# HABITAT USE BY ADULT BROWN TROUT AND RAINBOW TROUT IN RESPONSE TO GAS SUPERSATURATION DOWNSTREAM OF THE YELLOWTAIL AFTERBAY DAM, BIGHORN RIVER, MONTANA

by

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# APPROVAL

of a thesis submitted by

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# VITA

Thomas Herbert Williams III, son of Thomas and Sandra Williams, was born in La Mesa, California, 27 July, 1961. He graduated from Serra High School, San Diego, California, in June 1980. In September 1980 he entered Humboldt State University, Arcata, California, and received a Bachelor of Science degree in Fisheries Biology in March 1985. He began graduate studies at Montana State University in January 1986.

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# ABSTRACT

High levels of gas supersaturation did not have a detectable influence on the distribution of brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* in the Bighorn River downstream of Yellowtail Afterbay Dam. Snorkel surveys indicated that trout were concentrated along river banks during winter and spring and used bank and midchannel areas during summer and fall. Although gas levels remained high, the percentage of trout exhibiting external symptoms of gas bubble trauma decreased during periods of midchannel use. Seasonal trout movement appeared to be related to changes in availability of energetically suitable habitat created by aquatic vegetation. I hypothesize that vegetation in midchannel areas created usable habitat with adequate depth to provide hydrostatic compensation, reducing the incidence of gas bubble trauma. Radio telemetry data collected during gas supersaturation manipulation tests (delta P values 63 mmHg to 123 mmHg) indicated that adult brown trout and rainbow trout did not actively avoid high dissolved gas levels. Trout movements were restricted to localized areas and sounding by trout as an avoidance behavior was not detected by pressure sensitive radio transmitters.

# INTRODUCTION

Gas bubble trauma (GBT) is a physically induced condition caused by supersaturation of dissolved gases that often occurs in fish living below dams. Plunging water entrains atmospheric gases and forces them to a depth where water becomes supersaturated (Bouck 1980). Bouck (1980) describes GBT as "a noninfectious process caused by uncompensated, hyperbaric total dissolved gas pressure, that produces primary lesions in blood (emboli) and in tissues (emphysema) and subsequent physiological dysfunctions." Much of the information available on dissolved gas supersaturation and GBT is related to problems associated with Columbia River hydroelectric dams (Weitkamp and Katz 1980). In most cases, existing spillways and stilling basins have been modified to reduce supersaturation (Crunkilton et al. 1980). Recent literature reviews by Weitkamp and Katz (1980) and Colt et al. (1986) describe the history and sources of GBT in fishes.

Detection and avoidance of supersaturated water by fish may influence their survival in waters that contain high levels of dissolved gases (Jenson et al. 1986). Avoidance can occur by fish sounding or moving away from supersaturated water (Stevens et al. 1980). Change in hydrostatic pressure associated with an increase in water depth of 1 m reduces gas saturation by approximately 10% (Gray and Haynes 1977). Most studies of detection, avoidance, and tolerance of supersaturated waters by salmonids have been conducted with juvenile fish.

Weitkamp and Katz (1980) state that it is generally accepted that fish are not able to detect supersaturated water and therefore do not avoid it, although there appear to be exceptions. Lund and Heggberget (1985) found that 2-year-old rainbow trout

(*Oncorhynchus mykiss*) did not avoid 115 to 125% supersaturated water in tank experiments. An apparent avoidance of high dissolved gas levels by squawfish (*Ptychocheilus oregonenis*) below Little Goose Dam on the Snake River was described by Bentley et al. (1976). They collected fewer squawfish during periods of high supersaturation than during periods of lower supersaturation. Stickney (1968) found that Atlantic herring (*Clupea harengus harengus*) avoided gas supersaturated water when dissolved gas levels were high enough to produce GBT (122% TGP). Dawley et al. (1976) reported that juvenile chinook salmon ( *Oncorhynchus tschawytscha*) and steelhead trout (*Oncorhynchus mykiss*) apparently avoided high dissolved gas levels by using deeper water that provided hydrostatic compensation. Both species were found at deeper average depths as gas concentrations increased in deep (2.4 m) tank experiments. Stevens et al. (1980) found that rainbow trout (30 to 45 g) moved laterally to avoid supersaturated water in tank experiments. Heggberget (1984) found that brown trout (*Salmo trutta*) were less tolerant to supersaturated water than were perch (*Perca fluviatilis*) and eel (*Anguilla anguilla*) in river cage studies.

Because of its relatively small size compared to other western hydroelectric projects where gas supersaturation problems exist (e.g., the Columbia River), the Bighorn River downstream of Yellowtail Afterbay Dam, Montana, provided a unique opportunity to examine the relationships between gas supersaturation and fish behavior. Gas bubble trauma was first documented in the Bighorn River downstream of Yellowtail Afterbay Dam in 1973 (Swedberg 1973). Deflector plates where installed in 1982 to reduce supersaturation, but were removed in 1983 due to turbulence that threatened to erode the base of the dam.

The Bighorn River supports a major trout sport fishery. Angler use days were estimated to be 17,737 in 1987 and 15,548 in 1988 on the upper 19.3 km of river (J.

Darling, personal communication). Trout population estimates for 1987 in the upper 6.1 km of river were over 6000 trout/km (April and September estimates), with brown trout outnumbering rainbow trout approximately 10 to 1 (White et al. 1988). Incidence of GBT in the Bighorn River appears to be higher in brown trout than in rainbow trout, and highest in brown trout longer than 356 mm (White et al. 1988). Reasons for these differences in incidence of GBT are not known, but could be related to differences in habitat selection between brown trout and rainbow trout and among different size or age classes. Differences in habitat selection that expose a particular species or age class to high gas supersaturation may also influence relative abundance of these species by causing a differential mortality. The objectives of this study were to conduct *in situ* observations of trout behavioral distribution in the Bighorn River to determine: 1) whether differences in incidence of GBT between brown trout and rainbow trout can be explained by habitat use, 2) whether habitat used by different length groups of trout results in differences in exposure to GBT between length groups, and 3) whether brown trout and rainbow trout avoid high dissolved gas levels. Field observations were conducted between June 1986 and December 1988.

# DESCRIPTION OF STUDY AREA

Yellowtail and Afterbay Dams are located in south-central Montana on the Bighorn River approximately 69 km southeast of Billings, Montana (Figure 1). The Yellowtail/Afterbay facility was constructed from 1963-1966 (WPRS 1980). The principal uses of the Yellowtail facility include irrigation, power generation, flood control, and fish and wildlife enhancement. Yellowtail Dam is a thin-arch concrete structure with a height of 160 m and a crest length of 442 m. A 250 MW peaking plant is located at its base. Afterbay Dam is a reregulating facility located 3.5 km downstream of Yellowtail Dam. The height of Afterbay Dam is 22 m, crest length is 414.5 m, and crest elevation is 956 m. The spillway has a discharge capacity of 566.4 $m^3/s$, and is 49.4 m wide; flows are controlled by five 9.1 m x 4.1 m radial gates and by a 10.4 m wide sluiceway. The sluiceway discharge is adjusted by three 3 m x 2.4 m vertical slide gates. The height from the streambed to the maximum controlled water surface is 16.1 m; the sluiceway gates can release water 6.9 m lower than the radial gates. Flow is continually adjusted, usually by the automated sluiceway slide gates, to maintain a relatively uniform flow to the river. Mean daily discharge from Afterbay Dam was 73.97 $m^3/s$ (range: 49.56 $m^3/s$ - 113.28 $m^3/s$) in 1987 and 58.37 $m^3/s$ (40.44 $m^3/s$ - 84.79 $m^3/s$) in 1988. High dissolved gas levels result from gas entrainment when water passes through gates in the Afterbay Dam, particularly the sluiceway gates.

The study area extended approximately 4.8 km downstream of Afterbay Dam (Figure 1). River gradient is approximately 1.9 m per river kilometer (Stevenson 1975) and the channel has a relatively uniform rectangular shape, with several islands. River

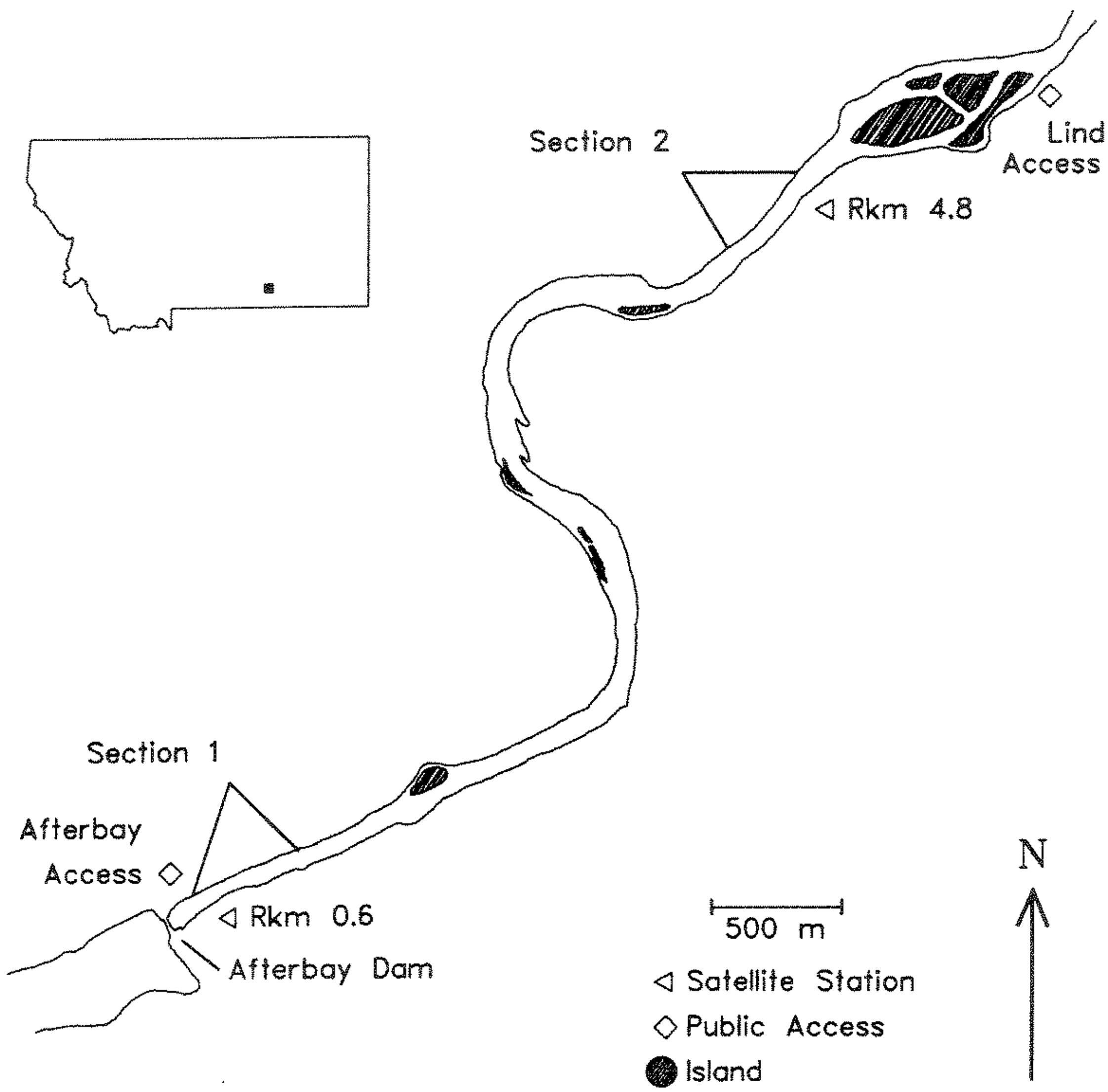


Figure 1. Bighorn River study area downstream of Afterbay Dam showing sections for micro- and macrohabitat study, satellite stations, and public access.

width was approximately 80 m throughout the study area, and midchannel water depth was approximately 1.80 m. Channel substrate was homogeneous throughout the study area, dominated by large (256 mm -128 mm) and small cobble (128 mm - 64 mm). Areas with low velocities were characterized by gravel less than 20 mm in diameter.

Two, 400 m long sections were established to observe trout macro- and microhabitat use in relation to stream habitat characteristics such as water depth, focal point velocity, distance to bank, side of river, substrate, depth of vegetation, discharge, cover, dissolved gases, and water temperature (Figure 1). Locations were designated in relationship to distance downstream (river kilometer: Rkm) from the Afterbay Dam. Section 1 extended from Rkm 0.5 to 0.9. High nitrogen saturation and high delta P levels (delta P: difference between total gas pressure and barometric pressure) were typical for this area (Table 1). A slight gradient of decreasing gas levels from the right to left bank occurred (right and left when facing downstream; White et al. 1988) to operation of the sluiceway, located at the right side of Afterbay Dam. Section 2, located at Rkm 4.5 to 4.9, had lower nitrogen levels, and higher oxygen levels than section 1. Section 2 had lower delta P levels in 1987 and higher levels in 1988 than section 1. Incidence of GBT in brown trout was higher in section 1 than in section 2 (Tables 2-5). Incidence of GBT in rainbow trout was higher in section 2 than in section 1.

The river floodplain is dominated by cottonwood (*Populus* sp.). The riparian vegetation is dominated by willow (*Salix* sp.), salt ceder (*Tamarix chinensis*), snowberry (*Symphoricarpos occidentalis*), cattails (*Typha latifolia* and *T. angustilfolia*), box elder (*Acer glabrum*), and wild rose (*Rosa woodsii* and *R. sayi*) (Knight 1987). Aquatic vegetation, dominated by horned pond weed (*Zannichellia palustris*) and a moss (*Fontinalis hypnoides*) was dense from late spring through early fall of the study period.

Table 1. Means and ranges of water temperature, barometric, delta P, oxygen, and calculated nitrogen pressures (mmHg) at Rkm 0.6 and 4.8 on the Bighorn River below Afterbay Dam, 1987 and 1988 (White et al. 1988).

| River km | Temperature (C) | Barometric (mmHg) | Delta P (mmHg) | O (mmHg) | N + Ar (mmHg) |
|---|---|---|---|---|---|
| | | | **1987** | | |
| 0.6 | 7.6<br>(2.2 - 15.6) | 680<br>(667 - 691) | 111<br>(63 - 153) | 152<br>(134 - 167) | 630<br>(590 - 664) |
| 4.8 | 9.6<br>(2.8 - 17.2) | 680<br>(665 - 691) | 107<br>(46 - 188) | 193<br>(145 - 277) | 584<br>(522 - 647) |
| | | | **1988** | | |
| 0.6 | 5.9<br>(2.8 - 13.1) | 676<br>(658 - 692) | 109<br>(65 - 140) | 158<br>(139 - 169) | 622<br>(580 - 648) |
| 4.8 | 8.4<br>(3.9 - 13.6) | 676<br>(661 - 684) | 122<br>(63 - 169) | 203<br>(163 - 257) | 587<br>(534 - 623) |

Table 2. Incidence of gas bubble trauma (GBT) in brown trout from Rkm 0.0 - 1.9, total gas pressure (TGP) from satellite station Rkm 0.6, Bighorn River, Montana, 1987 (White et al. 1988).

| Date | TGP (mmHg) | All brown trout | | Brown trout ≥ 356 mm | |
|---|---|---|---|---|---|
| | | No. caught | % w/GBT | No. caught | % w/GBT |
| 4 February | 780 | 168 | 30 | 44 | 55 |
| 24 March | 790 | 166 | 36 | 27 | 70 |
| 14 April | 760 | 338 | 30 | 54 | 56 |
| 28 April | 760 | 453 | 30 | 76 | 70 |
| 28 May | 800 | 161 | 45 | 32 | 88 |
| 23 July | 775 | 159 | 44 | 32 | 75 |
| 1 September | 760 | 151 | 23 | 49 | 43 |
| 15 September | 740 | 339 | 5 | 94 | 6 |
| 29 September | 755 | 355 | 3 | 98 | 1 |
| 11 November | 815 | 170 | 8 | 63 | 10 |
| 29 December | 760 | 159 | 31 | 51 | 47 |

Table 3. Incidence of gas bubble trauma (GBT) in rainbow trout from Rkm 0.0 - 1.9, total gas pressure (TGP) from satellite station Rkm 0.6, Bighorn River, Montana, 1987 (White et al. 1988).

| Date | TGP (mmHg) | All rainbow trout | | Rainbow trout ≥ 356 mm | |
|---|---|---|---|---|---|
| | | No. caught | % w/GBT | No. caught | % w/GBT |
| 4 February | 780 | 26 | 8 | 2 | 0 |
| 24 March | 790 | 64 | 5 | 9 | 11 |
| 16 April | 795 | 222 | 7 | 91 | 12 |
| 30 April | 750 | 276 | 8 | 102 | 17 |
| 28 May | 800 | 39 | 10 | 20 | 20 |
| 23 July | 775 | 30 | 17 | 13 | 31 |
| 1 September | 760 | 27 | 7 | 15 | 13 |
| 17 September | 760 | 159 | 1 | 75 | 0 |
| 30 September | 750 | 140 | 1 | 60 | 2 |
| 11 November | 805 | 29 | 0 | 7 | 0 |
| 29 December | 760 | 22 | 18 | 10 | 40 |

Table 4. Incidence of gas bubble trauma (GBT) in brown trout from Rkm 3.9 - 6.1, total gas pressure (TGP) from satellite Rkm 4.8, Bighorn River, Montana, 1987 (White et al. 1988).

| Date | TGP (mmHg) | All brown trout | | Brown trout ≥ 356 mm | |
|---|---|---|---|---|---|
| | | No. caught | % w/GBT | No. caught | % w/GBT |
| 3 February | 755 | 157 | 6 | 52 | 10 |
| 24 March | 770 | 151 | 8 | 68 | 15 |
| 14 April | 780 | 196 | 17 | 91 | 25 |
| 28 April | 790 | 177 | 16 | 97 | 23 |
| 2 June | 830 | 169 | 19 | 66 | 33 |
| 23 July | 800 | 180 | 23 | 71 | 48 |
| 1 September | 755 | 159 | 1 | 97 | 1 |
| 17 September | 760 | 160 | 0 | 101 | 0 |
| 28 September | 770 | 224 | 1 | 137 | 0 |
| 11 November | 770 | 159 | 2 | 72 | 0 |

Table 5. Incidence of gas bubble trauma (GBT) in rainbow trout from Rkm 3.9 - 6.1, total gas pressure (TGP) from satellite station Rkm 4.8, Bighorn River, Montana, 1987 (White et al. 1988).

| Date | TGP (mmHg) | All rainbow trout | | Rainbow trout ≥ 356 mm | |
|---|---|---|---|---|---|
| | | No. caught | % w/GBT | No. caught | % w/GBT |
| 3 February | 775 | 18 | 11 | 6 | 33 |
| 24 March | 770 | 14 | 0 | 8 | 0 |
| 16 April | 760 | 109 | 17 | 77 | 22 |
| 30 April | 830 | 156 | 17 | 130 | 21 |
| 2 June | 830 | 12 | 33 | 8 | 50 |
| 23 July | 800 | 8 | 0 | 0 | 0 |
| 1 September | 755 | 6 | 0 | 2 | 0 |
| 18 September | 755 | 46 | 0 | 17 | 0 |
| 30 September | 760 | 30 | 0 | 12 | 0 |
| 11 November | 770 | 12 | 0 | 6 | 0 |

# METHODS

## Water Quality Parameters

Continuous recording water quality monitoring stations at Rkm 0.6 and Rkm 4.8 consisted of a Common Sensing tensionometer (model TBO-F at Rkm 0.6 and TGO-F at Rkm 4.8) and a Hydrolab system 8000 at each site. Tensionometers measured water temperature, total gas, oxygen, and nitrogen pressures. Model TBO-F at Rkm 0.6 also measured barometric pressure. Water temperature, dissolved oxygen, pH, conductivity and oxidation-reduction potential were measured by the Hydrolab monitors. Tensionometers and Hydrolab monitors were interfaced with a Sutron satellite system which relayed measurements taken every 30 min to an earth station in Boise, Idaho, and a computer in Billings, Montana. Calibration of equipment followed the manufacturer's recommended procedures. Accuracy was assessed by comparing meter readings with water temperatures from a mercury thermometer, dissolved oxygen concentration determined from a Winkler titration (APHA 1976) and total gas pressure from a Bouck gasometer (Bouck 1982).

## Macrohabitat

To contrast fish distribution in shallow near bank areas with deeper midchannel areas, three 400 m long snorkel lanes (left, middle, and right) were monitored from late May to October in 1987 and January to November in 1988 in both study sections. Snorkel lanes along the left and right banks were surveyed while maintaining a distance of approximately 9 m from shore and counting trout between myself and the bank. Middle lane surveys were conducted while maintaining a midchannel position and counting trout visible in a forward direction. Middle lane water depths were greater than 1.75 m. Water velocities 0.5 m above the stream bottom in the middle lanes during periods without aquatic vegetation where approximately 2.2 to 2.6 m/s. Lanes were swum moving downstream counting the total numbers of brown trout and rainbow trout and the numbers of each species >36 cm total length (TL). Data were recorded on underwater slates. All counts were made during daylight hours between 0900 and 1700 (MDT). Above-water light levels were measured using a Li-Cor integrating quantum/radiometer/photometer.

**Microhabitat**

To examine possible differences between brown trout and rainbow trout habitat use in relation to physical habitat and water quality conditions, individual trout were located while snorkeling, and microhabitat variables were recorded. All microhabitat data were collected within the two snorkel sections used for macrohabitat studies. Microhabitat use was analyzed for three time periods (June, July, September - October) to determine if time-related changes in habitat use existed.

Locations of individual trout observed using mask and snorkel were marked with a weight attached to a line and float. I entered the stream at the upstream end of a section and floated downstream until a trout was located. Since I was drifting with the current, trout position had to be determined rapidly before trout moved due to my presence. Only trout that were initially observed maintaining a relatively constant position were used. The weight was placed directly below the fish position (the location trout was first observed was marked with a weight attached to a line and float) and the float number was recorded. Several trout positions were marked before taking measurements. Habitat measurements were recorded on an underwater slate. Fish habitat parameters included: 1) water depth, 2) fish depth (distance from fish to substrate, estimated), 3) velocity at focal point of fish, 4) size of fish (estimated), 5) species, 6) signs of GBT, 7) distance to bank (0-3 m, 3-9 m, 9+ m, estimated), 8) side of river, 9) substrate (fines <0.2 cm, gravel 0.2-6.4 cm, cobble 6.42-24.99 cm, boulder >24.99 cm), 10) height of vegetation at the location of the marking weight, 11) surface light, 12) cover type within 0.5 m from the focal point (substrate, vegetation, and bank associated, i.e. overhanging vegetation, fences, undercut banks). Water depth, fish depth, and vegetation height were measured to the nearest 0.03 m with a metal measuring rod. Focal point velocity was measured at the estimated fish depth with an electromagnetic current meter (Marsh/McBirney model 201). Discharge, dissolved gases, and water temperature data were obtained from satellite stations. Air temperature was measured with a mercury thermometer.

Plywood cutouts of various sizes in the shape of trout were used to practice underwater estimation of trout size. Accuracy of length estimates was typically within 2.54 cm of actual length. Trout observed for microhabitat measurements were estimated to the nearest 2.54 cm and divided into three size groups (<15 cm, 15 - 40 cm, and >40 cm TL) for data analysis.

**Radio Telemetry**

Pressure sensitive radio transmitters (PSRTs) were implanted in four brown trout and four rainbow trout in 1987 and in two brown trout and one rainbow trout in 1988. Six brown trout and four rainbow trout were implanted with location transmitters in

1987. Transmitters were designed and built by Custom Telemetry and Consulting (CTC), Athens, Georgia. Pressure sensitive transmitters were temperature compensating. Transmitter frequencies were individually identifiable and were in the 30 MHz range in order to operate in the highly conductive (mean: 737 micromhos/cm; Appendix A) Bighorn River water. The eight PSRTs used in 1987 were cylindrical in shape with a mean length of 70.9 mm, a mean diameter of 20.3 mm, and an average weight of 9.6 g in water (Table 6). The three PSRTs used in 1988 were similar in shape to those used in 1987, but mean diameter was 14.0 mm and average weight was 6.3 g in water (Table 7). Lithium batteries used in the 1987 PSRTs were replaced by silver batteries in the 1988 PSRTs. Mean size of location transmitters used in 1987 was 29 mm long by 16 mm diameter and average weight in water was 2.5 g (Table 8).

Prior to implantation, pressure sensitive transmitters were operated for 3 d to prevent false calibration due to electronic drift from battery power drain (Haynes 1978). Calibration tests were conducted in Afterbay Reservoir, where water quality and temperature were the same as in the Bighorn River (Appendix B). Each transmitter was suspended on a metered line at depths of 0, 1, 2, and 3 m and pulse repetitions were measured. Pulse repetition was measured from the leading edge of one pulse to the leading edge of the succeeding pulse as determined from pulse counters. Pulse repetition time decreased with increases in hydrostatic pressure (depth).

Transmitters were surgically implanted in the abdomens of brown trout and rainbow trout ranging in weight from 0.29 kg to 1.83 kg and total length from 29.2 cm to 53.1 cm (Tables 9 and 10). The general procedures of Hart and Summerfelt (1975) were followed. Fish were collected by electrofishing within the upper 4 km of the river. Fish were anesthetized (MS-222) and were inverted for surgery so that gills were submerged in anesthetic solution. Fish were tagged with a bright orange anchor tag (Floy Tag Company) behind the dorsal fin for identification. Radio-tagged trout were held for less

Table 6. Specifications of eight pressure sensitive radio transmitters implanted in brown trout and rainbow trout, 1987, Bighorn River, Montana.

| | |
|---|---|
| Length (mean) | 70.9 mm |
| Diameter (mean) | 20.3 mm |
| Weight in air | 33.6 - 35.0 g |
| Weight in water | 9.3 - 10.0 g |
| Battery type | 3.5 V lithium |
| Sensor | Cantlever silicon, with pleated stainless steel diaphragm |
| Frequency | 30.071 - 30.276 MHz |
| Theoretical life | 28 - 35 d |

Table 7. Specifications of three pressure sensitive radio transmitters implanted in brown trout and rainbow trout, 1988, Bighorn River, Montana.

| | |
|---|---|
| Length (mean) | 72.3 mm |
| Diameter (mean) | 14.0 mm |
| Weight in air | 17.0 - 17.5 g |
| Weight in water | 6.0 - 6.5 g |
| Battery type | silver |
| Sensor | Cantlever silicon, with pleated stainless steel diaphragm |
| Frequency | 30.255 - 30.279 MHz |
| Theoretical life | 18 - 22 d |

Table 8. Specifications of ten location radio transmitters implanted in brown trout and rainbow trout, 1987, Bighorn River, Montana.

| | |
|---|---|
| Dimension (mean) | 29 X 16 mm |
| Weight in air | 5.4 - 6.4 g |
| Weight in water | 1.7 - 3.1 g |
| Battery type | silver |
| Frequency | 30.043 - 30.237 MHz |
| Theoretical life | 90 d |

than 20 h before release at the location of capture in 1987. In 1988 trout were released as soon as they recovered from anesthesia. A curved cutting needle with 2-0 synthetic absorbable suture (Ethicon J-4534) was used to close incisions. Two to three subcutaneous stitches and four to six exterior stitches were used. Erythromycin (Erythro-200, 25 mg/1 kg) was injected into the dorsal sinus and tetracycline (Polyotic) was applied to the incision to reduce possible infection. Transmitter weight in water did not exceed 1.25% of trout weight out of water as recommended by Winter et al. (1978).

After release, radio tagged trout were located and monitored using a 124 $cm^2$ "loop" antenna and one of two different receivers. A programmable scanning-receiver and pulse counter (Model 2000 Challenger Programmable Scanner and Pulse Decoder) manufactured by Advanced Telemetry Systems, Incorporated (ATS), Isanti, Minnesota, and a second receiver and pulse counter, manufactured by CTC (Model CTC-AR-12 and Pulse Counter), were used to locate radio-tagged trout and record pulse repetition. Transmitter range was approximately 300 m depending on transmitter depth and orientation to the antenna. During 1987 an attempt was made to locate each fish daily, and 24 h monitoring of PSRTs was done on two occasions on two different transmitters

Table. 9. Length and weight of brown trout and rainbow trout implanted with pressure sensitive radio transmitters, 1987 and 1988, Bighorn River, Montana (Percent of trout weight - transmitter weight in water as a percentage of trout weight).

| Transmitter frequency (MHz) | Trout species | Trout length (cm) | Trout weight (kg) | Transmitter weight in water (g) | Percent of trout weight |
|---|---|---|---|---|---|
| | | | **1987** | | |
| 30.071 | Brown | 51.3 | 1.09 | 10.0 | 0.92 |
| 30.088 | Rainbow | 50.8 | 1.31 | 9.6 | 0.73 |
| 30.097 | Rainbow | 52.6 | 1.83 | 9.5 | 0.52 |
| 30.110 | Brown | 51.8 | 0.99 | 9.3 | 0.94 |
| 30.125 | Brown | 51.1 | 1.00 | 9.8 | 1.00 |
| 30.138 | Brown | 53.1 | 1.72 | 9.3 | 0.54 |
| 30.258 | Rainbow | 46.2 | 1.13 | 9.5 | 0.84 |
| 30.276 | Rainbow | 44.7 | 0.98 | 10.0 | 1.02 |
| | | | **1988** | | |
| 30.255 | Brown | 48.8 | 1.10 | 6.4 | 0.58 |
| 30.270 | Brown | 49.3 | 1.17 | 6.0 | 0.51 |
| 30.280 | Rainbow | 48.2 | 1.20 | 6.3 | 0.53 |

Table. 10. Length and weight of brown trout and rainbow trout implanted with location radio transmitters, 1987, Bighorn River, Montana (Percent of trout weight - transmitter water as a percentage of trout weight).

| Transmitter frequency (MHz) | Trout species | Trout length (cm) | Trout weight (kg) | Transmitter weight in water (g) | Percent of trout weight |
|---|---|---|---|---|---|
| 30.043 | Rainbow | 42.2 | 0.79 | 2.5 | 0.003 |
| 30.062 | Brown | 31.8 | 0.46 | 2.4 | 0.005 |
| 30.065 | Brown | 45.5 | 0.83 | 2.7 | 0.003 |
| 30.168 | Brown | 31.2 | 0.35 | 1.7 | 0.005 |
| 30.188 | Rainbow | 47.8 | 1.03 | 2.7 | 0.003 |
| 30.196 | Rainbow | 47.2 | 0.93 | 3.1 | 0.003 |
| 30.207 | Rainbow | 29.2 | 0.29 | 2.5 | 0.009 |
| 30.215 | Brown | 45.7 | 0.91 | 2.4 | 0.003 |
| 30.227 | Brown | 44.7 | 0.78 | 2.3 | 0.003 |
| 30.237 | Brown | 42.2 | 0.61 | 2.8 | 0.005 |

(radio-tagged trout) to assess diurnal trout movements. Fish were also located at night to evaluate night time habitat use. Monitoring of radio-tagged trout in 1988 was done 24 h/day. Fish locations were determined by triangulation and by signal strength. Fish locations were plotted on maps that were overlaid with a grid so that XY coordinates could be determined for each fish location. A computer program designed by Dan Gustafson (Montana State University) was used to analyze the data and produce location graphics.

Four of the eight PSRTs implanted into trout in 1987 were recovered after 21 d and were recalibrated to determine if electronic drift had occurred. All three trout radio tagged in 1988 were recovered after 10 d. The approach used for preimplant calibration was repeated.

Flow pattern through Afterbay Dam were modified to manipulate gas levels and examine behavior of trout when exposed to various levels of supersaturated water (Table 11). Radio-tagged trout were exposed to three different gas regimes in 1987 (Figure 2). From 9 August (release date) until 16 August, trout were exposed to moderate delta P levels with low variation (77 mmHg - 103 mmHg). High delta P levels with low variation (123 mmHg - 152 mmHg) were present from 16 August to 23 August. After 23 August radio-tagged trout were exposed to moderate delta P levels with high variation (57 mmHg - 125 mmHg). Total gas pressure and nitrogen pressure followed the pattern of delta P levels (Appendix C: Figures 29 - 32). Oxygen pressure ranged from 133 mmHg to 158 mmHg. Three levels of discharge ranging from 52.5 $m^3/s$ to 66.0 $m^3/s$ were encountered over the period (Figure 3).

Five periods of dissolved gas levels were created by changes in Afterbay Dam sluice gate/radial gate configuration during the 1988 radio telemetry study (Figure 4). From 19 to 20 July and from 27 to 29 July trout were exposed to moderate delta P levels with

Table 11. Configurations of Afterbay Dam sluice gate and radial gates for manipulating gas levels during telemetry studies, 1987 and 1988, Bighorn River, Montana.

| Date | Sluice gate | Radial gates | Result |
|---|---|---|---|
| | | 1987 | |
| 6 August - 17 August | Closed | Open | Moderate delta P values, low variation |
| 17 August - 23 August | Open | Closed | High delta P values, low variation |
| 23 August - 19 September | Open | Open | Moderate delta P values, high variation |
| | | 1988 | |
| 18 July - 20 July | Open | Open | Moderate delta P values, high variation |
| 20 July - 22 July | Open | Closed | High delta P values, low variation |
| 22 July - 25 July | Closed | Open | Moderate delta P values, low variation |
| 25 July - 27 July | Open | Closed | High delta P values, low variation |
| 27 July - 29 July | Open | Open | Moderate delta P values, high variation |

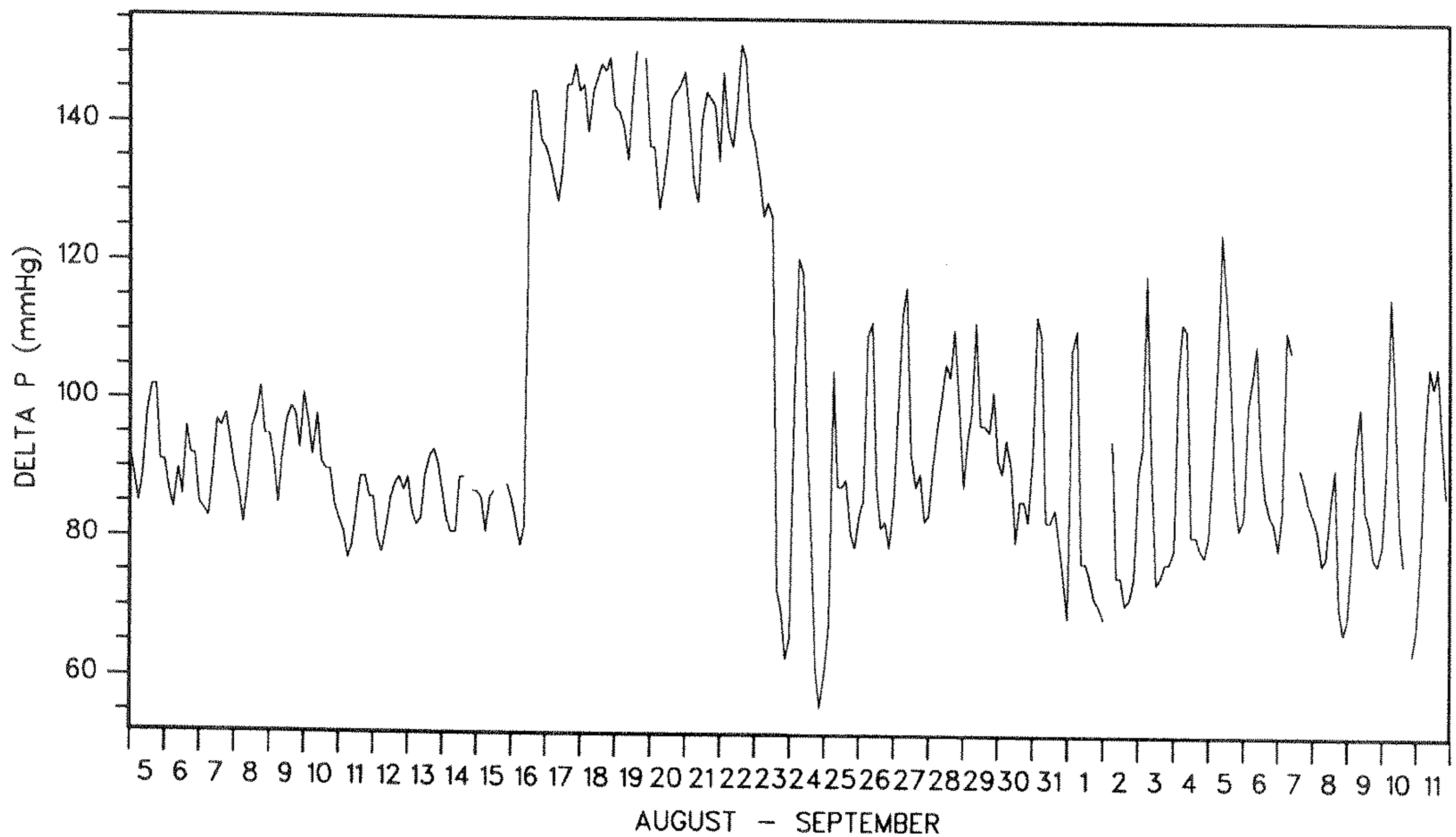


Figure 2. Delta P levels (mmHg) measured at satellite station Rkm 0.6 showing three different gas regimes created by changes in Afterbay Dam operation, 5 August - 11 September 1987, Bighorn River, Montana.

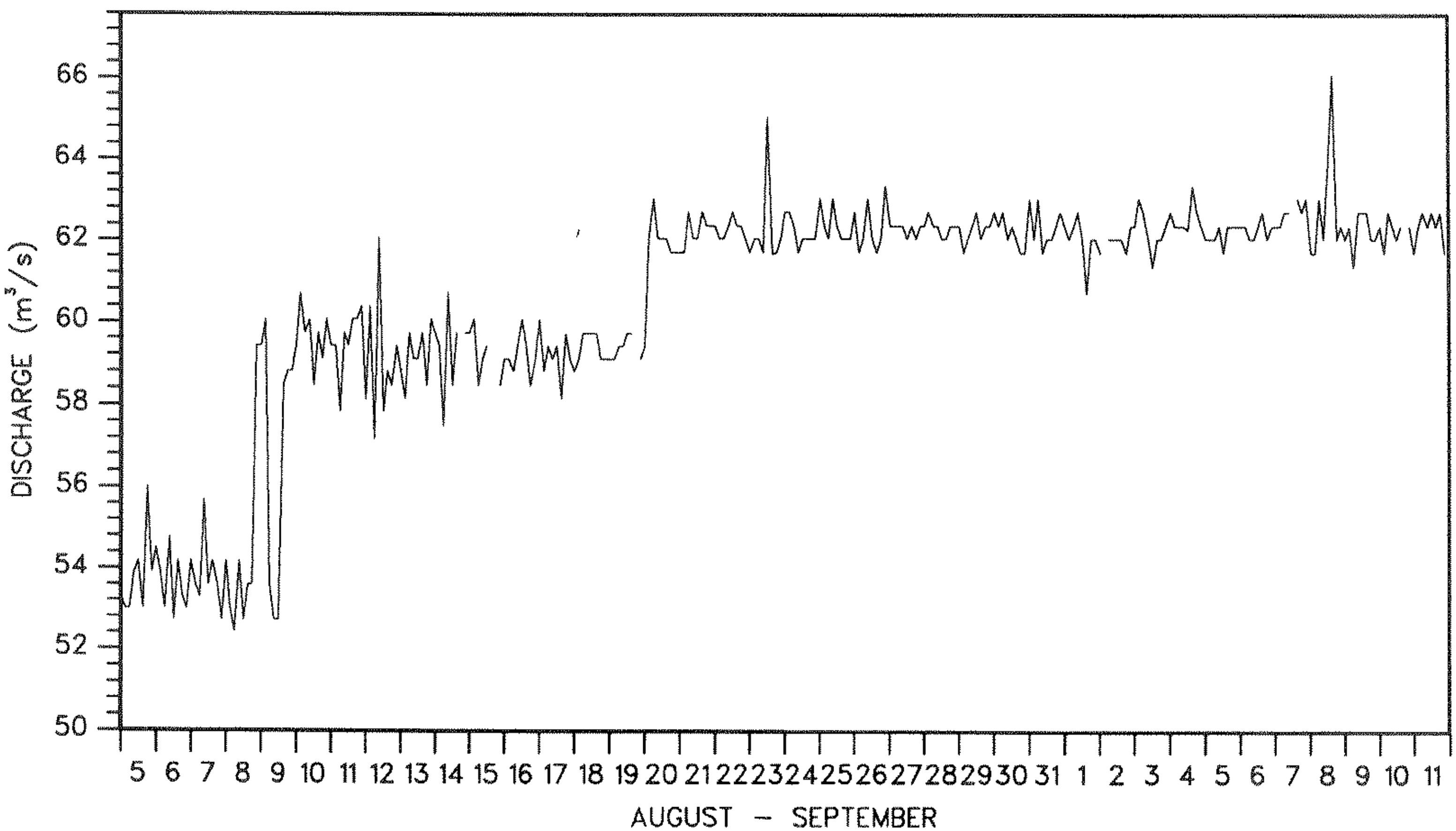


Figure 3. Discharge ($m^3/s$) during 1987 radio telemetry study, 5 August - 11 September 1987, Bighorn River, Montana.

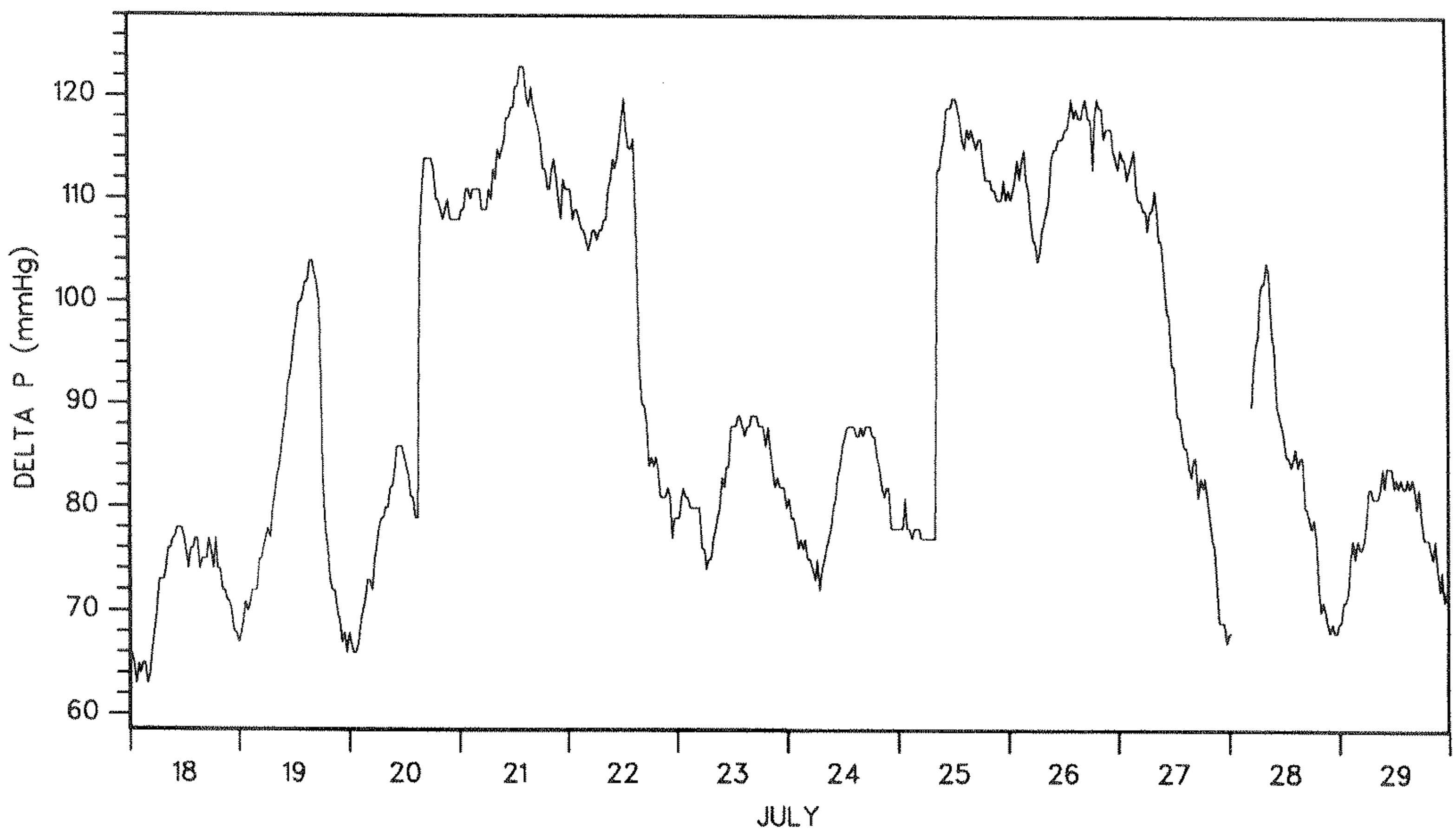


Figure 4. Delta P levels (mmHg) measured at Rkm 0.6 showing five periods of dissolved gas levels created by changes in Afterbay Dam operation, 18 July - 29 July 1988, Bighorn River, Montana.

high variation (63 mmHg - 104 mmHg). High delta P levels with low variation were present for two periods, 20 to 22 July and 25 to 27 July (104 mmHg - 123 mmHg). From 22 to 25 July moderate delta P levels with low variation were created (72 mmHg - 90 mmHg). Discharge was relatively constant during the 10 d period (Figure 5). A large increase in discharge (54 $m^3/s$ - 74 $m^3/s$) occurred for 3 h on 22 July due to problems with Afterbay Dam operation.

## Statistics

### Microhabitat

Discriminant analysis was used to determine if brown trout and rainbow trout were selecting different habitat locations. Fisherian discriminant analysis (Mardia et al. 1979) attempts to construct a rule which best allocates an individual fish to either brown trout or rainbow trout on the basis of the measured variables for that observation. This analysis finds sets of axes where the ratio of between group variance to within group variance is maximized and is unaffected by scaling of variables. A jackknife validation procedure was used on discriminant analysis results to prevent over-fitting the data. Over-fitting occurs when the number of variables is large relative to the number of observations. The jackknife validation estimates the true predictive ability of the discriminant function. A jackknife validation repeats the original analysis for the entire data set after removing one observation at a time. Each time the jackknife validation is done, its performance is evaluated using the excluded observation. Analysis of variance was used to examine differences within species.

Microhabitat data were also examined using principal component analysis (PCA) (Mardia et al. 1979). The use of PCA assumed no group membership and therefore is

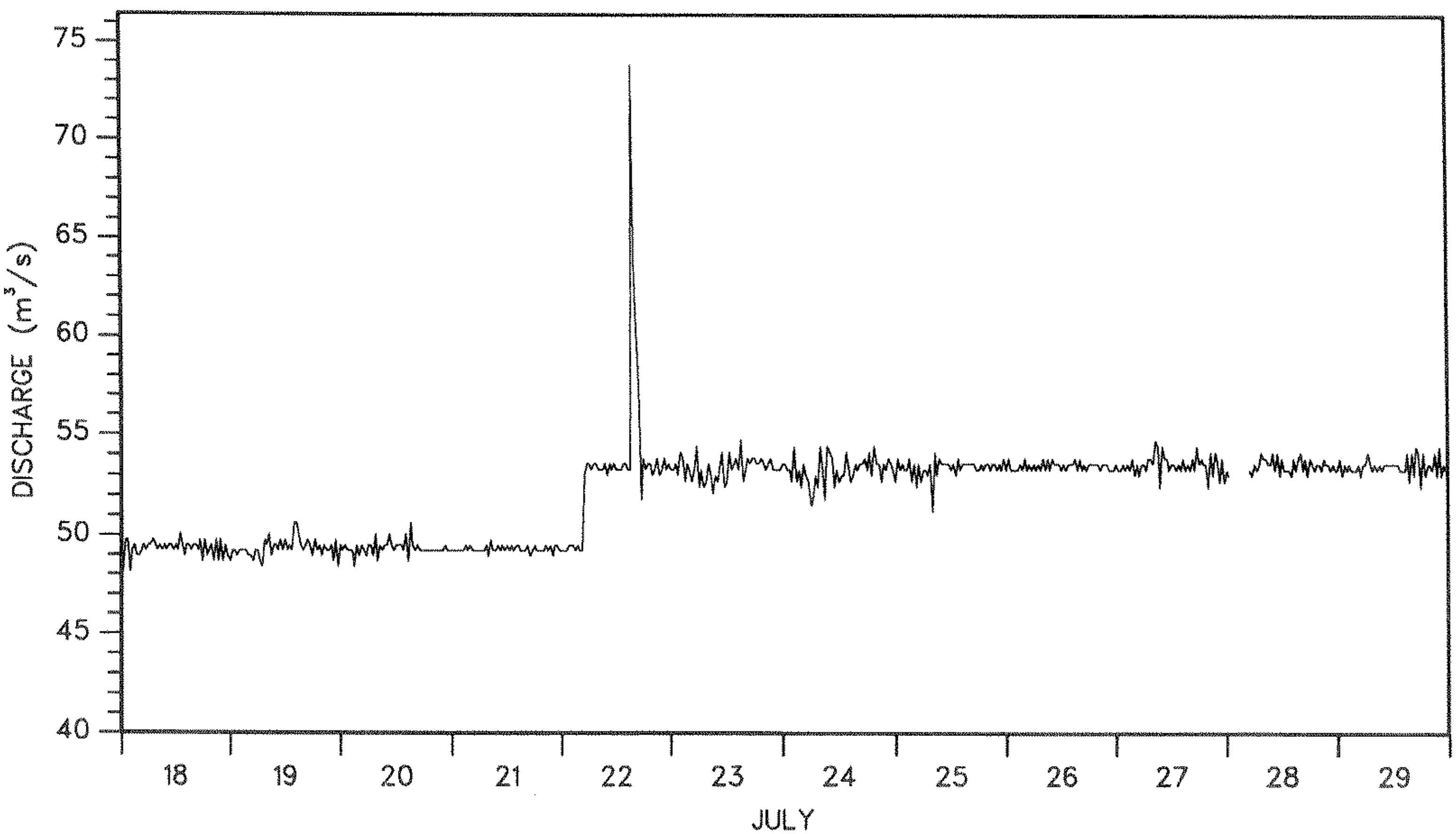


Figure 5. Discharge ($m^3/s$) during 1988 radio telemetry study, 18 July - 29 July 1987, Bighorn River, Montana.

not biased for finding groups. Principal component analysis maximally separated the fish on axes which can facilitate comparison between groups. Plots of principal components were examined to identify groups, if any. A correlation matrix was used for PCA.

Monte Carlo simulations were used to repeat PCA many times using randomly constructed data. Data were constructed to represent the null hypotheses of random correlation. Monte Carlo simulations assess the probability of obtaining an observed statistical result, given the null hypotheses is true.

**Macrohabitat**

Correlations of trout number and day number (Julian day) were used to examine seasonal changes in fish distribution. A non-parametric sign test was used on the correlation results (Sprent 1981). Testing the null hypotheses that correlations have a binomial distribution ($p = 0.5$), the non-parametric sign test determined the probability of getting the observed correlations by chance. To ensure independence of trout counts (the number of trout in middle lane is not independent to the number of fish in near bank lanes) for the sign test, only one lane count per size group and species was used. Lack of significance of correlations does not affect the sign test.

**Radio Telemetry**

A linear regression was used to determine the relationship between pulse repetition and depth for each transmitter. To determine depth resolution, unlimited simultaneous discrimination intervals were used (Lieberman et al. 1967). This method accounts for both the uncertainty in the observed pulse rate and the uncertainty in the relationship between pulse repetition and depth. Methods which do not take both uncertainties into account are not appropriate for measurements from precalibrated instruments. Transmitter calibration was done by regressing pulse rate on known depths. Field pulse rates were then converted to confidence intervals for depth using this regression equation, along with estimates of both types of uncertainty (Appendix B). A computer program designed by Milo Adkison and Dan Gustafson (Montana State University) performed the regression analysis.

# RESULTS

## Macrohabitat

Correlation among snorkel lane counts and day number indicated seasonal changes in trout distribution in 1987. Trout numbers generally decreased along banks and increased in middle lanes from 26 May to 17 October (Figures 6 and 7). Trout abundance was negatively correlated with day number for all near bank lanes (Table 12). The probability of getting all eight 1987 left or right lane counts to correlate the same as was observed was 0.004. Positive correlations with day number were observed in all middle lane counts in 1987 with the exception of section 1, rainbow trout >36 cm TL, which was negatively correlated with day number ($r=-0.19$). The probability of one or less of the eight correlations being negative due to chance alone was 0.035 (sign test) for 1987 middle lane counts. Twelve of the 24 correlations were significant ($P < 0.05$).

Correlations among snorkel lane counts and day number in 1988 were not similar to 1987 results. Trout numbers did not show similar decreases along banks and increases in the middle lanes as in 1987 (Figures 8 and 9). Only 1 of 24 correlations was significant (Table 13). Sample sizes for 1988 were smaller than in 1987 (1987, $N = 27$ for both sections; 1988, $N = 7$ for section 1, $N = 6$ for section 2). Six of the eight middle lane counts were positively correlated with day number, and three of eight left lane counts had positive correlation with day number. Assuming binomial distribution, the probability of two or less of eight middle lane counts being negative was 0.145. The probability of three or fewer left lane counts being positive as was observed was 0.363.

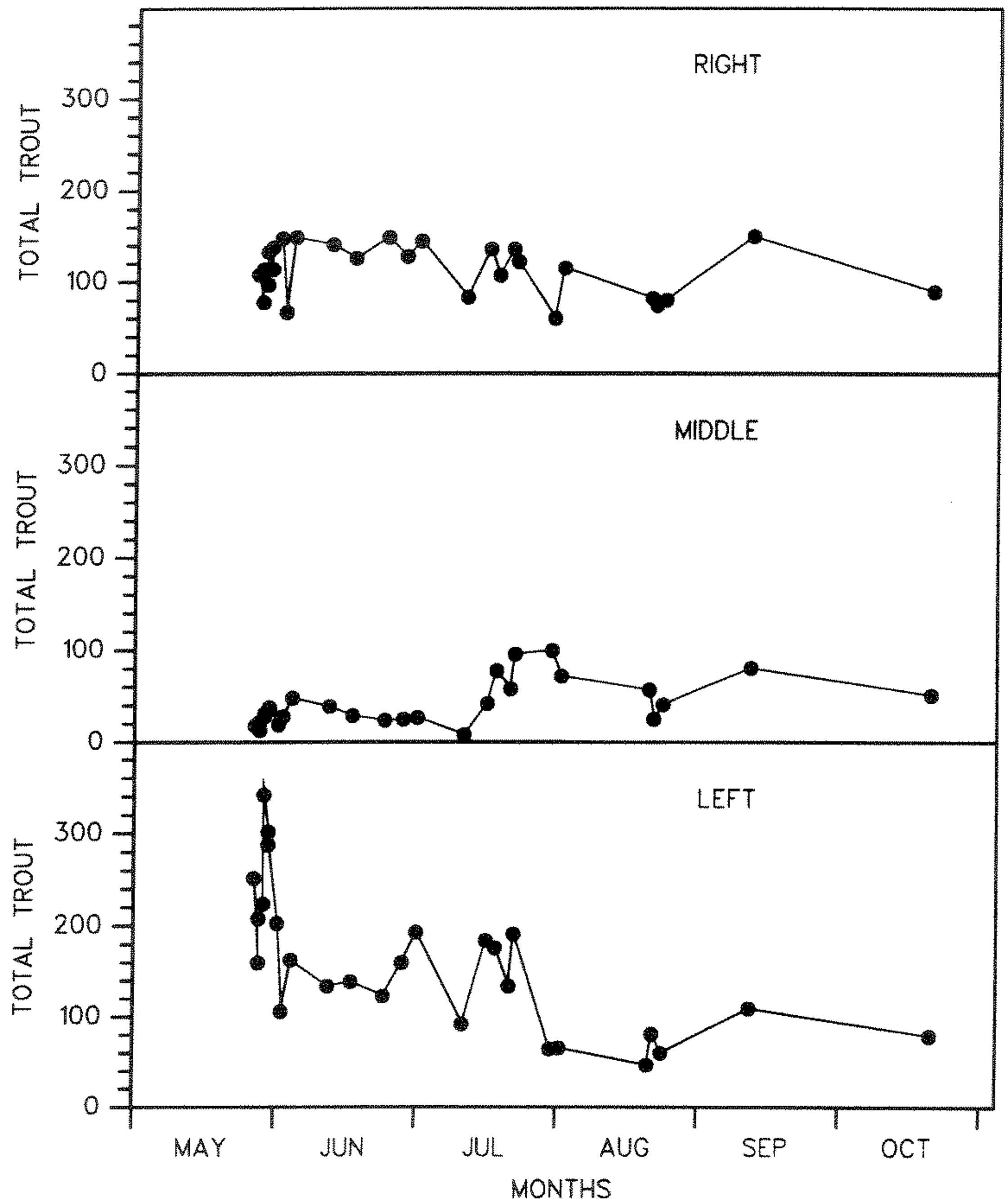


Figure 6. Number of rainbow trout and brown trout counted in section 1 snorkel lanes, 26 May - 17 October, 1987, Bighorn River, Montana.

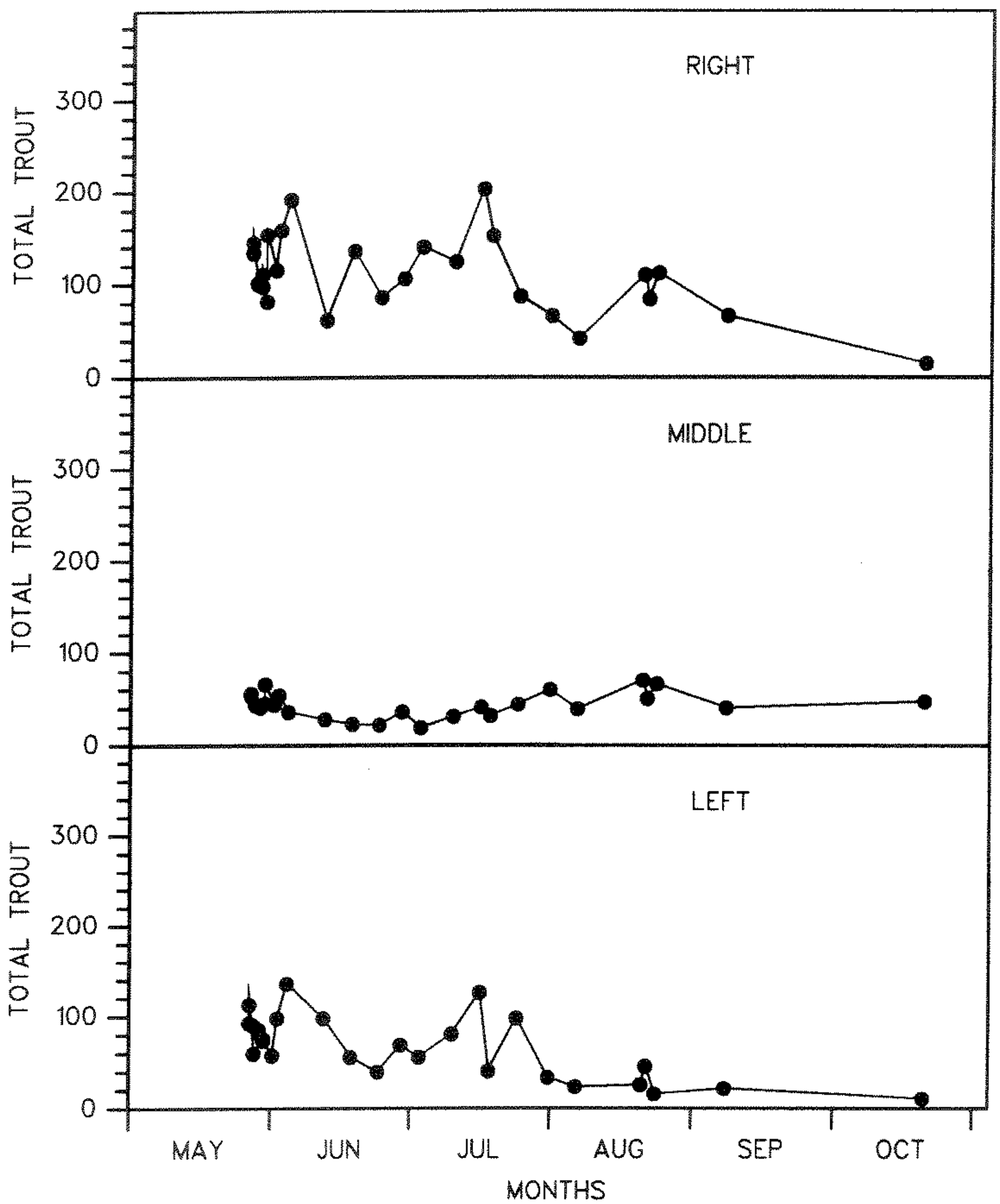


Figure 7. Number of rainbow trout and brown trout counted in section 2 snorkel lanes, 26 May - 17 October, 1987, Bighorn River, Montana.

Table 12. Correlation among trout abundance in sections 1 and 2 snorkel lane counts and day number (26 May - 17 October) 1987, Bighorn River, Montana (N=27 for both sections).

| Section | Species | Size | Bank[a] | Correlation coefficient (r) | Significance[b] |
|---|---|---|---|---|---|
| 1 | Brown | <36 cm | LB | -0.52 | ** |
| 1 | Brown | >36 cm | LB | -0.64 | ** |
| 1 | Brown | <36 cm | M | 0.47 | * |
| 1 | Brown | >36 cm | M | 0.34 | NS |
| 1 | Brown | <36 cm | RB | -0.20 | NS |
| 1 | Brown | >36 cm | RB | -0.14 | NS |
| 1 | Rainbow | <36 cm | LB | -0.79 | ** |
| 1 | Rainbow | >36 cm | LB | -0.55 | ** |
| 1 | Rainbow | <36 cm | M | 0.63 | ** |
| 1 | Rainbow | >36 cm | M | -0.19 | NS |
| 1 | Rainbow | <36 cm | RB | -0.09 | NS |
| 1 | Rainbow | >36 cm | RB | -0.35 | NS |
| 2 | Brown | <36 cm | LB | -0.60 | ** |
| 2 | Brown | >36 cm | LB | -0.72 | ** |
| 2 | Brown | <36 cm | M | 0.09 | NS |
| 2 | Brown | >36 cm | M | 0.04 | NS |
| 2 | Brown | <36 cm | RB | -0.41 | * |
| 2 | Brown | >36 cm | RB | -0.51 | ** |
| 2 | Rainbow | <36 cm | LB | -0.35 | NS |
| 2 | Rainbow | >36 cm | LB | -0.30 | NS |
| 2 | Rainbow | <36 cm | M | 0.46 | * |
| 2 | Rainbow | >36 cm | M | 0.16 | NS |
| 2 | Rainbow | <36 cm | RB | -0.22 | NS |
| 2 | Rainbow | >36 cm | RB | -0.50 | ** |

[a] LB - left bank, M - middle, RB - right bank

[b] NS P > 0.05, * P < 0.05, ** P < 0.01

The percentage of total trout counted in the middle snorkel lanes during 1987 had significant, positive, correlation with day number (26 May - 17 October) also indicating seasonal movement away from near bank areas (Table 14, Figure 10). A less pronounced increase in the percentages of total trout in middle lanes was observed in 1988 (Table 14, Figure 11). Neither 1988 correlations are significant (P < 0.05).

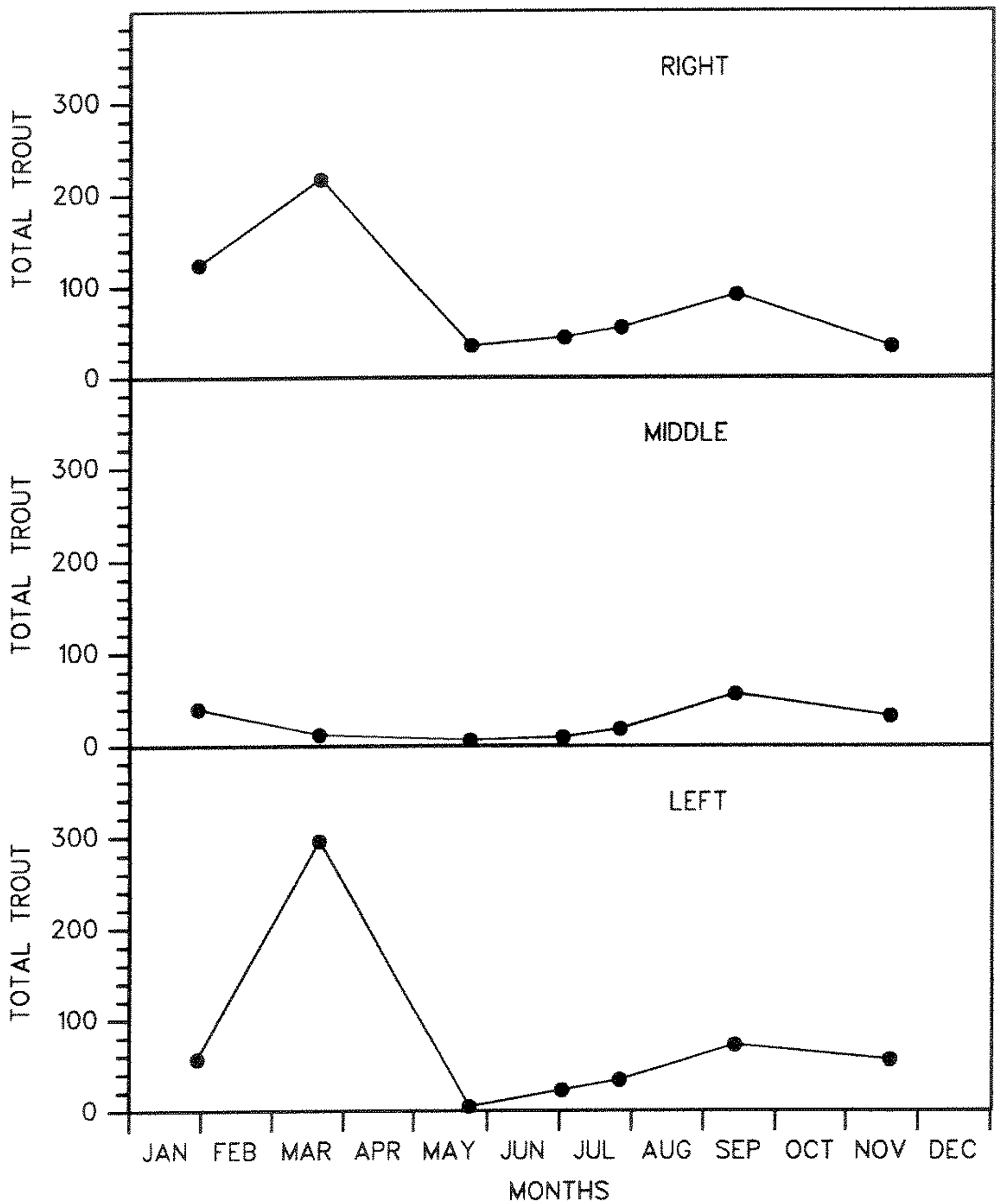


Figure 8. Number of rainbow trout and brown trout counted in section 1 snorkel lanes, 30 January - 23 November, 1988, Bighorn River, Montana.

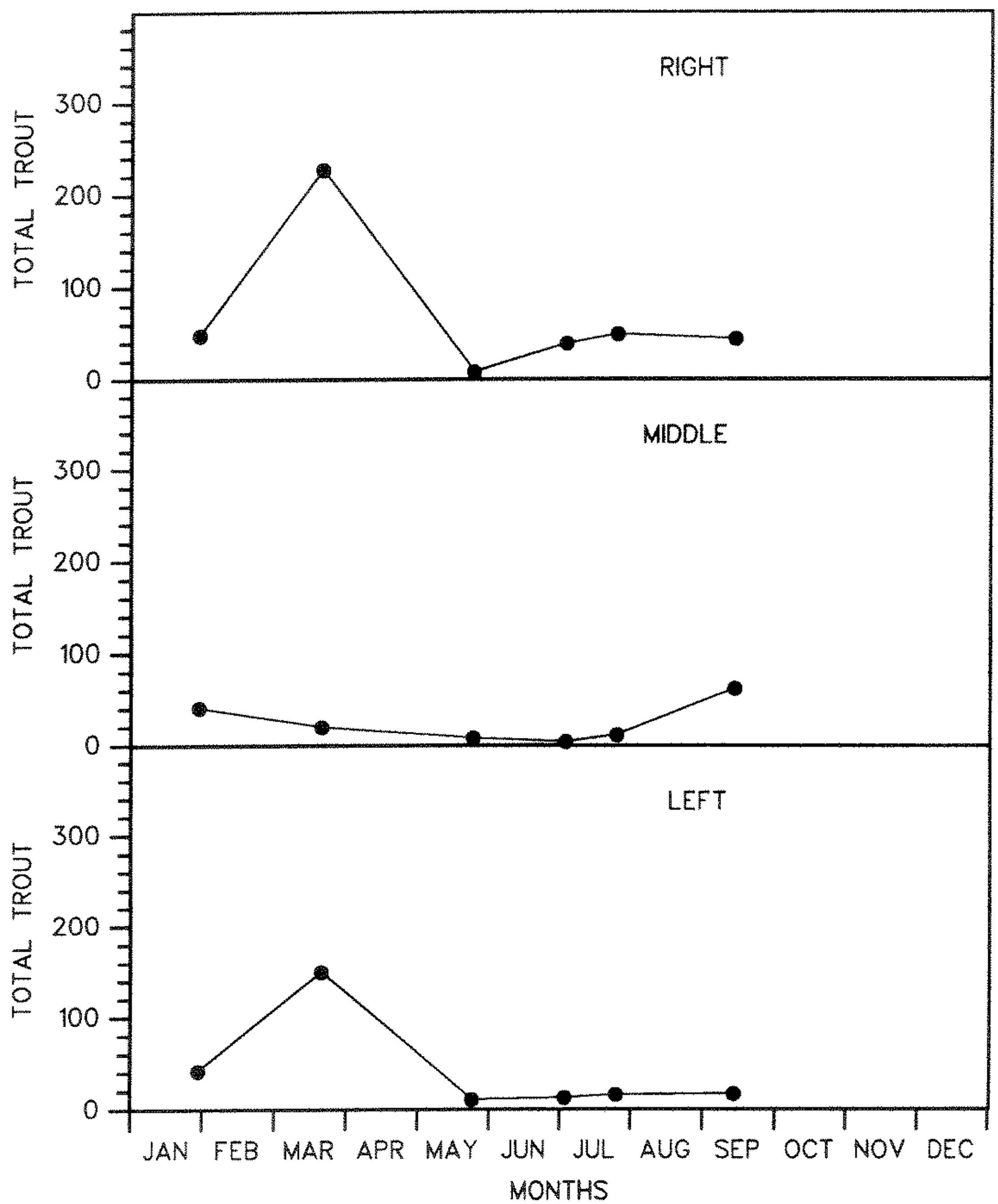


Figure 9. Number of rainbow trout and brown trout counted in section 2 snorkel lanes, 30 January - 18 September, 1988, Bighorn River, Montana.

Table 13. Correlation among trout abundance in sections 1 and 2 snorkel lane counts and day number (30 January - 23 November) 1988, Bighorn River, Montana (N=7 for section 1, N=6 for section 2).

| Section | Species | Size | Bank[a] | Correlation coefficient (r) | Significance[b] |
|---|---|---|---|---|---|
| 1 | Brown | <36 cm | LB | -0.31 | NS |
| 1 | Brown | >36 cm | LB | 0.20 | NS |
| 1 | Brown | <36 cm | M | 0.12 | NS |
| 1 | Brown | >36 cm | M | 0.48 | NS |
| 1 | Brown | <36 cm | RB | -0.47 | NS |
| 1 | Brown | >36 cm | RB | -0.23 | NS |
| 1 | Rainbow | <36 cm | LB | -0.22 | NS |
| 1 | Rainbow | >36 cm | LB | 0.14 | NS |
| 1 | Rainbow | <36 cm | M | 0.08 | NS |
| 1 | Rainbow | >36 cm | M | 0.56 | NS |
| 1 | Rainbow | <36 cm | RB | -0.68 | NS |
| 1 | Rainbow | >36 cm | RB | -0.10 | NS |
| 2 | Brown | <36 cm | LB | -0.40 | NS |
| 2 | Brown | >36 cm | LB | -0.47 | NS |
| 2 | Brown | <36 cm | M | -0.38 | NS |
| 2 | Brown | >36 cm | M | 0.71 | NS |
| 2 | Brown | <36 cm | RB | -0.05 | NS |
| 2 | Brown | >36 cm | RB | -0.36 | NS |
| 2 | Rainbow | <36 cm | LB | -0.41 | NS |
| 2 | Rainbow | >36 cm | LB | 0.30 | NS |
| 2 | Rainbow | <36 cm | M | -0.24 | NS |
| 2 | Rainbow | >36 cm | M | 0.97 | ** |
| 2 | Rainbow | <36 cm | RB | 0.00 | NS |
| 2 | Rainbow | >36 cm | RB | 0.50 | NS |

[a] LB - left bank, M - middle, RB - right bank

[b] NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$

Correlations between total gas pressure (TGP) and trout number in snorkel lanes were observed only with middle lane counts (Tables 15 and 16). Trout numbers in the middle lane of section 1 were the only counts significantly correlated with TGP in 1987. Trout numbers in the middle lane of sections 1 and 2 were significantly correlated with TGP in 1988. Correlations between water temperature and discharge followed seasonal

Table 14. Correlation among percentage of total trout in the middle snorkel lane in sections 1 and 2 and day number, 1987 and 1988, Bighorn River, Montana (N=27 for 1987; N=7 for section 1, N=6 for section 2 for 1988).

| Section | Mean percentage of trout in middle lane (range) | Correlation coefficient (r) | Significance[a] |
|---|---|---|---|
| | | **1987** | |
| 1 | 0.15 (0.04 - 0.44) | 0.68 | ** |
| 2 | 0.22 (0.09 - 0.64) | 0.74 | ** |
| | | **1988** | |
| 1 | 0.23 (0.05 - 0.50) | 0.29 | NS |
| 2 | 0.16 (0.02 - 0.26) | 0.67 | NS |

[a] NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$

trends. Water temperature increased from 5 C to 15 C (section 1, 1987: correlation between water temperature and day number: $r = 0.95$, $P < 0.01$) during the field seasons and discharge decreased from 70.8 $m^3/s$ to 53.8 $m^3/s$ (section 1, 1987: correlation between discharge and day number: $r = -0.66$, $P < 0.01$).

## Microhabitat

Significant differences in microhabitat use (ANOVA) between the three size groups of rainbow trout were found for water depth, fish depth, substrate, velocity, and cover (Table 17). Small rainbow trout (<15 cm TL) were significantly ($P < 0.05$)

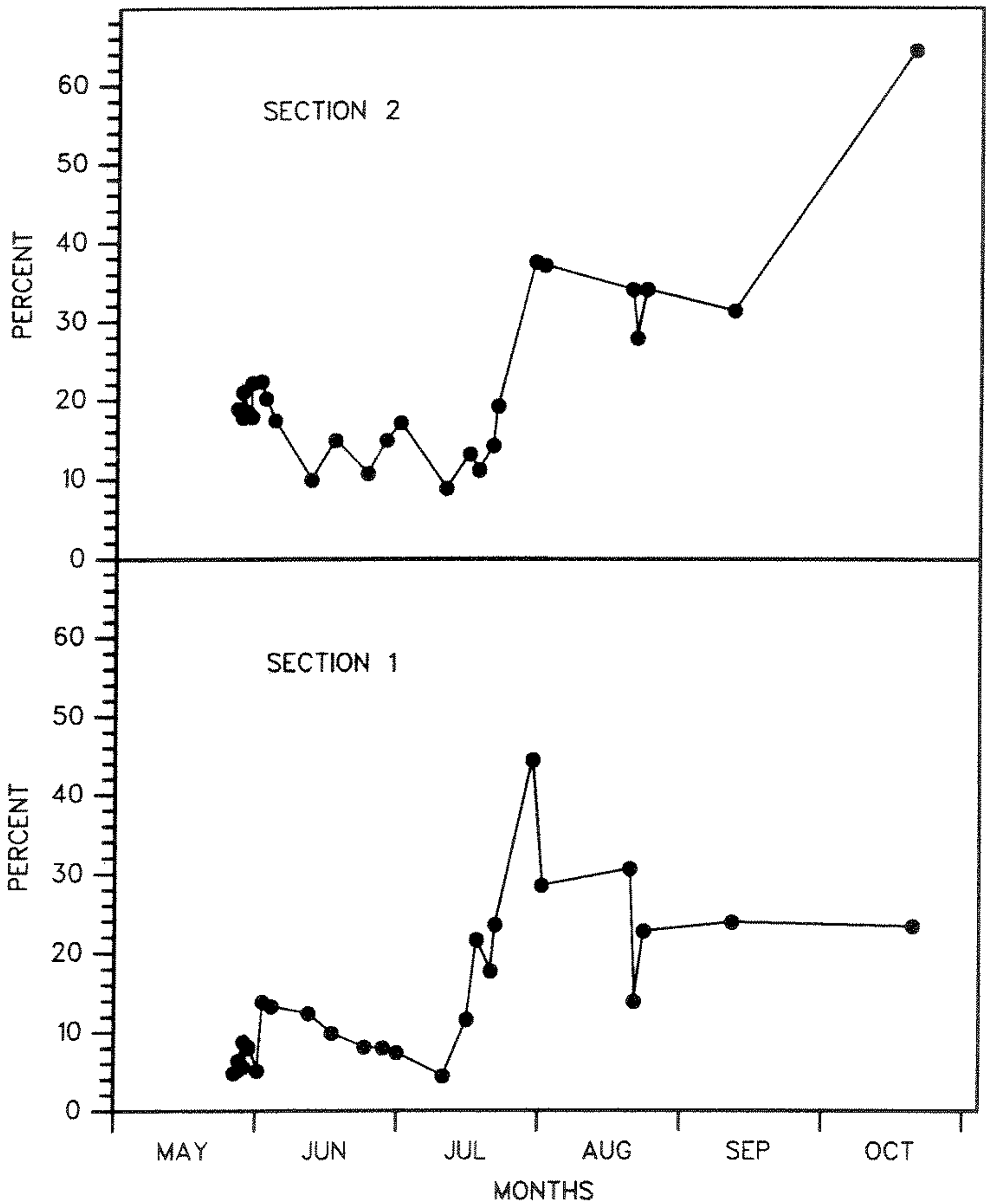


Figure 10. Percentage of total rainbow trout and brown trout counted in middle lane of snorkel sections 1 and 2, 1987, Bighorn River, Montana.

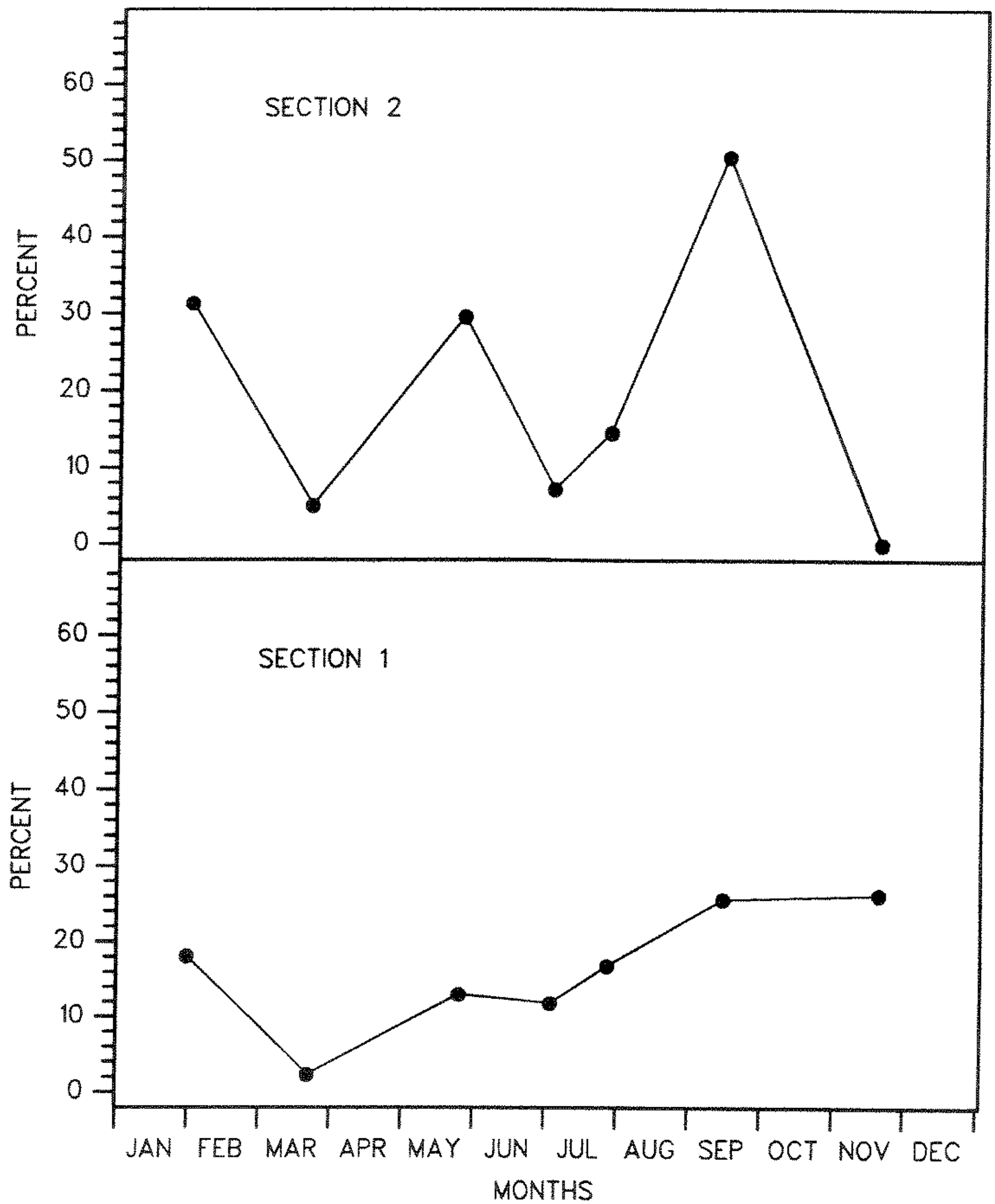


Figure 11. Percentage of total rainbow trout and brown trout counted in middle lane of snorkel sections 1 and 2, 1988, Bighorn River, Montana.

Table 15. Correlations among trout number in snorkel lanes and discharge, visibility, water temperature, above water light level, and total gas pressure, sections 1 and 2, 1987, Bighorn River, Montana (N=27). The upper triangular matrix indicates simple significance levels[a].

Section 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Trout, left lane | -- | NS | * | NS | ** | NS | ** | NS |
| 2 Trout, middle lane | -.29 | -- | NS | ** | NS | NS | * | ** |
| 3 Trout, right lane | .44 | -.03 | -- | NS | NS | NS | * | NS |
| 4 Discharge | .38 | -.69 | .39 | -- | NS | NS | ** | * |
| 5 Visibility | .75 | -.21 | .32 | .38 | -- | NS | ** | NS |
| 6 Light | .07 | .02 | .28 | .17 | .25 | -- | NS | NS |
| 7 Water temperature | -.67 | .45 | -.40 | -.75 | -.79 | -.06 | -- | NS |
| 8 TGP | -.06 | -.54 | -.02 | .40 | -.02 | .24 | -.07 | -- |

Section 2

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Trout, left lane | -- | NS | ** | NS | ** | ** | NS | NS |
| 2 Trout, middle lane | -.12 | -- | NS | ** | NS | NS | NS | NS |
| 3 Trout, right bank | .62 | .00 | -- | NS | * | NS | NS | NS |
| 4 Discharge | .32 | -.64 | .27 | -- | ** | ** | ** | NS |
| 5 Visibility | .66 | -.17 | .42 | .64 | -- | ** | * | NS |
| 6 Light | -.18 | .15 | .01 | -.55 | -.41 | .64 | -- | NS |
| 7 Water temperature | -.58 | .33 | -.36 | -.81 | -.86 | -- | ** | NS |
| 8 TGP | .17 | -.20 | .27 | -.13 | -.13 | .37 | .26 | -- |

[a] NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$

different from larger rainbow trout in microhabitat use for the variables measured (Table 17). Rainbow trout 15 - 40 cm TL and >40 cm TL used similar microhabitat with only slight differences in vegetation height and velocity. The mean vegetation height used by rainbow trout 15 - 40 cm TL was greater than that used by rainbow trout >40 cm TL. The mean focal point velocity was greater for rainbow trout 15 - 40 cm TL than for the larger rainbow trout.

Significant differences ($P < 0.05$) in the use of water depth, fish depth, substrate, vegetation height, velocity, and cover were observed between brown trout of different size groups (ANOVA, Table 18). Brown trout <15 cm TL were found in shallower

Table 16. Correlations among trout number in snorkel lanes and discharge, visibility, water temperature, above water light level, and total gas pressure, sections 1 and 2, 1988, Bighorn River, Montana (N=7 for section 1, N=6 for section 2). The upper triangular matrix indicates simple significance levels[a].

Section 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Trout, left lane | -- | NS | ** | NS | NS | NS | NS | NS |
| 2 Trout, middle lane | -.08 | -- | NS | NS | * | NS | NS | * |
| 3 Trout, right lane | .92 | .07 | -- | NS | NS | NS | NS | NS |
| 4 Discharge | .04 | -.65 | -.01 | -- | NS | NS | NS | * |
| 5 Visibility | .42 | -.76 | .37 | .28 | -- | NS | NS | NS |
| 6 Light | -.62 | -.64 | -.67 | .32 | .37 | -- | NS | NS |
| 7 Water temperature | -.43 | .56 | -.48 | -.75 | -.48 | .13 | -- | NS |
| 8 TGP | .12 | -.82 | -.07 | .85 | .61 | .51 | -.55 | -- |

Section 2

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Trout, left lane | -- | NS | ** | NS | NS | NS | NS | NS |
| 2 Trout, middle lane | .01 | -- | NS | NS | NS | NS | NS | * |
| 3 Trout, right bank | .98 | -.01 | -- | NS | NS | NS | NS | NS |
| 4 Discharge | .18 | -.53 | .04 | -- | NS | NS | NS | NS |
| 5 Visibility | .56 | -.56 | .53 | .49 | -- | NS | NS | NS |
| 6 Light | -.53 | -.76 | -.45 | .11 | -.01 | -- | NS | * |
| 7 Water temperature | -.60 | .22 | -.45 | -.60 | -.56 | .41 | -- | NS |
| 8 TGP | -.19 | -.90 | -.12 | .34 | .40 | .89 | .20 | -- |

[a] NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$

water and lower velocities than brown trout >15 cm TL. Brown trout >15 cm TL were found using similar water depth, fish depth, substrate, vegetation height, and cover. Brown trout 15 - 40 cm TL had higher focal point velocities than brown trout >40 cm TL (Table 18).

Discriminant analysis of microhabitat use (1987) by small brown trout and rainbow trout (<15 cm TL, N=56) resulted in a jackknife misclassification of 52% (Table 19). Fish depth had the largest weighting (absolute value), -0.95, followed by substrate and water depth with values of 0.22 and 0.20, respectively (Table 19). Seasonal differences could not be determined due to differences in time of fry emergence.

Table 17. Comparison of microhabitat use between rainbow trout size groups using analysis of variance, 1987, Bighorn River, Montana (1=rainbow trout less than 15 cm, N=23; 2=rainbow trout 15 - 40 cm, N=65; 3=rainbow trout greater than 40 cm, N=27; * P<0.05, ** P<0.01).

| Variable | Size group 1 Mean (SD) | Size group 2 Mean (SD) | Size group 3 Mean (SD) | $F_{2,112}$ |
|---|---|---|---|---|
| Water depth (m) | 0.56 (0.42) | 1.14 (0.28) | 1.22 (0.38) | 31.07** |
| Fish depth (m) | 0.45 (0.33) | 0.81 (0.34) | 1.02 (0.40) | 16.93** |
| Substrate | 1.39 (0.50) | 1.86 (0.39) | 1.82 (0.17) | 11.24** |
| Vegetation height (cm) | 17.67 (13.56) | 16.57 (14.67) | 12.98 (15.36) | 0.77 |
| Velocity (cm/s) | 11.13 (15.96) | 32.03 (13.16) | 18.37 (18.37) | 16.62** |
| Cover | 1.04 (0.64) | 1.80 (0.72) | 1.70 (0.67) | 10.50** |

Discrimination between rainbow trout and brown trout >15 cm TL (N=104) based on microhabitat use in June 1987 had a jackknife misclassification of 46% using the same variables analyzed for size group 1 (Table 20). Fish depth and water depth were the largest weighted variables. No significant differences (P < 0.05) were found in microhabitat use between brown trout and rainbow trout for variables measured (t test, Table 21), although rainbow trout used slightly higher water velocities (P=0.069, 26.93 cm/s vs. 32.70 cm/s).

Misclassification of brown trout and rainbow trout >15 cm TL using discriminant analysis decreased to 36% in July 1987 (Table 20). Water depth and fish depth again

Table 18. Comparison of microhabitat use between brown trout size groups using analysis of variance, 1987, Bighorn River, Montana (1=brown trout less than 15 cm, N=33; 2=brown trout 15 - 40 cm, N=141; 3=brown trout greater than 40 cm, N=44; * P<0.05, ** P<0.01).

| Variable | Size group 1 Mean (SD) | Size group 2 Mean (SD) | Size group 3 Mean (SD) | $F_{2,215}$ |
|---|---|---|---|---|
| Water depth (m) | 0.57 (0.38) | 1.08 (0.29) | 1.03 (0.23) | 42.18** |
| Fish depth (m) | 0.49 (0.33) | 0.91 (0.30) | 0.90 (0.23) | 28.98** |
| Substrate | 1.24 (0.61) | 1.85 (0.41) | 1.73 0.54) | 21.89** |
| Vegetation height (cm) | 13.16 (16.48) | 12.16 (11.53) | 11.49 (10.31) | 0.18 |
| Velocity (cm/s) | 8.22 (9.86) | 24.69 (12.74) | 17.39 (12.41) | 26.05** |
| Cover | 1.27 (1.35) | 1.83 (0.78) | 1.68 (1.01) | 4.78** |

received the largest weighting. The eigen value increased from 0.108 in June to 0.154 in July, an increase in the ratio of between group variance to within group variance, indicating an increase in the separation of species (Table 20). Significant differences in water depth (P=0.009) and velocity (P=0.000) were observed (t test, Table 22). Discrimination between brown trout and rainbow trout >15 cm TL (N=40) in September - October 1987 was improved over other time periods with a misclassification of 20% (Table 20). As in June and July, water depth and fish depth had the largest weighting, 0.76 and -0.65, respectively. Significant differences were found in use of depth (P=0.001) and velocity (P=0.000) by brown trout and rainbow trout (t test,

Table 19. Discriminant analysis of use of selected microhabitat variables by brown trout and rainbow trout <15 cm TL, June - October 1987, Bighorn River, Montana (brown trout N=33, rainbow trout N=23; JK=jackknife validation).

| Variable | Discriminant eigen vector | Eigen value | Number misclassified | Number misclassified (JK) |
|---|---|---|---|---|
| Water depth | 0.20 | | | |
| Fish depth | -0.95 | | | |
| Substrate | 0.22 | | | |
| Vegetation height | 0.01 | | | |
| Velocity | 0.01 | | | |
| Cover | -0.08 | | | |
| | | 0.094 | 22 (39%) | 29 (52%) |

Table 23). Brown trout were closer to the river bottom (deeper in the water column, mean fish depth) and in slower water than rainbow trout. Rainbow trout were found in deeper water (mean water depth 1.14 m) but closer to the surface (mean fish depth 0.59 m), than brown trout.

Principal component analysis of microhabitat use by all trout from all periods produced no detectable differences between brown trout and rainbow trout (Figure 12). Principal component (PC) I was heavily weighted (absolute value) by water depth, fish depth, velocity, and substrate (Table 24). The explained variances of all principal components except PC I was expected, indicating that PC I was capturing a distinct feature of the data not due to chance (Appendix D: Table 36). Plotting PC I versus PC II indicates a clustering of size groups (Figure 13). Size group 1 was scored lower on PC

Table 20. Discriminant analysis of use of selected microhabitat variables by brown trout and rainbow trout >15 cm TL, June - October 1987, Bighorn River, Montana (June: brown trout N=71, rainbow trout N=33; July: brown trout N=92, rainbow trout N=41; September/October: brown trout N=22, rainbow trout N=18; JK=jackknife validation).

| Variable | Discriminant eigen vector | Eigen value | Number misclassified | Number misclassified (JK) |
|---|---|---|---|---|
| | | June | | |
| Water depth | 0.67 | | | |
| Fish depth | -0.72 | | | |
| Substrate | 0.18 | | | |
| Vegetation height | 0.00 | | | |
| Velocity | 0.00 | | | |
| Cover | 0.00 | | | |
| | | 0.108 | 42 (40%) | 48 (46%) |
| | | July | | |
| Water depth | 0.78 | | | |
| Fish depth | -0.61 | | | |
| Substrate | -0.15 | | | |
| Vegetation height | 0.00 | | | |
| Velocity | 0.01 | | | |
| Cover | -0.07 | | | |
| | | 0.154 | 44 (33%) | 49 (36%) |
| | | September - October | | |
| Water depth | 0.76 | | | |
| Fish depth | -0.65 | | | |
| Substrate | 0.03 | | | |
| Vegetation height | -0.00 | | | |
| Velocity | 0.01 | | | |
| Cover | -0.01 | | | |
| | | 1.046 | 5 (13%) | 8 (20%) |

Table 21. Comparisons between brown trout and rainbow trout >15 cm TL use of selected microhabitat variables, t test for equality of means, June 1987, Bighorn River, Montana (brown trout N=71, rainbow trout N=33).

| Variable | Brown trout Mean (SD) | Rainbow trout Mean (SD) | t | P value |
|---|---|---|---|---|
| Water depth (m) | 1.09 (0.26) | 1.12 (0.31) | -0.39 | 0.700 |
| Fish depth (m) | 0.92 (0.29) | 0.87 (0.33) | 0.79 | 0.433 |
| Substrate | 1.83 (0.48) | 1.97 (0.17) | -1.62 | 0.109 |
| Vegetation height (cm) | 11.20 (8.03) | 11.47 (5.72) | -0.17 | 0.862 |
| Velocity (cm/s) | 26.92 (15.02) | 32.70 (14.80) | -1.83 | 0.069 |
| Cover | 1.92 (0.69) | 2.06 (0.35) | -1.14 | 0.258 |

I than size groups 2 and 3. No separation between groups 2 and 3 was detected. Microhabitat use by all trout <15 cm TL observed in 1987 produced no detectable separation of brown trout and rainbow trout using principal component analysis (Figure 14). Principal component I explained 52% of the variance and had an eigen value of 3.13 (Table 25). Monte Carlo simulations indicated that a variance of 20 - 31% was expected and there was less than a 1 in 1000 chance of obtaining the observed value of 52% (Appendix D: Table 37).

Table 22. Comparisons between brown trout and rainbow trout >15 cm TL use of selected microhabitat variables, t test for equality of means, July 1987, Bighorn River, Montana (brown trout N=92, rainbow trout N=41).

| Variable | Brown trout Mean (SD) | Rainbow trout Mean (SD) | t | P value |
|---|---|---|---|---|
| Water depth (m) | 1.06 (0.29) | 1.21 (0.36) | -2.63 | 0.009 |
| Fish depth (m) | 0.91 (0.29) | 1.01 (0.38) | -1.51 | 0.132 |
| Substrate | 1.89 (0.38) | 1.88 (0.40) | 0.18 | 0.854 |
| Vegetation height (cm) | 8.70 (5.00) | 9.97 (5.43) | -1.33 | 0.187 |
| Velocity (cm/s) | 21.63 (11.28) | 30.70 (15.23) | -3.83 | 0.000 |
| Cover | 1.84 (0.89) | 1.66 (0.73) | 1.12 | 0.263 |

Principal component analysis of microhabitat use of all trout >15 cm TL from June 1987 resulted in a first principal component that explained 40% of the variance (Table 26). All weightings of variables were positive, with water depth, fish depth, and velocity having the largest values. Monte Carlo simulations indicated that PC I was capturing a unique feature in the data (Appendix D: Table 38). Principal component II captured a structural aspect of the data with the heaviest weighting being cover and substrate. Water depth and fish depth switched from positive weighting in PC I to negative weighting in PC II. The structural aspect of the data was also captured by PC III with the largest weighting being vegetation height, substrate, and cover. Brown trout tended to receive lower scores in PC I than rainbow trout although considerable overlap still occurred between species (Figure 15).

Table 23. Comparisons between brown trout and rainbow trout >15 cm TL use of selected microhabitat variables, t test for equality of means, September - October 1987, Bighorn River, Montana (brown trout N=22, rainbow trout N=18).

| Variable | Brown trout Mean (SD) | Rainbow trout Mean (SD) | t | P value |
|---|---|---|---|---|
| Water depth (m) | 1.05 (0.25) | 1.14 (0.14) | -1.40 | 0.168 |
| Fish depth (m) | 0.86 (0.28) | 0.59 (0.22) | 3.49 | 0.001 |
| Substrate | 1.50 (0.51) | 1.56 (0.51) | -0.34 | 0.734 |
| Vegetation height (cm) | 28.40 (21.20) | 35.56 (22.87) | -1.02 | 0.312 |
| Velocity (cm/s) | 15.66 (7.89) | 29.46 (14.52) | -3.83 | 0.000 |
| Cover | 1.23 (0.87) | 1.50 (0.92) | -0.96 | 0.343 |

Water depth and fish depth had the largest weighting of the six variables used in PC I for trout >15 cm TL observed in July (Table 27). Unlike PC I from June observations, a negative weighting was contained in PC I of July data. A value of -0.03 for cover differed from the June weighting of 0.09. In PC II vegetation height had the largest weighting and velocity the smallest. As in the June data, brown trout generally had lower scores than rainbow trout in PC I (Figure 16).

Principal component I obtained from microhabitat of trout >15 cm TL during September - October 1987 of differed considerably from earlier months. Water depth had the largest value, followed by vegetation height and cover (Table 28). Fish depth received a low weighting of -0.03 in PC I. Monte Carlo simulations indicated that the

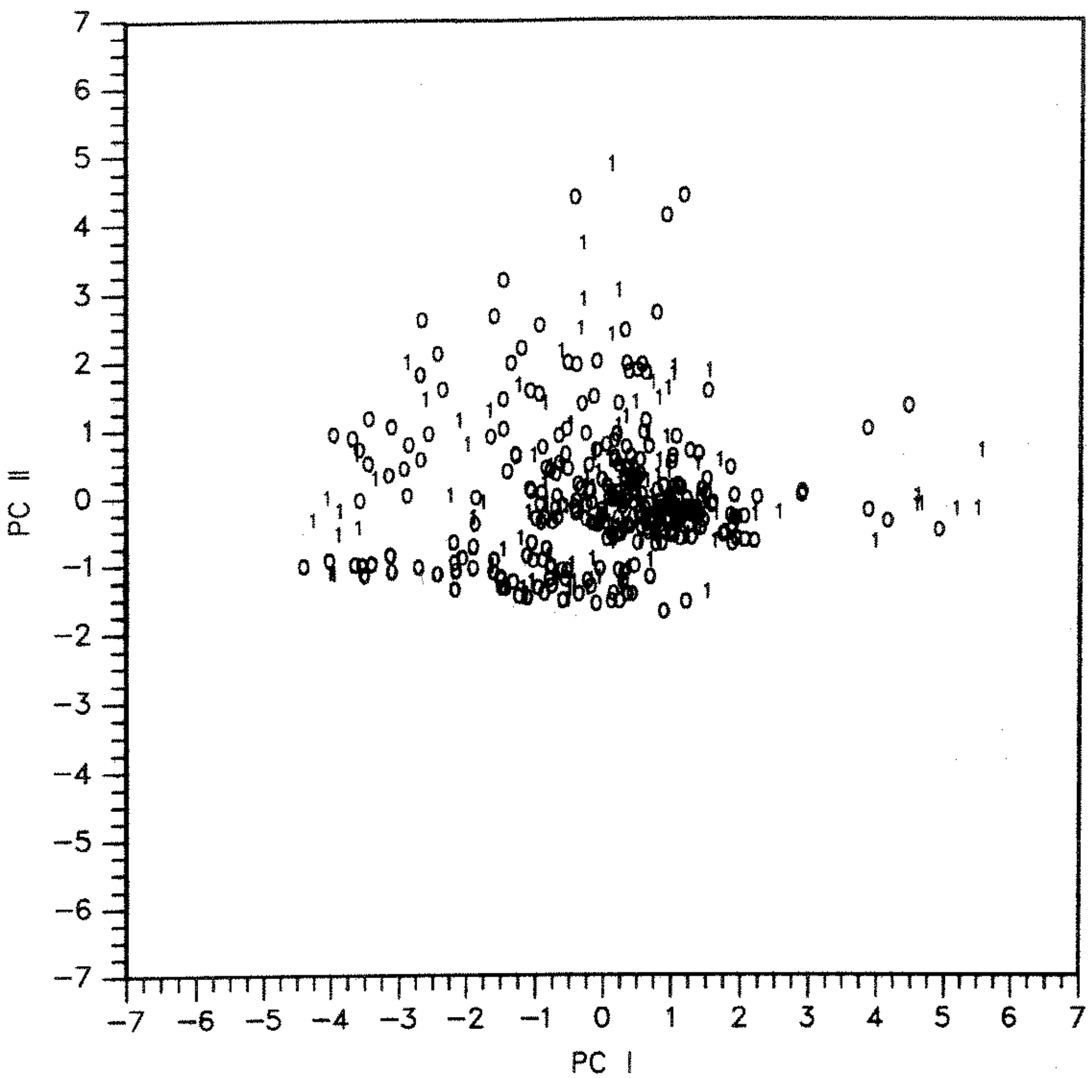


Figure 12. Principal component I versus principal component II for brown trout and rainbow trout of all size groups using the variables water depth, fish depth, substrate, vegetation height, velocity, and cover, June - October 1987, Bighorn River, Montana (0=brown trout, 1=rainbow trout).

Table 24. Principle component analysis for all brown trout and rainbow trout using selected habitat variables, June - October 1987. Bighorn River, Montana.

| Variable | Principle component I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Water depth | 0.58 | 0.05 | -0.01 | -0.34 | -0.00 | -0.74 |
| Fish depth | 0.53 | -0.14 | 0.03 | -0.47 | -0.29 | 0.63 |
| Substrate | 0.38 | -0.07 | -0.32 | 0.70 | -0.51 | -0.03 |
| Vegetation depth | 0.05 | 0.91 | -0.37 | -0.07 | 0.04 | 0.14 |
| Velocity | 0.44 | -0.12 | -0.12 | 0.29 | 0.81 | 0.20 |
| Cover | 0.21 | 0.36 | 0.86 | 0.28 | -0.05 | 0.05 |
| Eigen value | 2.58 | 1.03 | 0.93 | 0.76 | 0.63 | 0.07 |
| Percent of variance | 42.93 | 17.20 | 15.54 | 12.70 | 10.44 | 1.19 |
| Cumulative percent | 42.93 | 60.13 | 75.67 | 88.37 | 98.81 | 100.00 |

percent of the variance explained by all principal components was within expected ranges (Appendix D: Table 40). Principal component II had its largest weighting from the variables fish depth and velocity. Brown trout received lower scores than rainbow trout producing more distinct differences between species than that found in June and July data when plotted (Figure 17).

## Fish Movements

Pressure sensitive radio transmitters in two brown trout and one rainbow trout were monitored from 19 July to 28 July 1988 (Tables 29, 30, and 31). The rainbow trout (Fish 280) occupied a deeper position following surgery and release than at other times during the observation period (Figure 18). After the initial location, this fish maintained a relatively constant depth. None of the fish appeared to change depth in response to changes in dissolved gas levels (Figures 19 and 20). Depths occupied by the two brown

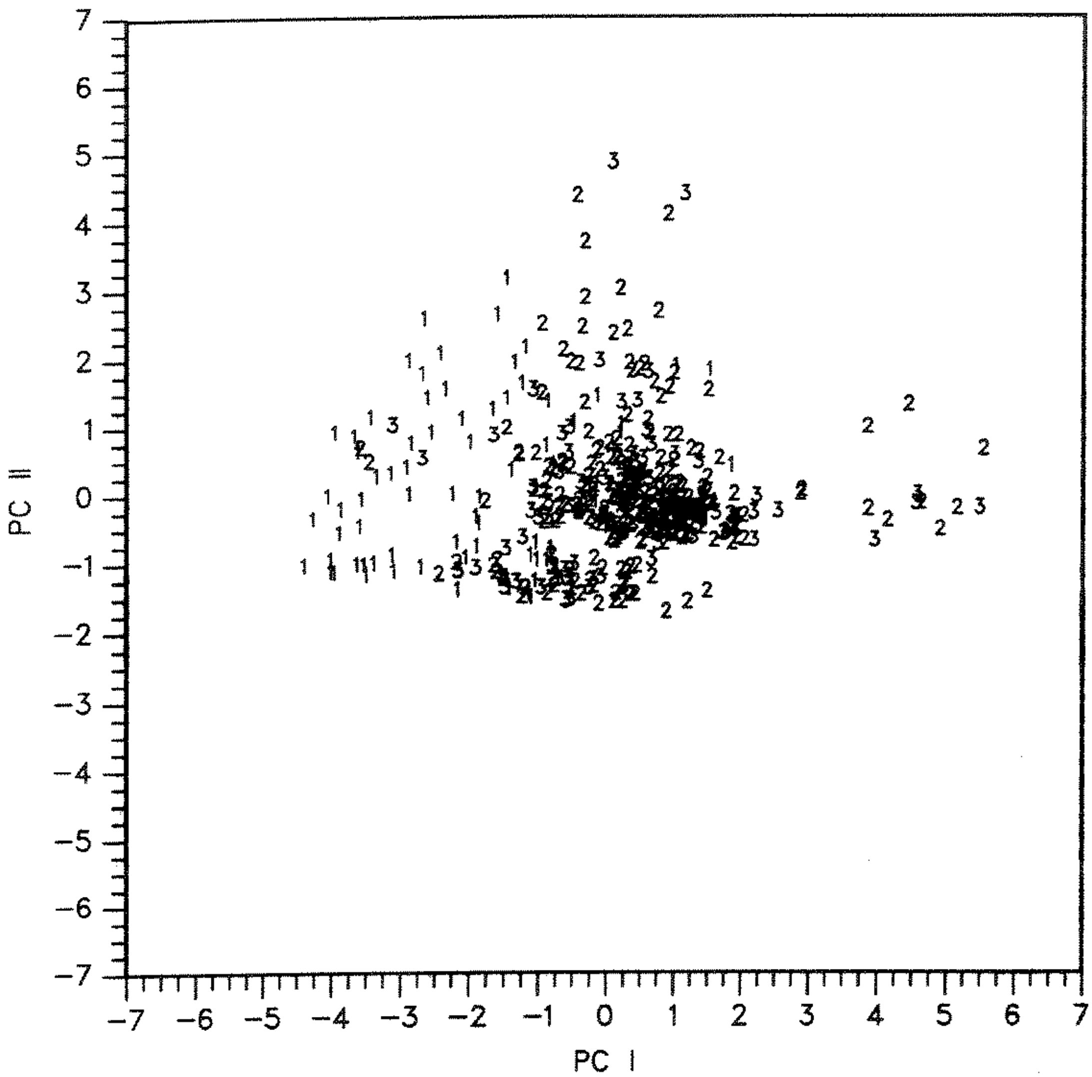


Figure 13. Principal component I versus principal component II for brown trout and rainbow trout of all size groups using the variables water depth, fish depth, substrate, vegetation height, velocity, and cover, June - October 1987, Bighorn River, Montana (1=size group 1, <15 cm TL; 2=size group 2, 15 - 40 cm TL; 3=size group 3, >40 cm TL).

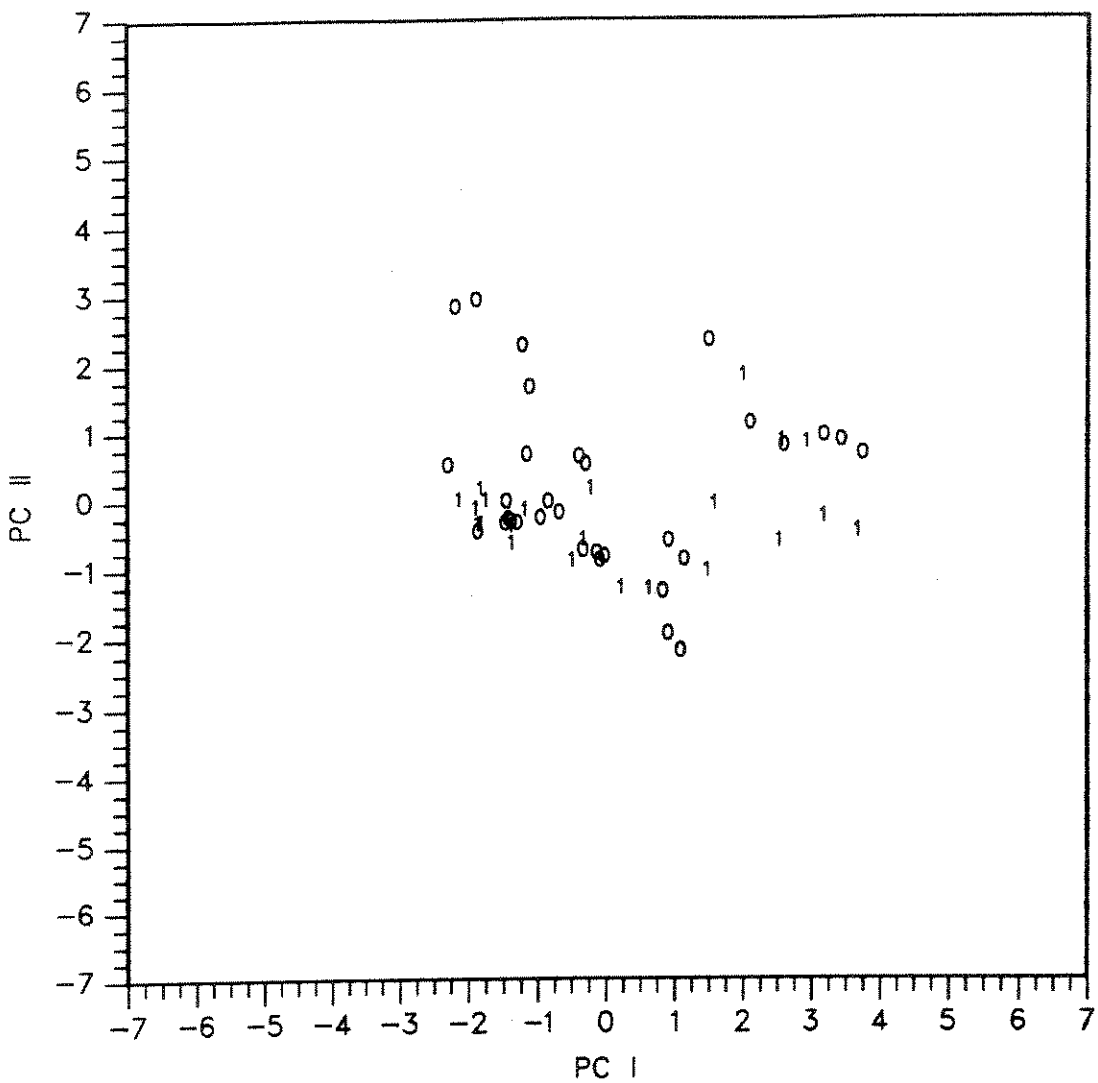


Figure 14. Principal component I versus principal component II for brown trout and rainbow trout <15 cm TL using the variables water depth, fish depth, substrate, vegetation height, velocity, and cover, June - October 1987, Bighorn River, Montana (0=brown trout, 1=rainbow trout).

Table 25. Principle component analysis for all brown trout and rainbow trout <15 cm TL using selected habitat variables, June - October 1987, Bighorn River, Montana.

| Variable | Principle component | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| Water depth | 0.54 | 0.15 | -0.10 | -0.18 | -0.26 | -0.76 |
| Fish depth | 0.51 | 0.09 | -0.13 | -0.52 | -0.27 | 0.61 |
| Substrate | 0.43 | -0.44 | -0.01 | -0.08 | 0.78 | -0.02 |
| Vegetation depth | 0.22 | -0.49 | 0.73 | 0.19 | -0.37 | 0.05 |
| Velocity | 0.44 | 0.18 | -0.27 | 0.81 | -0.06 | 0.21 |
| Cover | 0.13 | 0.71 | 0.61 | -0.01 | 0.33 | 0.05 |
| Eigen value | 3.13 | 1.10 | 0.98 | 0.45 | 0.33 | 0.02 |
| Percent of variance | 52.09 | 18.34 | 16.24 | 7.54 | 5.42 | 0.36 |
| Cumulative percent | 52.09 | 70.43 | 86.68 | 94.22 | 99.64 | 100.00 |

Table 26. Principle component analysis for brown trout and rainbow trout >15 cm TL using selected habitat variables, June 1987, Bighorn River, Montana.

| Variable | Principle component | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| Water depth | 0.58 | -0.25 | 0.10 | -0.27 | 0.16 | -0.70 |
| Fish depth | 0.54 | -0.43 | 0.01 | -0.25 | -0.16 | 0.66 |
| Substrate | 0.34 | 0.43 | -0.53 | 0.08 | -0.63 | -0.12 |
| Vegetation depth | 0.27 | 0.05 | 0.65 | 0.66 | -0.28 | -0.02 |
| Velocity | 0.41 | 0.37 | -0.24 | 0.35 | 0.69 | 0.20 |
| Cover | 0.09 | 0.66 | 0.48 | -0.56 | 0.00 | 0.12 |
| Eigen value | 2.39 | 1.11 | 0.99 | 0.86 | 0.58 | 0.07 |
| Percent of variance | 39.90 | 18.50 | 16.51 | 14.35 | 9.66 | 1.09 |
| Cumulative percent | 39.90 | 58.40 | 74.90 | 89.25 | 98.91 | 100.00 |

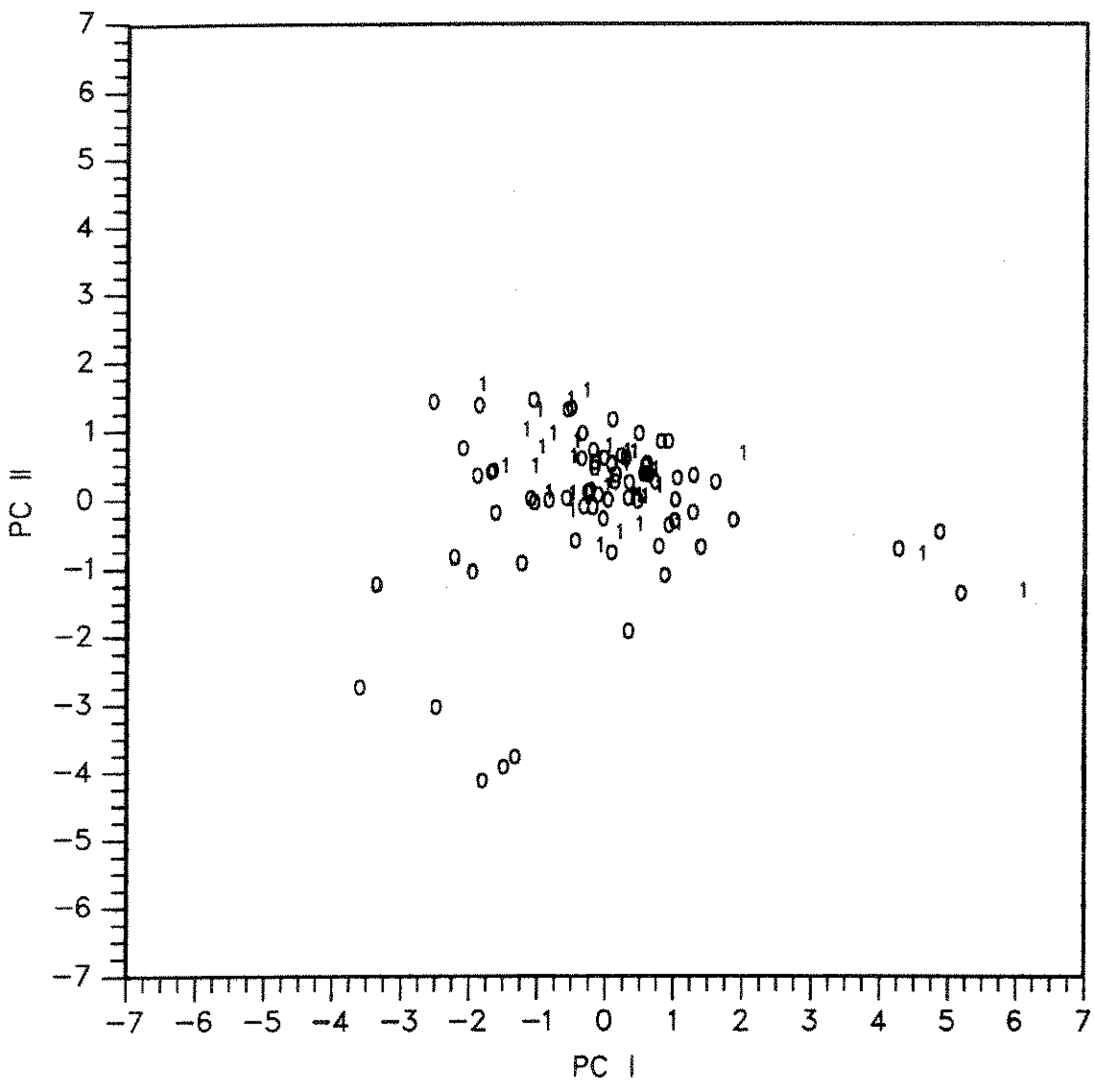


Figure 15. Principal component I versus principal component II for brown trout and rainbow trout >15 cm TL using the variables water depth, fish depth, substrate, vegetation height, velocity, and cover, June 1987, Bighorn River, Montana (0=brown trout, 1=rainbow trout).

Table 27. Principle component analysis for brown trout and rainbow trout > 15 cm TL using selected habitat variables, July 1987, Bighorn River, Montana.

| Variable | Principle component | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| Water depth | 0.57 | -0.26 | 0.23 | 0.10 | -0.07 | -0.74 |
| Fish depth | 0.52 | -0.37 | 0.22 | 0.33 | -0.11 | 0.65 |
| Substrate | 0.28 | 0.36 | -0.59 | 0.57 | 0.35 | -0.05 |
| Vegetation depth | 0.35 | 0.63 | -0.04 | -0.19 | -0.66 | 0.08 |
| Velocity | 0.46 | 0.07 | -0.09 | -0.69 | 0.53 | 0.15 |
| Cover | -0.03 | 0.52 | 0.74 | 0.22 | 0.37 | 0.02 |
| Eigen value | 2.57 | 1.19 | 1.07 | 0.68 | 0.44 | 0.05 |
| Percent of variance | 42.86 | 19.85 | 17.90 | 11.36 | 7.27 | 0.77 |
| Cumulative percent | 42.86 | 62.70 | 80.60 | 91.96 | 99.23 | 100.00 |

trout (Fish 255 and Fish 270) varied considerably throughout the 10 d monitoring period.

Light levels (Figure 21) or time of day (Figure 22) had no apparent influence on fish depth, although fish 270 was often located at shallow depths during periods when field notes indicated high levels of trout surface feeding activity and insect emergence (0600 - 1100 and 1400 - 1600). Fish 255 also was frequently located in shallow water during the early morning when high levels of feeding activity were noted (0500 - 0900). The large increase in discharge on 22 July did not appear to influence fish depth (Figure 18).

Fourteen of 18 brown trout and rainbow trout implanted with radio tags in 1987 were subsequently located for up to 35 days (Table 32). Four of the radio-tagged trout were not located after release. Most movement of the 14 radio-tagged trout occurred during the first 5 d following release (Figure 23). During the period, little upstream/downstream movement occurred. Average daily distance traveled for all radio-

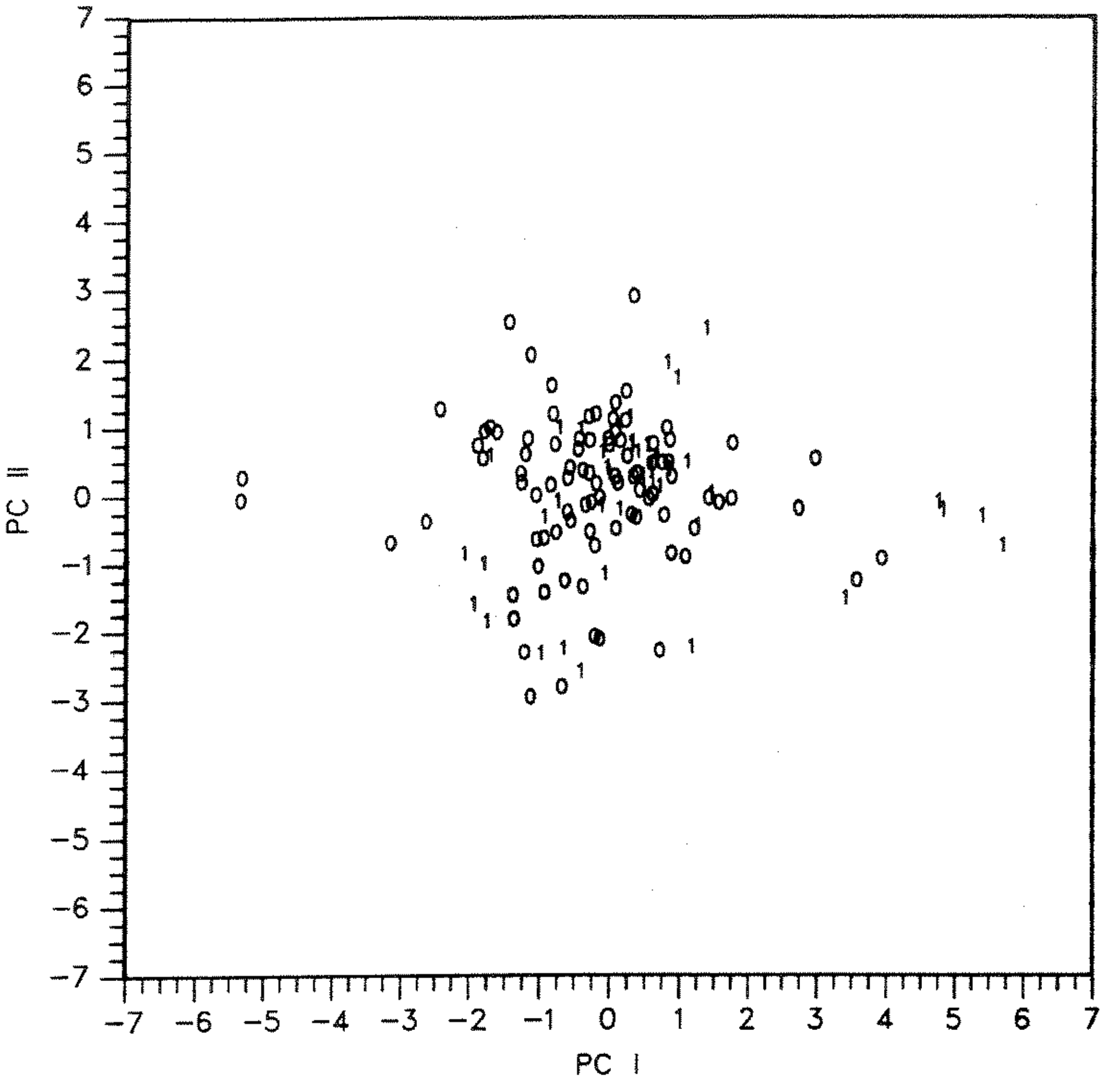


Figure 16. Principal component I versus principal component II for brown trout and rainbow trout >15 cm TL using the variables water depth, fish depth, substrate, vegetation height, velocity, and cover, July 1987, Bighorn River, Montana (0=brown trout, 1=rainbow trout).

Table 28. Principle component analysis for brown trout and rainbow trout >15 cm TL using selected habitat variables, September - October 1987, Bighorn River, Montana.

| Variable | Principle component | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| Water depth | 0.53 | 0.38 | 0.03 | -0.44 | -0.29 | -0.55 |
| Fish depth | -0.03 | 0.63 | 0.56 | -0.00 | -0.15 | 0.51 |
| Substrate | 0.41 | -0.61 | 0.03 | 0.80 | -0.43 | -0.06 |
| Vegetation depth | 0.52 | 0.17 | -0.60 | -0.08 | 0.21 | 0.54 |
| Velocity | 0.23 | -0.61 | 0.24 | -0.40 | -0.47 | 0.37 |
| Cover | 0.48 | -0.22 | 0.52 | 0.07 | 0.67 | -0.06 |
| Eigen value | 1.84 | 1.53 | 1.07 | 0.94 | 0.46 | 0.15 |
| Percent of variance | 30.71 | 25.52 | 17.89 | 15.60 | 7.72 | 2.56 |
| Cumulative percent | 30.71 | 56.23 | 74.12 | 89.72 | 97.44 | 100.00 |

tagged trout was -0.82 m (Appendix E: Figures 37 - 50). Changes in dissolved gas levels did not have a detectable influence on daily distance traveled.

Location data from 1988 radio-tagged trout indicated that two radio-tagged trout (Fish 270 and 280) increased their daily range during periods of high dissolved gas levels (104 mmHg - 123 mmHg delta P) on 20 July to 22 July and 25 July to 27 July (Figures 24 and 25). Mean daily range for the 10 d period was largest for the two brown trout (Tables 29, 30, and 31; Appendix E: Figures 51 - 53). One brown trout increased its daily range throughout the 10 d period; largest movements were on days with moderate gas levels (Figure 26).

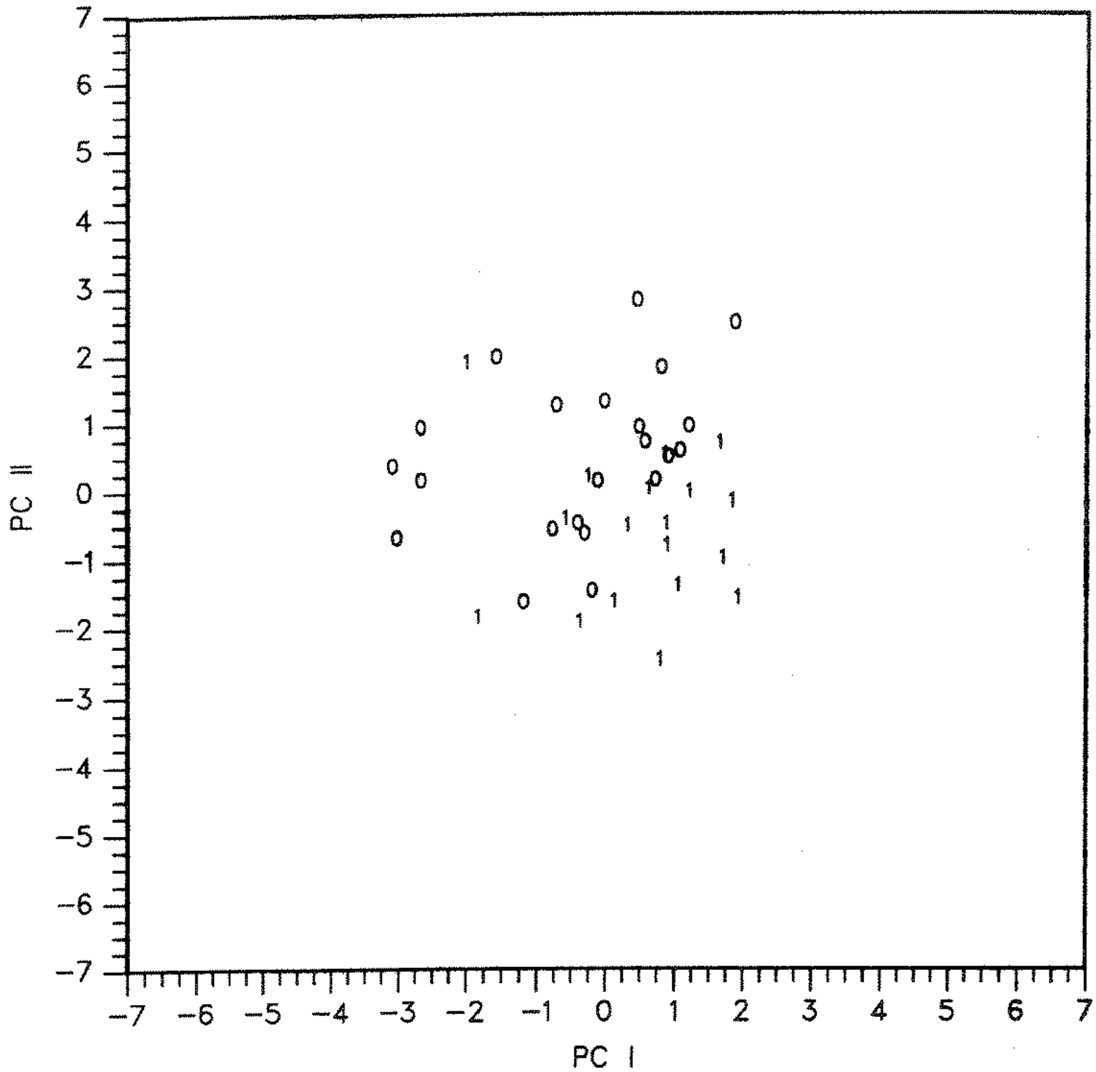


Figure 17. Principal component I versus principal component II for brown trout and rainbow trout >15 cm TL using the variables water depth, fish depth, substrate, vegetation height, velocity, and cover, September - October 1987, Bighorn River, Montana (0=brown trout, 1=rainbow trout).

Table 29. Number of locations per day and daily range of fish 255 (brown trout) implanted with pressure sensitive radio transmitter, 19 July - 28 July 1988, Bighorn River, Montana.

| July | Number | Daily range (m) |
|---|---|---|
| 19 | 3 | 0.00 |
| 20 | 14 | 10.06 |
| 21 | 15 | 17.83 |
| 22 | 19 | 17.83 |
| 23 | 22 | 29.34 |
| 24 | 19 | 19.96 |
| 25 | 17 | 21.70 |
| 26 | 12 | 26.26 |
| 27 | 7 | 67.34 |
| 28 | 1 | - |
| | Total 129 | Mean 23.38 |

Table 30. Number of locations per day and daily range of fish 270 (brown trout) implanted with pressure sensitive radio transmitter, 19 July - 28 July 1988, Bighorn River, Montana.

| July | Number | Daily range (m) |
|---|---|---|
| 19 | 2 | 0.00 |
| 20 | 14 | 0.00 |
| 21 | 12 | 59.86 |
| 22 | 17 | 27.02 |
| 23 | 19 | 28.57 |
| 24 | 15 | 32.57 |
| 25 | 23 | 51.38 |
| 26 | 19 | 65.94 |
| 27 | 19 | 45.94 |
| 28 | 1 | - |
| | Total 141 | Mean 34.59 |

Table 31. Number of locations per day and daily range of fish 280 (rainbow trout) implanted with pressure sensitive radio transmitter, 19 July - 28 July 1988, Bighorn River, Montana.

| July | Number | Daily range (m) |
|---|---|---|
| 19 | 3 | 0.00 |
| 20 | 21 | 8.46 |
| 21 | 10 | 0.00 |
| 22 | 19 | 2.64 |
| 23 | 10 | 0.00 |
| 24 | 17 | 0.00 |
| 25 | 10 | 0.00 |
| 26 | 8 | 4.18 |
| 27 | 5 | 0.00 |
| 28 | 1 | 0.00 |
| | Total 104 | Mean 1.70 |

Table 32. Number of locations and duration of monitoring (days) of trout implanted with radio transmitters, 8 August - 11 September 1987, Bighorn River, Montana.

| Fish number | Species | Number of locations | Duration of monitoring (days) |
|---|---|---|---|
| 43 | Rainbow | 31 | 35 |
| 62 | Brown | 31 | 35 |
| 65 | Brown | 36 | 35 |
| 71 | Brown | 21 | 20 |
| 88 | Rainbow | 21 | 20 |
| 97 | Rainbow | 23 | 20 |
| 110 | Brown | 12 | 11 |
| 125 | Brown | 21 | 20 |
| 138[a] | Brown | | |
| 168 | Brown | 35 | 35 |
| 188 | Rainbow | 34 | 35 |
| 196[a] | Rainbow | | |
| 207[a] | Rainbow | | |
| 215 | Brown | 21 | 35 |
| 227 | Brown | 27 | 35 |
| 237 | Brown | 34 | 35 |
| 258[a] | Rainbow | | |
| 276 | Rainbow | 16 | 20 |

[a] Trout not located after release.

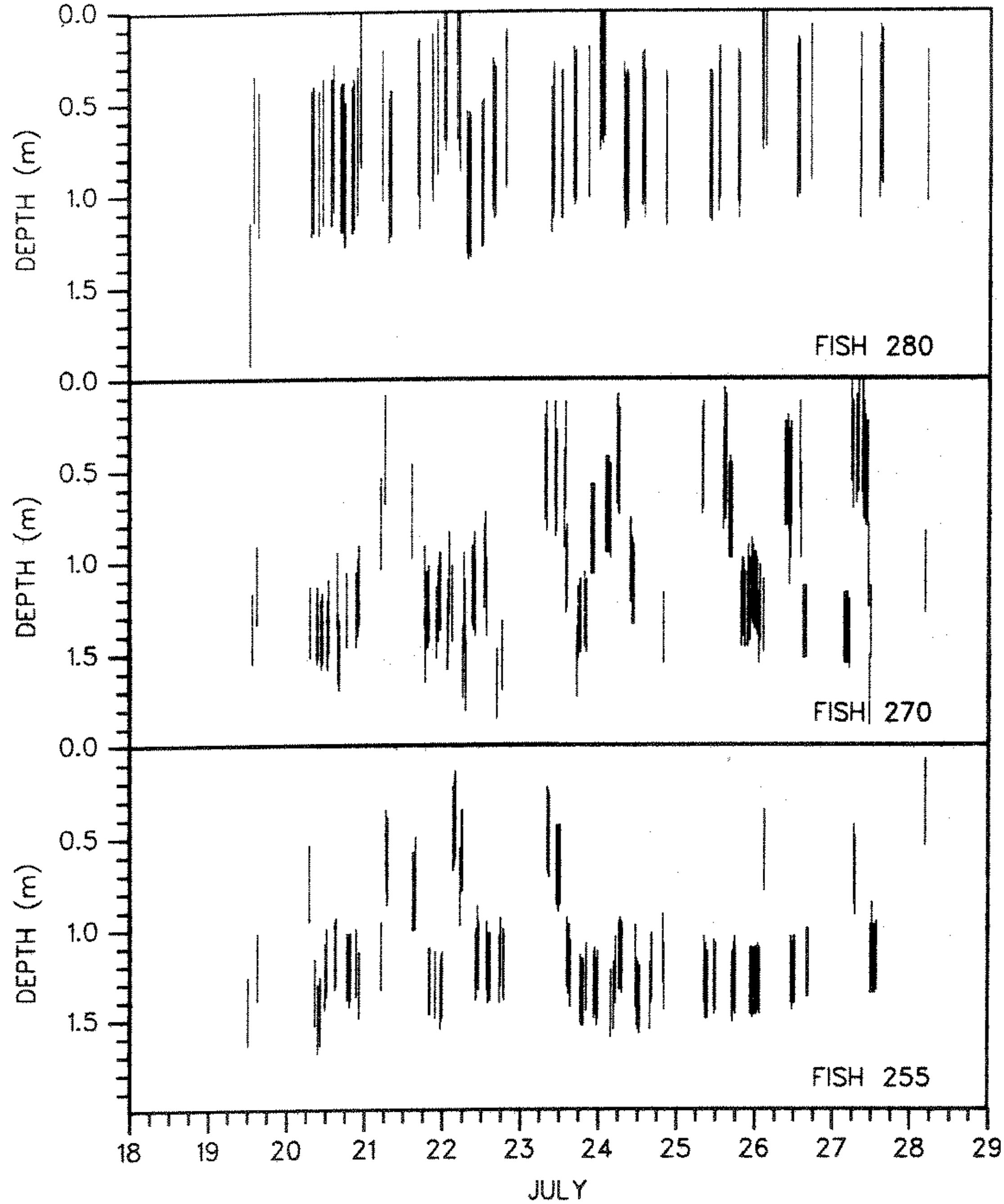


Figure 18. Fish depth determined from pressure sensitive radio transmitters, 19 July - 28 July 1988, Bighorn River, Montana (bars represent confidence interval for depth from measured pulse repetition).

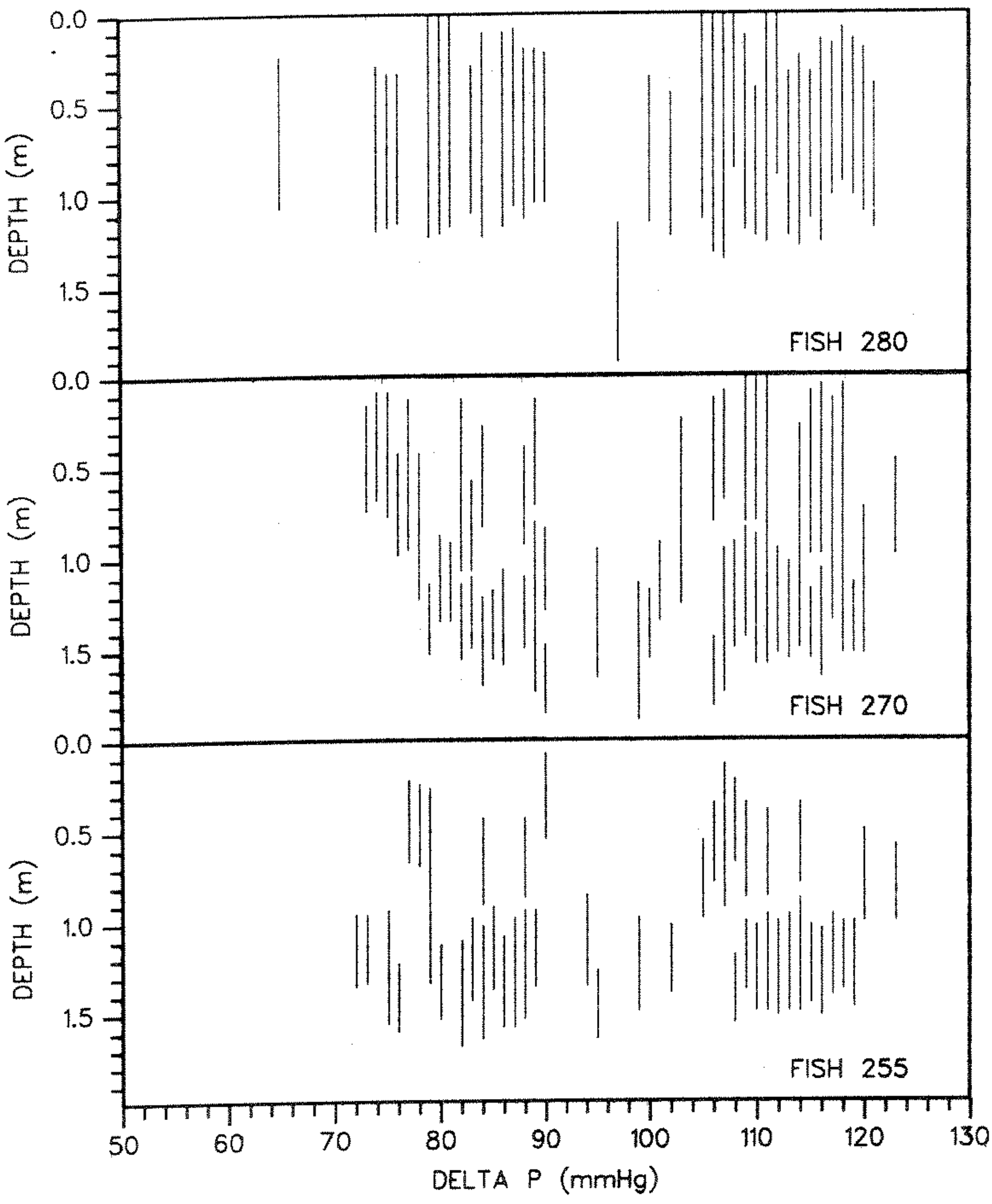


Figure 19. Fish depth determined from pressure sensitive radio transmitters at delta P levels encountered during monitoring period, 19 July - 28 July 1988, Bighorn River, Montana (bars represent confidence interval for depth from measured pulse repetition).

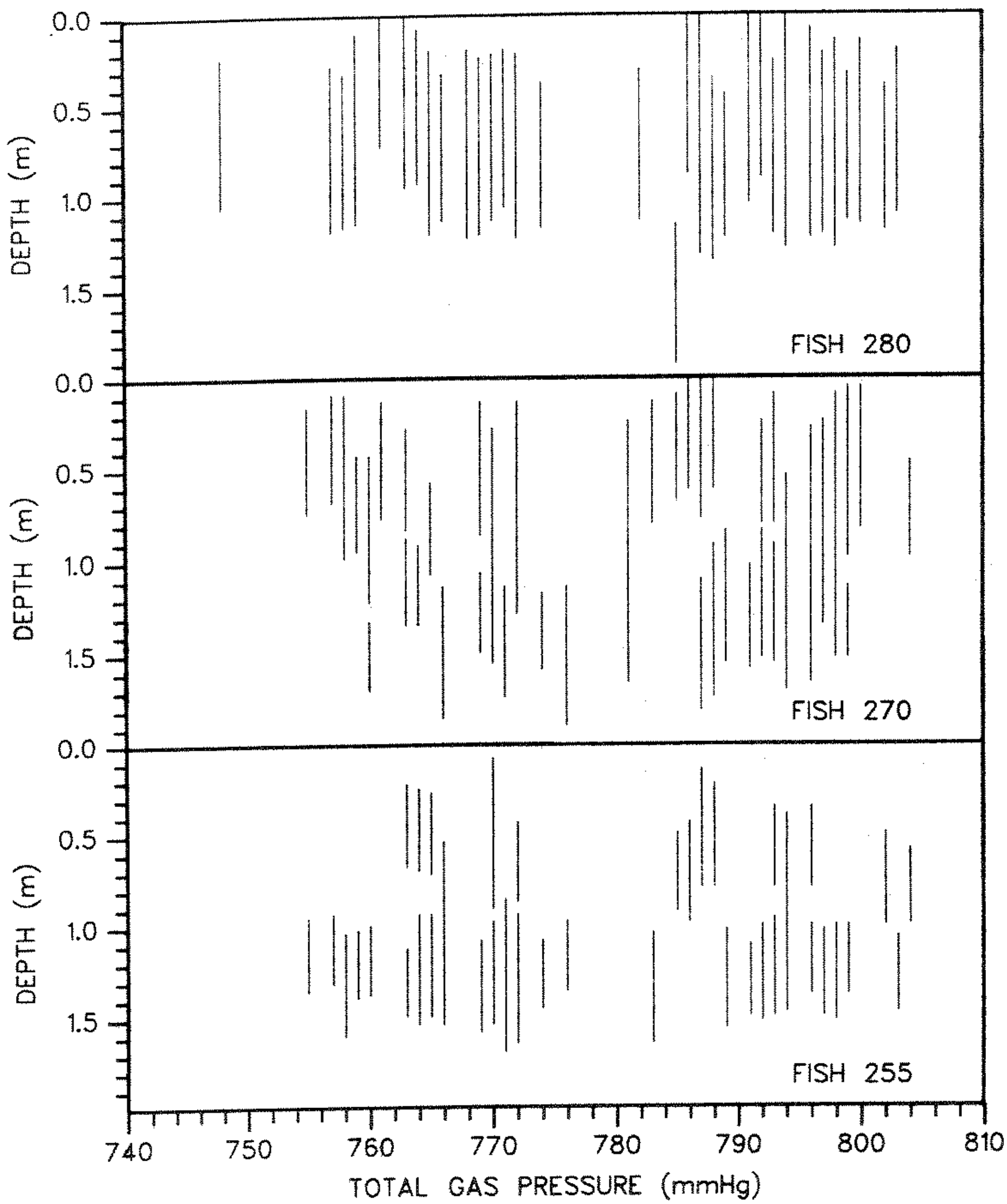


Figure 20. Fish depth determined from pressure sensitive radio transmitters at total gas pressures encountered during monitoring period, 19 July - 28 July 1988, Bighorn River, Montana (bars represent confidence interval for depth from measured pulse repetition).

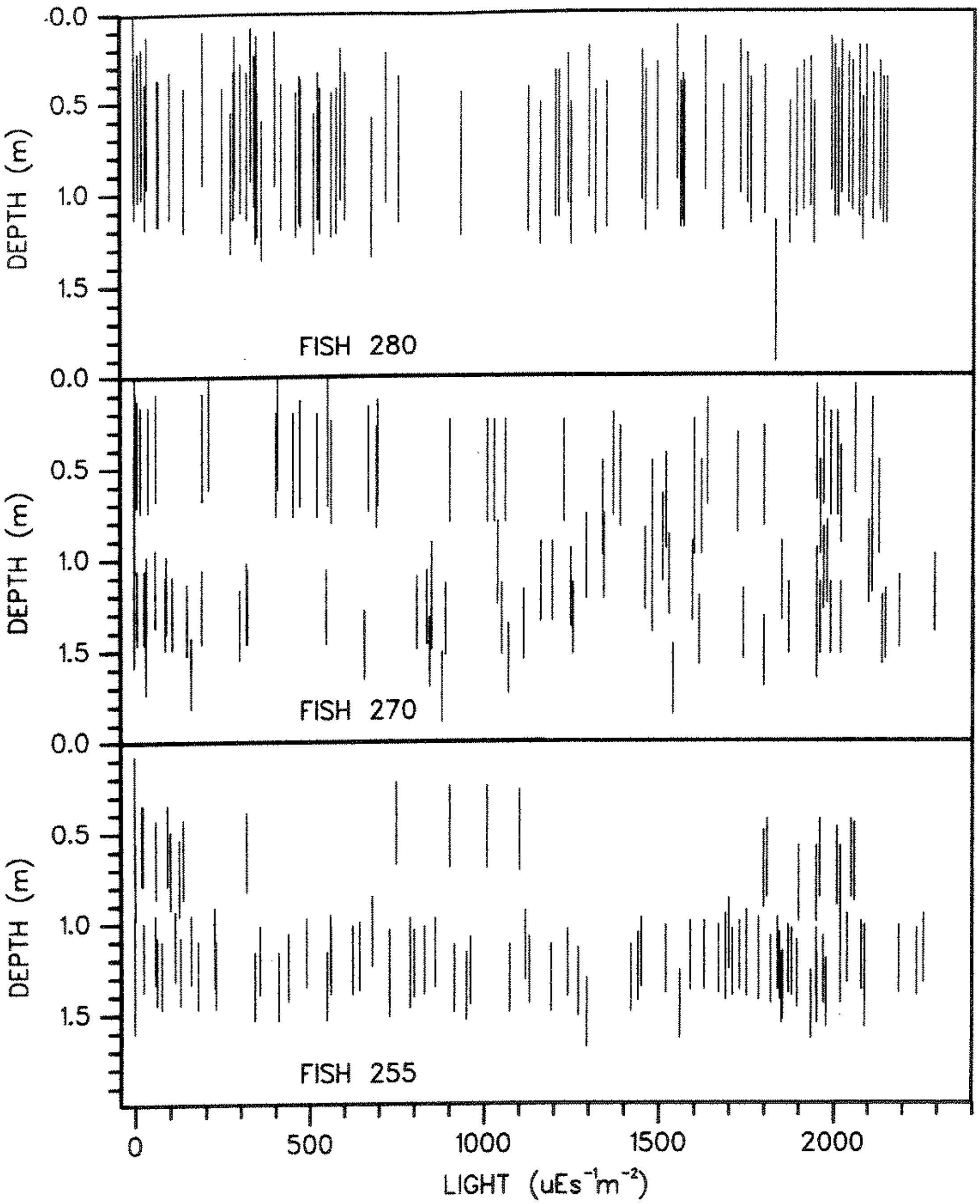


Figure 21. Fish depth determined from pressure sensitive radio transmitters at light levels recorded at time of observation, 19 July - 28 July 1988, Bighorn River, Montana (bars represent confidence interval for depth from measured pulse repetition).

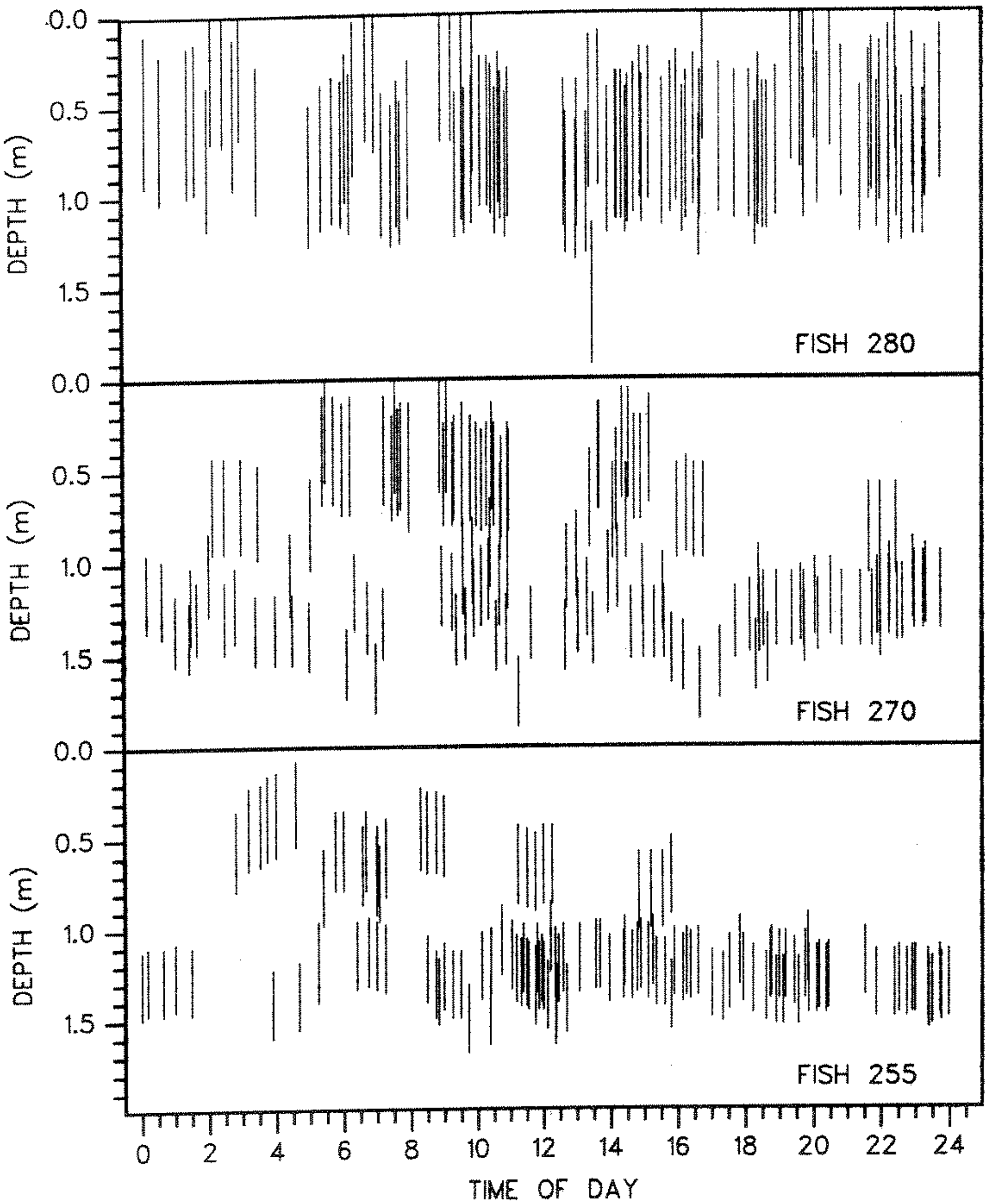


Figure 22. Fish depth determined from pressure sensitive radio transmitters at various times of day, data combined from 19 July - 28 July 1988, Bighorn River, Montana (bars represent confidence interval for depth from measured pulse repetition).

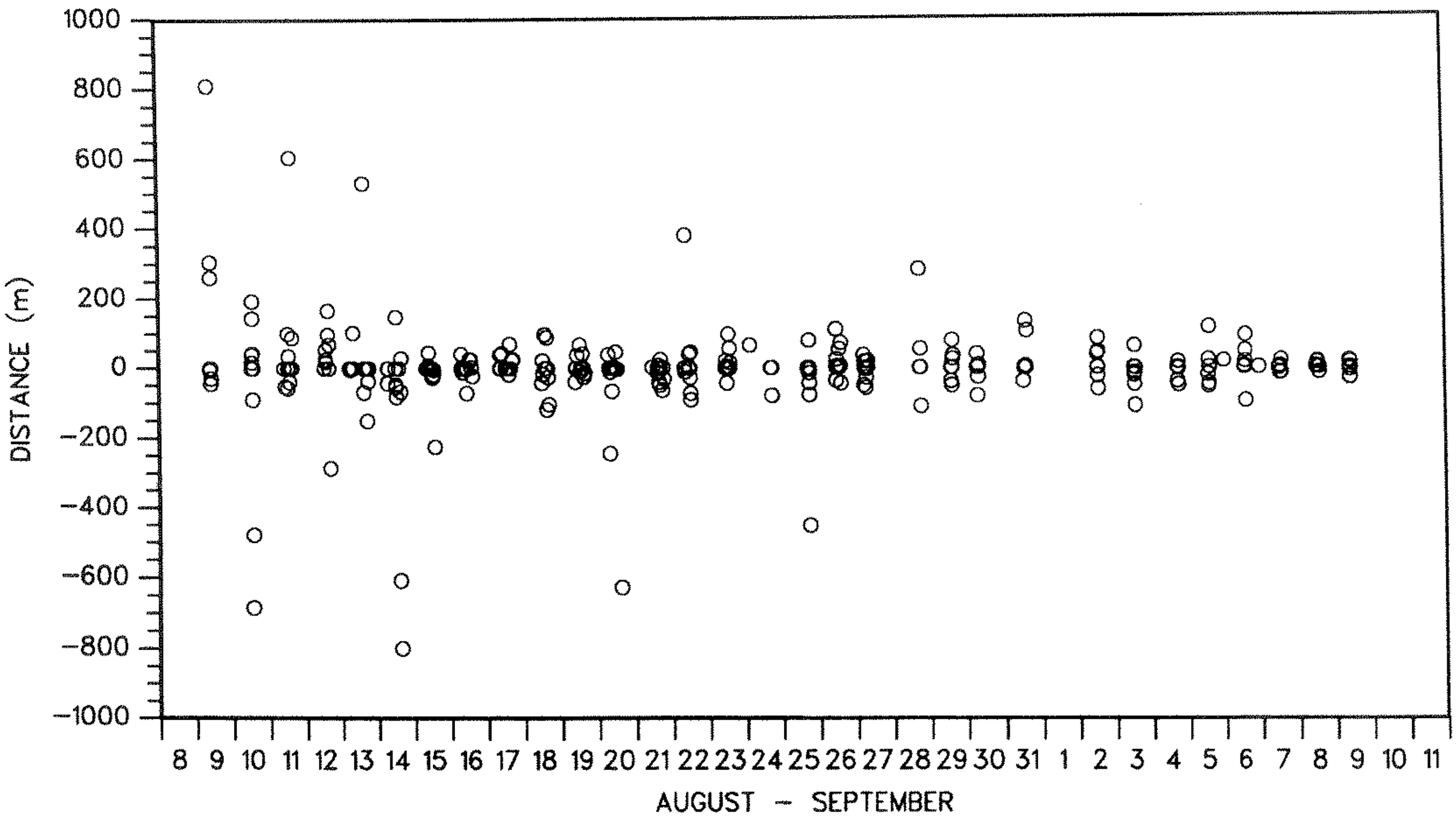


Figure 23. Distance traveled per day by radio-tagged trout, 8 August - 11 September 1987, Bighorn River, Montana (each point is an individual trout, positive distance represents movement upstream, negative distance represents movement downstream).

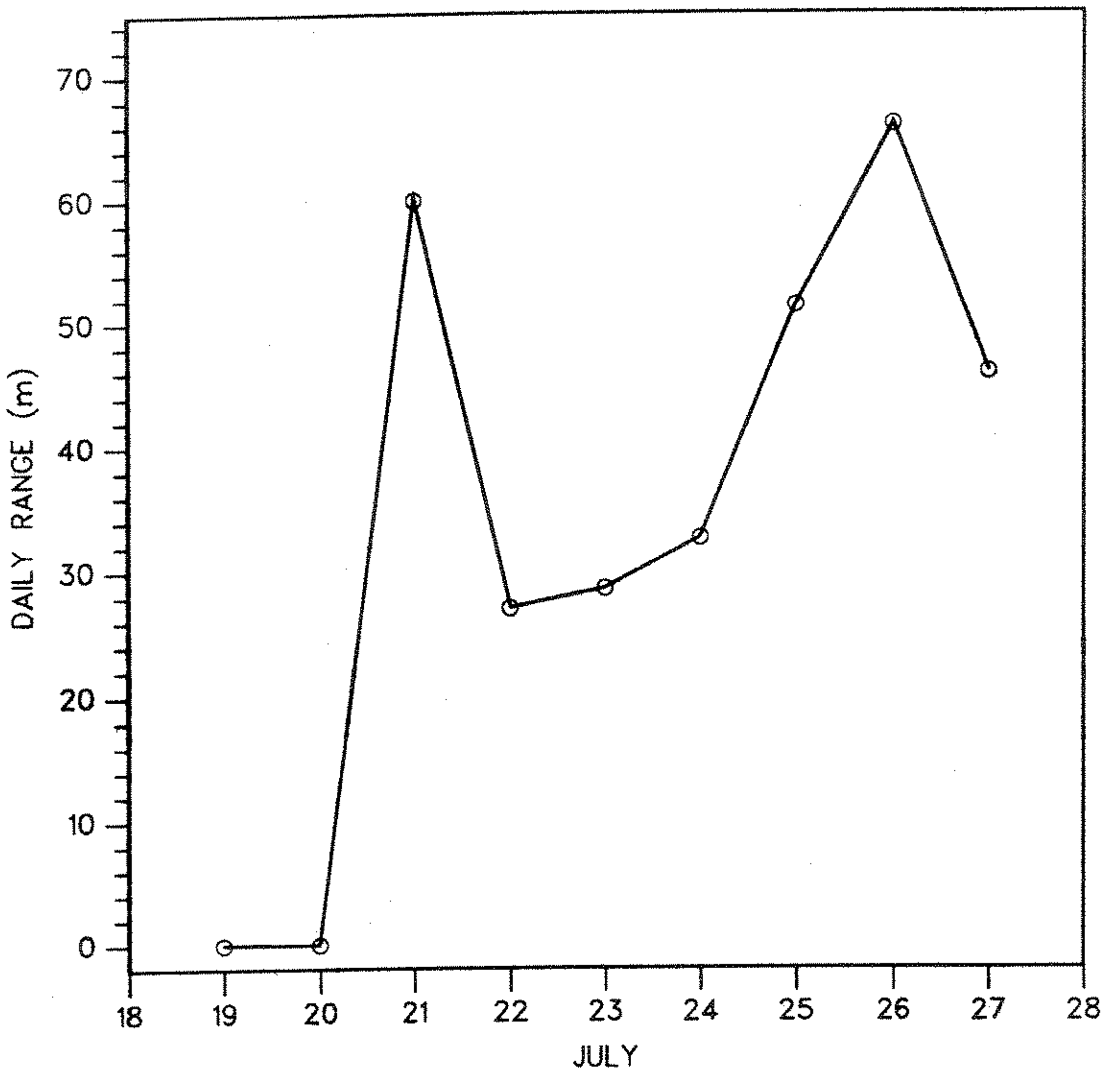


Figure 24. Daily range (m) of fish 270 (brown trout), 19 July - 28 July 1988, Bighorn River, Montana.

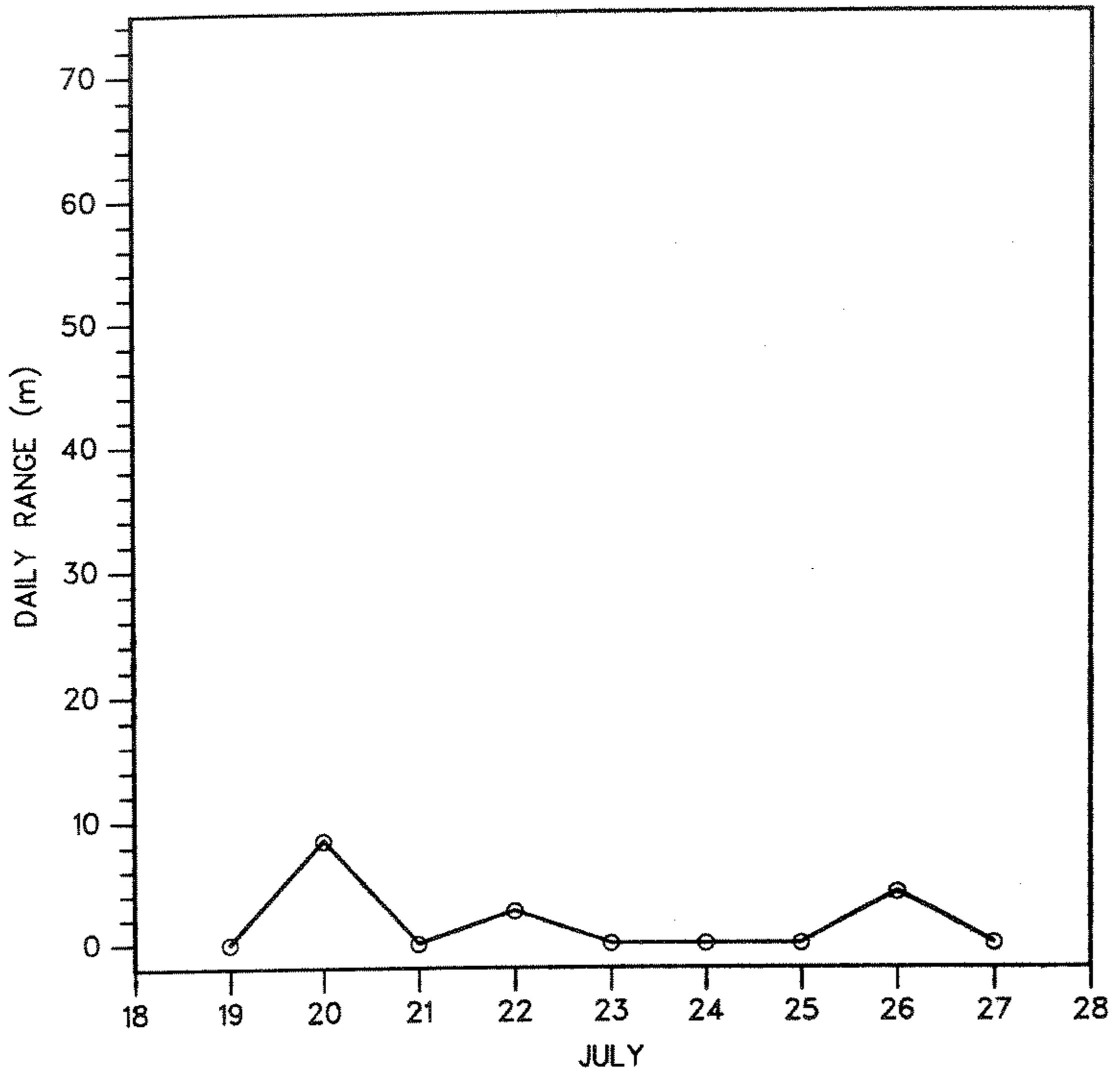


Figure 25. Daily range (m) of fish 280 (rainbow trout), 19 July - 28 July 1988, Bighorn River, Montana.

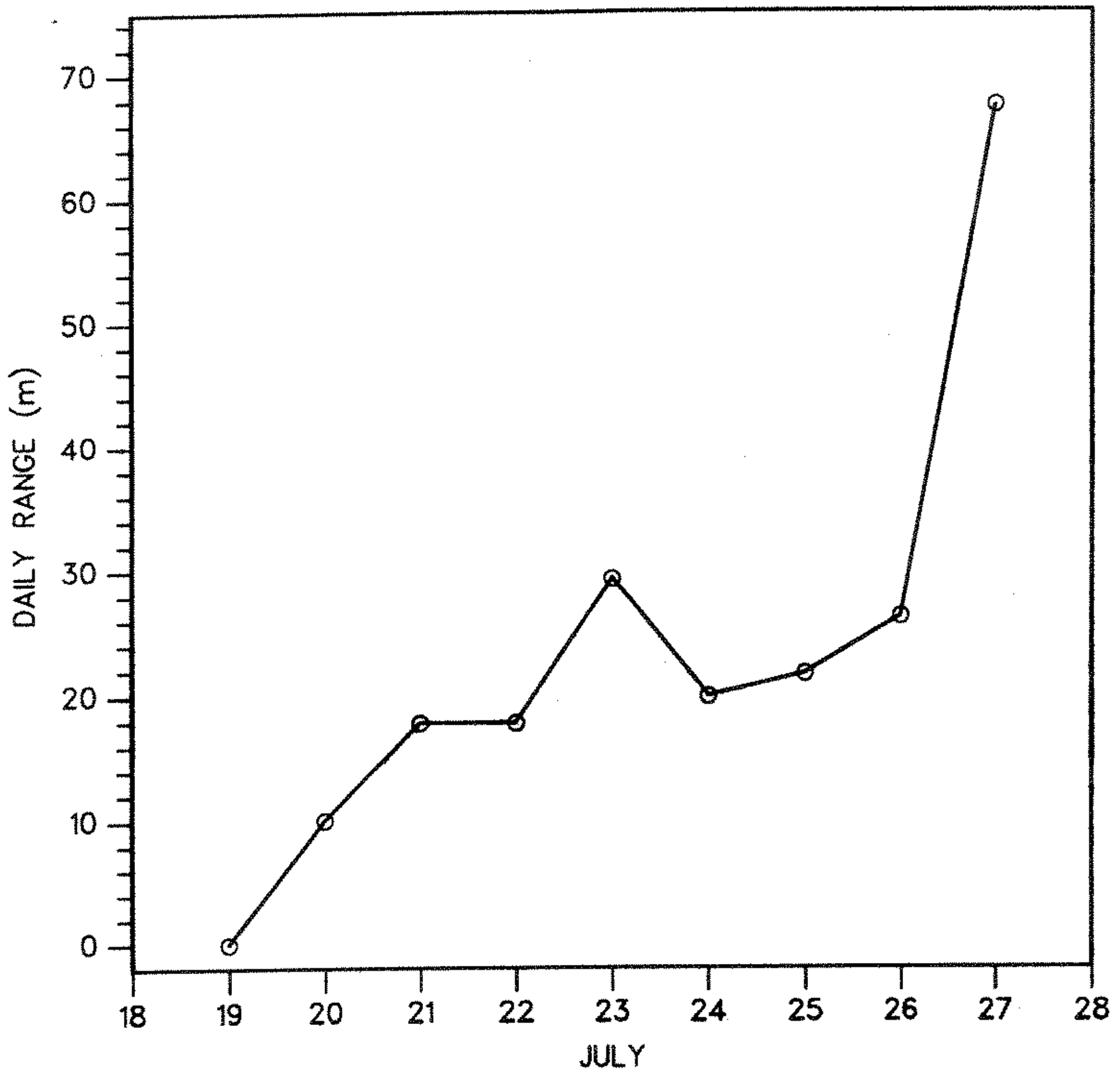


Figure 26. Daily range (m) of fish 255 (brown trout), 19 July - 28 July 1988, Bighorn River, Montana.

# DISCUSSION

Differences in habitat use between brown trout and rainbow trout did not account for the higher incidence of GBT observed in the adult brown trout population and the large difference in relative abundance between the two species. Habitat use varied seasonally as well as between size groups with few interspecific differences observed. Brown trout larger than 15 cm maintained positions relatively close to the substrate whereas rainbow trout larger than 15 cm were found at shallower average depth (fish depth). Rainbow trout, however, used a wider range of depths within the water column. Hearn and Kynard (1986) reported similar use of pool habitat by rainbow trout determined from electrofishing habitat use surveys in tributaries of the White River, Vermont. In stream channel experiments they found that rainbow trout tended to occupy positions off the substrate. The maximum difference in mean fish depth between brown trout and rainbow trout for all time periods studied in the Bighorn River was 27 cm in September - October, with brown trout occupying deeper water. For depth compensation to account for lower GBT incidence in rainbow trout, the opposite pattern of habitat use would have been expected.

Although fish depth did not differ greatly between species, rainbow trout were usually associated with slightly deeper water areas than were brown trout (1.16 m versus 1.07 m). If rainbow trout were to use the complete water column in these areas, a small amount (10 cm would provide a 1% decrease in gas supersaturation) of hydrostatic compensation would be provided. It is conceivable that rainbow trout occupied deeper water at night, decreasing their exposure to gas supersaturation, and that brown trout moved into shallower water at night, increasing their exposure. However, no diurnal movements of this type were detected using radio telemetry.

Differences in habitat use between brown trout and rainbow trout varied seasonally, with the most significant differences being fish depth and velocity. Brown trout occupied significantly deeper habitat in only one time period, September-October, whereas rainbow trout used significantly higher velocity water during all three time periods. The most critical variable in habitat selection by fluvial trout is generally thought to be water velocity (Jenkins 1969; Bachman 1984; Fausch 1984; Gatz et al. 1987), followed by cover (Lewis 1969; Gatz et al. 1987). Similar water velocities (26.7 cm/s versus 22.95 cm/s in this study) and slightly shallower depths (0.65 m versus 0.91 m) were found for adult brown trout in this study compared to those reported by Shrivell and Dungey (1983). Velocities and depths found in this study were similar to those reported for brown trout and rainbow trout in sympatry by Gatz et al. (1987). Velocity and depth used by adult brown trout and rainbow trout in the Bighorn River fell within the optimal conditions described by the suitability index (SI) curves developed for instream flow analysis (brown trout adult velocity: SI=1.0 at 15.24 cm/s; depth: SI=1.0 at 0.79 m (Raleigh et al. 1986); rainbow trout adult velocity: SI=1.0 at 15.24-60.96 cm/s; depth: SI=1.0 at >0.45 m (Raleigh et al. 1984)).

Observed differences in habitat use by adult trout of both species did not result in differences in exposure to high dissolved gas levels between length groups. Thus, size specific mortality of trout >15 cm was unlikely in the Bighorn River and does not account for the large difference in relative abundance between the two species.

Use of shallow water habitat by brown trout (mean water depth = 0.49 m) and rainbow trout (mean water depth = 0.45 m) <15 cm exposed this size group to a greater potential of developing GBT than that encountered by larger trout. Juvenile brown trout and rainbow trout are typically found at shallower depths and lower velocities than adults (Raleigh et al. 1984; Raleigh et al. 1986). Gatz et al. (1987) found allopatric age 0 rainbow trout and brown trout occupied similar water depth (25 to 35 cm), but age 0 brown trout displaced age 0 rainbow trout from shallow water in sympatric situations. Exclusion of juvenile rainbow trout from shallow water was not observed in the Bighorn River. Differences in emergence time between the two species may reduce overlap of habitat use by trout <15 cm TL. Habitat occupied by trout <15 cm TL provided less than a 0.5% reduction in hydrostatic pressure and thus exposure to gas saturation was highest in these size groups. White et al. (1988) found that 32 to 50% of brown trout fry held in cages in the Bighorn River exhibited excessive buoyancy. Connor (1988) found that daily mortality of juvenile brown trout exposed to 125% gas saturation was always greater than for rainbow trout of similar size. He found no difference in vulnerability to predation between juvenile brown trout and rainbow trout exposed to high dissolved gas levels in circular tanks compared to controls, but this may have been an artifact of the experimental design. Mortality indirectly related to high dissolved gas levels of juvenile trout with excessive buoyancy might be expected in the Bighorn River due to increased vulnerability to predation, to decreased feeding efficiency, and/or to increased energy demand related to maintaining their position in the water column. If differences in species specific mortality of juvenile trout related to dissolved gas levels occur in the Bighorn River, they are not due to differences in habitat use.

Few studies have examined sympatric populations of brown trout and rainbow trout. Of the studies examining sympatric populations of the two species, similar habitat use was found (Lewis 1969; Jenkins 1969; Bachman 1984; Baltz and Moyle 1984; Carty 1985). Gatz et al. (1987) reported evidence of asymmetrical interspecific competition. Habitat use varied significantly between allopatric and sympatric rainbow trout in their comparison. They found the water velocity the fish faced, followed by cover, to be the most critical habitat variables in the interaction between the two species.

Contrary to other studies that have found slight differences in habitat use (Raleigh et al. 1984, Raleigh et al. 1986), simialr-sized brown trout and rainbow trout in the Bighorn River occupied similar habitat with respect to water depth, fish depth (except September-October), substrate, vegetation height, and cover. Several possible conditions in the study area may account for this similarity of habitat use: 1) lack of forage fish, 2) food limitation, 3) evolutionary isolation, and 4) homogeneous habitat.

Brown trout and rainbow trout have similar diets except that brown trout >30 cm are predominantly piscivorous (Kaeding and Kaya 1978; Scott and Crossman 1973). Few forage fish were present within the study area, thus large brown trout were relegated to feed primarily on aquatic invertebrates. If food were limited in the Bighorn River, brown trout and rainbow trout could be forced to use similar habitat due to the premium it would put on food availability and on associated bioenergetically suitable feeding locations (Fausch 1984). This does not appear to be a likely explanation since aquatic invertebrates were much more abundant than reported for most Montana streams (Jim Brammer, personal communication); but since trout densities in the Bighorn River are higher than trout densities in most other Montana streams, the possibility exists that food may have been limiting.

Brown trout and rainbow trout evolved in geographic isolation, thus overlap in habitat use is not unexpected. Nikolskii (1963) maintained that species with similar geographic origins have evolved mechanisms allowing coexistence. Where brown trout have been introduced into streams with other salmonids, a decline in the other salmonid populations often occurs (Nilsson 1967).

The most likely explanation for use of similar habitat by brown trout and rainbow trout is the homogeneous nature of the Bighorn River channel. Lack of habitat diversity appears to force the species into similar patterns of habitat use. Interspecific competition (interactive segregation; Nilsson 1967) cannot be assumed simply because brown trout and rainbow trout overlapped in their use of habitat variables examined. For competition to occur the demand for the resource must exceed resource availability at any particular point in time (Birch 1957). Since allopatric conditions were not available, I could not determine if brown trout were being forced to occupy feeding locations similar to rainbow trout or if differences in water velocity use were due to species interactions. The latter appears unlikely since rainbow trout have been reported to use higher velocities, even in allopatric situations (Raleigh et al. 1984). The possibility exits that similarities in habitat use by the two species resulted from observing them at feeding sites, not refuge sites. Jenkins (1969) reported that brown trout and rainbow trout used similar feeding sites but different refuge sites. Since this study was designed to determine differences in habitat use between the two species, questions concerning interactive segregation cannot be addressed.

Seasonal shifts of trout distribution in the Bighorn River appeared to be related to seasonal changes in availability of suitable habitat created by aquatic vegetation. Trout were concentrated along river banks during winter and spring and used bank and midchannel areas during summer and fall. I hypothesize that increased abundance of trout in midchannel areas during late spring and summer was associated with habitat refuges provided by aquatic vegetation growth. As water temperature and photo-period increased in summer and fall, aquatic vegetation became dense. Because of uniform stream channel shape and the scarcity of low velocity microhabitat locations in the midchannel areas during winter and early spring, I believe trout concentrated along the banks to take advantage of lower river velocities. Maximum velocity theoretically occurs at the surface in the centerline of the channel (Leopold et al. 1964). Near-bank areas in shallow water provide large quantities of substrate area per volume of water (compared to the volume of water over an equal size area in deeper midchannel area) creating microhabitat locations energetically suitable for trout. As the season progressed, growth of aquatic vegetation may have provided reduced velocity areas in midchannel, making this habitat more available to trout.

Movement of trout into midchannel areas and the decrease of external symptoms of GBT coincided with seasonal increases in aquatic vegetation. The Bighorn River was typically free of dense aquatic vegetation in the winter and spring. The seasonal shift in distribution of trout was more apparent in 1987 than in 1988, perhaps due to small sample size in 1988 and/or reduced amounts of aquatic vegetation that year. Water temperature was cooler in 1988 than in 1987 (maximum in section 1 in 1987: 15.0 C, in 1988: 11.3 C) and remained relatively constant from spring through fall, probably explaining the reduced growth of aquatic vegetation. A seasonal shift in trout distribution was detected even with similar spring, summer, and fall water temperatures in 1988 suggesting that even small amounts of cover created by aquatic vegetation influenced trout distribution. No correlations among snorkel lane counts and dissolved gas level, visibility, light, and discharge were detected; some snorkel lane counts were correlated with water temperature. Dissolved gas levels remained relatively high throughout the year (Tables 2-5), and the percent of contribution of oxygen and nitrogen remained relatively constant at various levels of TGP (White et al. 1988).

The importance of aquatic vegetation as cover for trout has been reported by several authors. Gosse and Helm (1979) found that aquatic macrophytes were very important to brown trout as cover in the Provo River, Utah. The aquatic macrophytes produced areas of reduced velocity near the stream bottom. Brown trout used this cover to a larger extent than available bankside cover. Boussu (1954) also found that aquatic vegetation provided cover for trout in Trout Creek, Gallatin County, Montana.

In a study to determine relationships between a trout population and cover, he found a 71% reduction in total trout biomass after aquatic vegetation was removed. In a study to determine if microhabitat use changed temporally or spatially, Ross et al. (1987) reported findings (discriminant function analysis) that suggest that seasonal changes in aquatic vegetation may result in seasonal shifts in habitat use of fish in Black Creek, Mississippi.

Bighorn River trout appear to show seasonal variation in microhabitat use, changing their distribution in response to changes in habitat availability. Felley and Felley (1987) found habitat choice to be a dynamic process. Using factor analysis they found that different species select habitat according to different environmental parameters and seasonally change their habitat use. Of the species studied, most selected habitats based on current speed, amount of debris (leaves and sticks on bottom: presence or absence), and cover (defined as structure or vegetation in which fish might hide: presence or absence). Grossman et al. (1987a and 1987b) found seasonal variation in cyprinid (*Barbus haasi*, *Barbus graellsii*, and *Chondrostoma toxostoma*) microhabitat use was strongly correlated with seasonal changes in microhabitat availability.

The availability of midchannel habitat may have provided hydrostatic compensation for trout moving in and out of deeper midchannel areas. An increase in hydrostatic pressure associated with an increase in water depth of 1 m would decrease gas saturation by approximately 10% (Gray and Haynes 1977). If dissolved gas levels were near thresholds for bubble growth in salmonids (White et al. 1988), the compensation provided by midchannel depths (approximately 1.80 m) would provide a refuge from gas supersaturation. Critical thresholds for bubble growth vary, ranging from swimbladder overinflation, which is the lowest, to the threshold for bubble formation in the cardiovascular system (White et al. 1988). Estimates of threshold levels for bubble formation (swimbladder and cardiovascular) range from 110 - 117% TGP saturation (Connor 1988, White et al. 1988). Total gas pressure averaged 116.3% saturation (range: 109.2 - 122.7) at Rkm 0.6 and averaged 115.5% saturation (range: 106.8 - 127.9) at Rkm 4.8 in 1987. Threshold criteria apply to fish at the water surface. Hydrostatic compensation may be important in minimizing mortality. This may explain the decreased incidence of GBT in trout during late spring and early summer though dissolved gas levels remained high and relatively constant. When sufficient vegetation was present, trout used deeper water areas that may have compensated for high gas levels. Shallow depths provided little hydrostatic compensation when trout were concentrated along the banks. In section 1 during 1987, cardiovascular bubble growth would not have occurred in fish at a depth > 0.5 m (White et al. 1988). The only alternative to depth compensation for avoiding high dissolved gas levels was for trout to move downstream into areas of lower dissolved gas pressure. Downstream movements would have had to be large due to the persistence of high dissolved gas levels throughout the length of the study area. Such large downstream movements were not detected among radio tagged brown trout and rainbow trout. Also, the number of trout counted in section 1 (highest dissolved gas levels) was always greater than in section 2.

Radio tagged trout did not appear to compensate for high dissolved gas levels. During tests in which river dissolved gas levels were modified, radio tagged trout generally did not shift location or depth. Diel shifts in fish depth were probably associated with insect emergence. Both brown trout tagged in 1988 used a wider range of depth than the rainbow trout and were often located in shallow riffle areas during periods of insect emergence. Movement of the rainbow trout was very localized. The only indication of a possible behavioral response was a slight increase in daily range (not sounding) in one brown trout and the rainbow trout during periods of high dissolved gas levels in 1988. The larger amount of local movement during the 6 d following release in 1987 may have been due to handling stress rather than dissolved gas levels since these trout were held for up to 20 h before release. This increased movement activity was not detected in 1988 when fish were released immediately after surgery.

Resident trout have been reported to remain in localized areas during most of the year. Using mark and recapture methods Harcup et al. (1984) found that movements >50 m of brown trout (1+ years and older) were rare with the majority being <15 m. Hesthagen (1988) recaptured between 85 - 89% of resident brown trout (age 2+ to 9+ years) within 45 m of their release point throughout a 3 month period. My data and other tagging data from the Bighorn River (White et al. 1988) indicated a similar lack of movement.

Modifications of flow pattern through Afterbay Dam were an effective way to alter gas levels in the Bighorn River. A sufficient reduction in dissolved gas levels may reduce the incidence of GBT observed downstream. The amount of reduction in gas levels needed to reduce incidence of GBT depends on physiological thresholds for bubble formation (White et al. 1988). An operational schedule that favored use of radial gates and minimized use of sluiceway gates reduced gas supersaturation at the discharge levels experienced during the study. Such an operational schedule is under the constraints of Afterbay Reservoir water level and operation of the Yellowtail Dam power plant.

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# APPENDICES

# APPENDIX A

Water Quality

Table 33. Mean and ranges of water quality parameters of 12 samples from the Bighorn River at the gagehouse below Afterbay Dam from 5 January - 1 December, 1987 (meq/l - milliequivalent/liter).

| Parameter | Mean | Range | meq/l |
|---|---|---|---|
| Total hardness (mg/l as $CaCO_3$) | 284.00 | 209 - 332 | 5.68 |
| Total alkalinity (mg/l as $CaCO_3$) | 153.00 | 80 - 172 | 3.06 |
| Bicarbonate alkalinity (mg/l $HCO_3$) | 186.00 | 98 - 210 | 3.05 |
| Calcium (mg/l) | 73.00 | 49 - 85 | 3.65 |
| Magnesium (mg/l) | 25.00 | 20 - 29 | 2.08 |
| Sodium (mg/l) | 73.00 | 59 - 92 | 3.17 |
| Potassium (mg/l) | 4.00 | 2 - 4 | 0.10 |
| Chloride (mg/l) | 10.00 | 7 - 13 | 0.29 |
| Fluoride (mg/l) | 0.40 | 0.3 - 0.6 | 0.02 |
| Nitrate + Nitrite (mg/l) | 0.53 | 0.36 - 0.96 | 0.04 |
| Sulfate (mg/l) | 264.00 | 188 - 332 | 5.50 |
| Total dissolved solids (mg/l) | 549.00 | 452 - 452 | |
| Conductivity (micromhos/cm) | 737.00 | 590 - 937 | |
| pH | 8.10 | 7.9 - 8.3 | |
| Total phosphorus as P (mg/l) | 0.08 | <0.02 - 0.28 | |
| Ortho-phospahate as P (mg/l) | 0.05 | <0.02 - 0.18 | |
| Ammonia nitrogen as N (mg/l) | 0.20 | 0.13 - 0.22 | |
| Total Kjeldahl | 0.50 | <0.20 - 1.52 | |

# APPENDIX B

## Calibration of Pressure Sensitive Radio Transmitters

## Calibration of Pressure Sensitive Radio Transmitters

Pressure sensitive radio transmitters used in 1987 were ineffective for determining depth selection by trout. Accurate determination of depth was not possible due to insufficient pulse repetition change with changes in depth and to electronic drift.

Lack of sufficient change in pulse repetition with depth change resulted in a low calculated regression slope (Table 34). Since the regression slope was used to interpret depth change, and influence depth resolution of the transmitter (discrimination interval), resolution was not sufficient to accurately measure water depth occupied by radio-tagged trout.

Electronic drift, determined by calibrating recovered transmitters, was also large. Electronic drift resulted in a change in the relationship between pulse repetition and depth and also reduced the strength of the relationship (Table 34). Electronic drift, determined by calibrating recovered transmitters, was also large.

The graph illustrating how unlimited simultaneous discrimination intervals were generated indicates the need for a steeper regression slope for accurate depth resolution (Figure 27). Pressure sensitive radio transmitters used in 1988 where designed with a larger change in pulse repetition with change in depth creating a steeper slope. A steeper regression slope (with a high correlation between pulse repetition and depth) in the calibration of 1988 PSRTs decreased the width of the discrimination interval.

Electronic drift occurred in all 1987 PSRTs that were recovered and recalibrated (Table 34). The relationship between pulse repetition time and depth changed and became weaker. Because of electronic drift, determination of depth resolution was calculated by using the most extreme low and high depth value at a particular pulse repetition from both the preimplantation calibration and recovery calibration (Figure 28). Electronic drift occurred in 1988 PSRTs, but was very slight (Table 35). The three PSRTs used in 1988 were effective in determining fish depth. There was high correlation between pulse repetition and depth which lead to steeper regression slopes.

Table 34. Slope and Y-intercept values for regression equations and pulse repetition/depth relationships for pressure sensitive radio transmitters implanted in brown trout and rainbow trout, August 1987, Bighorn River, Montana (second entry for a transmitter is recovered and recalibrated radio transmitter data).

| Transmitter frequency | Slope | Y-intercept | Pulse repetition (s) at depth: 0 m | 1 m | 2 m | 3 m | r-squared |
|---|---|---|---|---|---|---|---|
| 30.071 | 0.00083 | 1.554 | 1.554 | 1.555 | 1.555 | 1.556 | 0.6658 |
| 30.071 | -0.00132 | 1.539 | 1.539 | 1.537 | 1.536 | 1.535 | 0.1801 |
| 30.088 | -0.01196 | 1.298 | 1.298 | 1.287 | 1.275 | 1.263 | 0.9914 |
| 30.097 | -0.01612 | 1.1551 | 1.551 | 1.535 | 1.519 | 1.503 | 0.9818 |
| 30.097 | -0.01402 | 1.528 | 1.528 | 1.513 | 1.498 | 1.482 | 0.9438 |
| 30.110 | -0.01616 | 1.629 | 1.629 | 1.613 | 1.597 | 1.581 | 0.9928 |
| 30.125 | -0.01274 | 1.582 | 1.582 | 1.569 | 1.557 | 1.554 | 0.9580 |
| 30.125 | -0.01027 | 1.526 | 1.526 | 1.515 | 1.505 | 1.495 | 0.4044 |
| 30.138 | -0.00838 | 1.548 | 1.548 | 1.539 | 1.531 | 1.523 | 0.9720 |
| 30.258 | -0.00917 | 1.527 | 1.527 | 1.518 | 1.509 | 1.500 | 0.9278 |
| 30.276 | -0.01472 | 1.551 | 1.551 | 1.536 | 1.521 | 1.507 | 0.9729 |
| 30.276 | -0.01235 | 1.542 | 1.542 | 1.530 | 1.518 | 1.505 | 0.3348 |

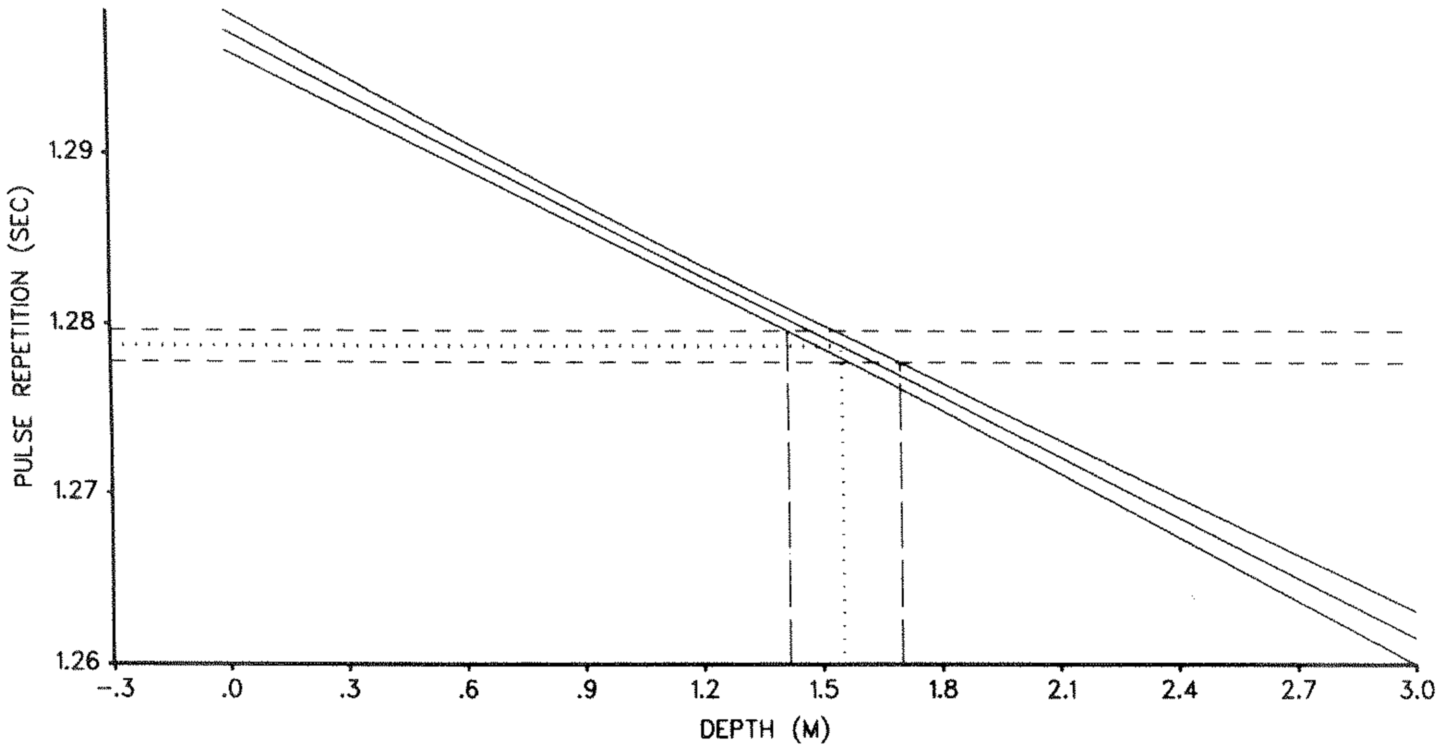


Figure 27. Unlimited simultaneous discrimination intervals for pressure sensitive radio transmitter 30.088 before implantation, 1987, Bighorn River, Montana (solid line = regression of pulse repetition on depth, with confidence interval bands; dashed lines = confidence interval for mean Y given observed Y; dotted lines = point estimate of X based on regression; broken lines = discrimination interval for X given Y).

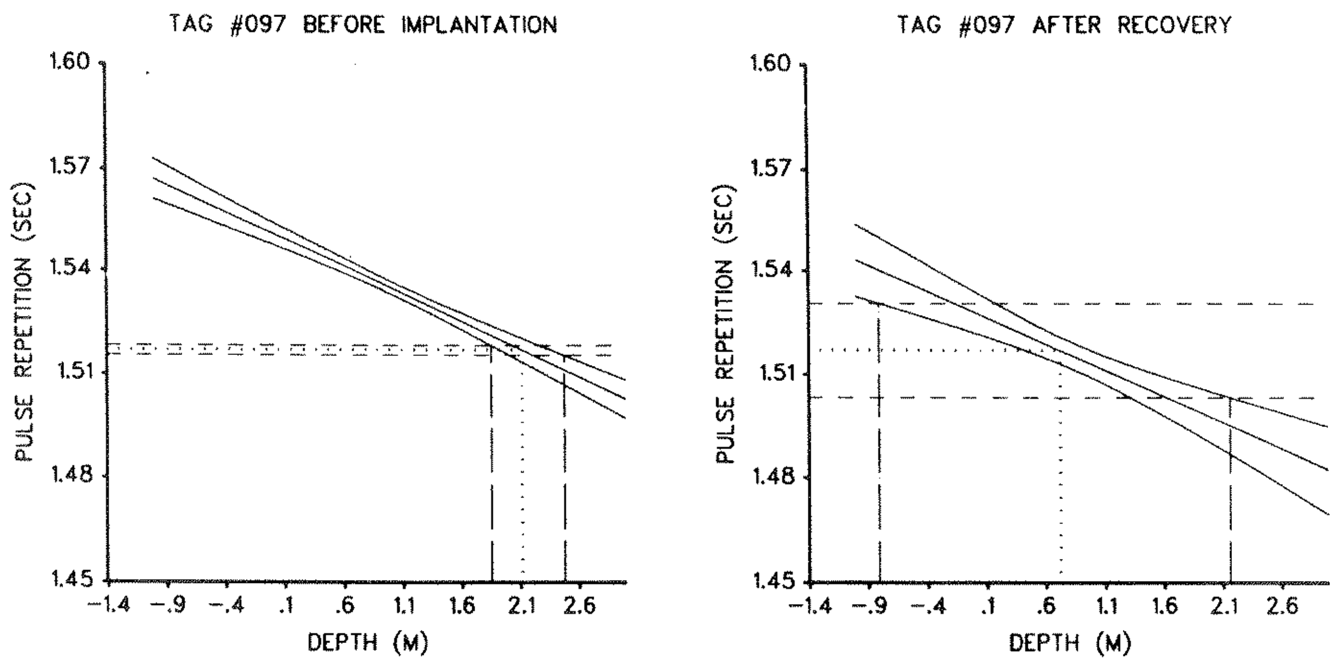


Figure 28. Unlimited simultaneous discrimination intervals for pressure sensitive radio transmitter 30.097 before implantation and recovery, 1987, Bighorn River, Montana (solid line = regression of pulse repetition on depth, with confidence interval bands; dashed lines = confidence interval for mean Y given observed Y; dotted lines = point estimate of X based on regression; broken lines = discrimination interval for X given Y).

Table 35. Slope and Y-intercept values for regression equations and pulse repetition/depth relationships for pressure sensitive radio transmitters implanted in brown trout and rainbow trout, July 1988, Bighorn River, Montana (second entry for a transmitter is recovered and recalibrated radio transmitter data).

| Transmitter frequency | Slope | Y-intercept | Pulse repetition (s) at depth: | | | | r-squared |
|---|---|---|---|---|---|---|---|
| | | | 0 m | 1 m | 2 m | 3 m | |
| 30.255 | 0.05015 | 0.720 | 0.720 | 0.770 | 0.820 | 0.870 | 0.9919 |
| 30.255 | 0.05145 | 0.724 | 0.724 | 0.776 | 0.827 | 0.878 | 0.9913 |
| 30.270 | 0.02964 | 0.398 | 0.398 | 0.428 | 0.457 | 0.487 | 0.9818 |
| 30.270 | 0.03084 | 0.305 | 0.395 | 0.425 | 0.456 | 0.487 | 0.9936 |
| 30.280 | 0.04764 | 0.720 | 0.720 | 0.768 | 0.815 | 0.863 | 0.9516 |
| 30.280 | 0.04975 | 0.729 | 0.729 | 0.778 | 0.828 | 0.878 | 0.9796 |

# APPENDIX C

## Gas Levels

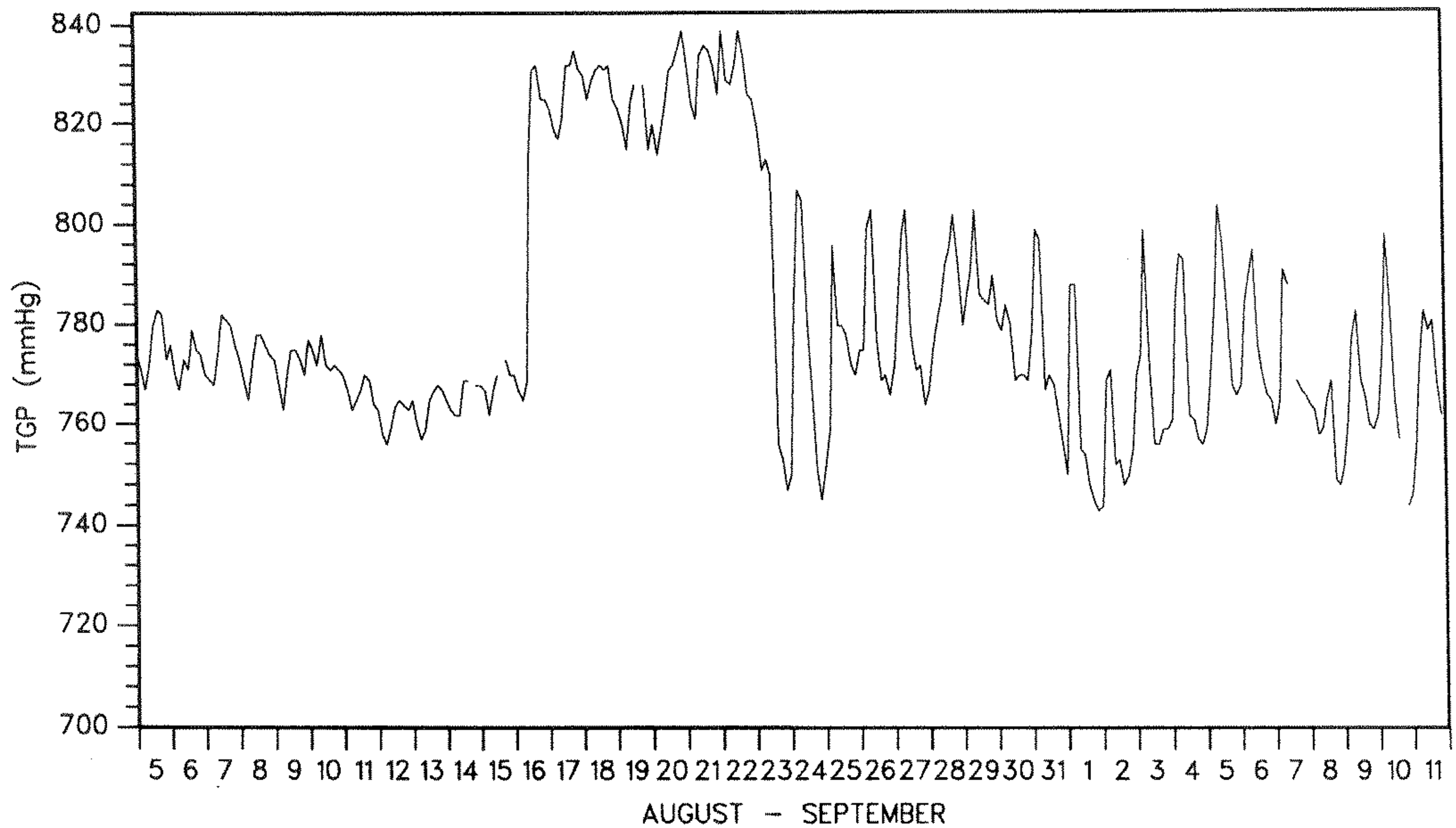


Figure 29. Total gas pressure (mmHg) measured at satellite station Rkm 0.6, 5 August - 11 September 1987, Bighorn River, Montana.

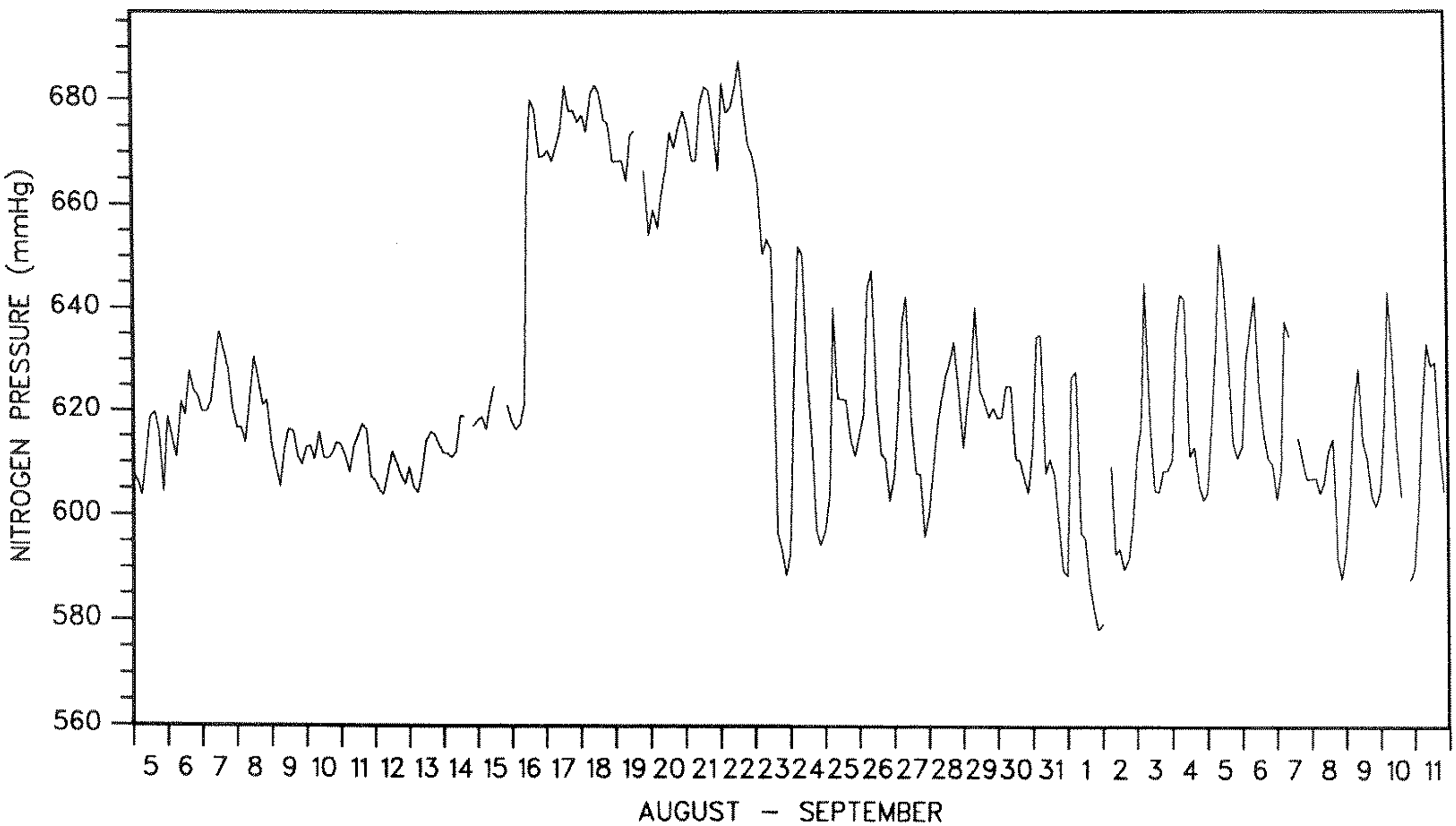


Figure 30. Nitrogen pressure (mmHg) measured at satellite station Rkm 0.6, 5 August - 11 September 1987, Bighorn River, Montana.

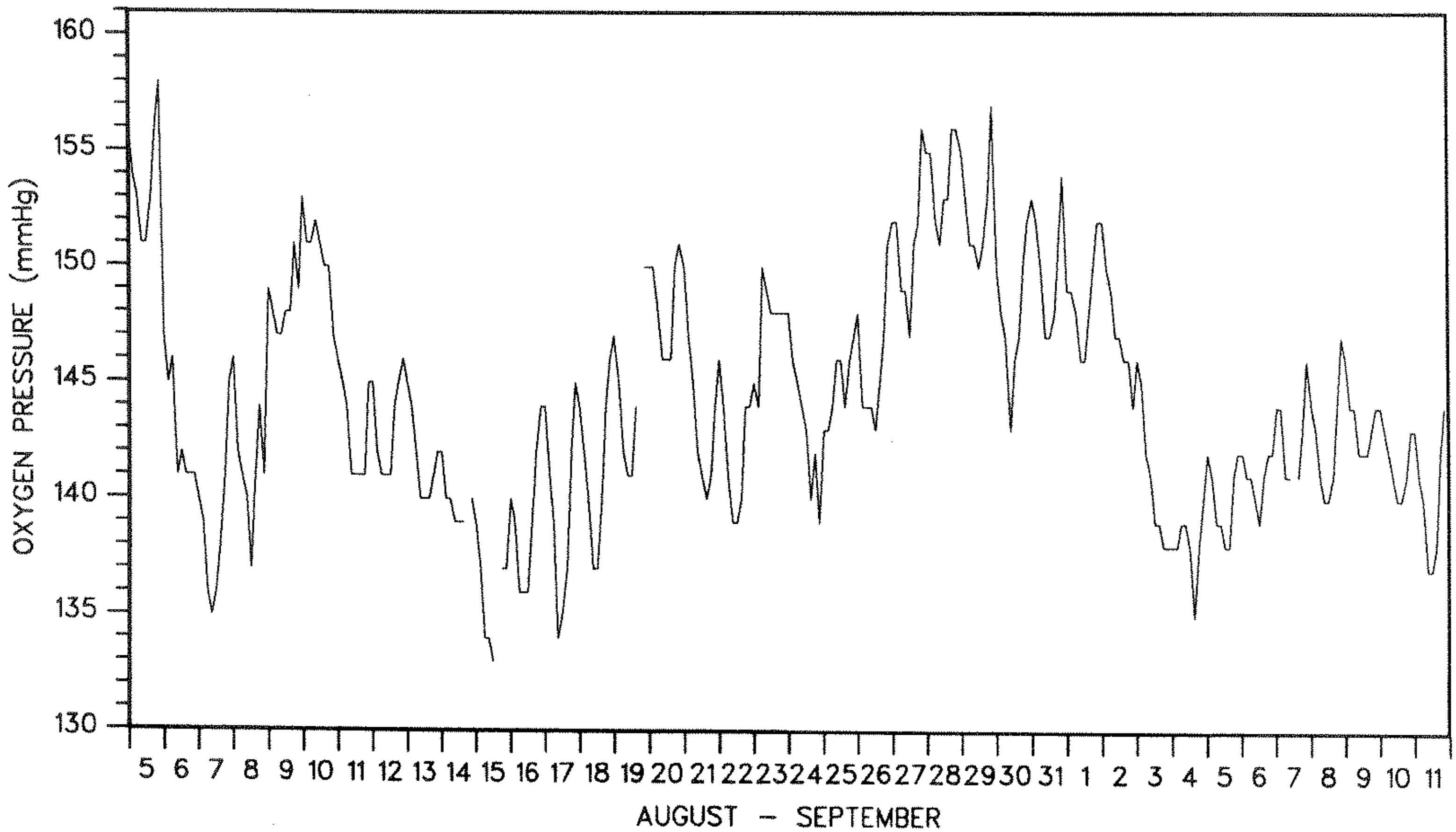


Figure 31. Oxygen pressure (mmHg) measured at satellite station Rkm 0.6, 5 August - 11 September 1987, Bighorn River, Montana.

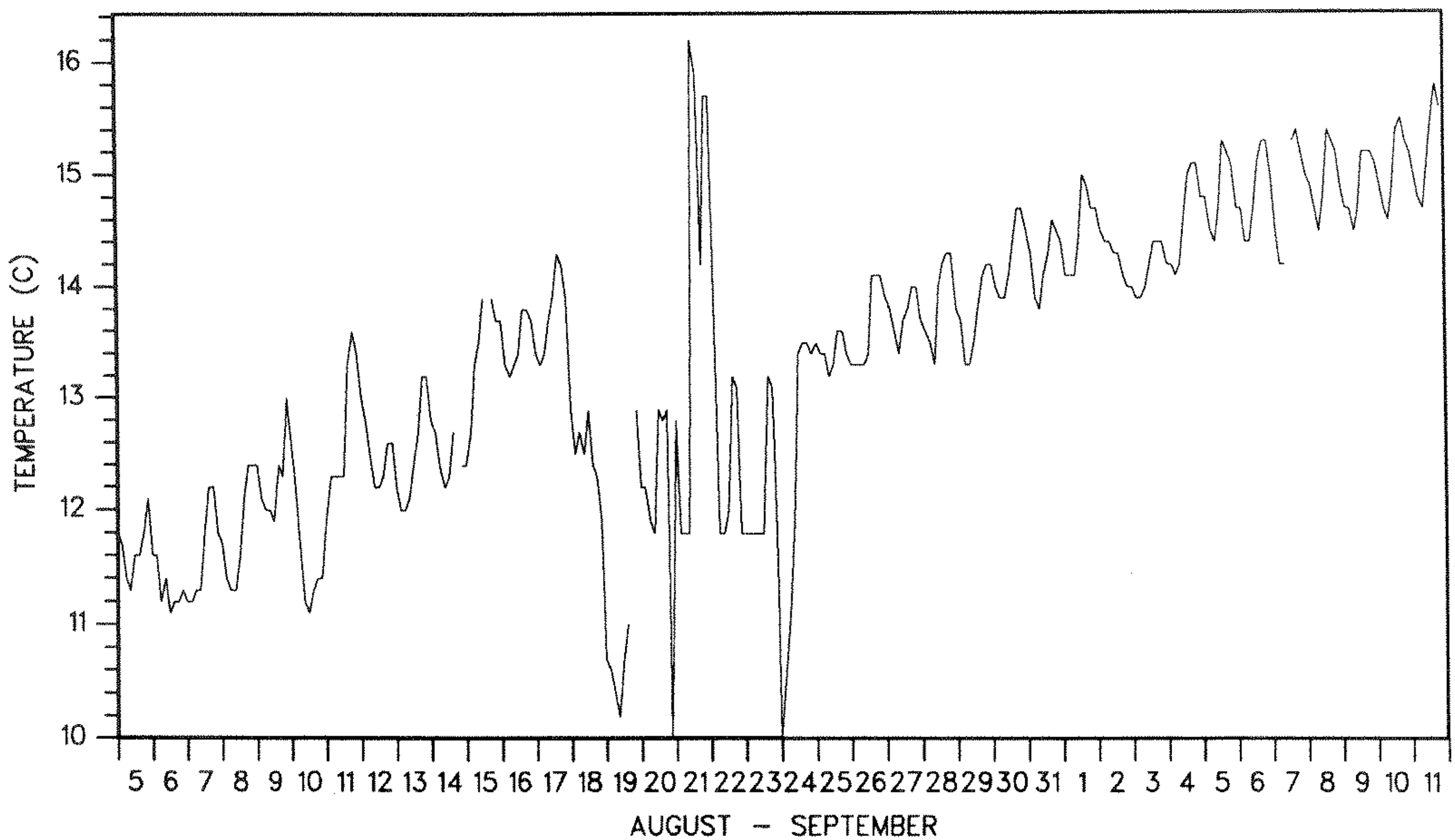


Figure 32. Water temperature (C) measured at satellite station Rkm 0.6, 5 August - 11 September 1987, Bighorn River, Montana.

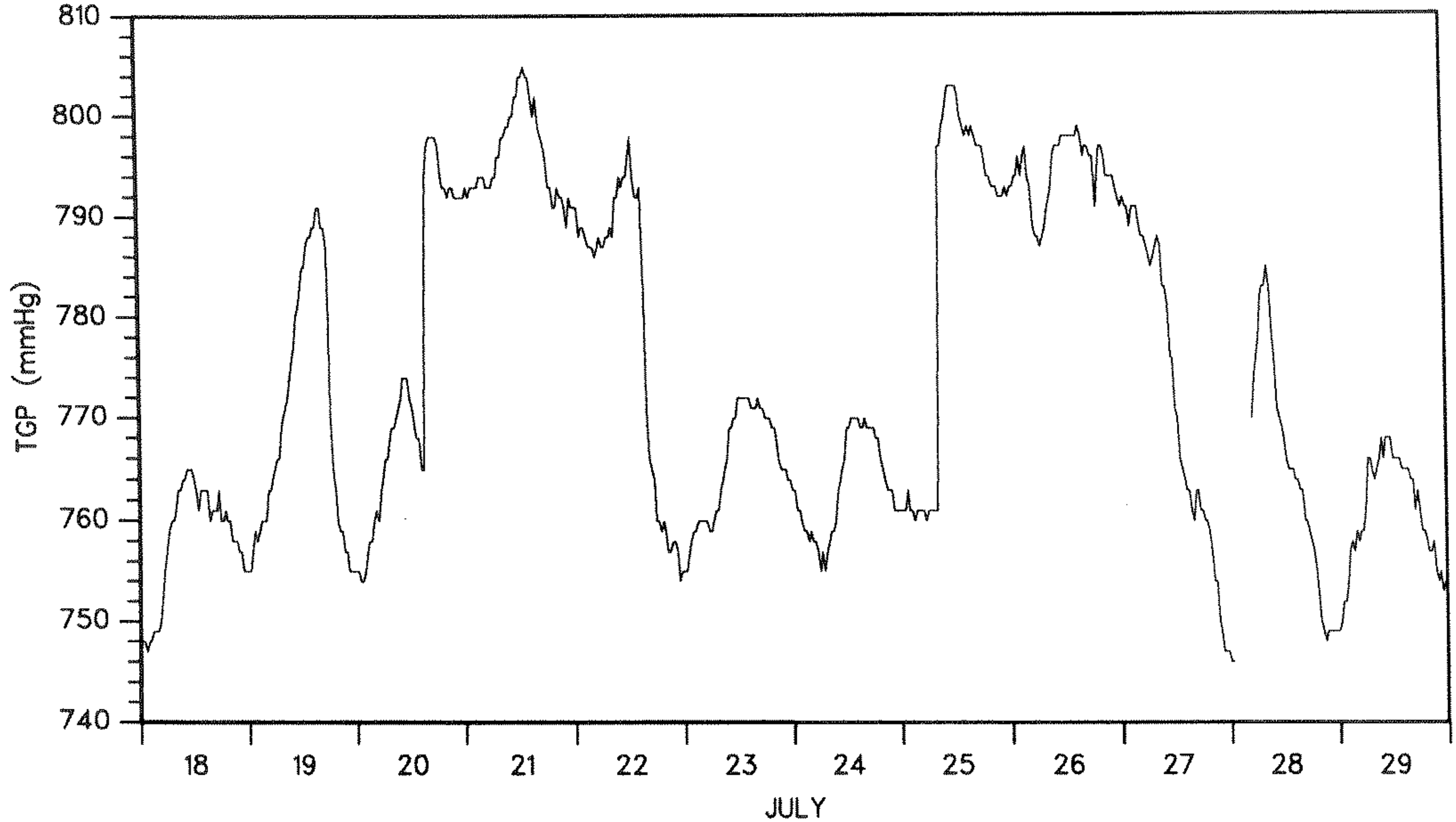


Figure 33. Total gas pressure (mmHg) measured at satellite station Rkm 0.6, 18 July - 29 July 1988, Bighorn River, Montana.

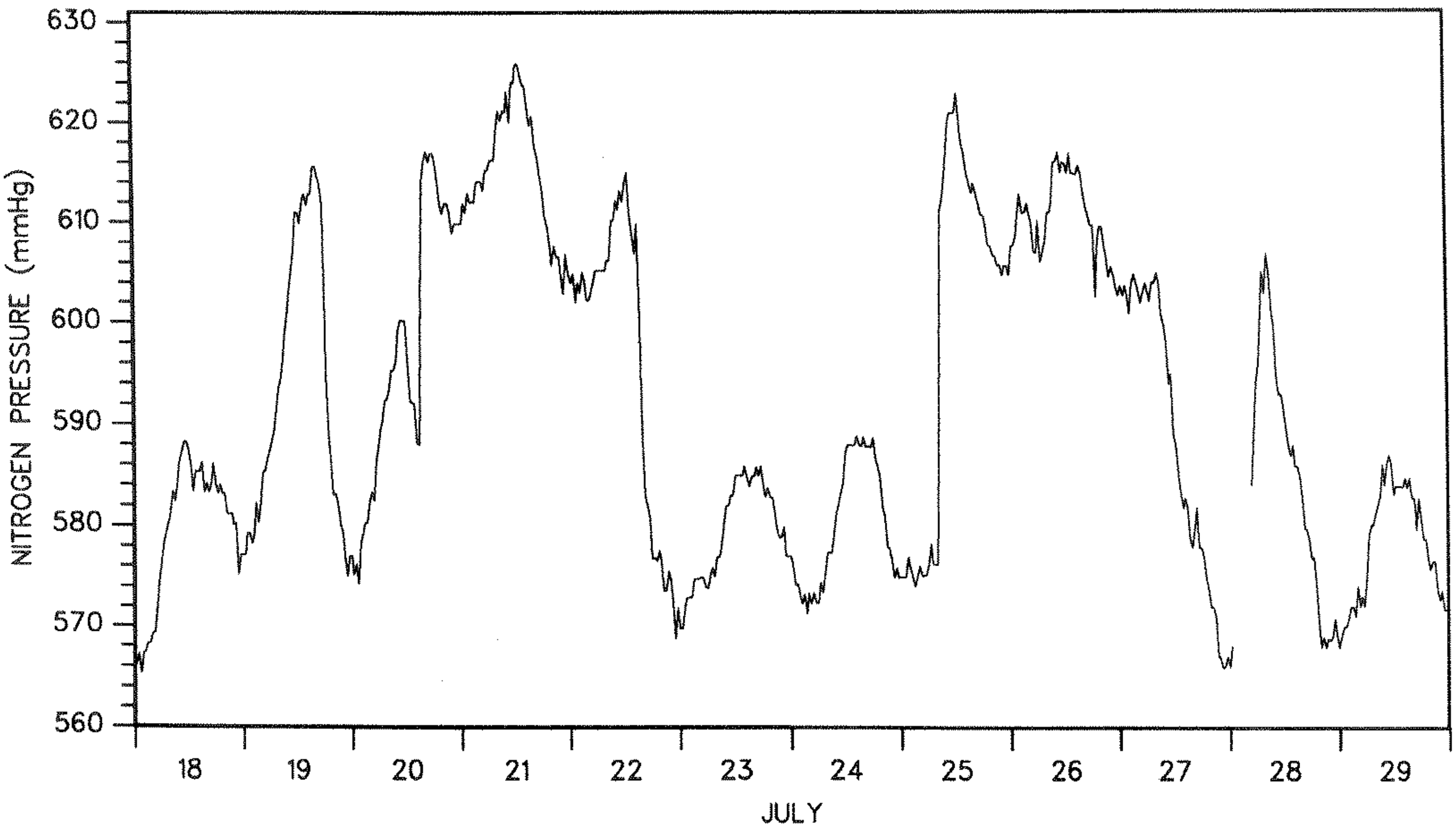


Figure 34. Nitrogen pressure (mmHg) measured at satellite station Rkm 0.6, 18 July - 29 July 1988, Bighorn River, Montana.

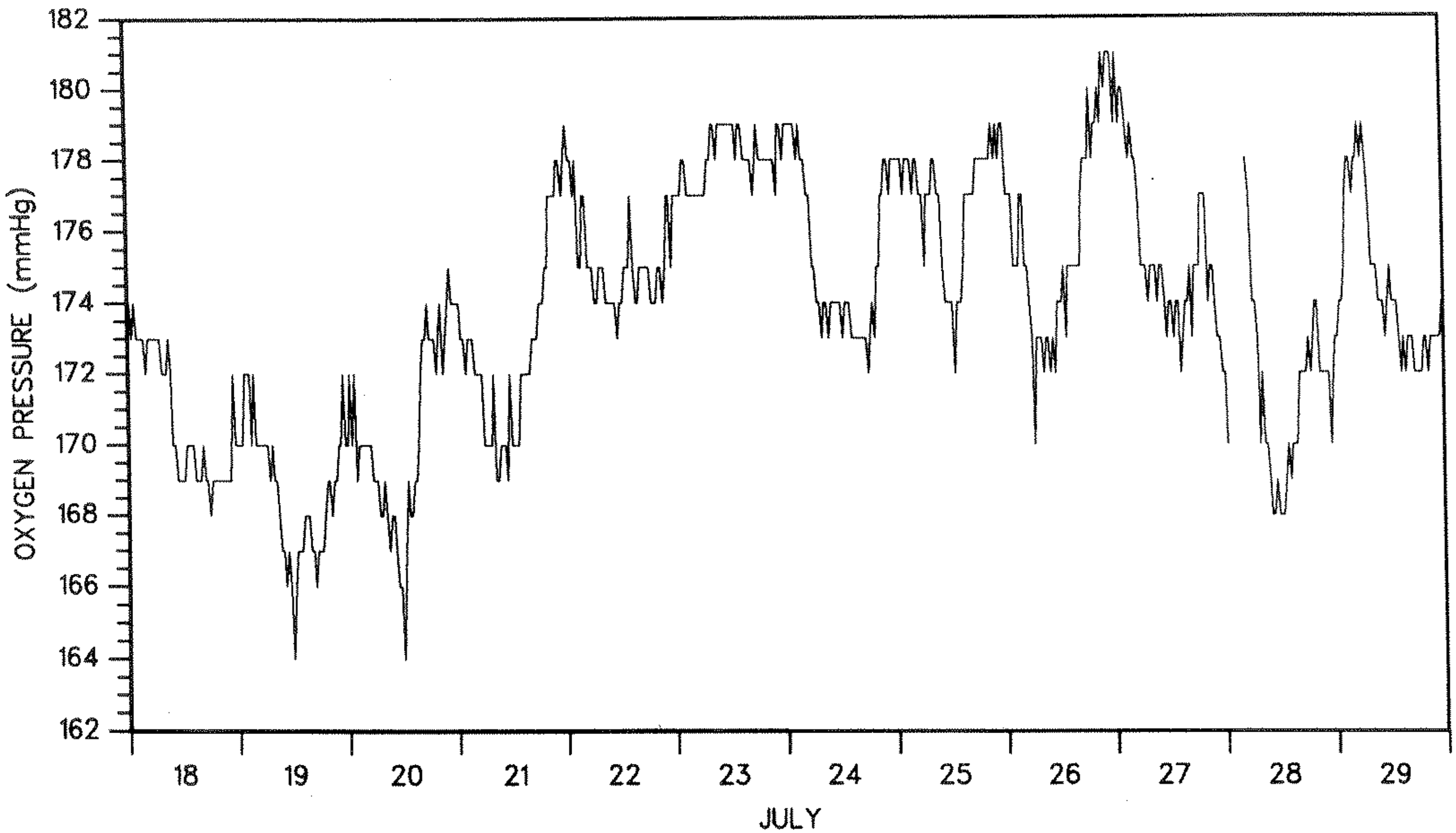


Figure 35. Oxygen pressure (mmHg) measured at satellite station Rkm 0.6, 18 July - 29 July 1988, Bighorn River, Montana.

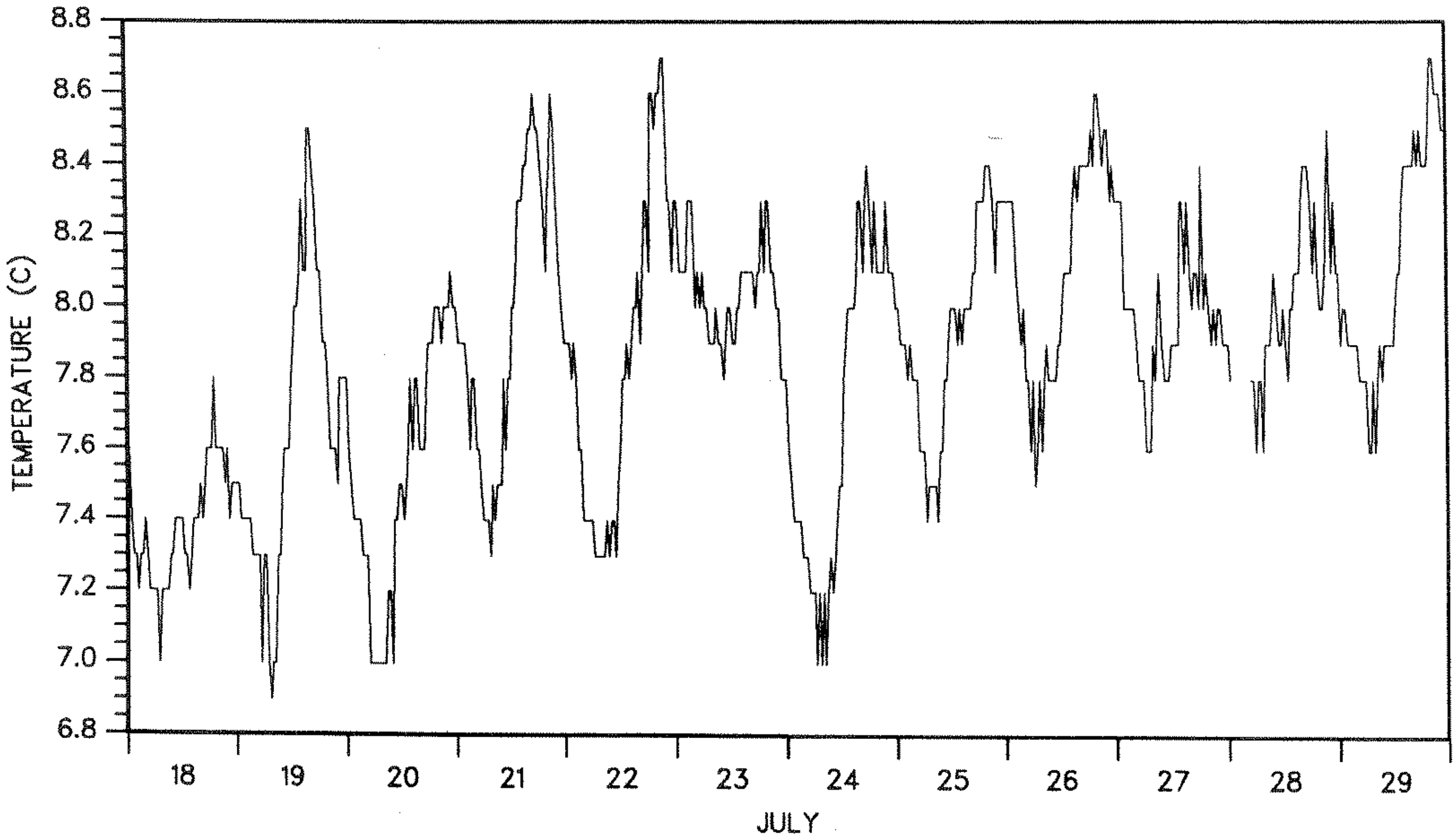


Figure 36. Water temperature (C) measured at satellite station Rkm 0.6, 18 July - 29 July 1988, Bighorn River, Montana.

# APPENDIX D

## Monte Carlo Simulations

Table 36. Monte Carlo simulations to access the probability of obtaining the observed PCA result, all brown trout and rainbow trout, percent of variance explained by eigen vector, June - October 1987, Bighorn River, Montana.

| Principal component | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| I | 1000 | 19.32 | 0.61 | 17.84 | 21.44 |
| II | 1000 | 18.07 | 0.42 | 17.01 | 19.69 |
| III | 1000 | 17.10 | 0.36 | 15.91 | 18.32 |
| IV | 1000 | 16.18 | 0.37 | 14.98 | 17.75 |
| V | 1000 | 15.24 | 0.42 | 13.87 | 16.32 |
| VI | 1000 | 14.09 | 0.55 | 11.88 | 15.43 |

Table 37. Monte Carlo simulations to access the probability of obtaining the observed PCA result, brown trout and rainbow trout <15 cm TL, percent of variance explained by eigen vector, June - October 1987, Bighorn River, Montana.

| Principal component | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| I | 1000 | 24.48 | 1.86 | 19.70 | 30.77 |
| II | 1000 | 20.45 | 1.26 | 16.89 | 25.02 |
| III | 1000 | 17.59 | 0.98 | 14.65 | 20.88 |
| IV | 1000 | 15.06 | 1.03 | 11.86 | 17.88 |
| V | 1000 | 12.62 | 1.07 | 8.90 | 15.91 |
| VI | 1000 | 9.81 | 1.30 | 4.83 | 13.83 |

Table 38. Monte Carlo simulations to access the probability of obtaining the observed PCA result, brown trout and rainbow trout >15 cm TL, percent of variance explained by eigen vector, June 1987, Bighorn River, Montana.

| Principal component | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| I | 1000 | 22.31 | 1.34 | 19.32 | 27.71 |
| II | 1000 | 19.49 | 0.89 | 17.41 | 22.30 |
| III | 1000 | 17.39 | 0.71 | 15.28 | 19.67 |
| IV | 1000 | 15.57 | 0.76 | 12.86 | 17.57 |
| V | 1000 | 13.72 | 0.80 | 11.10 | 15.97 |
| VI | 1000 | 11.52 | 1.04 | 8.12 | 14.60 |

Table 39. Monte Carlo simulations to access the probability of obtaining the observed PCA result, brown trout and rainbow trout >15 cm TL, percent of eigen vector explained by eigen vector, July 1987, Bighorn River, Montana.

| Principal component | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| I | 1000 | 21.61 | 1.17 | 18.64 | 26.66 |
| II | 1000 | 19.18 | 0.83 | 16.91 | 22.12 |
| III | 1000 | 17.31 | 0.62 | 15.52 | 19.30 |
| IV | 1000 | 15.70 | 0.64 | 13.41 | 17.50 |
| V | 1000 | 14.08 | 0.75 | 11.54 | 16.19 |
| VI | 1000 | 12.13 | 0.94 | 9.18 | 14.60 |

Table 40. Monte Carlo simulations to access the probability of obtaining the observed PCA result, brown trout and rainbow trout >15 cm TL, percent of eigen vector explained by eigen vector, September and October 1987, Bighorn River, Montana.

| Principal component | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| I | 1000 | 26.08 | 2.34 | 20.11 | 34.83 |
| II | 1000 | 21.16 | 1.53 | 17.57 | 26.60 |
| III | 1000 | 17.63 | 1.20 | 13.48 | 21.15 |
| IV | 1000 | 14.68 | 1.22 | 10.68 | 17.73 |
| V | 1000 | 11.78 | 1.32 | 7.52 | 15.88 |
| VI | 1000 | 8.67 | 1.44 | 4.70 | 12.73 |

# APPENDIX E

Fish Movement Maps

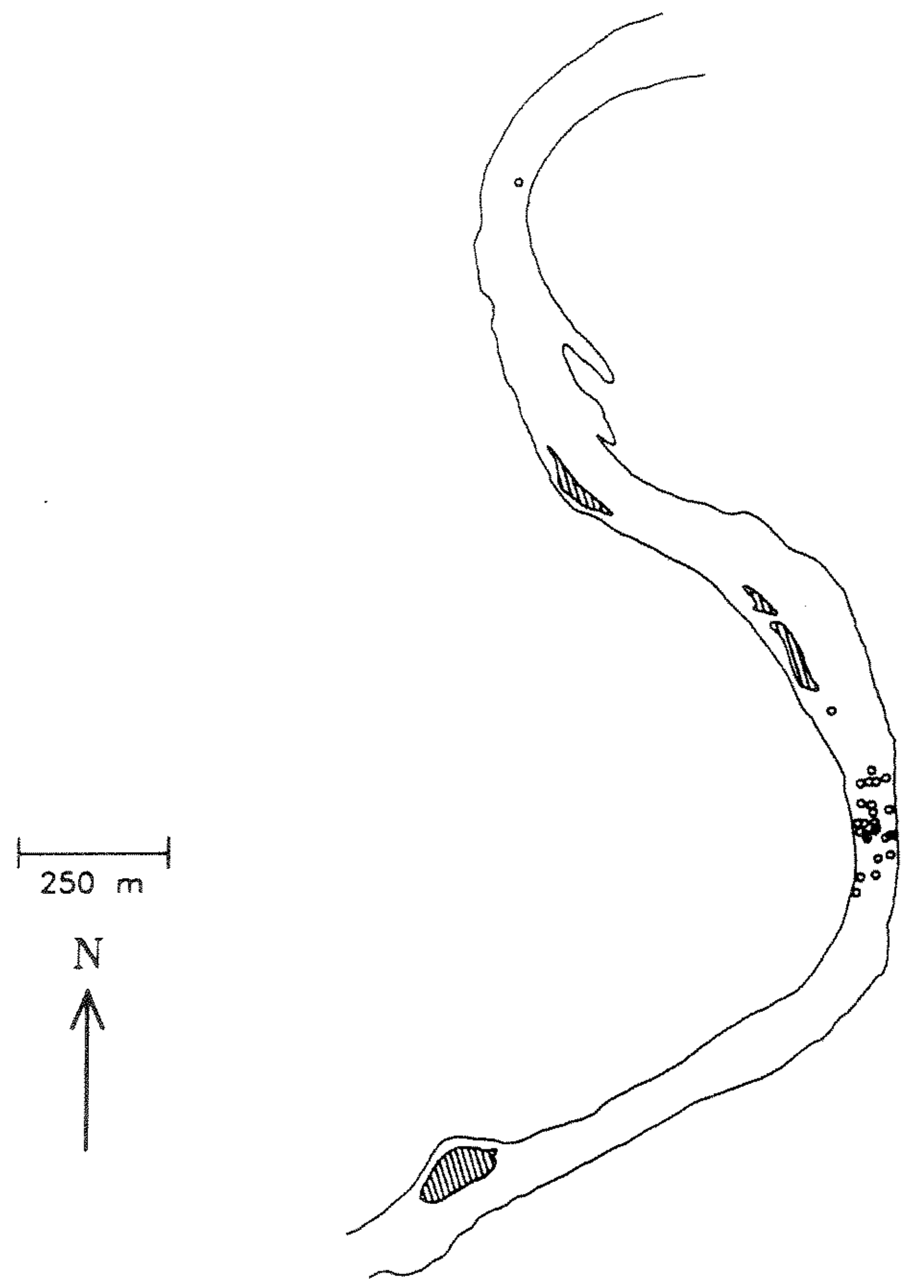


Figure 37. Movement of radio-tagged trout 43 (30.043 MHz), 1987, Bighorn River, Montana.

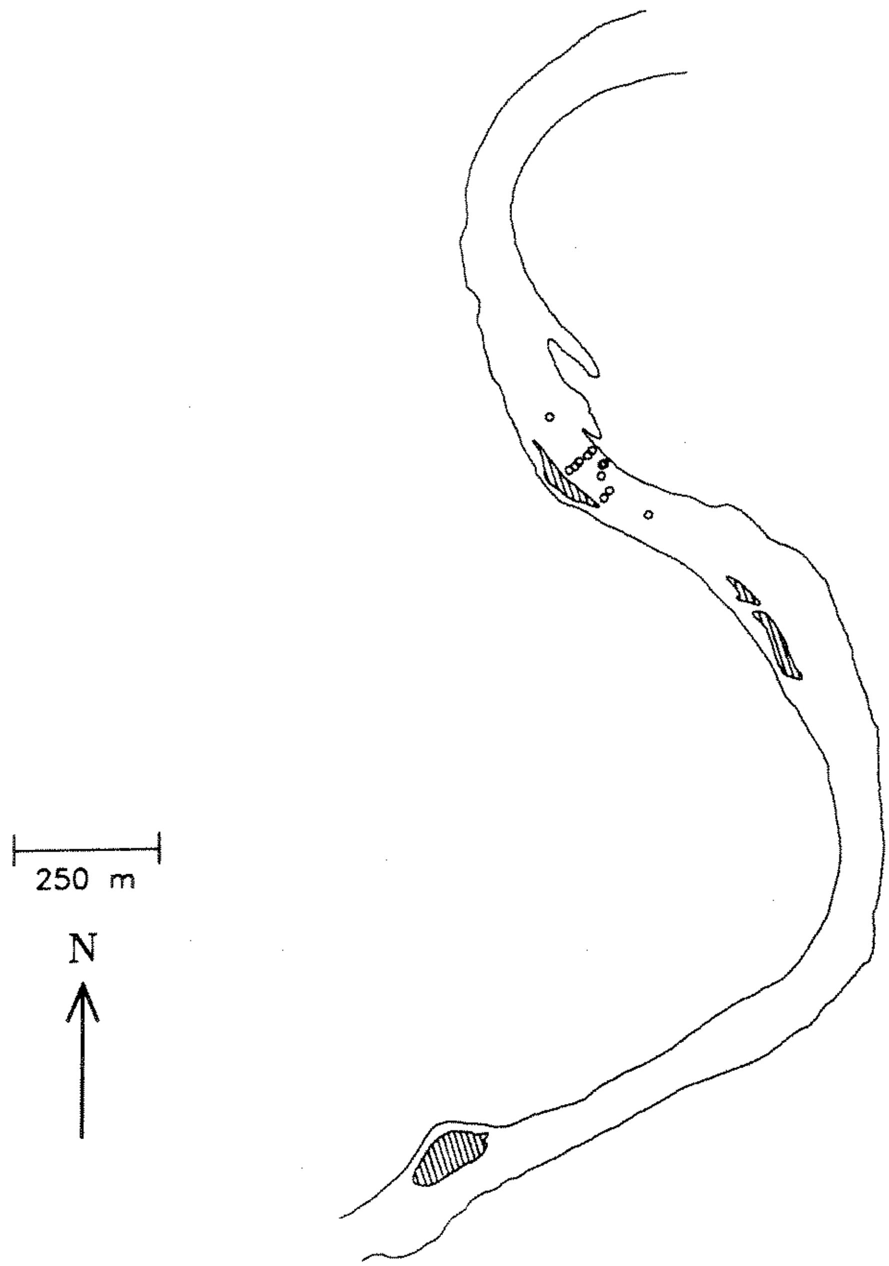


Figure 38. Movement of radio-tagged trout 62 (30.062 MHz), 1987, Bighorn River, Montana.

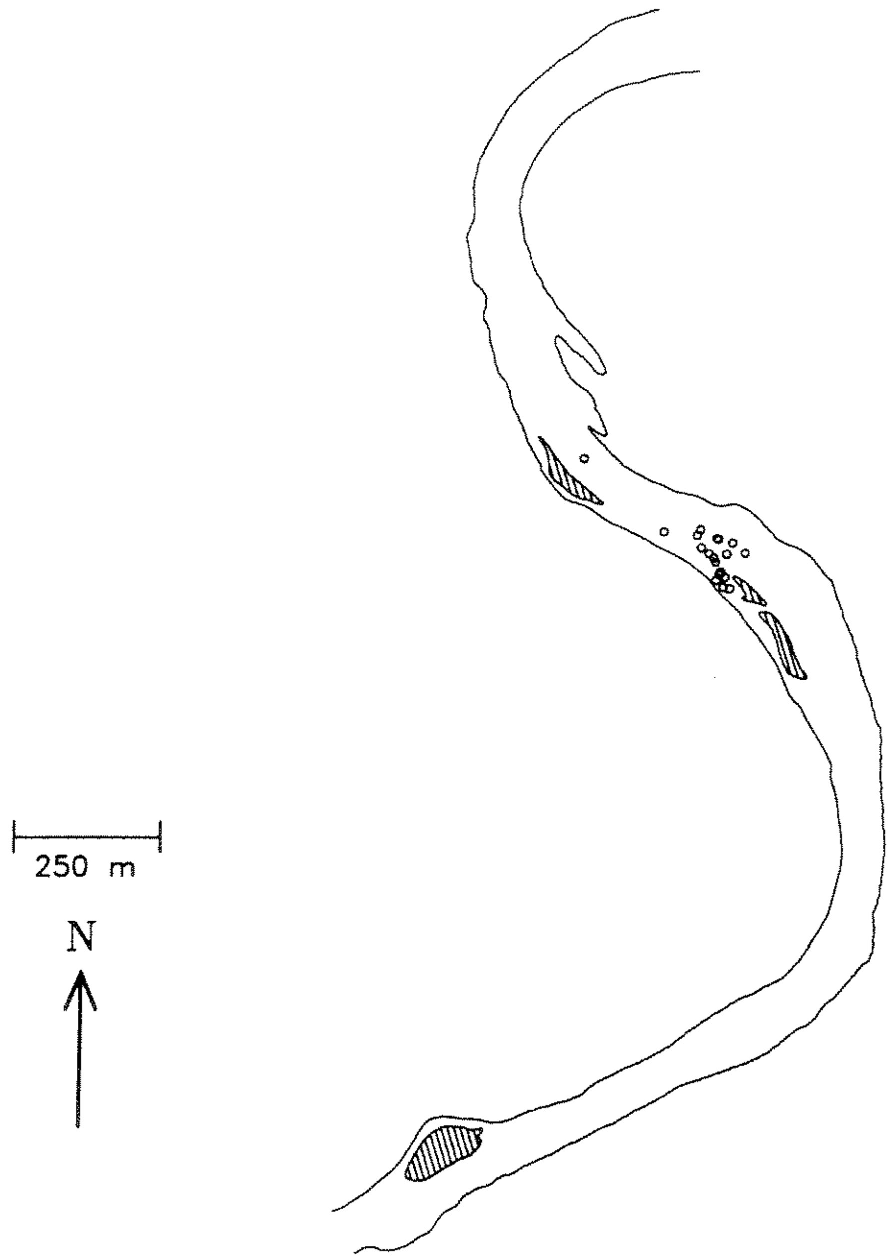


Figure 39. Movement of radio-tagged trout 65 (30.065 MHz), 1987, Bighorn River, Montana.

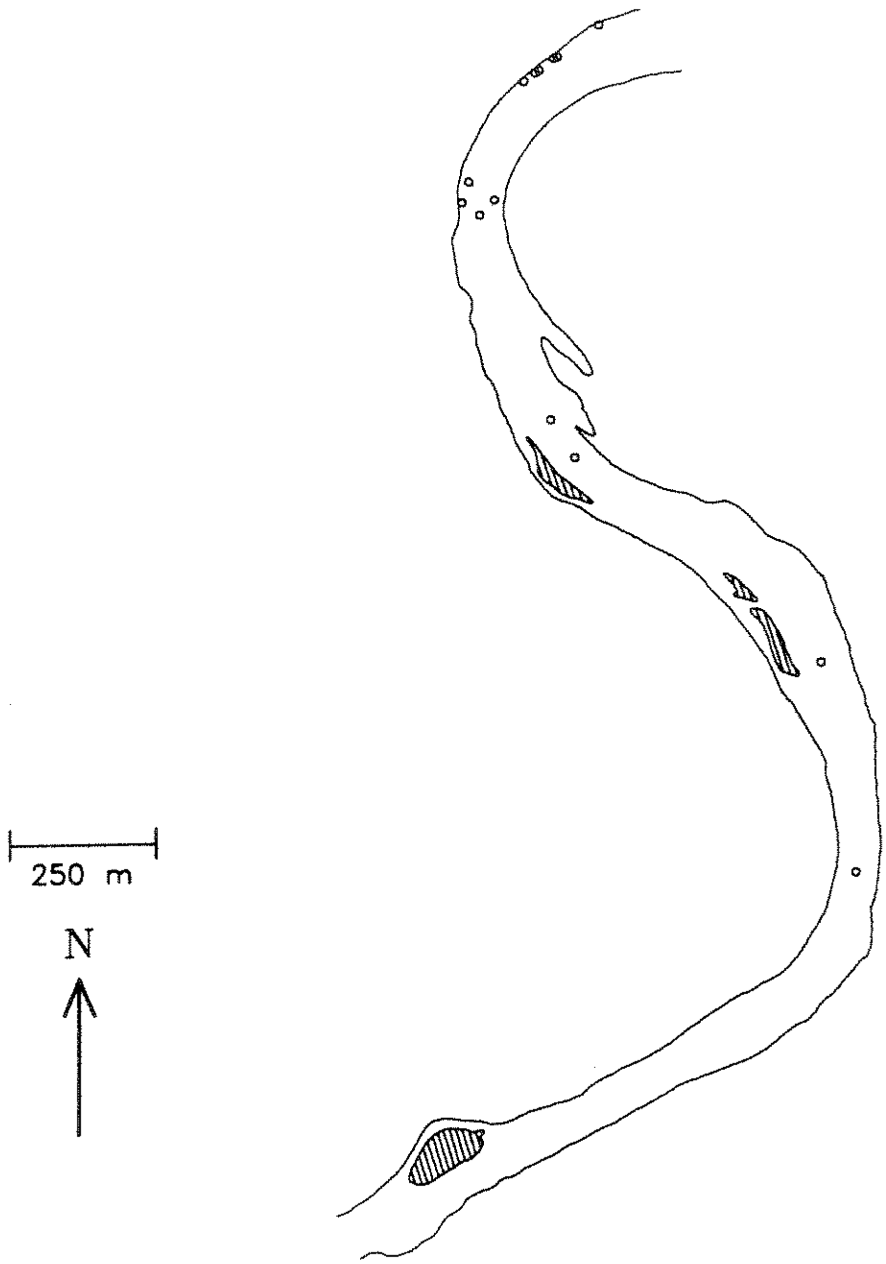


Figure 40. Movement of radio-tagged trout 71 (30.071 MHz), 1987, Bighorn River, Montana.

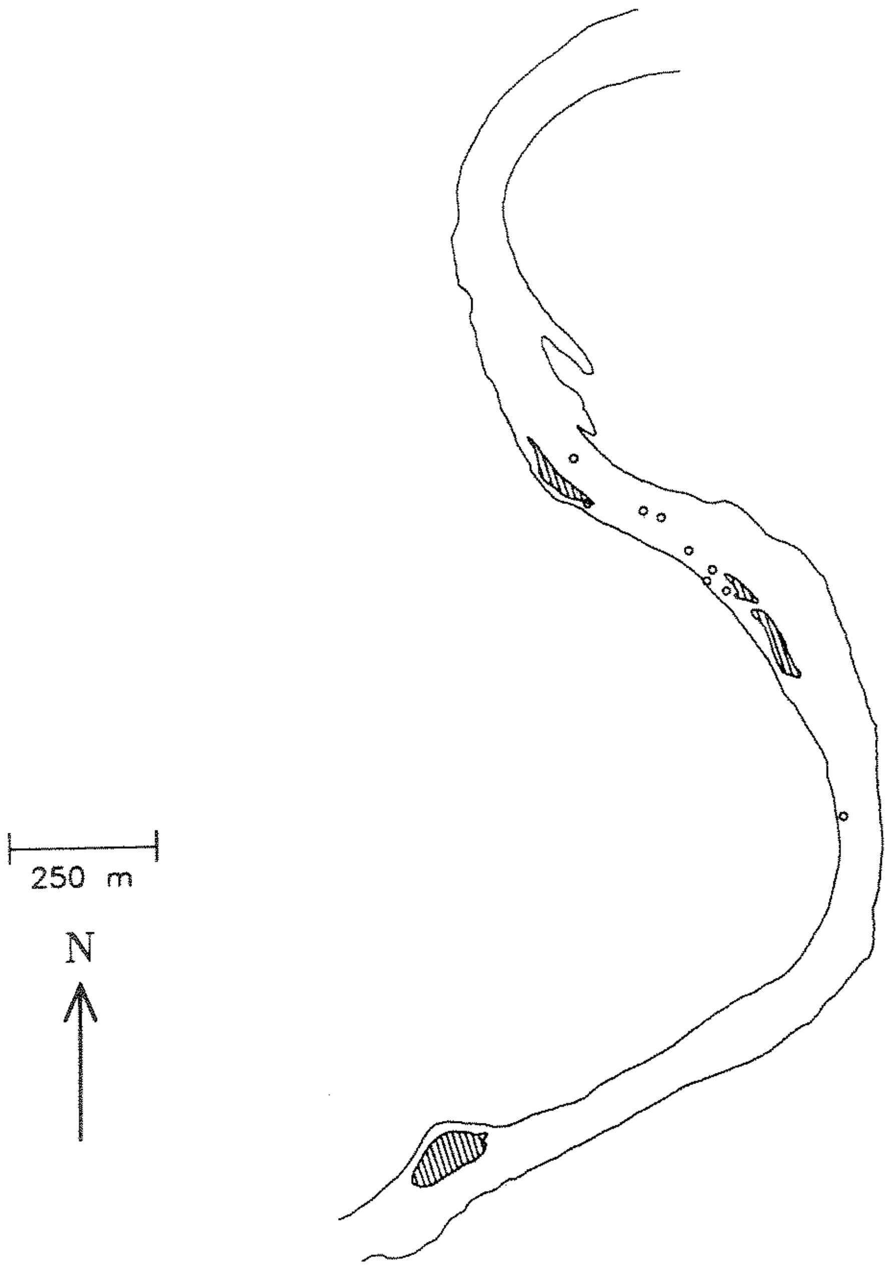


Figure 41. Movement of radio-tagged trout 88 (30.088 MHz), 1987, Bighorn River, Montana.

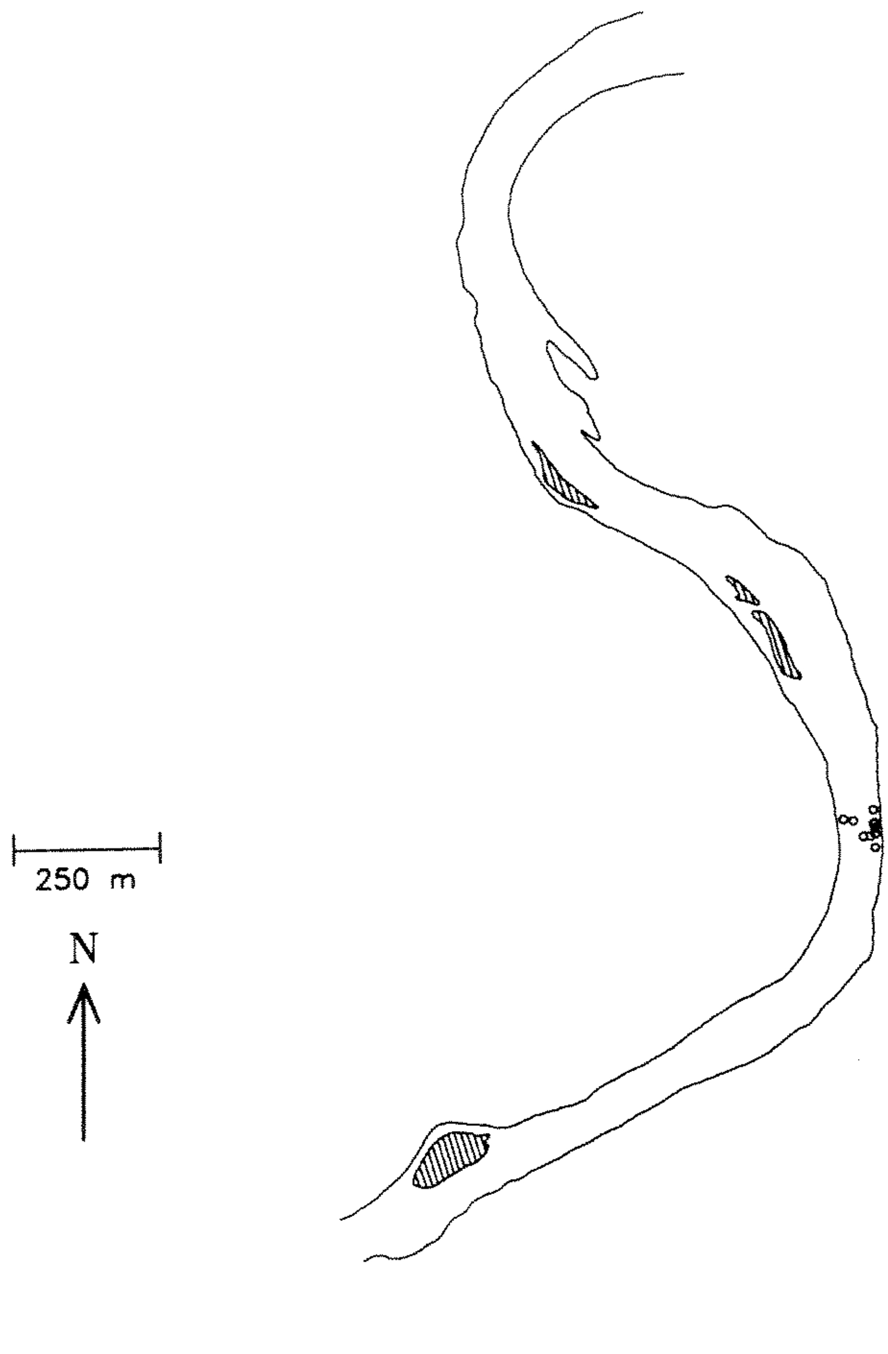


Figure 42. Movement of radio-tagged trout 97 (30.097 MHz), 1987, Bighorn River, Montana.

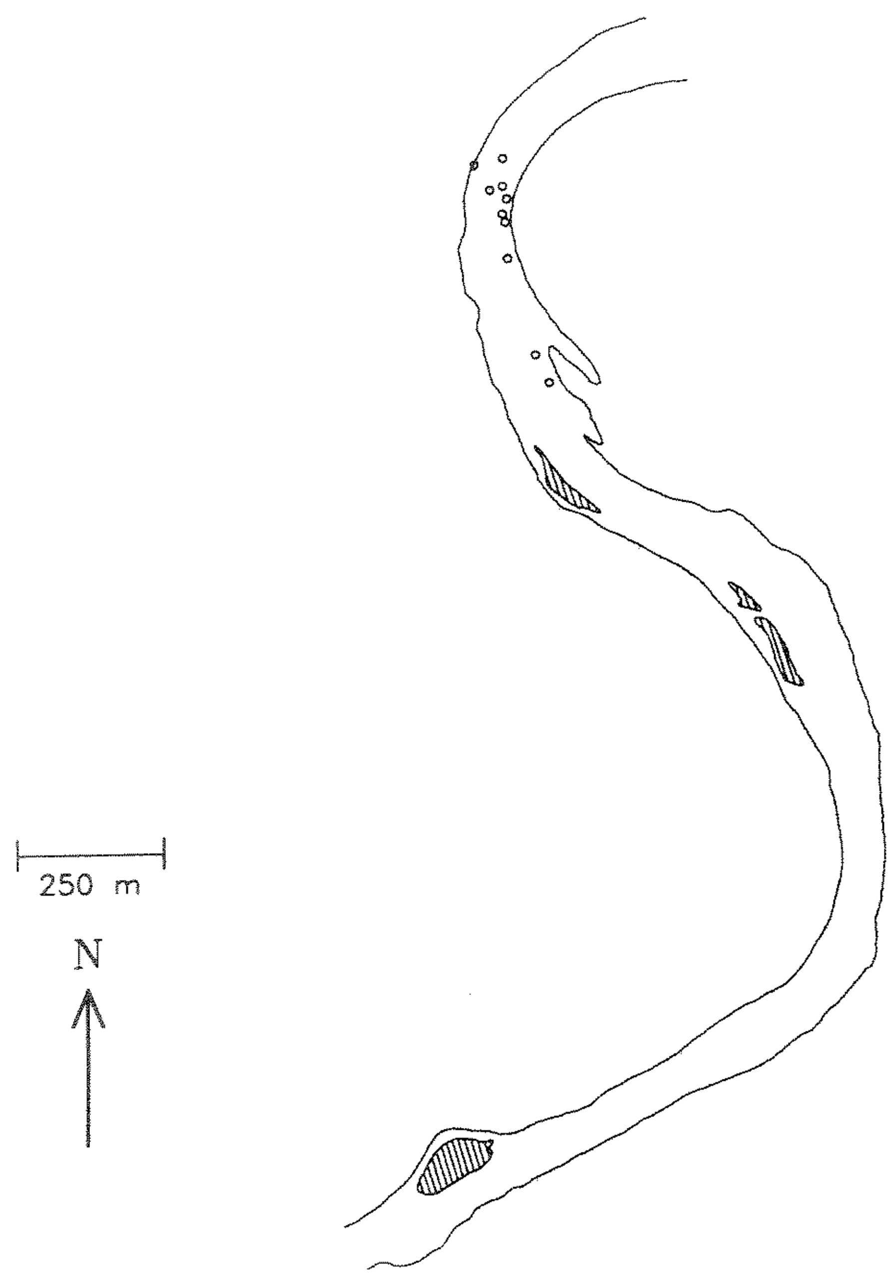


Figure 43. Movement of radio-tagged trout 110 (30.110 MHz), 1987, Bighorn River, Montana.

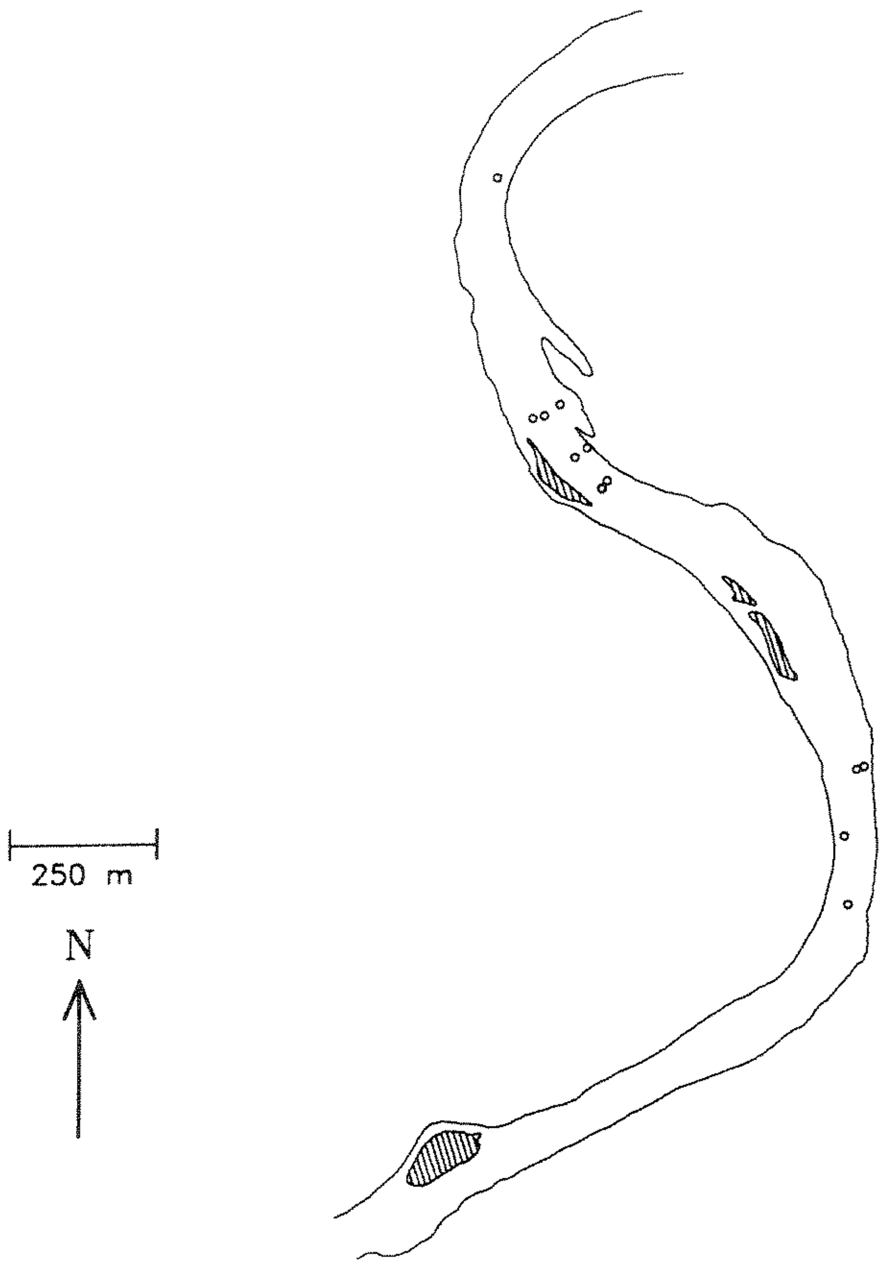


Figure 44. Movement of radio-tagged trout 125 (30.125 MHz), 1987, Bighorn River, Montana.

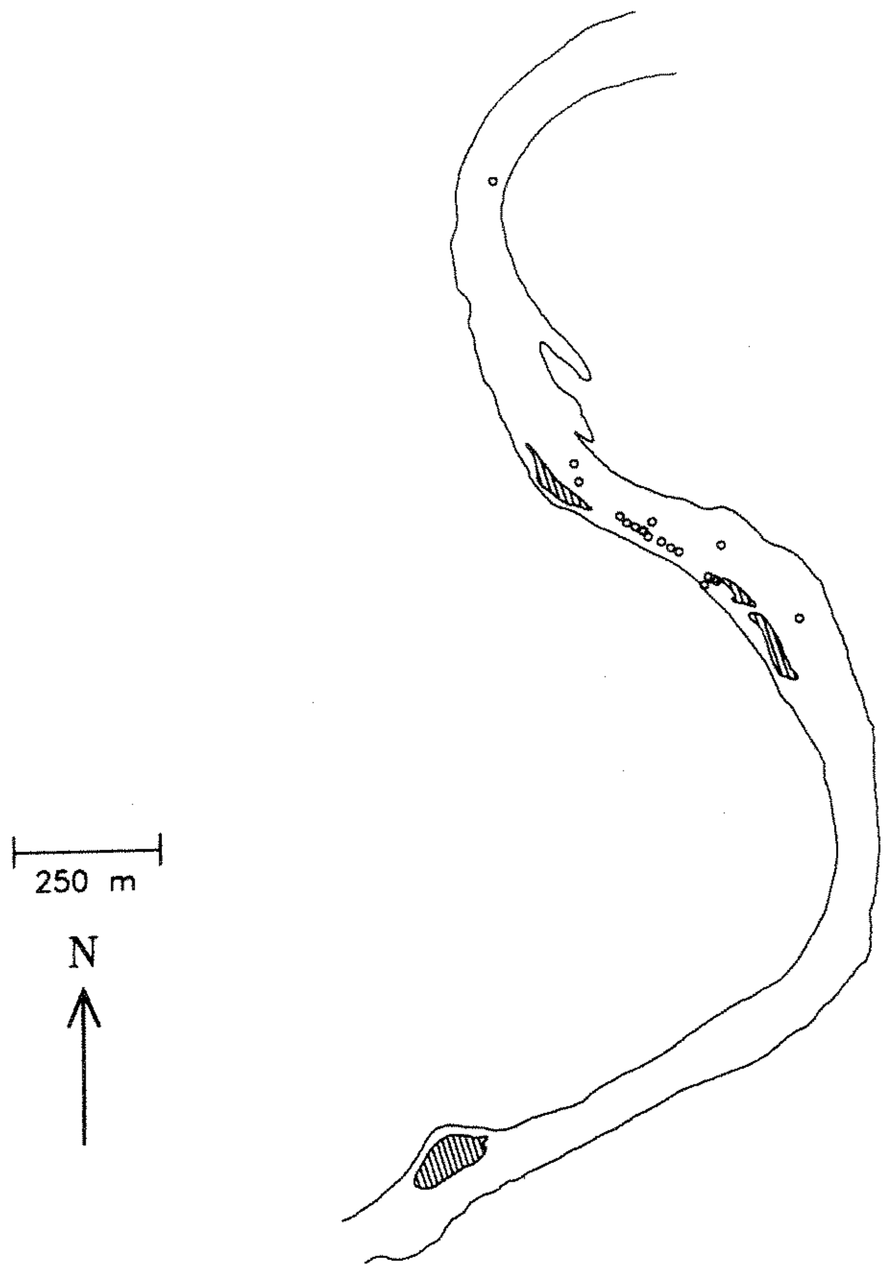


Figure 45. Movement of radio-tagged trout 168 (30.168 MHz), 1987, Bighorn River, Montana.

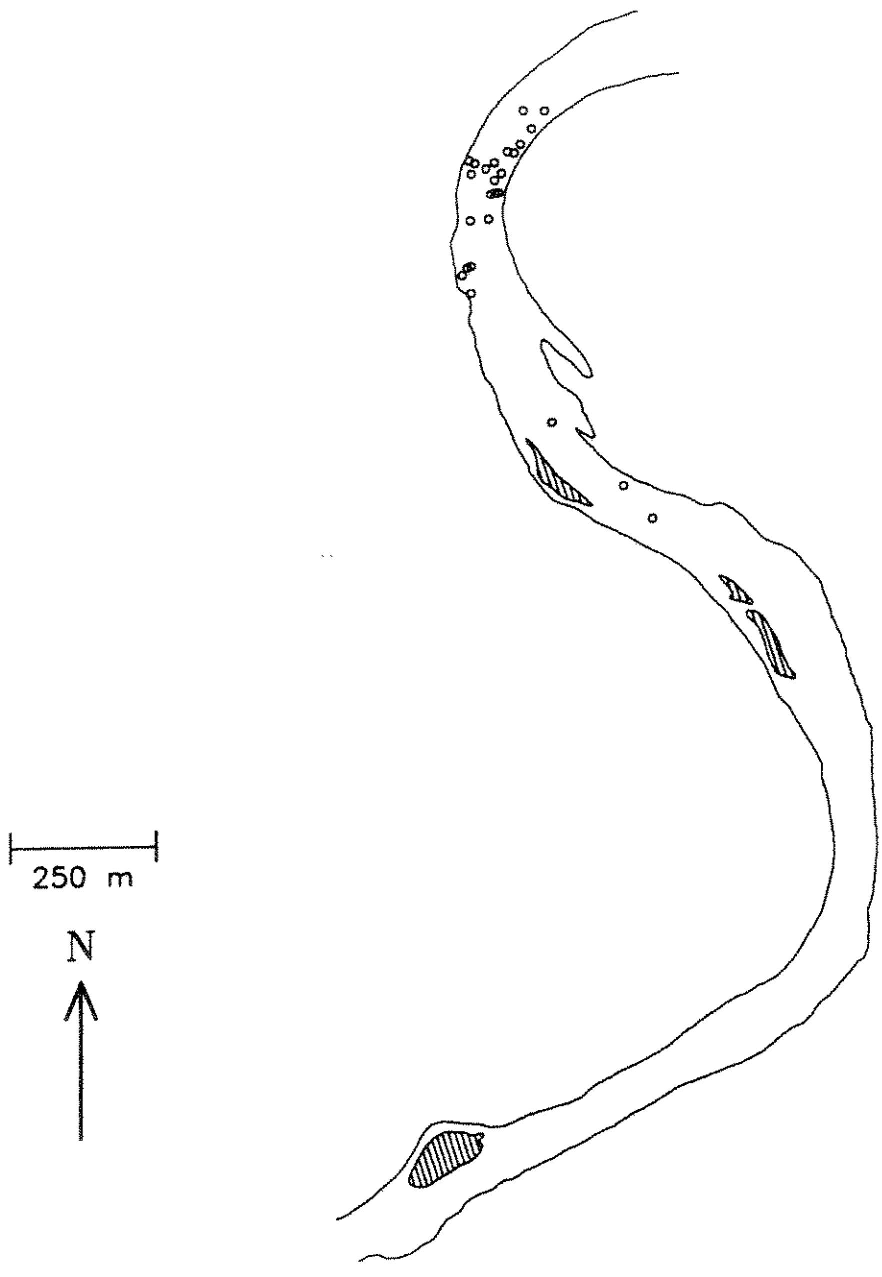


Figure 46. Movement of radio-tagged trout 188 (30.188 MHz), 1987, Bighorn River, Montana.

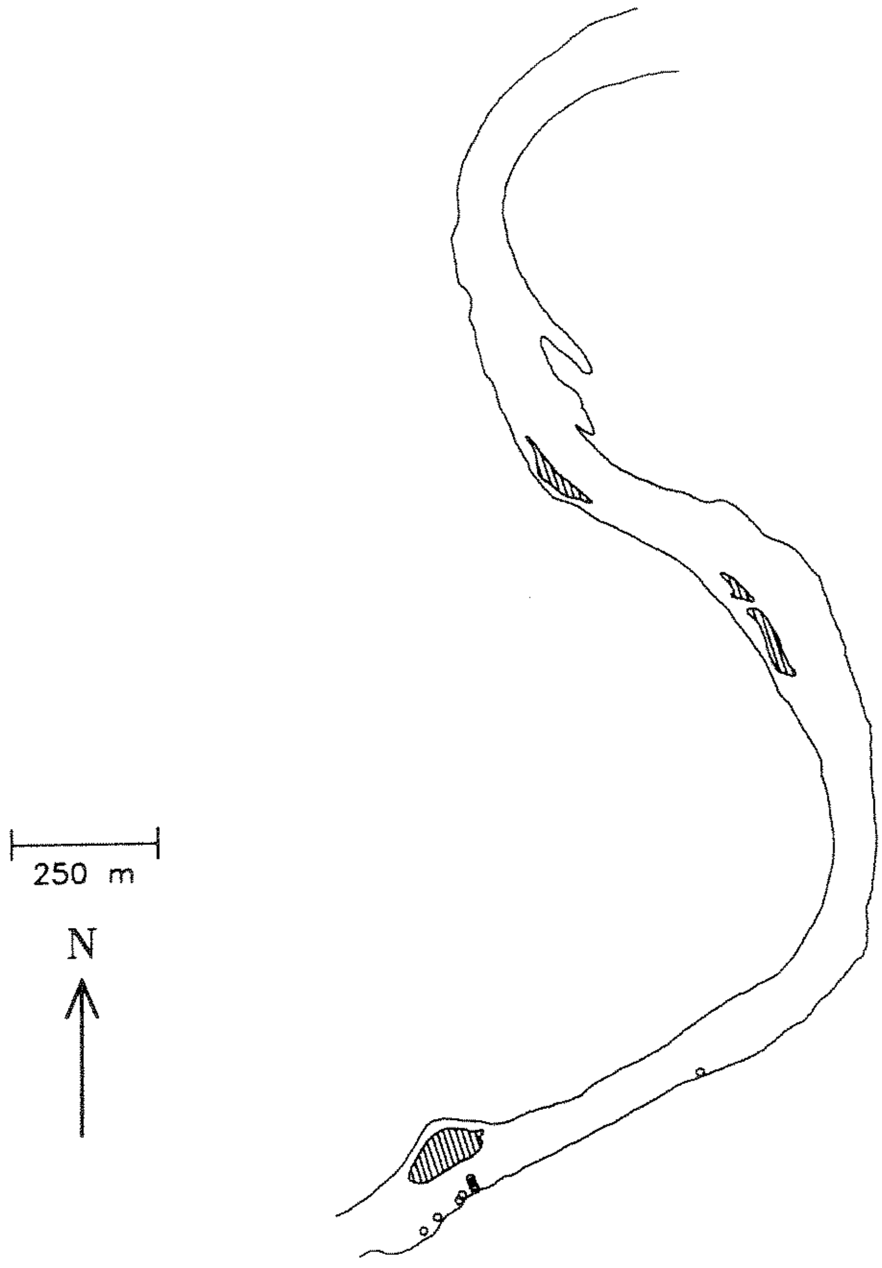


Figure 47. Movement of radio-tagged trout 215 (30.215 MHz), 1987, Bighorn River, Montana.

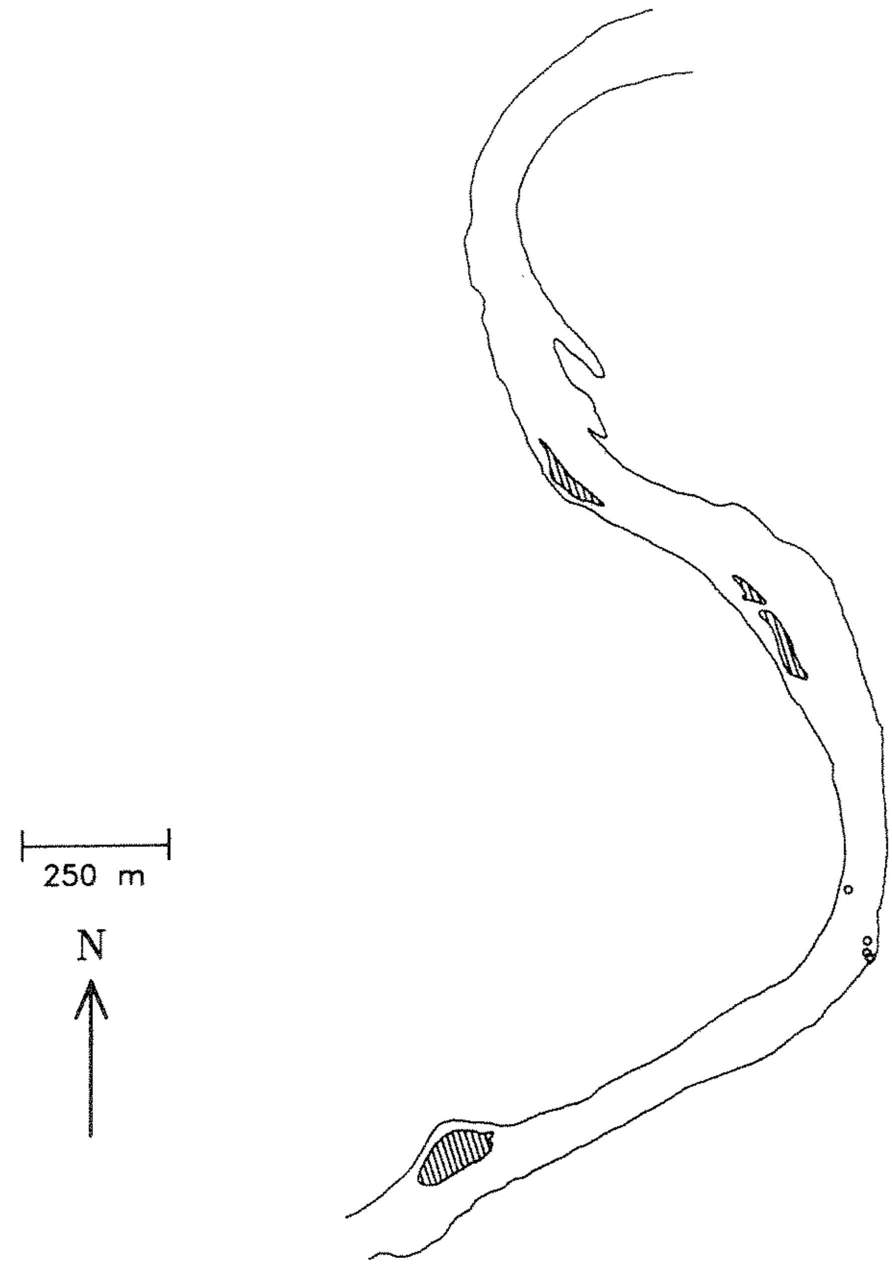


Figure 48. Movement of radio-tagged trout 227 (30.227 MHz), 1987, Bighorn River, Montana.

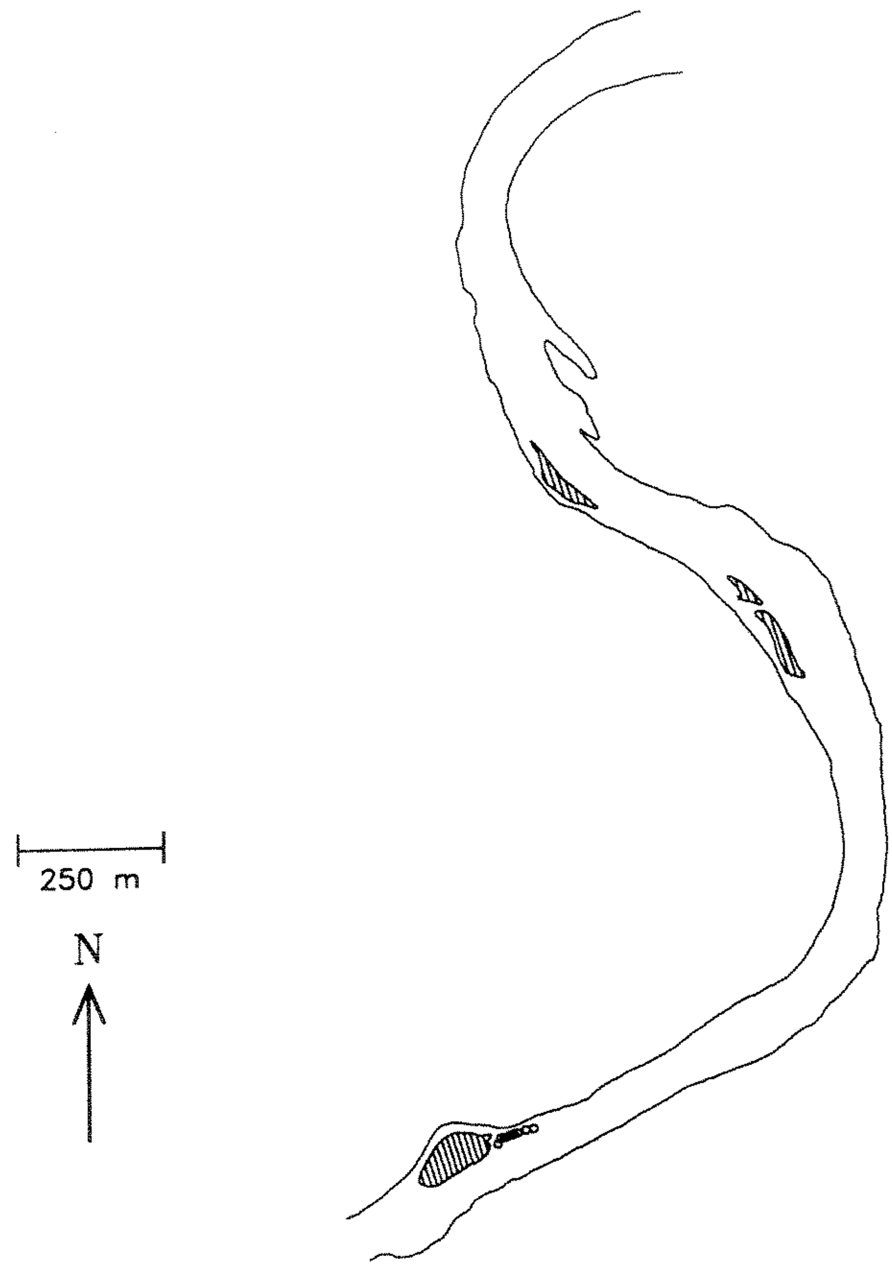


Figure 49. Movement of radio-tagged trout 237 (30.237 MHz), 1987, Bighorn River, Montana.

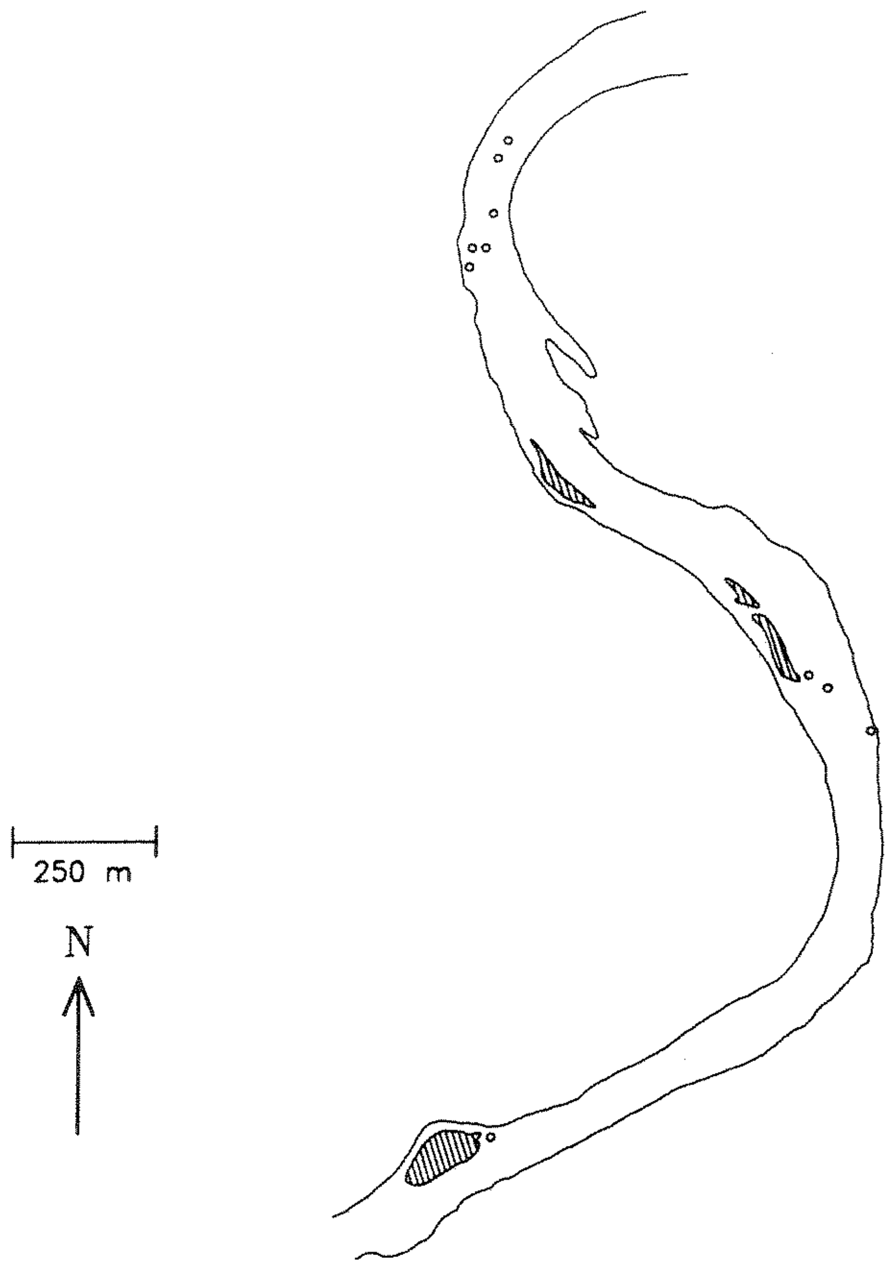


Figure 50. Movement of radio-tagged trout 276 (30.276 MHz), 1987, Bighorn River, Montana.

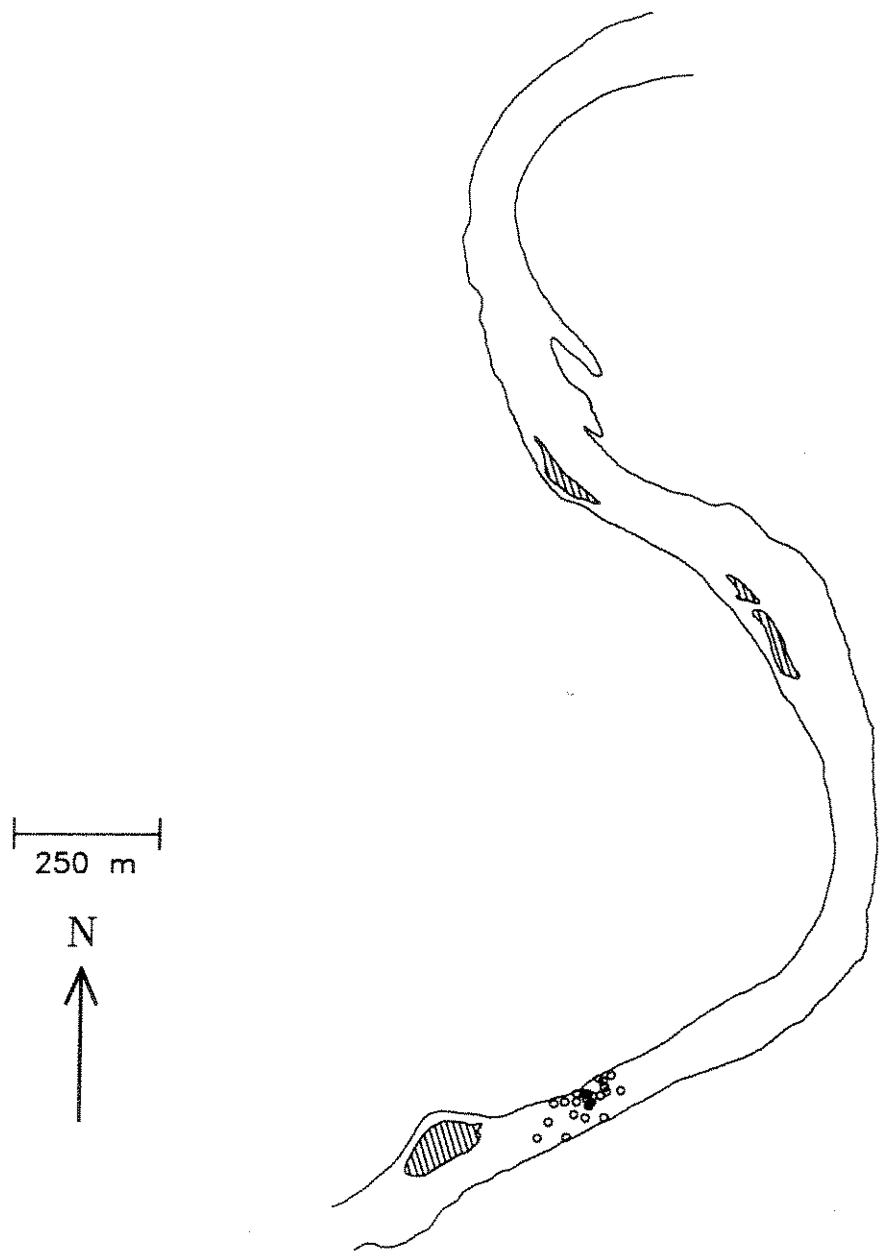


Figure 51. Movement of radio-tagged trout 255 (30.255 MHz), 1988, Bighorn River, Montana.

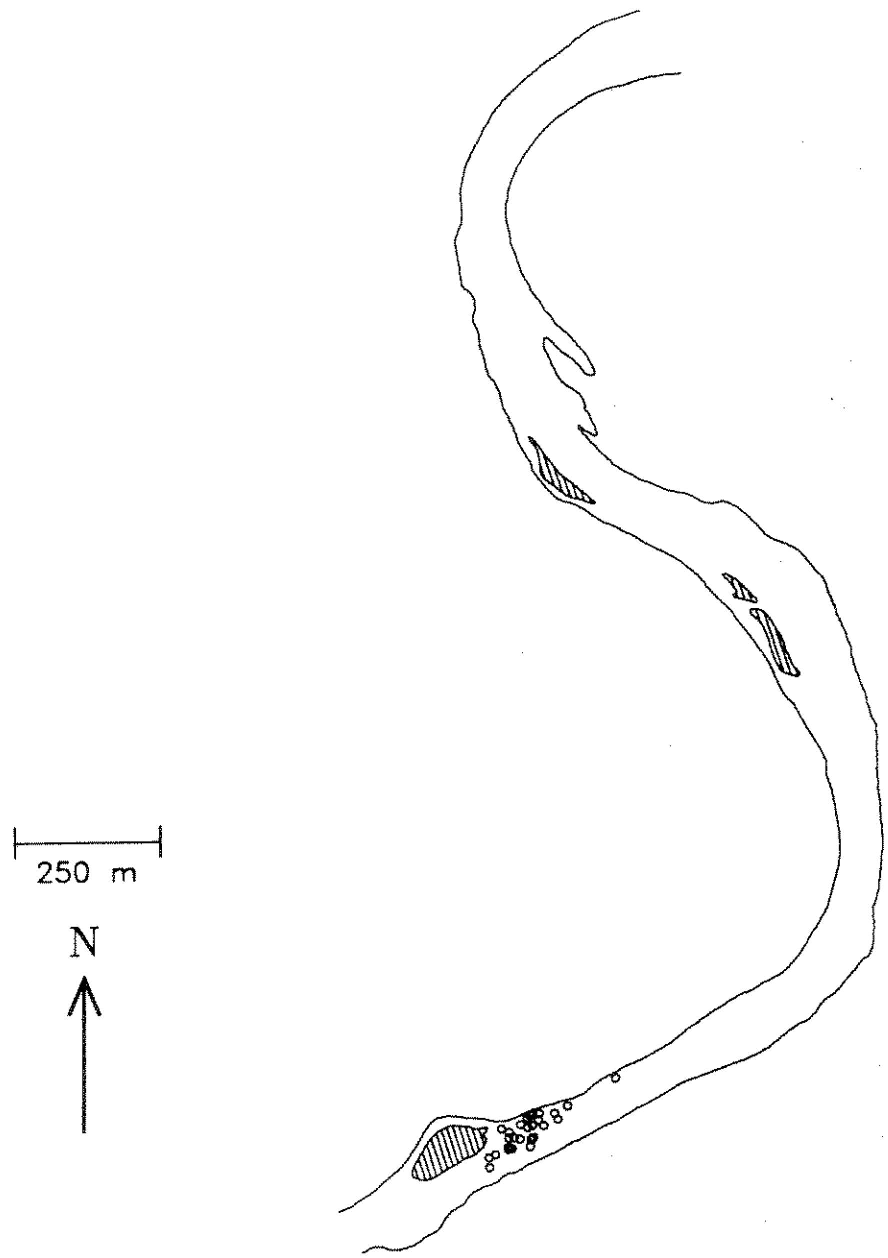


Figure 52. Movement of radio-tagged trout 270 (30.270 MHz), 1988, Bighorn River, Montana.

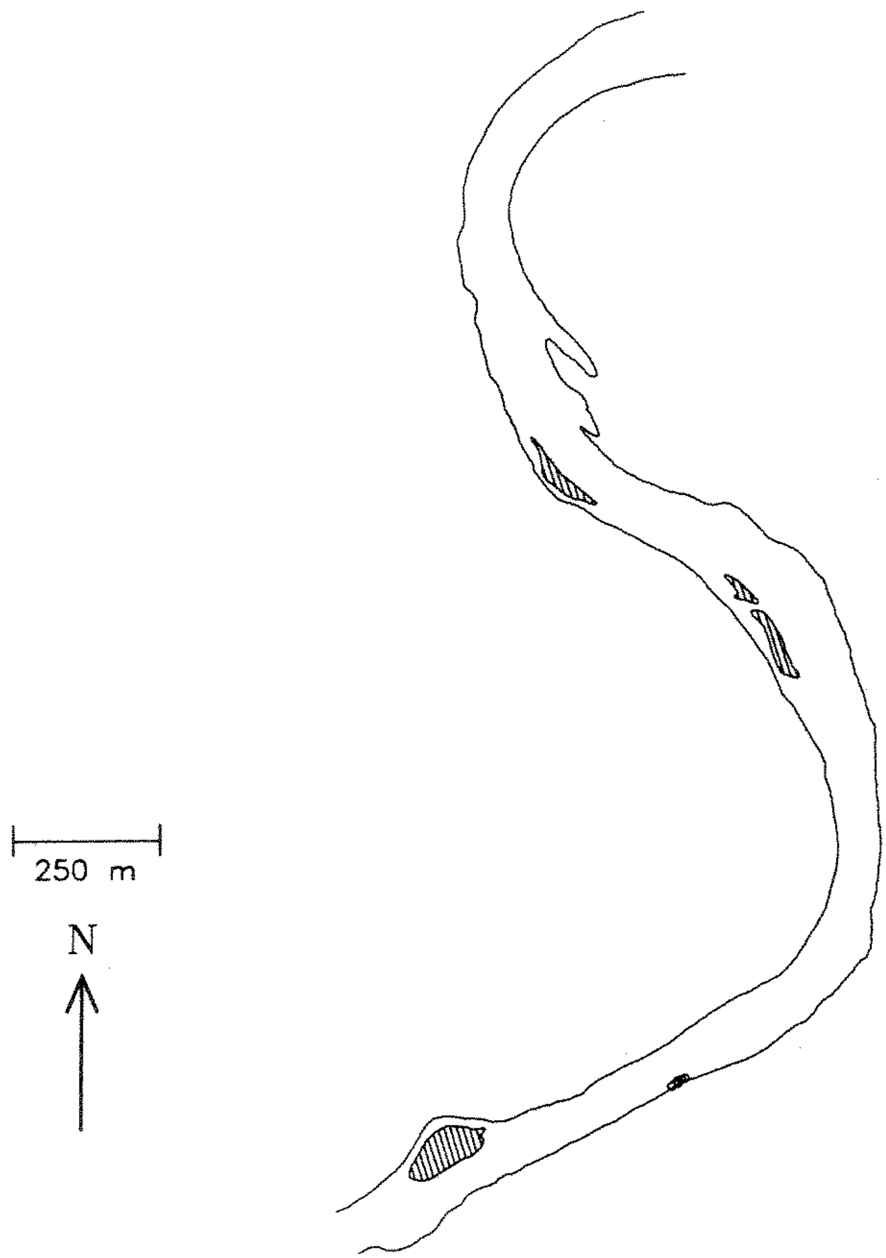


Figure 53. Movement of radio-tagged trout 280 (30.280 MHz), 1988, Bighorn River, Montana.