THE ECOLOGY OF RAINBOW TROUT

IN THE BIGHORN RIVER, MONTANA

by

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APPROVAL

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VITA

Brian William Sanborn was born to Rosemary and Marion Sanborn on August 30, 1957 in Chicago, Illinois. He attended and graduated from Loyola Academy, Wilmette, Illinois in June 1975 and University of Montana, Missoula, Montana with a Bachelor of Science degree in Wildlife Biology in June 1981. He was accepted to graduate school at Montana State University in March 1983 and completed course work in June 1985.

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ABSTRACT

Investigations were conducted to evaluate reproductive success of rainbow trout (*Onchorynchus mykis*) in the Bighorn River below Yellowtail Dam and its major tributary Soap Creek. Initiation of spawning in the Bighorn River began in early April following an increase in water temperature which was preceded by an extended period of constant temperature. Spawning occurred throughout the study area, but was predominantly within 9.0 km of Afterbay Dam and was associated with side channels. Bighorn River rainbow trout utilized Soap Creek extensively for spawning. Age of 180 upstream migrants ranged from 2+ to 5+ and the male:female sex ratio was 1.0:1.8. Spawning occurred from 28.0 to 43.5 km above the mouth. Average depth was higher and point velocity lower at redds in the Bighorn River than in Soap Creek. Mean percentage of fine sediment (<0.85 mm) in the Bighorn River ranged from 10.47 - 15.23% in three spawning areas sampled. Associated embryo survival to hatching ranged from 17.0 - 29.7%, but differences were not significant. Amount of fine sediment in four spawning areas sampled in Soap Creek increased in a downstream direction. Embryo mortality also increased with progression downstream. Juvenile rainbow trout migrated out of Soap Creek, predominantly at age 1+(58.9%) and 2+(38.6%). Outmigration of juveniles appeared related to increases in stream flow. Embryo survival differed significantly between four Bighorn River field bioassay tests, but differences in mean delta P between tests did not influence survival. Survival of embryos ranged from 26.1 - 68.8% and mean delta P ranged from 118.3 - 130.1 mm Hg. Mortality of embryos during tests was attributed to silt deposition in incubation boxes. The effect of dissolved gas levels on survival of rainbow trout fry in the Bighorn River was not clearly established during the study. Fluctuating delta P and component levels of oxygen and nitrogen did not allow adequate differentiation between bioassay sites. Difference in mortality rates may be due to dissolved gas interactions not measured during the study.

INTRODUCTION

The completion of Yellowtail Dam in 1965 and subsequent deepwater releases from Bighorn Lake provided favorable conditions for the establishment of a tailwater trout fishery in the Bighorn River. From the time of dam closure through 1977 the rainbow trout (*Onchorynchus mykis*) fishery was managed on a put-grow-and-take basis, relying on annual stocking of hatchery reared fish. Management work during this period was limited to a creel census conducted during 1972 and 1973 (Stevenson 1975) and occasional electrofishing surveys.

In 1976, the portion of the Bighorn River within the Crow Indian Reservation was closed to fishing by non-tribal members by order of the Montana Fish and Game Commission due to a dispute over ownership of the river. On 24 March 1981 the U.S. Supreme Court ruled that the bed of the river belonged to the State of Montana and not the Crow Indian Tribe. Management of the river was returned to the Montana Department of Fish, Wildlife and Parks (MDFWP), who were faced with managing a valuable high-use fishery with limited biological information (Fredenberg 1984).

Management of the Bighorn River has been complicated by problems with gas supersaturation caused by entrainment of air in water released through the sluice gates on Afterbay Dam. The first reported verification of the problem was in April 1973 when several dead rainbow trout with symptoms of gas bubble disease were located 0.8 km below Afterbay Dam (Swedberg 1973). Several investigations were conducted (Bureau of Reclamation 1973; Swedberg 1973, 1975; U.S. Fish and Wildlife Service 1981) which identified the cause of the problem. In October 1982 the Bureau of Reclamation installed a set of steel deflectors in the Afterbay Dam to reduce entrainment of air. Unforeseen problems of large rock becoming trapped in the stilling basin and causing damage to the dam structure prompted removal of the deflectors on 19 July 1983.

Although rainbow trout spawning occurs in the Bighorn River, fish population data collected from July 1981 through 1982 showed that the rainbow trout population was dominated by hatchery origin fish with very limited natural recruitment (Fredenberg 1984). Brown trout (*Salmo trutta*) reproduce successfully in the Bighorn River, using the same spawning areas as rainbow trout. The brown trout population had increased from small localized populations at tributary mouths prior to dam construction to over 3000 fish (age 1 and older) per kilometer.

This study was initiated to investigate the reproductive success of rainbow trout in the Bighorn River and Soap Creek, its major tributary, and to evaluate effects of supersaturation of dissolved gases on early life history stages of rainbow trout in the Bighorn River. Field work was conducted from mid-March through August, 1983 and 1984.

DESCRIPTION OF STUDY AREA

The Bighorn River originates in the Wind River mountains in Wyoming and flows through Bighorn and Treasure counties in south-central Montana. Yellowtail Dam is located 138.7 km upstream from its confluence with the Yellowstone River.

Yellowtail Dam was constructed in 1964 for the purpose of power generation, irrigation, flood control, and fish and wildlife enhancement (Bureau of Reclamation 1962). The dam is a concrete arch structure with a 250 megawatt peaking powerplant. Afterbay Dam, located 3.5 km below Yellowtail Dam, is a reregulating facility which reduces daily flow fluctuations in the Bighorn River. Afterbay Dam is a concrete structure with earthen embankment wings, with a height of 16.2 m above the streambed at maximum controlled water surface elevation. Water is released into the river through a 49.4 m wide spillway (controlled by five radial gates) and a 10.4 m wide sluiceway (controlled by three slide gates).

The study area included the Bighorn River from Afterbay Dam downstream 19.3 km to the Bighorn Fishing Access Site, and Soap Creek, its major tributary (Figure 1). The Bighorn River within the study area is characterized by a gently meandering channel with braided areas forming numerous islands. Gradient is approximately 1.9 m/km (Stevenson 1975), and land use consists primarily of livestock grazing.

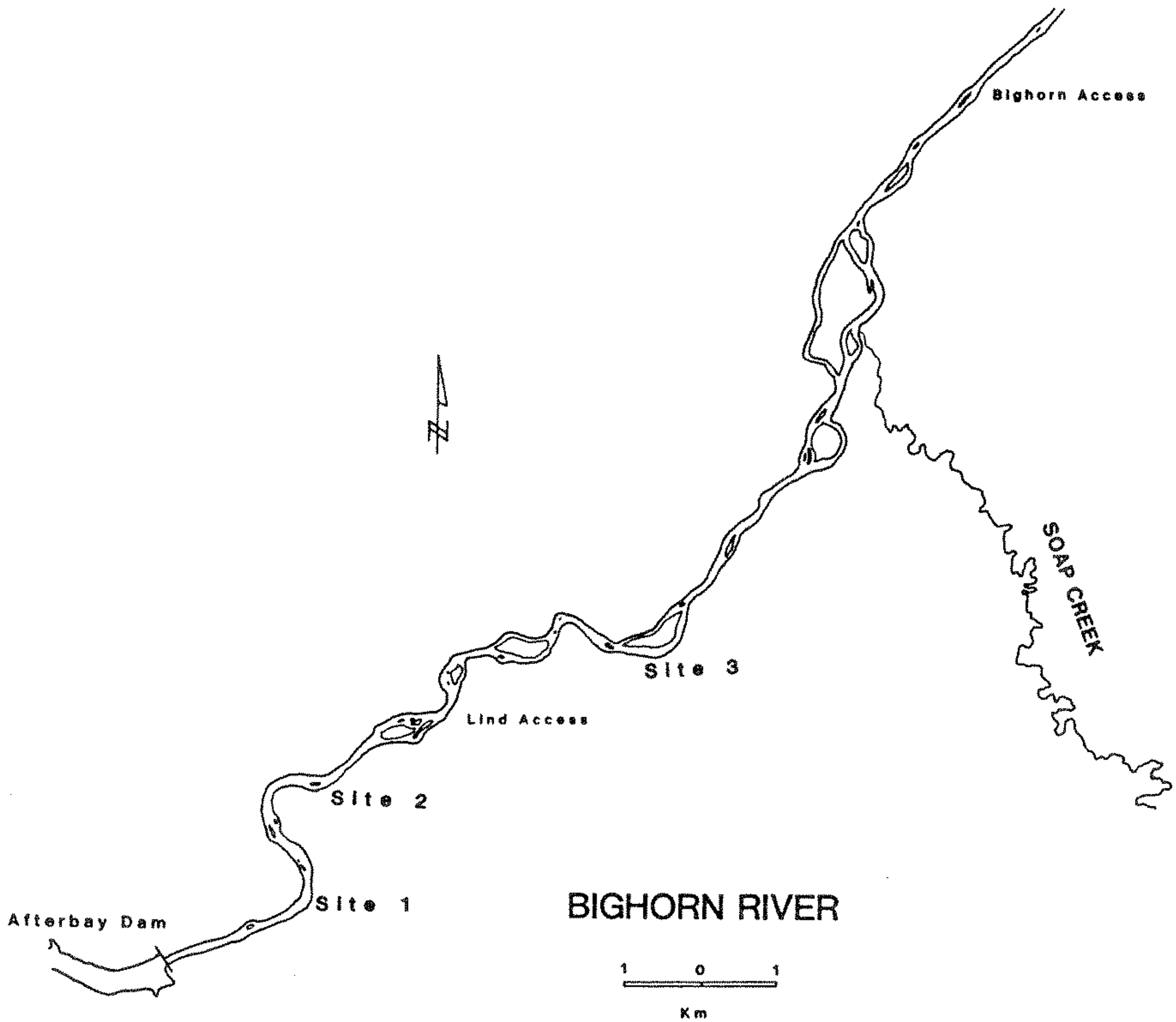

Figure 1. Bighorn River study area showing gas supersaturation study sites.

The presence of Yellowtail and Afterbay Dams has a pronounced effect on the flow regime in the Bighorn River. Annual flow peaks have been reduced and minimum flows increased relative to pre-impoundment conditions (Stevenson 1975). The mean annual monthly flow at Afterbay Dam for the period 1970-1982 was 103.4 m^3/s. Mean monthly flow for this period was highest in June (143.2 m^3/s), and lowest in September (75.1 m^3/s). In 1983, mean monthly flows were higher than the 1970-1982 average during all months except May, while flows in 1984 were more typical of the 1970-1982 period (Figure 2). The drainage area above Afterbay Dam is 50,938 km^2.

Operation of Afterbay Dam as a reregulation facility greatly reduces daily flow fluctuations in the river due to hydro-power peaking operations of Yellowtail Dam. Although water levels within Afterbay Reservoir fluctuate as much as 4.5 m daily, a stable daily flow regime is maintained in the river.

Hypolimnetic releases from Yellowtail Reservoir have reduced maximum and increased minimum stream water temperatures compared to pre-impoundment (Stevenson 1975). Mean monthly water temperature for the period 1976-1982 ranged from 2.3 °C in March to 14.2 °C in September (Figure 3). In 1983 maximum mean monthly water temperature occurred during August (18.9 °C) and minimum mean monthly water temperature occurred in February (3.3°C). During 1984 the maximum mean monthly water temperature was in September (17.3°C) and the minimum occurred during March (2.8°C).

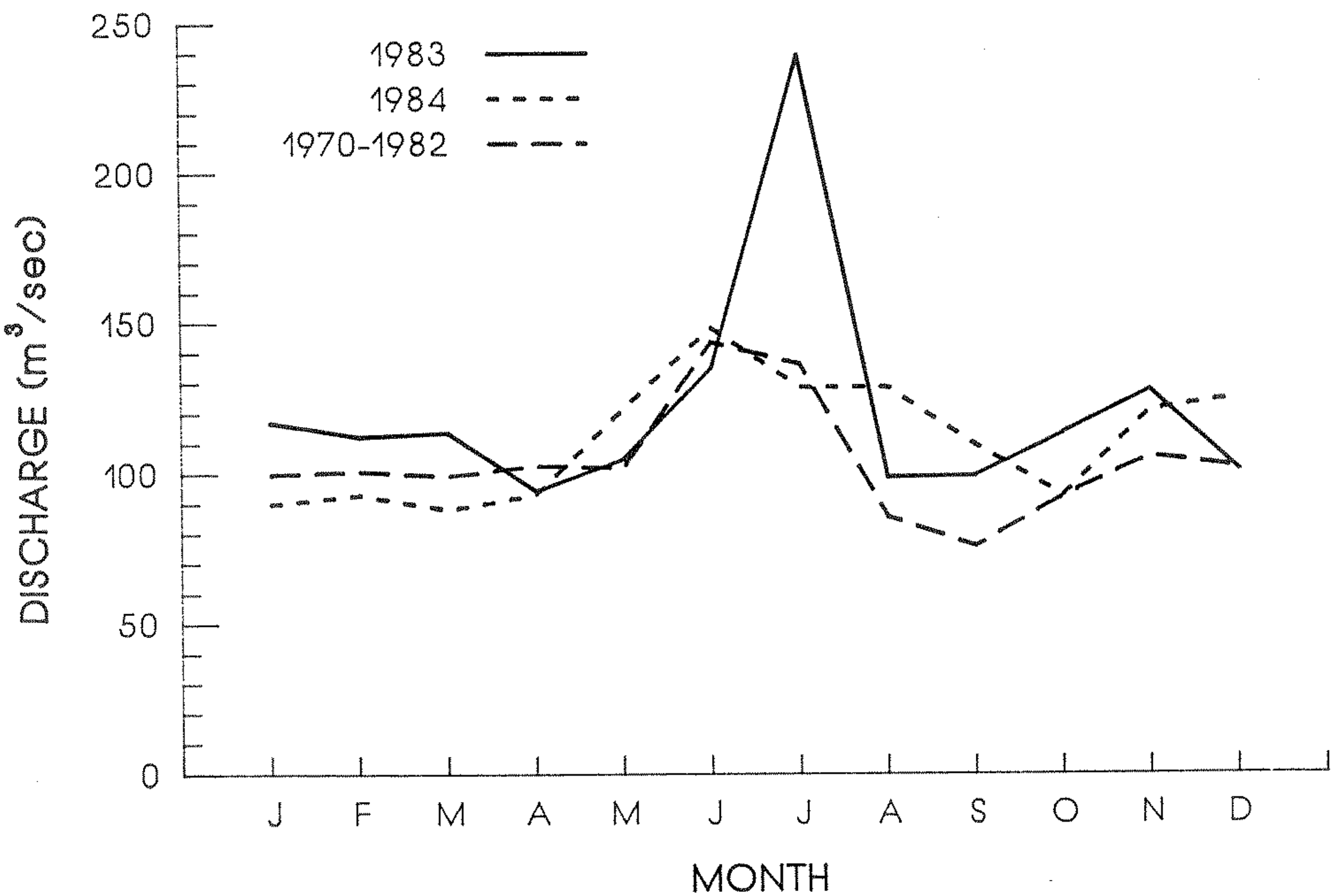

Figure 2. Mean monthly flows in the Bighorn River during study years 1983 and 1984, and for the period 1970-1982.

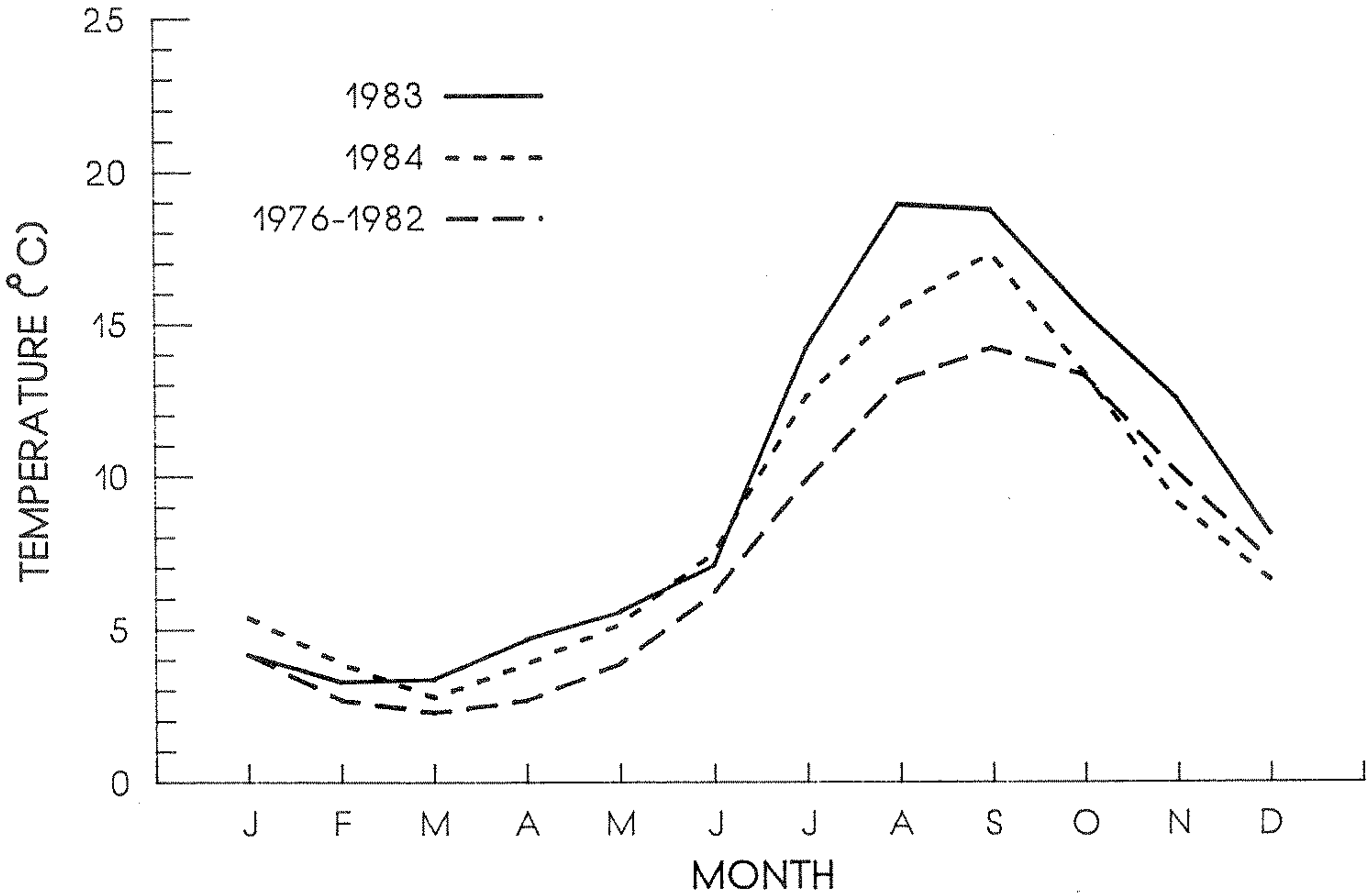

Figure 3. Mean monthly water temperature in the Bighorn River during study years, 1983 and 1984, and for the period 1976-1982.

Levels of conductivity, hardness, alkalinity, and calcium in the Bighorn River are relatively high (Hem 1985) and pH is alkaline (Table 1). Wright and Soltero (1973) described the nitrogen-phosphorous ratio as favorable, indicating the river has a high potential of biological productivity.

Soap Creek, the only major tributary in the study section, originates at the confluence of Limestone and Soap Creek canyons and flows in a southeasterly direction 50.8 km to its confluence with the Bighorn River (Figure 4). A series of small springs located near the origin provide the majority of summer flow. The Soap Creek Oil Field, operated by Soap Creek Associates, is located 30.0 km above the mouth and an irrigation diversion dam is located 13.1 km above the mouth.

Table 1. Mean and range of selected water quality parameters of the Bighorn River below Afterbay Dam from periodic measurements made from October 1980 to August 1981 (U.S.G.S 1982).

Parameter	Mean	Range
Conductivity (micromhos)	925	813-1070
pH	8.2	8.0-9.0
Hardness (mg/l as $CaCO_3$)	307	270-360
Ca, dissolved (mg/l)	78	68-93
Alkalinity (mg/l as $CaCO_3$)	162	130-190
Total dissolved solids (mg/l)	610	539-684
Nitrogen (mg/l as N)	0.58	0.01-2.20
Phosphorous (mg/l as P)[1]	0.02	0.01-0.04

[1] Missing data for August.

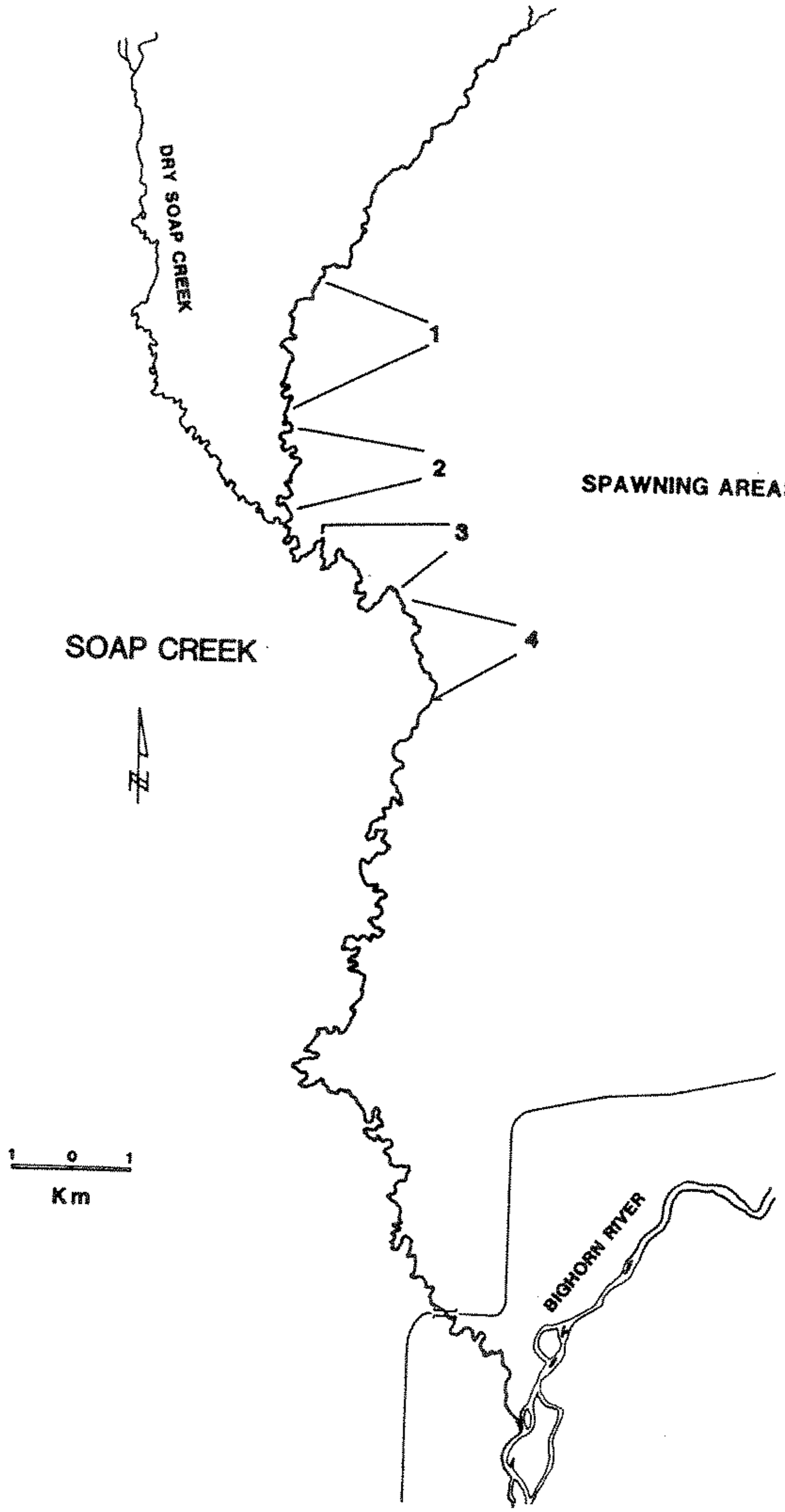

Figure 4. Soap Creek study area showing rainbow trout spawning areas.

Approximately 0.51 m^3/s is removed from Soap Creek for irrigation during the period mid-May through mid-October.

Primary land uses adjacent to Soap Creek were cattle grazing in the upper reaches and small grain and hay production in the lower reaches. Numerous beaver dams were located along the stream.

Mean monthly discharge in Soap Creek for the period 1968-1972 (most recent gauging station records) was 1.04 m^3/s (U. S. Geological Survey 1969, 1970, 1971, 1972, and 1973). Mean monthly discharge was highest in May (2.06 m^3/s) and lowest in December (0.54 m^3/s). The gradient of Soap Creek ranges from 3.5 m/km in the lower reaches (0-28 km) to 8.0 m/km in the upper reaches (28-50.8 km).

METHODS

Redd Distribution and Abundance

Bighorn River

A 6.1 km section of the Bighorn River between Afterbay Dam and the Lind Fishing Access Site was monitored regularly to record progression of rainbow trout spawning during the 1983 field season. Redds were located by walking the shorelines and by floating in a canoe. Each redd located was counted and marked with a painted rock to avoid recounting on subsequent surveys. The remainder of the river within the study section was searched for redds twice during the spawning period to identify spawning areas and downstream distribution of redds. During the 1984 field season, three high-use spawning areas identified in 1983 (located 1.6, 2.2, and 4.2 km below Afterbay Dam) were observed regularly to record timing and duration of spawning.

Soap Creek

Use of Soap Creek for spawning by migratory Bighorn River rainbow trout was examined during April and May 1983. Distribution of spawning was determined by foot surveys progressing downstream from the mouth of Soap Creek canyon. Surveys were conducted only during periods of low water turbidity. Redds constructed by migrant and resident fish were easily distinguished by size (based on observations of both migrants and residents constructing redds). Although a total count of redds was not possible due to periods of turbid water, longitudinal distribution and areas of high use were determined.

Physical and Hydraulic Characteristics of Redds

Measurements of water depth, point velocity (2.0 cm above substrate) and mean water column velocity (0.6 depth) were taken at the upper edge of 85 redds in the Bighorn River and 80 redds in Soap Creek. Newly constructed redds were chosen so measurements would reflect conditions at time of spawning. Water depths were measured using a top-setting rod and velocities measured with a Montedoro Whitney Model PVM-2 current meter.

Spawning substrate was sampled using a modified McNeil sampler with a 178 mm diameter tube (McNeil 1964). The tube was embedded 190 mm into the stream bottom. The enclosed substrate and suspended solids were extracted and stored for later particle size analysis. Thirty samples (10 at each of three spawning areas) were taken in the Bighorn River and 40 samples (10 at each of four spawning areas) from Soap Creek. Due to water conditions during the spawning period, substrate samples were not collected at individual redds but were collected from sites marked during the spawning period. Samples were collected 20-24 June 1983 in Soap Creek and 20 October 1983 in the Bighorn River.

Substrate samples were dried in a forced air oven for a minimum of 12 h at 150 $^{\circ}$C. Each sample was sieved through a series of nine U.S. Standard Testing Sieves (50.8, 25.4, 12.7, 9.52, 6.30, 4.76, 2.00, 0.85, 0.42 mm) on a Tyler Ro-Tap sieve shaker for 10 min. The material retained by each sieve and a bottom collecting pan was weighed (nearest 0.1 gm) and percentage of total sample computed.

Fish Trapping

To monitor outmigration of young-of-year rainbow trout from Soap Creek, drift nets were placed downstream from identified spawning areas (Figure 4). Drift nets consisted of tapered fiberglass screen nets with 80 cm by 50 cm mouths. The downstream end of each net was attached to a holding box (Porter 1973) which provided captured fish refuge from the current. The nets were fished passively in the main flow of the stream. Two drift nets were installed in Soap Creek on 25 June 1983 and checked for fish twice daily. On 24 August 1983, one drift net was moved to the Soap Creek irrigation ditch to check for loss of fish into the ditch during periods of low stream flow. The drift nets were operated through 7 September 1983.

A stream-wide weir was installed in Soap Creek during spring 1984 to capture rainbow trout moving upstream and downstream. The weir consisted of two wooden frame holding boxes with 2.54 cm wire mesh leads. The wire mesh leads were secured to the stream bottom by excavating a shallow (5.0 cm) trench and anchoring with large cobbles. The basic weir design was modified from that reported by Montana Department of Fish, Wildlife and Parks (1979). The weir was located approximately 50 m below the Soap Creek diversion dam (Figure 4) and was operated between 21 March and 26 April 1984. All fish captured were identified to species, weighed, and measured (TL). Rainbow trout were sexed when possible. Sexual development of rainbow trout was classified as: 1) gravid - sex products well developed; small quantities of milt extruded from males when light pressure was applied to abdomen; eggs in females well developed but not released when pressure was applied, 2) ripe - milt and eggs readily released when light pressure was applied to the abdomen, and 3) spent - testes and ovaries empty, females had flaccid abdomens. Scale samples were taken from all fish for age determination. Adult rainbow trout were tagged with numbered T-tags placed behind the dorsal fin and each fish released in the direction of its movement.

Embryo Survival

Bighorn River

Embryo survival to hatching was determined for three spawning areas in the Bighorn River during spring 1984. Eggs were taken from Bighorn River rainbow trout collected by electrofishing, fertilized and allowed to water harden for 1 h. One hundred eggs were placed in a fiberglass screen bag containing gravel obtained from the river and the bag was stapled closed and buried 15.0 to 20.0 cm in the gravel. Although artificial redds were not created, the egg bags were placed in close proximity to existing redds. The closed fiberglass screen bags only allowed determination of embryo survival to hatching, since alevins were unable to emerge through the small mesh screen. Five egg bags (25 cm by 15 cm) were buried in each of three spawning areas located 2.2, temperature was monitored with a Taylor 30 day thermograph located approximately 100 m below Afterbay Dam. The egg bags were retrieved on 24 June 1984, 7 d after predicted hatching time as determined from accumulated temperature units (Leitritz and Lewis 1976). Upon removal of egg bags, dead eggs were counted.

<u>Soap Creek</u>

Procedures similar to those described for embryo survival in the Bighorn River were used to determine embryo survival in Soap Creek, except Whitlock-Viebert boxes were used in place of the closed fiberglass screen bags and eggs were obtained from Bighorn River rainbow trout migrants collected in Soap Creek. Five boxes, each containing 100 eggs, were buried in each of four spawning areas (Figure 4) on 4 May 1983. Stream temperatures were monitored with a Taylor 7 day thermograph located at the downstream end of spawning area 2. The boxes were retrieved 10 June 1983, 7 d after predicted hatching time as determined from accumulated temperature units Upon removal of the boxes, dead eggs were counted. The Whitlock-Viebert boxes allowed determination of embryo survival to emergence. Eggs not accounted for from the original 100 placed in each Whitlock-Veibert box were assumed to have emerged.

Gas Supersaturation Bioassay

The severity of dissolved gas supersaturation and its possible effects on rainbow trout recruitment were investigated during the 1984 field season. Field bioassays were conducted at sites located 2.2 (Site

1), 4.2 (Site 2) and 9.0 km (Site 3) below Afterbay Dam (Figure 1). The sites were chosen on the basis of decreasing levels of dissolved gas (Fredenberg 1985), proximity to high use spawning areas, and inaccessibility to fishermen (to avoid disturbance).

Four field bioassays were conducted to investigate effects of elevated dissolved gas levels in the Bighorn River on eggs and fry of rainbow trout (Table 2). The test groups were separated into two time periods. Initiation of each test was separated by approximately 30 d for the embryo test groups and 7 d for the fry test groups to encompass the period of exposure expected to occur in the Bighorn River. Each time period contained two test groups, one test group at each of two sites (Figure 1).

Table 2. Test period and sites of field bioassays designed to investigate effects of elevated dissolved gas levels on rainbow trout embryos and fry.

Test group	Period of test	Site[1]
Embryo		
1	04/21 - 06/27/84	1
2	04/21 - 06/27/84	2
3	05/22 - 07/17/84	1
4	05/22 - 07/17/84	2 and 3[2]
Fry		
1	07/05 - 08/04/84	1
2	07/05 - 08/04/84	3
3	07/12 - 08/11/84	1
4	07/12 - 08/11/84	3

[1] Sites 1, 2, and 3 were located 2.2, 4.2, and 9.0 km below Afterbay Dam, respectively.

[2] Embryos were relocated to Site 3 during the eyed stage.

Eggs were obtained for the bioassays from rainbow trout collected from the Bighorn River. Eggs were artificially spawned, mixing eggs and milt from several fish to reduce influence of parental effects on egg survival. The eggs were incubated on artificial turf substrate (Swanson 1982) stacked on shelves in modified fry holding boxes (Porter 1973). The boxes were anchored to the stream bottom in approximately 0.5 m water depth. The boxes had inside dimensions of 20 cm by 45 cm and a depth of 25 cm. Water was supplied to the box through a screened 5.0 cm inside diameter plastic pipe and exited through the screened sides.

For embryo test groups 1 and 2, 1,000 eggs were placed in each box on the artificial turf substrate (250 eggs per layer of substrate). One box was located at each of the two sites. A control group of 1000 eggs was incubated on artificial turf substrate in the laboratory at similar water temperatures to determine fertilization success and to monitor embryo development. Upon eye-up of eggs in the laboratory, embryos in holding boxes were counted and dead eggs removed. Soon after hatching, sac fry and dead eggs were counted. Similar methods were used for embryo test groups 3 and 4, except 500 eggs were used for each test group and the control group.

Sac fry from embryo tests 1 (N=242) and 2 (N=100) were used in corresponding fry tests (tests 1 and 2). Because of low numbers of surviving fry from embryo tests 3 and 4, fry tests 3 (N=200) and 4 (N=200) utilized swim-up fry obtained from the laboratory control groups. Fry bioassays were conducted at the same location and held in the same holding boxes used in the embryo bioassay. Fry were checked at least every other day for mortality for the first 8 d of the test and daily thereafter. The fry were fed daily with Oregon Moist feed after yolk sacs were absorbed. Fry of each test group were observed for 30 d.

Dissolved gas levels were monitored on most days at the bioassay sites (Site 1 - 21 April to 4 August, Site 2 - 21 April through 5 July, Site 3 - 22 June through 4 August), and measurements were taken during mid-day. Delta P (the difference between total gas pressure in the water and in the air) was measured using a Bouck Gasometer (Bouck 1982). Water temperature was recorded and concentrations of dissolved oxygen were measured using the azide-modification of the Winkler method (APHA 1976). Barometric pressure used in dissolved gas equations was obtained from the National Oceanic and Atmospheric Administration station at Billings, Montana and corrected for elevation (Colt 1984). Gas levels were computed using equations reported by Colt (1984) and include :

$$\% \text{ TGP} = \left[\frac{(BP + \Delta P)}{BP}\right] 100$$

$$\% \text{ } N_2 + Ar = \left[\frac{BP + \Delta P - \left[\frac{CO_2}{\beta O_2}\right](0.5318) - PH_2O}{(BP - PH_2O)\ 0.7902}\right]$$

$$\% \text{ } O_2 = \left[\frac{\frac{CO_2}{\beta O_2}(0.5318)}{(BP - PH_2O)\ 0.20946}\right] 100$$

$$\Delta P - O_2 = \left[\frac{CO_2}{\beta O_2} (0.5318)\right] - 0.20946(BP - PH_2O)$$

$$\Delta P - N_2 + Ar = BP + \Delta P - \left[\frac{CO_2}{\beta O_2} (0.5318)\right] - PH_2O - 0.7905(BP - PH_2O)$$

$$\beta O_2 = e^{[A1 + A2(100/T) + A3 \log e(T/100)]}$$

$$PH_2O = 760 \times e^{[24.453 - 67.4509(100/T) - 4.8489 \log e(T/100)]}$$

Where: BP[1] = Barometric Pressure (mm Hg)
ΔP = Delta P (mm Hg)
CO_2 = Dissolved oxygen concentration (mg/l)
βO_2 = Bunsen coefficient of oxygen (L/L x atm)
PH_2O = Vapor pressure of water (mm Hg)
TGP = Total gas pressure (mm Hg)
T = Absolute water temperature ($^{\circ}$C + 273.15)
A1 = -58.3877
A2 = 85.8079
A3 = 23.8439

Statistical Analysis

Statistical tests were accomplished using SAS/STAT software for personal computers (SAS Institute, Inc. 1987). Scheffe's test was used for multiple comparison of means for variables in analysis of variance. The Chi-square test of independence was used to test for significant differences in embryo survival during the gas supersaturation field bioassay. Product limit survival estimates were used to test for significant differences in mortality of fry during the gas supersaturation field bioassay. This test utilizes a generalized Wilcoxon rank test to test for differences in rate of mortality.

RESULTS AND DISCUSSION

Redd Distribution and Abundance

Bighorn River

Rainbow trout spawning was first observed on 1 April 1983 and continued until 24 June. More than 40% of the spawning occurred during the first 3 weeks in April (Figure 5). A similar pattern was observed during 1984; spawning began 8 April and continued through 23 June. Mean daily water temperature at the onset of spawning was 3.9 °C in 1983 and 3.3 °C in 1984. During both years initiation of spawning appeared to be related to an increase in water temperature following an extended period of constant temperature (Figure 6). Initiation of rainbow trout spawning in the Bighorn occurred at lower temperature than reported as optimal for rainbow trout (5.5 - 15.5 °C) by Bovee (1978). However, water temperature during spawning was similar to the Missouri River and Beaver Creek (Spoon 1985).

In 1983, 517 redds were located in the 6.1 km section below Afterbay Dam. Five of the six high-use spawning areas (30 or more redds) were associated with side channels (Figure 7) and accounted for 80.2% of the redds counted (Table 3). The six high use areas contained 88% of redds located (Table 3). The largest concentration of redds

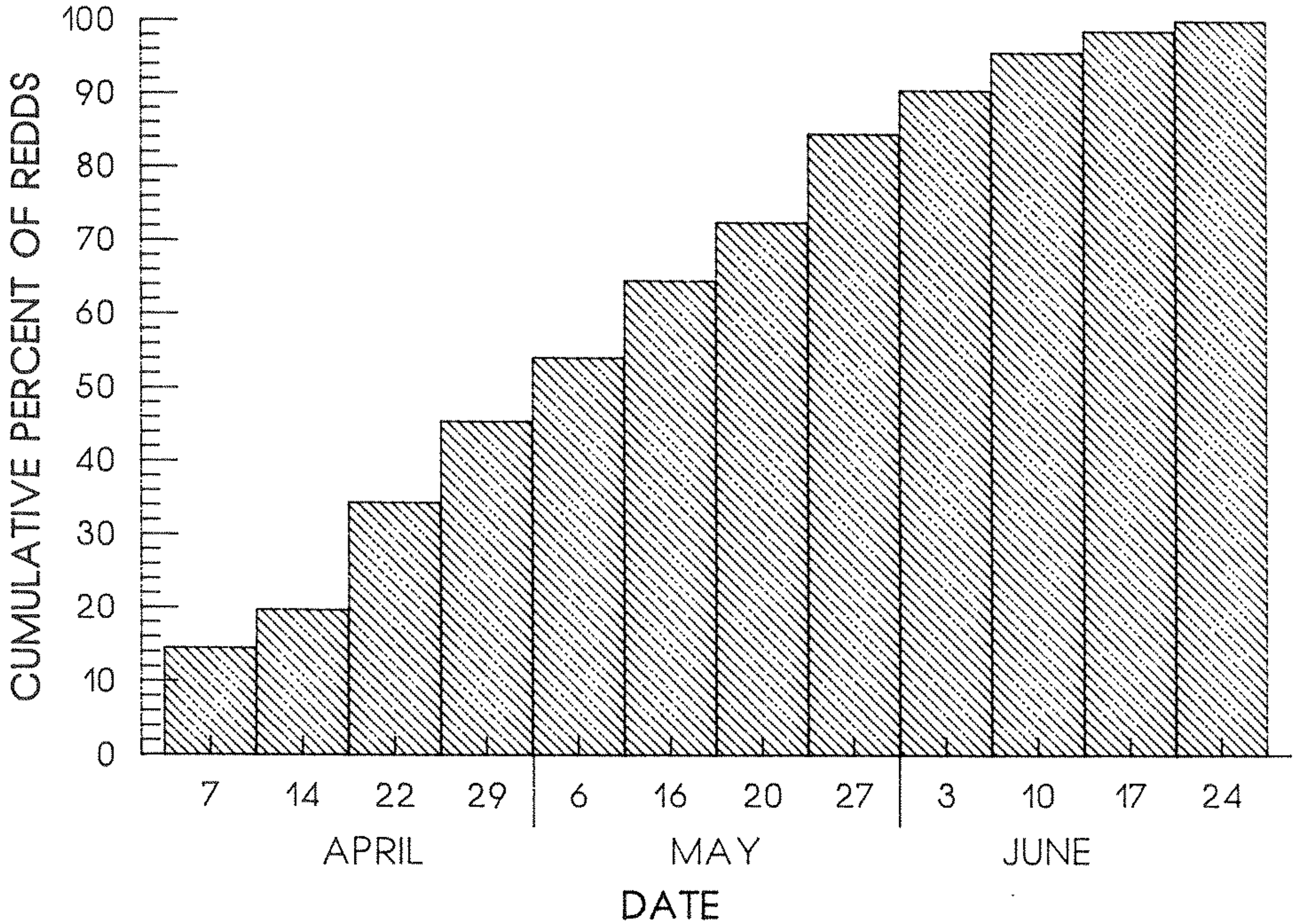

Figure 5. Temporal distribution of new rainbow trout redds in the Bighorn River, 1983.

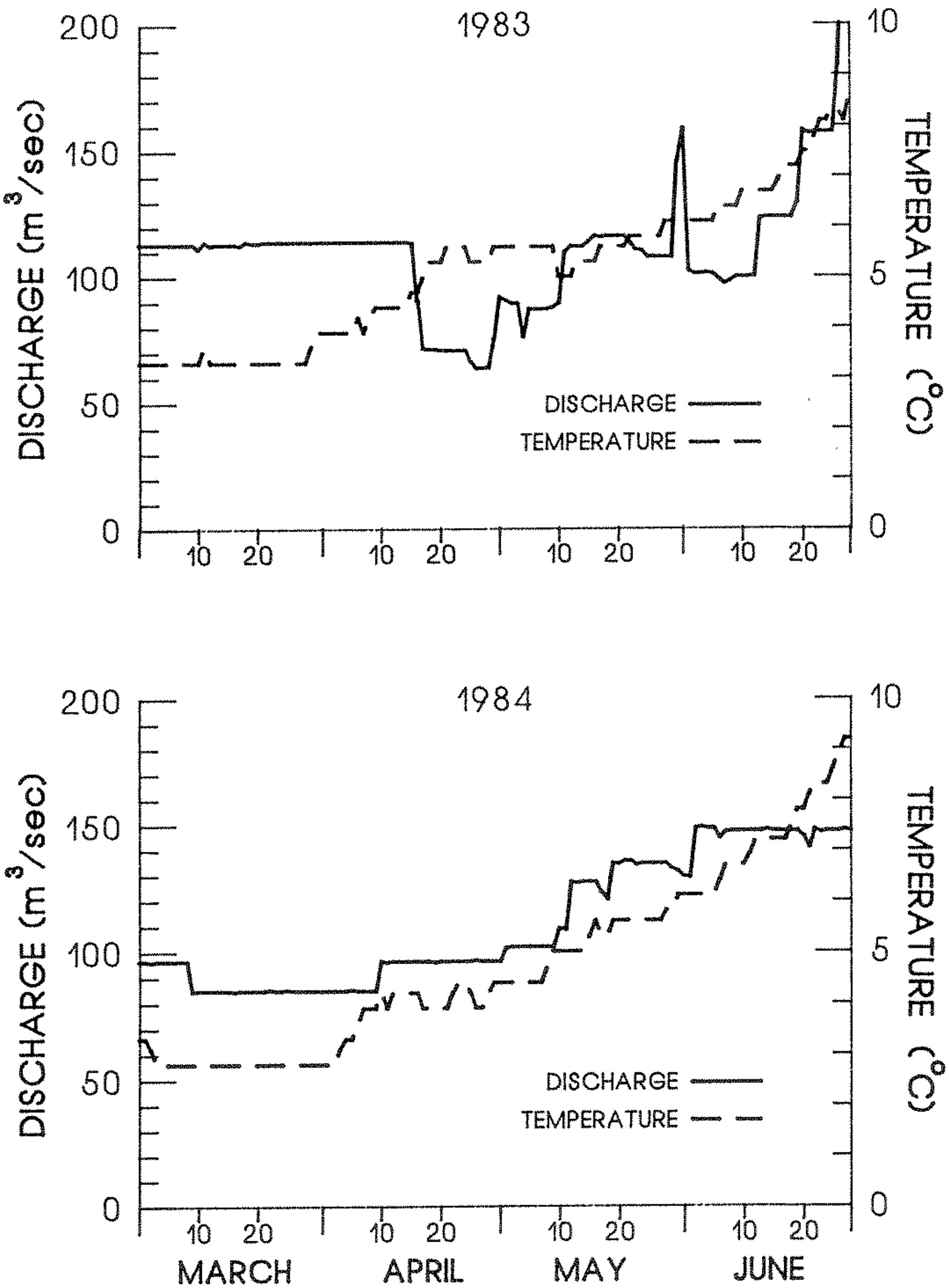

Figure 6. Water temperature and discharge in the Bighorn River during rainbow trout spawning, 1983 and 1984.

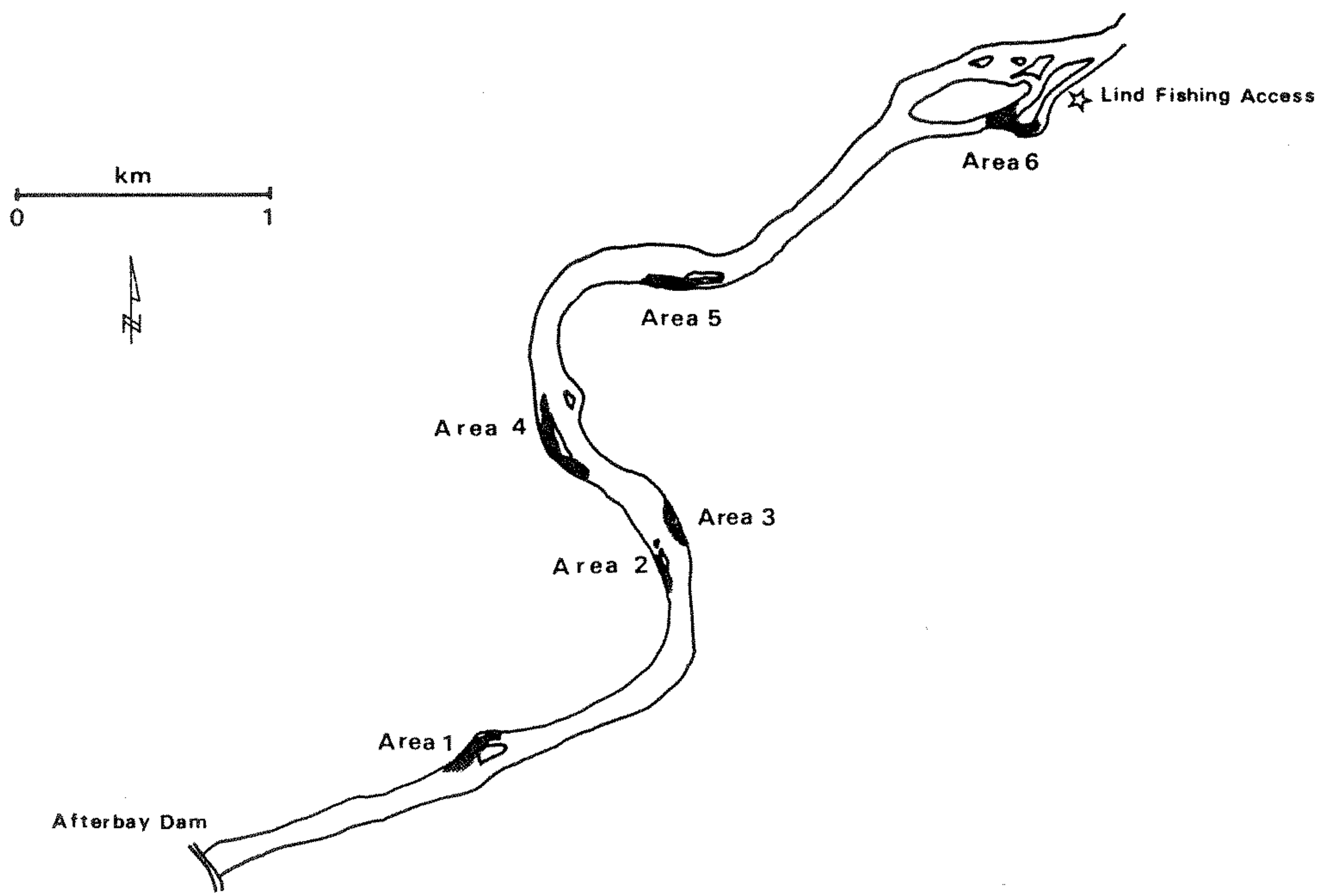

Figure 7. Location of high use rainbow trout spawning areas in the Bighorn River, 1983 and 1984. Hatched areas indicate spawning sites.

Table 3. Number and percentage of rainbow trout redds in the 6.1-km section of the Bighorn River below Afterbay Dam, 1983.

Area	Location (km below dam)	Number of Redds	% of Total
1	1.6	85	16.4
2	2.1	64	12.4
3	2.2	67	13.0
4	2.9	88	17.0
5	4.2	113	21.8
6	6.0	64	12.4
Misc.	-	36	7.0

(113) was in and above a side channel 4.2 km below Afterbay Dam (Area 5).

The remainder of the study section (6.1 - 19.3 km below Afterbay Dam) was surveyed for redds on 20 April and 24 May 1983. Although a total redd count was not made, high-use areas and downstream distribution of redds were identified. The only two high use areas were associated with side channels (9.0 and 9.7 km below Afterbay Dam). The farthest downstream redd observed was in a side channel 18.5 km below Afterbay Dam and was 3.7 km below the next redd upstream.

Soap Creek

Rainbow trout from the Bighorn River utilize Soap Creek extensively for spawning. In 1983, spawning was primarily confined to the stream section between 28.0 and 43.5 km above the mouth (Figure 4). Spawning

areas were separated by stream sections inundated by beaver dams or entrenched areas with low water velocity. Spawning had begun by 24 March, the first day the stream was searched. Fish were last observed on redds 28 May, indicating a spawning period of over 2 months.

During redd counts conducted between 5 April and 25 April, 183 migrant rainbow trout redds were located in Soap Creek. This is a partial count since each section of stream was searched only once during this period. Redds constructed early may have been obscured during periods of turbid water and spawning was known to have continued until late May. These data give an indication of the importance of Soap Creek as a spawning tributary for Bighorn River rainbow trout.

Downstream distribution of redds in Soap Creek appeared to be limited by availability of habitat. The lower 28 km of the creek are deeply entrenched, with low gradient, low water velocities and few riffles. Upstream distribution of redds was limited by beaver dams which were barriers to fish passage, even though there appeared to be suitable spawning habitat above the dams. In 1983, high concentrations of migrant fish and redds were observed below a beaver dam 43.5 km above the mouth. Failure to locate any redds above the dam was evidence that the dam constituted a barrier to passage. In 1984 a new spillway had developed which allowed fish to move above this dam. However, another beaver dam 0.8 km upstream appeared to block upstream migration since large numbers of migrant fish and redds were observed immediately below the dam and redds were not observed above the dam.

Physical and Hydraulic Characteristics of Redds

Bighorn River

During 1983, measurements of depth, mean column velocity, and point velocity were taken at 85 rainbow trout redds to describe characteristics of spawning sites in the Bighorn River (Figures 8, 9, 10). Rainbow trout spawned at an average depth of 40.9 cm; mean column velocity measured at the upstream edge of the redd averaged 0.73 m/sec, with an average point velocity (2.0 cm above the substrate) of 0.12m/sec (Table 4). River discharge at time of redd construction and when measurements were taken was 113.9 m^3/sec.

Soap Creek

Measurements were taken at 80 migrant rainbow trout redds in Soap Creek in 1983 (Figures 8, 9, and 10). Depth at spawning sites averaged 23.6 cm, with an average mean column velocity of 0.66 cm/sec and average point velocity of 0.28 m/sec (Table 5).

Table 4. Mean, standard deviation, and range of depth and velocities at rainbow trout spawning sites in the Bighorn River, 1983.

Parameter	Mean (± S.D.)	Range
Depth (cm)	40.9 (± 15.50)	12.2 - 97.5
Mean column vel. (m/sec)	0.73 (± 0.19)	0.25 - 1.27
Point velocity (m/sec)	0.12 (± 0.12)	0.01 - 0.61

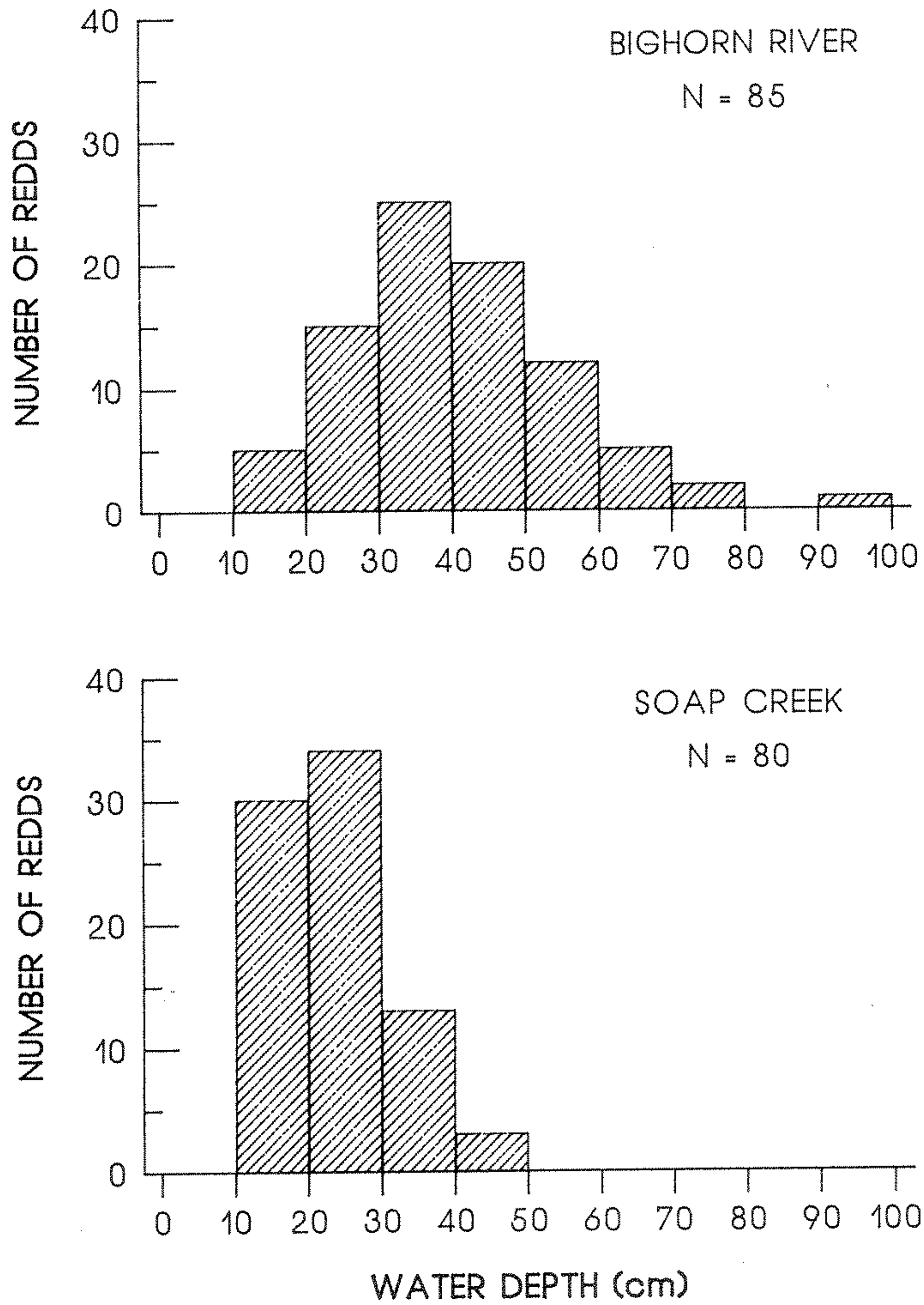

Figure 8. Depth of rainbow trout redds measured in the Bighorn River and Soap Creek, 1983.

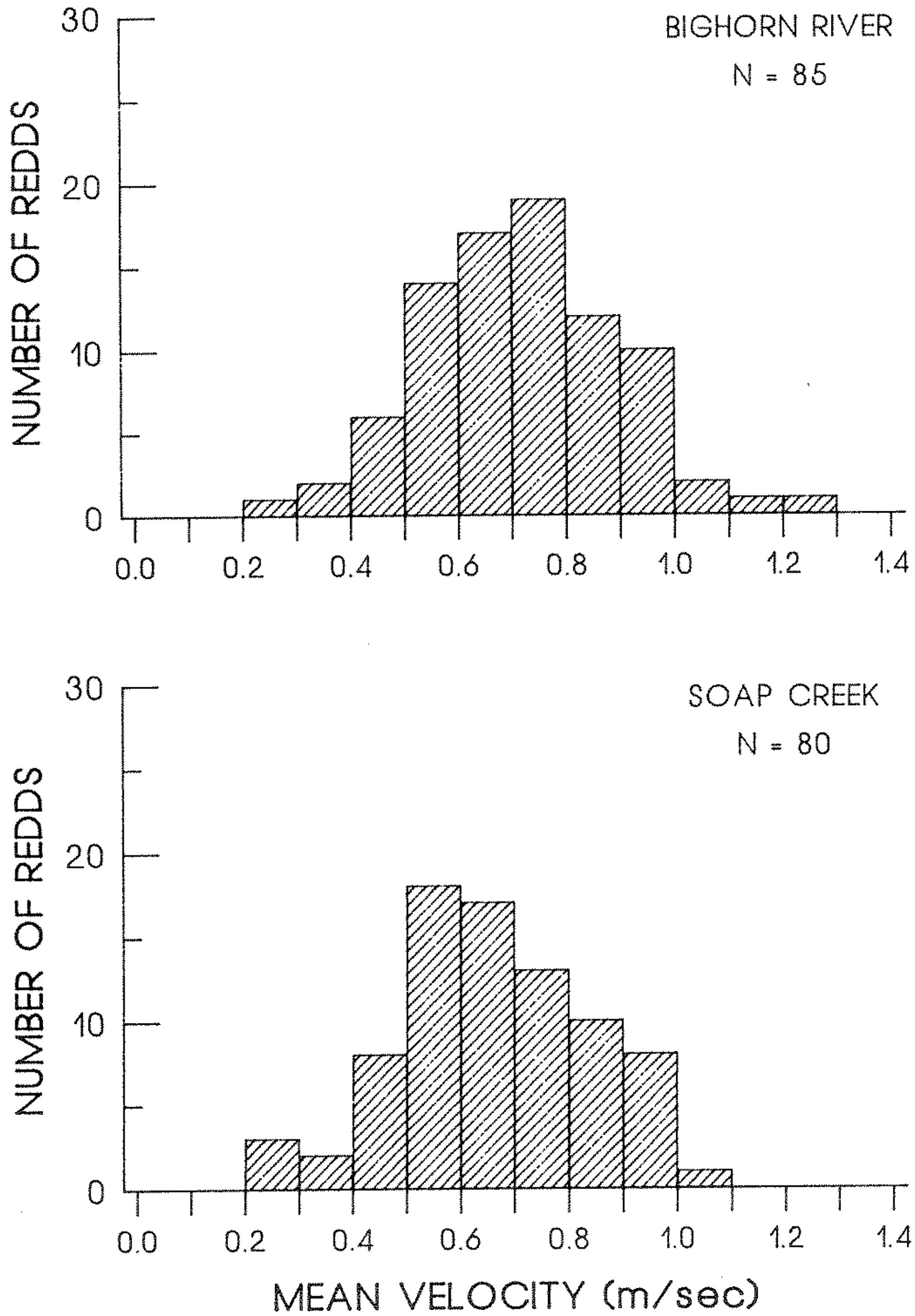

Figure 9. Mean column velocity measured at rainbow trout redds in the Bighorn River and Soap Creek, 1983.

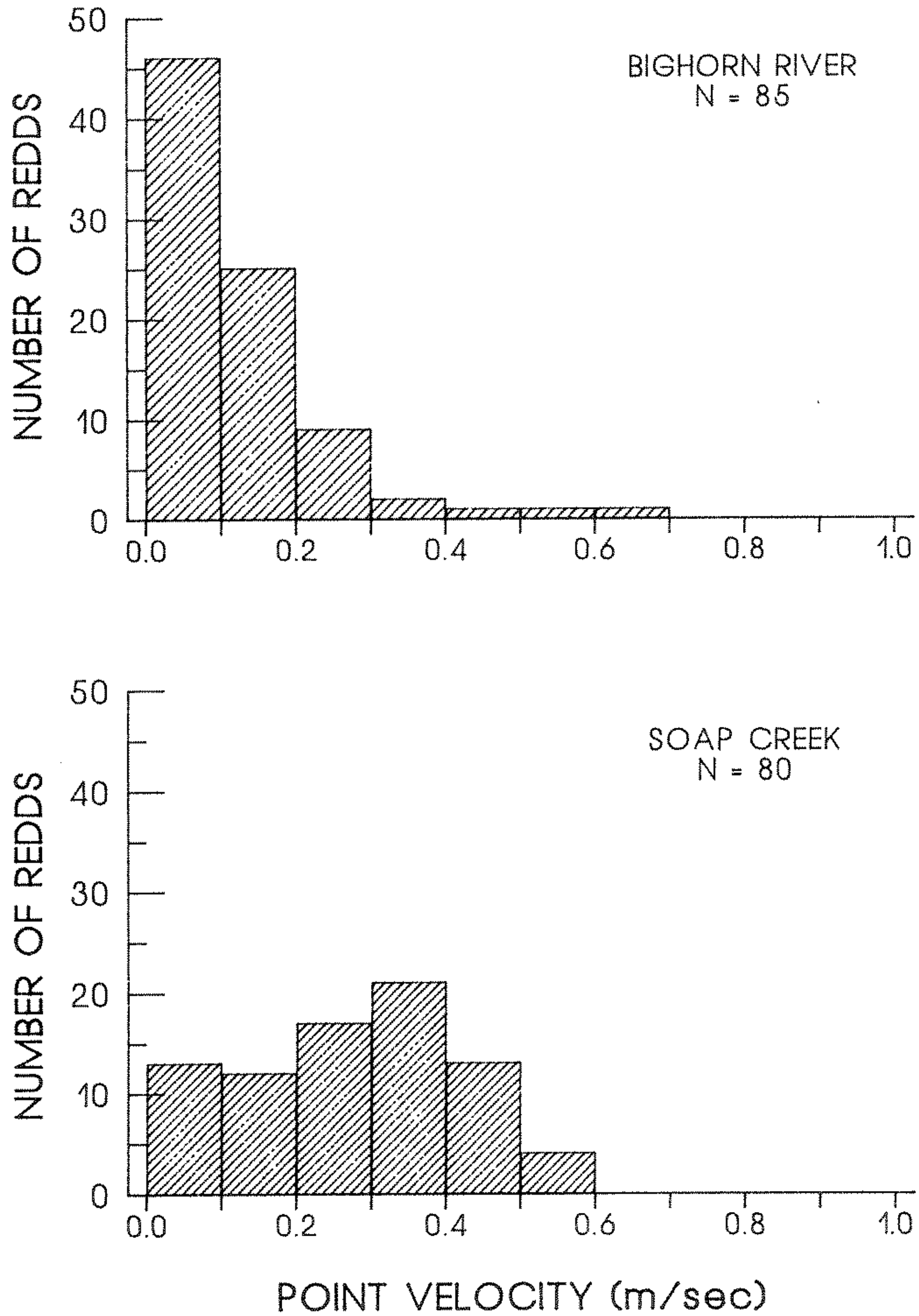

Figure 10. Point velocity measured at rainbow trout redds in the Bighorn River and Soap Creek, 1983.

Table 5. Mean, standard deviation, and range of depth and velocities at rainbow trout spawning sites in Soap Creek, 1983.

Parameter	Mean (± S.D.)	Range
Depth (cm)	23.6 (± 7.30)	12.2 - 48.8
Mean column vel. (m/sec)	0.66 (± 0.18)	0.27 - 1.04
Point velocity	0.28 (± 0.15)	0.01 - 0.35

Spawning sites chosen by rainbow trout in the Bighorn River and Soap Creek were similar to those reported for other streams (Table 6). Rainbow trout spawning in the Bighorn River utilized a wider range of depths and velocities than those spawning in Soap Creek. Average depth at spawning sites was greater and point velocities lower in the Bighorn River than in Soap Creek, while mean column velocity was similar for both streams. These differences in depth and point velocity are to be expected due to the large difference in size of the two streams. Spoon (1985) found similar differences between rainbow trout spawning sites in the Missouri River and Beaver Creek. Depth at spawning sites in the Bighorn River fit the probability of use curves developed for the Missouri River (Spoon 1985). Whereas, depths at sites in Soap Creek agree more favorably with the probability of use curves reported by Bovee (1978) and Sando (1981), which were developed from data collected in smaller streams than either the Bighorn or Missouri rivers.

Water velocity appears to be more important than depth for selection of spawning sites (Spoon 1985). Probability of use curves for

Table 6. Minimum depth, range of velocity, and water temperature associated with rainbow trout spawning. Modified from Spoon (1985).

Parameter	Value	Source
Depth (cm)	12.2	Present study (Bighorn River)
	12.2	Present study (Soap Creek)
	10.7	Spoon 1985 (Beaver Creek)
	24.4	Spoon 1985 (Missouri River)
	4.4	Sando 1981 (Beaverhead River)
	22.0	Sando 1981 (Yellowstone River)
	18.3	Smith 1973
	15.2	Thompson 1972
	12.2	Bovee 1975
Mean column velocity (m/sec)	0.25-1.27	Present study (Bighorn River)
	0.27-1.04	Present study (Soap Creek)
	0.20-1.19	Spoon 1985 (Beaver Creek)
	0.09-1.37	Spoon 1985 (Missouri River)
	0.22-1.21	Sando 1981 (Beaverhead River)
	0.41-0.65	Sando 1981 (Yellowstone River)
	0.30-0.91	Smith 1973
	0.43-0.82	Thompson 1972
	0.10-1.23	Bovee 1975
Water temperature (^{o}C)	3.3	Present study (Bighorn River)
	3-6	Spoon 1985 (Beaver Creek)
	3.5	Spoon 1985 (Missouri River)
	7-13	Bovee 1975

mean water column velocity at spawning sites developed for the Missouri (Spoon 1985), Yellowstone, and Beaverhead (Sando 1981) rivers and those of Bovee (1978) tend to agree, with optimums between 0.50 and 0.75 m/sec. These curves represent a variety of stream sizes, yet mean water column velocity at spawning sites agrees between streams. Average mean water column velocities were comparable for spawning sites in the Bighorn River and Soap Creek.

Substrate Composition and Embryo Survival

Bighorn River

Substrate core samples were taken at three spawning areas (Area A = 2.2 km, Area B = 4.2 km, and Area C = 9.0 km below Afterbay Dam) to evaluate substrate suitability for embryo survival at locations used by spawning rainbow trout. Mean percentage of fine sediments (<0.85 mm) was 15.30%, 10.47%, and 15.23% at Areas A, B, and C, respectively (Table 7). Substrate at Area B had significantly lower amounts of sediment <9.50 mm (p=0.0007) and <0.85 mm (p=0.0181) than Areas A and C.

Table 7. Amounts of fine material sampled at rainbow trout redds and adjusted percent embryo survival to hatching in egg bags at three locations in the Bighorn River.

Location	Percent fines smaller than 9.50 mm (N=10)	Percent fines smaller than 0.85 mm (N=10)	Observed % Survival[1] (N)[2]
Area A (2.2 km below Afterbay dam)	39.19	15.30	29.7 (5)
Area B[3] (4.2 km below Afterbay Dam)	29.15	10.47	23.3 (5)
Area C 9.0 km below Afterbay Dam	37.18	15.23	17.0 (5)

[1] - No significant difference in embryo survival between locations (P=0.2476)

[2] - Sample size refers to number of egg bags planted at each site. Each egg bag held approximately 100 eggs.

[3] - Significantly less sediment smaller than 9.50 mm (p=0.0007) and 0.85 mm (p=0.0181).

Sampling of substrate was delayed until the October following redd construction when stream flow had receded sufficiently to allow samples to be taken. Although core samples were taken at redds marked during the spawning season, the delay in sample collection may have influenced particle size distribution in the samples. Deposition of smaller sediments may have occurred as stream flow and velocities decreased following the spawning season. The amount of fine sediment in stream substrate varies temporally (Adams and Beschta 1980). Fine sediments are flushed from gravel during high flows, and increase over time as flows recede. Chapman (1988) describes the process of intrusion of fine sediments into gravel and how this relates to structure of salmonid redds. The amount of fine material in the egg pocket is low following redd construction, but intrusion of fine material occurs over time.

Embryo survival to hatching was evaluated at the same locations (Areas A, B, and C) for which substrate composition was determined. Survival of embryos was adjusted, using survival of a control group of eggs incubated in the laboratory, to eliminate non-test related mortality. Adjusted survival was computed by dividing observed test survival by survival of the control group, which was 79.2%.

Embryo survival decreased with distance downstream of Afterbay Dam (Table 7). Mean survival to hatching was greatest at Area A (29.7%) and least at Area C (17.0%) but differences were not significant ($p=0.248$).

Spawning substrate utilized by rainbow trout in the Bighorn River had relatively high levels of fine sediment (Table 7). Tappel and Bjornn (1983) found that survival to emergence of rainbow trout embryos was most affected by fine sediment <0.85 mm. Reiser and White (1988) reported similar effects on survival of steelhead embryo survival to hatching.

Equations developed to predict embryo survival (Tappel and Bjornn 1983) from substrate composition estimate survival to emergence in the Bighorn River in the range of 9.0 - 27.5%. Estimated survival, utilizing the same equation, for rainbow trout in the Missouri River (19.7%) and Beaver Creek (27.2%) (Spoon 1985) were at the mid to high range of those for the Bighorn River. Substrate samples collected in the Bighorn River may represent extreme conditions since samples were collected 5 months after the spawning period. Core sampling of streambed substrate provides information to quantify the sediment composition in areas utilized by salmonids for spawning. However, Chapman (1988) states that sediment composition analysis may not provide appropriate data for predictive relationships for embryo survival and that the conditions within the egg pocket of natural redds need to be determined in order to develop predictive relationships. Therefore, equations developed by Tappel and Bjornn (1983) may not be appropriate for use in comparing relative embryo survival between streams.

Soap Creek

Spawning sites selected by rainbow trout in Soap Creek contained relatively high amounts of fine material (< 0.85 mm) (Figure 11). The percentage of fine sediment in substrate samples from four sections of Soap Creek increased in a downstream direction, with the exception of Area 1 (Figure 4). The high amount of fine sediment in the substrate

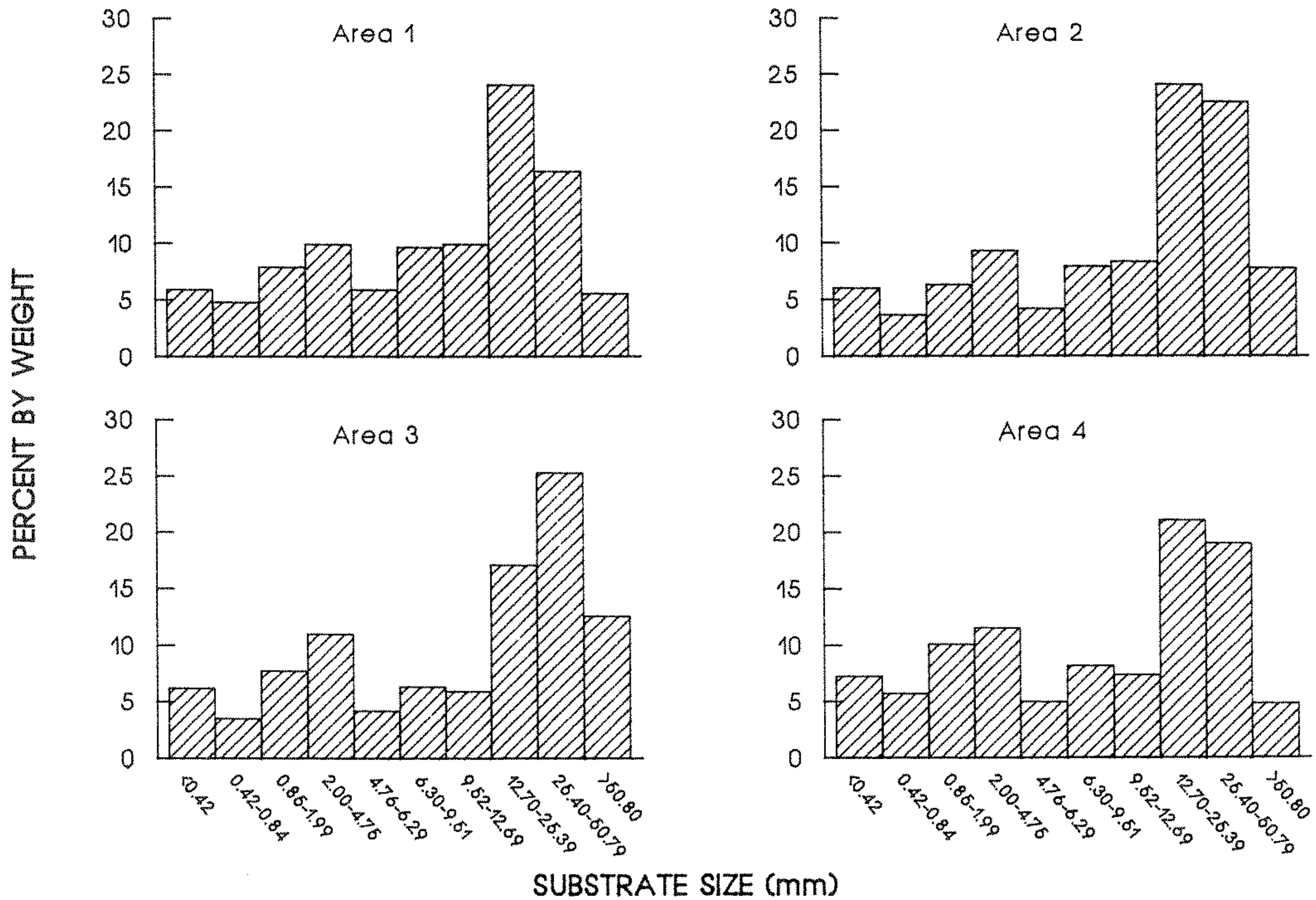

Figure 11. Sediment paricle size distribution sampled at rainbow trout spawning sites in Soap Creek during 1983.

sampled from Area 1 is a result of the analysis procedure. The stream substrate in this section of Soap Creek is modified by the chemical properties of the water in the stream. Springs at the head of Soap Creek contribute a large portion of the stream flow except during annual runoff. The stream substrate in this section is encrusted with calcite, which is a result of precipitation of $CaCO_3$ (Hynes 1979). The vigorous shaking of the substrate samples during analysis caused the encrusted layer to break free into small particles. This increased the percentage of fine particles in the sample. The substrate samples from Area 2 had only small amounts of encrusted calcite.

Survival to emergence of rainbow trout embryos in the Whitlock-Viebert boxes was highest at Area 1 (59.25%) and lowest at Areas 3 and 4 (0.00%) (Table 8). Embryo survival at Area 2 was 33.33%. Estimated

Table 8. Amounts of fine material sampled at rainbow trout redds, percent embryo survival to emergence, and predicted embryo survival to emergence for four spawning areas in Soap Creek.

Location	Percent fines smaller than 9.50 mm (N=10)	Percent fines smaller than 0.85 mm (N=10)	Observed % survival (N)	Predicted % survival[1]
Area 1	44.06	10.73	59.25 (400)	18.67
Area 2	37.43	9.71	33.33 (300)	27.21
Area 3	39.99	10.41	0.00 (400)	22.40
Area 4	47.73	12.96	0.00 (300)	8.07

[1] From equation of Irving and Bjornn (1984)

rainbow trout embryo survival to emergence, based on the amount of substrate particles smaller than 9.50 and 0.85 mm (Irving and Bjornn 1984), differed from observed survival (Table 8). The increased amount of fine particles due to the substrate analysis procedure may account for the low estimated survival at Area 1. The large difference between estimated (22.40%) and observed (0.00%) embryo survival at Area 3 suggests that some factor other than substrate particle composition at time of sampling influenced survival. Dry Soap Creek, an intermittent tributary, enters Soap Creek immediately upstream of Area 3. Although quantitative data are not available, bottom material in the lower reaches of Dry Soap Creek appeared to be predominately fines. Flows in Dry Soap Creek may transport large amounts of fine sediment following precipitation events, which may have influenced embryo survival in Area 3. Sampling method or timing of sample collection may have precluded accurate representation of substrate composition at spawning sites since individual redds were not sampled and samples were collected after emergence of fry.

Fish Migration in Soap Creek

One hundred thirty-six trap days in Soap Creek and 14 trap days in the diversion channel failed to capture any young-of-year rainbow trout migrating downstream. Fish captured included longnose dace (*Rhinichthys cataractae*), longnose sucker (*Catostomus catostomus*), lake chub (*Couesius plumbeus*), flathead chub (*Hybopsis gracilis*), carp (*Cyprinus carpio*), and many unidentified young-of-year catostomids and cyprinids.

A stream-wide weir was installed in Soap Creek to monitor migration of rainbow trout into and out of Soap Creek. The weir was operated from 22 March through 25 April 1984 when the it was severely damaged by high flows. Due to periodic high stream flow, the weir leads were removed on 11 days during the period of operation. Two hundred eighty rainbow trout were captured at the weir, 122 in the upstream trap and 158 in the downstream trap.

Upstream movement of rainbow trout was first documented on 24 March, but migration probably began prior to weir installation. Since the weir was operated for only 33 d, only a portion of the migrating rainbow trout were sampled. Movement of rainbow trout through the weir continued throughout the period of operation (25 April). The peak number of upstream migrants during weir operation occurred on 19 April. Upstream migration probably continued past the end of weir operation. Although a staff gage was installed at the weir site, it was dislodged by high flows before a stage-discharge relationship could be developed. Upstream movement did not appear to be related to changes in stream gage height (Figure 12).

The male:female sex ratio for upstream migrating Bighorn River rainbow trout captured at the Soap Creek weir was 1.0:1.8. Age was determined for 113 of the fish captured in the upstream weir and ranged from 2+ to 5+, with most fish being age 3+ (45.2%) and 4+ (47.8%) (Table 9). Age distribution was similar for males and females.

Age composition of spawning Bighorn River rainbow trout captured in Soap Creek was similar to that reported for tributary spawning runs

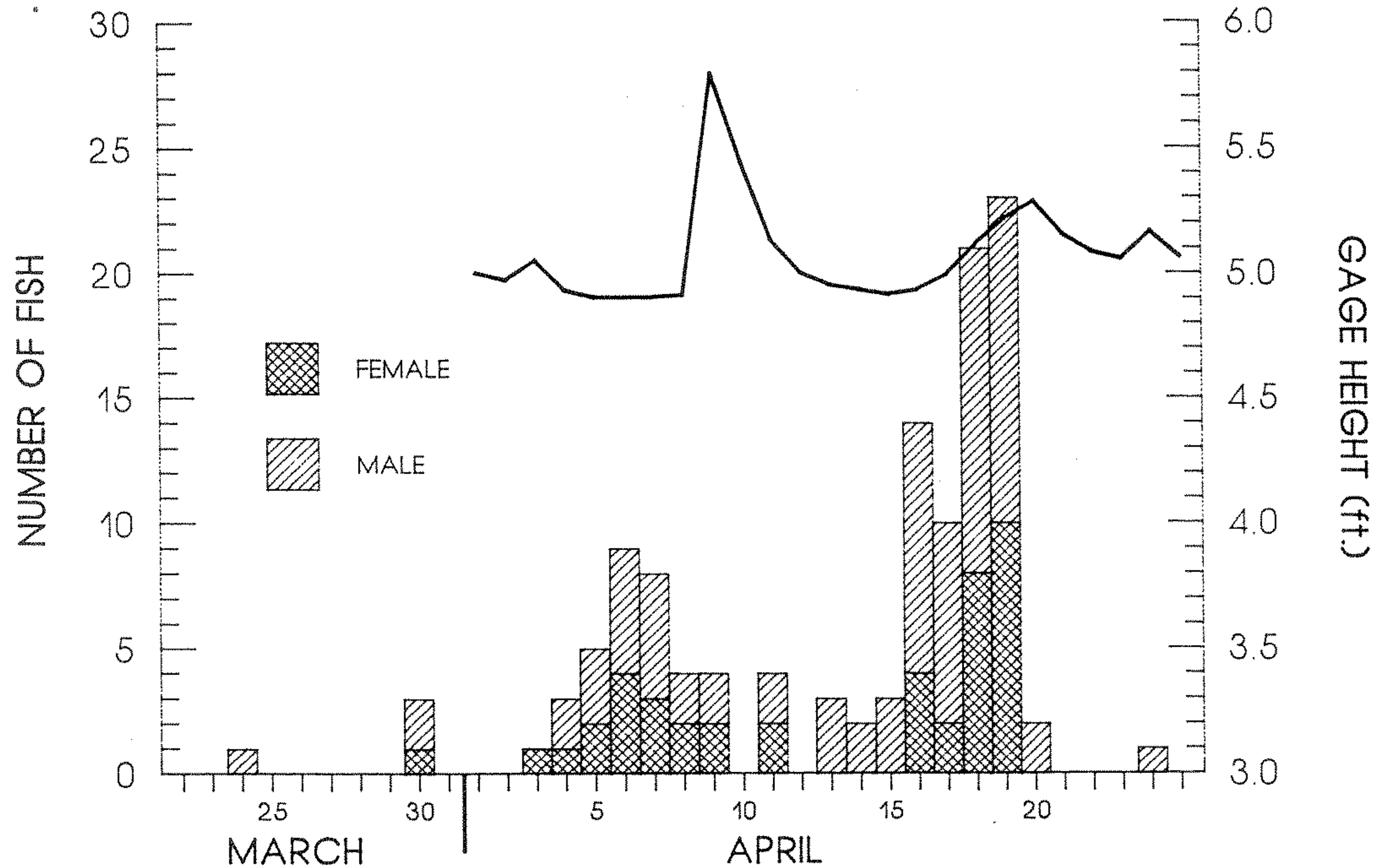

Figure 12. Temporal distribution and sex of Bighorn River migrant rainbow trout captured moving upstream in relation to staff gage height at the Soap Creek weir, 1984.

Age	Males N	Males (%)	Females N	Females (%)	Total N	Total (%)
2+	3	7.9	1	1.3	4	3.5
3+	15	39.5	36	48.0	51	45.2
4+	19	50.0	25	46.7	54	47.8
5+	1	2.6	3	4.0	4	3.5

in other Montana streams. Huston et al. (1984) reported rainbow trout spawning runs into the Tobacco River, a tributary to Lake Koocanusa, consisted primarily of age 3+ (51.2%) and 4+ (35.7) fish. Rainbow trout spawning runs into tributaries of the lower Flathead River were dominated by age 3+ and 4+ fish (DosSantos et al. 1988). Age 3+ and 4+ fish comprised 95% of migrant rainbow trout spawning in Mission and Post Creeks and 84% in Crow Creek. However, in the Jocko River the spawning run consisted of 84% age 4+ and 5+ rainbow trout.

Downstream migration of juvenile rainbow trout occurred throughout the period of weir operation. Age distribution of the 158 downstream migrants captured (Table 10) indicates that outmigration to the Bighorn River occurs primarily at age 1+ (58.9%) and 2+ (38.6%). Downstream migration appeared to be influenced by stream discharge, with larger numbers of fish migrating during periods of increased gage height (Figure 13). Outmigration of juvenile rainbow trout from tributaries

NUMBER OF FISH

Table 10. Age composition of downsteam migrating rainbow trout captured at the Soap Creek weir, 1984.

Age	N	Percent
1+	93	58.9
2+	61	38.6
3+	4	2.5

into Lake Koocanusa occurred at age 0+ (18.3%), 1+ (55.1%), and 2+ (26.6%) during the years 1979-1982 (Huston et al. 1984).

Gas Supersaturation Bioassay

Rainbow Trout Embryo Bioassay

Survival of embryos in incubation boxes in the Bighorn River varied between test groups, but did not appear to be influenced by dissolved gas levels. Hyperbaric pressure tended to increase during the incubation period (Figures 14 and 15). Mean ΔP was greater for tests 3 and 4, which were initiated later and extended to a later date, than tests 1 and 2. The test groups at the upstream bioassay site (1 and 3) were also exposed to consistently higher ΔPs than the test groups which ran concurrently (2 and 4) at a downstream site. Embryo survival to the eyed stage was highest for test 2 (74.3%) and lowest for test 4 (59.2%) (Table 11), which were both located at the downstream test site. Survival at the upstream sites was similar (test 1, 67.7% and test 2, 68.7%).

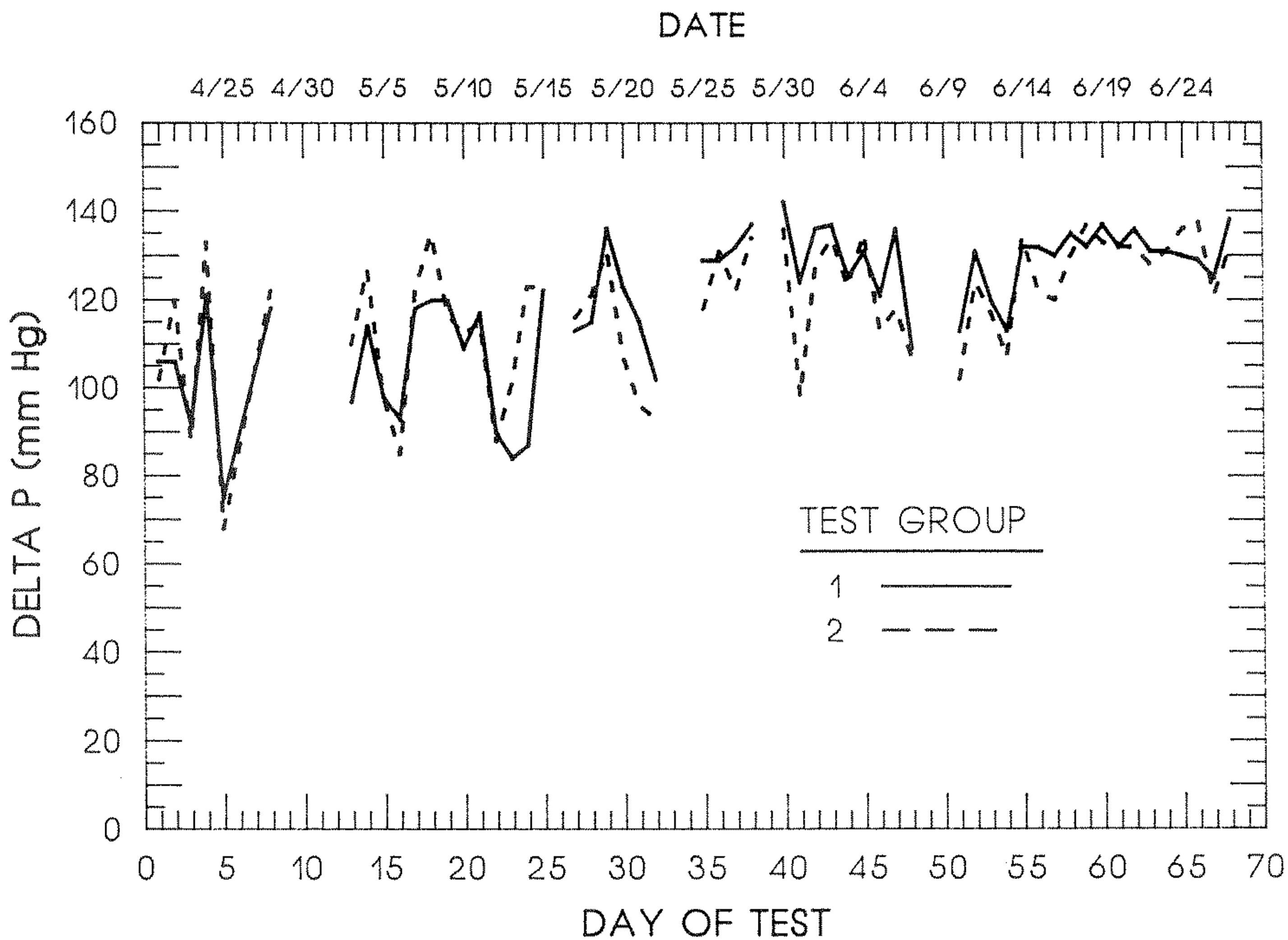

Figure 14. Daily delta P levels measured during rainbow trout embryo bioassay tests 1 and 2.

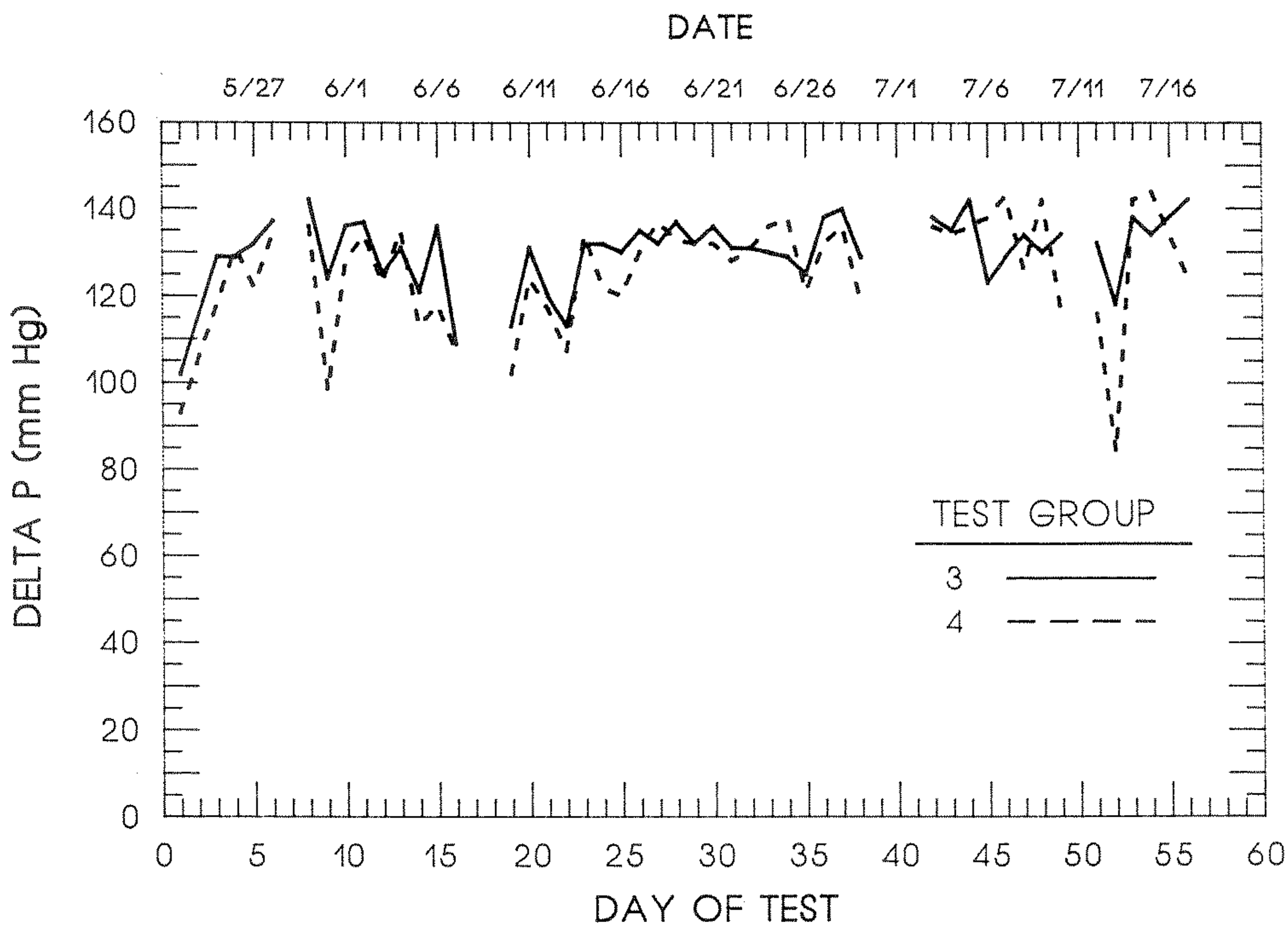

Figure 15. Daily delta P levels measured during rainbow trout embryo bioassay tests 3 and 4.

Table 11. Adjusted survival[1] of rainbow trout embryos for the four test groups of the embryo bioassay.

Test Group (N)	% Survival to eyed stage	% Survival to hatching[2]	Mean ▲P (range)	Mean $▲P-O_2$ (range)	Mean $▲P-N_2$ (range)
1 (937)	67.7	50.3	119.75 (75-142)	22.1 (8-56)	97.7 (53-116)
2 (981)	74.3	68.8	118.32 (68-138)	29.9 (12-76)	88.4 (46-109)
3 (513)	68.7	61.5	130.11 (102-142)	20.2 (8-29)	109.9 (94-120)
4 (494)	59.2	26.1	125.05 (93-138)	31.0 (12-38)	94.6 (78-109)

[1] Adjusted survival = observed survival/survival of control group x 100. Survival of control group was 71.1% for treatments 1A and 1B, and 86.2% for treatments 2A and 2B.

[2] Significantly different (X^2=208.7, 3 d.f., $p<0.001$)

Embryo survival to hatching followed a similar pattern, however there was a greater difference in survival between tests 1 (50.3%) and 3 (61.5%). Survival to hatching was 68.8% for test 2 and 26.1% for test 4. The low survival to hatching for test group 4 may be a result of relocating the incubation box after eye-up. Disturbance of eggs during transportation from Site 2 to Site 3 may have increased mortality.

Embryo survival differed significantly between tests (X^2 = 208.7, 3 d.f, $p<0.001$). However, differences in mean ▲P between test groups did not appear to influence embryo survival. Embryo survival was significantly greater ($p<0.05$) for test 2 compared to all other tests (Table 12) and mean ▲P for test 2 was significantly lower ($p<0.05$) than test 3, but did not differ significantly from tests 1 and 4 which had

Table 12. Comparison of embryo survival and ΔP for the four embryo survival test groups in the Bighorn River.

Embryo survival comparison[1]	ΔP comparison[2]
1 < 2 *	1 = 2
1 < 3 *	1 < 3 *
1 > 4 *	1 = 4
2 > 3 *	2 < 3 *
2 > 4 *	2 = 4
3 > 4 *	3 = 4

[1] - Chi-square test for independence.

[2] - Multiple comparison of means using Scheffe's test for comparison between groups.

* - Statistically different at alpha = 0.05.

the lowest embryo survival (Table 12). Test 1 embryo survival was significantly lower than test 3, but mean ΔP was also significantly lower. In contrast, embryo survival during test 4 was significantly less than tests 1 and 2, but there was not a significant difference in mean ΔP.

Siltation within the incubation boxes may have reduced survival of embryos in all test groups. High amounts of sediment were observed surrounding the eggs, which may have suffocated. The majority of dead eggs were located in the center area of the astro-turf substrate indicating that water velocities surrounding the eggs in the astro-turf substrate were not high enough to prevent deposition of fine sediment.

Fungal growth observed on dead eggs may also have spread to adjacent eggs and reduced survival.

Salmonid embryos appear to be resistant to high dissolved gas concentrations (Alderdice and Jensen 1985). The resistance of salmonid embryos to gas supersaturated water is due to the hydrostatic pressure maintained within the egg capsule, and the location of eggs at the bottom of the water column where maximum hydrostatic compensation occurs. Jensen (1988) found no effect on steelhead trout embryo survival for total gas pressures as high as 110% and Nebeker et al. (1978) found no mortality due to gas supersaturation at total dissolved gas levels up to 126.2%. White et al. (1986) found no effect of dissolved gas levels on survival of rainbow trout eggs incubated in the Bighorn River, using methods similar to this study, and exposed to mean ΔP up to 124 mm Hg. Conversely, Alderdice and Jensen (1985) hypothesized that salmonid eggs with internal pressures of 50-90 mm Hg could be subject to chronic gas bubble trauma in the range of 111-116% total gas pressure and subject to acute gas bubble trauma at total gas pressures of 117-122%. Rainbow trout embryos in this study were exposed to mean total gas pressures from 117-119%. However, this range of total dissolved gas levels did not appear to affect embryo survival.

Rainbow Trout Fry Bioassay

Survival of rainbow trout fry held in incubation boxes was lowest for test groups 1 and 2 (Table 13). Cumulative mortality for the 30 d test was 33.3% for test group 1 and 30.8% for test 2. Tests 3 and 4, which were initiated 7 d later, resulted in significantly lower fry

Table 13. Percent mortality, cumulative mortality, mean ▲P, mean ▲P-O_2, mean ▲P-N_2, and oxygen-nitrogen ratio after 5, 10, 15, 20, 25, and 30 d for rainbow trout fry test groups in the Bighorn River.

Test group	Day of test	Percent mortality	Cummulative mortality	Mean ▲P (± std. dev.)	Mean TGP% (± std. dev.)	Mean ▲P-O_2 (± std. dev.)	Mean ▲P-N_2[1] (± std. dev.)	O_2/N_2 Ratio
1	5	26.8	26.8	131.6 ± 7.0	119.5 ± 1.0	21.0 ± 5.8	110.6 ± 7.0	0.19
	10	4.6	31.4	130.5 ± 8.7	119.3 ± 1.2	17.5 ± 5.0	113.1 ± 4.5	0.15
	15	1.9	33.3	124.5 ± 18.3	118.3 ± 2.7	21.9 ± 6.0	102.6 ± 18.2	0.21
	20	0.0	33.3	110.0 ± 11.7	116.2 ± 1.8	22.9 ± 6.7	87.1 ± 7.3	0.26
	25	0.0	33.3	109.0 ± 5.6	116.0 ± 0.9	22.5 ± 8.4	86.5 ± 3.8	0.26
	30	0.0	33.3	122.8 ± 6.2	118.1 ± 0.9	21.6 ± 6.3	101.2 ± 2.6	0.21
	Mean			121.9 ± 13.0	118.0 ± 1.9	21.2 ± 5.9	100.7 ± 12.9	0.21
2	5	21.2	21.2	132.6 ± 12.4	119.6 ± 1.8	47.7 ± 13.0	84.9 ± 2.0	0.56
	10	6.5	27.8	114.8 ± 23.8	116.9 ± 3.5	31.9 ± 23.6	82.9 ± 1.9	0.38
	15	1.4	29.2	107.5 ± 38.1	115.8 ± 5.6	41.1 ± 30.4	66.4 ± 14.6	0.62
	20	0.0	29.2	98.2 ± 33.1	114.4 ± 4.9	46.7 ± 41.2	51.5 ± 12.0	0.91
	25	0.0	29.2	108.3 ± 35.2	116.0 ± 5.2	49.6 ± 39.9	58.8 ± 4.7	0.84
	30	1.6	30.8	102.0 ± 19.3	115.0 ± 2.8	41.5 ± 27.8	60.5 ± 9.1	0.69
	Mean			110.7 ± 27.4	116.3 ± 4.1	43.1 ± 27.6	67.6 ± 15.3	0.63
3	5	4.6	4.6	130.5 ± 8.7	119.3 ± 1.2	17.9 ± 5.4	112.6 ± 4.6	0.16
	10	0.0	4.6	121.2 ± 14.9	117.9 ± 2.2	24.3 ± 6.5	96.9 ± 15.6	0.25
	15	0.6	5.1	103.0 ± 7.0	115.1 ± 1.0	17.8 ± 5.8	85.2 ± 6.7	0.21
	20	0.6	5.7	119.3 ± 9.9	117.5 ± 1.4	26.9 ± 2.6	92.4 ± 9.4	0.29
	25	1.7	7.4	120.0 ± 5.6	117.7 ± 0.8	18.3 ± 5.8	101.8 ± 2.6	0.18
	30	0.6	7.9	-	-	-	-	
	Mean			118.9 ± 13.0	117.5 ± 1.9	21.3 ± 6.2	97.6 ± 12.8	0.22

Table 13. continued.

Test group	Day of test	Percent mortality	Cummulative mortality	Mean ▲P (± std. dev.)	Mean TGP% (± std. dev.)	Mean ▲P-O_2 (± std. dev.)	Mean ▲P-N_2[1] (± std. dev.)	O_2/N_2 Ratio
4	5	0.5	0.5	121.5 ± 28.1	117.9 ± 4.1	39.4 ± 28.2	82.1 ± 1.6	0.48
	10	2.6	3.1	103.8 ± 28.3	115.3 ± 4.2	44.3 ± 27.7	59.5 ± 9.5	0.74
	15	1.1	4.2	82.3 ± 33.4	112.0 ± 4.9	30.3 ± 47.7	52.0 ± 14.9	0.58
	20	1.1	5.3	122.5 ± 14.2	118.0 ± 2.1	67.4 ± 18.6	55.1 ± 6.4	1.22
	25	0.6	5.8	91.3 ± 15.9	113.4 ± 2.3	26.4 ± 21.2	65.0 ± 6.0	0.41
	30	0.0	5.8	-	-	-	-	
Mean				104.9 ± 28.1	115.4 ± 4.1	42.5 ± 30.9	62.4 ± 13.6	0.68

mortality rates (p=0.0001). Cumulative mortality for test group 3 was 7.9% and for test 4 was 5.8%. Mortality rate of rainbow trout fry was not significantly different for test groups run concurrently at separate locations in the river. Mortality rate of test group 1, located at the upstream site, did not differ significantly (p=0.3375) from test group 2 which was located at the downstream test site (Table 14). Likewise, test 3 (upstream site) mortality rate was not significantly different (p=0.3722) from test 4 (downstream site).

Delta P differed significantly between tests when compared collectively (F=2.87, p=0.041). However, multiple comparison of means showed no significant difference ($p<0.05$) in mean ΔP between tests. Measured ΔP fluctuated widely during all bioassays (Figures 16 and 17).

Table 14. Product limit survival estimate comparisons of rate of mortality for rainbow trout fry for the four field bioassay tests.

Mortality rate comparison	p-value
1 = 2	0.3375
1 > 3	0.0001*
1 > 4	0.0001*
2 > 3	0.0001*
2 > 4	0.0001*
3 = 4	0.3722

* - Statistically different at alpha = 0.05

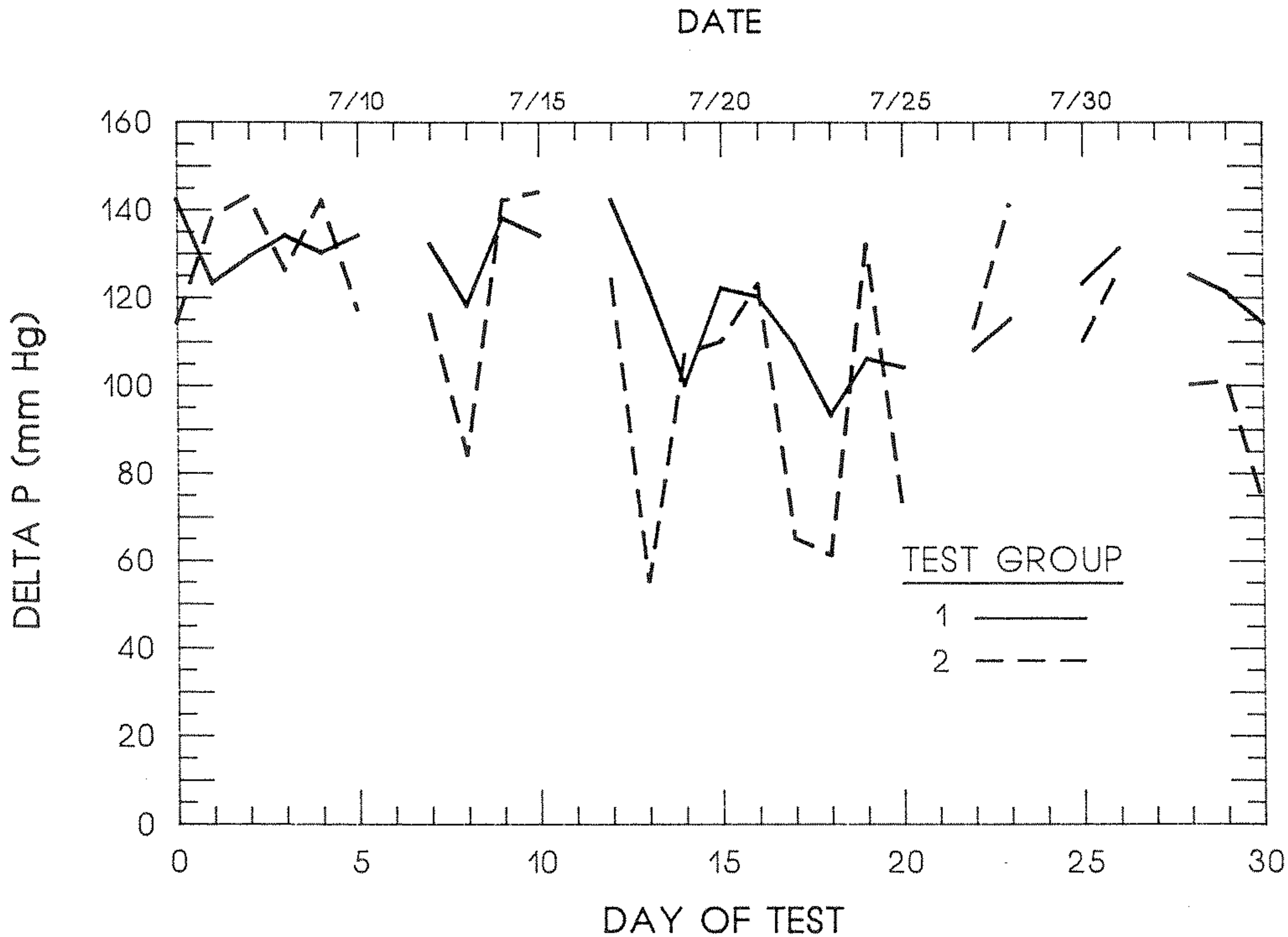

Figure 16. Daily delta P levels measured during rainbow trout fry bioassay tests 1 and 2.

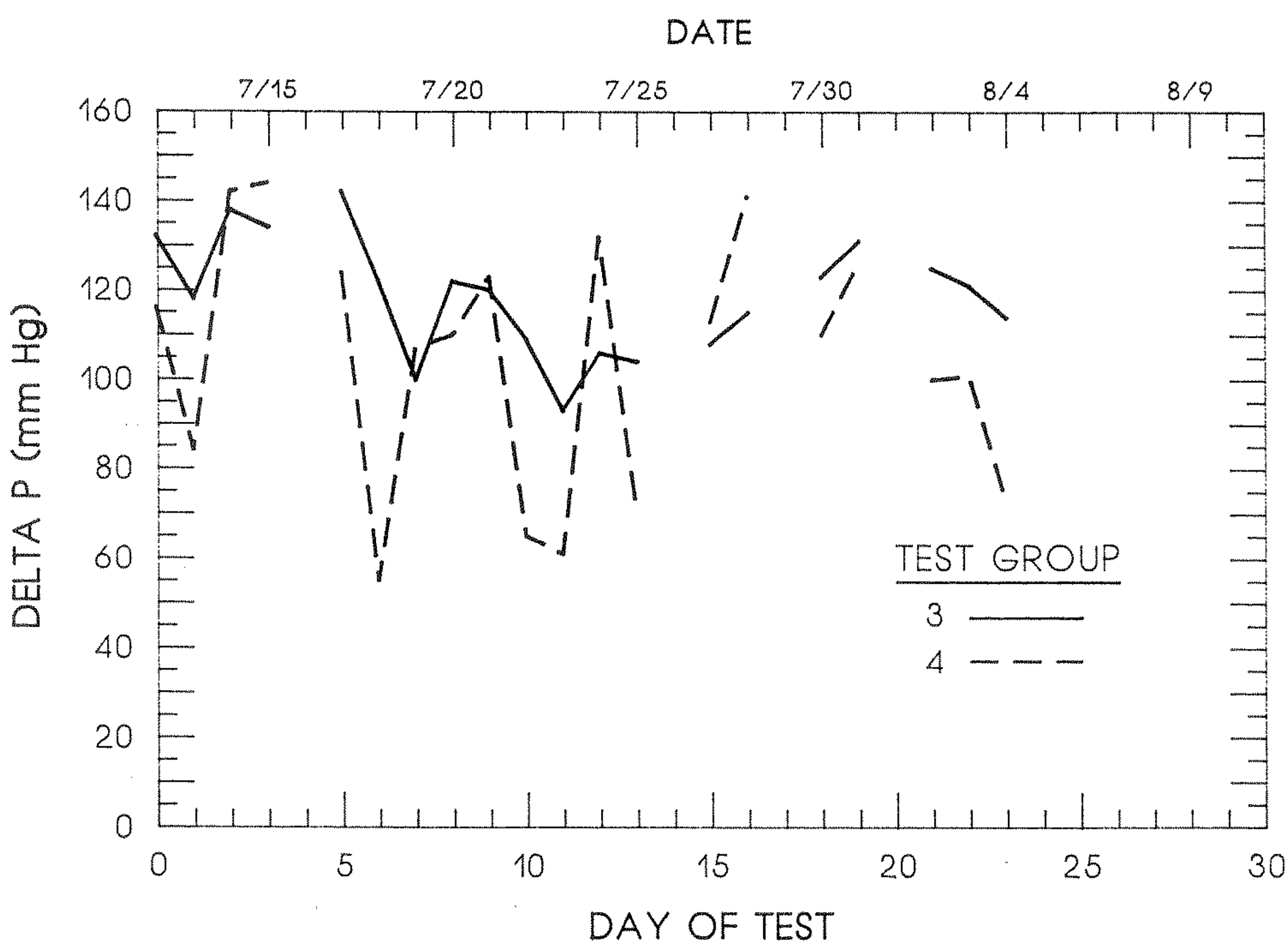

Figure 17. Daily Delta P levels measured during rainbow trout fry bioassay tests 3 and 4.

The finding of no significant difference in mean ΔP between tests is a result of the wide variation in ΔP readings during each test period. Daily ΔP readings at the downstream site (Site 3) fluctuated over a wider range and had lower minimum ΔP than the upstream site (Site 1). Delta P was higher at Site 3 on 10 of the 26 d sampled during the test period which is probably a result of high oxygen levels, as indicated by the higher O_2/N_2 ratio (Table 13).

Delta P readings during tests 3 and 4 were the same as for day 7 through 30 for tests 1 and 2, respectively, since tests were conducted at the same sites. Mortality of rainbow trout fry occurred mostly during the first 5 d of tests 1 and 2, 80.5% and 68.8% of total mortality, respectively (Figure 18). Mortality rate for test 1 from day 6 through day 30 did not differ significantly from test 3, day 1 through day 30 (p=0.9011). However, mortality rate during test 2 was significantly greater than test 4 using the same comparison (p=0.0325). Mean ΔP was not different during the first 5 d of test 1 and test 3 (131.6 ± 7.0, n=5; vs 130.5 ± 8.7, n=4; t=0.14, 7 d.f., p>0.25) or during the first 5 d of test 2 and test 4 (132.6 ± 12.4, n=5; vs 121.5 ± 28.1, n=4; t=0.54, p>0.25). The high rate of fry mortality during the first 5 d of tests 1 and 2 may be a result of other dissolved gas interactions not measured during the study.

The effects of elevated dissolved gas levels on survival of rainbow trout fry were not clearly established during this study. Although mean ΔP varied from 104.9 to 121.9 between tests, the fluctuating ΔP values and component levels of oxygen and nitrogen which

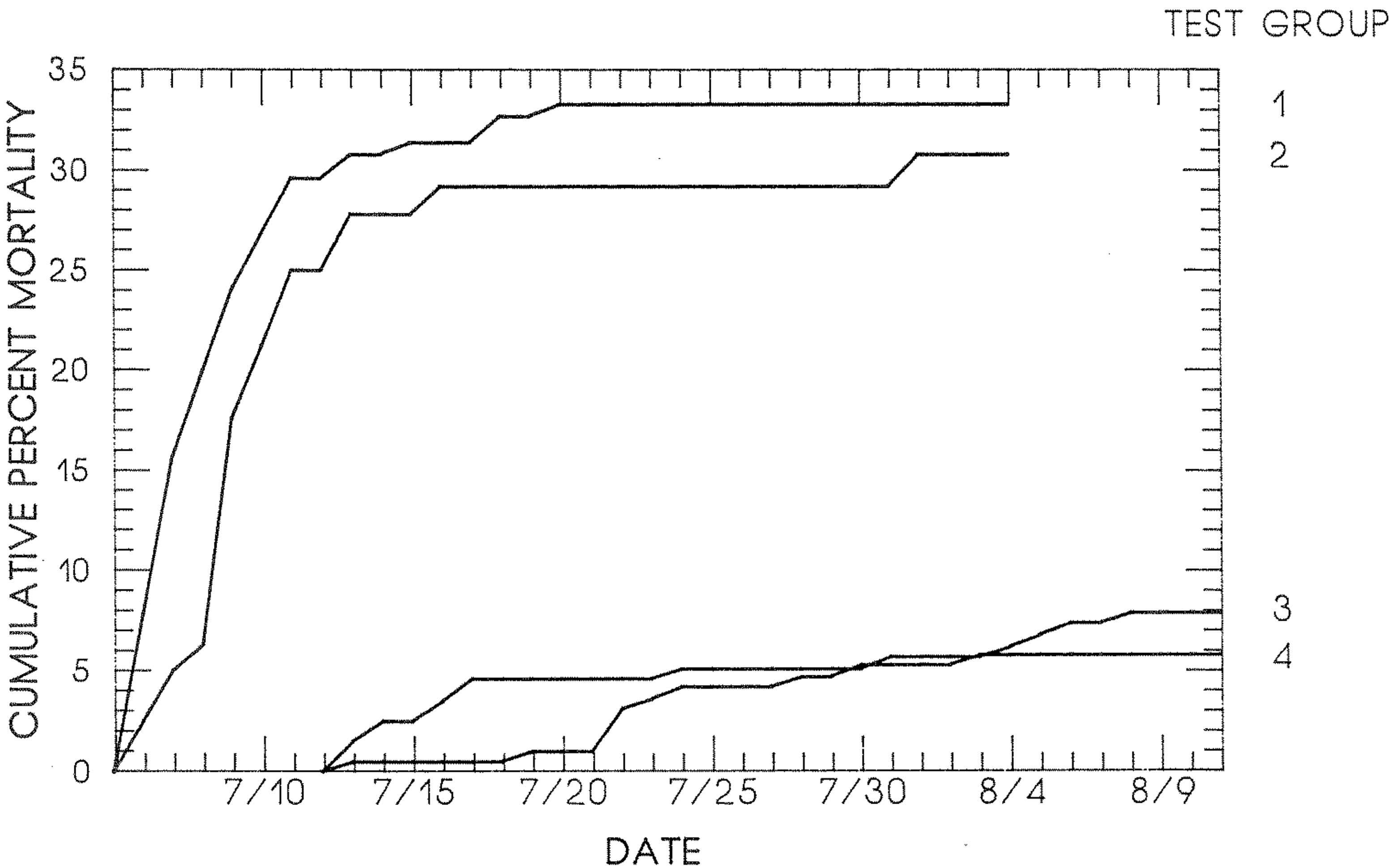

Figure 18. Percent cummulative mortality of rainbow trout fry during bioassay tests 1, 2, 3, and 4.

occurred in the Bighorn River did not allow enough differentiation between test sites. Most studies which have evaluated effects of high dissolved gas levels on survival of rainbow trout or steelhead fry (Nebeker et al. 1978, Jensen 1988, White et al. 1987) were conducted under controlled laboratory conditions and allowed for exposure to relatively constant levels of dissolved gas. Once-daily measurements of ΔP and dissolved oxygen are probably insufficient to quantify the diel fluctuations occurring in a natural river system.

Salmonid fry soon after hatching appear to be relatively tolerant of elevated dissolved gas levels, but tolerance decreases with size (Weitkamp and Katz 1980). Nebeker et al. (1978) reported few effects of total gas pressures as high as 126% to steelhead fry prior to the swim-up stage, but mortality occurred rapidly thereafter. They suggested that rapid growth and development of the gills at this stage may account for the lower observed tolerance. Tolerance of juvenile rainbow trout decreased with size when exposed to mean ΔP of 155 - 166 mm Hg (total gas pressure 124.9 - 125.4%) (White et al. 1987).

Mortality of rainbow trout fry in this study was within the range reported for rainbow trout and steelhead in other studies with similar dissolved gas levels. Mortality of steelhead fry exposed to total gas pressure of 115.3% from hatching to 55 d posthatch was 45% (Nebeker at al. 1978). Mortality was 33.3% and 30.8% for tests 1 and 2 from approximately 7 - 37 d posthatch during this study, and mean total gas pressure was 117.97 and 116.32, respectively. Test groups 1 and 2 were exposed to elevated gas pressure from hatching, and mortality of fry was known to occur between hatching and initiation of the tests. White et al. (1986) reported 10.4% mortality of rainbow trout fry in the Bighorn River exposed to mean ΔP of 99 - 127 mm Hg and 5.0% mortality for fry exposed to mean ΔP of 94 - 123 mm Hg. In laboratory tests, the same authors reported mortality of small rainbow trout fry (34.0 mm) was less than 10% when exposed to mean ΔP of 155.0 mm Hg for 29 days (White et al. 1987).

SUMMARY

Rainbow trout spawn in the Bighorn River from early April through mid June. Onset of spawning appeared to be related to an increase in water temperature following an extended period of constant low temperature. Rainbow trout spawned throughout the study section, although most spawning occurred within 9.0 km of Afterbay Dam. Most spawning occurred in side channel areas. Eight high-use (30 or more redds) spawning areas were located, of which six were within 6.1 km of Afterbay Dam.

Physical and hydraulic characteristics of rainbow trout redds in the Bighorn River were comparable to other streams of similar size. Substrate size composition sampled in three spawning areas were suitable for successful incubation and emergence of embryos. Survival of rainbow trout embryos decreased with distance downstream (29.7% Rkm 2.2, 23.3% Rkm 4.2, 17.0% Rkm 9.0). However, differences in embryo survival between areas was not significant.

Soap Creek was used extensively for spawning by Bighorn River rainbow trout. Spawning occurred in the section of stream between 28.0 and 43.5 km above the mouth. The downstream limit of spawning was due to lack of adequate habitat. This section of stream is deeply entrenched, has low gradient, low water velocities, and few riffles. Upstream extent of spawning was limited by beaver dams which blocked fish passage. However, habitat appeared to be suitable upstream of these beaver dams. The amount of fine sediment (<0.85 mm) in spawning areas sampled increased with distance downstream. Survival to emergence of rainbow trout embryos was 33.3 and 59.2% at the two most upstream spawning areas. These areas were located above the mouth of Dry Soap Creek, which enters Soap Creek 37.0 km above the Bighorn River. No test embryo survived in two spawning areas below the mouth of Dry Soap Creek.

Bighorn River rainbow trout migrating upstream to spawn in Soap Creek ranged from 2 to 5 years old, with most fish being age 3 (45.2%) and 4 (47.8%). The male:female sex ratio of spawning fish captured at the Soap Creek weir was 1.0:1.8. Drift nets fished for 136 d failed to catch any young-of-year rainbow trout migrating downstream. Downstream migrating juvenile rainbow trout captured at the Soap Creek weir were age 1 (58.9%), 2 (38.6%), and 3 (2.5%).

Embryo survival in field bioassays differed significantly between the 4 test groups, but survival was not related to dissolved gas levels during tests. Survival of embryos ranged from 26.1 - 68.8% during the 4 tests and mean ΔP ranged from 118.3 - 130.1 mm Hg. Mortality of embryos during tests was attributed to siltation which occurred in the incubation boxes.

The effects of dissolved gas levels on survival of rainbow trout fry was not clearly established during the study. Mortality rate of fry during field bioassay tests 1 and 2 differed significantly from tests 3 and 4. Tests 3 and 4 were initiated 7 d later and at the same sites as tests 1 and 2. Total mortality was 33.3% for test 1 (mean ΔP

121.9±13.0) and 30.8% for test 2 (mean ΔP 110.7±27.4). Mortality of fry was 7.9% for test 3 (mean ΔP 118.9±13.0) and 5.8% for test 4 (mean ΔP 104.9±28.1). Mean ΔP did not differ significantly between the four tests due to wide variations in daily ΔP which occurred in the river. Fluctuating ΔP and component levels of oxygen and nitrogen which occurred in the Bighorn River did not allow adequate differentiation between test sites. The difference in mortality between tests 1 and 2 and tests 3 and 4 may be due to dissolved gas interactions not measured during the study.

Suitable spawning habitat and incubation conditions are present in the Bighorn River and Soap Creek for successful natural reproduction of rainbow trout. During 1983 and 1984 there appeared to be sufficient spawning activity in the study area for successful recruitment into the population. However, successful recruitment into the adult population is also dependent on survival of fry following emergence. The results of the field bioassay on rainbow trout fry indicate that dissolved gas levels which occurred in 1984 may have affected the survival of rainbow trout fry which emerged prior to 12 July. This corresponds to egg fertilization and deposition date of approximately 20 May. Most rainbow trout spawning in the Bighorn River occurred prior to this date, 70% of spawning was completed by 20 May in 1983. This suggests that fry of rainbow trout which spawned early in the spawning season may be more susceptible to mortality from ambient dissolved gas levels in the Bighorn River.

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