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WATER REQUIREMENTS
AND
APPLICATION RATES FOR LAWNS

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TWO TECHNIQUES FOR LOCATING AND SAMPLING BROWN TROUT MICROHABITAT UNDER COMPLETE ICE COVER

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ABSTRACT

Two techniques for locating and sampling instream brown trout microhabitat under complete ice cover conditions were devised, conducted and evaluated. Results indicate that radio telemetry by means of implanted transmitters is a superior technique over implantation of radioisotope capsules for tracking under-ice movements and locating microhabitat locations. The major drawback with transmitters was battery failure. Winter microhabitat preferences of brown trout were tentatively defined for resting and cover in terms of water depth, water velocity and substrate type.

Key Words

Instream flow, brown trout, microhabitat, radio telemetry, radioisotope, winter habitat requirements, fish tracking, ice

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INTRODUCTION

In recent years, much research has centered around the determination of instream flows necessary to maintain salmonid habitat in light of increasing out-of-channel water demands. A review of existing instream flow methodologies for fisheries (Stalnaker and Arnette, 1976; Wesche and Rechard, 1980) indicates that while a great deal is known about habitat requirements during the ice-free period of the year and subsequent methods for measurement of this habitat, little research effort has been extended regarding habitat conditions and requirements during the critical winter season, when complete ice-cover blankets many of our northern latitude streams. It is hoped that this report will help to fill this knowledge gap.

The need for winter studies on freshwater fish populations was recognized as early as 1935 by Hubbs and Trautman. At that time interest was centered around over-winter survival of stocked fish. Today's interests in winter data also center around survival of wintering fish, but as related to determination of instream flows to maintain these fisheries during winter low-water conditions. Unfortunately, little research has been done on fish winter movements, feeding needs and habits, cover needs, microhabitat occupation, or other aspects of life-history under ice-cover. A search of the literature indicates that no one has ever determined any salmonid habitat or instream flow requirements for streams with complete ice cover. For this there is a very definite need.

Maciolek and Needham (1952) conducted winter studies on Convict Creek, California (elevation 7,200 feet) to determine the effects of winter conditions on trout and trout foods. Extensive ice formations and freezing water temperatures were present, but none of the four controlled experimental sections were ever completely frozen over. Brown and rainbow trout were found to be active and feeding even at water temperatures of 32°F, contradicting the popular belief that trout are less active in winter. Some trout were caught by angling with bait when water temperatures ranged from 35°F to 42°F. When available, surface sheet ice was observed to be used as cover by trout. Maciolek and Needham also observed that Convict Creek supported higher standing crops of benthic organisms during the winter than in summer. This was attributed to the fact that the bulk of organisms are present in immature stages, unable to emerge until warmer weather. Stomach content analysis of trout showed that 50 percent of the total food ingested is digested in 14 hours at temperatures between 32°F and 35°F.

A study of the over-winter survival of summer-planted hatchery-reared trout (catchable size) and wild trout was also conducted at Convict Creek, California, by Reimers (1963). He found that general body condition of the summer-planted hatchery trout declined continuously from time of planting throughout the winter season. With the advent of spring and warmer water temperatures, high mortality rates of the hatchery trout occurred due to increased activity of trout in a weakened condition. Wild trout, however, were able to survive the onset of warmer temperatures and increased activity due to adequate energy reserves. Reimers noted that fluctuating periods of freezing temperatures (32°F) with warmer temperatures (40°F) caused weakened conditions during warmer periods. He also noted that a stable freezing water temperature is a successful mechanism for survival of over-wintering trout due to the reduction of metabolism to near-basal levels and the subsequent reduction in use of fat reserves. Winter intake of food by wild trout was often less than half that normally consumed in the summer and fall. Reimers stated that winter food availability should be based upon the extent of feeding rather than benthic samples as these samples may falsely indicate what food is actually available.

An underwater observation tank was used by Needham and Jones (1959) in Sagehen Creek, California (elevation 6,337 feet) to observe trout behavior during the winter season. Air and water temperatures, solar radiation, water levels, and general fish activity were monitored from the station. Consistent with the findings of Maciolek and Needham (1952), Needham and Jones observed trout actively feeding when water temperatures were between 32.0°F and 33.0°F. Trout actively swam up to drifting food particles, selectively ate them, and also fed directly off the bottom of the stream. Bottom macrofauna was abundant and active. Anchor ice, when dispersing and breaking up, was noticed to dislodge considerable numbers of invertebrates, thus making food available to trout. Brown, Clothier, and Alvord (1953) could not detect any change in numbers of bottom organisms where anchor ice formed, but did state that bottom organisms could be dislodged and carried away with ice dispersal.

Needham and Jones noticed that during winter, trout preferred areas of very dark cover. Ice and snow banks were used as cover, and a definite territorial behavior was exhibited for sheltered locations. Other conclusions by the authors were: (1) high winter mortalities of trout were probably not the result of low temperatures or lack of food, but due to physical catastrophes such as floods, entrapment under collapsed snow banks, or stream dewatering; and (2) 32°F is within the zone of tolerance of trout; and (3) trout can resist water temperatures below 32°F for short periods of time.

Benson (1955) studied anchor ice in the Pigeon River, Michigan, in attempts to determine the possible influence of ice on trout stream ecology. Anchor ice was not found to affect trout eggs as they were buried in gravel below the influence of anchor ice. Trout fry in the egg sac stage, however, were found to be highly vulnerable to mortality if they were emerging at the time of anchor ice formation. Contrary to the findings of Maciolek and Needham (1952) and Needham and Jones (1959), trout in the Pigeon River did not actively feed, and their coefficient of condition was low. All trout were found in quiet eddies and under the stream banks. Benson questioned whether trout actually benefited from winter feeding, and doubted the value of making food available for trout during the winter.

The effects of ice, temperature, and fluctuating water levels on benthic fauna and movements of trout were investigated by Logan (1963) in Bridger Creek, Montana. Severe winters with prolonged periods of below-freezing air temperatures were characteristic of the study site, but as with all the previous studies, surface ice never entirely covered the stream. Portions of surface ice that were occasionally present were found to have no effect on the abundance of bottom organisms. Again, numbers of organisms were high during the winter months. However, abundance of drift organisms was low during the late fall and winter due to low streamflows. Conclusions Logan made pertaining to winter movements of trout in Bridger Creek were: (1) more than 50 percent of trout within the section migrated no farther than 150 feet from their original location of capture; (2) movements appeared to be slightly greater in December, January and February, when temperatures were low and surface ice was present; and (3) seasonal location preferences occurred--trout moved out of spring, summer and fall inhabited pools to shallower water under surface ice cover in winter.

Chapman (1966) discussed the aspects of food and space as regulators of salmonid populations in streams. In areas where food is more available, Chapman reasoned that territory size of fish is reduced because less space is required to obtain food. In this case, population densities may be greater in a smaller area, with less territoriality. Chapman also proposed that in spring, summer, and fall, density is regulated primarily by the space-food convention while, in winter, density may be regulated by space alone, as related to protection.

In 1968, Chapman and Bjornn reviewed the distribution of salmonids in streams as related to food and feeding. Conclusions of the authors were: (1) during the period from spring to fall most salmonids occupied stream depths and water velocities proportionate to their body size, moving to faster, deeper areas which provide greater food supply and cover as they grow larger; (2) winter cover was important in holding over-wintering fish, especially substrate areas with large rocks. Fish moved closer to the substrate as water temperatures approached freezing; (3) hiding behavior was common during winter among stream salmonids, and was often preceded by downstream movements in the fall.

The determination of fish locations and microhabitat preferences during winter under total ice cover obviously poses a problem. However, electronic telemetry as a means of pinpointing fish locations has recently reached the stage of technology which now makes it mechanically and economically feasible for use in an under-ice study.

Two parallel developments in the field of telemetry have produced ultrasonic and radio-frequency telemetry. Ultrasonic (sonar) telemetry requires tracking fish with a submerged hydrophone, which, in turn, relays transmissions to a receiver. Constant contact with open water is necessary to pick up sound transmissions from the sonic transmitter. With the use of radio-frequency telemetry, contact with the water is not necessary for tracking fish, thus making it ideal for under-ice work. Radio-frequency energy will transmit from the radio transmitter beneath the surface of the water to a receiving antenna in free space, eliminating the constraint of constant water contact.

A radio-tracking system was used for locating Lahantan cutthroat trout (Salmo clarki henshawi) in the Truckee River between Lake Tahoe and Pyramid Lake, Nevada, by Weeks et al. (1977). Subcutaneous implant of the radio transmitters (2 cm x 1 cm x 10 cm; 25 grams) into adult cutthroat trout was successful. Transmitter lifespan was approximately 45 days, with tracking occurring in the spring and summer seasons. The type of transmitter used in the Nevada study was later modified by Weeks into a small package with predicted longer battery lifetime for use in this winter study project.

A study by Lonsdale and Baxter (1968) on the Big Laramie River, Wyoming, demonstrated that radio transmitters could be used successfully in streams and lakes of the Rocky Mountain area, due to relatively low salt content of the water. Radio tags were attached to three white suckers (Catostomas commersoni) and one brown trout (Salmo trutta) with Petersen disc tags. The transmitting unit weighed 38 grams in air, 17 grams in water, and length was 6.3 cm. Maximum lifespan was five weeks. A two-inch (50.8 mm) covering of ice on the river at one time during the study appeared to have no noticeable effect on the tag range.

The only total under-ice telemetric study of fish behavior that could be found in the literature was by Poddubnyi, Malinin and Gaiduk (1971). The authors employed ultrasonic techniques in Rybinsk Reservoir, Russia, to study the behaviors of wintering bream and pike. Fish were located by the triangulation method, mapping locations from several ice-holes. Tag life was approximately 2 to 3-1/2 days. Winter movements of bream were found to be insignificant, while pike were found to have two periods of increased activity, early morning and late afternoon, similar to summer behavior. Ultrasonic tags were found to operate better in winter than in summer because the water contained less suspended matter, organisms and air bubbles to impair signal transmissions.

The objectives of this report will be to (1) describe and evaluate two methods (radio telemetry and radioisotopes) used during the winters of 1977-78 and 1979-80 to locate and sample brown trout microhabitat under complete ice cover on two Wyoming foothills streams; and (2) present tentative findings, based on #1 above, regarding the hydraulic characteristics of the microhabitat occupied by and movements of brown trout under total ice cover.

DESCRIPTION OF STUDY AREA

Two streams were selected for study during the course of these investigations. The first, the Laramie River through the Boswell Ranch, served as the study site for radio telemetry testing and evaluation during the winter of 1977-78. The second, Wagonhound Creek through the Medicine Bow Big Game Winter Range, was utilized during the winter of 1979-80 to test the feasibility of using radioisotopes to track brown trout movements and microhabitat occupation under ice cover.

A 4,010 foot (1.22 km) section of the Laramie River located on the Boswell Ranch property near Jelm, Wyoming, was selected to study the winter microhabitat preferences of adult brown trout. The Laramie River headwaters rise in the Medicine Bow Mountains of Colorado, less than 10 miles (16.1 km) north of Rocky Mountain National Park. The river flows approximately 30 miles (48.3 km) northwest to the Wyoming border, where it flows an additional 200 miles (321.9 km) to its confluence with the North Platte River near the town of Fort Laramie, Wyoming. Figure 1 illustrates the location of the Laramie River and the Boswell Ranch study site.

The Boswell Ranch study site is located 1.25 miles (2.8 km) north of the Colorado-Wyoming state line in Section 15, T. 12 N., R. 77 W., Albany County. The drainage area encompasses 294 square miles (761.5 km^2).

A U.S. Geological Survey (USGS) stream gaging station was established 0.25 miles (0.40 km) north of the Colorado-Wyoming

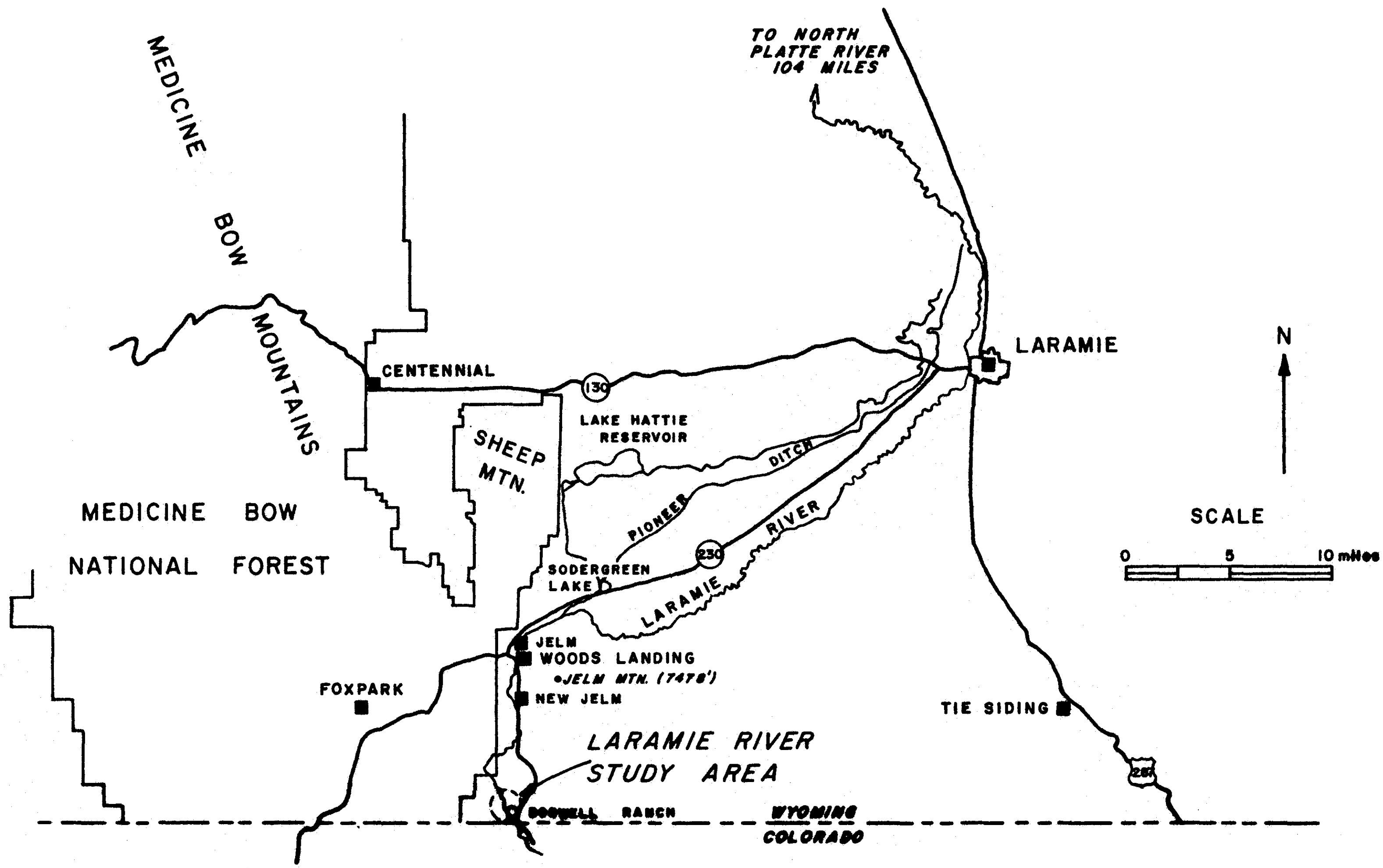

Figure 1. Map showing the location of the Laramie River study area.

border in 1904, and discontinued in 1970. The gage, #6-6585, is located approximately 1.5 miles (2.4 km) upstream from the study site. Records from the USGS gage station for water years 1911-1970 show a maximum daily discharge of 4,200 cubic feet per second (cfs) (118.9 m^3/s) on June 9, 1923, and a minimum discharge of 5.6 cfs (0.16 m^3/s) on December 2, 1933.

The flow pattern of the Laramie River is typical of most Wyoming rivers, with high runoff in late spring due to snowmelt in the high mountains, loss of flow to irrigation in summer, reduction of flow in fall until a baseflow is reached and maintained through the winter. Ice formation occurs around the middle of November, becoming total from December through February. Areas of open water appear again in March. Gage records indicate poor records during the winter period, due to ice cover. The mean daily discharge for the period of record during the winter months (November-February) was 32 cfs (0.90 m^3/s).

One small tributary stream, Johnson Creek, enters the Laramie River approximately 300 feet upstream from the upper end of the study site. Johnson Creek contributes less than 5 cfs (0.14 m^3/s) of flow to the river during most of the year, with higher flows occurring during spring runoff. The creek supports a population of brown trout, and possibly some rainbow trout.

The Boswell Ranch is located in a floodplain area at elevation 7,739 feet (2,358.8 m) above mean sea level (msl), surrounded by the mountains of the Medicine Bow Range. Willows (*Salix* sp.), thin-leaf alder (*Alnus* sp.), water birches (*Betula* sp.), and various grasses line the river banks, while large native hay meadows dominate the bottomlands. The foothills away from the river are drier and are typical sagebrush (Artemesia sp.), bunchgrass (Agropyron sp.) rangelands. The surrounding mountains are dominated by a mixture of logdepole pine (Pinus contorta) and aspen (Populus tremuloides). Land use of the area consists primarily of ranching--the haying of native grasses and cattle grazing.

Brown trout populations in the study reach of the Laramie River are excellent. Wesche, sampling in 1975, reports standing crops ranging from 44.8 lbs/acre (50.2 kg/ha) to 123.7 lbs/acre (138.7 kg/ha) at three study sites (Wesche, 1980). In 1977, standing crops averaged 54.1 lbs/acre (61.1 kg/ha). Average fish length in 1975 was 10.0 inches (254.5 mm) and 10.8 inches (273.8 mm) in 1977.

Rainbow trout (Salmo gairdneri) are also present in the Laramie River, but few occur through the study reach. One rainbow was captured by Wesche in 1975, but none were collected during this study. White suckers (Catastomus commersoni), longnose suckers (Catastomus catostomus), and longnose dace (Rhynicthes cataractae) are also present.

The Wagonhound Creek study area was located in Carbon County, Wyoming, where it flows through the north portion of the Medicine Bow Big Game Winter Range, managed by the Wyoming Game and Fish Department. This property is also referred to as the Wicks Brother's Ranch. The study section was located in the southwestern quarter of Section 5, T. 19 N., R. 79 W., and was bounded on the south, at its upstream end, by Interstate 80 (see Figure 2).

Wagonhound Creek in the area of the study section is an ungaged, meandering foothills stream at an elevation of 7,420 feet (2,261 m).

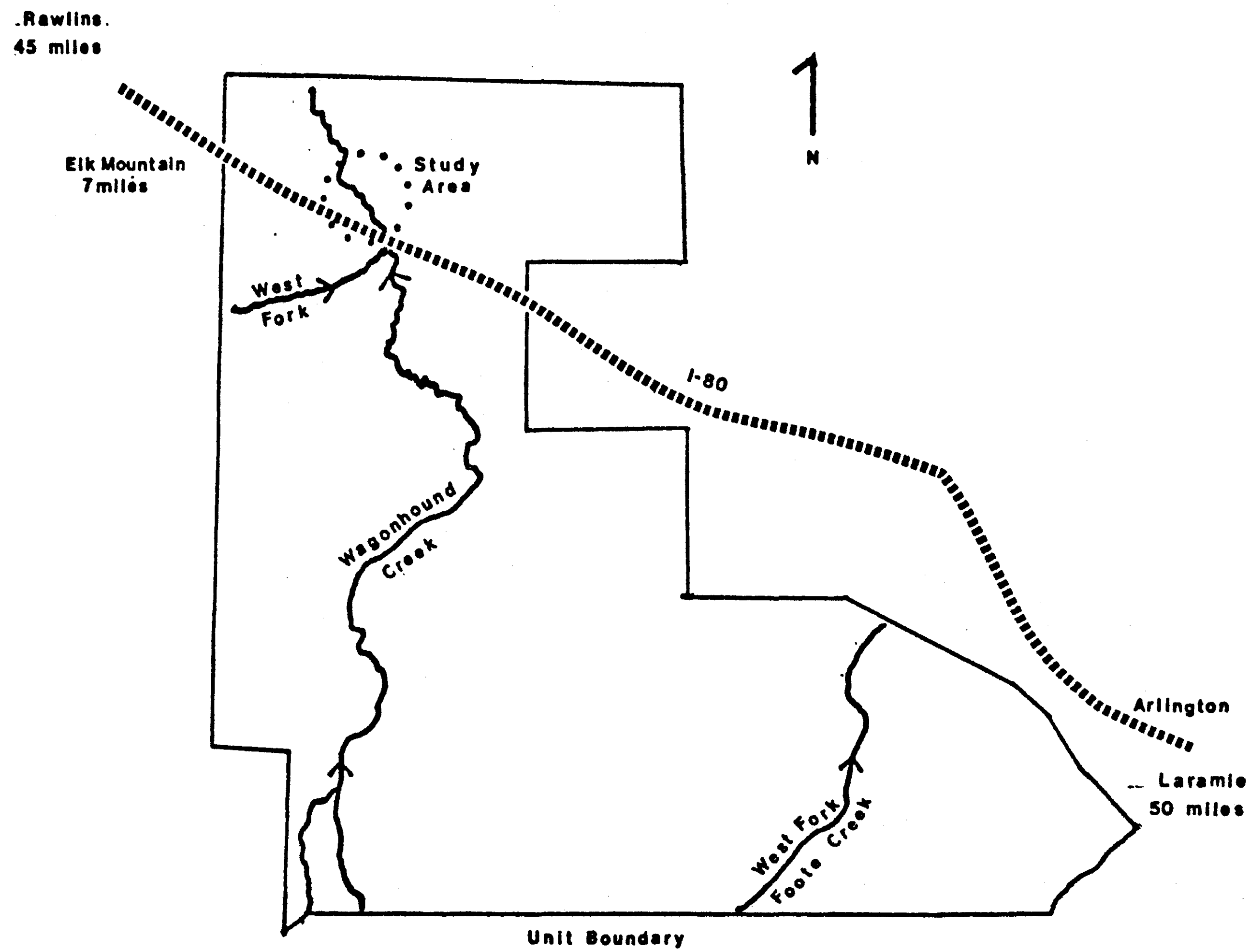

Figure 2. Map depicting location of the Wagonhound Creek study area within the Wyoming Game and Fish, Wicks Brothers' Management Unit.

The stream is characterized by a typical riffle-pool-run complex with stream widths varying from 15-45 feet (4.5-14 m).

Mean water velocity through the 2,000 feet (610 m) study section was measured by a dye dilution study at 0.254 feet per second (fps) (7.74 cm/s) in September. Discharge from September through March ranged from 2.6 to 7.7 cfs (.07 to .22 m^3/s). Total alkalinity averaged 339 mg/1 and pH was recorded at 8.2 for September and October. Water temperature was consistently 0°C after ice cover came on at the end of November.

The general topography of the area is rolling foothills covered with sagebrush (*Artemesia* sp.) and mountain mahogany (*Cercocarpus montanus*). Summer riparian land use immediately upstream of the study area is cultivated hay fields. During winter months, land use reverts to an elk wintering area. Summer cattle grazing is the primary land use directly adjacent to the study section. Riparian vegetation includes willow (*Salix* sp.), rose (*Rosacea* sp.), and cottonwood (*Populus sargenteii*).

METHODS

Radio Telemetry

Transmitter Development

Transmitters used in this project were developed and constructed by Mr. Richard Weeks, Department of Electrical Engineering, University of Wyoming. The electronics for the transmitters were built in small, hermetically sealed packages. These packages were mounted on fiberglass printed circuit boards alongside Eveready size 76 mercury or silver oxide batteries. The antennas were etched on the printed circuit boards. Once the electronics and batteries were mounted, the total units were coated with the following:

1. First coating: fifty-fifty mixture of beeswax and paraffin (initial waterproofing);
2. Second coating: thin coating of dental acrylic (additional waterproofing and mechanical protection); and
3. Final coating: very thin coating of the beeswax and paraffin mixture (waterproof sealing and physiological inertness).

The finished tags weighed from 15 to 20 grams and measured an average of 15 mm by 10 mm by 55 mm, or approximately 2.2 inches long. Lifespan of each transmitter was estimated to be six months.

Each tag operated on one of 12 radio channels assigned to the U.S. Fish and Wildlife Service for experimental use. No licensing was required as radiated power levels were less than 10 milliwatts. Channels could be distinguished by differences in frequencies. A 12-channel receiver was utilized to pick up transmitted signals, or "beeps," from the tags.

Transmitter Implantation

Transmitters which could be internally implanted as opposed to external attachment were chosen because in long duration studies, chances for losing externally attached tags are much greater than internally placed tags. Morris (1977) evaluated three different methods of attaching ultrasonic transmitters to adult walleye: (1) oral insertion into the stomach, (2) external attachment to the nape, and (3) surgical implantation into the peritoneal cavity. External attachment, using floy tags, was found to be inadequate, with only 13 percent retention. Oral insertion was also found to be inadequate with 87.5 percent of the transmitters being regurgitated. Surgical implantation was found to be adequate and is recommended for use in future studies. Peterson (1975) also found after six months of preliminary testing that surgical implantation of transmitters into the coelom was superior to stomach insertion. Personal communications with Hart (1976) indicated that no problems should arise when surgically implanting transmitters in trout.

Surgical techniques were perfected using cutthroat trout (*Salmo clarki*) in laboratory surroundings. For the size of transmitter used in this study (2.2 inches, 55 mm long), trout with lengths of 11 inches (279 mm) or larger were determined to be suitable for implantation. Techniques used were very quick (under 5 minutes), very simple, and non-sterile as this method was used for streamside implantation of transmitters into freshly caught brown trout.

Materials used for the surgical implantation were:

- MS-222 (Tricaine Methansulfonate)
- Chromic gut with attached 00-suture needle
- Dissecting scalpel
- Blunt-nose scissors
- Hemostat
- Bucket
- Towel

Fish were anesthetized in a plastic bucket with MS-222 in a direct dosage according to water temperature. Effective anesthesia occurred within 10 minutes, also depending upon water temperature. Once sedated, the fish's total length (mm) and weight (grams) were measured and recorded. The fish was then positioned on a towel, with its ventral surface up, enabling the trout to be easily held in place.

The incision was made anterior to the pelvic girdle, extending no longer than necessary to insert the transmitter. The 2.2 inch (55 mm) long transmitters required an incision of 1.0 to 1.5 inches (25 to 28 mm). A dissecting scalpel was used to open the incision through the body wall and peritoneum. The incision was completed with blunt-nose scissors. Fresh water was splashed on the gills at frequent intervals throughout the operation. Next, the transmitter was inserted and arranged within the body cavity.

Stitches were sewn using a hemostat with absorbable chromic gut suture attached to a 00-needle, and tied with a basic square knot reinforced with a half-hitch. Stitches were placed approximately 1/4 inch (8 mm) apart. No bacteriocidal agents were administered internally or externally throughout the entire process. A penicillin-salve administered on the incision after implantation appeared to inhibit healing of the incision in two experimental cutthroat trout. Instruments and transmitters used were clean, but non-sterile. After surgery, fish were resuscitated by grasping their lower jaw and moving them through fresh water. Trout recovered (righted themselves in water) in 5 to 15 minutes. Incisions made on aquarium fish appeared to be completely healed in approximately 1-1/2 months.

Wild brown trout used for the study were captured using electrofishing techniques. Adult browns ranging from 11.5 inches (292 mm) to 16 inches (406 mm) were kept for implantation. Most fish were captured within the study site, but as ice cover progressed fish were harder to find and it became necessary to obtain fish outside of the study area. The same operating procedure was performed streamside as in the laboratory, with a towel placed on the stream bank as an "operating table." Each trout's adipose fin was clipped before release to enable identification in future recovery efforts. Wild trout also revived in 5 to 15 minutes and were immediately released back into the river, within the study site.

<u>Tracking Procedure</u>

For streamside tracking of tagged fish, two procedures were used. Tag transmissions were picked up from a distance, "macrolocation," with a three-element horizontally directed Yagi antenna attached to the receiver. A pair of stereo headphones was also plugged into the receiver to amplify the received signal. A car-door antenna mount was built for the Yagi, enabling streamside tracking by driving along the river banks. The Yagi antenna gave reception ranges up to approximately 200 yards (182.9 m), with directional accuracies of about

10 degrees. Once the macrolocation was found, specific "microlocation" was accomplished by replacing the Yagi antenna with a small loop antenna. The loop antenna had a maximum reception range of 100 feet (30.5 m), and location accuracy of one to two feet. Both antennas produced stronger (louder) transmissions when pointed directly at a transmitter; therefore, specific location was pinpointed by use of signal strength.

Fish were easily located using this method. Before ice cover, tagged trout could be located to a specific weed bed in which they were hiding, and visually identified. With ice cover, the transmitting signals were actually enhanced, and fish were easily located by walking out on the ice.

A single-engine aircraft was used on three occasions for attempts to locate tagged fish. A four-element vertically directed antenna was mounted on a wheel strut of the plane, and attached to the receiver and headphones within the plane. "Macrolocation" of tagged fish was possible by flying at elevations of 500 to 1,000 feet (152.4 to 304.8 m) above ground level.

Microhabitat Assessment

Fish were located as to a specific baseline marker when possible. A chain saw and a power ice auger were used to cut through the ice to enable assessing the tagged trout's specific under-ice microhabitat. Once through the ice, the following parameters were measured:

1. Date;
2. Time;
3. Gage height (reading from the upstream gage station);

4. Location (according to baseline);

5. Distance (feet, m) from the water's edge to the specific location;

6. Total water depth (welled up to the top of the ice, to the nearest .05 feet (.015 m));

7. Ice depth (to the nearest .05 feet (.015 m));

8. Velocity in fps (cm/s), using Price AA and pygmy current meters:

   a. at substrate;

   b. at 0.6 depth;

   c. at surface;

9. Substrate; and

10. Cover type.

Measurements were taken at the first location a fish was found (original location), and again at the location the fish moved to after being scared by disruptions caused by the measurements. These second locations were noted as "hiding" locations, as opposed to first, or "original" locations.

Radioisotopes

Due to the use of radiation in this portion of the study, selection of a study stream required very careful consideration based upon the following criteria:

1. The presence of a viable brown trout population;

2. Landowner permission to gain access to the stream;

3. The flexibility to close the area to fishing without causing undue frustration to fishermen;

4. No municipal water supply located downstream of the study site such that an hazardous situation might be created by the use of radioisotopes; and

5. A low potential for winter kill.

As no private landowners felt comfortable in granting access across their property, only sites managed by the Wyoming Game and Fish Department were considered. Wagonhound Creek was then chosen as the most satisfactory site for the following reasons:

1. A naturally reproducing brown trout population was present.

2. Access to Wagonhound could be gained from Wyoming Game and Fish Department property.

3. The area receives little use by anglers in the fall so that closing the area to fishing did not cause angler frustration.

4. No municipal water supply intake was located for 60 miles downstream.

5. Sufficient flow occurred to keep ice cover from extending to the substrate.

Antimony 124 (^{124}Sb) was selected as the radioisotope to be implanted. ^{124}Sb has a short half-life (60 days) and high energy gamma emissions (0.505 to 2.740 MdV) which would allow detection through 3 feet of water and 4 feet of air at an activity of 0.5 milliCuries (mCi). An hazard evaluation written by the University of Wyoming's Radiation Safety Officer was submitted to the Nuclear Regulatory Commission (NRC) to obtain a permit for the use of the antimony.

Several precautions were taken due to the potential danger presented by the radiation. Barricades were constructed across the upstream and downstream ends of the study reach in an attempt to confine the implanted fish within the reach. These barricades were fences placed perpendicular to the flow and constructed from 6 foot steel posts spaced 3 feet apart and covered with 0.5 inch (1.35 cm) metal mesh. The barricades were expected to remain standing until the surface ice had melted, when an attempt to recover the implanted fish by electrofishing could be made. Fish were implanted as late in the fall as could reasonably be expected without encountering ice cover. Ice cover would have prohibited collecting fish by electrofishing. This was also done to eliminate competition with fishermen for use of the stream and to maximize the length of time after ice cover during which the ^{124}Sb would be active enough to detect. Signs closing the area to fishing and warning of the presence of radioactive sources were posted.

Capsules used to implant the antimony consisted of 2.5 cm pieces of polyurethane tubing sealed at both ends with silicone rubber and had the message "DANGER--RADIOACTIVE" imprinted on them (printing by Floy Tag and Manufacturing, Inc.). Each capsule was loaded with 0.5 mCi of aqueous antimony (^{124}Sb) under the supervision of the Radiation Safety Officer.

In the field, fish were collected using Coffelt BP-2 backpack shockers. Fish were anesthetized, weighed and measured to the nearest gram and millimeter, and implanted streamside using proper radiation safety procedures (i.e., film badges, plastic gloves, lead shielding and monitoring for radioactive leaks). The implant technique used was the same as that described earlier. All fish were tagged externally with a bright yellow Floy spaghetti tag imprinted with the following message: "RADIOACTIVE--CONTACT 307-766-2143". Fish were then allowed to recover in a "live-car" (a five-sided perforated plexiglas box placed in the stream) before being released.

Attempts to locate the fish were made two times a week from November 11, 1979 to January 5, 1980. Fish locations were determined using a single channel analyzer (model number FS-8) and a NaI (TL)

3 x 3 crystal and photomultiplier tube (model number PGS3X3) manufactured by Technical Associates. The analyzer window was set to detect the 1.692 MeV gamma emitted by ^{124}Sb. At each location, a hole was either chipped or drilled with a power ice auger and microhabitat data, similar to that described earlier, were collected.

RESULTS AND DISCUSSION

Radio Telemetry

Transmitter Performance

Originally, 12 fish were to be tagged for the study, each having a six-month period of tracking time (battery lifespan). Instead, 18 tags were built which, unfortunately, had varying lifespans of several hours to a maximum of three months. A total of 16 fish were implanted with transmitters in the Laramie River, and their history of operation is as follows:

Transmitter No.	Date First Implanted	History
1	September 27	Last located on December 15.
2	November 11	Last located on November 11.
3	September 27	Last located on October 3. A new #3 was built and implanted on November 29 and was last located on December 13.
4	November 29	Last located on February 22.
5	December 8	Last located on March 4.
6	August 30	Last located on September 6. A new #6 was built and implanted on November 18 and was last located on February 3.
7	August 30	Last located on November 3.
8	November 10	Last located on November 15.
9	November 18	Last located on December 15.
10	November 10	Last located on December 1.

Transmitter No.	Date First Implanted	History
11	October 25	Last located on October 25. A new #11 was built and implanted on November 10 and was last located on November 10.
12	October 25	Last located on October 27. A new #12 was built and implanted on November 10 and was last located on November 27.

Battery failure was the assumed cause for not locating the fish in the river. A small single-engine aircraft was chartered three times in efforts to locate fish from the air approximately 15 miles (24.14 km) upstream from the study site (into Colorado), and approximately 15 miles (24.14 km) downstream below the study site. No transmissions were received, and batteries were assumed to be dead.

One transmitter used in laboratory trout behavioral studies was removed from the host fish and dismantled to evaluate possible causes of failure. It was discovered that the transmitters built for the project had a predicted lifespan of only three months, instead of six months, due to an error in the electrical wiring. To reinforce the fact that lost transmitters were due to battery failure and probably not due to tagged fish moving out of the study area, sections of the study area were sampled by electrofishing. Fish numbers 8 and 10 were recovered on May 5, 1978, no farther than 65 feet (19.8 m) from their last noted location. Transmitters 8 and 10 were active for only 5 and 22 days, respectively.

Tracking procedures were considered successful before and after ice cover. Location accuracy for the small loop antenna appeared to be from 1-2 feet (0.30-0.61 m) before ice cover, and was assumed to have the same accuracy after ice cover. On several occasions before ice cover, fish were located in a specific weed bed and visually identified by their adipose clip when flushed from their area of cover. Location accuracy by aircraft tracking at altitudes from 500 feet (152.4 m) to 1,000 feet averaged from 200-300 feet (61.0-9.14 m) either side of the specific location, consistent with the findings of Weeks, Lorz, Lindsay, Baily and Green (1977). Signal strength was strongest when directly over the transmitter. Ice cover appeared to reduce the horizontal signal distance by as much as 50 yards (45.7 m) and enhanced the vertical signal distance with the Yagi antenna.

Implant Response

No physical distress or mortality was known to have occurred due to transmitter implantation. Brook trout used for laboratory behavioral studies were completely healed, with no more than a trace scar visible in approximately 1-1/2 months. Tagged brown trout recaptured in May, 1978, showed excellent healing. Skin and subcutaneous tissue were quite thick in the area of the incisions, and stitches were still visible. Freezing water temperatures are thought to be the reason stitches were present, although incision closure was complete. Both fish recaptured had been implanted and released in November, 1977, six months prior to recapture. Body condition was good, with fish number 10 losing only 15 grams in weight since November, a change of K_{TL} from 0.85 to 0.80. Fish number 8 gained 21 grams, increasing in K_{TL} from 0.89 to 0.93. The tagged fish had been actively feeding as stomach analysis showed both trout stomachs were full of stonefly (Plecoptera) nymphs, mayfly (Ephemeroptera) nymphs and other unidentifiable matter.

Microhabitat Assessment

For under-ice microhabitat identification, eight tagged fish were tracked and located (numbers 1, 3, 4, 5, 6, 9, 10 and 12) for a total of 109 readings. The 109 readings were further broken down into original location (resting area) and to their "hiding location" (cover microhabitat)--the area the tagged fish moved to after being disturbed by measurements of their original location.

Water depths occupied by tagged brown trout in relation to the amount of that particular depth available in the habitat are demonstrated in Figure 3. 47.4 percent of the time browns were observed in water depths of 0.50-0.99 feet. Time occupying other depth classes was 12.8 percent in <0.50 feet, 24.8 percent in 1.00-1.49 feet, and 14.7 percent in ≥1.50 feet. Average water depth in microhabitat locations was 0.97 feet (0.30 m).

Mean water velocities found in brown trout microhabitats were dominated by the <0.50 fps mean velocity class (Figure 4). Tagged trout utilized the <0.50 fps class 44.2 percent of the time, 0.50-0.99 fps 17.9 percent, 1.00-1.49 fps 28.4 percent, and ≥1.50 fps 9.5 percent of the time. An overall average of mean velocities found at the 109 locations was 0.75 fps (0.23 m/s). Point velocities, measured at the substrate level, were composed of 63.3 percent <0.50 fps, 29.4 percent 0.50-0.99 fps, 4.6 percent 1.00-1.49 fps, and 2.8 percent ≥1.50 fps. Point velocities averaged 0.10 fps (0.03 m/s) in the microhabitat locations.

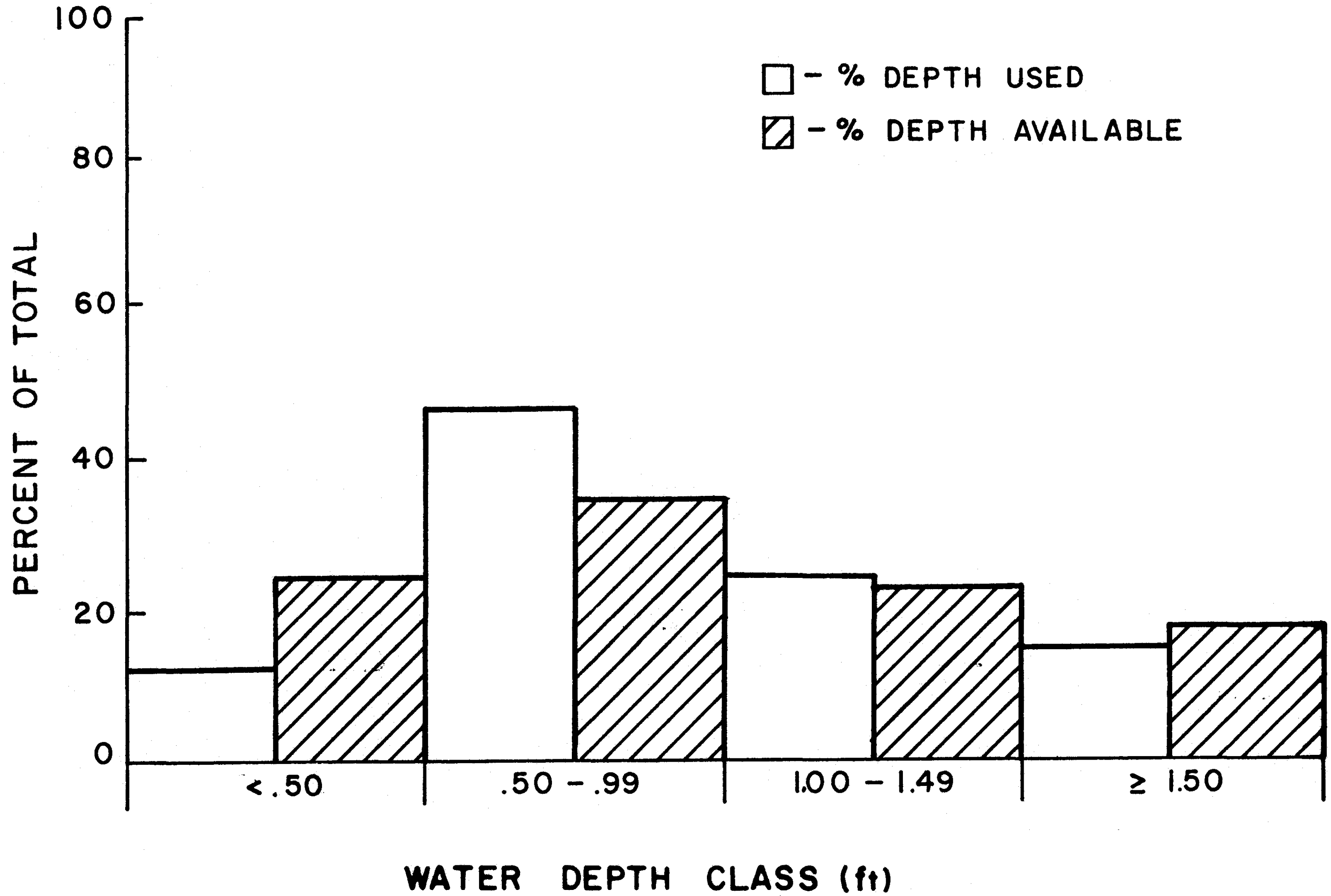

Figure 3. Comparisons of water depths found in brown trout microhabitats with water depths available, during ice cover. (ft x 0.3048 = meters)

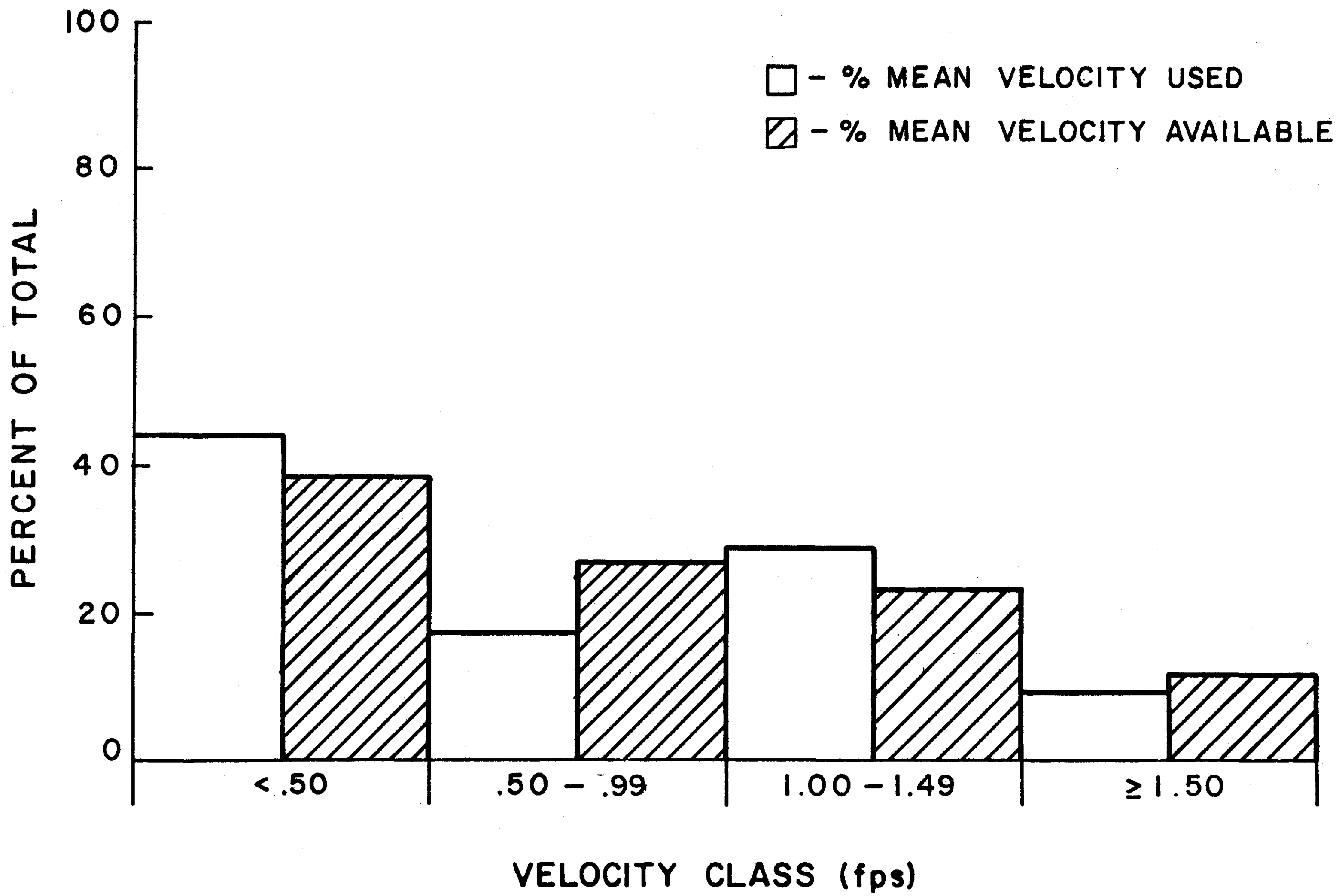

Figure 4. Comparison of mean velocities found in brown trout microhabitats with mean velocities available, during ice cover. (fps x 0.3048 = m/s)

Preferences for particular depth-velocity classes are shown in Figure 5. Percentage of depth and mean velocity intervals most often occupied in post-ice cover locations as compared to percent availability of those intervals are as follows:

Available Depth-Velocity	Depth-Velocity Used
9.2% (0.50-0.99 ft, <0.50 fps) (0.15-0.30 m, <0.15 m/s)	23.2% (0.50-0.99 ft, <0.50 fps) (0.15-0.30 m, <0.15 m/s)
9.6% (0.50-0.99 ft, 1.00-1.49 fps) (0.15-0.30 m, 0.30-0.45 m/s)	13.7% (0.50-0.99 ft, 1.00-1.49 fps) (0.15-0.30 m, 0.30-0.45 m/s)
5.4% (1.00-1.49 ft, <0.50 fps) (0.30-0.45 m, <0.15 m/s)	10.5% (1.00-1.49 ft, <0.50 fps) (0.30-0.45 m, <0.15 m/s)
7.9% (1.00-1.49 ft, 1.00-1.49 fps) (0.30-0.45 m, 0.30-0.45 m/s)	10.5% (1.00-1.49 ft, 1.00-1.49 fps) (0.30-0.45 m, 0.30-0.45 m/s)

It appears from these data that several types of microhabitats are present. Resting microhabitats, or focal points, are assumed to be the most highly used areas, indicating that winter under-ice preferences for these points are areas with water depths of 0.50-0.99 feet (0.15-0.30 m) and mean velocities of <0.50 fps (<0.15 m/s). In the preferred resting area, substrate consisted of rubble and gravels. Cover used in the resting microhabitat appeared to be a function of substrate, ice cover and water depth. Types of cover utilized by percentage are as follows:

Cover Type	% Time Used
Rubble and ice cover	52.4
Rubble, aquatic vegetation and ice cover	42.9
Ice cover only	4.8

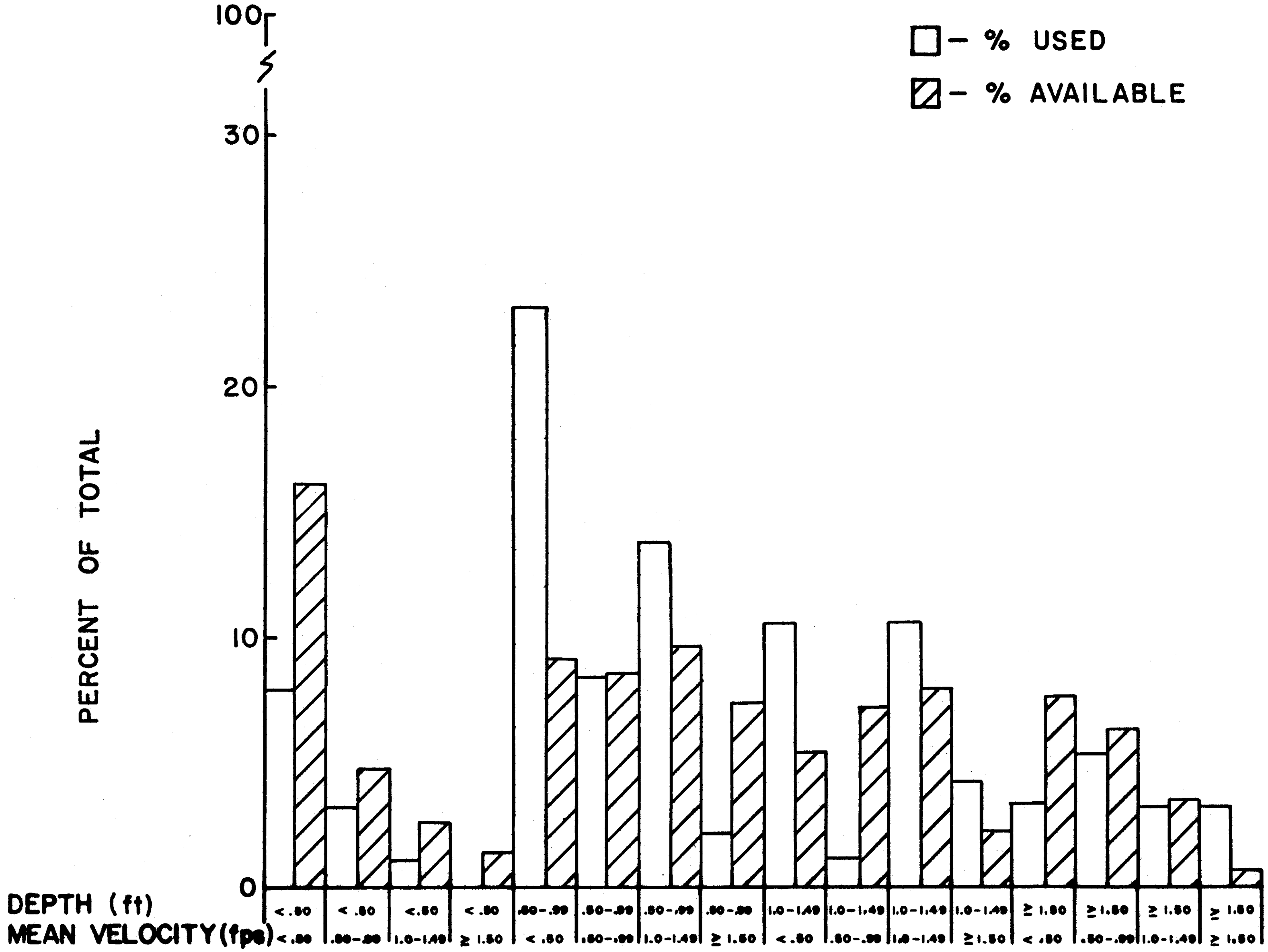

Figure 5. **Comparison** of depth-mean velocity intervals found in brown trout microhabitats with depth-mean velocity intervals available, during ice cover.

Average ice thickness at the preferred 0.50-0.99 feet, <0.50 fps interval was 1.13 feet (0.34 m). Hartman (1963) demonstrated that the winter behavior of brown trout was highly associated with bottom structures, and the use of substrate as cover. Point velocities at the preferred locations ranged from 0 to 0.52 fps (0-0.16 m/s), with a mean of 0.05 fps (0.015 m/s).

In contrast to the pre-ice cover resting preference of brown trout for deep pools and slow velocities, the fish preferred shallower depths with slow velocities under total ice cover. Logan (1963) also observed that trout in a Montana stream were mainly found in pools during spring, summer and fall, while in winter the trout moved to shallower water depths under surface ice cover. Trout seemed to prefer the close proximity of overhead ice cover while in shallower water depths.

Hiding location, a cover microhabitat, was considered to explain the preference for the depth-velocity interval of 1.00-1.49 feet (0.30-0.45 m) and <0.50 fps (<0.15 m/s). Measurements of the original locations where tagged fish were found were separated from their hiding locations, to further emphasize resting and cover microhabitat preferences. Figure 6 illustrates the depth-mean velocity preferences for brown trout original stream locations, while Figure 7 illustrates hiding location preferences. In Figure 6, the resting microhabitat interval of 0.50-0.99 feet, <0.50 fps is greatly emphasized, being occupied by trout 28.7 percent of the time. Cover microhabitat preferences of 1.00-1.49 feet, <0.50 fps are not so prominent until singled out, as in Figure 7. From Figure 7 it is also seen that other

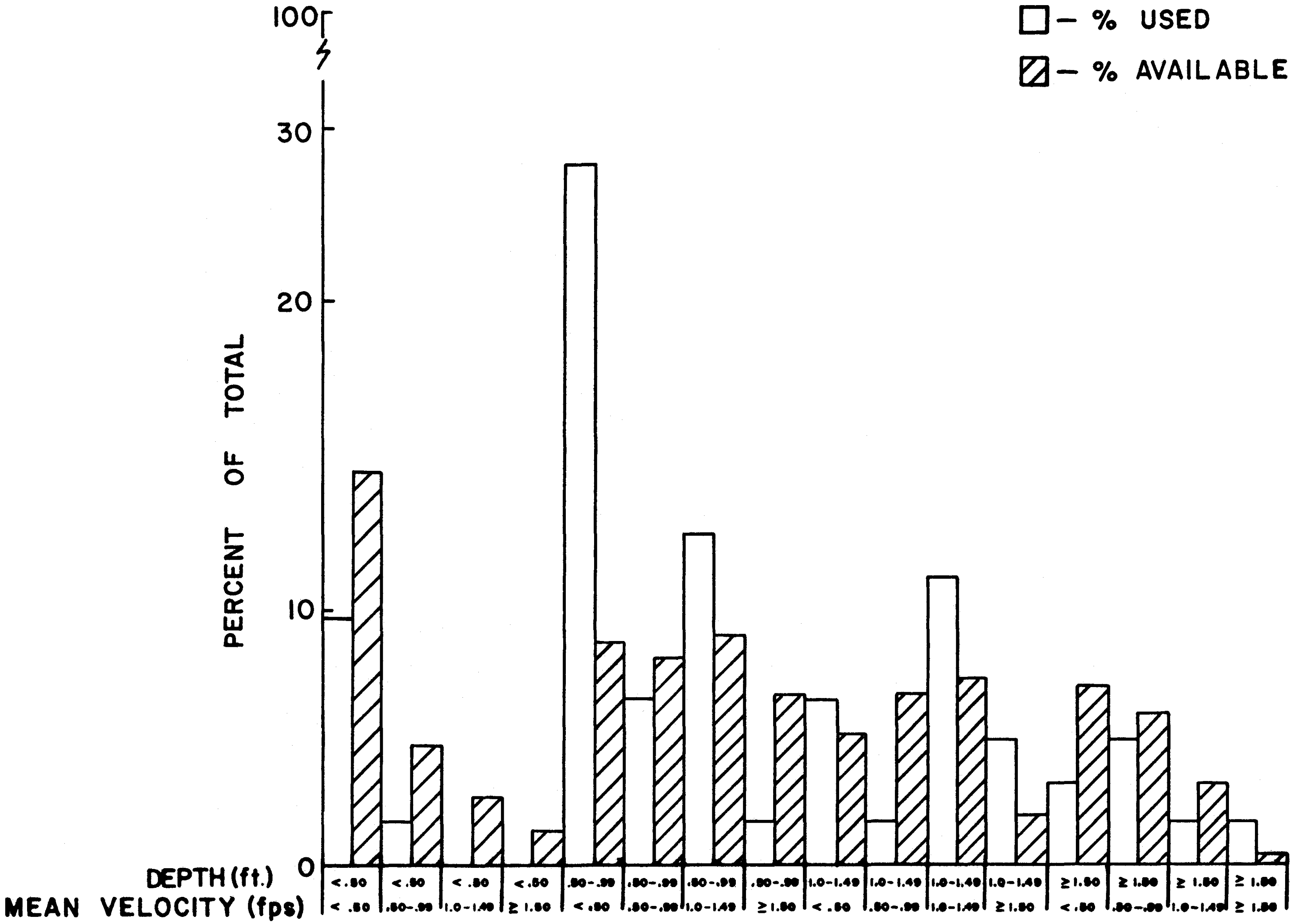

Figure 6. Comparison of depth-mean velocity intervals found in brown trout "original location" microhabitats with depth-mean velocity intervals available, during ice cover.

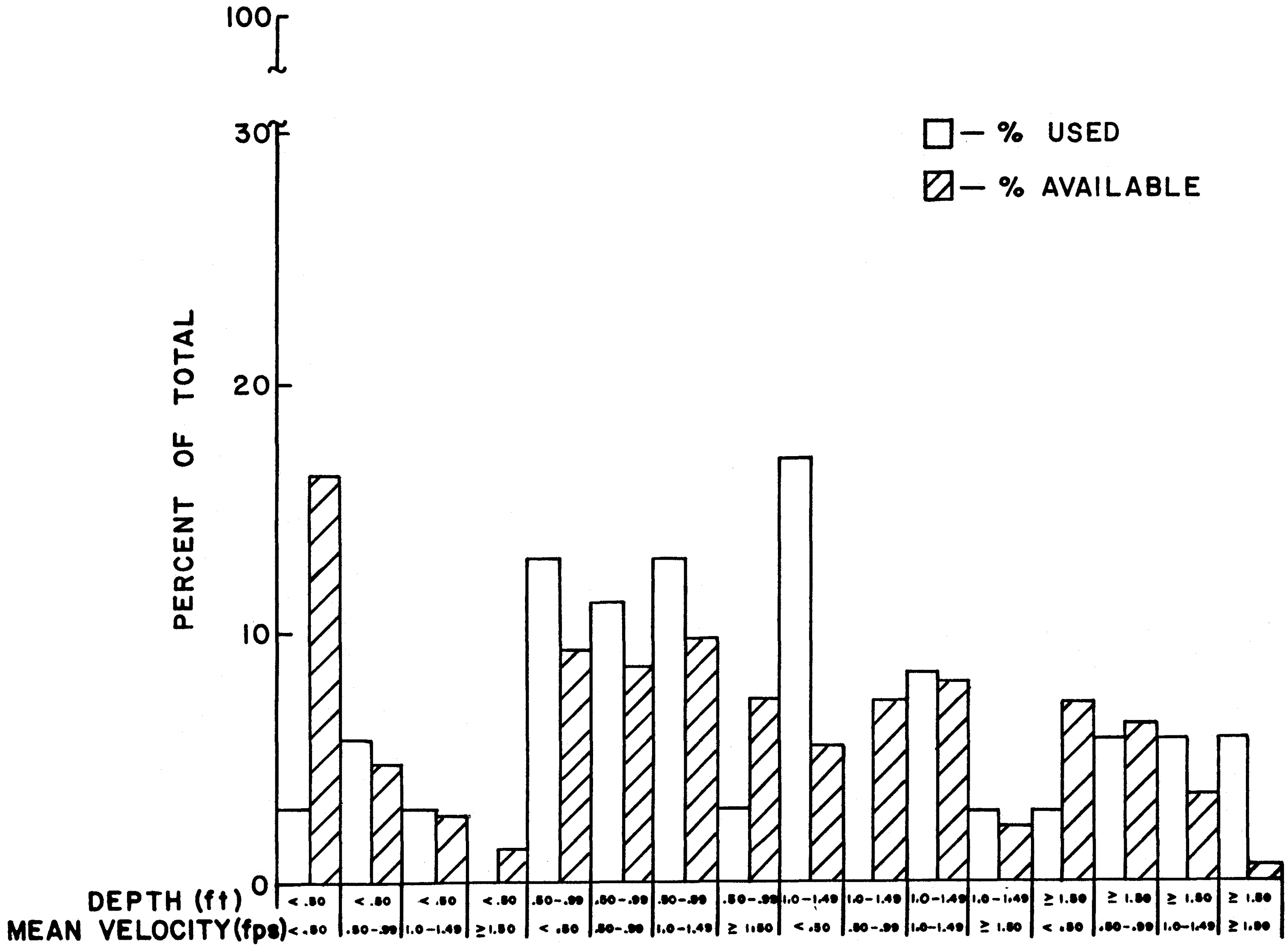

Figure 7. Comparison of depth-mean velocity intervals found in brown trout "hiding location" microhabitats with depth-mean velocity intervals available, during ice cover.

preferences for cover microhabitat do occur, but none are nearly as prominent as the 1.00-1.49 ft, <0.50 fps interval.

Average ice thickness above hiding locations was 1.34 feet (0.41 m). Point velocities were <0.50 fps (<0.15 m/s) 58.3 percent of the time, 0.50-0.99 fps (0.15-0.30 m/s) 33.3 percent, 1.0-1.49 fps (0.30-0.45 m/s) 5.6 percent, and $\geq$1.50 fps ($\geq$0.46 m/s) 2.8 percent of the time. Average point velocity was 0.41 fps (0.12 m/s). Cover utilized in the hiding locations again consisted of rubble, submerged vegetation and ice. The percentages of cover found in the hiding locations are as follows:

Cover Type	Percentage Used
Rubble, aquatic vegetation, ice	38.9
Aquatic vegetation	13.9
Rubble, ice	41.7
Ice only	5.6

Deep water may also be used as a cover type in this situation, in combination with the 1.34 feet (0.41 m) ice thickness, to form a dense, shaded cover. Fish moved an average distance of 16.6 feet (5.06 m) to cover when disturbed. Movements to cover had a wide range of from 1.5-74.0 feet (0.46-22.56 m), possibly indicating that a true preference for the particular hiding location's characteristics does exist.

Movements of Tagged Brown Trout

Total movements of tagged brown trout are summarized by month in Table 1. Total movements must be considered to be minimum as trout

Table 1. Summary of tagged brown trout movements, September, 1977 through March, 1978.

Fish		September, 1977 Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Move-ment (ft)
#7	Dist. moved betw. trackings	450	0	116	30.48	54.9	1165
	Dist. moved to cover	5	5	5			
#1	Dist. moved betw. trackings	850	850	850	30.48	54.9	850
	Dist. moved to cover	-	-	-			
#8	Dist. moved betw. trackings						
	Dist. moved to cover						
#9	Dist. moved betw. trackings						
	Dist. moved to cover						
#10	Dist. moved betw. trackings						
	Dist. moved to cover						
#12	Dist. moved betw. trackings						
	Dist. moved to cover						
#3	Dist. moved betw. trackings						
	Dist. moved to cover						
#4	Dist. moved betw. trackings						
	Dist. moved to cover						
#5	Dist. moved betw. trackings						
	Dist. moved to cover						
#6	Dist. moved betw. trackings						
	Dist. moved to cover						
	TOTAL MOVEMENT						2015.0
	AVERAGE MOVEMENT PER FISH						1007.5

Fish		October, 1977 Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Move-ment (ft)
#7	Dist. moved betw. trackings	340	0	86.3	50.12	45.2	700
	Dist. moved to cover						
#1	Dist. moved betw. trackings	2740	0	355	50.12	45.2	2840
	Dist. moved to cover	-	-	-			
#8	Dist. moved betw. trackings						
	Dist. moved to cover						
#9	Dist. moved betw. trackings						
	Dist. moved to cover						
#10	Dist. moved betw. trackings						
	Dist. moved to cover						
#12	Dist. moved betw. trackings						
	Dist. moved to cover						
#3	Dist. moved betw. trackings						
	Dist. moved to cover						
#4	Dist. moved betw. trackings						
	Dist. moved to cover						
#5	Dist. moved betw. trackings						
	Dist. moved to cover						
#6	Dist. moved betw. trackings						
	Dist. moved to cover						
	TOTAL MOVEMENT						3540.0
	AVERAGE MOVEMENT PER FISH						1770.0

Fish		November, 1977 Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Move-ment (ft)
#7	Dist. moved betw. trackings	230	230	230	39.95	40.3	230
	Dist. moved to cover						
#1	Dist. moved betw. trackings	10	0	3.3	39.95	40.3	10
	Dist. moved to cover	-	-	-			
#8	Dist. moved betw. trackings	70	65	67.5	39.95	40.3	135
	Dist. moved to cover	-	-	-			
#9	Dist. moved betw. trackings	920	920	920	39.95	40.3	920
	Dist. moved to cover	-	-	-			
#10	Dist. moved betw. trackings	230	80	120	39.95	40.3	480
	Dist. moved to cover	-	-	-			
#12	Dist. moved betw. trackings	620	40	256.7	39.95	40.3	770
	Dist. moved to cover	-	-	-			
#3	Dist. moved betw. trackings						
	Dist. moved to cover						
#4	Dist. moved betw. trackings						
	Dist. moved to cover						
#5	Dist. moved betw. trackings						
	Dist. moved to cover						
#6	Dist. moved betw. trackings	624	426	525	39.95	40.3	1050
	Dist. moved to cover	-	-	-			
	TOTAL MOVEMENT						3595.0
	AVERAGE MOVEMENT PER FISH						513.6

ft x 0.3048 = m
cfs x 0.0283 = m^3/sec

Table 1. (continued)

December, 1977						January, 1978						February, 1978						March, 1978 (up to 3/4)					
Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Movement (ft)	Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Movement (ft)	Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Movement (ft)	Max. (ft)	Min. (ft)	$\bar{x}$ (ft)	ADF (cfs)	Mean Temp. (°F)	Total Movement (ft)
10	0	4.7	28.92	33.0	47																		
20	5	11																					
3390	78	1523	28.92	33.0	4580.5																		
10.5	10.5	10.5																					
205	4	105	28.92	33.0	209																		
-	-	-																					
3680	60	1870	28.92	33.0	3751.2																		
11.2	11.2	11.2																					
1040	7	338.8	28.92	33.0	2414.5	41	0	11	29.40	33.0	243.6	119	9	39.9	29.51	33.0	196.4						
18.6	8.5	14.3				50.3	6.9	20.6				11.4	6	9.2									
1719	10	444.1	28.92	33.0	2257.5	119	0	45.1	29.40	33.0	485.2	107	1.5	35.9	29.51	33.0	296.1	39.3	6	21.8	29.48	-	171.1
26	11	18.5				74	1.5	30.5				28	9	16.2				31.5	8	21.0			
680	7	238.7	28.92	33.0	1926.3	294	0	42.1	29.40	33.0	373.2	306	19.5	162.8	29.51	33.0	365.3						
3	9.6	5.5				10.2	3.5	7.2				32.3	7.5	19.9									
					15186.0						1102						857.8						171.1
					2169.4						**367.3**						285.9						171.1

could have moved undetectable distances between periods of tracking. Because of months with varying numbers of transmitters operating, and the varying lifespans of transmitters, estimates of movements are considered only fair. According to Table 1, the greatest average movement per fish occurred in December, with a monthly average of 2,169.4 feet (661.2 m). Estimates of movement in September and October may be low due to the lack of data during this time period. Percentage of upstream movement in September, October and November (Table 2) was very high, possibly indicating an upstream migration to areas of spawning. Spawning in brown trout usually occurs from the middle of October through the middle of November, at water temperatures of 44°-48°F (6.7°-8.9°C) (Scott and Crossman, 1973). Average water temperatures for September were 54.9°F (12.7°C), October 45.2°F (7.3°C), and November 40.3°F (4.6°C). Highest percentage of upstream movement was noted in October corresponding with the most suitable water temperatures for spawning. It is not known whether the tagged fish demonstrated spawning activities due to implantation of the transmitters, but it appears highly possible.

A large increase in activity, mainly upstream, was noted during December, with decreases in activity following in January, February and March. Possible reasons for the increase in activity could be due to the tagged trout moving from either spawning areas or pre-ice cover microhabitats to more preferred over-wintering areas. Migrations of brown trout are known to occur after spawning to areas of increased food availability, or feeding grounds (Stuart, 1957). By January, tagged trout appeared to have found their preferred area to over-winter as movement rapidly decreased. Changes in discharge or water

Table 2. Percentages of distances moved upstream, downstream and across-channel during pre-ice cover and ice cover periods.

	Percent Movement Upstream	Percent Movement Downstream	Percent Movement Across-Channel
Pre-Ice Cover			
September	77.4	22.6	
October	81.1	18.9	
Mean Percentage	79.3	20.8	
Post-Ice Cover			
November	55.1	44.9	
December	88.1	11.8	.1
January	58.8	37.6	3.6
February	26.8	65.2	8.0
Mean Percentage	57.2	39.9	3.9

temperature did not appear to cause increased activity in December as discharge levels remained steady with an average daily flow (ADF) of 28.9 cfs (0.82 m^3/s). Average daily water temperature was 33°F (0.6°C) with a maximum of 33.5°F (0.8°C) and a minimum of 32°F (0°C). Ice depth in December averaged 0.80 feet (0.24 m). Other monthly movements were compared to daily discharge levels and water temperatures. No distinct relationships were found between movements and flow or water temperature change.

As was seen in Table 2, percentages of upstream, downstream and across-channel movements varied from month to month. Upstream movements predominated during the pre-ice cover period with 79.3 percent of movements. During winter months, upstream and downstream movements did not differ as greatly. In the winter months, fish appeared to find their over-wintering area and concentrated their movements within this area.

Large initial upstream movements, immediately following release after transmitter implantation, were characteristic of 70 percent of the tagged fish. The average distance moved immediately following release (fish were tracked the day after release) was 827 feet (252 m), with a range of 70-3,680 feet (21-1,122 m). The physical disturbances of electrofishing, anesthesia and transmitter implantation may have been enough to cause the fish to quickly move out of an area. Stefanich (1951) noted that sampling by electrofishing appeared to disturb a population of brown trout enough to cause significant reduction in numbers by trout moving out of the sampled section.

Long distance movements made by tagged trout were usually followed by periods of decreased movement which were concentrated in one area of the stream. These areas were deemed as focal areas, corresponding to areas containing focal points (resting microhabitats). Due to the small sample size available in this study, the number of microhabitats within each focal area was not determined. Microhabitats of three fish with the highest number of movements within a focal area, under ice-cover, were analyzed to see if focal points existed within the focal areas. As expected, the most utilized microhabitat within the focal area was the resting microhabitat with preferred water depth of 0.50-0.99 feet (0.15-0.45 m), and mean velocity of <0.50 fps (<0.15 m/s).

Radioisotopes

Five brown trout ranging in length from 9.6-13.1 inches (243-333 mm) were implanted with radioisotope capsules during early November, 1979. From November 11, 1979 to January 5, 1980, only 12 fish locations from two fish were determined. After this latter date, it became apparent that the ^{124}Sb was no longer active enough to detect. The remaining three implanted fish were never located. For the sake of brevity, the scanty microhabitat data obtained through the use of radioisotope capsules will not be presented here. Suffice it to say that these few data closely paralleled those found on the Laramie River by means of radio telemetry.

Based upon this experience, it appears quite reasonable that the use of an implanted radioisotope to track fish has some obvious drawbacks. These are: the potential dangers present to human beings, the health hazard present to the fish, the need to estimate activity levels that will be high enough to detect given varying field conditions, and the safety precautions necessary when handling radiation. Some advantages are that sufficient amounts of radiation can be contained in a very small capsule. This would be of benefit when working with small fish. Another advantage would be that no possibility of battery failure is present as when working with radio transmitters.

In evaluating this technique, the first comment must be that given certain conditions the method did work in pinpointing fish locations. After a general area of elevated activity was recognized, it was very easy to "zero in" on one spot where counts were elevated even above levels only six inches away. Before ice cover was complete it was very difficult to survey the creek, as patches of ice alternated with areas of open water, which produced a rather treacherous situation. It was necessary to be within 1-3 feet of the fish in order to detect the radiation, the distance being dependent on the depth of the water over the fish. This very restricted area in which the fish could be detected made it practically impossible to survey the stream from the banks. Complete ice cover was necessary before the stream could be efficiently and safely surveyed.

After complete ice cover occurred, good weather conditions were necessary. On extremely cold days (<-6.67°C), the detector's operating time was substantially reduced (from 4 hours to 1 hour). In an effort to counteract the effects of the cold, the analyzer and probe were insulated and warmed with hand warmers of the type used by sportsmen. However, no noticeable increase in operating time was observed using this procedure.

The short operating time of the analyzer became a serious drawback when locating fish that did not remain in the general location from which they were originally sampled. That one fish was responsible for 9 of the 12 measurements was a result of this fish remaining within 6 feet of the release point. Normally, 10 minutes of detector operating time was sufficient to mark its exact location. Efforts to locate the other four fish, which apparently did not remain at their release points, were made by surveying the 2,000 feet of the study reach. Often, this could not be accomplished due to the short operating time of the analyzer and probe.

Detection was also made difficult when the snowpack over the creek increased to depths exceeding 6 feet in spots. In determining the level of activity to be put in the capsules, calculations were made assuming 3 feet of water and 4 feet of air. Therefore, 6 feet of snow in addition to the water and ice over the fish exceeded the detection limits imposed by the amount of implanted radiation and the sensitivity of the monitoring device.

Presumably another detection problem occurred when fish were located beneath undercut banks and a large drift prevented surveying the area at the water line. In such a case it was difficult to detect the radiation. This can be justified by comparing the linear absorption coefficient (μ) of the 1.692 MeV gamma emitted by ^{124}Sb for both water and soil. The linear absorption coefficient is defined as a factor expressing the fraction of a beam of x or gamma radiation absorbed in a unit thickness of material (Bureau of Radiological Health, 1970).

The relationship of μ to the half-thickness of a substance can be expressed as:

$$\frac{\ln 2}{\mu} = \text{half-thickness}$$

where the half-thickness is that thickness of a specified substance that reduces exposure by half. The half-thickness is inversely proportional to density. This is reasonable given that, in general, the more dense a substance the more electrons available to absorb the gamma. Therefore, by comparing the density of water with the density of soil an estimate of the differences in linear absorption may be made.

The density of water is equal to one, while a good estimate of the bulk density for soils of the type typical of the riparian zone through the study area is 1.3. Soils are silt loams to loams and are probably slightly compacted due to livestock grazing (Brady, 1974; Barndt, personal communication). Since these soils are 33 percent more dense than water, it would require only 2 feet of soil versus 3 feet of water to absorb the 1.64 MeV gamma. Soil depth of undercut banks in the study area often met or exceeded this depth.

CONCLUSIONS

• Overall, radio telemetry through the use of implanted transmitters appears to be superior from several aspects to the use of radioisotope capsules for the tracking of fish under ice cover. First, transmitters do not present a potentially hazardous situation. Second, the capability of locating fish with transmitters is not impaired by severe weather conditions. Third, the detection range of the transmitters is far superior to that of radiation. Signals could be picked up from a distance of 200 m and were not affected by depth of water, ice, snow, the bulk density of soils in undercut banks and temperature. The major drawbacks we experienced with the use of transmitters were battery failure and faulty wiring. Hopefully, these problems can be overcome (if not already done so by the time of this writing) through advances in technology. Regarding determination of microlocation of fish (to within 0.3 to 0.6 m), both techniques proved quite accurate when working correctly.

• Surgical techniques used in this study were very successful. No mortality was known to have occurred due to transmitter implantation. This procedure should be reliable for use on other species of fish with the same success. Behavioral studies indicated that implantation did not cause harmful disturbances in the trout's normal behaviorisms. Additional long-term behavioral studies, preferably within a natural stream environment using implanted fish and normal non-implanted fish, could demonstrate true impacts of transmitter implantation, if any.

• Movements of brown trout under ice cover indicate that freezing water temperatures do significantly decrease activity. Brown trout appear to have a period of re-orientation, with an increase in activity, when ice cover and freezing water temperatures first occur. Once established, trout prefer to remain within focal areas, which provide resting microhabitat, and activity decreases as winter conditions progress. It is possible that brown trout were observed moving in only part of their actual home range. Continued studies of tagged fish through the spring period may show that a trout may extend his home range much farther than what was observed in winter.

• Microhabitat preferences developed in this study should assist in recommending suitable winter instream flows for medium-sized brown trout streams which undergo total ice cover during winter. The developed preferences for adult brown trout ice-cover microhabitats were tentatively determined to be:

Microhabitat	Depth (ft)	Velocity (fps)	Substrate Type	Cover Type
Resting	0.50-0.99	<0.50	rubble, gravel	rubble, sheet ice
Cover	1.00-1.49	≤ 0.50	rubble, gravel	rubble, sheet ice

BIBLIOGRAPHY

Barndt, Skip. 1980. Personal communication. Soils Scientist with U.S. Forest Service.

Benson, N. G. 1955. Observations of anchor ice in a Michigan trout stream. Ecology 36:529-530.

Brady, Nyle C. 1974. The Nature and Properties of Soil. Macmillan Publishing Co., Inc., New York, 639 p.

Brown, C. J. D., W. D. Clothier, and W. Alvord. 1953. Observations on ice conditions and bottom organisms in the West Gallatin River, Montana. Proceedings of the Montana Academy of Sciences 13:21-27.

Bureau of Radiological Health. 1970. Radiological Health Handbook. U.S. Department of Health, Education and Welfare, 458 p.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Am. Natur. 100:345-357.

Chapman, D. W., and T. C. Bjorn. 1968. Distribution of salmonids in streams with special reference to food and feeding. In Symposium on Salmon and Trout in Streams, H. R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C., pp. 153-176.

Hart, L. G. 1976. Personal communication, Oklahoma Cooperative Fishery Research Unit, Okalhoma State University, Stillwater, Oklahoma.

Hartman, G. F. 1963. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. J. Fish. Res. Board Can. 20:769-787.

Hubbs, C. L., and M. B. Trautman. 1935. The need for investigating fish conditions in winter. Trans. Am. Fish. Soc. 65:51-56.

Logan, S. L. 1963. Winter observations on bottom organisms and trout in Bridger Creek, Montana. Trans. Amer. Fish. Soc. 92:140-145.

Lonsdale, E. M., and G. T. Baxter. 1968. Design and field tests of a radio-wave transmitter for fish tagging. Prog. Fish-Cult. 30:47-52.

Maciolek, John A., and P. R. Needham. 1952. Ecological effects of winter conditions on trout and trout foods in Convict Creek, California. Trans. Amer. Fish. Soc. 81:202-217.

Morris, K. W. 1977. Evaluation of methods of attaching simulated ultrasonic transmitters to adult male walleye, Stizostedian vitreum vitreum, under adverse environmental conditions. Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma, 128 p.

Needham, Paul R., and Albert C. Jones. 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology 40:465-474.

Peterson, D. C. 1975. Ultrasonic tracking of three species of black basses, Micropterus spp., in Center Hill Reservoir, Tennessee. M.S. Thesis, Tennessee Technological University, 129 p.

Poddubnyi, A. G., L. K. Malinin, and V. V. Gaiduk. 1971. Experimentation in under-ice telemetric observations of the behavior of wintering fish. Acad. Sci. USSR, Biology of Inland Waters, Information Bull. 6:65-70. English Translation: Fish. Res. Board Can., Transl. Series 1817:9 p.

Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery-reared trout in Convict Creek, California. Trans. Amer. Fish. Soc. 92(1):39-46.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board of Can., 184 p.

Stefanick, F. A. 1951. The population and movement of fish in Prickly Pear Creek, Montana. Trans. Amer. Fish. Soc. 81:260-274.

Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies for the determination of stream resource flow requirements: An assessment. Report prepared for U.S. Fish and Wildlife Service, Office of Biological Services, by Utah State University, Logan. 199 p.

Stuart, T. A. 1957. The migrations and homing behavior of brown trout (Salmo trutta). Fresh. and Sal. Fish. Res. Home Dept., Scotland. Rept. No. 18, 27 p.

Weeks, R. W., F. M. Long, J. E. Lindsay, R. Bailey, D. Patula, and M. Green. 1977. Fish tracing from the air. In Proceedings First International Conference on Wildlife Biotelemetry, University of Wyoming, Laramie, F. Long, ed.

Wesche, T. A. 1980. The WRRI Trout Cover Rating Method: Development and application. Water Resources Series Publication No. 78. Water Resources Research Institute, University of Wyoming, Laramie, 46 p.

Wesche, T. A., and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Eisenhower Consortium Bulletin #9. 122 p.