry weight for each substrate size class (Platts et al. 1983; Shirazi and Seim 1979).

To allow comparisons to other studies, substrate composition was expressed as the percent fine sediment less than 9.5, 6.35, 2.36, and 0.85 mm in diameter (Everest et al. 1987; Chapman 1988) and by a quality index based on measurement of central tendency, the fredle index (Everest et al. 1982; Young et al. 1991b). In accord with previous studies, particle sizes greater than 50.8 mm were excluded from fredle index calculations in order to compare results to studies using truncated data (Grost et al. 1991; Thurow and King 1994; Magee et al. 1996). The following formula was used to calculate Fredle index values (Lotspeich and Everest 1981; Young et al. 1991b):

$$F_i = D_g/S_o$$

where

$$D_g = D_a^{Pa} \text{ x } D_b^{Pb} \text{ x } \ldots \text{ x } Di^{Pi};$$

D_g = the geometric mean (mm);
D_i = the mean diameter (mm) of substrate retained on sieve i;
P_i = the proportion by weight of the entire sample consisting of material retained on sieve i.

and

$$S_o = (D_{75}/D_{25})^{0.5};$$

S_o = a sorting coefficient;
D_{75}, D_{25} = the substrate diameters below which 75% and 25% of the sample lie.

Substrate composition (fine sediment less than 9.5, 6.35, 2.36, and 0.85 mm and fredle index values) was compared among tributaries with Kruskal-Wallis nonparametric analysis of variance tests and between tributaries with Kruskal-Wallis multiple-comparison Z-Value tests (NCSS 2004).

Young-of-the-Year Production Estimates

Young-of-the-year rainbow trout production per tributary (Y) was estimated by combining data on the total number of redds (R), estimated egg deposition (E), and survival-to-emergence (STE) based on substrate composition of redds, using the equation: $Y = R \times E \times STE$ (Magee 1993). Egg deposition was estimated by a length-fecundity equation for rainbow trout (Carlander 1969): number of eggs = 7.12 x fork length mm -164 mm. This equation was applied to all female rainbow trout captured at the Duck Creek adult trap site (n = 2,503 females) and the average number of eggs per female was applied to all redds in the basin. Survival to emergence estimates were based on the average percent fine sediment composition (particles less than 9.5 and 0.85 mm) of all redds sampled in each tributary (Magee et al. 1996). Survival to emergence for rainbow trout was estimated using the following equation (Irving and Bjornn 1984):

$$\% \text{ survival} = 113.58 - 10.77(\% < 0.85 \text{ mm}) - 0.007(\% < 9.5 \text{ mm})^2 + 0.301(\% < 0.85 \text{ mm})^2$$

where

$\% < 9.5$ mm = the percent fine sediment less than 9.5 mm

$\% < 0.85$ mm = the percent fine sediment less than 0.85 mm.

RESULTS

Redd Surveys

A total of 5,642 rainbow trout redds were counted in the Hebgen Reservoir basin during 2002 (n = 4,349) and 2003 (n = 1,293) (Table 2). The number of redds inventoried in 2003 was far below (30%) that of 2002. However, the proportion of redds encountered among tributaries was similar between years (Table 2). Based on excavation of a random sample of 567 (≈10%) of the purported redds, about 22% of the total (≈21% in 2002 and ≈27% in 2003) were likely false redds that did not contain ova, resulting in an adjusted total redd count of 3,452 in 2002 and 941 in 2003 (Table 2). Adjusted totals were used for tributary YOY production estimates, whereas unadjusted redd totals were used for comparisons among tributaries because the exact distribution and number of false redds was uncertain.

Of the 170 linear stream kilometers of available habitat inventoried, the majority (82% in 2002, 74% in 2003) of redds in the Hebgen basin occurred in two tributaries, Duck Creek and the South Fork of the Madison River. Duck Creek contained the highest number overall, with about 47% of the total. Of the redds identified in Duck Creek in 2002 (n = 2,232) and 2003 (n = 428), 10% (n = 227) in 2002 and 53% (n = 226) in 2003 were found between Koelzer Pond and U.S. Highway 191, whereas all remaining redds inventoried (2,005 in 2002 and 202 in 2003) were found in the upper drainage within Yellowstone National Park (YNP), primarily in Gneiss Creek (Figure 2; Table 2). The South Fork of the Madison River contained about 34% of the basin total. Most of the 1,874 redds found in the South Fork of the Madison River drainage were concentrated in two sites: Black Sand Spring Creek and the mainstem river primarily upstream from U.S. Highway 20 (Figure 2).

Most of the remaining redds were located in three tributaries, Cougar and Grayling creeks, and the Madison River. Nearly all (≥ 87%) of the 235 total redds observed in the Cougar Creek drainage were found in headwater areas over 5 stream kilometers upstream of the YNP boundary. Most redds in the Grayling Creek drainage were found from the U.S. Highway 191 bridge upstream to a bedrock falls within YNP, about 13 stream kilometers from Hebgen Reservoir. The Madison River, which included the Firehole and Gibbon Rivers, contained less than 10% of the total number of redds. The smaller tributaries, Trapper, Watkins, Cherry, Rumbaugh, and Red Canyon creeks, contained very few redds and combined contributed less than 2% to the total.

Superimposition of redds was rare. In both years, only in a high density spawning area on Duck Creek, below Koelzer Pond, was superimposition observed (Figure 3). In this localized area, several redd pits and associated tailspills of raised gravel overlapped (62 redds in 2002 and 57 in 2003); about one-half of these redds were included in redd count totals.

Table 2. Distribution of rainbow trout redds in the Hebgen basin based on surveys in 2002 and 2003. Distance surveyed is in linear stream kilometers, percent false redds was estimated based on excavations of at least 10% of all redds detected in each tributary, and adjusted totals incorporate percent false redd estimates. Major tributaries are listed by stream order and minor tributaries are indented and listed alphabetically. Minor tributary totals in parentheses are a subset of the mainstem tributary listed directly above them.

	2002					2003				
Major Tributary Minor Tributary	Distance Surveyed (km)	Total Redds Detected	% of Basin Total	Estimated % False	Total Redds Adjusted	Distance Surveyed (km)	Total Redds Detected	% of Basin Total	Estimated % False	Total Redds Adjusted
Madison River	16.9	248	6	11	221	53.3	198	15	44	111
Firehole River	--	--	--	--	--	(2.1)	(3)	(<1)	--	--
Gibbon River	--	--	--	--	--	(12.1)	(39)	(3)	--	--
S. F. Madison River	31.6	1,339	31	27	978	31.6	535	41	22	419
Black Sand Spring Creek	(1.8)	(494)	(11)	--	--	(1.8)	(58)	(4)	--	--
Grayling Creek	19.9	258	6	25	194	19.9	59	5	44	33
Duck Creek	29.1	2,232	51	17	1,853	29.1	428	33	23	330
Campanula Creek	(3.4)	(223)	(5)	--	--	(3.4)	(72)	(6)	--	--
Gneiss Creek	(11.8)	(1,703)	(39)	--	--	(11.8)	(94)	(7)	--	--
Richards Creek	(1.0)	(0)	(0)	--	--	(1.0)	(0)	(0)	--	--
Cougar Creek	27.5	228	5	18	187	27.5	7	<1	50	4
Trapper Creek	1.6	26	<1	75	7	1.6	26	2	33	17
Watkins Creek	4.9	12	<1	0	12	4.9	27	2	25	20
Cherry Creek	0.7	0	0	0	0	0.7	0	0	0	0
Red Canyon Creek	0.5	0	0	0	0	0.5	4	<1	50	2
Rumbaugh Creek	0.9	6	<1	100	0	0.9	9	<1	50	5
TOTAL	133.6	4,349	100	21*	3,452	170	1,293	100	27*	941

*Average percent false redds.

High flow conditions and the timing of redd surveys may have affected the accuracy of redd counts. Active spawning was observed during high water conditions and directly following peak runoff periods in both years, resulting in the construction of redds in areas that were no longer submerged during the redd surveys. In 2002, it was estimated that 50 redds in upper Duck and Cougar creeks were no longer submerged and were thus not counted. In addition, some redds lacked the presence of a distinct pit or depression and associated tail area of "clean" gravel and therefore were not distinguishable from brown trout redds constructed the preceding autumn. However, several excavations of redds in this condition (primarily in 2003) revealed ova, indicating that high flows partially obscured a number of rainbow trout redds constructed that spring. Consequently, basin redd totals are considered conservative for both 2002 and 2003.

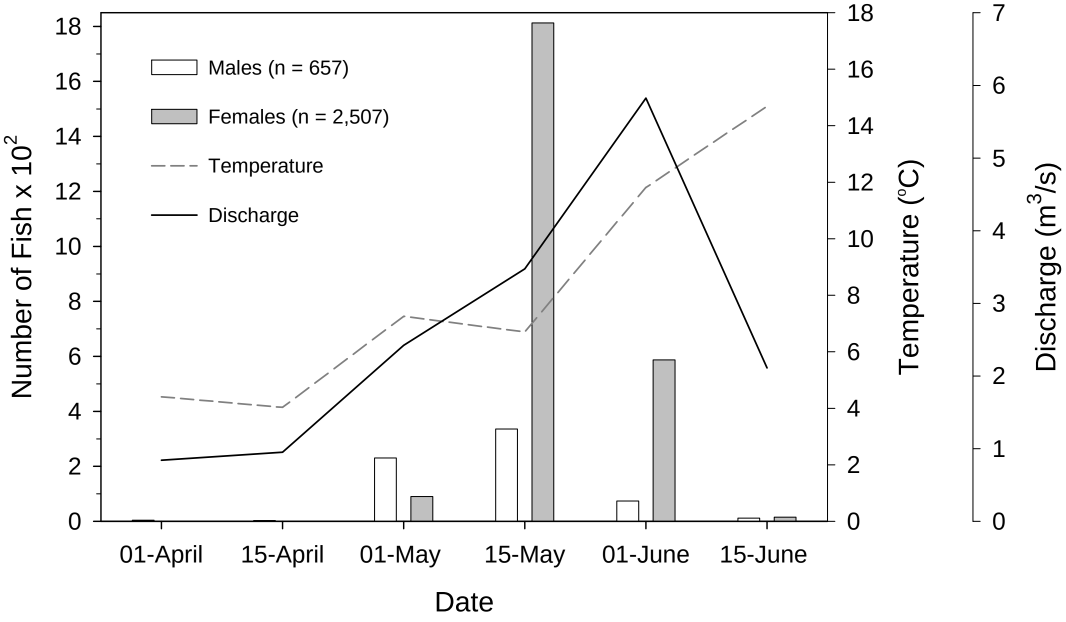
Adult Spawner and Outmigrant Trapping

Adults

In spring 2002, a total of 3,164 adult rainbow trout were captured at the Duck Creek adult trap sites (Figure 5). The lack of captures early in the trapping period and a sharp decline in captures towards the end of the trapping period suggested the total captured was an accurate count of total number of spawners. Females outnumbered males by a ratio of 3.8:1 (2,507 females to 657 males). The ratio of redds to the number of spawning females in Duck Creek (2,001:2,507) was 1:1.25, suggesting that redd superimposition was low and that spawning gravel availability was not limiting.

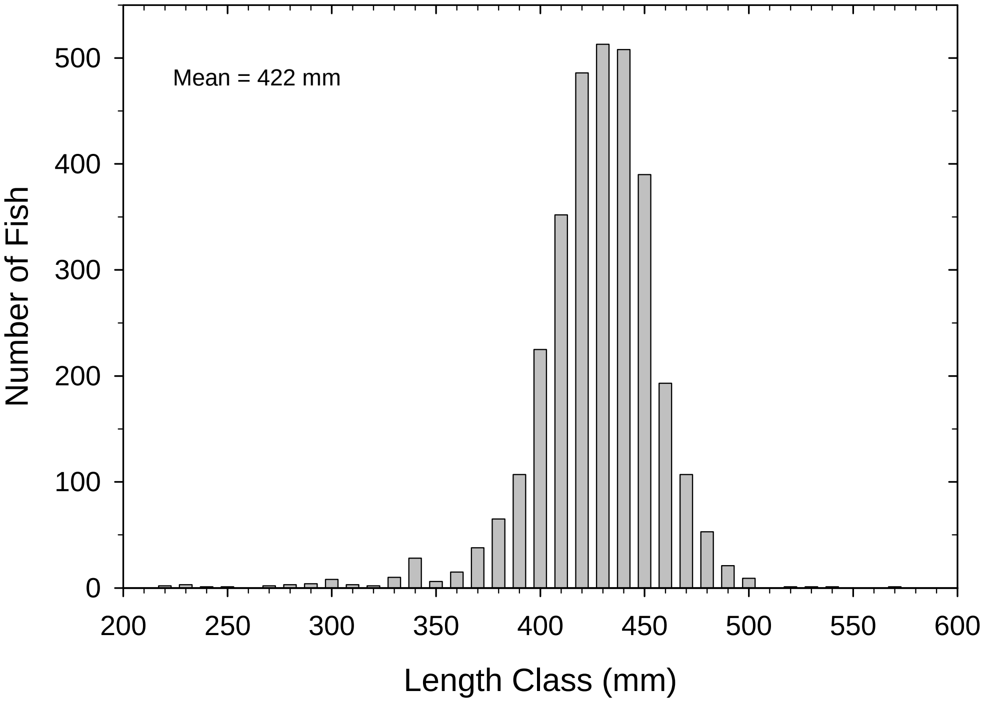
The Duck Creek spawning migration started in mid-April, at stream temperatures of 6 to 7 °C and flows from 1 to 2 m^3/s (Figure 5). Peak upstream migration of spawners occurred from mid-May to early June, corresponding with stream temperatures of 8 to 10.5 °C and rising flows from 3.5 to 6 m^3/s (Figure 5). Males comprised the early part of the spawning run in early May, and females outnumbered males 5 to 1 thereafter.

Figure 5. Relationship among the number (total number of fish in 15-day periods) of upstream migrant rainbow trout (n = 3,164), water temperature (mean temperature in 15-day period), and discharge (mean discharge in 15-day period) from the adult trap sites on Duck Creek, 2002.



Adult spawners ranged from 214 to 564 mm and averaged 422 mm in length (Figure 6). Mean length was similar between males and females (males 422 mm; females 423 mm) as were the minimum (males 220 mm; females 214 mm), and maximum lengths (males 535 mm; females 564 mm).

Figure 6. Length frequency distribution for all rainbow trout spawners (n = 3,164) captured at Duck Creek adult trap sites, 2002.

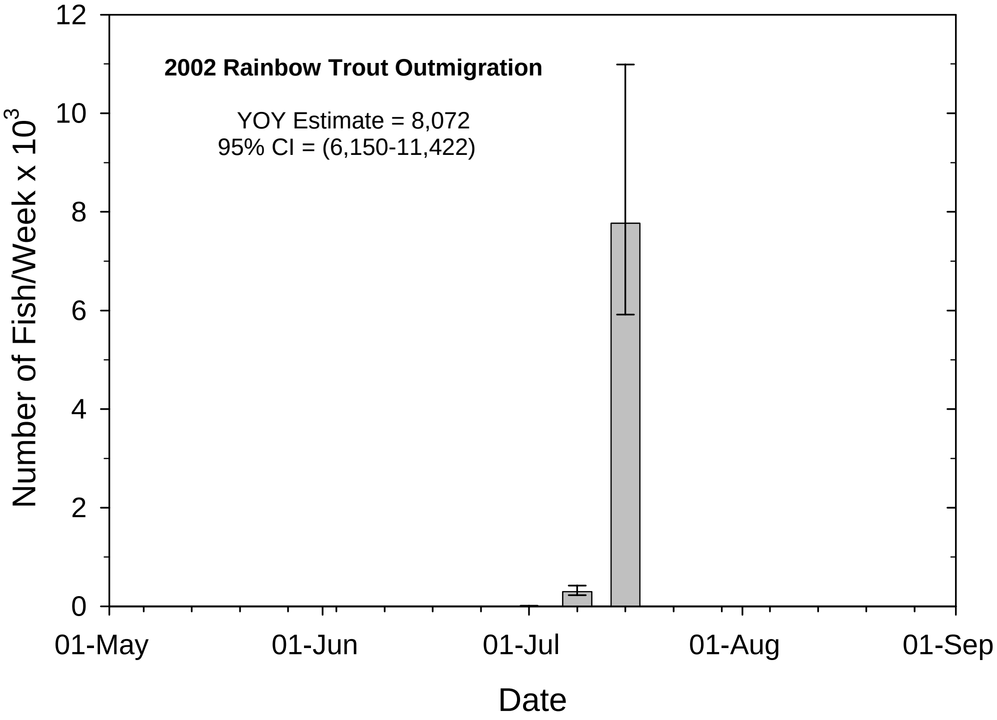


<u>Outmigrants</u>

Although over 2,000 redds were inventoried and large numbers of YOY were observed in 2002 in upper Duck Creek in YNP, only 26 outmigrant YOY were captured at the midstream and upstream trap sites (Figure 3). No efficiency estimates were obtained at these trapping locations due to the low number of captures. In an attempt to locate YOY, a visual survey was conducted in late August 2002 in the upper Duck Creek drainage in YNP. High numbers of YOY were observed in slow-water habitats (side channels, undercut banks, and beaver dam complexes), suggesting many YOY did not outmigrate until autumn or the following spring.

In contrast, a substantial number of rainbow trout YOY were captured outmigrating at the downstream fyke trap site on Duck Creek in 2002 (Figure 3). The downstream fyke trap was placed below a low gradient riffle section about 0.5 km in length. This section, from U.S. Highway 191 upstream to the Koelzer pond, contained an estimated 229 redds. From 4 July through 18 July, over 1,100 rainbow trout YOY (mean total length, 29 mm) were captured at this trap site, with an average capture efficiency of 26%, yielding an estimated outmigration of 8,072 YOY (Figure 7). No additional YOY were captured at this site through 13 August.

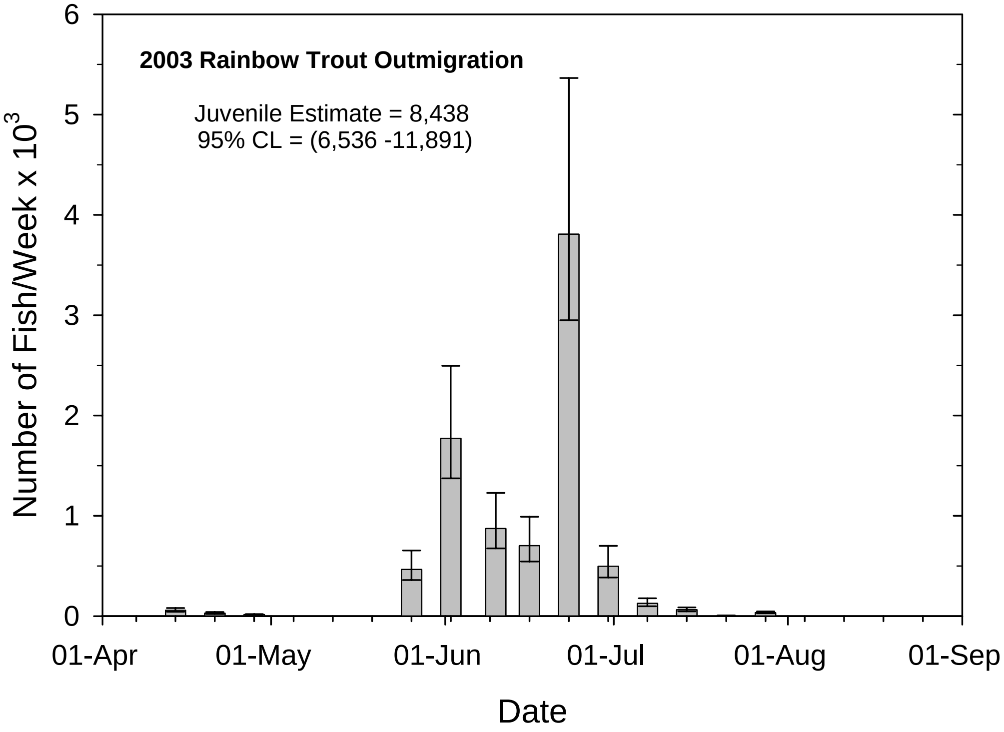
Figure 7. Estimated number of rainbow trout young-of-the-year (YOY) outmigrants from the downstream fyke trap site on Duck Creek, June - August 2002. Error bars are 95% confidence intervals.



Few outmigrant juvenile (age-1 and age- 2) rainbow trout (n = 10) were captured in 2002 at the three-fyke-trap sites on Duck Creek during the May-August trapping period. Similarly, only six juvenile (age-1 and age-2) brown trout (n = 6) and no brown trout YOY were captured. Other species captured in relatively low numbers included brook trout, longnose dace, and mottled sculpin (Appendix C).

Although traps were installed earlier in 2003 (mid-March) and several hundred redds were observed in upper Duck Creek, few rainbow trout YOY were captured during spring and summer 2003. However, a substantial number of outmigrant juvenile rainbow trout were captured at the screw trap site on Duck Creek in 2003 (Figure 8).

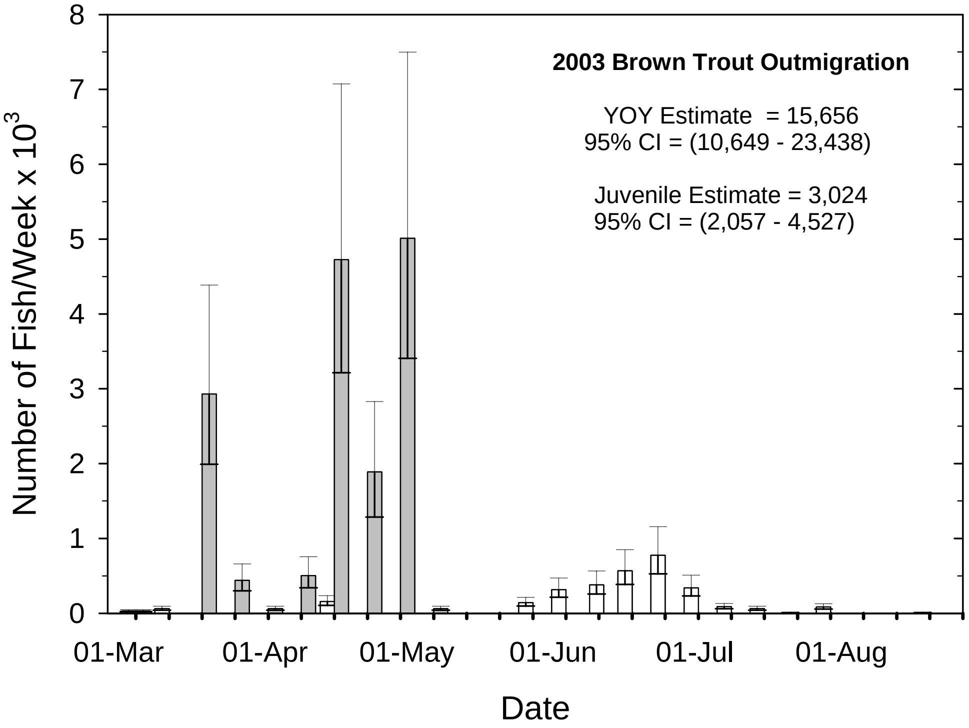
Figure 8. Estimated number of juvenile (age-1 and age-2) rainbow trout outmigrants from Duck Creek, April - August 2003. Error bars are 95% confidence intervals.



The Duck Creek juvenile rainbow trout outmigration began in early June during high flow conditions (> 4 m^3/s) with water temperatures exceeding 8 °C, similar to the timing of the peak adult spawning migration in 2002. Juvenile outmigrant numbers peaked in late June and thereafter tapered off throughout July (Figure 8). Trap efficiency, based on five estimates, was similar, ranging from 17 to 27%, at all Duck Creek fyke and screw trap sites. Therefore, a pooled efficiency of 24.5% was extrapolated to both trap sites for the juvenile rainbow trout outmigration period. The total estimated number of juvenile outmigrants for Duck Creek in 2003 was 8,438 (Figure 8).

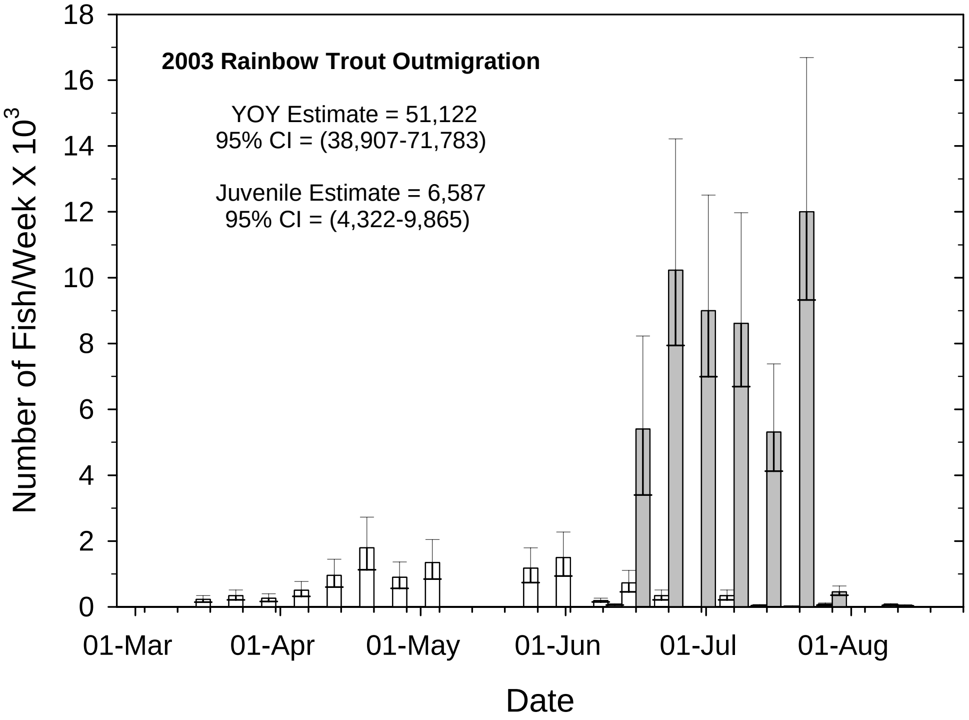
In addition to the juvenile rainbow trout outmigration, significant numbers of YOY and juvenile brown trout were captured on Duck Creek in 2003. Brown trout YOY began emerging and outmigrating as early as 3 March and continued through May, with an estimated total of over 15,000 outmigrants (Figure 9). The brown trout YOY outmigration corresponded to low water levels (< 1 m^3/s) and stream temperatures ranging from 4 to 8 °C. The juvenile (age-1 and age-2) brown trout outmigration overlapped with the juvenile rainbow trout outmigration. Over 3,000 brown trout, between 45 and 165 mm, were estimated to have outmigrated from Duck Creek during spring and summer 2003 (Figure 9). Overall, trap efficiencies on Duck Creek were lower (pooled efficiency of approximately 11%) for brown trout than for juvenile rainbow trout. In addition to brown trout, brook trout, longnose dace, mountain whitefish, mottled sculpin, and Utah chub were also captured in the fyke and screw traps throughout spring and summer 2003 in Duck Creek (Appendix C).

Figure 9. Estimated number of brown trout young-of-the-year (YOY) (gray bars) and juvenile (age-1 and age-2) (open bars) outmigrants from fyke and screw traps (Figure 3) on Duck Creek, March - August 2003. Error bars are 95% confidence intervals.



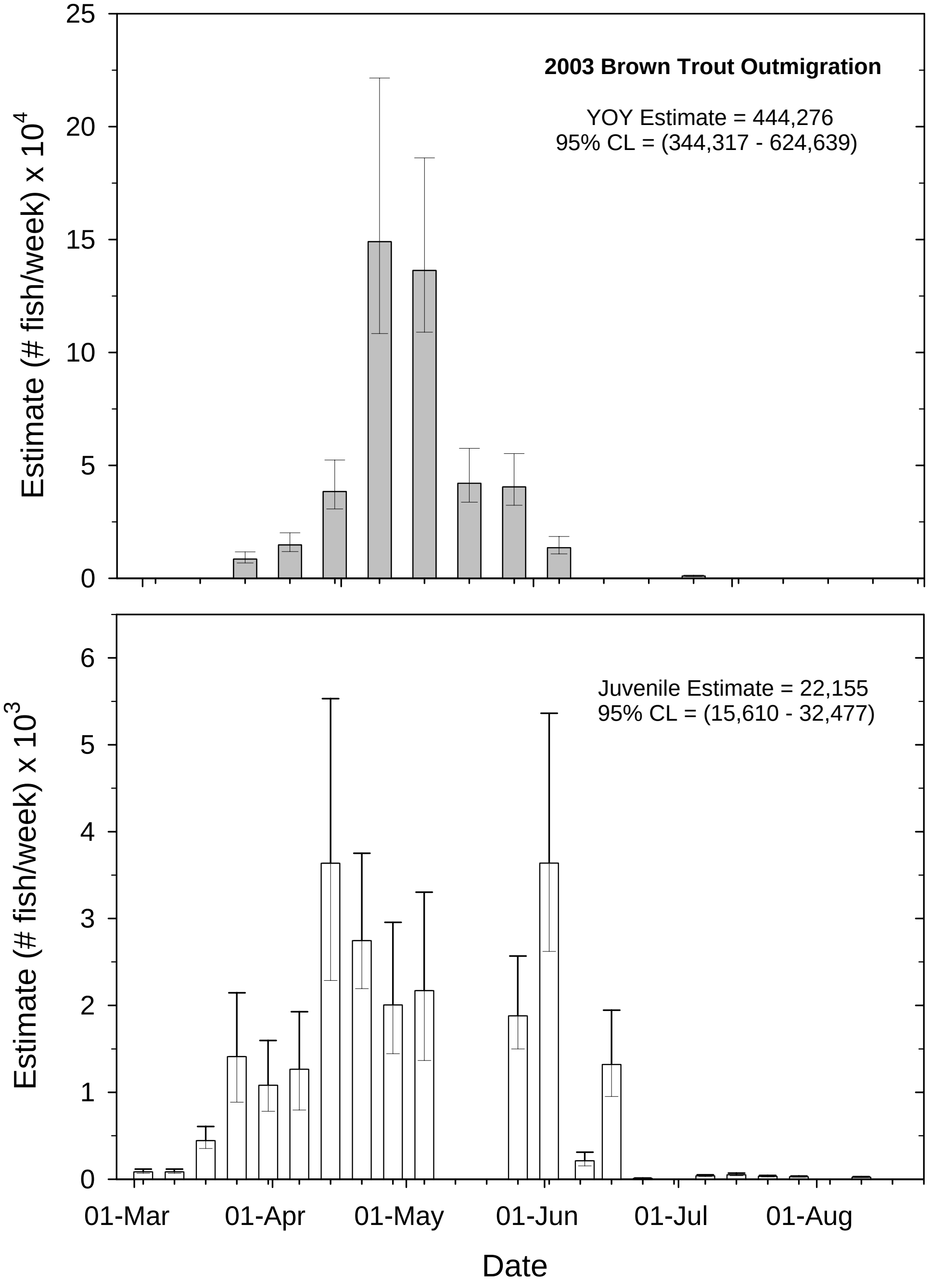
Fyke and screw traps operated on the South Fork of the Madison River in 2003 revealed substantial outmigrations of both YOY and juvenile rainbow trout. An estimated 6,587 juvenile (age-1 and age-2) rainbow trout outmigrated from mid-March through early August (Figure 10). The juvenile outmigration began pre-runoff and continued during high flows (3 to 5 m^3/s) and increasing temperature (6 to 9 ˚C; Appendix D). In contrast to Duck Creek, large numbers of YOY rainbow trout (estimate of 51,122) were captured on the South Fork of the Madison River from late June through late July 2003 (Figure 10). Trap efficiencies varied temporally within and between life stages, ranging from 6% to 33%, and were not pooled between weeks.

Figure 10. Estimated number of rainbow trout young-of-the-year (YOY) (grey bars) and juvenile (age-1 and age-2) (open bars) outmigrants from fyke and screw traps on the South Fork of the Madison River, March - August 2003. Error bars are 95% confidence intervals.



A substantial number of YOY and juvenile brown trout were also captured in the South Fork of the Madison River. Brown trout YOY estimates exceeded 440,000 outmigrants (Figure 11) based on relatively high efficiencies of about 32%. The brown trout YOY outmigration began in mid-March, peaked in mid-April, and tapered off by early May (Figure 11). Brown trout YOY emergence and outmigration corresponded with pre-runoff conditions, near base level flows, and continued through the rising limb of the hydrograph, at temperatures ranging from 6 to 9 °C (Appendix D).

Figure 11. Estimated number of brown trout young-of-the-year (YOY) and juvenile (age-1 and age-2) outmigrants from fyke and screw traps on the South Fork of the Madison River, March - August 2003. Error bars are 95% confidence intervals.



Over 22,000 juvenile brown trout were estimated to have outmigrated from the South Fork of the Madison River in early March through mid-June, with peak outmigration occurring from mid-April through early June (Figure 11; Table 3). Similar to the pattern observed in Duck Creek, the juvenile brown trout outmigration overlapped with the juvenile rainbow trout outmigration in the South Fork of the Madison River. However, the juvenile brown trout outmigration began nearly two months earlier in the South Fork of the Madison River than in Duck Creek. Trap efficiencies varied widely for juvenile brown trout and weeks were pooled into three groups (6, 14, and 33%). Mountain whitefish and mottled sculpin were also captured in the South Fork of the Madison River (Appendix C).

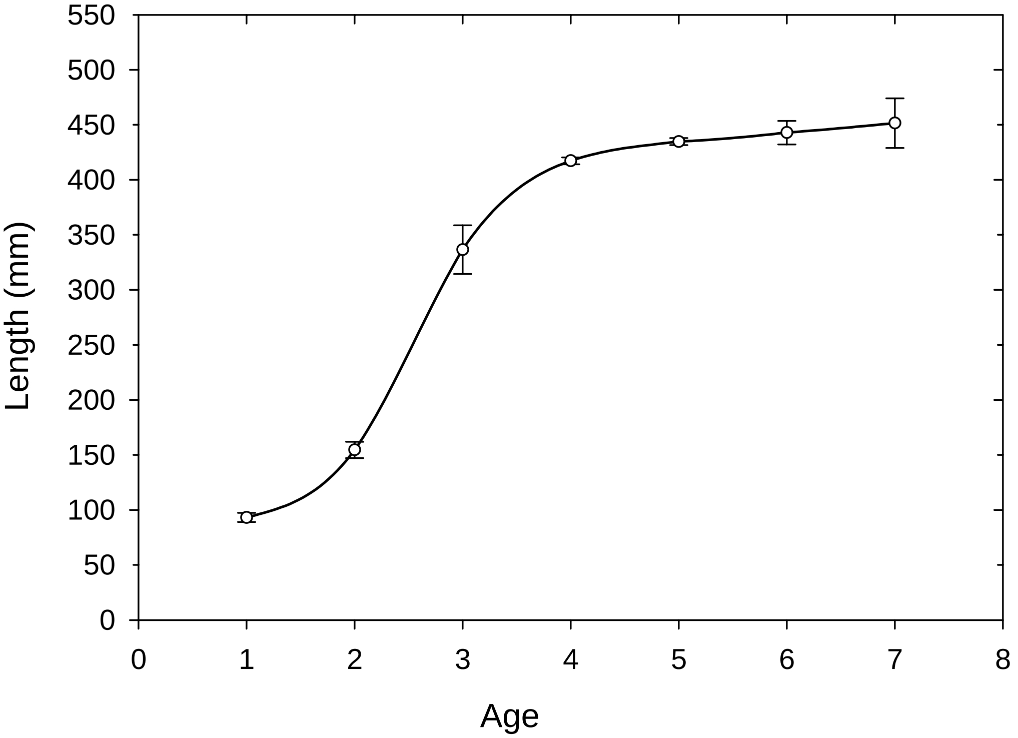
Table 3. Summary of outmigrant trapping estimates for both rainbow trout and brown trout young-of-the-year (YOY) and juveniles (age-1 and age-2) for Duck Creek (2002 and 2003) and the South Fork of the Madison River (2003).

	Species			
	Rainbow Trout		Brown Trout	
Tributary – Year Trap Types	YOY Estimate	Juvenile Estimate	YOY Estimate	Juvenile Estimate
Duck Creek - 2002				
Fyke Traps	8,072	0	0	0
Duck Creek - 2003				
Fyke and Screw Traps	0	8,438	15,656	3,024
S F Madison River - 2003				
Fyke and Screw Traps	51,122	6,587	444,276	22,155

Age and Growth

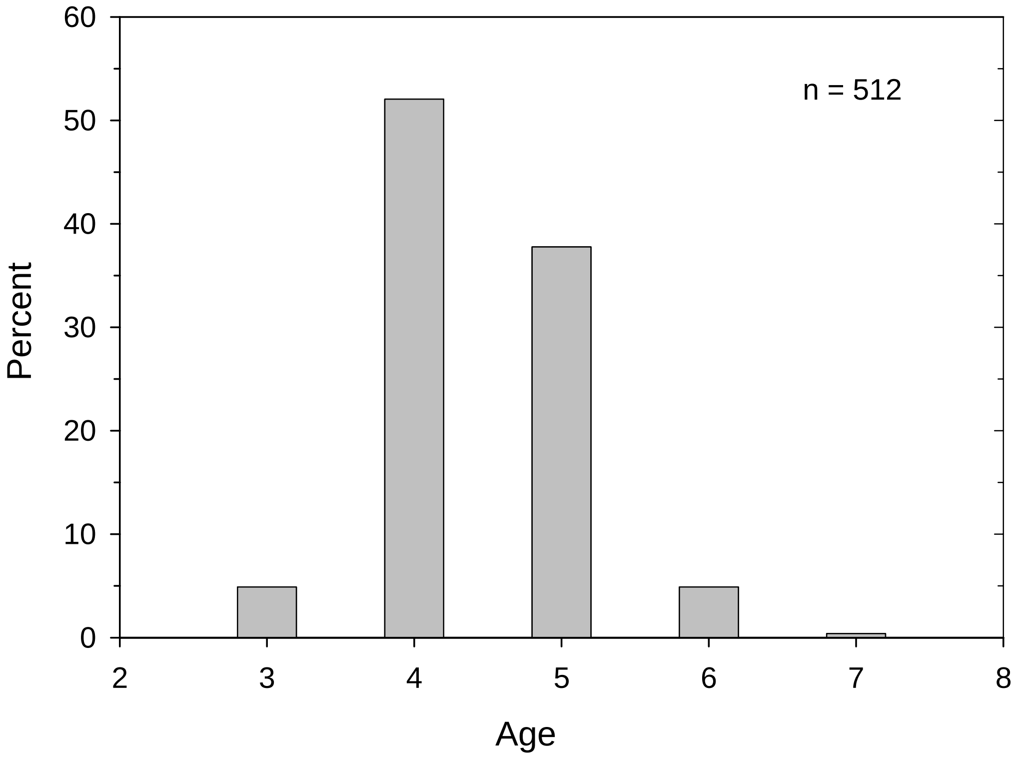
Age and growth data were analyzed from 512 adult and 109 juvenile (age-1 and age-2) rainbow trout scales from Duck Creek. The average length-at-age, fit with a simple spline curve, for the Duck Creek rainbow trout population is depicted by the growth curve in Figure 12. Growth rate increased rapidly during the first year of life, was greatest from age 2 to age 3, and thereafter increased little to age 4 and older (Figure 12).

Figure 12. Growth curve for the adfluvial rainbow trout population of Hebgen Reservoir based on mean length-at-age determined from scales (n = 621) collected at fyke, screw, and adult trap sites in Duck Creek, 2002 and 2003. Error bars are 95% confidence intervals.



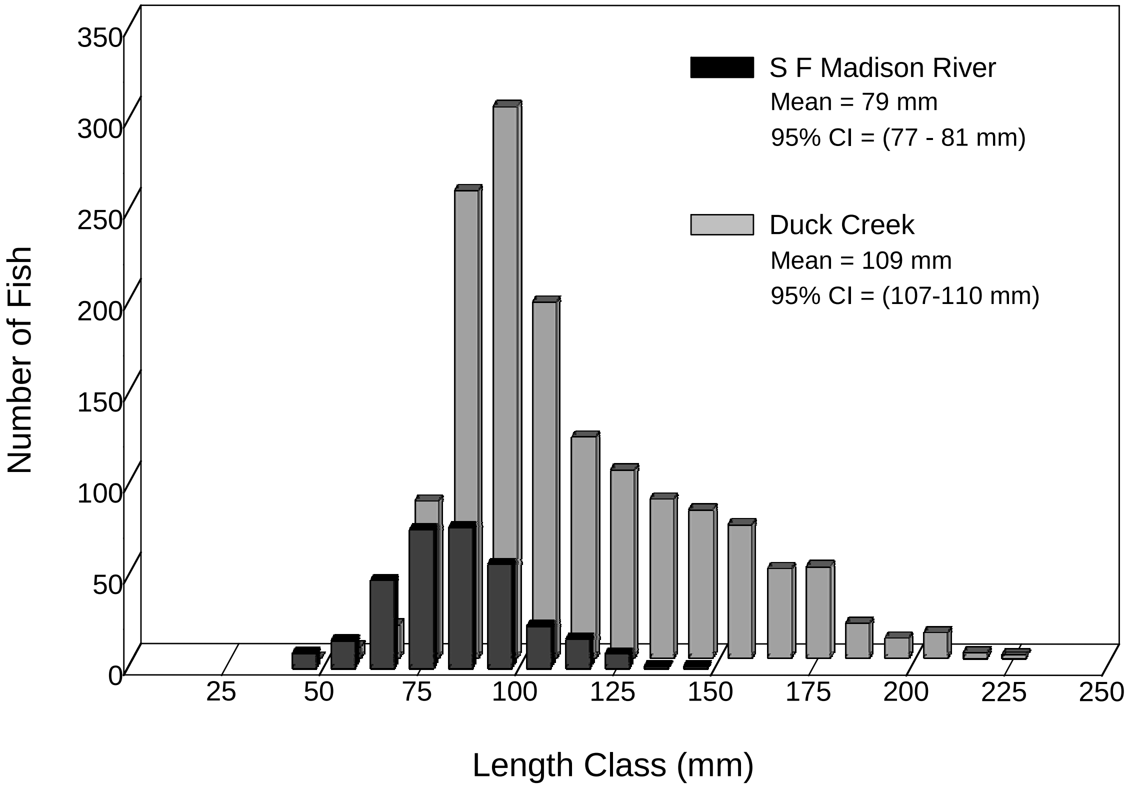
The age structure of the spawning adult population of Duck Creek, based on the age distribution of a random sample of 512 adult scales, was primarily comprised of age-4 fish (Figure 13). Age at sexual maturity of Duck Creek spawners was from age 3 to age 6. However age-4 spawners made up over 52% of the sample, whereas age-3 fish contributed less than 5% overall. Age-5 adults accounted for about 40% of the spawning run and age 6 and older contributed 6% (Figure 13).

Figure 13. Age distribution of the 2002 Duck Creek spawning population based on a random sample of 512 adult scales.



Length frequency distributions for juvenile (age-1 and age-2) rainbow trout outmigrants from Duck Creek and the South Fork of the Madison River varied between tributaries (Figure 14). Juveniles captured in Duck Creek (n = 1,476) had a mean length of 109 mm (95% CI = 107-110 mm), whereas juveniles from the South Fork of the Madison River (n = 330) averaged 79 mm (95% CI = 77-81 mm).

Figure 14. Length frequency distribution for juvenile (age-1 and age-2) rainbow trout outmigrants from fyke and screw trap sites on Duck Creek (n = 1,476) and the South Fork of the Madison River (n = 330), 2003.



The average length-at-age for juvenile rainbow trout captured in Duck Creek was 93 mm for age-1 and 155 mm for age-2 fish, respectively. Based on mean length-at-age from Duck Creek scales and decomposed composite length frequency distributions from Duck Creek and South Fork Madison River (NORMSEP, FiSAT II 2004), it was estimated that age-1 juveniles comprised 51% of the juvenile outmigration in Duck Creek and 66% in the South Fork of the Madison River (Table 4).

Table 4. Comparison of ages at outmigration of juvenile (age-1 and age-2) rainbow trout from outmigrant estimates and estimated proportions of juvenile life history forms for Duck Creek and the South Fork of the Madison River, 2003. Proportions of age-1 and age-2 juveniles are based on length frequency distributions for all captured juveniles on each tributary (Figure 14). Average length-at-age estimates were based on a random sample of 109 juvenile scales from Duck Creek 2003.

	Age-1 and Age-2			Proportion	
Tributary	Capture	Estimate	95 % CI	Age-1	Age-2
Duck Creek	1,476	8,438	(6,536 – 11,891)	51 %	49 %
S F Madison River	344	6,587	(4,322 – 9,865)	66 %	33 %

Migration checks were identified on 233 or 46% of the 512 adult scales from Duck Creek. Of the scales that contained migration checks, outmigration into Hebgen Reservoir at age 2 was the predominant life history identified, comprising 31% of the total number of outmigrants and 68% of the total number of outmigrants with migration checks (Table 5). Adults that were age 1 and age 3 at outmigration were rare (age 1 = 9%; age 3 = 5%). The remaining 279 scales (54%) were assumed to represent a YOY outmigration form as no migration check was detected (Table 5).

Age determination of juvenile scales revealed that migration checks were present on nearly one half (54 of 109) of the sample (Table 5). As these fish are assumed to not yet have entered Hebgen Reservoir, the checks are likely associated with increased growth achieved while entering a more productive habitat type such as a large beaver dam complex or pond. Therefore, it cannot be assumed that migration checks found on adult scales are indicative of increased growth achieved upon entry into Hebgen Reservoir. In addition, the mean distance from the focus to areas of increased growth differed between juvenile and adult scales. The mean distances to migration checks on adult scales were greater than distances found on juvenile scales at both age 1 (0.48 mm adults; 0.33 mm juveniles) and age 2 (0.81 mm adults; 0.64 mm juveniles) (Table 5), further suggesting the formation of checks among some juveniles during tributary rearing.

Table 5. Comparison of outmigration forms for adult and juvenile (age-1 and age-2) rainbow trout collected from Duck Creek in 2002 and 2003. Age at outmigration was estimated from scale growth patterns. Adults with no apparent migration check were assumed to enter the reservoir as young-of-the-year (YOY).

		Approximate Age at Migration Check			
Scales	*n*	YOY	Age-1	Age-2	Age-3
Adults	512	279	48	158	27
Juveniles	109	0	35	19	0

		Adults				Juveniles			
Distance to Check (mm)		YOY	Age-1	Age-2	Age-3	YOY	Age-1	Age-2	Age-3
Mean		0	0.48	0.81	1.11	--	0.33	0.64	--
95% CI	Lower	0	0.45	0.77	1.04	--	0.32	0.59	--
	Upper	0	0.51	0.84	1.18	--	0.35	0.68	--

Tributary Characteristics Influencing Rainbow Trout Production

Temperature

Stream temperature varied markedly among the tributaries to Hebgen Reservoir in both 2002 and 2003 (Figure 15; Appendix E). The Madison River exhibited the warmest overall temperature regime, likely the result of its headwaters (Firehole and

Gibbon Rivers) in YNP draining geothermally influenced areas. Mean daily temperature in the Madison rarely dropped below 10 °C during the study period (Figure 15) and the average of mean daily temperature through the spring upstream migration and spawning period exceeded 13 °C (Figure 15). In contrast, mean daily temperature in Trapper, Watkins, Cherry, Rumbaugh, and Red Canyon creeks, which are considerably smaller and drain heavily forested areas, rarely exceeded 6 °C except from late June through early August (Figure 15). Grayling Creek experienced temperatures similar to the five smaller tributaries with an average daily mean of 5.6 °C for the migration and spawning period (Figure 15).

The South Fork of the Madison River and Duck and Cougar creeks exhibited temperatures intermediate to the other tributaries (Figure 15). The South Fork of the Madison River (including Black Sand Spring Creek) and Duck and Cougar creeks experienced mean daily temperatures of between 8.4 and 9.7 °C throughout the rainbow trout upstream migration and spawning period (Figure 15). Temperature in Black Sand Spring Creek, a tributary to the South Fork of the Madison River, remained nearly constant at 9.7 °C throughout the study period (Figure 15).

Temperature appeared to influence redd abundance. Eighty-five percent of the total redds inventoried were found in tributaries that exhibited average mean daily temperature, during the upstream migration and spawning period (1 April through 1 July), ranging from 8.4 to 9.7 °C (Cougar and Duck creeks and the South Fork of the Madison River) (Figure 16). Warmer and colder tributaries generally contained many fewer redds. However, Cougar Creek contained far fewer redds than Duck Creek and the South Fork of the Madison River indicating that temperature did not solely influence redd distribution (Figure 16).

Figure 15. Comparison of water temperature during the rainbow trout upstream migration and spawning period (1 April through 1 July) among all major Hebgen Reservoir tributaries for 2002 and 2003. The boxes depict the 1st and 3rd quartiles, mean (dotted line), median (central solid line), and individual outliers outside the 5th and 95th percentiles (whiskers) are represented by black squares. Data presented for Red Canyon 2002, Watkins 2002, and Rumbaugh 2003 are not complete (no data was collected for April and early May) therefore, actual temperature values for these tributaries are less than values reported in the box plots. No data is presented for Cherry and Rumbaugh 2002, and Red Canyon and Watkins Creek 2003 because of incomplete data.

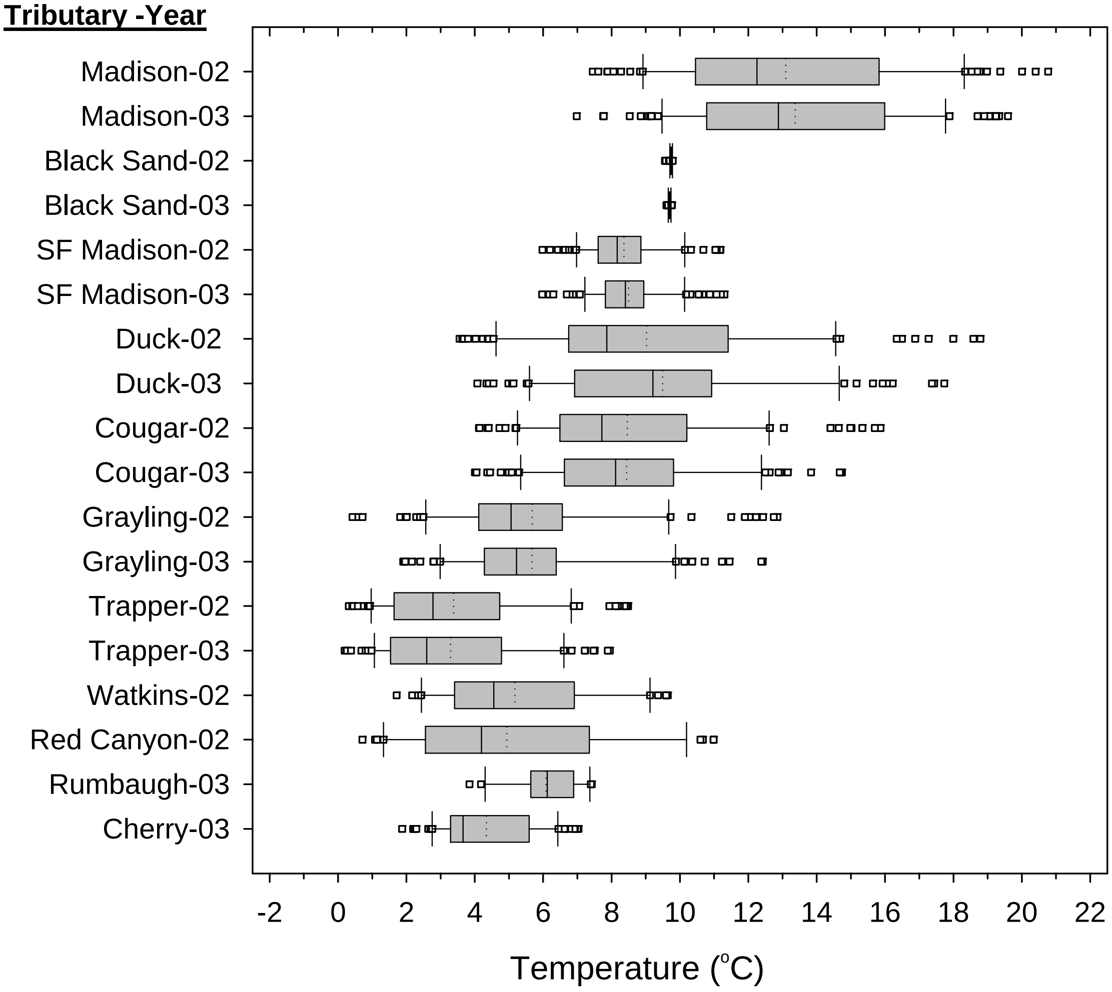
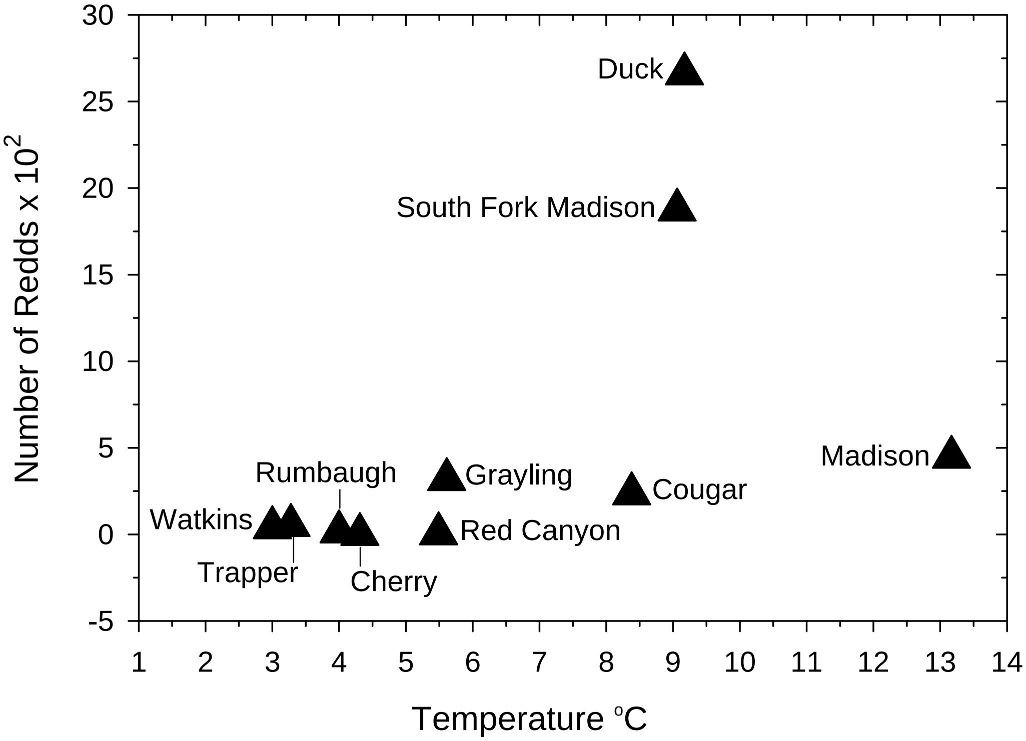


Figure 16. Relation between total number of redds (years combined) among major tributaries to Hebgen Reservoir and mean daily water temperature during the upstream migration and spawning period (1 April through 1 July).



Spawning and Rearing Habitat

Overall, access to spawning habitat did not appear to be limiting rainbow trout spawners. About 170 kilometers of stream habitat were accessible to rainbow trout of Hebgen Reservoir (Table 6). However, potential migration barriers were identified in the Duck and Grayling creek drainages. The U.S. Highway 191 culvert on Duck Creek was substantially undercutting on the downstream end and had created a 1.5 m outlet drop. Throughout the spawning run in 2002 and 2003, large numbers of rainbow trout staged below the culvert in the downstream plunge pool. On 28 May 2002, at flows near 4 m^3/s, over 40 attempts were made by rainbow trout to bypass upstream through the culvert with only one success recorded. However, over 3,000 rainbow trout spawners were captured upstream of the culvert in 2002 and a large proportion (47%) of the redds inventoried in the Hebgen basin in 2002 and 2003 were found upstream of this site indicating that migrants readily bypass the structure.

In Grayling Creek, a possible migration barrier (waterfall) was identified in YNP, about 13 stream kilometers upstream from the mouth. The height of falls was greater than 2 m, had a bedrock foundation and was within a high gradient, highly entrenched canyon section of the stream. The falls likely prohibits upstream passage; no redds or adult spawners were observed in a 1 km reach surveyed immediately upstream of the barrier.

Of the 170 stream kilometers (wetted surface area of over 340 ha) of tributary habitat inventoried in 2003, over 7 ha were classified as available spawning habitat and 79 ha (1.1 x 10^6 m^3 by volume) were classified as available rearing habitat (Table 6). Of the total surface area of available tributary habitat inventoried, approximately 23% was categorized as rearing habitat, whereas only 2% was categorized as spawning habitat.

Considerable variation in the composition of spawning and rearing habitat was observed among tributaries. Most (51%) of the available spawning habitat was found within the largest tributary (by wetted surface area), the Madison River (Table 6), which included the Firehole and Gibbon Rivers upstream to known barrier falls on both tributaries. In contrast, the Madison contained less than 10% (9.4 x 10^4 m^3) of the total estimate of available rearing habitat.

Table 6. Hebgen basin habitat inventory estimate totals for 2003. Spawning (m^2) and rearing (m^3) habitat represent the total of each habitat feature available within a tributary; LWD is the total number of large woody debris pieces per linear stream kilometer; gradient is the average gradient over the tributary length surveyed. Major tributaries are listed by stream order and minor tributaries are indented and listed alphabetically. Minor tributary totals in parentheses are a subset of the mainstem tributary listed directly above them.

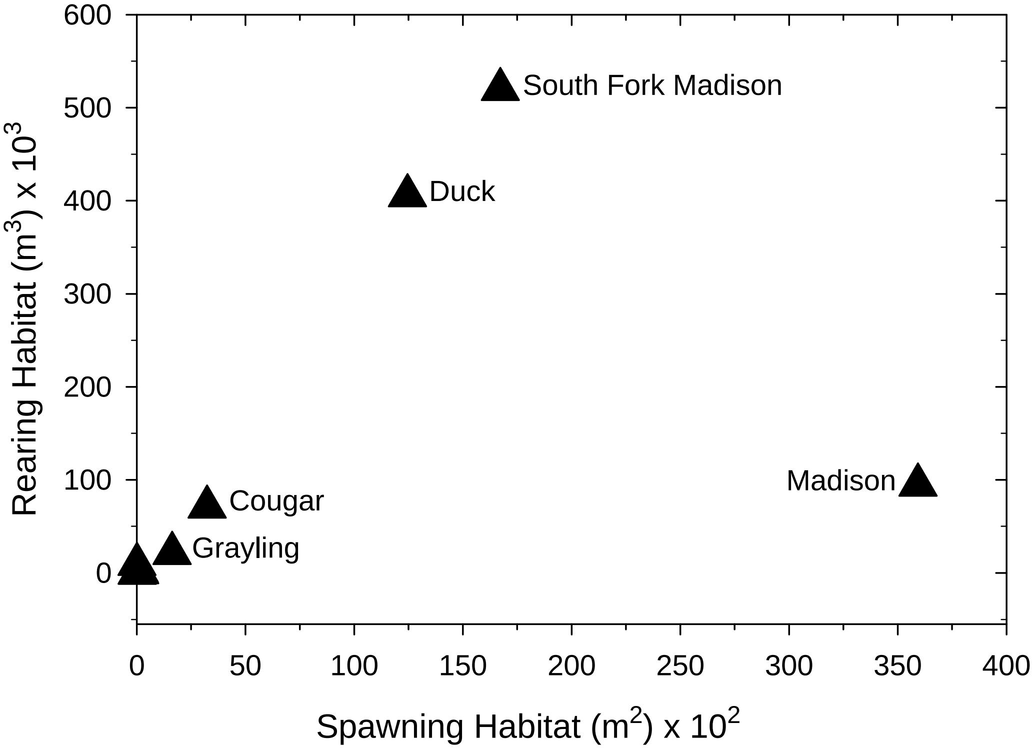
Major Tributary Minor Tributary	2003							
	Length Surveyed (m)	Surface Area Surveyed (m^2)	Spawning Habitat (m^2)	Rearing Habitat (m^3)	LWD (no./km)	Gradient (%)	% of Basin Spawning Habitat	% of Basin Rearing Habitat
Madison River	53,360	2,003,240	35,929	94,353	25	0.5	51	8
Firehole River	(2,106)	(45,776)	(381)	(714)	37	(1.4)	(1)	(<1)
Gibbon River	(12,060)	(213,078)	(12,987)	(49,066)	31	(0.4)	(18)	(4)
S. F. Madison River	31,631	523,764	16,706	519,674	27	0.2	24	46
Black Sand Spring	(1,833)	(31,215)	(1,578)	(5,536)	186	(0.3)	(2)	(<1)
Grayling Creek	19,851	235,581	1,627	21,052	32	0.8	2	2
Duck Creek	29,133	468,477	12,448	405,446	10	0.4	18	36
Campanula Creek	(3,426)	(30,713)	(1,987)	(15,012)	71	(1.0)	(3)	(1)
Gneiss Creek	(11,811)	(97,073)	(5,658)	(91,064)	3	(0.3)	(8)	(8)
Richards Creek	(991)	(58,453)	(0)	(132,502)	0	(0.2)	(0)	(12)
Cougar Creek	27,493	231,398	3,224	70,848	41	0.2	5	6
Trapper Creek	1,628	6,255	129	224	330	4.7	<1	<1
Watkins Creek	4,866	11,199	106	1,990	34	3.1	<1	<1
Cherry Creek	688	10,936	12	9,249	260	1.4	<1	1
Red Canyon Creek	522	540	23	17	128	3.3	<1	<1
Rumbaugh Creek	874	773	26	0	319	3.7	<1	0
TOTAL	170,045	3,492,161	70,231	1,122,854	---	---	100	100

The second and third largest tributary systems, the South Fork Madison River (including Black Sand Spring Creek) and Duck Creek (including Campanula, Gneiss, and Richards creeks), contained 40% of the available spawning habitat and 82% of the available rearing habitat in the basin (Table 6). Duck Creek had slightly less available spawning (12 ha) and rearing (405,446 m^3) habitat than the South Fork of the Madison River (17 ha spawning and 519,674 m^3 rearing), but both tributaries exhibited a high proportion of rearing habitat in relation to abundant spawning habitat (Table 6).

Cougar and Grayling creeks ranked fourth and fifth for availability of spawning and rearing habitat, with Cougar Creek having approximately double that of Grayling Creek for both habitat features (Table 6). The five remaining smaller tributaries contained less the 5% of the available spawning and rearing habitat in the Hebgen basin.

Highest redd counts corresponded to tributaries with the highest relative available spawning and rearing habitat. Duck Creek and the South Fork of the Madison River had comparably high quantities of both features overall and combined accounted for 80% of the redds found in the basin (Figure 17; Table 2). In contrast, the Madison River had abundant spawning habitat, but moderate available rearing habitat and possessed only about 8% of the total redds inventoried. The remaining 12% of the redds identified throughout this study were found in Cougar, Grayling, and the five smaller creeks; all had considerably lesser amounts of both habitat features than the aforementioned tributaries (Figure 17).

Figure 17. Relationship between available spawning and available rearing habitat for tributaries of the Hebgen basin. The “cluster” of triangles to the left of Grayling Creek refers to 5 tributaries (Cherry, Red Canyon, Rumbaugh, Trapper, and Watkins Creeks).



Habitat Analysis

Unit Scale

Pool habitats (n = 899) were the most frequent habitat unit type inventoried in the Hebgen basin in 2003, followed by riffle (n = 777), glide (n = 315), and pond units (n = 53). Of the 2,044 habitat units inventoried, 242 contained redds (Table 7). Of these, 69% of redds observed were found within riffles, whereas the remaining 31% were in glides (18%) and pool tailouts (13%) (Table 7).

Table 7. Descriptive summary of habitat unit type in relation to presence and abundance of redds for all Hebgen Reservoir tributaries inventoried in 2003.

Unit Totals	Unit Type				Total Units
	Glide	Pond	Pool	Riffle	
Number of units	315	53	899	777	2,044
Number of units with redds	51	0	55	136	242
Number of redds in unit type	234	0	165	894	1,293
Percent of unit type with redds	16	0	6	18	12
Percent of redds in unit type	18	0	13	69	100

Redd occurrence within habitat units was significantly related to amount of spawning gravel, rearing habitat, and LWD. The binary logistic regression model included all three explanatory variables in the final model at the predetermined significance level ($\alpha = 0.05$), based on the chi-square distribution. None of the odds ratio 95% Wald confidence intervals contained one, further conveying that all main effects included in the model were significant (Table 8). Odds ratios indicated that, with all other variables held constant, for every one unit increase in spawning habitat density (corresponds to a 2.7 fold increase for nontransformed data) in a habitat unit, redds were 1.5 times more likely to occur. Similarly, when LWD density was increased by one, redds were 1.1 times more likely to occur in the unit. Conversely, an increase of one unit of rearing habitat density (residual volume of pool or pond units) reduced the likelihood of redds present (odds ratio point estimate = 0.890) (Table 8).

Table 8. Summary of main effects included in the unit scale binary logistic regression model. The model was used to determine the probability of redds being present (dependent variable) in relation to habitat unit characteristics (independent variables). Backward selection was used to determine which habitat characteristic variables were included ($\alpha = 0.05$).

	Analysis of Maximum Likelihood				
Main Effects	df	Estimate (βi)	Standard Error	Wald Chi-Square	Pr < Chi-Square
Intercept	1	-4.752	0.268	313.639	< 0.0001
Spawning Habitat Density	1	0.429	0.026	264.514	< 0.0001
Rearing Habitat Density	1	-0.117	0.029	16.211	< 0.0001
LWD Density	1	0.116	0.025	21.235	< 0.0001

	Odds Ratio Estimates	
	Point Estimate = $\exp.^{\beta i}$	95 % Wald Confidence Limits
Spawning Habitat Density	1.536	(1.458 - 1.617)
Rearing Habitat Density	0.890	(0.841 - 0.942)
LWD Density	1.123	(1.069 - 1.179)

The Hosmer-Lemeshow goodness-of-fit test indicated that the fit of the model was not ideal (chi-square = 52.57; df = 7; Pr > chi-square = < 0.0001). However, the deviance chi-square statistic was not significant, (deviance = 1, 063; df = 1,291; deviance/df = 0.82; Pr > chi-square = 1.00) indicating a fairly robust model. In addition, posterior probabilities discriminated between units with and without redds; of 436,084 possible paired habitat units with one unit containing redds and the other not containing redds the unit with the higher computed probability of redd occurrence experienced the event 85.8 % of the time (Table 9).

Table 9. Summary of the association of predicted probabilities and observed responses.

Association of Predicted Probabilities and Observed Responses			
Percent Concordant	85.8	Somer's D	0.718
Percent Discordant	14.0	Gamma	0.719
Percent Tied	0.1	Tau-a	0.150
Pairs	436,084	c	0.859

A stepwise multiple regression model (PROC REG, SAS Institute 2000) was developed to determine associations between redd density and habitat features identified as significant in the logistic regression model (spawning habitat, rearing habitat, and large woody debris densities) for units containing redds. The stepwise procedure, at the 0.05 significance level, first included spawning habitat density ($r^2 = 0.34$, $P < 0.0001$), followed by LWD density ($r^2 = 0.03$, $P = 0.001$); rearing habitat density was excluded from the model (Table 10). Figure 18 illustrates the linear relation between redd density and spawning habitat density.

Table 10. Summary of variable selection steps and final model parameters for the unit-scale multiple regression model with dependent variable redd density, for all habitat units that contained redds (n = 242).

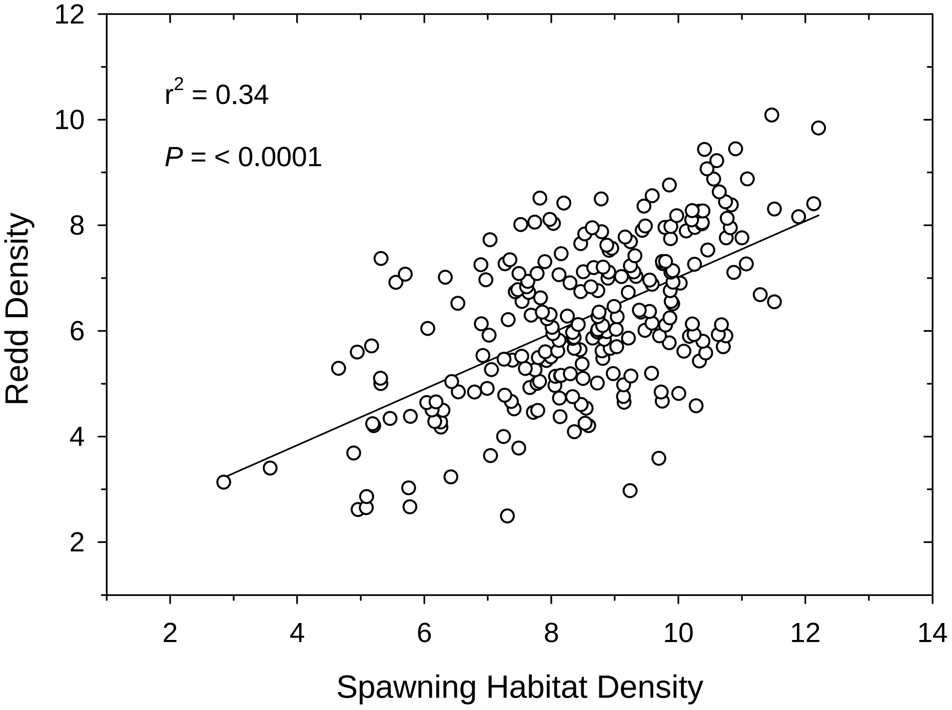
Summary of Stepwise Selection

Step	Variable Selection	df	r^2	Mallows' C_p	F Value	Pr > F
1	Spawning Habitat Density	1	0.34	10.99	123.67	< 0.0001
2	LWD Density	2	0.03	2.05	10.99	0.0011

Final Model Parameter Estimates

Variable	df	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	1.1338	0.4417	2.57	0.0109
Spawning Habitat Density	1	0.5628	0.0478	11.97	< 0.0001
LWD Density	1	0.0893	0.0270	3.31	0.0011

Figure 18. Relation between redd density (number of redds per m^2 of habitat unit surface area) in habitat units with redds (n = 242) and spawning habitat density (m^2 spawning gravel per m^2 of habitat unit surface area).



Tributary Scale

Although tributary redd abundance varied markedly between years (Table 2), similar significant relationships were observed among redd abundance and available spawning and rearing habitat at the tributary scale in both 2002 and 2003, indicating similar spatial distributions between years.

Spearman's rank correlation revealed significant ($P < 0.05$) positive correlations between redd abundance and both available spawning habitat and available rearing habitat in 2002 and 2003 (Table 11). In 2002, a significant correlation was also observed between redd abundance and spawning temperature.

Table 11. Spearman's coefficient of rank correlation (r_s) and level of significance (*P*) of habitat characteristic totals and redd abundance at the tributary scale for 2002 and 2003 in the Hebgen basin.

	2002		2003	
Habitat Characteristic Variable	r_s	*P*	r_s	*P*
Spawning Habitat (m^2)	0.9496	<0.0001	0.8303	0.0029
Rearing Habitat (m^3)	0.8404	0.0046	0.6970	0.0251
Large Woody Debris	0.6135	0.0789	0.5030	0.1383
Gradient	-0.4706	0.2011	-0.2970	0.4047
Spawning Temp (˚C)	0.7647	0.0164	0.5273	0.1173

Redd Substrate Composition

A total of 82 redd substrate core samples, from eight tributaries, were obtained in 2003. Analysis of substrate composition size classes over the entire basin revealed low-to-moderate levels of fine sediment accumulation in redds. The mean percent for fine sediment classes inversely related to survival of emergence of salmonid YOY (Everest et al. 1987; Chapman 1988) were: 26.9 % for material < 6.35 mm, 13.1 % for < 2.36 mm, and 5.5 % for < 0.85 mm (Figure 19).

Overall, redd substrate composition varied little among tributaries. Kruskal-Wallis nonparametric analysis of variance rank tests indicated no significant difference among median fredle index values (*P* > 0.05) for the eight tributaries (Figure 20; Table 12); the mean fredle index value for the basin was about 4.5.

Figure 19. Mean substrate particle size distribution for rainbow trout redd core samples (n = 82) from eight Hebgen Reservoir tributaries. Error bars are ± 2 standard error.

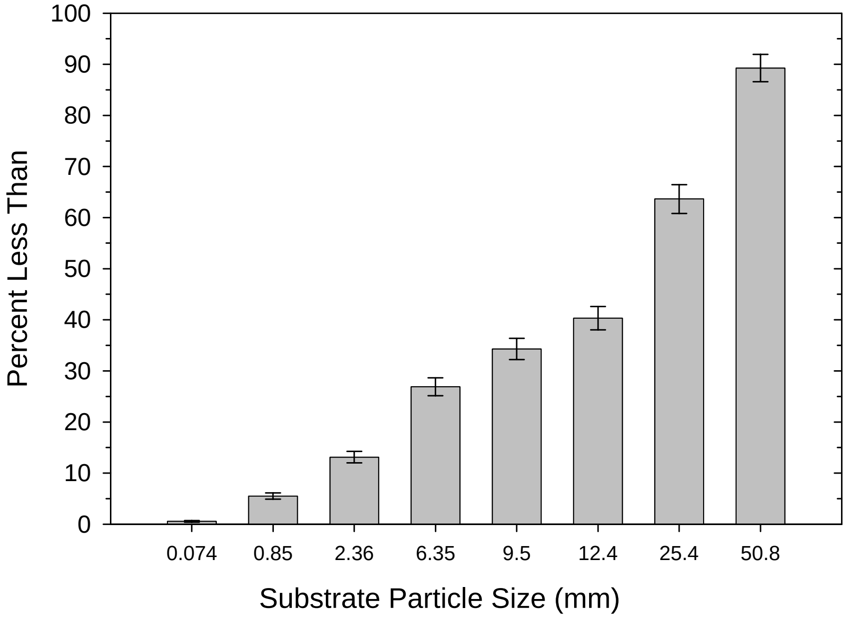
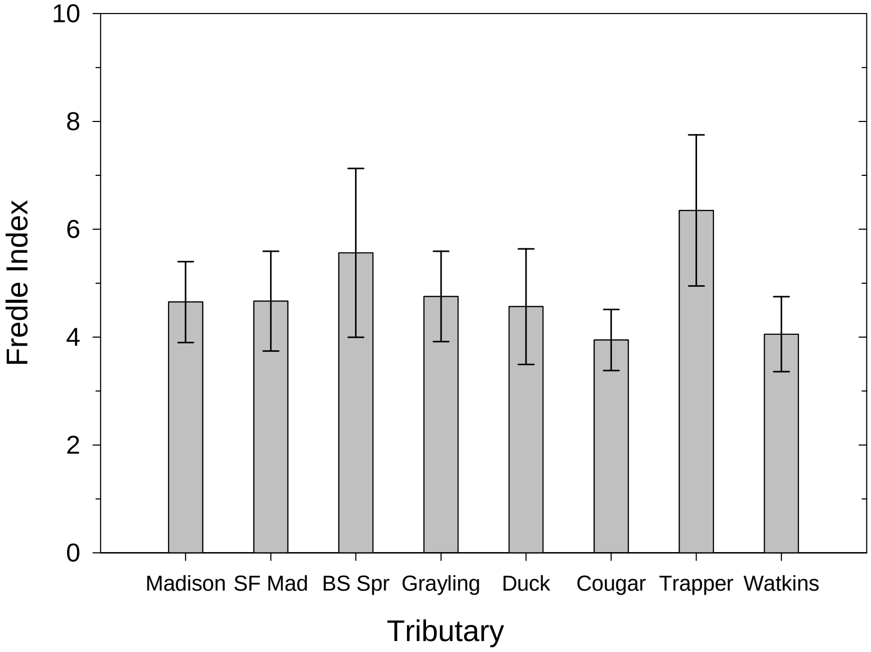


Figure 20. Comparison of mean fredle index values from redd core samples (n = 82) from eight Hebgen Reservoir tributaries. Error bars are ± 2 standard error.



Although there was no significant variation in percent of fines < 6.35 and < 9.5 mm among tributaries, the percent of very fine sediments, < 2.36 and < 0.85 mm, varied significantly among some tributaries (Table 12). Cougar, Duck, and Watkins creeks and the Madison River contained a higher percentage of material less than 2.36 and 0.85 mm than did the other tributaries (Table 12). The highest quality redd substrate material available in the basin was found within the South Fork of the Madison River and Black Sand Springs, Grayling, and Trapper creeks. These four tributaries exhibited the lowest proportion of fine particle material overall (Table 12).

Table 12. Substrate composition (percent by weight) and fredle index (FI) of redds sampled in Hebgen Reservoir tributaries. Significant differences among tributaries are based on Kruskal-Wallis nonparametric analysis of variance (ANOVA) rank tests ($\alpha = 0.05$). Kruskal-Wallis multiple-comparison Z-Value tests were used to determine significant differences between individual tributaries. There are no significant differences between tributaries with a letter in common.

Tributary	n	< 9.5 (mm)	< 6.35 (mm)	< 2.36 (mm)	< 0.85 (mm)	FI
Madison River	10	35.99z	26.48z	12.60zyxv	7.47 v	4.52z
S F Madison River	11	33.12z	26.20z	9.40 yx	3.17zyx	4.41z
Black Sand Creek	10	37.44z	30.00z	11.19zyx	2.29 x	4.66z
Grayling Creek	10	30.20z	21.30z	10.81zyx	3.66 yx	4.44z
Duck Creek	11	31.54z	26.45z	12.30zyxv	5.05zy v	4.17z
Cougar Creek	10	37.21z	30.06z	15.77z v	6.21zy v	3.85z
Trapper Creek	10	24.12z	19.72z	10.40 x	4.97 yx	6.03z
Watkins Creek	10	36.66z	29.46z	15.83 v	7.52 v	3.97z
ANOVA	--	11.79	9.99	15.22	31.36	12.14
P-Value	--	0.108	0.189	0.033	< 0.001	0.096

Young-of-the-Year Production Estimates

Estimated survival to emergence (STE) was moderate to high for all eight tributaries where redd substrate was sampled, ranging from 39.5 to 70.9% (mean, 56.7%; Table 13). Of the 2,503 spawning females captured at the Duck Creek traps in 2002, lengths ranged from 214 to 564 mm with a mean length of 422 mm. Average egg deposition per female, based on the mean female length of 422 mm from Duck Creek, was 1,841 eggs. This mean fecundity was extrapolated to all Hebgen basin tributaries in order to obtain YOY production estimates (Table 13).

Table 13. Rainbow trout YOY production estimates for tributaries of Hebgen Reservoir based on adjusted redd totals, survival to emergence (STE) estimates, and fecundity estimated from females captured in Duck Creek 2002.

	Adjusted Redd Total		Mean % STE	YOY Production	
Tributary	2002	2003		2002	2003
Madison River	221	111	39.50	160,527	80,642
S F Madison River	583	368	64.96	697,412	440,188
Black Sand Creek	395	51	70.94	516,193	66,666
Grayling Creek	194	33	65.92	234,845	40,100
Duck Creek	1,853	330	55.74	1,901,419	338,252
Cougar Creek	187	4	49.74	171,224	3,205
Trapper Creek	7	17	66.85	8,001	21,442
Watkins Creek	12	20	39.75	8,783	14,821
Total	3,452	941	≈58.10*	3,698,404	1,005,316

*Weighted Average

Young-of-the-year production estimates for the Hebgen Basin exceeded 3.5 million in 2002 and 1 million in 2003 (Table 13). Duck Creek and the South Fork of the

Madison River (including Black Sand Spring Creek) generated 84% of the total estimated YOY production in 2002 and 2003. Young-of-the-year production quantities closely followed adjusted redd totals per tributary, except in the two tributaries with lower STE values (Madison River, Watkins Creek) due to poorer redd gravel quality. For example, the Madison River had about 30% more redds than Grayling Creek (332 vs. 227, 2002 and 2003 combined) yet yielded 12% fewer YOY due to a lower STE (40% vs. 67%).

DISCUSSION

Spawning

My redd survey results indicated high levels of adfluvial rainbow trout reproduction in tributaries to Hebgen Reservoir. Although redd counts in 2002 far exceeded that of 2003, a total of over 5,500 redds were counted in the two years of this study, suggesting wild reproduction contributes substantially to rainbow trout production in the Hebgen basin. I found no comparable studies of redd production estimates for other adfluvial rainbow trout populations inhabiting reservoirs. However, Downing et al. (2002) recorded a total of 1,705 fluvial rainbow trout redds on a 46 km section of the mainstem Madison River downstream from Hebgen Reservoir in 1998 and 1999. In comparison, more rainbow trout redds were detected in the Duck Creek drainage alone in 2002 and 2003 (91.4 redds/km) than reported for this section of the Madison River in 1998 and 1999 (37.1 redds/km).

Why there were fewer redds counted in 2003 (70% fewer than 2002) is uncertain. The substantially lower number of redds counted in 2003 occurred in all major spawning tributaries in the Hebgen basin. I suspect the difference is likely due to underestimation of redd abundance rather than many fewer spawners. Redd construction began earlier in 2003 than in 2002, coinciding with peak discharge. For example, although an upstream migrant trap was not operated in Duck Creek in 2003, large numbers of upstream migrants were observed ascending the U.S. Highway 191 culvert in mid-April through early May. Additionally, landowners at the Koelzer Pond (who observe the spring rainbow trout migration at the Koelzer fish ladder yearly) reported an earlier than normal upstream migration in 2003, but the number of migrants observed was typical of other years (Dale Koelzer and Jim Criner, personal communication).

Timing of salmonid spawning has likely evolved in response to water temperature during spawning and flows that allow upstream migration of adults (Bjornn and Reiser 1991). Higher water temperature appeared to be involved in earlier run timing of Hebgen spawners in 2003. For instance, the average mean daily water temperature in Duck Creek for the month of April was about 1 °C higher in 2003 than 2002 (Appendix F). Fredenberg (1991) reported peak upstream migration in Duck Creek in May when the average mean daily stream temperature was about 8 °C. The average mean daily stream temperature in Duck Creek was 7.2 °C in May 2002 and 8 °C in May 2003. Although timing of peak discharge was similar between years (Appendix F), earlier migration would have exposed spawning rainbow trout to higher discharge during spawning, which I suspect diminished the characteristic pit used to identify redds.

Survey timing was another potential source of error in my redd counts. Basin wide surveys of the 170 km of available spawning tributaries required approximately two months to complete. Therefore, some redds could have been constructed over a month prior to surveying. Although observer accuracy was not explicitly tested in this study, only redds meeting the criteria of “newly constructed” were counted and 10% of all redds were excavated to estimate the proportion of false redds recorded. Superimposition was only evident in one reach on lower Duck Creek and correction for this source of potential bias was accounted for in my calculation of redd totals.

Variation in spawning life history also may have led to underestimates of actual redd numbers. Despite abundant available spawning habitat and moderate levels of available rearing habitat, few rainbow trout redds were detected in the Madison River in the spring. I counted redds in the summer immediately following spring spawning, but in the mainstem Madison River, autumn and winter spawning of rainbow trout has been observed (Hetrick 1993a). Hetrick (1993a) detected young-of-the-year (YOY) rainbow trout outmigrations in February through April 1992 on the Madison, Firehole, and Gibbon Rivers. Redd surveys were not conducted in autumn and winter in this study due to the inability to distinguish rainbow trout redds from brown trout redds. Therefore, my redd estimates for the Madison River drainage may be below annual levels of wild rainbow trout reproduction in that drainage.

Outmigration

Earlier studies identified YOY outmigration as the predominant life history pattern among rainbow trout in Hebgen Reservoir (Fredenberg 1991; Hetrick 1993a). In this study, through multiple outmigrant trapping efforts, I captured YOY rainbow trout outmigrants but also detected juvenile (age-1 and age-2) outmigrations of rainbow trout in Duck Creek and the South Fork of the Madison River. Fredenberg (1991) reported that YOY rainbow trout in upper Duck Creek might delay emigration upon emergence or rear in the headwaters of the upper drainage. I captured few YOY rainbow trout outmigrants from redds constructed in upper Duck Creek in 2002 and 2003 despite large numbers of redds constructed upstream. The upstream fyke trap, operated upstream of the Koelzer Pond, in 2002 was possibly inefficient in capturing YOY due to low water velocities and trap avoidance. However, the downstream fyke trap in 2002 experienced similar flow conditions and was relatively efficient (26 %) in 2002, and further supported limited downstream movement in the upper drainage.

A spring-early summer juvenile (age-1 and age-2) rainbow trout outmigration likely occurs annually in Duck Creek. However, I was only able to detect the outmigration when screw traps were employed in 2003. Based on screw trapping results, over 8,000 juvenile (age-1 and age-2) rainbow trout and 3,000 juvenile brown trout were estimated to have outmigrated from the Duck Creek drainage in 2003. The juvenile outmigration corresponded with high flow conditions in late May to early June, overlapping with the timing of adult upstream migration. However, outmigrant numbers peaked in late June, corresponding with a marked drop in water level. Studies have demonstrated that efficiency of juvenile salmonid capture in rotary screw traps can be negatively affected by extreme low or extreme high river stages (Kennen et al. 1994; Thedinga et al. 1994). Therefore, estimates of total juvenile outmigrants may have been underestimated at high flows in this study.

Fyke and screw trapping efforts revealed substantial numbers of YOY and juvenile outmigrants of both rainbow and brown trout on the South Fork of the Madison River. The screw trap on the South Fork of the Madison River in 2003 proved to be effective at capturing YOY outmigrants in addition to capturing juveniles. In contrast to Duck Creek, large numbers (over 50,000) of YOY rainbow trout were estimated to have outmigrated from the South Fork of the Madison River shortly after emergence in 2003.

This further suggests that a mid to late summer outmigration of newly emergent YOY rainbow trout did not occur in Duck Creek, as few YOY outmigrants were captured in the Duck Creek screw trap during the same time period. Young-of-the-year brown trout were also captured in the South Fork of the Madison River from mid-March through early May, but numbers far exceeded that of Duck Creek (estimate of 444,276 vs. 15,656). Timing of outmigrations of both juvenile (age-1 and age-2) rainbow and brown trout occurred about two months earlier in the South Fork of the Madison (in mid-March, corresponding with pre-runoff conditions) than in Duck Creek and continued through early August.

Several factors could account for the differences in species abundance, life history, and outmigration timing between these tributaries. First, differences in timing of juvenile outmigration between tributaries may be due to the predominance of beaver ponds as overwintering habitat in upper Duck Creek. Similar to upstream passage of beaver dams by adult spawners, overwintering juveniles may be unable to outmigrate from beaver ponds until periods of high flows create side channels and partially breach dams, permitting downstream movement (Swanston 1991; Olson and Hubert 1994). Second, a longer juvenile overwintering period in the Duck Creek drainage may also be associated with a greater abundance of pond habitat than found in the South Fork of the Madison River. Beaver ponds provide low-velocity, deep, productive environments suitable for overwintering stream rearing salmonids (Olsen and Hubert 1994; Cunjak 1996). Duck Creek contained over two times the pond-rearing habitat of the South Fork of the Madison River (13.0 ha vs. 5.9 ha by surface area). Similar water temperatures were experienced in both tributaries in mid-March – April and therefore did not appear to be a factor in the earlier outmigration of juveniles in the South Fork of the Madison River.

Although levels of available spawning and rearing habitat are similar between the South Fork of the Madison River and Duck Creek, higher levels of brown trout reproduction in the South Fork of the Madison River may be attributed to warmer autumn water temperature due to thermal inputs from Black Sand Spring Creek. For example, water temperature likely corresponding with the brown trout upstream migration in October is markedly higher in the South Fork of the Madison River than in Duck Creek (7-9 °C compared to 5-6 °C; Appendix E).

Tributary production of YOY and juvenile brown trout was comparable to rainbow trout production in Duck Creek and far exceeded estimates of both YOY and juvenile rainbow outmigrants in the South Fork of the Madison River. Therefore, wild brown trout production may be substantially greater than wild rainbow trout production in the Hebgen basin overall. Trapping results support the existence of multiple life history forms in the wild brown trout population of Hebgen Reservoir, including juveniles overwintering in tributary rearing habitats. Brown trout YOY emerged in both Duck Creek and the South Fork of the Madison River from early March through April and YOY brown trout that remained in tributaries had reached 40-55 mm in length by the time YOY rainbow trout (22-30 mm) had emerged in mid-July. Predation and competition by juvenile brown trout, owing to a substantial size advantage due to earlier emergence, can adversely affect juvenile rainbow trout survival and influence outmigration timing (Hayes 1988). Consequently, high densities of YOY and juvenile brown trout overwintering in rearing habitats in both Duck Creek and the South Fork of the Madison River may adversely affect YOY and juvenile rainbow trout survival through competition and predation. High densities of overwintered brown trout in the South Fork of the Madison River may also displace emergent YOY rainbow trout and induce earlier outmigrations than observed in Duck Creek.

Why there was such a large discrepancy between the number of YOY estimated to have emerged in Duck Creek in 2002 and 2003 and outmigration trapping estimates of YOY and juvenile rainbow trout is not clear. For example, over 8,000 age-1 and age-2 juvenile rainbow trout were estimated to have outmigrated from the Duck Creek drainage in spring 2003. However, the number of age-1 outmigrants was well below expected based on the 2002 YOY production estimate of 1.9×10^6 in Duck Creek (Table 13) and the lack of YOY outmigrants captured in summer 2002. Similar discrepancies were observed in the South Fork of the Madison River in 2003. Although speculative, the discrepancy in data between years may be attributed to: 1) a substantial autumn YOY and juvenile rainbow trout outmigration, 2) trap avoidance by YOY during the emergence and summer outmigration period, 3) poor screw trap efficiencies during high flow periods resulting in an underestimation of age-1 and age-2 outmigrants, 4) a large proportion of the 2002 cohort delaying migration until spring 2004, 5) low overwinter survival in tributary rearing habitats, and 6) a combination of the aforementioned factors.

Autumn juvenile outmigrations may be occurring in tributaries in the Hebgen basin and, as noted above, may account for discrepancies between redd counts and outmigration estimates. Munro (2004) found that most juvenile rainbow trout outmigrate from tributary rearing habitats to the mainstem Missouri River, Montana in the late spring to early summer period. However, a second, late autumn outmigration was also detected annually (Munro 2004). Therefore, an autumn YOY and juvenile outmigration is plausible in Hebgen basin tributaries also and autumn trapping should be included in future research projects.

Life History Characteristics

Spawner Life History

Spring spawning migrations of adfluvial rainbow trout have been documented in several tributaries in past studies of Hebgen Reservoir (Oswald et al. 1990; Fredenberg 1991; Hetrick 1993a, 1994a, 1994b; ERI and NWPS 2002). In this study, a total of 3,164 adult rainbow trout were captured at the Duck Creek trap sites from 1 April to 19 June 2002. Fredenberg (1991) captured fewer upstream migrants (1,277), however, trapping was limited to a shorter period (3 May to 27 May) in 1990. Similar to Fredenberg's (1991) results, I also found that: 1) males dominated the early migration period, 2) females outnumbered males, 3) stream temperatures of 8 °C corresponded with peak migration and, 4) most spawners were between 355 and 500 mm.

Females outnumbering males in rainbow trout spawning runs have been documented in several rainbow trout studies (Van Velson 1974; Biette et al. 1981;

Sanborn 1990; Hetrick 1994b). Although males dominated the early period of the spawning run, overall few males were captured during the prespawning period (1 April – 1 May) in 2002 in Duck Creek. The likelihood of a substantial male upstream migration prior to April, corresponding with water temperature below 4 °C, seems unlikely. However, males being outnumbered by females may be related to increased mortality rates in the male population, age at sexual maturity in relation to the strength of year classes represented in the spawning population, or the occurrence of a proportion of males expressing a tributary resident life history form similar to that of some anadromous salmonids (Metcalfe 1998).

Lengths of adult spawners were comparable between 1990 and 2002. Fredenberg (1991) reported all females and 95% of males were between 355 and 500 mm in length. Similarly, 98.5% of the females and 93% of the males and were within this range in 2002. Therefore, although the quantity of spawners in Duck Creek likely fluctuates annually, growth achieved in the reservoir appears to be consistent temporally.

Rainbow trout spawners in Duck Creek in 2002 were older, on average, than previously reported in the Hebgen Reservoir system. Over 50% of Duck Creek spawners in 2002 were estimated to be age 4, nearly 40% were age 5, whereas age-3 spawners contributed less than 10%. Fredenberg (1991) reported that adult spawners from Duck and Grayling creeks and the South Fork of the Madison Rivers were most likely 3 or 4 years old. However, Fredenberg (1991) did not feel confident in age analysis results due to scale patterns being very complex and inconsistent, with numerous check marks present. Although I also found variation in migration check location, annulus formation was consistent throughout the Duck Creek scale sample.

Juvenile Life History

Salmonids populations may possess several outmigration patterns (Kwain 1971) and plasticity in rainbow trout life history is well documented (Alexander and MacCrimmon 1974; Van Velson 1974; Biette et al. 1981; Rosenau 1991; Munro 2004). Juvenile salmonids often undertake a period of stream rearing in order obtain a minimum size required for increased survival in mainstem rivers, lakes, or oceans (Rosenau 1991; Hayes 1995). In accordance with my hypothesis, I found that tributary rearing of wild juvenile rainbow trout (age-1 and age-2) was prevalent in the two tributaries trapped and juvenile outmigrants likely contribute substantially to tributary recruitment to Hebgen Reservoir (Table 3).

The multiple outmigration forms observed in the Hebgen Reservoir rainbow trout population may be in part due to the strain of rainbow trout utilized. Eagle Lake rainbow trout have been stocked in Hebgen Reservoir since 1983. Based on gill net data trends and the number and size of strains stocked, Hetrick (1994a) suggested that Eagle Lake rainbow trout experience higher winter survival rates than the Desmet strain and from 1996 to present Eagle Lake has been the only strain of rainbow trout utilized to bolster angler harvest and establish wild spawning runs (Appendix A). Therefore, it is assumed that a large proportion of the adult life forms that comprise the current wild spawning population are derived from this strain.

The Eagle Lake rainbow trout, thought to be indigenous to Eagle Lake of Lassen County, California, historically spawned in Piney Creek, the only tributary to Eagle Lake (McAfee 1966). Prior to Piney Creek becoming dewatered near the mouth, Eagle Lake spawners migrated 45 kilometers upstream to reach primary spawning grounds where juveniles remained for 1-2 years before outmigrating to the lake (McAfee 1966; P. Chappel, Fisheries Biologist, Eagle Lake California, California Department of Fish and Game, personal communication). Similar overwintering rearing forms were observed in the Hebgen Reservoir rainbow trout population in tributaries where adequate rearing habitat was available (Duck Creek and the South Fork of the Madison River).

Table 14, adapted from Kwain (1971) and Munro (2004), illustrates the variation in life history forms of stream rearing in fluvial and adfluvial rainbow trout populations based on interpretation of scale growth patterns of adult spawners and outmigrant trapping. As noted by Munro (2004), the predominance of age-1 (6 out of 13 locations) and age-2 (5 out of 13 locations) outmigrants recruited to adult populations is common (Table 14). Munro (2004) found the predominant life history form recruited to the adult rainbow trout population in the Missouri River, Montana to be age-1, where nearly 90% of the adult mainstem population was comprised of yearling outmigrants (Table 14).

The YOY outmigration form is not commonly expressed in adult populations despite large numbers of YOY outmigrants in some cases. For example, only Rosenau 1991) found that YOY outmigrants contributed significantly to adult recruitment (Table 14). Similar to Rosenau's (1991) findings a significant proportion of Duck Creek spawners were estimated to be YOY outmigrants (Table 14). More common to the other studies, 30% of the Duck Creek sample was comprised of age-2 outmigrants (Table 14), yet only 9% represented age-1 forms despite the large numbers of outmigrants of this age that we recorded.

Table 14. List of results from studies that investigated the duration of stream rearing in rainbow trout, illustrating the variation in life history forms[1]. Results are presented as percent composition of outmigrant population.

		Years of stream rearing			
		0	1	2	3
Author	Location	Rainbow trout			
Hartman 1959	Grout Br., NY	–	13.5	62.5	–
	Cold Br., NY	–	24.7	49.2	–
	Catherine Cr., NY	–	73.0	0.0	–
Northcote 1969	Pothole L., BC	6.1	54.3	31.8	7.8
Dodge & MacCrimmon 1970	Bothwell, Cr. ON	–	–	99.0	–
Kwain 1971	Batchawana Bay, ON	–	38.2	58.1	3.7
Stauffer 1972	Black River, MI	–	64.0	34.0	2.0
Van Velson 1974	McConaughy Res., NE	–	92.0	8.0	–
Kwain 1981	Stokely Creek, ON	–	41.0	53.0	6.0
Rosenau 1991	Waimarino R, NZ	29.8	70.2	–	–
	Tokaanu R., NZ	50.6	49.4	–	–
	Hinemaiaia R., NZ	63.8	36.2	–	–
Munro 2004	Craig section, Missouri R., MT	11.3	87.8	0.9	–
Present Study					
Adult Scales 2002	Duck Creek, MT	54.4	9.3	30.1	5.3
Outmigrant Trapping 2003	Duck Creek, MT	–	51.0	49.0	–
	S. F. Madison R, MT	88.6	7.5	3.9	–

[1] Table adapted from Kwain (1971) and Munro (2004).

Although I attempted to quantify primary life history recruited to the adult population, due to subjectivity of the scale migration check analysis and the complex nature of the rearing environment, it can only be speculated that my interpretation of checks present in adult scales accurately depict early rearing forms. In the Duck Creek population, the mean distance to migration checks for age-1 and age-2 life history forms in adults was greater than the mean distance recorded to juvenile migration check locations for comparable age classes, suggesting that checks among some juveniles may have been formed in rearing habitats less productive than the reservoir, or that fish in the adult population that were larger at the time of migration, when they entered Hebgen Reservoir, had better survival (Table 5).

However, Hebgen Reservoir rainbow trout do appear to exhibit multiple juvenile outmigration life history forms. Outmigrant YOY and juvenile (age-1 and age-2) rainbow trout were captured on both the Duck Creek and the South Fork of the Madison River and scale growth patterns observed in the adult spawning population of Duck Creek revealed a protracted period of tributary rearing in addition to a large outmigrant YOY component. However, there was much variation in the proportion of outmigrant age classes between tributaries and between the adult scale analysis and outmigrants captured in Duck Creek (Table 14). This marked variation made it difficult to determine the primary life history form recruited to the adult population, and suggests that the Hebgen Reservoir population is comprised of a complex subset of life history forms that vary among tributaries.

Tributary Habitat

Significant positive relations were found between redds and the amount of available spawning habitat at both the habitat unit and tributary scale. In addition, at the tributary scale I found a significant positive relation between redd abundance and rearing habitat availability. Therefore, within a tributary, adfluvial rainbow trout from Hebgen Reservoir selected spawning areas, in part, by the quantity of available spawning habitat, but tributaries selected by most Hebgen spawners also contained high amounts of available rearing habitat. In addition to most redds being found in tributaries with high quantities of available spawning and rearing habitat, most spring spawners (about 85%) ascended tributaries where water temperature increased to approximately 7 °C by late May, and that maintained mean daily temperature from 1 April through 1 July of 8 – 10 °C. Therefore, a combination of these three key habitat features appears to strongly influence tributary selection by spring spawning rainbow trout in the Hebgen basin.

Positive relationships between salmonid redd density and potential spawning habitat availability, at various spatial scales, have been documented in other studies (Cope 1957; Beard and Carline 1991; Magee et al. 1996). Although juvenile salmonid production is thought to be largely controlled by the quantity and quality of rearing habitat in many stream systems (Meehan 1991), little has been documented relating spawning to rearing habitat availability. The high redd abundance I observed in the two tributaries with the most rearing habitat suggests that abundant spawning habitat alone does not appear to drive reproduction and a combination of both habitat features, as found in Duck Creek and the South Fork of the Madison River, likely provides optimal habitat for wild rainbow trout production in this system.

Substantial variation was observed in redd distribution within tributaries. For example, the majority of spawning in Duck Creek occurred in second order headwater tributaries (Campanula and Gneiss creeks) within YNP. Numerous beaver dam complexes separated by low gradient riffle sections characterized these areas, affording the combination of spawning and rearing habitat. The formation of beaver ponds often limit anchor ice development and the effects of supercooling in streams, while providing deep pools, undercut banks, and overhead cover often selected for overwintering habitat by stream rearing salmonids (Olson and Hubert 1994; Cunjak 1996; Jakober et al. 1998; Pollock et al. 2004). Movement into low velocity deeper water, in winter, appears to be a general response of juvenile salmonids in lotic systems (Baltz et al. 1991) and stream rearing salmonids often select pool, backwater, and beaver pond environments as overwintering habitat when available (Cunjak 1996). Forty-one individual beaver dams and associated ponds were documented in the upper Duck Creek drainage in 2003. High redd densities were found immediately downstream of and between beaver dam complexes. Despite the numerous beaver dams in the upper Duck Creek drainage, I found no evidence that they limited upstream passage. During runoff, numerous side channels and breached dam sections appeared to readily allow upstream passage around most of the beaver dams. The beaver ponds, the Koelzer Pond, and two large ponds at the headwaters of Richards Creek accounted for the large quantity of rearing habitat recorded in Duck Creek.

Although similar in spawning and rearing habitat availability, stream habitat in the South Fork of the Madison River was markedly different from that found in Duck Creek. The South Fork of the Madison River is within a broad, well-defined flood plain and possesses deep meander pools with point bar deposition throughout. Abundant spawning gravels in the South Fork of the Madison River were primarily associated with point bars, low gradient riffles, and pool tailouts. Although, fewer beaver dams and associated ponds (8) were found on the South Fork of the Madison River in comparison to the Duck Creek drainage, deep lateral scour pools provided most of the available rearing habitat. In a Wyoming foothill stream morphologically similar to the South Fork of the Madison River, Lindstrom and Hubert (2004) found both beaver ponds and deep lateral scour pools to be critical overwintering habitats for cutthroat and brown trout.

Although the upper Madison River drainage provided most of the available spawning habitat recorded in this study (51%), rearing habitat comparable to that found in the Duck Creek and South Fork of the Madison River drainages was not prevalent. The upper Madison River contained little pool or pond habitat and was comprised mostly of long glide, riffle, and run habitats. However, juvenile rainbow trout overwintering survival, in medium sized rivers comparable to the upper Madison River, may be substantial in riverine habitats with abundant cover and interstitial spaces (Mitro and Zale 2002). Therefore, some areas of the Madison River with abundant instream vegetation, large boulders, and undercut banks likely provide substantial rearing habitat. However, very few redds were identified in the Madison River in comparison to tributaries that contained a high proportion of pool and pond habitat. A combination of warmer temperature in late spring and early summer (Figure 15) and a lack of deep pools and ponds as rearing habitat may limit the number of spring spawning rainbow trout from Hebgen Reservoir that utilize the Madison River.

In comparison to Duck Creek and the South Fork of the Madison River, Grayling Creek lacked spawning and rearing habitat and experienced markedly colder water temperature (average daily mean of 5.6 °C) throughout the spring and summer spawning period. Although Grayling Creek was the fourth largest major tributary (by surface area, Table 6) inventoried in the Hebgen basin, it only contained about 2% of the available spawning habitat and 2% of the available rearing habitat (Table 6), and contained relatively few redds. Of the redds identified in Grayling Creek, most were found from the U.S. Highway 191 bridge upstream to a bedrock falls within YNP, approximately 13 stream kilometers upstream from Hebgen Reservoir (Figure 2). In this localized area, the actively eroding channel provided newly recruited spawning gravels in pool tailouts and in depositional areas on point bars.

Numerous, heavily silted beaver dams and a lack of spawning gravel in the lower drainage appeared to limit wild rainbow trout production in Cougar Creek. Nearly all (97%) of the redds observed in the Cougar Creek drainage were found in headwater areas over 5 stream kilometers upstream in YNP. Similar to Duck Creek and the South Fork of the Madison River, temperature, throughout the spring upstream migration and spawning period, in Cougar Creek was from 8 – 10 °C. However, despite moderate quantities of rearing habitat, available spawning habitat appeared to limit spawning in Cougar Creek (Table 6). Most spawning habitat in Cougar Creek was limited to localized headwater habitats that may have been difficult to access by spawners. Several beaver dams (18) found in lower Cougar Creek were fortified with mud and silt with limited side channel development around them, possibly limiting passage through and around dams.

The smaller tributary systems possessed limited quantities of spawning and rearing habitat and experienced some of the coldest water temperatures in the basin. In general, Cherry, Red Canyon, Rumbaugh, Trapper, and Watkins creeks were characterized by higher gradients, high to moderate large woody debris densities (Table 6), frequent small pools, large cobble and small boulder substrates, and dense conifer overstory canopies. Spawning was minimal in these tributaries when compared to reproduction levels throughout the basin; however, rainbow trout production was documented in several of these streams through the course of this study and has been documented in all prior investigations of the Hebgen basin (Oswald et al.1990; Fredenberg 1991; Hetrick 1993b). Therefore, their combined contribution and potential to bolster wild reproduction should not be overlooked.

Redd Substrate Composition

Fredenberg (1991) recommended evaluating substrate composition in critical spawning reaches of the Hebgen basin and to minimize environmental perturbations in drainages with high levels of fine sediment accumulation. No tributaries in the Hebgen basin appeared to have redd substrate quality that would greatly impede embryo survival. Overall, my redd core sampling results revealed only low to moderate levels of fine sediment in spawning gravels in Hebgen basin tributaries and my estimates may have been conservative.

Few redd core samples processed in this study contained ova (11 of 82) and YOY were observed in most tributaries during sampling, indicating that timing of egg pocket coring was often later than ideal. Intrusion of fine sediment into redds post spawning has been well documented (Chapman 1988; Bjornn and Reiser 1991; Grost et al. 1991). During redd construction, fine sediments and organic material tends to be transported downstream, therefore, the redd environment is most favorable to embryos immediately after construction (Bjornn and Reiser 1991). Therefore, fine sediment levels in spawning gravels sampled in this study could have been overestimated.

I compared fredle index (FI) values and percent of fine sediment < 0.85 mm and < 6.35 mm of redd core samples from the Hebgen basin with other streams in the Rocky Mountain Region (Table 15; adapted from Magee 1993). Similar to Magee (1993), most of my core samples were collected during or shortly after emergence, whereas samples in the other studies (Table 15) were collected earlier, during incubation, and therefore may have accumulated fewer fines.

Overall, substrate quality in the Hebgen basin appears to be of moderate to high quality in comparison to the other areas reported (Table 15). The average FI value for tributaries in the Hebgen basin was higher than two of the four reported values in the comparison studies. The Hebgen basin tributary average for percent fine sediment < 0.85 mm was lower than all but two of the six reported values and average % < 6.35 mm ranked lower than three of the six reported values from streams in the Rocky Mountain region (Table 15).

Although variation in fine sediment composition of redds was observed throughout the Hebgen basin, redd densities generally were not higher in tributaries with the highest quality substrates (lower levels of fines), indicating that homing (Northcote

1997), spawning gravel availability (Magee et al. 1996), and rearing habitat availability likely influence redd abundance to a greater degree than gravel quality.

Table 15. Comparison of fredle index (FI) values and percent fine sediment < 0.85 mm and < 6.35 mm in salmonid redds within the Rocky Mountain Region. Species represented include: brook trout (BRK), brown trout (BRN), steelhead (STLH), rainbow trout (RBT), westslope cutthroat trout (WCT), and Yellowstone cutthroat trout (YCT).

Stream	Species	N	FI	% < 0.85 (mm)	% < 6.35 (mm)	Reference
Douglas Cr., WY.	BRN	69	--	3.0	15.0	Grost et al. 1991
Hungry Horse Cr., MT	WCT	3	4.9	5.9	27.4	Weaver and Fraley 1991
Pine Cr., ID.	YCT	16	7.6	5.0	20.0	Thurow and King 1994
Taylor Fork, MT.	WCT	11	2.7	16.8	39.0	Magee 1993
Telephone Cr., WY.	BRK	31	--	6.4	12.1	Young et al. 1989
Upper Salmon R., ID.	STLH	9	3.9	10.2	32.8	Thurow and King Unpublished
Black Sand Spring Cr., MT	RBT	10	5.6	3.5	30.6	This Study
Cougar Cr., MT.	RBT	10	3.9	7.0	28.9	This Study
Duck Cr., MT.	RBT	11	4.6	6.2	27.0	This Study
Grayling Cr., MT	RBT	10	4.8	5.6	22.8	This Study
Madison R., MT.	RBT	10	4.6	8.7	27.2	This Study
South Fork Madison R., MT.	RBT	11	4.7	4.8	27.5	This Study
Trapper Cr., MT.	RBT	10	6.3	5.2	21.6	This Study
Watkins Cr., MT.	RBT	10	4.1	8.2	29.4	This Study
Total	RBT	82	4.5*	5.5*	26.9*	This Study

Table adapted from Magee (1993). Average*

Young-of-the-Year Production Estimates

Survival to emergence (STE) averages ranged from 40-71% and the Hebgen basin average about 58% (Table 13). My STE estimates, derived from an equation produced for rainbow trout STE in relation to % fine sediment < 9.5 mm and < 0.85 mm (Irving and Bjornn 1984), may be conservative when compared to findings of laboratory studies other than Irving and Bjornn (1984) that have also evaluated rainbow trout STE in relation to substrate composition of the redd environment. Lotspeich and Everest (1981) reported a linear relation between fredle index (FI) values and STE of incubating steelhead. Fredle index values between 4 and 5 were associated with 60-70% STE for steelhead (Lotspeich and Everest 1981). Similarly, the average FI value among Hebgen tributaries was about 4.5 (Figure 20; Table 12); however, my basin STE estimate average was 57%. In addition, redd substrate composition with 40% fine sediment < 6.35 mm has been found to correspond to 50% STE of rainbow trout embryos (NCASI 1984; as reported in Kondolf 2000) and 39% fine sediment < 6.35 mm was correlated with 50% survival of steelhead embryos by Tappel and Bjornn (1983). Average percentage of fine sediment < 6.35 mm ranged from 22-31% in Hebgen Reservoir tributaries and averaged 27% across the basin. Therefore, the basin estimate average of 55% STE may be conservative.

In addition, rainbow trout embryo survival models based on substrate size composition may not be accurate when assessing quality of redds in groundwater-fed streams (Sowden and Power 1985). Areas with upwelling ground water may have survival advantages for incubating salmonids over areas without ground water influence

(Bjornn and Reiser 1991). High densities of redds were observed in areas of active upwelling in the headwaters of the South Fork of the Madison River and in Black Sand Spring Creek. Consequently, survival to emergence in these areas may have been higher than estimated.

Although levels of fine sediment in Hebgen basin spawning areas were low to moderate compared to other Rocky Mountain streams, YOY production estimates could be strongly influenced by changes in sediment levels because most of the spawning was concentrate in only two tributaries. For example, in Duck Creek, a slight increase in fine sediment accumulation, corresponding with a 5% decrease in STE, could decrease YOY production by 200,000 individuals or more. This example illustrates the importance of minimizing accelerated rates of fine sediment delivery in tributaries within the Hebgen basin.

Overall, given the present quality of tributary spawning habitats in the Hebgen basin, I estimated over 4.7 million YOY rainbow trout were produced in 2002 and 2003. Based on extensive YOY trapping, Fredenberg (1991) estimated 590,000 YOY rainbow trout were recruited to Hebgen Reservoir in 1990. Fredenberg (1991) considered his estimate very conservative and predicted YOY production to reach a level, over time, which perpetuates a self-sustaining rainbow trout fishery in Hebgen Reservoir. My data suggests that tributary habitat could support an exclusively self sustaining wild rainbow trout population that could satisfy the recreational demands of the Hebgen Reservoir fishery. However, many factors not addressed in this study could affect tributary and reservoir survival rates and thus recruitment to the adult rainbow trout population.

Limiting Factor Analysis

Bisson (1992) stressed the importance of identifying limiting factors when analyzing stream habitat quantity and quality in relation to the production of salmonids. He advised that limiting factor analyses should be comprised of: 1) detailed and accurate habitat inventory information, 2) knowledge of the life histories of the species of interest, 3) an appreciation of the complexity of the stream system, and 4) a basin oriented perspective (Bisson 1992).

I incorporated this approach in my assessment of tributary potential for rainbow trout recruitment in Hebgen Reservoir. Redd surveys and habitat inventories were conducted at the habitat unit and tributary scales and included all lotic environments accessible to adfluvial spawners of Hebgen Reservoir. I also intensively trapped adults, YOY, and juvenile (age-1 and age-2) life stages in a subset of tributaries to assess population abundance and to better understand the life history complexity of Hebgen Reservoir rainbow trout.

Overall, my basin wide limiting factor analysis found little evidence that tributary habitat is a population bottleneck limiting wild rainbow trout reproduction and production in the Hebgen basin. Hebgen basin tributaries produced and estimated 4.7 million YOY in 2002 and 2003 and supported thousands of overwintered juvenile rainbow trout with over 170 kilometers of accessible tributary habitat providing abundant spawning habitat (over 7 ha) and rearing habitat (over 11×10^5 m^3). However, thresholds of spawning and rearing habitat required to sustain the wild rainbow trout population of Hebgen Reservoir at a satisfactory level to support the recreational demands of the fishery were not explicitly addressed in this study because of additional factors influencing tributary survival and recruitment to the adult population.

Spawning gravel availability does not appear to limit the rainbow trout population. Rainbow trout redds can vary in size, requiring areas of spawning gravels ranging from about 0.5 m^2 (Muhlfeld 2002) to over 4.0 m^2 (Bjornn and Reiser 1991). Although, I did not measure redd size in this study I did not observe any redds in Hebgen basin tributaries larger than 2 m^2. Therefore, if one half of the purported available spawning habitat (about 35,000 m^2) was unitized by female adfluvial rainbow trout requiring 2 m^2 of spawning gravel to reproduce, Hebgen basin tributaries could produce over 17,000 redds annually. Additionally, spring rainbow trout runs and autumn brown trout runs do not temporally overlap in regard to spawning, incubation, and emergence periods in the Hebgen basin and interspecific competition for spawning habitat should not affect rainbow trout reproduction levels.

My data suggests that rearing habitat, with over 11×10^5 m^3 available, is likely not limiting rainbow trout production, but high levels of predation and competition may be exerted by sympatric brown trout juveniles thereby substantially decreasing tributary survival of young rainbow trout. As Bisson (1992) cautioned, a thorough evaluation of habitat limiting factors requires an appreciation for the complexity of the stream environment. Ploskey (1986) suggested that spawning success alone does not insure a strong year class, but may enhance the chances of producing one, given the environmental and trophic conditions favorable for YOY survival. Brown trout, once past the YOY stage, have been shown to socially dominate young rainbow trout in small streams through competitive interaction (Hayes 1988). Although inconclusive, the high densities of YOY and juvenile brown trout outmigrants captured in this study suggests that tributary rearing habitat availability could be limiting the wild rainbow trout population.

Fluctuations in gill net data have raised concern that the Hebgen Reservoir rainbow trout population is currently at a level lower than expected. However, the gill net data set may underestimate population size. Age 3 rainbow trout are the predominant age class captured in spring gill nets and spring gill net trends have shown a fluctuating rainbow trout population in Hebgen Reservoir. However, I found that age-4 and age-5 rainbow trout comprised the bulk of the Duck Creek spawning run and that age-3 fish accounted for less than 5% of the Duck Creek spawning population in 2002. Also, there is temporal overlap between gill net sampling and upstream migration in Duck Creek. Spring gill net sampling is generally conducted in late May. Spawner numbers peaked in Duck Creek from mid to late May in both 1990 (Fredenberg 1991) and 2002. This may indicate that a large proportion of older adfluvial spawners, age 4 and age 5, ascend tributaries prior to gill net sampling and are absent from the reservoir during the gill net sampling period. Therefore, the age distribution and possibly the spring gill net catch rate of rainbow trout in Hebgen Reservoir may be an underestimate. A better understanding of the current status of the reservoir population will be necessary before determination of limitations to the population can be addressed.

Byorth (2004) reported angler catch rates for rainbow trout averaging 0.31 fish/hr for the Hebgen Reservoir fishery from June 2000 to June 2001 and spring gill net catch rates have averaged about 5.5 fish/net from 1982 to 2003 (Figure 1). In comparison to other large reservoir rainbow trout fisheries in Montana, these data support Hebgen Reservoir being a quality rainbow trout fishery. For example, three large reservoirs on the Upper Missouri River, Canyon Ferry, Holter and Hauser Reservoirs, that are considered good quality recreational trout fisheries experience similar angler harvest and gill net catch rates as Hebgen Reservoir. The current management objectives included in the 2000-2009 Reservoir Fisheries Management Plan (MTFWP 2000) for these reservoirs includes obtaining angler rainbow trout catch rates of: 0.15 fish/hr for Canyon Ferry Reservoir, 0.15 fish/hr for Hauser Reservoir, and 0.25 fish/hr for Holter Reservoir. Similar objectives for gill net catch rates are as follows: 9 fish/net in Canyon Ferry, 5 fish/net in Hauser Reservoir, and 8 fish/net in Holter Reservoir (MTFWP 2000). From 1986-2004 Canyon Ferry Reservoir has experienced winter angler harvest rates for rainbow trout of about 0.4 fish/hr and summer catch rates of about 0.3 fish/hr (MTFWP 2004b). Similarly, from 1986-2004 angler rainbow trout catch rates have averaged 0.27 fish/hr in Hauser Reservoir and 0.42 fish/hr in Holter Reservoir (MTFWP 2004c). Gill net catch rates for rainbow trout from 1986 to 2004 have averaged about 9 fish/net in Canyon Ferry Reservoir, 3.4 fish/net in Hauser Reservoir, and 5.4 fish/net in Holter Reservoir. Therefore, Hebgen Reservoir may currently provide a quality rainbow trout fishery and future research should more closely examine the strength of the adult population.

CONCLUSION

I found little evidence that access to and the availability of tributary spawning and rearing habitat limits wild rainbow trout production in the Hebgen basin. Overall, tributary habitat in the Hebgen basin is abundant, is of moderate to high quality, and supports a high level of wild rainbow trout reproduction, YOY production, and juvenile rearing. However, juvenile brown trout may be adversely affecting overwinter survival of rainbow trout in tributary rearing habitats. I found that wild reproduction (80%) was concentrated in two tributaries, Duck Creek and the South Fork of the Madison River. These tributaries had a unique combination of a high quantity of rearing habitat in the form of deep pools and beaver ponds, an abundance of spawning gravels, and water temperatures throughout the upstream migration and spawning period of 8-10 °C. Tributaries that had only one or two of these characteristics had many fewer redds. This study identified high quality tributaries (Duck Creek and the South Fork of the Madison River) that are critical to wild rainbow trout production that should be monitored and protected. Future research, threats to the fishery, management recommendations, and tributary habitat enhancement possibilities are outlined in Appendix G.

Wild trout management in reservoir systems is a viable option when high quality tributaries are present or when improvements can be made to increase water flow and habitat quality in existing reservoir tributaries. Basin wide assessments, as used in this study, could be adopted elsewhere to assess the quality and quantity of tributary habitat available to manage other reservoirs as wild trout fisheries. It is important to recognize that limiting factor analyses of tributary habitat are highly variable among systems and need to be addressed on a site-specific basis (Bisson 1992). For example, the Hebgen basin likely possesses marked differences in complexity in comparison to many other reservoir systems. However, the Hebgen basin provided a unique opportunity to assess tributary habitats related to adfluvial salmonid reproduction and production in a complex system. Therefore, this analysis and methodologies developed within may provide a useful template for assessing tributary potential for wild trout production in similar systems in future studies. This type of analyses could assist fisheries managers in identifying: 1) reservoirs that have potential to become self-sustaining fisheries, 2) potential bottlenecks limiting wild trout production in other reservoirs, and 3) opportunities for tributary habitat improvements to support wild production.

APPENDICES

APPENDIX A

HEBGEN RESERVOIR TROUT STOCKING HISTORY

Table A.1.Hebgen Reservoir trout stocking history, quantities (thousands) and strains from 1954-2003 (ERI and NWPS 2002, MTFWP 2004a).

Year	Arlee and Shasta Rainbow	McBride Cutthroat	West Slope Cutthroat	Eagle Lake Rainbow	DeSmet Rainbow
1954-61*	217	---	---	---	---
1962-66*	79	---	---	---	---
1967-74*	158	---	---	---	---
1975-79*	153	208**	---	---	---
1980	52	221	55	---	---
1981	---	282	31	---	---
1982	---	329	---		---
1983	---	365	---	70	---
1984	---	83	---	70	---
1985	---	22	---	---	---
1986	---	76	---	84	---
1987	---	---	---	124	351
1988	---	---	---	210	360
1989	---	---	---	---	280
1990	---	---	---	---	268
1991	---	---	---	---	204
1992	---	---	---	---	295
1993	---	---	---	15	---
1994	---	---	---	4	149
1995	---	---	---	50	55
1996	---	---	---	125	---
1997	---	---	---	97	---
1998	---	---	---	107	---
1999	---	---	---	98	---
2000	---	---	---	100	---
2001	---	---	---	107	---
2002	---	---	---	107	---
2003	---	---	---	107	---

* Average per year

** 1979 only

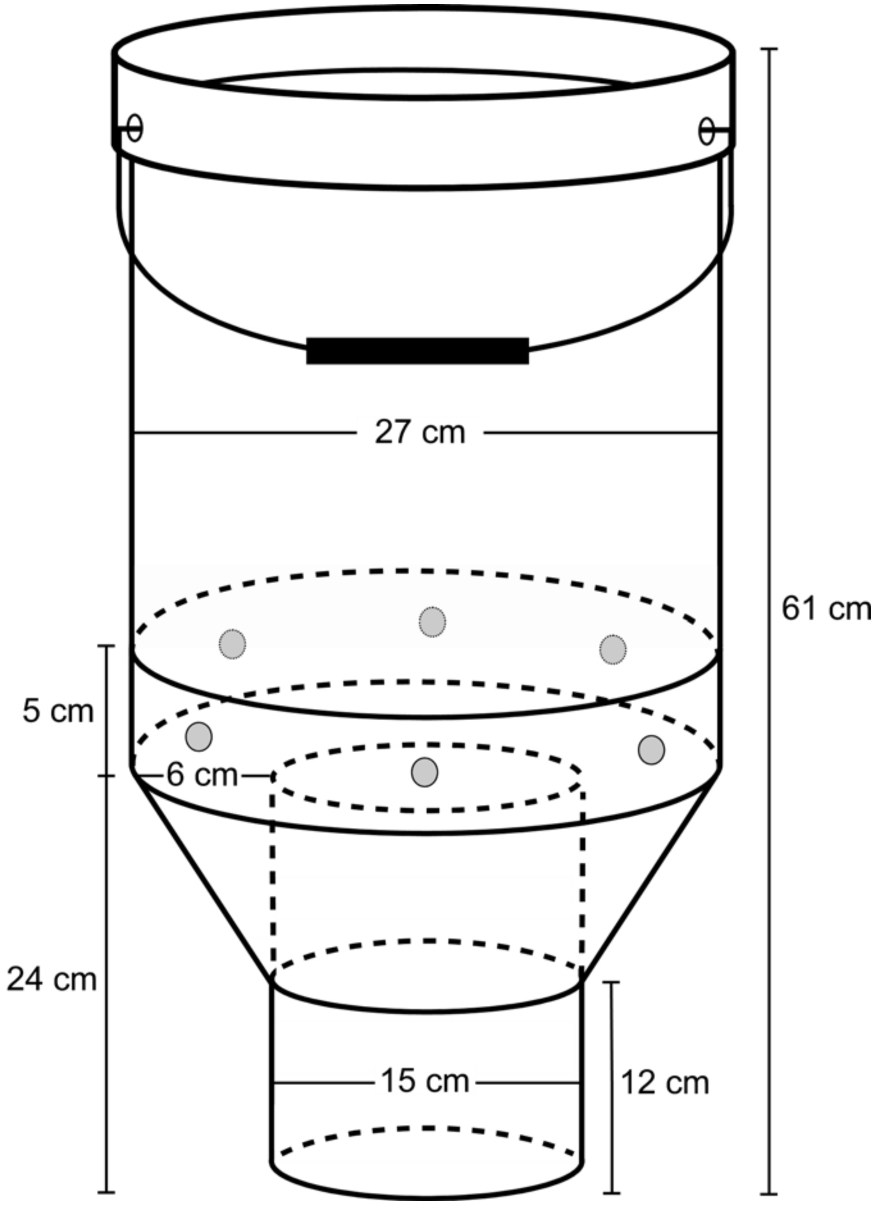
APPENDIX B

A LIGHTWEIGHT MODIFICATON OF THE MCNEIL CORE SUBSTRATE SAMPLER

The McNeil core substrate sampler (McNeil and Ahnell 1960, 1964) is widely used for quantitative bulk sampling of streambed sediments because it combines desired sampling features of accuracy, portability, and ease of use compared to freeze-core samplers (preservation of vertical stratification but low portability) or shovel-based methods (portable, simple to use, but less accurate)(Everest et al. 1982; Platts et al. 1983; Young et al. 1991a; Schuet-Hames et al. 1996). The original McNeil substrate sampler was designed for sampling spawning gravels of Pacific salmon redds in large rivers, which required a large, heavy-duty device. However, its large size and heavy steel-gauge construction limits its portability and use for sampling spawning redds of resident salmonids in remote field locations in a large drainage basin (Magee et al. 1996).

For this study, the standard McNeil core sampler was modified to facilitate its use in remote locations by designing a more portable, lighter-weight device (Platts et al. 1983). To reduce weight, a design incorporating a 19-L (5 gallon) plastic bucket was developed (Figure B.1.). Use of the plastic bucket reduced the diameter of the upper ‘stilling basin’ of the sampler (27 cm) by about half of the 50-cm standard size (Kondolf 2000). Further weight reduction was achieved by fabricating (Midwest Industries, Bozeman, Montana) the core tube and collection basin with 16-gauge stainless steel instead of the 10-gauge steel used in the standard McNeil sampler. A standard core diameter of 15 cm was retained in the design to insure adequate sampling of spawning gravel sizes used by resident stream salmonids (Thurow and King 1994; Magee et al. 1996).

Figure B.1. Schematic of the lightweight modification of the McNeil core sampler comprised of a stainless steel core tube and collection basin attached to a 19-L plastic bucket.



The bucket bottom was removed and the bucket attached to the basin collar with six stainless steel bolts (12.7 mm diameter), nuts, lock-washers, and rubber grommets in evenly-spaced, pre-drilled holes (Figure B.1.). Aquaseal™ sealant was applied to the bucket and basin collar joint to prevent leakage. The 5-cm-deep basin collar provided a tight-fitting sleeve for the bottom of the bucket and added stability to the device. The modified sampler was only one-third of the weight of the standard McNeil sampler (3.9 kg versus 11.5 kg).

The modified sampler performed well in this study when used to sample substrate composition of about 100 rainbow trout redds in 170 km of spawning tributaries to Hebgen Reservoir, Montana. The sampler was strapped to a pack frame and items required for onsite measurement of substrate composition via the wet sieve method (Platts et al. 1983; McMahon et al. 1996) were carried inside the sampler. The modified sampler was stable, lightweight, and leak-free, yet sufficiently robust that insertion of the core tube into the streambed was achieved without difficulty. The bucket handle also facilitated transfer of sampled material from the collection basin to substrate sorting sieves and to Imhoff fine sediment-settling cones used during the wet sieving process. The total cost of the sampler was $330.00 USD. This design further extends the versatility of the “5-gallon plastic bucket” for fisheries work (e.g., Isaak and Hubert 1997).

APPENDIX C

SUMMARY OF TRAP CAPTURE DATA, DUCK CREEK AND THE SOUTH FORK OF THE MADISON RIVER

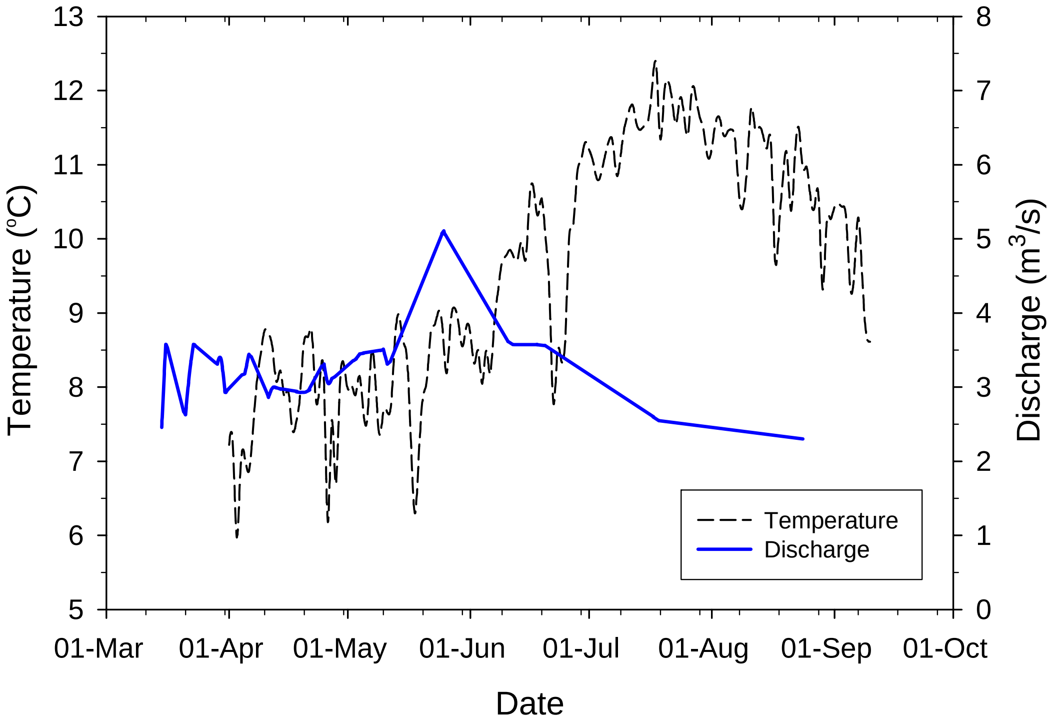
Table C.1. Summary of fish species captured at the Duck Creek (March – August 2002 and 2003) and South Fork of the Madison River (March – August 2003) fyke and screw trap sites (Figure 3, 4), excluding rainbow and brown trout. The number of fish column represents the actual number captured.

Tributary - Year	Species	Number of Fish	Length Range (mm)
Duck Creek - 2002	Brook Trout	5	75 - 152
	Longnose Dace	30	38 - 75
	Mottled Sculpin	203	12 - 83
Duck Creek - 2003	Brook Trout	5	131 - 373
	Longnose Dace	1,067	31 - 170
	Mottled Sculpin	310	36 - 77
	Mountain Whitefish	88	57 - 143
	Utah Chub	49	62 - 345
S F Madison - 2003	Mottled Sculpin	25	32 - 94
	Mountain Whitefish	25	65 - 114

APPENDIX D

TEMPERATURE AND DISCHARGE IN THE SOUTH FORK OF THE MADISON RIVER DURING THE JUVENILE RAINBOW TROUT OUTMIGRATION PERIOD

Figure D.1. Relation between temperature and discharge in the South Fork of the Madison River 1 April through 1 September 2003.



APPENDIX E

TRIBUTARY WATER TEMPERATURE IN THE HEBGEN BASIN IN 2002 AND 2003

Figure E.1. Comparison of water temperature regimes from 1 April through 15 October for thermally influenced tributaries in the Hebgen basin for 2002 and 2003.

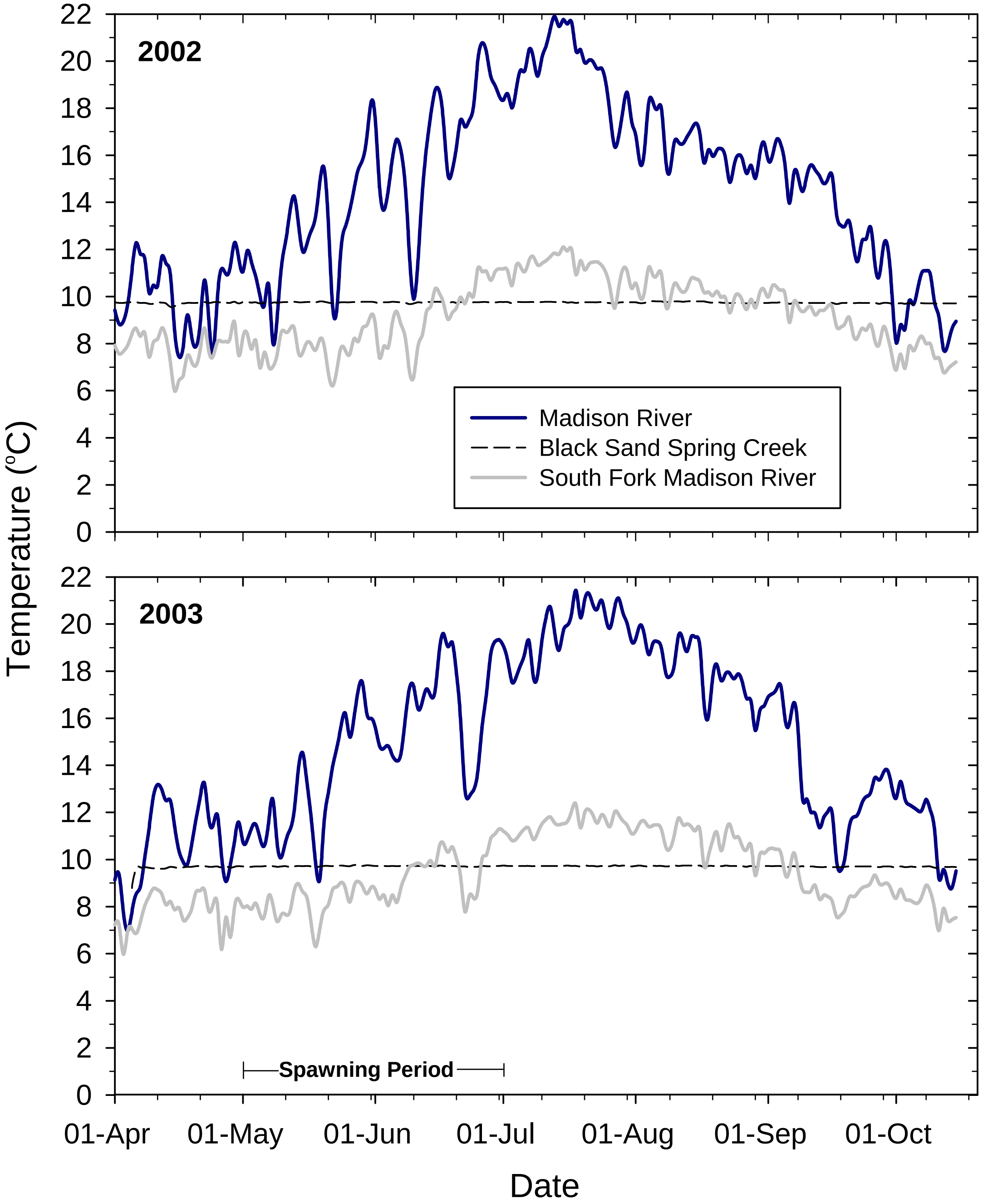


Figure E.2. Comparison of water temperature regimes from 1 April through 15 October for conifer dominated, 2nd and 3rd order tributaries in the Hebgen basin for 2002 and 2003.

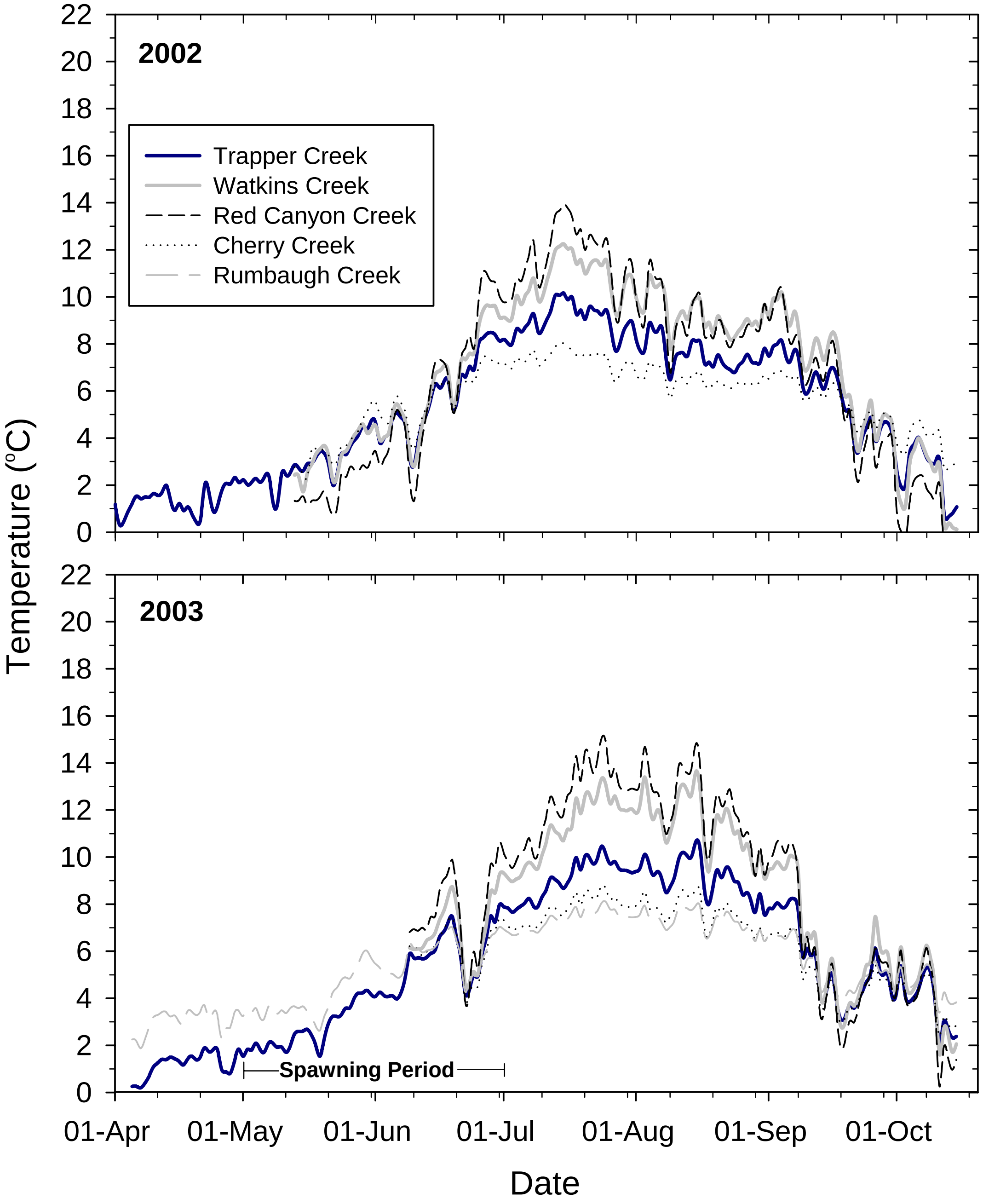
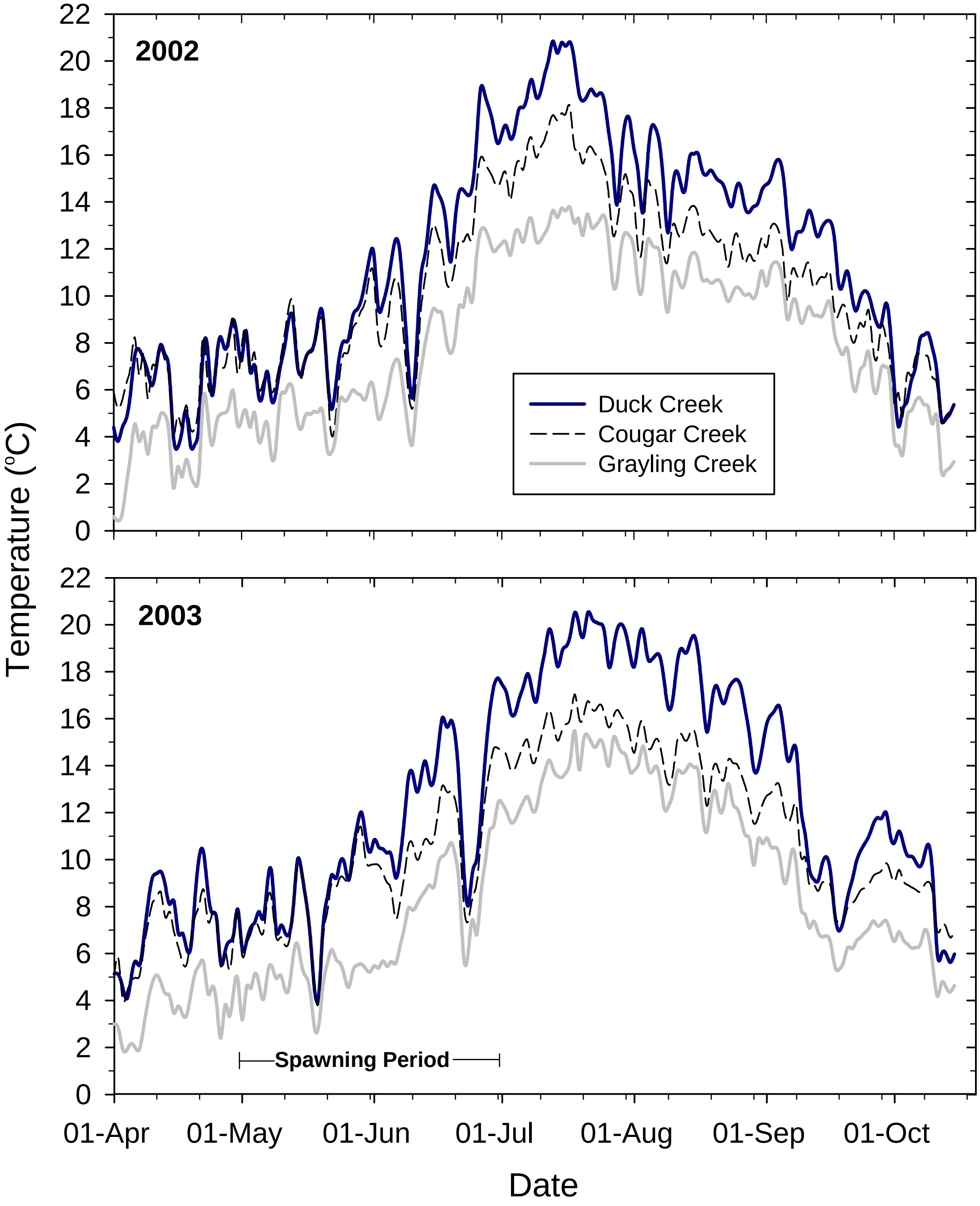


Figure E.3. Comparison of water temperature regimes from 1 April through 15 October for 3rd and 4th order tributaries occupying well defined flood plains with low to moderate conifer canopy in the Hebgen basin for 2002 and 2003.



APPENDIX F

TEMPERATURE AND DISCHARGE IN DUCK CREEK DURING THE ADFLUVIAL RAINBOW TROUT UPSTREAM SPAWNING MIGRATION

Figure F.1. Comparison of temperature in Duck Creek in 2002 and 2003 for the month of April (upper graph) and from 1 April – 30 May (lower graph).

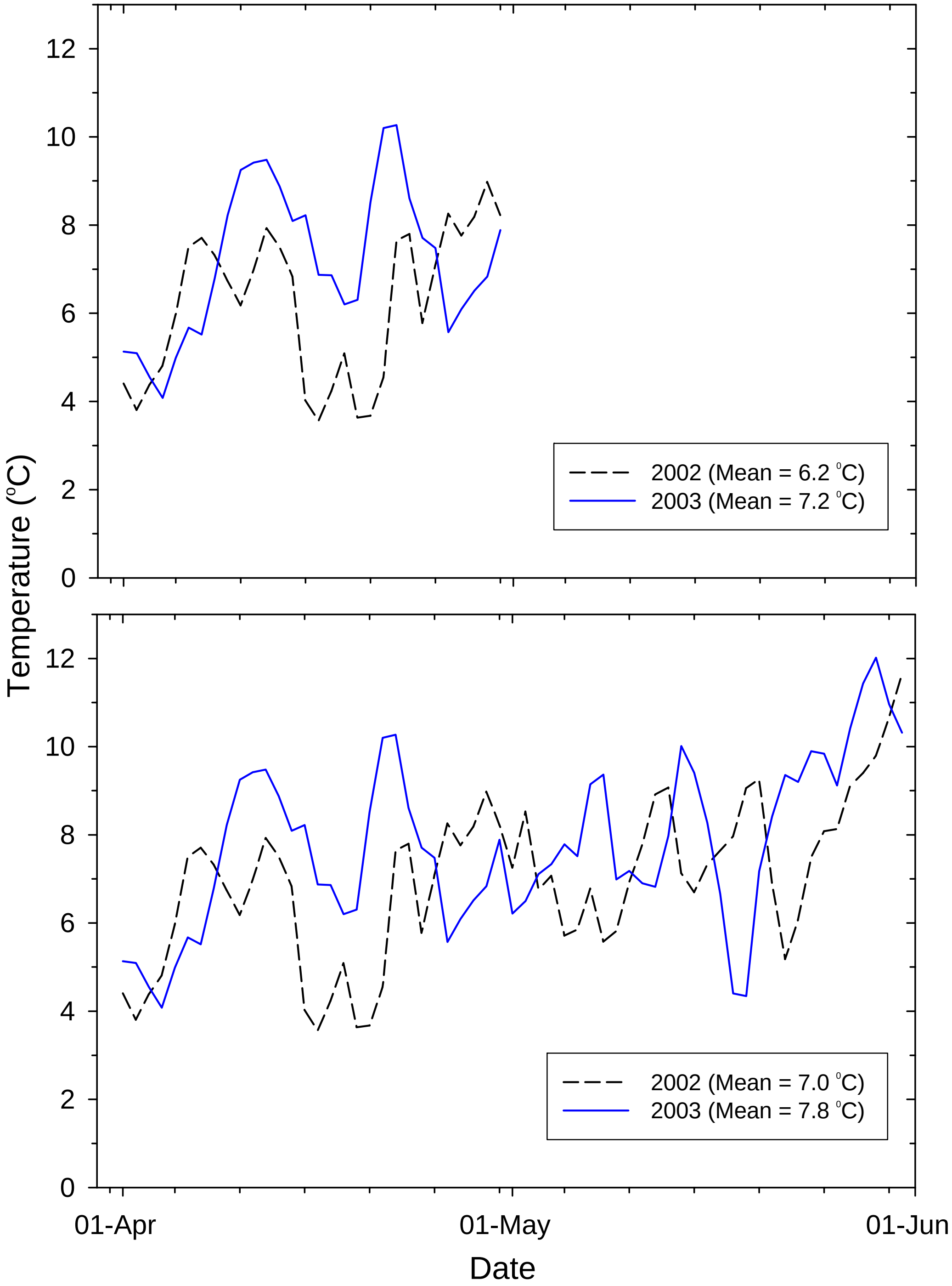
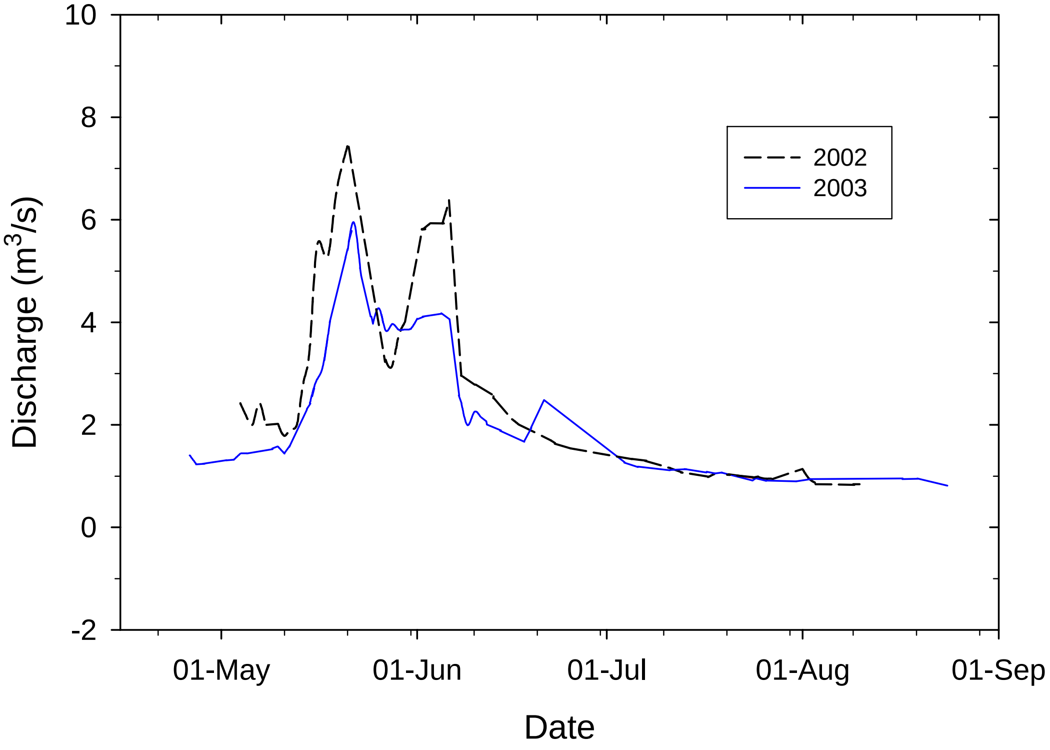


Figure F.2. Discharge comparison between 2002 and 2003 in Duck Creek from 1 May through 1 August.



APPENDIX G

HABITAT ENHANCEMENT, THREATS, FUTURE RESEARCH AND MONITORING IN THE HEBGEN BASIN

Though I found no evidence that tributary habitat overall was limiting wild rainbow trout production, my basin wide assessment did identify possible habitat enhancements within specific tributaries that could increase juvenile recruitment to the reservoir.

Enhancement of tributary habitat critical to salmonid production, including creating new spawning and rearing areas, reducing fine sediment inputs to improve spawning habitat quality, and providing access to areas previously inaccessible to migratory spawners, can be an effective management tool (Reeves et al. 1991). As tributary habitats reside on public and private lands, a cooperative effort between landowners and fisheries managers will be essential in executing tributary enhancement projects in some areas of the Hebgen basin. Habitat enhancement should not be considered a substitute for proper habitat protection (Reeves et al. 1991) and implementation should include pre and post project evaluation and long term monitoring plans.

Habitat Enhancement

Fine Sediment in the Hebgen Basin

Cougar and Duck creeks and the Madison River contained a high percentage of substrate material less than 2.36 and 0.85 mm, resulting in moderate estimates of survival-to-emergence (40-56%). Nearly all of the core samples collected in these tributaries were in Yellowstone National Park (YNP). High levels of fine material in Cougar and Duck creeks and the Madison River are likely attributed to the geology of the upper Hebgen basin in YNP, post fire effects of the 1988 fires, and high levels of ungulate grazing in meadows adjacent to riparian areas. In addition, redds were often found immediately downstream of and between beaver complexes in headwater areas of both Duck and Cougar creeks. Beaver dam construction can inundate lotic environments, resulting in spawning areas covered in deeper water and possibly blanketed with fine sediment (Swanston 1991) and fine sediments retained in beaver ponds can be flushed during high flow events and consequently delivered downstream. A reduction in fine sediment in these areas could potentially result in increased YOY survival; however, no habitat restoration is recommended for stream environments within YNP.

Duck Creek

Steel et al. (2004) recommended prioritizing barrier removal by considering the total length of stream above a barrier and the expected number of new redds predicted for the new area. Duck Creek contained the highest number of redds recorded in the basin and alone was estimated to have produced over 2.2 million YOY rainbow trout in 2002 and 2003. Although over 3,000 spawners successfully passed through the U.S. Highway 191 culvert on Duck Creek in 2002, I did count numerous failed attempts of passage at the downstream end of the culvert during high flows. Although this culvert is not a total barrier to upstream passage, it is recommended that the culvert should be replaced with a bridge or reconstructed to minimize velocity and leap height to improve fish passage success during upstream migration (Table G.1).

Table G.1. Summary of areas identified in tributaries to Hebgen Reservoir that pose possibilities for future habitat enhancement projects.

Tributary	Description	LOCATION	
		Latitude	Longitude
Duck Creek	U.S. Highway 191 culvert enhancement or replacement	44^{o} 46.804’ N	111^{o} 06.795’ W
Grayling Creek	Bank stabilization	44^{o} 47.767’ N	111^{o} 07.757’ W
Grayling Creek	Horse access	44^{o} 47.802’ N	111^{o} 08.310’ W
South Fork Madison River	Pool habitat enhancement	44^{o} 36.879’ N	111^{o} 09.632’ W
Black Sand Creek	Pool and mid-channel velocity enhancement with LWD	44^{o} 39.594’ N	111^{o} 09.806’ W
Denny Creek	Bank stabilization and cattle access	44^{o} 42.490’ N	111^{o} 13.409’ W
Watkins Creek	Dewatering	44^{o} 47.652’ N	111^{o} 17.506’ W
Watkins Creek	Overwintering enhancement	44^{o} 48.258’ N	111^{o} 16.745’ W
Ruof Ditch	Bank stabilization	44^{o} 48.511’ N	111^{o} 17.386’ W

Grayling Creek

Livestock access and erosion control practices on private lands have adversely affected a localized area in the lower Grayling Creek drainage. This 1.5 km section of Grayling Creek, approximately 2 km upstream from Hebgen Reservoir, has been subject to extensive rip rapping and bank trampling and contains several high activity livestock crossings and in-stream watering areas (Table G.1). It is recommended that area fisheries managers work with private landowners in the lower Grayling Creek drainage to lessen the effects of these practices (accelerated fine sediment delivery and possibly hindering recruitment of larger substrates).

South Forth of the Madison River

A 2 km section of key spawning habitat in the upper South Fork of the Madison River drainage, adjacent to and downstream of Mosquito Gulch, lacks pool habitat and instream cover (Table G.1). This area was selected by high numbers of spawners in 2002 and 2003. Large woody debris (LWD) accumulation in small to intermediate channels assists in sediment storage, bank stability, pool and overwintering habitat development, and spawning gravel retention (McMahon and Hartman 1989; Swanston 1991; Rosenfeld and Huato 2003). Large woody debris formed pools could be constructed throughout this section in an effort to provide security cover for adult migrants and rearing habitat for young-of-the-year and juvenile (age-1 and age-2) rainbow trout.

Black Sand Spring Creek

The headwaters of Black Sand Spring Creek provide one of the most pristine spawning and rearing environments in the Hebgen basin. This spring fed channel is wide (20-40 m) and shallow (0.20 – 0.50 m) with low gradient laminar flows, and the substrate is characterized by small obsidian gravels and abundant aquatic vegetation. Spawning largely occurs near the head of the spring (where gradient and water velocities expose larger spawning gravels) and mid channel in areas where LWD has been naturally recruited and resultant scour exposes spawning gravels. Additionally, scour pools have formed under much of the existing LWD, providing overhead cover and spawning gravels in the pool tailouts. Gravels retained in pool tailouts are often selected by salmonids in headwater streams for spawning (Schmetterling 2000; Muhlfeld 2002). However, most of this headwater area lacks LWD and is dominated by small gravel and obsidian sands. Introducing LWD aggregates that mimic the naturally recruited formations may enhance spawning and rearing capacity in this area.

Denny Creek

Denny Creek, a tributary to the South Fork of the Madison River, occurs almost entirely on private lands. Lower Denny Creek is highly impacted by livestock use downstream of Forest Road 167 to its confluence with the South Fork of the Madison River. Stream banks in this area are devoid of riparian vegetation, the channel is over widened, and trail crossings and corrals near the stream are apparent sources of excessive fine sediment delivery. A marked increase in fine sediment accumulation is noticeable on the South Fork of the Madison River downstream of the Denny Creek confluence. Fisheries managers should work cooperatively with private landowners in the lower Denny Creek area in an attempt to stabilize stream banks and reduce fine sediment input.

Watkins Creek

Adfluvial rainbow trout spawners utilize the lower 2.5 km of Watkins Creek, which flows through both private and Gallatin National Forest (GNF) land. The Ruof Ditch, an irrigation ditch and dude ranch water supply, diverts water from Watkins Creek on GNF land about 0.6 km upstream from the private land boundary.

Several enhancement possibilities exist in the Watkins Creek drainage. Lower Watkins Creek, downstream of the Ruof diversion, is subject to dewatering in late summer. Therefore, area fisheries managers should work with the landowners in an attempt to secure adequate flows in Watkins Creek during critical stages of embryo development and early rearing. Additionally, pool habitat is limited in lower Watkins Creek, with the exception of a few constructed v-shaped LWD plunge pools. A pool enhancement project in the lower reach, following the template of the LWD structures, could provide additional staging, spawning, and rearing habitat for rainbow trout.

Limited spawning and rearing were also observed within the Ruof Ditch. However, horses heavily graze most of the lower ditch and a large horse corral was built over the ditch to provide water for the livestock. Fisheries managers should work with the landowner to determine the benefit or detriment of the Ruof Ditch to Watkins Creek and the Hebgen Reservoir fishery. Upon further investigation, it may be recommended to screen the Ruof diversion structure to preclude fish in Watkins Creek from entering the Ruof ditch.

Hebgen Reservoir Habitat Enhancement

In this study, identification of factors limiting wild rainbow trout production in Hebgen Reservoir was restricted to lotic habitat required for adult reproduction, YOY production, and juvenile rearing. An assessment of recruitment to the adult spawning population in the lentic environment of the reservoir will be required to thoroughly evaluate factors that may be limiting wild rainbow trout of Hebgen Reservoir.

Tabor and Wurtsbaugh (1991) recommended that fisheries managers should consider augmenting cover in reservoirs and lakes where juvenile trout are stocked to minimize losses of trout to predators. Predation risk for wild and hatchery stocks of juvenile rainbow trout is assumed to be high in Hebgen Reservoir. Future research should evaluate juvenile rainbow trout habits in the reservoir environment and the availability of and use of cover. Bioengineering techniques and water level management could be incorporated to augment cover in the reservoir if needed.

Threats

Threats to juvenile rainbow trout production in tributary habitats in the Hebgen basin include invasive aquatic nuisance species (ANS) and habitat loss. Whirling disease, a parasitic infection caused by the nonindigenous myxozoan *Myxobolus cerebralis,* is prevalent in the upper Madison River downstream of Hebgen Reservoir, and was recently detected in Cougar Creek (P. Clancey, Fisheries Biologist, Montana Department of Fish, Wildlife and Parks, personal communication). The whirling disease parasite requires two alternate hosts throughout its life cycle, *Tubifex tubifex*, an oligochaete worm and salmonids (Kerans and Zale 2002). Whirling disease has caused severe declines in rainbow trout populations across the West (Nehring and Walker 1996; Vincent 1996) and may now continue to spread throughout the tributaries of the Hebgen basin, possibly having a significant impact on the wild rainbow trout population. Duck and Cougar creeks appear particularly at risk because of their abundant pond habitat and associated fine sediment retention, providing optimal habitat for *Tubifex tubifex*.

The nonindigenous New Zealand Mud Snail *Potamopyrgus antipodarum* has also invaded the upper Madison River, upstream of Hebgen Reservoir. This mud snail asexually reproduces to high densities and competes with macroinvertebrates for periphyton (Cada 2004). Macroinvertebrates are an important food source for rainbow trout in stream environments and displacement of this food source, through competitive interactions with *P. antipodarum*, could alter trophic levels and may negatively affect trout populations (Cada 2004). Thermally influenced tributaries that experience stable, elevated temperature such as Black Sand Spring Creek, may be particularly susceptible to *P. antipodarum* colonization.

Much of the tributary habitat available to spawners of Hebgen Reservoir is within Yellowstone National Park. These protected, pristine stream environments may become critical areas for native fish conservation and restoration in the future. Therefore, fishing access sites to remote areas within YNP should be thoroughly posted to inform visitors of the danger of spreading ANS and to properly instruct visitors to disinfect their equipment before entering.

Future Research

Rainbow Trout Population

The extent of hatchery contribution to the adult spawning population remains largely unknown. In 1989, Oswald (1990) estimated the proportion of hatchery and wild rainbow trout collected in gill net sets and from night electrofishing in the reservoir. Hatchery fish were identified by the presence of “stocking checks” on scales and from tetracycline marked young-of-year stocked in 1989 (Oswald 1990). Oswald (1990) estimated 209 of the 301 rainbow trout (69%) collected in 1989 were of hatchery origin. Byorth (2004) assessed hatchery contribution from fish collected during creel surveys in 2000 and 2001. Hatchery fish were identified using three methods: 1) fin erosion, 2) stocking checks on scales, and 3) tetracycline marks. Byorth (2004) found identification of hatchery fish difficult to assess and reported inherent biases in all three methods. The proportion of hatchery rainbow trout in the creel ranged form 0 to 40% and averaged 19% (Byorth 2004). Determination of hatchery contribution from dorsal fin erosion and tetracycline marks gave estimates from 0-28% hatchery contribution, whereas determination from “stocking check” marks on scales suggested the highest proportion (47%) of hatchery rainbow trout to the creel, but this method was reported as subjective and the least reliable (Byorth 2004). Byorth (2004) concluded, in spite of discrepancies among methods, hatchery rainbow trout probably comprise up to one-third of rainbow trout to the creel and that ceasing stocking may substantially impact angler catch rates. Better knowledge of the proportion of hatchery and wild rainbow trout recruited to the adult fishery is vital for future management.

It was assumed that the Duck Creek spawning population is wild. However, the proportion of hatchery spawners was not assessed in this study. Byorth (2004) reported that wild rainbow trout may be more common in older age classes than hatchery trout from creel samples and commented that wild rainbow trout may be longer-lived and less susceptible to harvest. This may be reflected in the age distributions of spawners, gill net captures, and rainbow trout in the creel. Younger fish and possibly a higher number of hatchery rainbow trout may be prominent in gill net and creel data, whereas older wild trout dominate spawning runs as observed in Duck Creek in 2002.

A better understanding of the adult population size will also be important to effectively manage the rainbow trout fishery of Hebgen Reservoir. As addressed in the Discussion section of this thesis, the adult population may be underestimated because of temporal overlap between gill net sampling periods and spawning runs. Therefore, additional gears incorporating passive and active trapping strategies (such as trapping with large fyke nets, seines, or trawls) could be utilized in the reservoir.

Recruitment to the Adult Population

The stream environment, crucial to developing a self-sustaining rainbow trout population, was assessed in this study as a first step in identifying limiting factors to the reservoir fishery. My data suggest that tributary spawning and rearing is likely not limiting rainbow trout production and that future studies should focus on limiting factors in the reservoir environment, namely the fate of juveniles in the reservoir.

Once in the reservoir, competition and predation likely impact the number of YOY and juveniles recruited to the adult rainbow trout population. The Eagle Lake rainbow trout evolved primarily as a lacustrine predator on tui chub *Gila bicolor* (McAfee 1966; Behnke 1992). Gill net catch rates of Utah chub *Gila atraria* in Hebgen Reservoir have averaged over 50 fish/net since 1996. However, prior food habit studies investigating Eagle Lake piscivory on Utah chub in Hebgen Reservoir revealed no occurrences of predation (Hetrick 1994a). Similarly, Hubert et al. (1994) found Eagle Lake rainbow trout diets in Lake Desmet, Wyoming, in 1991 to be comprised almost exclusively of Cladocerans and insects, with very low levels of piscivory. Additionally, zooplankton diet overlap has been documented among Utah chub and rainbow trout in Flaming Gorge Reservoir, Wyoming-Utah (Schneidervin and Hubert 1987). Therefore, given the high densities of Utah chub in Hebgen Reservoir, competition with Utah chub may adversely affect survival rates of juvenile rainbow trout. Future studies should focus on identifying diet overlap between these species and life stages.

Predation on rainbow trout YOY and juveniles may also markedly decrease survival rates. Brown trout in Hebgen Reservoir can be highly piscivorous and individuals up to 9 kg (20 lbs) have been reported (Hetrick 1994a). In addition, rainbow and brook trout and possibly adult Utah chub may feed on YOY and juvenile rainbow trout once in the reservoir. Future food habitat studies could address impacts of predation on juvenile rainbow trout once in the reservoir environment.

Strain Analysis

In addition to determining the contribution of hatchery rainbow trout, determining the most successful strain of rainbow trout recruited to the spawning population would aid future managers. Although it has been assumed that Eagle Lake rainbow trout comprise the majority of the wild adult population, it has not been quantified. A genetic analysis of a sample of adult spawners could reveal the contribution of strains stocked in the past to the current population (Leary et al.1989; R. Leary, Geneticist, Wild Trout and Salmon Genetics Lab, University of Montana, personal communication) and may help guide which stocks may be most suitable for establishing wild adfluvial rainbow trout populations in other reservoirs.

Angling Harvest

Large adult salmonids, highly concentrated in spawning areas, are particularly vulnerable to exploitation by anglers (Schwanke and Hubert 2003). Anglers frequently harvest upstream migrants at the pool below the U.S. Highway 191 culvert on Duck Creek and several area-fishing guides target the upper Duck Creek drainage annually for the duration of the spring and early summer spawning period. Wade fishing was also observed throughout high density redd areas in the South Fork of the Madison River and on lower Duck Creek during spawning. Loss of spawners to angler harvest, hooking mortality, and incidental redd trampling are additional factors that could be influencing adult rainbow trout numbers and warrant further management consideration.

Contribution of the Upper Madison River

The Madison River upstream of Hebgen Reservoir is a complex system that provides many opportunities for future research. In the upper Madison River, because of the resident population of rainbow trout, it is difficult to: 1) determine if newly constructed redds are from adfluvial reservoir rainbow trout or from fluvial residents, and 2) assess the contribution of redds to the production of Hebgen Reservoir as it is likely that a large number of YOY remain in the resident fluvial population. Therefore, a study incorporating trapping and radio tagging of adfluvial spawners of Hebgen Reservoir, ascending the upper Madison River during spring, autumn and winter, in combination with motorized screw trapping near the mouth of the river (velocities are too slow near the reservoir to effectively trap outmigrants) could help identify the contribution of this large river to the rainbow trout production of Hebgen Reservoir.

Monitoring

Redd Surveys

The distribution of redds among and within tributaries was comparable between years of this study despite large differences in redd counts. Therefore, suggested redd survey index reaches, areas containing the majority of redds inventoried per tributary, are shown in Appendix H. Given the size of the Hebgen basin and the remote areas included, redd surveys required several months to complete annually. Therefore it is recommended that future redd surveys be conducted annually in the aforementioned redd index areas, with entire basin counts limited to every five years.

Additional Tributary Habitat

Three small tributaries (Buttermilk, Cream, and Denny creeks) that enter the South Fork of the Madison River downstream of U.S. Highway 21 from the west were not included in this study because of private land access issues. Tepee Creek, a second order tributary to upper Grayling Creek, was also not included in this study because of bear sightings in 2002 and active forest fires in the upper drainage in 2003. These four minor tributaries possess potential for wild rainbow trout production and should be included in future studies and monitoring efforts.

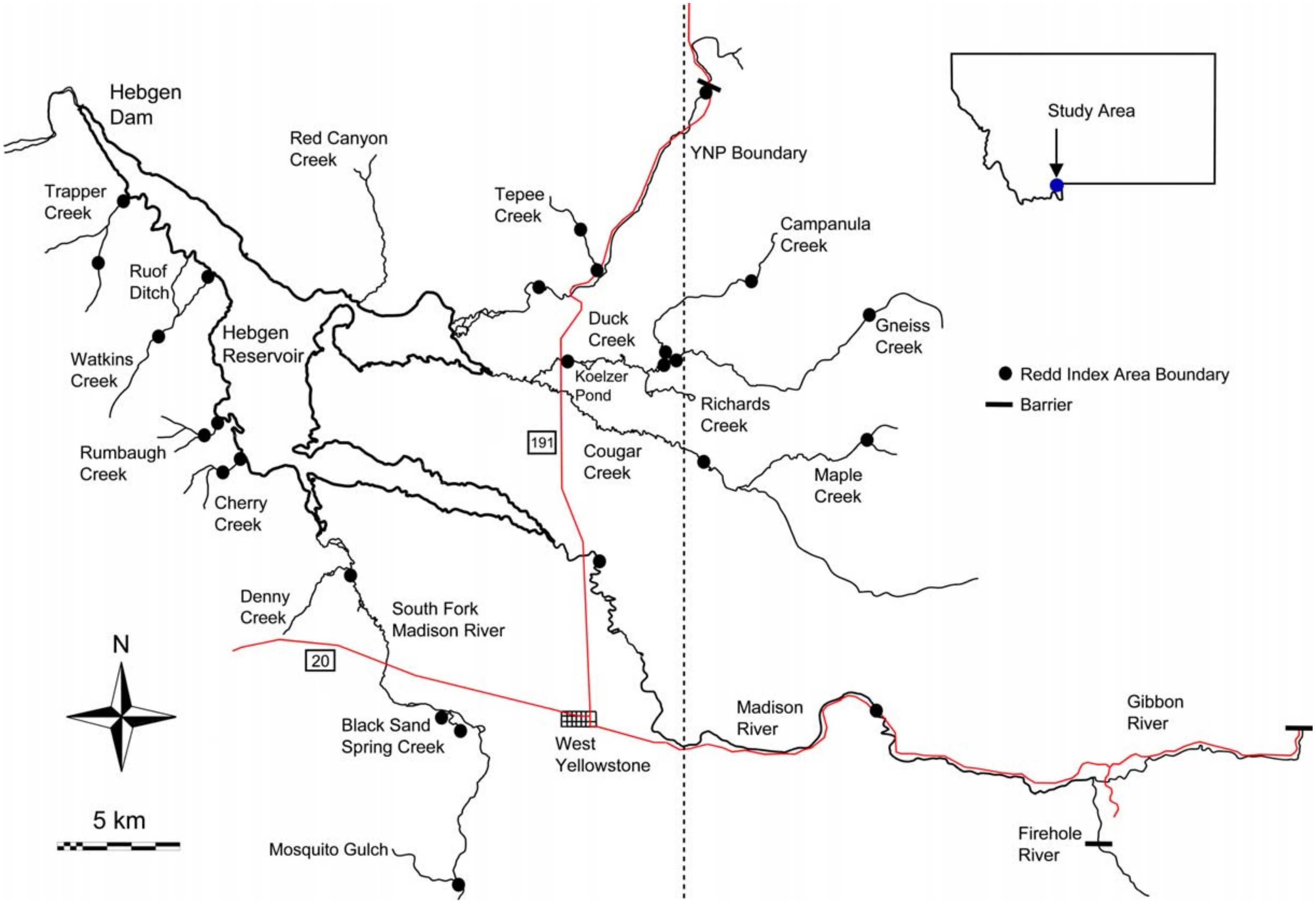
Juvenile Recruitment to Hebgen Reservoir

Fyke and screw trapping were both effective methods for estimating YOY and juvenile (age-1 and age-2) outmigrant numbers on tributaries to Hebgen Reservoir in this study. A continuation of spring outmigrant trapping and the implementation of autumn trapping are recommended to further evaluate annual levels of YOY and juvenile recruitment to the reservoir. Coded wire tagging of outmigrants using a tributary or age class batch mark (Munro et al. 2003) would be especially helpful to identify tributary and juvenile life history contribution to adult recruitment.

APPENDIX H

INDEX MAP FOR RAINBOW TROUT REDD SURVEYS IN THE HEBGEN BASIN

Figure H. 1. Redd index areas (stream length between index area boundary markers) for rainbow trout in the Hebgen basin.



APPENDIX I

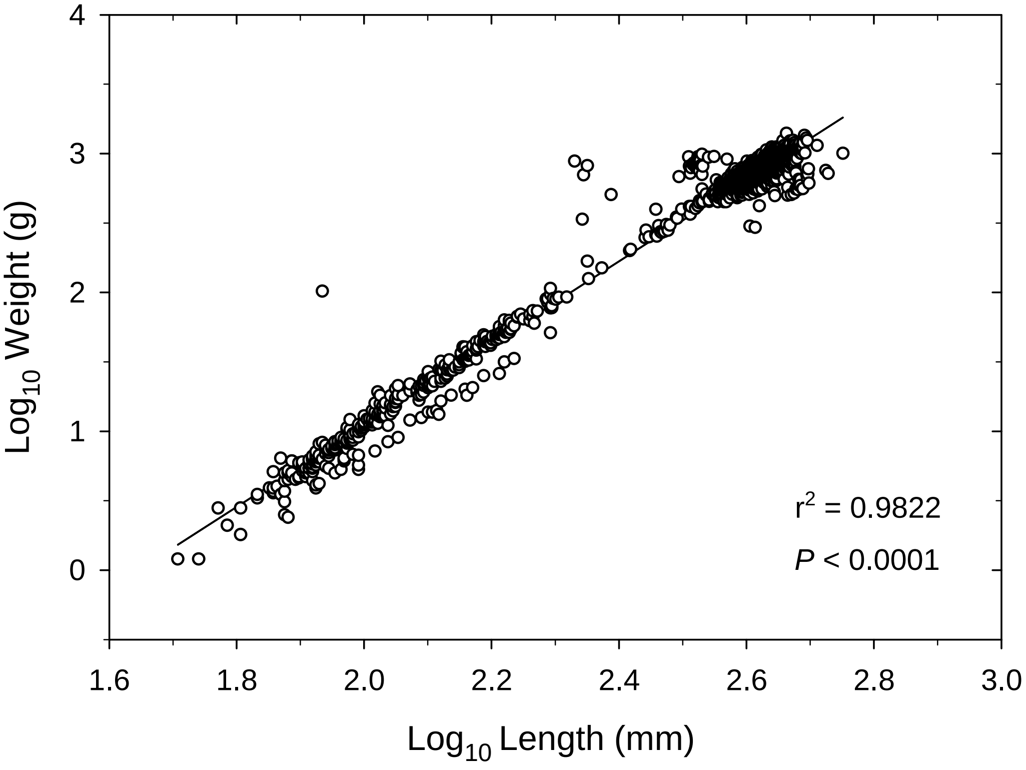
RAINBOW TROUT LENGTH WEIGHT RELATIONSHIP FOR DUCK CREEK

The relationship between rainbow trout weight and length for all fish captured and weighed on Duck Creek (n = 3,521) was described by a weighted least-squares regression (Figure I.1). The relation was described by the following equation:

$$\text{Log}_{10}\,\text{Weight} = (-4.8506 \pm 0.0172\ \text{SE}) + (2.9478 \pm 0.0067\ \text{SE})\ \text{Log}_{10}\,\text{Length}$$

$$(r^2 = 0.9822,\ P < 0.0001).$$

Figure I.1. Relation between log-transformed weight (y-axis) and length (x-axis) for migrant rainbow trout (n = 3,521) captured at Duck Creek fyke, screw, and adult trap sites in 2002 and 2003.



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