COLORADO SQUAWFISH WINTER HABITAT STUDY, YAMPA RIVER, COLORADO, 1986-1988

by

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February 1989

Final Report

Contribution 43

of the

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ACKNOWLEDGEMENTS

Funding for the winter project was provided by the Upper Yampa Water Conservancy District. Associated fall and spring studies were funded by the U. S. Bureau of Reclamation (BOR) and the Colorado Division of Wildlife (CDOW). We thank Dr. Harold Tyus technical advisor for the U.S. Fish and Wildlife Service (USFWS), Vernal, Utah, for his assistance during the study. Dr. Clarence Carlson served as co-principle investigator and reviewed an earlier version of the manuscript. Dr. Harold Tyus (USFWS) and Bob Williams (BOR) provided useful comments and criticisms of the draft report. Dan Beyers of CSU, Tom Nesler and Hal Copeland with CDOW assisted in field collections. Ralph Teller, Bob Bolger, and Ed Wilson from the U.S. Geological Survey, Meeker, Colorado, provided physical data and field assistance. Glen Larson, USFWS, Denver, assisted in establishing cross sections and measuring discharge. Lynn Bjork, CSU, illustrated the habitat maps and ice diagrams. Equipment was provided on temporary loan by Mr. Bob Williams, BOR, Salt Lake City, Utah; Lynn Keading, USFWS, Grand Junction; Pat Martinez, CDOW, Grand Junction; Tom Nesler, CDOW, Fort Collins; Jim Hendrickson, USFWS, Fort Collins; George Bowen, USFWS, Denver; Dr. Eric Bergersen, Colorado Cooperative Fisheries and Wildlife Research Unit, Colorado State University (CSU), Fort Collins; and Dr. Kurt Fausch, Department of Fisheries and Wildlife Biology, CSU.

Several sampling sites were on private land and we thank landowners at Lily Park, Juniper Springs, and Maybell: Catheryn and Sam Rinker, John Raftopoulas, Dave Burkett, Don and Darryl Steele, and Vince Carnahan. Kirk Navo, CDOW District Wildlife Manager in Maybell, assisted us in many ways.

We extend a very special thank you to our friends Doris and George Bear, Maybell, Colorado, who provided a warm "home away from home" and an extraordinary amount of assistance during the study.

SUMMARY

Radiotracking of adult Colorado squawfish (Ptychocheilus lucius) was conducted on the upper Yampa River, Colorado, over two winters (December 1986-March 1988) under conditions historically found in the upper portions of the Colorado River System. During Winter 1, 10 squawfish were radiotracked for 590.8 total observation hours, from which 118 hours were used to develop habitat utilization criteria. During the fall and winter of the second year, 74 observation hours were accumulated on 10 squawfish. Of these, 34 hours were used to develop winter habitat utilization criteria on depth, velocity and substrate. Squawfish were often active within a particular habitat but they did not move outside the river reach they selected for over-wintering. Squawfish showed fidelity to very specific habitat areas by remaining in either one or a few favorite habitats throughout the winter. During the ice covered period, total range of movement of all fish averaged only 0.3 miles each year. Several squawfish demonstrated fidelity to specific fall and winter habitats and river reaches over one or more years. During Winter 1, embayment, backwater, and run habitats were most frequently used. Pool and run habitat were used most often in Winter 2. Habitat use also differed between the three study areas. This appeared related to habitat availability and diversity. A backwater habitat was used almost exclusively by three fish in the Government Bridge study area, river mile (RMI) 95-100, during Winter 1. Run habitat was used most frequently the next year probably because channel bed changes prevented access to the area used most frequently in Winter 1. Embayment and run habitat appeared to be preferred over pool habitat in the Maybell study area (RMI 70-82) which had diverse habitat availability. Pool habitat was used almost exclusively in the Lily Park study area (RMI 51-54), in Winter 2, where pool habitat was dominant. Effective depth (ice free water under packed frazil and/or solid ice cover) and velocity utilization for each trip were averaged over the winter period for three habitat catagories. Shallowest mean effective depths (2 feet) and velocities [0.1 feet/second (ft/s)] were from backwater and embayment habitats. Eddys and pools had the deepest average effective depth utilization (3.3 feet) with an average mean velocity of 0.2 ft/s. The run and shoreline habitat category had the highest average velocity (0.5 ft/s) with an average effective depth of 2.4 feet. Naturally stable flow conditions allowed ice cover to exist throughout the majority of the winter period both years. Flows and air temperatures were above normal in Winter 1 and below normal in Winter 2.

Formation of different types of ice on the Yampa River changed hydraulic conditions. During early winter, water surface elevations were maintained in spite of reductions in discharge. During Winter 2, changes in effective depths used by squawfish were examined at the Maybell study site by comparing elevation changes of water surface, ice surface, and ice thickness in response to changes in discharge. Discharge increased throughout most of Winter 2, a relatively low water year, ranging from 142 cfs on December 15, 1987 to 340 cfs on March 3, 1988. Ice thickness increased from 0.85 feet December 15, 1987 to 2.12 feet March 15, 1988. Increasing water surface elevations compensated for increasing ice thickness resulting in relatively stable effective depth. Effective depths measured biweekly in embayment habitat between December 15 and February 17 varied only 0.1 feet. Regression analysis of discharge on water surface elevation was used to predict the effect of hypothetical reductions in flow below the lowest measured discharge of 142 cfs. For each 20 cfs loss in discharge, water surface elevation was predicted

to decrease approximately 0.2 feet during mid-winter, ice-covered conditions. Overall productivity of the winter ecosystem appeared to be maintained by natural flows which provided diverse low velocity habitats (embayments, backwaters, pools, and runs). During Winter 2, this diversity appeared to be best maintained in the 200-300 cfs flow range in mid-winter during ice cover. Flows below this range would result in less than optimum depth in preferred embayment habitat while higher flows flood and eliminate these habitats. Alterations in flow during winter due to water project impacts must be analyzed with respect to the portion of the winter in which they may occur. Effects will be different due to current ice conditions, air temperature, precipitation, and discharge. Reductions below natural baseflow at initial ice formation should be avoided. At this time actual discharge is already decreasing because water is being tied up in ice formation. Maintaining natural flows during the initial freeze period in late November or early December would insure that ice cover forms over the maximum amount of usable winter habitat. A key flow consideration during mid-winter is maintaining the natural conditions of steady discharge with little fluctuation. Flows normally do not fluctuate more than 140 cfs above or below the annual mean during the period from mid-December through February. It is important to avoid unnatural discharge fluctuations that could remove natural ice cover. The ice-out period, which usually occurs in March, can be the most critical part of winter. During this time, water surface elevations and effective depth decrease even though discharge is maintained. Therefore, any reductions in flow should be avoided until ice is completely out.

INTRODUCTION

The Colorado squawfish (Ptychocheilus lucius) was once distributed throughout the entire Colorado River Basin in main channels and larger tributaries. Today it is restricted to the remaining free-flowing segments of larger rivers above Glen Canyon Dam which forms Lake Powell. These rivers include the Green, Yampa, Gunnison, and White in Colorado and Utah, the mainstem Colorado River below Grand Junction, Colorado and the San Juan River of Utah and New Mexico (Holden and Wick 1982).

Rivers of the Colorado River Basin are characterized by extremes in flow, turbidity, and velocity. Historical flows varying from a few hundred cubic feet per second (cfs) to almost 400,000 cfs were reported at Yuma, Arizona (Behnke and Benson 1983). The environmental extremes of the River Basin, plus millions of years of isolation from neighboring river basins, caused a high degree of endemism (fish found only in the Colorado River Basin) in its fish fauna. Only 13 species are native (occur naturally) above Lake Powell. Of those, six are endemic (Behnke and Benson 1983). These include the Colorado squawfish, three chubs, and the razorback and flannelmouth suckers; all are members of the minnow and sucker families. The Colorado squawfish evolved into the role of the top predatory fish species, presumably because of its isolation from other large fish predators. In this evolutionary process, the Colorado squawfish adapted to the wide range of environmental conditions (flows, temperatures, and turbidities).

The Colorado squawfish also developed a unique reproductive strategy (Tyus 1986). Recent studies using radio-telemetry in the Upper Colorado River Basin (Tyus and McAda 1984; Wick et al. 1983) have documented that squawfish migrate hundreds of miles to preferred spawning areas and return to their pre-spawning locations. Colorado squawfish numbers have declined because dams have blocked migratory routes and cold tailwater releases have drastically altered temperature regimes throughout much of the Colorado River Basin (Holden and Crist 1978 and Seethaler 1978).

Habitat use by adult Colorado squawfish varies considerably depending upon flow, season, and habitat availability in specific rivers and river reaches (Carlson et al. 1979; Twedt and Holden 1980; Miller et al. 1982; Wick et al. 1985). On the Yampa River in early spring, as water levels are just beginning to rise, Colorado squawfish are found in main-channel runs and shoreline habitats. Colorado squawfish are also frequently found near the flooded mouths of tributary streams and in eddies. As run-off flows increase in May and June, use of low velocity backwater habitat increases considerably in areas where it is available. Otherwise, Colorado squawfish use large main-channel eddies (Wick et al. 1983).

Natural backwaters are formed when tributary streams and gulches are flooded at high run-off flows. Man-made backwaters are side channels that are modified by ranchers. Usually, the upstream end of the side channel is diked off to protect cultivated fields or provide watering areas for livestock. In late June, as water levels recede, squawfish move into the main stream and begin their spawning migration downstream into the lower portion of Yampa Canyon (Wick et al. 1983). This migration usually begins as maximum water temperatures warm to 14-20^{0}C (Tyus et al. 1987). Fish usually spend 3 to 4 weeks in Yampa Canyon during the spawning period. Pool and eddy habitats are used for staging. Run, rapid, side channel, and chute channel habitats with cobble substrates are used for spawning (Wick et al. 1983 and 1985). Spawning occurs at an average temperature of 22^{0}C (range 15-27.5^{0}C) (Tyus et al. 1987). After spawning, most Colorado squawfish return to their pre-spawning migration locations. During low-flow periods of August to early November, squawfish use pools along with run, eddy, and quiet shoreline areas (Wick et al. 1983 and 1986).

This study of Colorado squawfish winter habitat requirements resulted from Section 7 consultation pursuant to provisions of the Endangered Species Act of 1973. This consultation involved the Bureau of Reclamation (BOR) and the United States Fish and Wildlife Service (USFWS), regarding construction of Stagecoach Reservoir on the upper Yampa River near Steamboat Springs, Colorado by the Upper Yampa Water Conservancy District (UYWCD). Impacts on endangered species (primarily Colorado squawfish) from the project could occur during the winter months. Although adequate data have been previously collected on migration, spawning requirements, habitat preferences, and flow needs of Colorado squawfish during spring, summer, and early fall; no data had been collected on habitat requirements and behavior during the winter. Information on the winter habitat needs of Colorado squawfish would assist USFWS in making winter flow recommendations.

After completion of the first year of the winter study from December 1986 through March 1987 (Winter 1), additional funding was provided by the Bureau of Reclamation to radiotrack squawfish during fall months. This allowed field work to begin earlier in 1987, providing an opportunity to collect habitat-use information during the fall on the Yampa River, and ensured a smooth transition into the second winter from December 1987 through March 1988 (Winter 2). Funding was also provided to track squawfish through Spring 1988 to assist USFWS in determining movement and habitat use patterns during spring months and when spawning migrations began into Yampa Canyon.

We also cooperated with the Colorado Division of Wildlife (CDOW) on a study of northern pike spawning behavior and habitat use on the upper Yampa River. This study was conducted to gather preliminary information on how extensively northern pike and Colorado squawfish utilize the same habitat types.

The objectives of this investigation were to:

1. Determine if adult Colorado squawfish remain in specific river segments from fall to early spring in the upper Yampa River.
2. Determine habitats and microhabitats (depth, velocity, substrate, temperature, and cover) used by Colorado squawfish during fall and winter months.
3. Develop fall and winter habitat utilization curves based on microhabitat data (Bovee 1986) collected during the study.
4. Evaluate the applicability of the Physical Habitat Simulation (PHABSIM) model to determine flow requirements during winter months for Colorado squawfish on the Yampa River.
5. Track Colorado squawfish during spring 1988, to determine habitat use and time of spawning migration into Yampa Canyon.

STUDY AREA

Site selection

This study was conducted on the Yampa River from Lily Park, river mile (RMI) 51, to Morgan Gulch, RMI 105 (Figure 1). River segments selected for radiotagging squawfish were based on existing Instream Flow Incremental Methodology (IFIM) sites established by USFWS. These sites were located at Lily Park RMI 53.2, Maybell RMI 72, and Government Bridge RMI 97.2. Because initial radiotag implantation efforts at Lily Park were unsuccessful, fish were implanted only at Government Bridge (RMI 105-95) and Maybell (RMI 82-70) in the first year of the study. Lily Park (RMI 54-51) was successfully added to the study areas during Winter 2.

Description of study areas

Government Bridge (RMI 105-95)

A predominant habitat type of this river reach during the base flow period is eddy, mostly associated with man-made rock jetties. Because of heavy agricultural activity in this reach involving irrigation, rock stabilization of banks and irrigation structures are common. A unique habitat resulting from this activity was a large, 50x100 meter (m) backwater located at RMI 95.7 (Figure 2). Backwaters of this size and structure are not common habitat features on the Yampa River during the base-flow period. This backwater is relatively new, resulting from 1984 flood waters which eroded the river bank around car bodies and boulders placed along the river bank. About 100 m of dirt bank and alfalfa field were eroded away, resulting in extensive gravel bar deposition and a wide, braided channel. Another predominant habitat type of this reach is long, slow-moving run habitat. It is difficult to accurately identify this habitat because at first appearance the long, low velocity habitats appear to be pools. But they lack sufficient depth and reduction in velocity relative to the main current to warrant the classic pool definition (Appendix A). At extremely low winter flows, these shallow (2-5 foot deep) runs contain a large volume of low velocity habitat and could be called shallow pools. However, because of the ice cover, it was difficult to make these determinations and we tended to define run habitat based on channel characteristics during open water. Compared to other study areas, this river reach was most impacted by man. Deep pool habitat was not common, although a large, deep naturally occurring eddy and pool combination is located just below a high gradient reach at RMI 99. This river reach contains several backwaters which form as a result of high flows during spring runoff. These high-flow backwaters (dammed side channels, flooded tributary streams, and irrigation returns) are used frequently by squawfish (Wick et al. 1986).

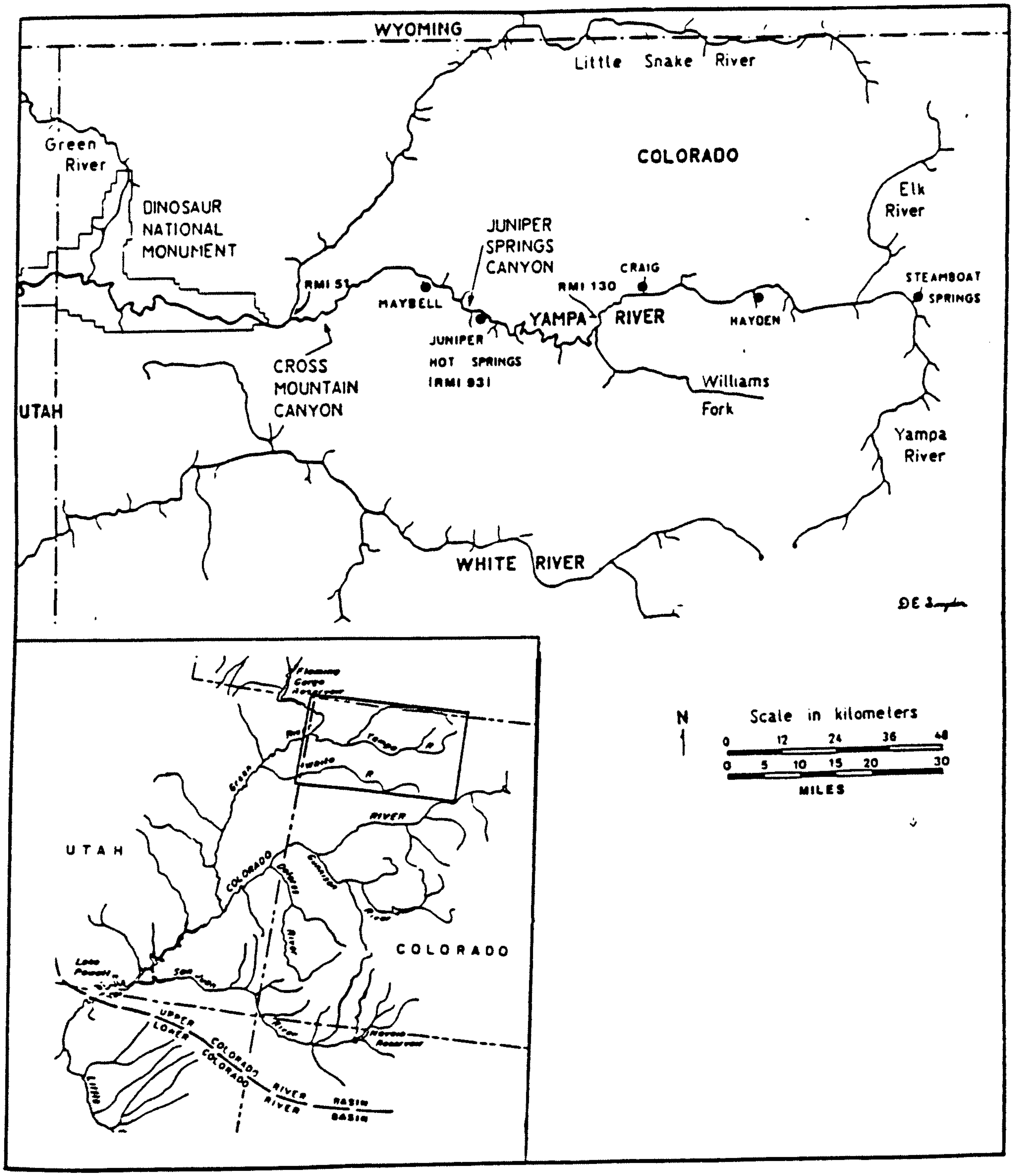


Figure 1. Map of Yampa River study area. River mile (RMI) distances begin at the confluence with the Green River.

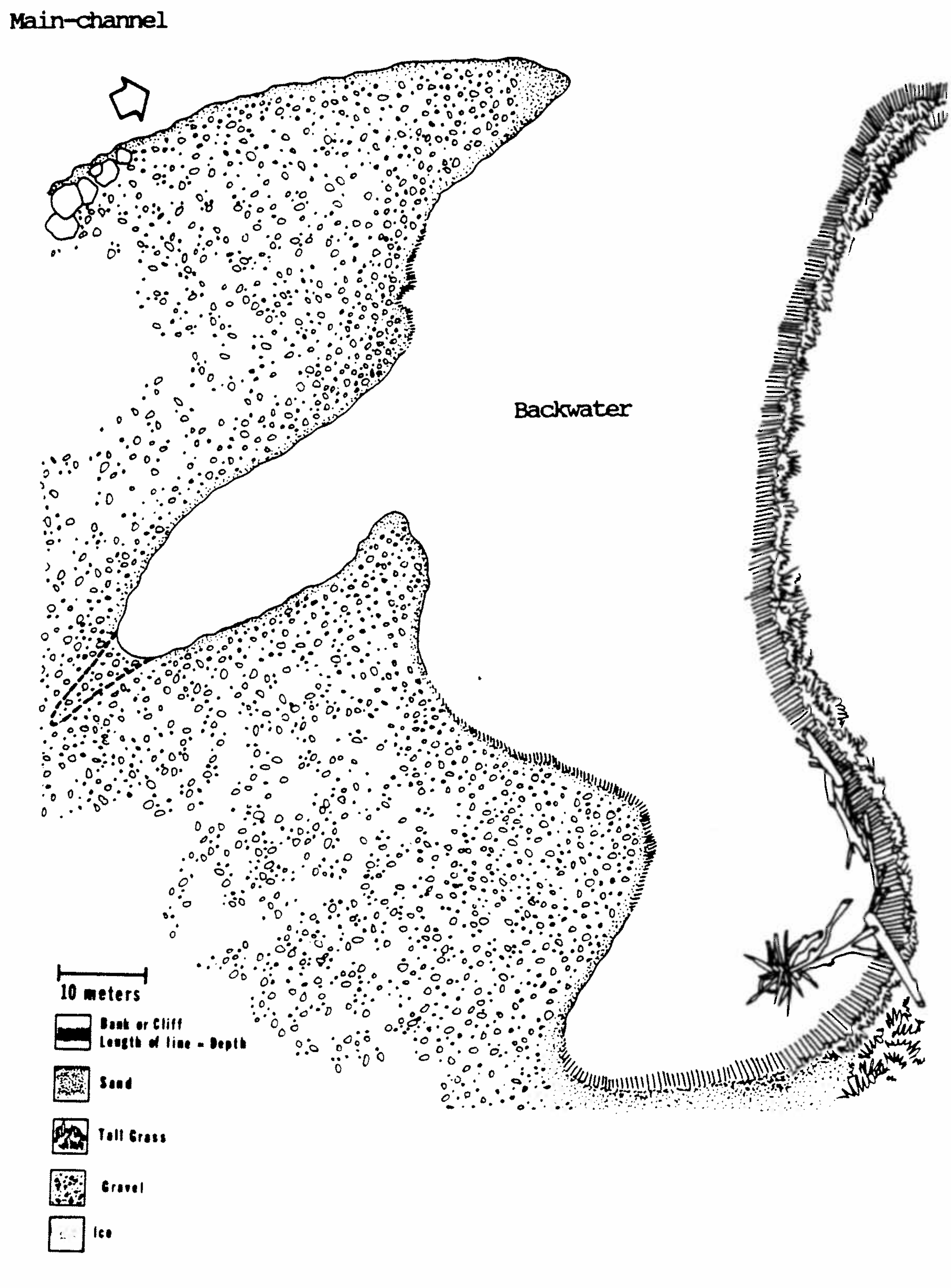


Figure 2. Map of backwater habitat during the winter at RMI 95.7 within the Government Bridge study area, Yampa River. This area was used by fish A07, A10, and A11 during Winter 1 and A10 during Winter 2.

Maybell (RMI 82-70)

This river reach passes through predominantly irrigated agricultural land. However, the river is less impacted by man-made structures. The upper section at RMI 81.4 has long stretches of run habitat with quiet vegetated shoreline, with eddys occurring along the shorelines. Downstream at RMI 81.1 is a large embayment created by a point bar which angles downstream along the right shoreline (Figure 3). The river current is directed away from 100m of quiet vegetated shoreline. Further downstream at RMI 80.8, a sharp meander creates a 13-14 feet deep pool. Other large pools with associated eddys occur at RMIs 79, 77, 76 and 71.6.

The Maybell river reach has a diverse mixture of fall and winter habitat types consisting of deep pools, eddys, vegetated embayments and shorelines. High-water habitat is not as abundant as it is in the Government Bridge area. Flooded tributary streams, irrigation returns, and shoreline vegetation are frequently used by squawfish as are eddys at island tips during the run-off period (Wick et al. 1986).

Lily Park (RMI 54-51)

This river segment contains more quality pool and eddy habitat per mile than any river segment on the upper Yampa River. The upper portion (RMI 54-53) has high-gradient riffles which cut deep (8-15 foot) pools and eddys. From RMI 53-52.5 there is a long run-pool sequence with large boulder substrates. This segment also has some low-velocity shoreline embayments behind boulder jetties. Just above County Road 24 Bridge at RMI 52.5, the river braids into several side channels which contain some small eddy habitat. Below the bridge, the river slows and substrate size decreases to small gravel and sand. Several side channel backwaters and eddy habitats are located in lower portions of the study area.

High-flow runoff habitat consists only of large eddys in the upper portion of this area. During the spring, high flows create low-gradient side channels and flooded backwaters in the lower portion of the area. The Little Snake River enters the Yampa at RMI 51.

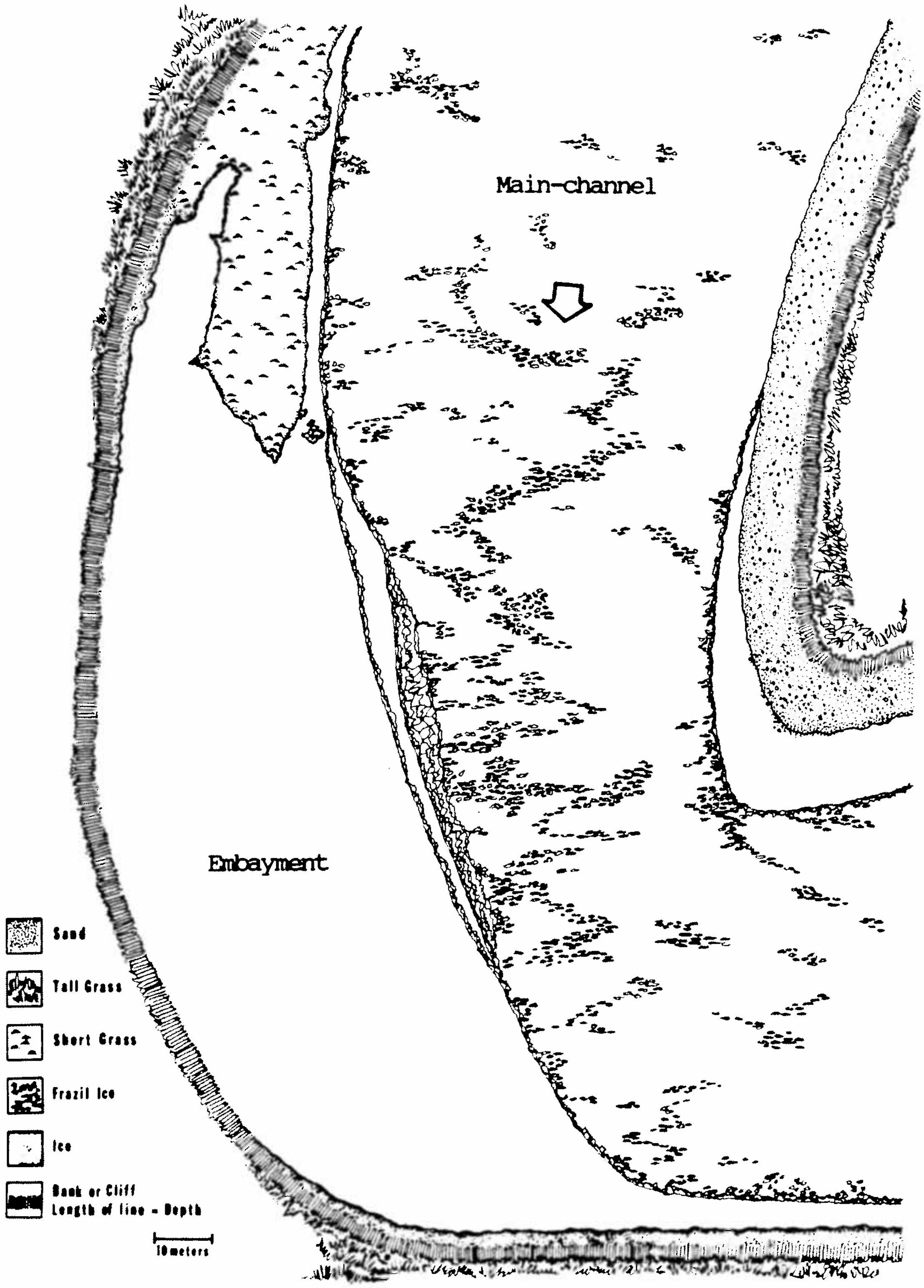


Figure 3. Map of embayment habitat during initial ice formation at river mile 81.1 within the Maybell study area, Yampa River. This area was used by fish A09, B08, B09, and B11 during Winter 1 and B07, B11, and B85 during Winter 2.

METHODS

Fish collections

Fish collections for transmitter implantation in Winter 1, were made on five occasions and were completed by the end of October. Fish were collected by trammel net, experimental gill net, electrofishing boat, and hook and line as described in Wick et al. (1985). Netting was conducted from canoe or 18-foot, flat-bottomed boat powered by an 80-horsepower, Mercury outboard equipped with a jet shoe. All fish collected were identified and enumerated. Catch-per-unit-time was recorded for netting and electrofishing samples. All Colorado squawfish captured were weighed to the nearest 10 to 50 grams and measured to the nearest millimeter. Colorado squawfish were tagged with orange Carlin tags supplied by USFWS. Previously tagged Colorado squawfish (recaptures) retained their original tags.

For the 1987 fall study, eight Colorado squawfish originally implanted in 1986 were radiotracked. In addition, one fish was implanted September 9 at Maybell RMI 80.8, and three were implanted September 11, at Lily Park RMI 53.2 for radiotracking. An additional six squawfish were implanted in October and November 1987 for radiotracking during the 1987-1988 winter. Three fish were tagged in the Government Bridge study area, one at Maybell and two at Lily Park.

Radiotelemetry

Radiotransmitters (radiotags) used in the first year were supplied by Custom Telemetry and Consulting. Frequencies ranged from 40.6614-40.7022 MHz. Ten of twelve tags purchased were implanted, the remaining two were used as test tags. Eight tags had a life expectancy of 18 months and were 4.5 centimeters (cm) in length and 1.8 cm in diameter. Four had life expectancies of 24 months and were 6 cm in length and 1.6 cm in diameter. Pulse rates varied from 28 to 45 pulses per minute. All transmitters were pre-tested and dipped in sterile, melted beeswax prior to shipping by the manufacturer. Upon receipt, all tags were started and tested for 2 weeks prior to implantation. Transmitters used in 1987-1988 were purchased from Smith Root Inc. These tags had a life expectancy of 12-14 months, were 1.6 cm in diameter, and ranged from 6.0-8.5 cm in length. Frequencies ranged between 40.687-40.695 MHz with pulse rates of either 50 or 70 per minute. These transmitters were dipped in melted beeswax prior to implantation.

Captured adult Colorado squawfish were held in live wells and implanted at capture sites or they were transported by boat to the implantation site, which was less than 1.5 miles from the capture site. They were anesthetized with a solution of tricaine methanosulfate (MS 222) and surgically implanted with radiotransmitters according to procedures described by Tyus and McAda (1984). Fish were held 10-30 minutes until they recovered from the anesthetic and released at or near their capture location.

Receivers from three different manufacturers were used during the study; Advanced Telemetry System's (ATS) programmable scanning receiver, Smith Root's Model RF40, and Custom Telemetry and Consulting's Model CE-12. Fish were tracked by boat when the main river channel was free of ice using 18-foot flat-bottomed jetboat or canoe. Once ice formed on the main channel, a four-wheel-drive truck was used on ranch roads for tracking where possible. Otherwise, fish were tracked on foot between vehicle access points. Because of heavy snows during Winter 2, snowmobiles, snowshoes and skis were used to track along the river.

During Winter 1, contact was maintained after implantation by tracking in October and November. From December through March, fish were tracked systematically on a bi-weekly schedule (Table 1). The two groups of five fish each (Government Bridge and Maybell) were alternated as target and non-target groups on each trip. During each trip, four fish from the target group were monitored for 2.5 hours (hrs) in each of the following 6-hour (hr) periods: morning (0600-1200 hrs), afternoon (1200-1800 hrs), evening (1800-2400 hrs), and night (0000-0600 hrs). In addition, a fifth fish from the target group was observed for a full 24-hr period on each trip. During mid-winter, on trips 5 and 6, two fish were monitored for 24-hr periods. In addition, during each bi-weekly trip all fish in the non-target group were monitored for at least 30 minutes and usually up to 2 hrs if time permitted.

Fish were initially detected using 1/2 or 1/4 wave whip antennas mounted on a boat, four-wheel-drive vehicle, snowmobile, or hand carried. Once detected, the fish location was triangulated using a Smith Root directional loop antenna according to methods described by Tyus (1988). Survey flags were placed along the bank marking each transect line. Transects were then checked every few minutes to determine if the fish remained along the same transects and thus in the same location. If a fish remained in the same location for 15 minutes, it was given a map location designation on both a field form and a habitat map depicting key features and fish locations within the area. Target fish were then observed for an additional 2-3 hrs in 5-20 minute intervals. Habitat criteria were measured at all sites at which fish spent at least 30 minutes. Fish being tracked for the full 24-hr period were similarly observed until a preferred site location was determined, then triangulation was conducted at least every hour to determine if any major movement or location change occurred over the 24-hr period. If more than one radiotagged squawfish were present in an area, data were gathered simultaneously on all fish present with the scheduled fish taking priority.

During the observation period, data recorded on field data sheets included radiotransmitter frequency, pulse rate, signal strength, weather, air temperature, river mile location, habitat type, presence of ice cover, time of each triangulation, actual contact duration, movement type, site location recorded on a habitat sketch (map ID), and presence and distance from other radiotagged fish (Appendix B). Habitat type was divided into primary and specific habitat types. Primary habitats were main channel, side channel, and tributary stream. Specific habitats included shoreline, eddy, embayment, run, backwater, pool, riffle, and rapid (Appendix A). Fish movement was designated as either stationary, active, local or moving. "Stationary" was used if no change in fish location could be detected between or during fish observation periods. A fish was noted as "active" if its location changed within a 5-m-diameter circle over its original location, as long as the specific habitat used remained the same. "Local" movement was designated if a fish moved to a new location outside the original 5-m-diameter circle about its original location but within the same specific habitat. The "moving" designation was used if a fish was observed in the process of moving to a new location or had moved to a different specific habitat type regardless of distance (i.e., fish moved from eddy to run or from one eddy to another eddy).

Table 1. Dates of each bi-weekly sampling trip during 1986-1987 and 1987-1988.

Trip Number	1986-1987 Sampling dates	1987-1988 Sampling dates
1	—	Aug 25-28
2	Sep 16-19	Sep 8-11
FALL		
3	Oct 1-3	Sep 21-26
4	Oct 7-10	Oct 5-9
5	Oct 15-17	Oct 19-26
6	Oct 28-30	Nov 2-7
7	Nov 11-15	Nov 16-20
WINTER		
8	Dec 1-6	Dec 1-5
9	Dec 15-20	Dec 14-18
10	Jan 5-9	Jan 4-10
11	Jan 19-24	Jan 19-25
12	Feb 2-7	Feb 1-6
13	Feb 16-20	Feb 15-20
14	Mar 2-6	Feb 29-Mar 4
15	Mar 16-21	Mar 14-18
SPRING		
16	—	Apr 5-8
17	—	Apr 19-22
18	—	May 3-5
19	—	May 17-26
20	—	Jun 6-15
21	—	Jun 27-30

Northern pike (Esox lucius) were radiotagged in all study areas in cooperation with CDOW to determine habitat use and movement during winter and spring and to gather spawning data. During Winter 1, northern pike were radiotracked only at locations where Colorado squawfish were present. All northern pike radiotags were on the 30 MHz frequency band as opposed to the 40 MHz Colorado squawfish band. Consequently, tracking the two species required different radio receivers and loop antennae. If northern pike were detected, habitat use, depth, velocity, and distance from squawfish were recorded. During Winter 2, CDOW research personnel tracked northern pike throughout the winter; therefore, our efforts were less intensive during winter but were intensified during spring when we tracked both squawfish and northern pike.

Fish were tracked on a biweekly schedule during fall 1987 (Table 1). On each trip, an attempt was made to contact all fish by floating in a canoe through each study area. When fish were located, they were monitored to obtain two 15-minute observations at a stationary location. In addition, two fish were monitored each week for an additional 4-hr period. These long-term observations were systematically alternated between the three study groups and three 8-hr daily time periods. This study design provided an observation in each of the 8-hr time periods in all three study groups while ensuring that different groups and time periods were monitored each week. The 8-hr time periods were: 0401-1200, 1201-2000, and 2001-0400. The starting time of each 4-hr observation period was randomly selected from the first 5 hr in each 8-hr daily time period. One fish from each group was selected without replacement from those found on each biweekly trip. The fall long-term sampling design included observations on a total of nine fish (three fish from each of three groups covering each of the three daily time periods in each group). Physical habitat measurements were recorded at each location at which a fish spent 15 minutes.

During Winter 2, fish were tracked in all three study areas on each biweekly trip. Fish were monitored as they were located in each study area. Two 15-minute observations were obtained on each fish located. Study areas were sampled according to a systematic schedule. Long-term observations were shortened from 24 to 2.5 hr and were made during twilight periods to ensure that times early and late in the day would be adequately represented in the data base. On each biweekly trip a fish was monitored during the morning and evening twilight periods according to a systematic sampling design.

Habitat measurements Winter 1

At the conclusion of a monitoring period, habitat measurements were taken at all sites at which fish spent 30 or more minutes. Sites were determined by triangulation from 2 to 5 transects which were previously marked by survey flags placed along the bank during monitoring. Measurements taken were water depth, velocity, substrate, cover, and water temperature. When fish habitat was free of ice, measurements were taken from a boat or by wading. When ice formed over the site and was considered unsafe to walk upon, access to the fish location was achieved by sitting in a small inflatable raft at waters edge and pushing it over the surface of the ice using a wading rod. Throughout most of the winter the ice was thick enough to walk upon safely. However, a small inflatable raft was often taken out on the ice as a safety precaution and to carry measurement equipment. Depth was measured using a 10-foot depth rod (1\2 inch electrical conduit marked in 0.1 foot increments). Velocity was measured using a Marsh-McBirney Model 201 current meter. Negative velocity was recorded if direction of current flow deviated more than 90 degrees from that of the main channel current. Substrate was identified visually or by 'feel' by probing with the depth rod. Substrate was categorized as a combination of primary and secondary components of clay, silt, sand, gravel, cobble, or boulder. Cover designations included vegetation, brush, and boulder.

Three sets of measurements were taken at each site; one set was at the triangulated fish location (main site) with additional sets taken 1-2 m, "in" toward shore and "out" away from shore. Velocity measurements at the main site were taken at 0.2, 0.6, and 0.8 depths from the water surface when ice free or from the bottom of the ice during ice cover. At the in and out measurement sites, velocity was measured at 0.6 depth. During ice cover, habitat measurements were taken through holes drilled in the ice. Holes were drilled using either an 8-inch Strikemaster hand auger or 7-inch Strikemaster gasoline powered auger. Additional measurements were then taken to determine ice-free water depth (effective depth). These included solid ice thickness (ice below the water surface in the hole), frazil ice thickness, and total depth (water depth in the hole). Water depth below the surface of the ice was then calculated by subtracting ice thickness from total water depth (Figure 4). When frazil ice was present under the hard ice cover, its thickness was determined by lowering the velocity probe to the bottom, getting a positive velocity reading, and then slowly raising the probe until the frazil could be felt touching the probe and velocity decreased to 0.0 feet per second (ft/s). The compact, non-moving, frazil ice deposits were treated as solid ice in making water depth and velocity measurements (Figure 5). Winter discharge measurements recorded at the United States Geological Survey (USGS) gaging station near Maybell, Colorado, were used during Winter 1 to provide a record of flow conditions.

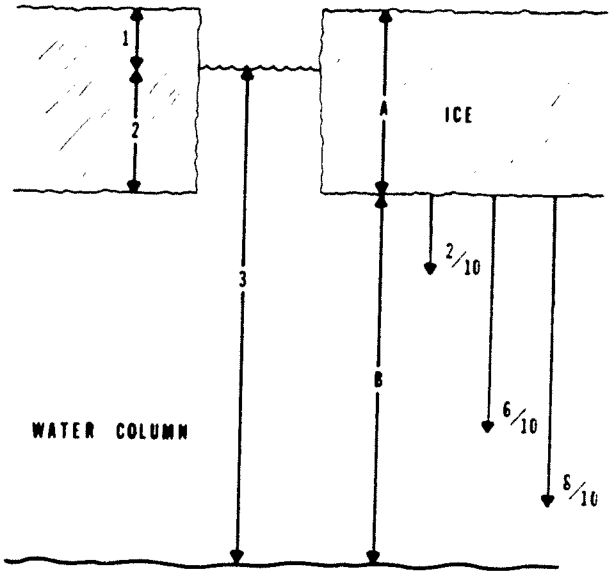
Habitat Measurements Winter 2

During Winter 2, habitat measurements were made at fish locations where fish spent 15 minutes or more. Velocity was measured at 0.6 depth only. In and out measurements were not taken unless extreme variation was suspected in a habitat.

To obtain accurate discharge data, a cross section station was established at RMI 81.1 near Maybell, and flow determinations were made on each biweekly trip. Fence posts were driven into each bank to mark the location. Holes were drilled through the ice 5 feet apart near the same location each trip for water depth, ice thickness, and velocity measurements. Velocity was measured using a Marsh McBirney Model 201 Current meter.

Cross sections were also established through embayment and backwater habitats at RMI 81.1 and 95.7. Measurements of water depth and ice thickness were taken from the same locations biweekly to determine how these habitats changed throughout the winter under various flow and temperature conditions. In addition, all cross section measurements were referenced to known benchmark elevations at each site by means of survey level to record elevation changes of the ice surface, water surface, and river bed throughout the winter.

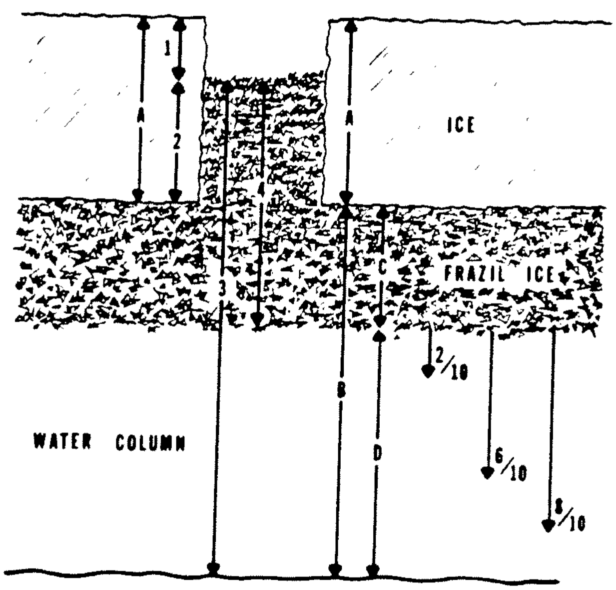
A series of dissolved oxygen measurements was taken during mid-winter to determine if oxygen depletions were occurring as a result of heavy snow covering the ice for an extended period. Measurements were taken by lowering



KEY
1. Ice thickness (above water surface)
2. Ice thickness (below water surface)
3. Water surface (in hole)

A. Total ice thickness (1+2)
B. Depth of water under solid ice (3-2)

Figure 4. Cross-section of solid ice and associated water depth and ice thickness measurements. Velocity measurements at Ø.2, Ø.6, and Ø.8 depth are indicated.



KEY
1. Ice thickness (above water surface)
2. Ice thickness (below water surface)
3. Water surface (in hole)
4. Thickness of frazil ice in hole

A. Total ice thickness (1+2)
B. Depth of water under solid ice (3-2)
C. Actual frazil ice thickness below solid ice
D. Depth of water under frazil ice (3-4)

Figure 5. Cross-section of solid ice, frazil ice, and associated water depth and ice thickness measurements. Velocity measurements at Ø.2, Ø.6, and Ø.8 depth are indicated.

a Lab-Line water sampler containing a 300-milliliter BOD (Biological Oxygen Demand) bottle to the desired depth and then triggering filling. Samples were fixed immediately in the field using the Winkler Method (fresh reagents supplied by Hach Chemical). Fixed samples were titrated indoors upon returning from the field within 1-6 hr of collection.

Weather data

Average daily minimum and maximum air temperatures at Maybell, Colorado, were obtained from the Colorado Climate Center, Department of Atmospheric Science, Colorado State University. Data were collected by the National Weather Service Cooperative Weather Station in Maybell, Colorado. Minimum and maximum temperatures during the 2 study years were compared to mean minimum and maximum temperatures for the 27-year period 1958-1985. The USGS in Meeker, Colorado, provided mean monthly flow data for the Yampa River from 1917-1988.

Data analysis

Data were transferred from field data sheets to database files using fields identified in Appendix B. Additional data fields were added to the database to aid in data stratification, calculations, and compatibility with other databases. Negative velocities were converted to positive values in calculation of descriptive statistics.

For compatibility between years, Winter 1 observations qualified for analysis only if they were short term (2.5 hr) or the first 2.5 hr of a 24-hr continuous observation period. Only sample types defined as AT, AN, AW, and BB (Appendix B) were included.

The long term (24 hr) data partition was used to examine behavioral differences between morning, afternoon, evening, and night partitions. The analysis was conducted to investigate temporal differences in depth, velocity, substrate, and habitat use. Results of this analysis are discussed in Wick and Hawkins (1987).

RESULTS AND DISCUSSION

During the first year of the study, 10 Colorado squawfish were captured and implanted with radiotransmitters (Table 2). Of the 10 fish, two (B07 and B09) were recaptured fish (fish that had been previously caught and tagged with numbered Carlin tags). Fish (A10) was recaptured twice during the second year of the study (Table 3). Radiotagged fish were monitored during ice covered conditions from December 1986 through March 1987. There were 590.8 total observation hours on these 10 fish from which 118 hours (472 15-minute observations) were used for analysis. Eight radiotagged fish from the first year were still operational and were monitored during the fall 1987, but only three (A10, A11, and B11) were operational into the second winter. During the second year, 10 additional fish were captured and implanted with radiotransmitters (Table 2). Of these 10 fish, four (BB7, C87, C95, and A91) were recaptures at time of implantation and two (B85 and C00) were recaptured after winter monitoring. During Winter 2 from December 1987 through March 1988 there were 74 total observation hours from which 34.5 hours (138 15-minute observations) were used for analysis. Three fish (A00, A91, and C95) tagged during the second year were not located during winter monitoring but were re-contacted in the spring 1988. During the first tagging trip for the second year, tag B09 was located and transmitting on a gravel shoreline at RMI 79.2. It is unlikely that the tag was expelled by the fish based on previous studies that indicate radiotag retention (Tyus 1988 and Wick et al. 1983). Fishermen frequent the area where the tag was found and it is possible that the tag was discarded during evisceration. This fish was originally caught during this study for implantation by angling. Natural death cannot be ruled out; however, the fish had behaved normally during previous contacts. During the second year, fish C93 apparently died in January 1988. This fish was caught in October 1987 and was carrying a large, red and white Dardevil embedded in the lower jaw. Attached to the lure was 6 feet fishing line which had tangled around a small tumbleweed. The fish appeared underweight but strong. Stress related to carrying this lure and of the implantation may have been factors contributing to the cause of death. The fish behaved normally after tagging until January but may not have been in good enough condition to make it through the entire winter. This may indicate the importance of fall feeding and conditioning prior to the winter period.

Fish movement

Of the 20 fish implanted during fall months in the 2 year period, only three (A09, B07, and BB7) moved downstream and relocated over 4 miles or out of the study area after implantation. Fourteen fish remained within the study areas in which they were tagged. The farthest-moving fish (A09) was tagged at RMI 96.4 in the Government Bridge study area during fall 1986, and was located 15 miles downstream in the Maybell study area at RMI 81.4, 3.5 weeks later (Table 4). Interestingly, A09 used the same embayment as four other radiotagged fish. These downstream movements could have been due to disorientation from the surgical process or the MS 222 anesthesia. However, not all fish moved downstream after release, and some downstream movement may be indicative of increased activity in the fall. B08 moved 4.4 miles in the fall of 1987 but had been implanted the previous year, thus eliminating implantation disorientation as the cause. All fish that moved downstream in

Table 2. Colorado squawfish implanted with radio transmitters by CSU on the Yampa River, 1986 and 1987.

Fish ID	Freq-ency 40mHz	ppm	Tag Life (months)	Carlin Tag number & color	Date of capture	Capture river mile	Total length (mm)	Weight (grams)	Habitat code	Gear type
<u>Juniper Springs study area (Group A)</u>										
<u>Year 1 (1986)</u>										
A07	.6614	44	18	3065 (O)	Oct 2	96.4	544	1200	MCED	GE
A08	.6716	34	24	3067 (O)	Oct 3	97.2	494	1200	MCED	GE
A09	.6824	43	18	3064 (O)	Oct 1	96.4	538	1100	MCED	GE
A10	.6917	35	18	3063 (O)	Oct 1	96.4	538	1000	MCED	GE
A11	.7015	29	24	3062 (O)	Oct 1	97.2	620	2000	MCED	TB
<u>Year 2 (1987)</u>										
AA8	.671	39	24	3243 (O)	Nov 4	95.7	556	1550	MCBM	GE
A91	.6914	70	12	REC 3459 (G)	Oct 23	104.3	594	1600	MCED	AN
A00	.7004	70/60	12	3241 (O)	Nov 4	95.7		1150	MCBM	GE
<u>Maybell study area (Group B)</u>										
<u>Year 1 (1986)</u>										
B07	.6617	29	24	REC 3608 (Y)	Oct 8	80.3	604	1800	MCPO	AN
B08	.6716	40	18	3079 (O)	Oct 29	81.1	530	1150	MCRU	EL
B09	.6816	34	18	REC 3618 (Y)	Oct 29	80.8	774	3000	MCPO	AN
B10	.6915	45	18	3069 (O)	Oct 9	81.4	512	990	MCED	TB
B11	.7022	35	18	3068 (O)	Oct 8	80.8	622	2100	MCPO	GE
<u>Year 2 (1987)</u>										
BB7	.661	38	18	REC 283 (G)	Sep 9	80.8	558	1350	MCPO	AN
B85	.685	50	12	3083 (O)	Nov 3	81.1	780	3300	MCEM	GE
<u>Lily Park study area (Group C)</u>										
<u>Year 2 (1987)</u>										
C87	.687	74?	12	REC 1029 (Y)	Sep 11	53.2	833	5500	MCPO	AN
C89	.689	50	12	3080 (O)	Sep 11	53.2	702	3300	MCPO	AN
C93	.6932	50	12	3082 (O)	Oct 26	52.9	745	3200	MCPO	GE
C95	.695	70	12	REC 1491 (Y)	Sep 11	53.2	641	2000	MCPO	AN
C00	.7004	50	12	3081 (O)	Oct 25	53.3	486	1100	MCPO	GE

ppm = pulses per minute of radiotag
mm = millimeter
REC = recaptured fish
Tag color codes:
- O = orange
- G = green
- Y = yellow

Habitat code = see Appendix A
Gear type = see Appendix B

Table 3. Recapture records of Colorado squawfish implanted with radio transmitters on the Yampa River, Colorado, 1986 and 1987.

Carlin Tag & color	Fish ID	Recaptured?	Date of capture	River	Capture River mile	Total Length (mm)	Weight (grams)	Agency
0283G		N	6/23/81	GR	322.8	446	715	FWS
0283G		Y	7/25/84	YA	18.2	526	1240	FWS
0283G		Y	9/21/85	YA	71.6	543		DOW
0283G	BB7	Y/RT	9/09/87	YA	80.8	558	1350	CSU
1029Y		N	10/09/80	YA	53.1	765	4082	DOW
1029Y	C87	Y/RT	9/11/87	YA	53.2	833	5500	CSU
1029Y	C87	Y	5/25/88	LS	5.7	834		CSU
1491Y		N	4/25/86	YA	53.4	638	1980	DOW
1491Y	C95	Y/RT	9/11/87	YA	53.2	641	2000	CSU
3063O		N/RT	10/01/86	YA	96.4	538	1000	CSU
3063O	A10	Y	9/22/87	YA	95.4	565	1350	CSU
3063O	A10	Y	6/15/88	YA	103.3	570	1550	CSU
3081O	C00	N/RT	10/25/87	YA	53.3	486	1100	CSU
3081O	C00	Y	5/05/88	YA	51.4	496	1000	DOW
3083O	B85	N/RT	11/03/87	YA	81.1	780	3300	CSU
3083O	B85	Y	5/03/88	YA	77.4	763	3550	DOW
3083O	B85	Y	10/ /88	YA	80.8			DOW
3459G		N	5/23/85	GR	255.8	521	1040	FWS
3459G	A91	Y/RT	10/23/87	YA	104.3	594	1600	CSU
3608Y		N	8/03/84	YA	18.4	593	1860	
3608Y	B07	Y/RT	10/08/86	YA	80.3	604	1800	CSU
3618Y		N	7/26/84	YA	9.5	762	4100	FWS
3618Y	B09	Y/RT	10/29/86	YA	80.8	774	3000	CSU

Recaptured codes: N = no (indicates first time fish was captured and tagged with numbered Carlin tag),
Y = yes (indicates fish had been previously tagged), and
RT = fish was implanted with radiotransmitter.
River: GR= Green River, YA= Yampa River, and LS= Little Snake River.
Agency: DOW= Colorado Division of Wildlife, CSU= Colorado State University, FWS= U.S. Fish and Wildlife Service.

Table 4. River mile locations of radiotagged Colorado squawfish on the Yampa River, Colorado, 1986-1987 (Year 1).

	Fall------------------------------				Winter--								Spring	Spawning
Fish ID	Oct 1-3	Oct 7-10	Oct 15-17	Oct 28-30	Nov 11-15	Dec 1-6	Dec 15-20	Jan 5-9	Jan 19-24	Feb 2-7	Feb 16-20	Mar 2-6	Mar 16-21	Jun 25-30
Government Bridge Area														
A07	**96.4		95.7		95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.7	93.9	
A08	**97.2		95.7	98.4	98.2	97.9	98.8	98.3	98.3	98.8	98.8	98.6	97.9	15.7
A09	**96.4			81.4	81.4	81.4	81.4	81.4	81.3	81.1	81.1	81.1	81.1	
A10	**96.4		95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.2	
A11	**97.2		95.7		95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.7	94.4	15.7
Maybell Study Area														
B07		**80.8			76.2	76.2	76.2		76.3	76.3	76.2	76.2	76.2	
B08				**80.9	81.4	81.1	81.4	81.1	81.3	81.1	81.1	81.4	81.1	
B09				**80.8	81.1	81.1	81.1	81.1	81.1	81.1	81.1	81.1	81.1	
B10		**81.4	80.8	80.7	80.8	81.1	80.8	81.3	81.3		81.9	81.9	81.6	
B11		**80.8	79.8	81.3	81.1	81.1	81.1	81.1	81.3	81.4	81.1	81.1	81.1	11.2

** fish caught and implanted with radiotransmitter.

the fall and relocated apparently recovered from any disorienting effects and were subsequently monitored through each winter.

After ice formation, in late November and early December, fish stayed within very specific river reaches (home sites or overwintering areas). Fish did not move outside of their overwintering areas until ice-out. In addition, fish used very specific areas within a given habitat. They often stayed in these areas throughout the winter or repeatedly returned to them after using other areas for a short time. This suggests homing and fidelity to very specific overwintering habitats. During the period of ice cover, movement averaged 0.3 mile each year with ranges of 0.0 - 1.1 miles in Winter 1 and 0.0 - 0.5 mile in Winter 2 (Table 5). The three fish that used the backwater at RMI 95.7 consistently utilized that habitat on every monitoring trip in Winter 1, and one fish (A10) used it both winters. In Winter 1, five fish used the embayment at RMI 81.1 in conjunction with main-channel habitats; only B09 used it each trip. The other four fish (A09, B08, B10, and B11) used the embayment with occasional forays into the main-channel pool and run area at RMI 81.4. Fish B11 returned and used this embayment in the fall and winter during the second year of the study. Fish in the Lily Park area tended to remain within a given pool throughout the winter, but there was some movement between pools within the river reach. All other fish were found in main channel habitats such as eddy, run, or shoreline; these fish tended to move the greatest distance during the winter. During Winter 2, A91, A70, and C91 could not be located during the winter period but were found after ice off.

Ice break-up (ice-off) occurred on March 7-9, 1987 and March 19-22, 1988. Radiotagged fish were located downstream of over-wintering areas within a week after ice-off both years, except the four fish (B08, B09, B11, and A09) that were within the embayment at RMI 81.1 in Winter 1. In Winter 1, all fish in the backwater (RMI 95.7) moved out during ice-off. This would be expected since the backwater was dramatically changed by the hydrologic events of ice-off and the resulting scouring and flooding of the dislodged ice and water. Downstream movement of 17 fish averaged 0.8 miles for both years. One other fish (BB7) was located 7.4 miles upstream after ice-off. It is likely that this fish did the majority or all of this movement after the ice-off event.

Eight transmitters in fish from the first year were operable during the fall of 1987. All eight of these fish were located within the same study site in which they were tagged during fall 1986. Three additional fish were tagged during 1987 in the Lily Park Study area for fall monitoring. Average movement of these eleven fish during the fall from September 21 through November 20, 1987 averaged 0.9 mile and ranged from 0.0 to 4.4 miles. Six fish moved between 0.1 and 0.7 mile and three showed no change in river mile location during the fall (Table 5).

Movement during non-spawning times was greatest in the spring, averaging 6.5 miles (range 0.0 - 43.2 miles) in spring 1988 with most fish moving in a downstream direction. No data were collected in spring 1987. Fish A00 moved 43.2 miles in April 1988 (24.6 miles occurred in a 2-day period from April 19 to April 21). The next farthest-moving fish moved only 8.5 miles. If A00 is not considered in the calculation, the average spring movement was 2.9 miles for the remaining 10 fish. Two fish (C00 and C87), in addition to moving downstream, moved up into the Little Snake River, 1 and 6.7 miles respectively, in May and June. These movements were probably in response to increased flows which altered habitats that had been suitable in the winter. Fish probably moved to habitats more suitable for high water conditions.

Table 5. River mile locations of radiotagged Colorado squawfish on the Yampa River, 1987-1988.

			FALL					WINTER							
Fish ID	Aug 25-28	Sep 8-11	Sep 21-26	Oct 5-9	Oct 19-26	Nov 2-7	Nov 16-20	Dec 1-5	Dec 14-18	Jan 4-10	Jan 19-25	Feb 1-6	Feb 15-20	Feb 4- Mar 29	Mar 14-18
Government Bridge Study Area															
A07	96.2		96.4	96.4											
A08	98.2		98.1	98.5/98.4	98.5		98.8	98.8							
A10	95.7		*95.4	95.7	95.7	95.9/96.1	95.7	95.7	95.7	95.7	95.7	95.7	95.7	95.7	
A11	96.4		98.1												
AA8						**95.7	96.2	96.2	96.2	96.2	96.0/96.2	96.2	96.2	96.2	96.2
A00						**95.7									
A91					**104.3	104.1									
Maybell Study Area															
B07	81.4		81.1	81.4	81.4	80.8/81.4	81.1	81.1	81.1	81.4	81.1/81.4	81.1	81.4	81.1	81.4
B08	84.9	80.8	85.2	81.1	80.8	80.8									
B10	81.4	80.8	81.4	81.4	81.4	81.4									
B11	81.1/80.8	81.1	81.4/81.1	81.1	81.1	80.8	81.1	81.1	81.1	81.3/81.1			81.4	81.4	81.4
BB7		**80.8			71.7		71.8	71.5	71.5/71.8		71.6	71.6	71.6	71.6	71.8
B85						**81.1	80.8	81.1	81.1	81.1/81.4	81.1	81.4	81.4	81.1	81.4
Lily Park Study Area															
C87		**53.2	53.3	53.3	53.3	52.8	53.2	53.0	52.8	53.1	53.0	53.3	53.3	53.3	53.3
C89		**53.2	51.1	53.3	52.9/53.3	53.3	53.3	53.3	53.3	53.3	53.3	53.3/53.4	53.3	53.3	53.3
C93					**52.9	52.9	52.7	52.9	52.7	52.9	52.9	52.6	52.6	52.3	52.5
C95		**53.2	53.3	53.3											
C00					**53.3	53.3	53.0	52.9	52.7	52.7	52.7	52.7	53.0	52.7	53.1

	SPRING						Spawning		Fall
Fish ID	Apr 5-8	Apr 19-22	May 3-5	May 17-26	Jun 6-15	Jun 27-30	Jul 5-12	Jul 26	Oct 2
Government Bridge Study Area									
A07									
A08									
A10					*103.3				
A11									
AA8	96.2	95.8		95.7	95.7				
A00	92.4	73.8/49.2							
A91				103.3	103.3		18.8		
Maybell Study Area									
B07	78.4		78.9	78.1	78.1				
B08									
B10									
B11		85.1	84.5						
BB7	79.2		87.0	84.6	85.6				
B85	79.2	77.4	77.5	77.5	77.0	78.4/77	11.0	34.0	
Lily Park Study Area									
C87	51.5			*LS5.7	LS6.7	51.0	16.5	38.0	52.8
C89	51.2					51.0	16.5	47.0	
C93	52.4	52.4	52.4	52.3	51.5	51.5			
C95		51.5	52.7	51.5	51.5	53.3/51.4		51.0	52.9
C00	52.6	52.6	*51.4	46.4	50.9/LS1	48/46.5			

*=FISH CAUGHT

**=FISH CAUGHT AND IMPLANTED WITH RADIOTRANSMITTER.

Squawfish could have been attracted to the warmer waters of the Little Snake River and to better feeding opportunities.

Average movement of radiotagged fish related to spawning was 65 miles (range 34.5 - 84.5 miles) for both years. This was the one-way distance from the point of last contact above Yampa Canyon to the lowest river mile location in Yampa Canyon. In the summer 1987, three fish (A08, A11, and B11) were located within the spawning area of Yampa Canyon (personal communication H.M. Tyus, USFWS, Vernal, Utah). All three fish were located back at their over-wintering areas in the fall, 1987. Four fish (A91, B85, C87, and C89) were known to migrate to the Yampa Canyon spawning area in the summer, 1988, (personal communication, H.M. Tyus, USFWS, Vernal, Utah). Fish C87 was located during a radiotelemetry spot check of the area by the authors. Fish B85 was collected by CDOW during the Fall 1988, at RMI 80.8 (Table 3). These fish exhibited a high degree of homing ability and fidelity by locating and using the same habitats previously used after spawning migration. Three of the implanted fish (BB7, C87, and C95) had capture histories that also indicated fidelity to a specific river reach over one or more years. For example, fish C87 was recaptured, radiotracked over an entire winter, and relocated during the fall of the next year only 0.1 mile from where it had been originally caught and Carlin tagged 7 years earlier (Table 3).

Although fish remained in specific areas during the winter, they were also quite active within each habitat. Fish in embayments and backwaters would move between several favored spots within the habitat, staying in a spot for several minutes to several hours before moving. Fish would often repeat this pattern of movement. These spots were often used by more than one squawfish at the same time. Movement did not appear to be influenced by the presence of other Colorado squawfish. This would often result in small congregations of two to three Colorado squawfish within a one meter diameter spot. Fish using run and shoreline habitats appeared to be more active, moving within and between habitats more frequently. Fish found in larger pools and eddys behaved similar to those in backwater and embayment habitats. Those using smaller pools and eddys behaved similar to fish in run and shoreline habitats.

Habitat Use

There was a distinct difference in winter habitat use between years. During Winter 1, fish most often used habitats off the main channel (off-channel habitats). In Winter 2, fish used main-channel habitats (Figures 6 and 7). Predominant habitats used Winter 1 were backwater, embayment, and run. Run and pool habitat were used more Winter 2. Flows during Winter 1 were higher, whereas flows during Winter 2 were lower than mean historic winter flows (Figure 8 and Appendix C). High use of pool habitat in Winter 2 was due to the addition of the Lily Park study area, which is characterized by pool and eddy habitat and absence of backwater and embayment habitat.

Habitat use by Colorado squawfish varied between study areas as did habitat availability. When a variety of habitats was available within a river reach, fish often selected off-channel habitats over main-channel types. Backwater use in Winter 1 was exclusively at the RMI 95.7 backwater. This backwater was drastically altered during ice-off and spring runoff the first year; this may be a reason for limited use in Winter 2. During Winter 1, this backwater habitat apparently satisfied the needs of fish sufficiently that

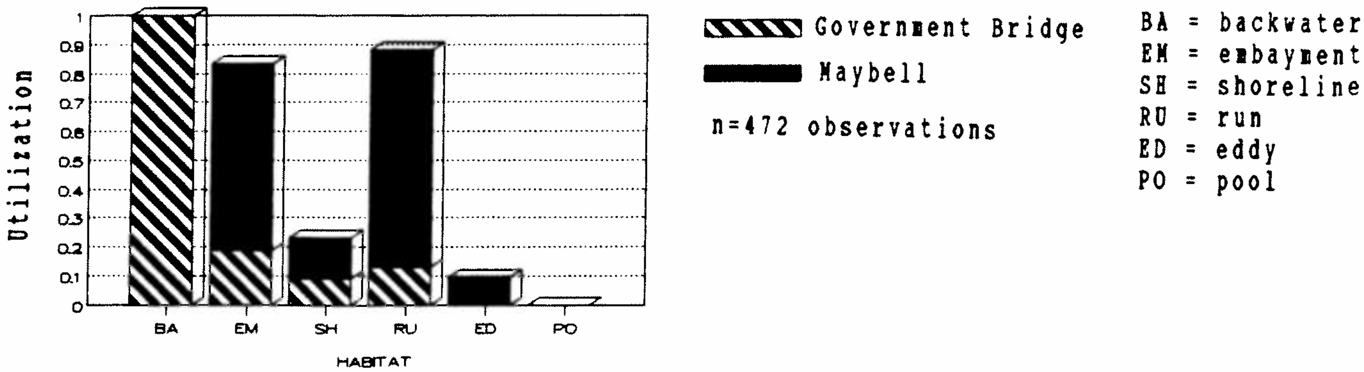


Figure 6 . Habitat utilization by radiotagged Colorado squawfish during the winter from December 1, 1986 to March 6, 1987 on the Yampa River.

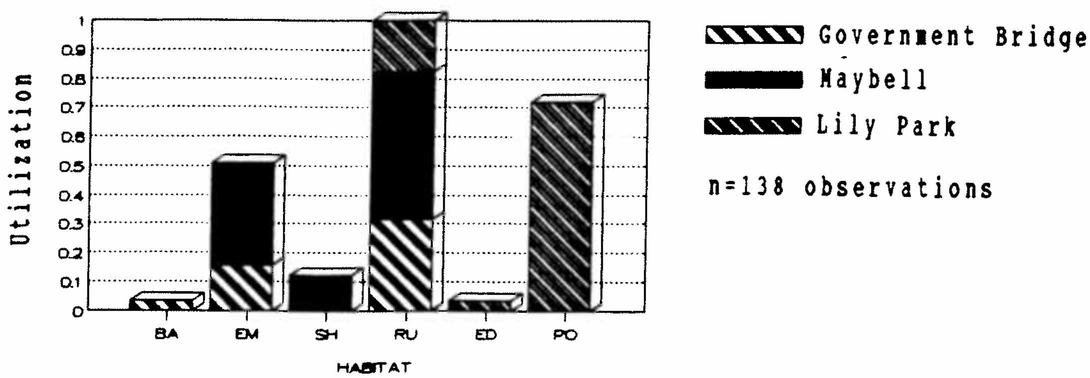


Figure 7 . Habitat utilization by radiotagged Colorado squawfish during the winter from December 1, 1987 to March 18, 1988 on the Yampa River.

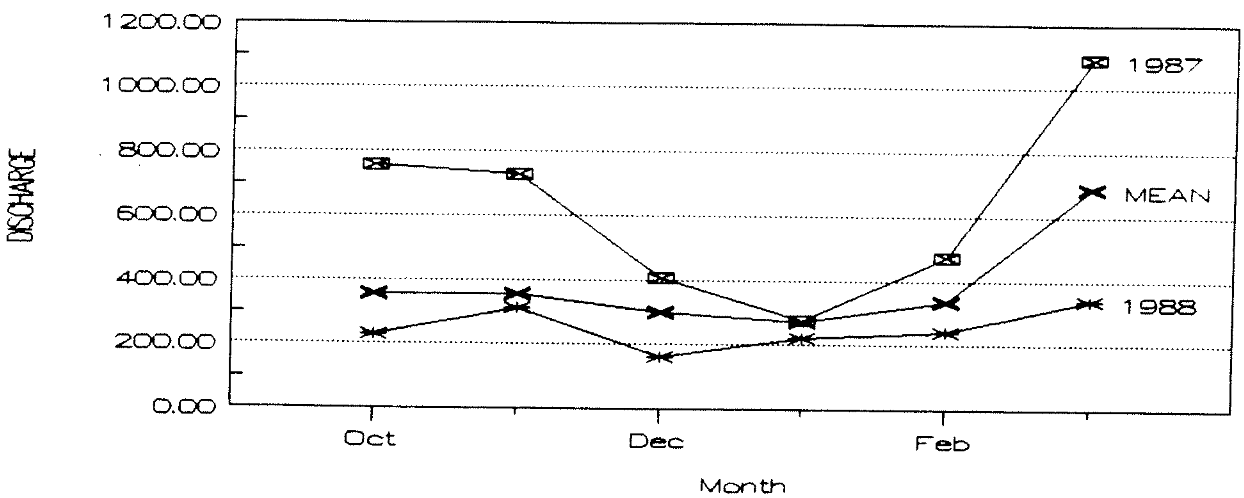


Figure 8. Mean monthly discharge on the Yampa River, October through March (1917-1988) at Maybell, Colorado, compared to monthly means in 1987 and 1988 water years (USGS).

they did not need to leave it often. Fish remained within this backwater during the entire winter and left it only a few times for only brief periods. Most embayment use was at RMI 81.1. This embayment remained relatively unchanged after ice-off and spring runoff. In addition to this embayment, one at RMI 71.6 was used in Winter 2 and another at Government Bridge (RMI 98.8) was used early in both years. Fish used embayments throughout the winter, but they would occasionally leave to use run and other associated main-channel habitat.

All pool habitat use was within a mile section at the Lily Park study site, a river segment characterized by eddy and pool habitat. This area has no backwater and very little embayment habitat available during low flow, winter conditions. All three fish (C87, C89, and C00) in this area used pool and occasionally run and/or eddy habitat during the winter.

In areas where a variety of habitats was available, fish appeared to select certain habitat types over others. There was pool habitat within 0.3 mile of both the backwater (RMI 95.7) and the embayments (RMI 98.8, 81.1 and 76.2,) but no fish were observed to use these during the winter.

Fish using main-channel habitats changed habitat more frequently than fish using off-channel habitats. Main-channel habitats may not provide as many of a fish's winter needs. Advantages to the use of off-channel (backwater and embayment) habitats may include:

1) low or zero velocity for energy conservation,
2) increased concentration of food,
3) easier identification of home range area through consistent visual or olfactory cues, and
4) protection from moving frazil ice

Off-channel habitats may also provide other indirect benefits, e.g., increased oxygen and primary productivity. The lower flows present during Winter 2 either made these off-channel habitats less suitable or made main-channel habitats more acceptable.

Squawfish evolved within a system that provided variability of flows between years. Natural yearly variability would be important to avoid food supply depletion during low-flow periods that would tend to concentrate prey within the main channel where less cover may be available. If low flows continued over several years, populations of prey species could be reduced since they would be subject to increased predation by the squawfish and introduced northern pike and have fewer highly productive feeding areas available during the winter.

Predominant habitat used in the fall, 1987, was pool; followed by run, shoreline, and eddy. Backwater and embayment habitats were used the least in contrast to high use of these habitats during the winter. Most pool use was within the Lily Park Study Area where this habitat dominates over other types. Habitats used in the fall within the Maybell area were equally distributed among almost all habitat types (Figure 9).

In the spring, eddy was the predominant habitat used followed by backwater and shoreline (Figure 10). Embayments were not used during this period probably since they tended to be flooded by the high flows. Run and pool habitats were used very little. Backwater habitat was used in all three study areas.

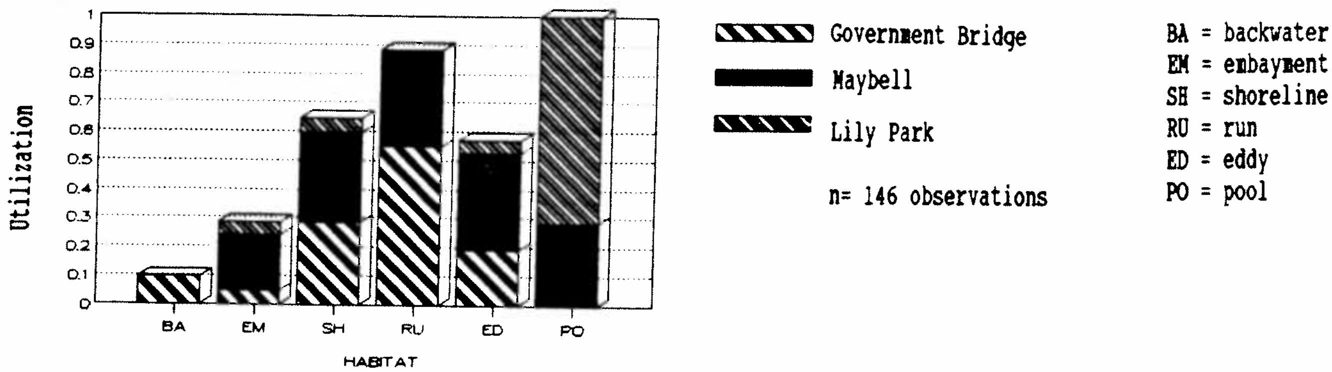


Figure 9. Habitat utilization by radiotagged Colorado squawfish during the fall from September 21, to November 20, 1987 on the Yampa River, Colorado. .

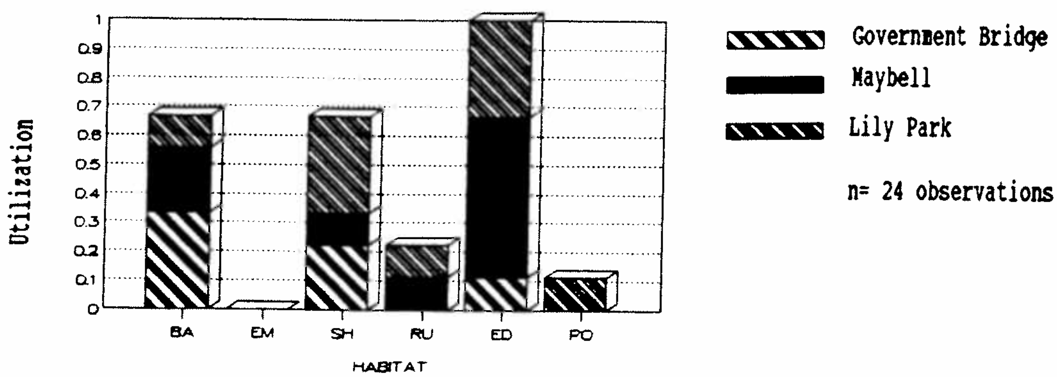


Figure 10. Habitat utilization by radiotagged Colorado squawfish during the spring from April 5 to June 30, 1988 on the Yampa River, Colorado.

Effects of ice on habitat use

Ice formation occurred on low-velocity habitats as early as November 11, 1986, and November 17, 1987. Squawfish were observed by radiotelemetry to move under the ice at the large backwater at RMI 95.7, at the large embayment at RMI 81.1, and along large ice pads in pool and eddy habitat at initial ice formation both years. On the first scheduled trip in December 1986, the main river channel was clogged with floating ice and slush during early morning hours. Low-velocity shoreline areas were frozen over. All nine squawfish located on that trip were in habitat areas that were iced over although the main channel would clear of ice by late afternoon. The initial ice over pattern outlined and identified habitat types that were used by squawfish throughout the rest of the winter. Because lower velocity waters were the first to freeze, ice served as a velocity indicator. Squawfish were apparently attracted to these frozen-over low-velocity areas for the cover and security they provided. In addition, large schools of small fish were observed through the thin clear ice near shore, so food may have been an additional attraction. Except for a few open riffle areas the river was completely covered by ice throughout most of the winter (mid December through early March) both years. Ice-out occurred March 7 in 1987 and March 21 in 1988.

The initial attraction squawfish have for ice-covered habitats at first ice formation suggests that surface ice provides a protective cover which permits utilization of habitat areas seldom used during other times of the year. Ice may provide needed security from overhead predators such as hawks and eagles, allowing squawfish to move into clear, shallow waters to forage with little danger. Ice insulates the water in backwater and embayment habitats maintaining temperatures slightly above freezing while allowing light penetration for photosynthesis. The importance of embayment habitat as a source of primary productivity was indicated by high dissolved oxygen levels of 17 parts per million (ppm) compared to 12 ppm saturation (Table 6). Schools of small fish were seen through the clear ice swimming along shorelines of shallow embayments and backwaters. Maintenance of these nutrient-rich embayment and backwater areas could be critical to the overall productivity of the winter ecosystem.

Oxygen measurements were taken during mid-winter the second year to determine if heavy ice and snow cover affected oxygen levels. Some depression of oxygen levels was noted in upstream study areas (Table 6). Reductions in oxygen levels in the main channel may have been due to oxygen demand from sewage inputs from upstream towns. The river recovered to saturation levels at the lower Lily Park study area. Recovery to oxygen saturation was probably assisted by open water in canyon areas (Juniper and Cross Mountain) and by mixing with supersaturated water in embayment habitats similar to the one measured at RMI 81.1.

Ice cover insulates the river from extremely cold air temperatures that occur frequently along the Yampa River. Ice cover reduces formation of excessive amounts of frazil ice which can occupy large volumes of run and pool habitat and when moving in the water column may damage fish gills.

Table 6. Dissolved oxygen measurements, Yampa River, 1988.

Date	Time	RMI	Habitat	Location	D.O.
Feb 19	1345	95.7	MCBA	1	7
Feb 19	1445	95.7	MCBA	2	7.4
Feb 19	1503	95.7	MCMB	3	7.1
Feb 19	1535	95.7	MCRU		7.4
Feb 16	1554	81.4	MCRU	1	9.4
Feb 16	1610	81.4	MCRU	1	8.7
Feb 16	1625	81.1	MCEM	Inside	17.5
Feb 16	1640	81.1	MCEM	Interface	9.2
Feb 17	1548	81.1	MCEM	Interface	9.6
Feb 17	1558	81.1	MCEM	Inside	17.7
Feb 17	1600	81.1	MCRU	1	9.4
Feb 17	1800	71.7	MCEM	1	7.6
Feb 18	1115	53.3	MCPO	3	12
Feb 18	1540	53.0	MCPO	4	12.5
Mar 4	1345	96.4	MCRU		10.1
Mar 2	1500	81.1	MCEM	Inside*	10.5
Mar 2	1500	81.1	MCEM	Interface	12.9
Mar 2	1510	81.1	MCRU	1	9.8
Mar 1	1730	71.7	MCEM	Inside*	11.9
Mar 1	1730	71.7	MCEM	Inside*	12
Mar 17	1400	95.7	MCBA	1	11.5
Mar 17	1400	95.7	MCBA	2	10.5
Mar 17	1420	95.7	MCED	3	10.4
Mar 17	1500	96.2	MCRU		10.8
Mar 15	1630	81.1	MCRU	1	12.6
Mar 15	1635	81.1	MCEM	Inside	16.7
Mar 15	1645	81.1	MCEM	Interface	14.4
Mar 18	1215	71.7	MCEM	Inside*	12
Mar 18	1215	71.7	MCEM	Inside*	12.6
Mar 16	1415	52.5	MCRU	Open	12.3

* Some water flowing over point bar.

Depth, velocity, and substrate utilization

Number of observations for total depth, effective depth, and velocity were normalized for each year within each habitat type during the winter. Total depth reflected distance from the river bottom to the top of the ice; this measurement included solid ice, packed non-moving frazil, and water (effective depth).

Backwater habitats showed the narrowest range of depths used, and pool habitat showed the broadest range and deepest depths. Generally, the difference between total depth and effective depth reflected surface ice thickness except in run and pool habitat where effective depth was substantially less due to very thick (packed) frazil ice. Highest frequency of use for total depths was 2.0-3.5 feet in backwater, embayment, run, and shoreline habitats. Frequency of effective depth use was highest between 1.0 to 2.0 feet. Total depths used most frequently in eddy habitat ranged 5.0 to 9.5 feet. Effective depths used most frequently in eddy habitat ranged between 3.5 to 9.0 feet. In pool habitat the most frequently used total depth was 10.0 feet; however, the most frequently used effective depth was 3.0 feet, showing the effect of packed frazil ice (Figures 11 and 12).

The predominant velocity within backwater, embayment and eddy habitats during the winter was 0.0 ft/s, but a few velocities over 0.0 ft/s indicated fish locations along the interface with the main channel. The positive velocities within eddy habitat indicate fish within the eddy-run interface. The greatest range and highest velocity were found in run habitat. Velocities used most in run and shoreline habitat were 0.0 to 0.4 ft/s. The most frequently used velocity in pool habitat was 0.6 ft/s (Figure 13). These velocities are not fish nose velocities but are mean column velocities taken at 0.6 effective depth. Fish may be utilizing micro-habitats that provide lower velocities. Depth and velocity summaries over extended periods can be misleading because a large number of observations on any given trip or period can heavily influence the over-all frequency. Therefore, depth and velocity are presented below on a trip by trip basis to better reflect habitat use over time.

Most depth measurements during the fall period were in ice-free water. Depth measurements which included ice are identified within the appropriate figures. Ice thickness during this time was 0.1 foot. Water depth in backwaters during the fall were between 3.0 and 4.0 feet. Embayment use was similar except for use of shallower 1.5 foot depth. Fish use of the shallowest depths in each habitat may have been facilitated by ice that provided overhead cover. Depth of eddy habitat was greatest at 4.0 and 4.5 feet. Pool depths showed a bimodality at 5.0 and 13.0 feet. Run and shoreline depth utilization ranged between 3.0 and 4.5 feet (Figure 14). Fall velocities were mostly 0.0 ft/s in backwater, embayment, eddy, and pool habitats and 0.5 ft/s in run habitat and 0.3 ft/s in shoreline habitat (Figure 15).

Winter substrate use was segregated by habitat type for each year of the study (Table 7 and 8). Of the 36 possible combinations of clay, silt, sand, gravel, cobble, boulder, and bedrock substrates, 21 were observed throughout the 2 years of the study. Sand (SASA) was the most commonly used substrate type in both years of the study. It was the dominant substrate used in run habitat during Winter 1 and in run and pool habitat in Winter 2. During

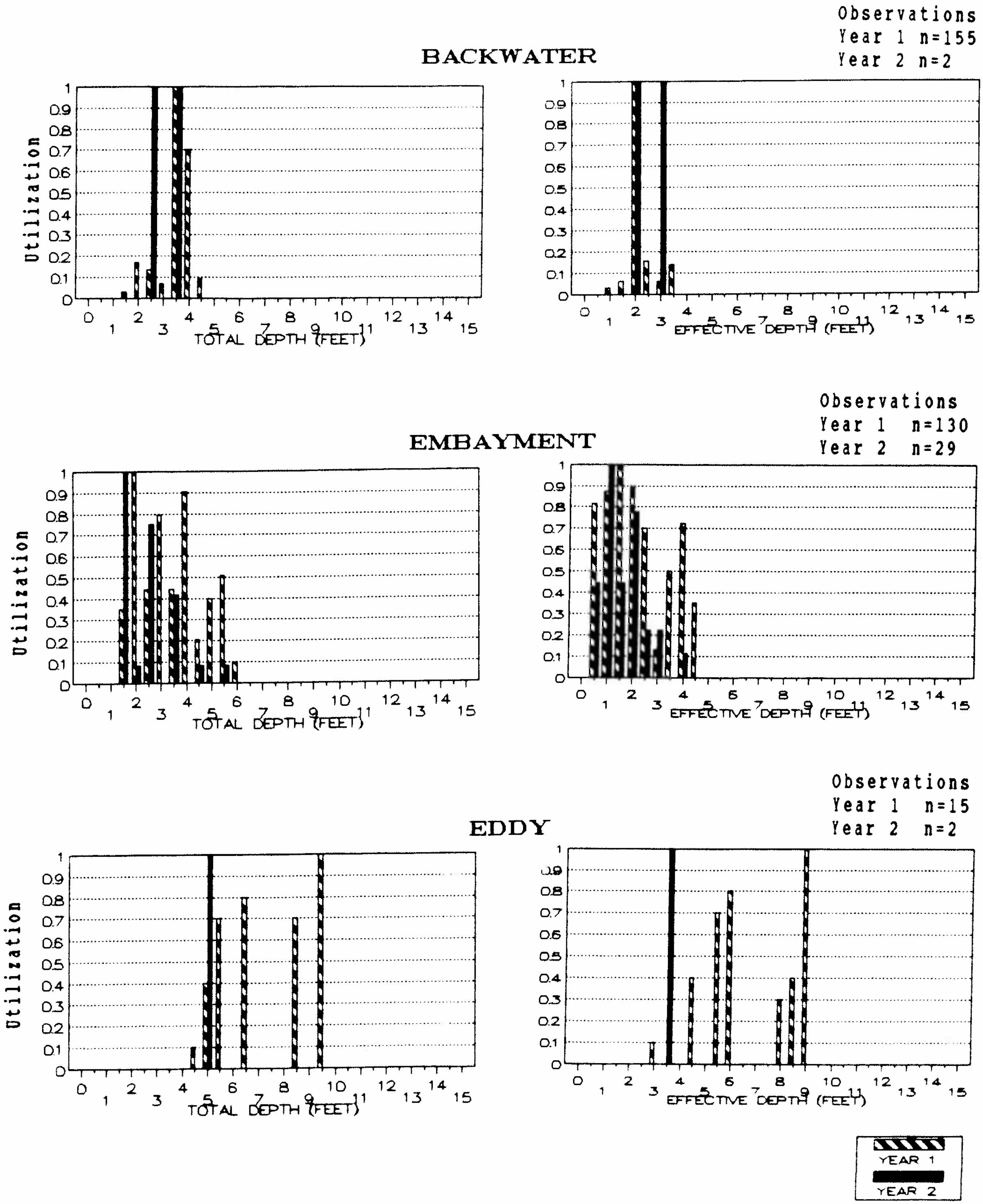


Figure 11. Total and effective depth utilization (normalized) of backwater, embayment, and eddy habitats by radiotagged Colorado squawfish during two winters (1986-1987 and 1987-1988) on the Yampa River.

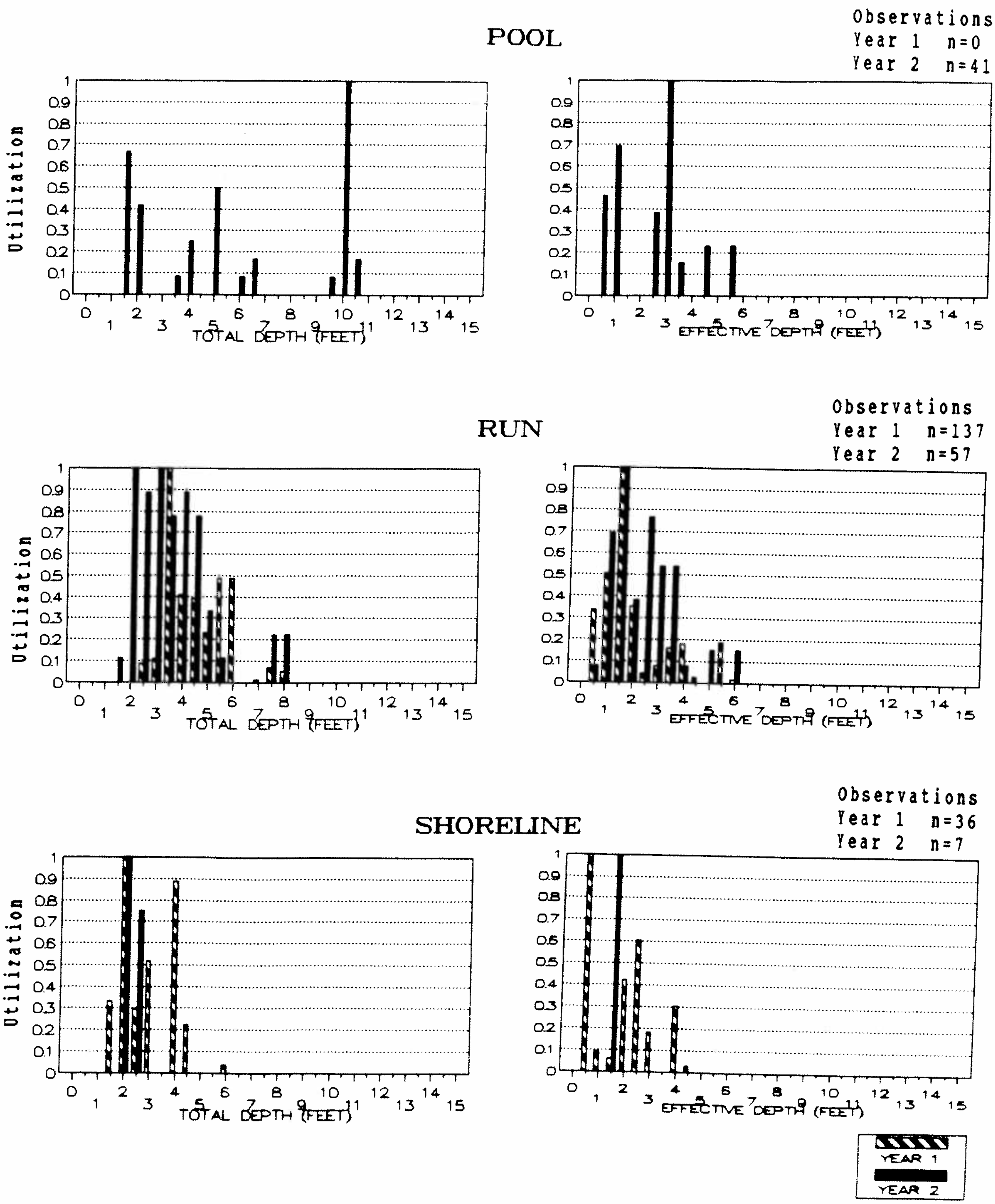


Figure 12. Total and effective depth utilization (normalized) of pool, run, and shoreline habitats by radiotagged Colorado squawfish during two winters (1986-1987 and 1987-1988) on the Yampa River.

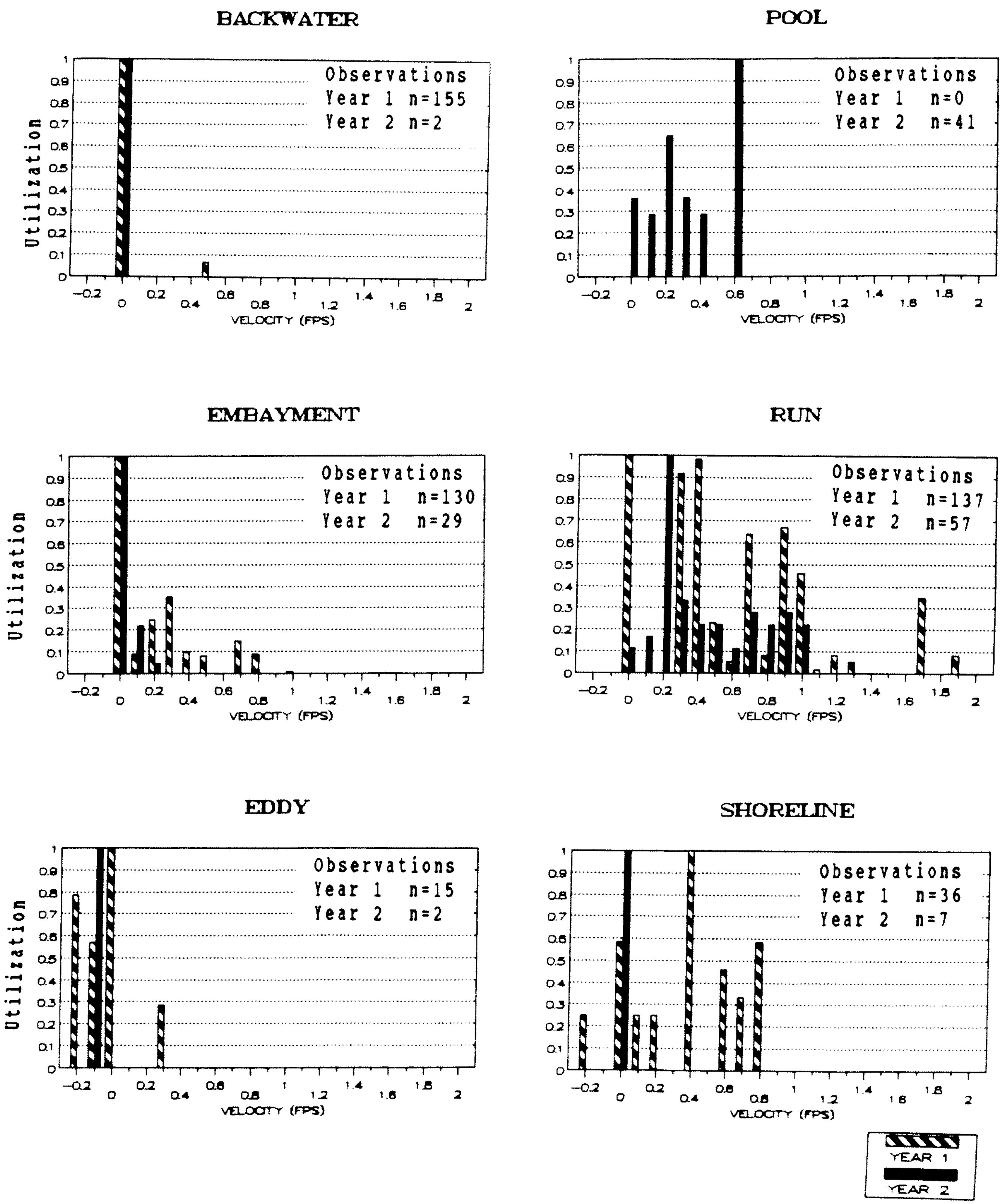


Figure 13. Velocity utilization (normalized) in each habitat type by radiotagged Colorado squawfish during two winters (1986-1987 and 1987-1988) on the Yampa River.

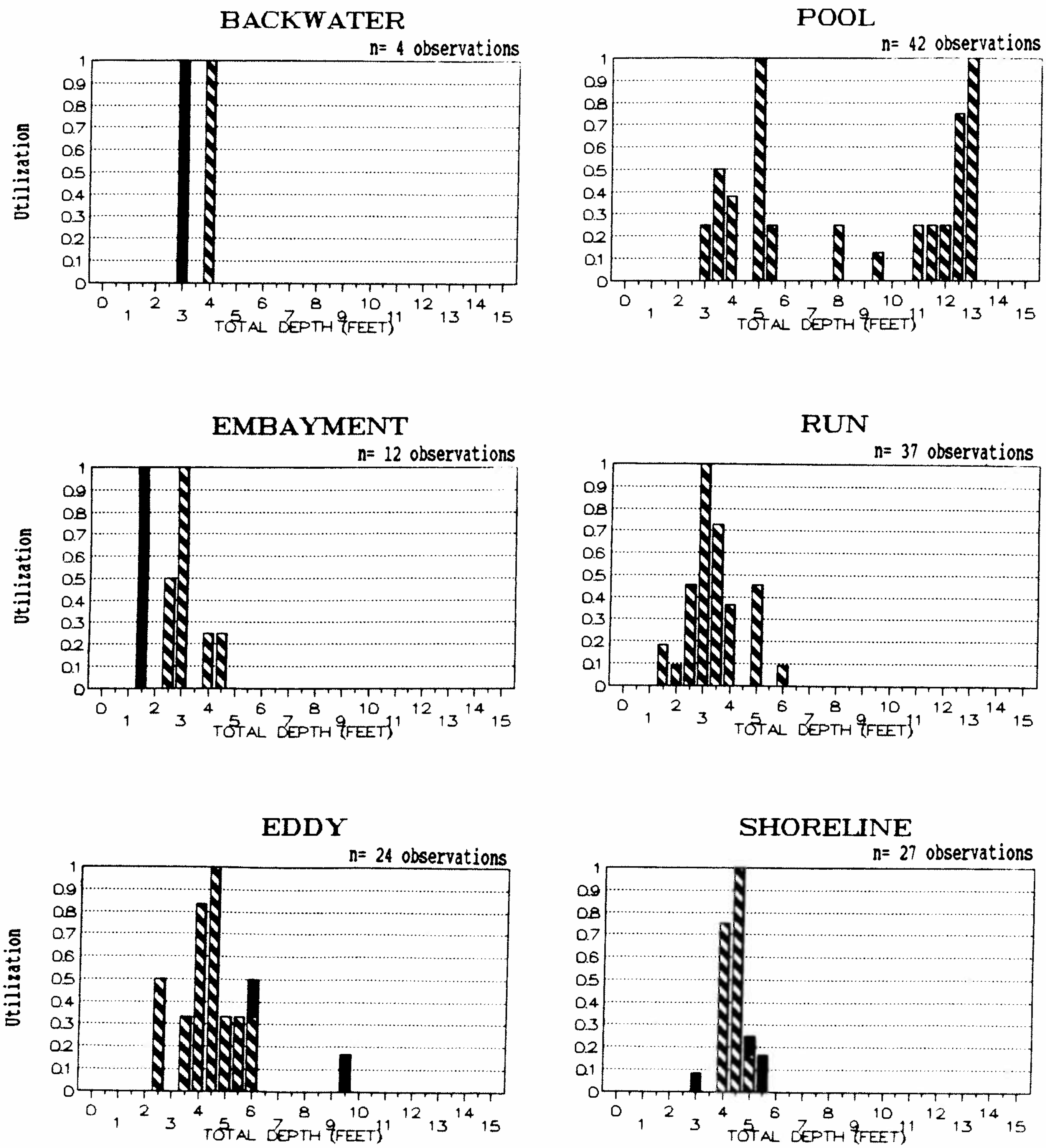
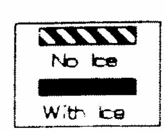


Figure 14. Total depth utilization (normalized) in each habitat by radiotagged Colorado squawfish during the fall 1987 on the Yampa River, Colorado. Utilization of depths with ice cover include 0.1 foot ice thickness.



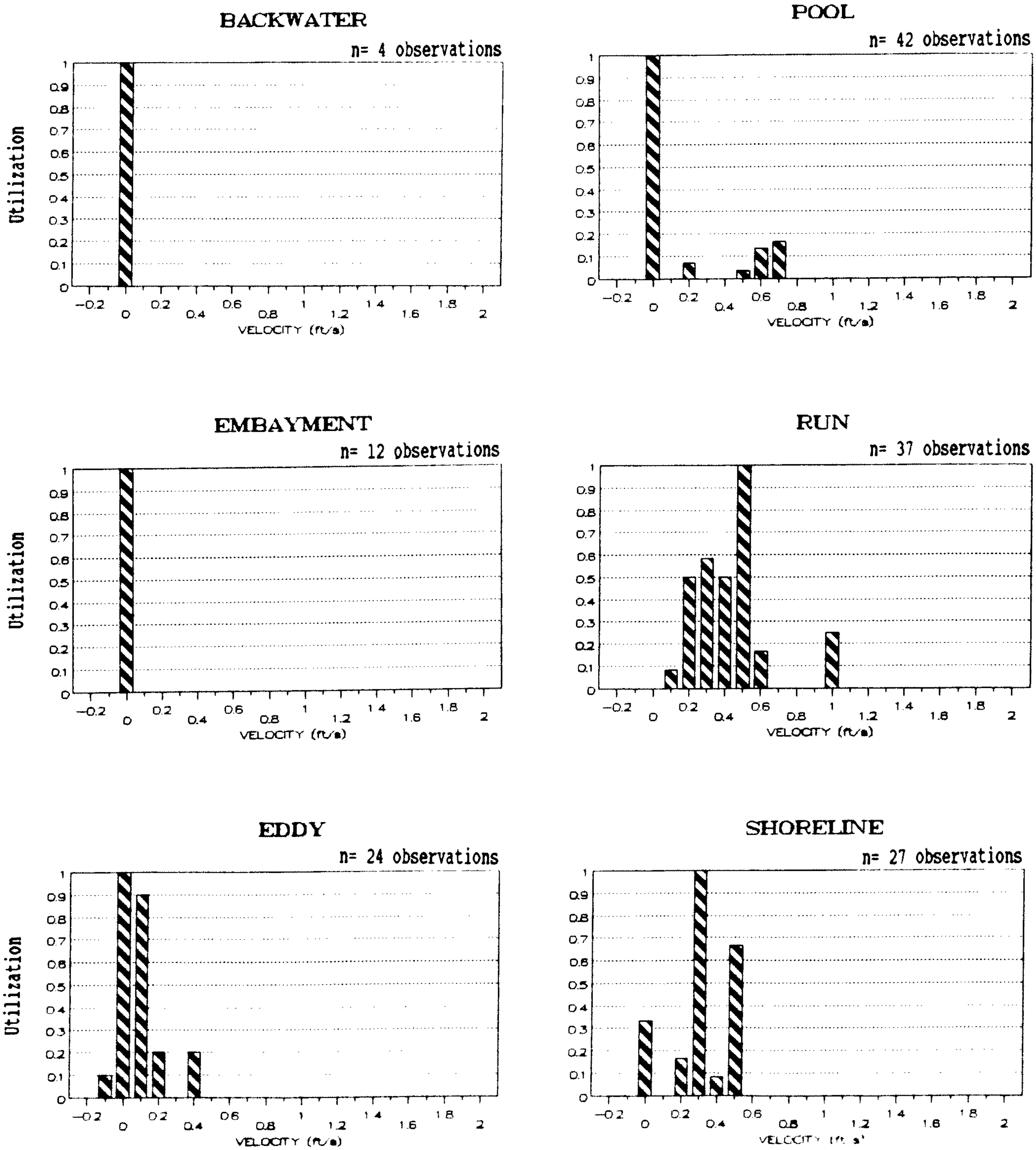


Figure 15. Velocity utilization (normalized) in each habitat by radiotagged Colorado squawfish during the fall 1987 on the Yampa River, Colorado.

Table 7. Frequency of substrate utilization within each habitat type during the winter, 1986-1987 (Winter 1). Substrate codes in Appendix B.

Substrate Code	Habitat Backwater	Eddy	Embayment	Run	Shoreline	Total
CLSI			7			7
COCL				2		2
COGR		2				2
COSA			5			5
GR	80		5	12	21	118
GRCO				8	2	10
GRSA	40		8	16	2	66
GRSI	1					1
SA	11		36	87	8	143
SACO		1	4	1		6
SAGR	6	3	10	5	2	27
SASI	8	2	16	5		31
SI	8	4	1			14
SICO		3				3
SISA			37			37
Total	155	15	130	137	36	472

Table 8. Frequency of substrate utilization within each habitat type during the winter, 1987-1988 (Winter 2). Substrate codes in Appendix B.

Substrate Code	Habitat Backwater	Embayment	Eddy	Pool	Run	Shoreline	Total
BEBE					2		2
BORU				2			2
COBO						4	4
COCO					1		1
COGR				2			2
COSI		1				3	4
GRCO		2					2
GRGR		1			2		3
GRSA		2			5		7
SABO				2			2
SACO					1		1
SAGR	1	12			1		14
SASA	1	5	2	32	43		83
SASI		1		1			2
SISA		1		2	1		4
SISI		4			1		5
Total	2	29	2	41	57	7	138

Winter 1, gravel (GRGR) was often used in backwater habitat, even though this was a zero-velocity area. In Winter 2, this substrate type was used very little, probably because the backwater area used in Winter 1 was not accessible. Substrate use was evenly distributed in the other habitat types. Sand was the predominant substrate used by fish during the fall (Table 9).

Habitat use over time

Habitat use patterns over time were examined by recording the number of observations in each study area according to habitat type used on each trip. This was done to determine if habitat use differed by study area or changed in response to season, discharge or weather conditions.

During Winter 1 in the Government Bridge study area, the majority of habitat use was in the backwater habitat at RMI 95.7. No shifts in habitat use were noted in fish using this backwater. However, the one fish not using this backwater alternated habitat use from embayment to run between January 5-10 and January 19-24 (Table 10). Use of run habitat coincided with lowest flows (250-300 cfs) and coldest winter temperatures during Winter 1 (Figure 16).

In the Maybell study area, habitat use during Winter 1 was evenly divided between embayments and runs. Again, use of run habitat coincided with low flows and cold air temperatures. Run habitat was used exclusively on January 19-24, 1987. This shift to run habitat did not appear to be related to changes in availability of habitat, since embayment areas were still accessible. Use of run habitat could be related to the presence of frazil ice. During this cold period, several squawfish were located under stationary frazil ice (0.1-4.7 feet thick), which was packed up beneath solid ice cover. Squawfish may have been attracted to habitats containing newly formed frazil ice (anchor ice broken free) because it contained or attracted food. Squawfish could feed directly on invertebrates but more likely would feed on small fish attracted to the small food items delivered by frazil ice. Turbid frazil ice often contained silt, pebbles, and aquatic invertebrates (mainly stoneflies).

In the second year of the study, biweekly habitat use patterns of squawfish were analyzed from mid September to the end of June. In early September, squawfish in the Government Bridge study area used eddy, embayment and shoreline habitat. In October through mid November run habitat was used predominantly. From late November through early December, backwater and embayment habitats were used most frequently. During this period, ice was beginning to form on these low-velocity habitats. From mid-December through ice-out squawfish were observed in run habitat almost exclusively, although other habitats were nearby and accessible. High use of run habitat in Winter 2 could be related to the generally lower flows and colder temperatures. During the spring (April-June) habitat use shifted to eddy and backwater habitat (Table 11).

During the fall, from mid-September through November, 1987, habitat use in the Maybell study area (RMI 85-80) was distributed between eddy, embayment, pool, run, and shoreline. During the remainder of Winter 2 until ice-out, habitat use alternated between embayment and run much as it had during Winter 1 (Table 11). Again, the exclusive use of run habitat appeared related to the coldest temperatures in early January and February (Figure 17). During the spring, habitat use shifted to eddy, backwater, and shoreline.

Table 9. Frequency of substrate utilization within each habitat type during the fall, 1987-1988. Substrate codes in Appendix B.

Substrate Code	Habitat Backwater	Embayment	Eddy	Pool	Run	Shoreline	Total
BEBE					16		16
BEBO				2			2
BESA					2		2
BOSA		2	2	2	2		8
COCO		1					1
COGR				1	2	1	4
COSA				5			5
GRCO				2		1	3
GRGR					1		1
GRSA		4	2			9	15
SABO			9	6			15
SACO				6	4		10
SAGR					1		1
SASA	4	4	11	18	9	16	62
SISI		1					1
Total	4	12	24	42	37	27	146

Table 10. Frequency of habitat use within each study area during the winter, 1986-1987. n= number of observations.

Government Bridge Study Area (n=220)

Date	Backwater	Embayment	Eddy	Pool	Run	Shoreline
Dec 1-8	29					2
Dec 14-18	10	10				
Jan 4-10	15				10	
Jan 19-25	25				10	
Feb 1-6	32	9				
Feb 15-20	20	10				
Feb 29-Mar 4	24					12
Mar 14-18					2	

Maybell Study Area (n=279)

Date	Backwater	Embayment	Eddy	Pool	Run	Shoreline
Dec 1-8		16	4			4
Dec 14-18		8	10		15	
Jan 4-10		16			23	
Jan 19-25					52	
Feb 1-6		20			8	6
Feb 15-20		29			8	6
Feb 29-Mar 4		12			10	6
Mar 14-18		14	10			2

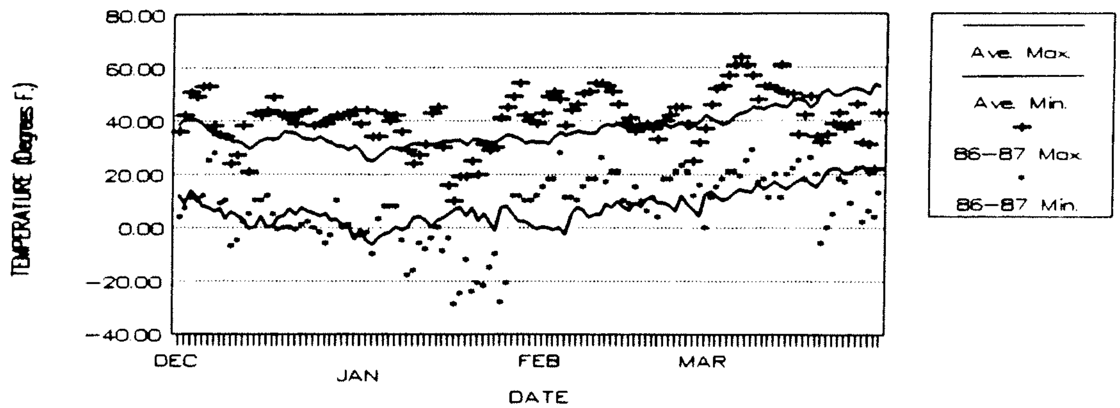


Figure 16. Average daily maximum and minimum air temperatures at Maybell, Colorado from 1958-1985, compared to daily maximum and minimum air temperatures in the winter 1986-1987.

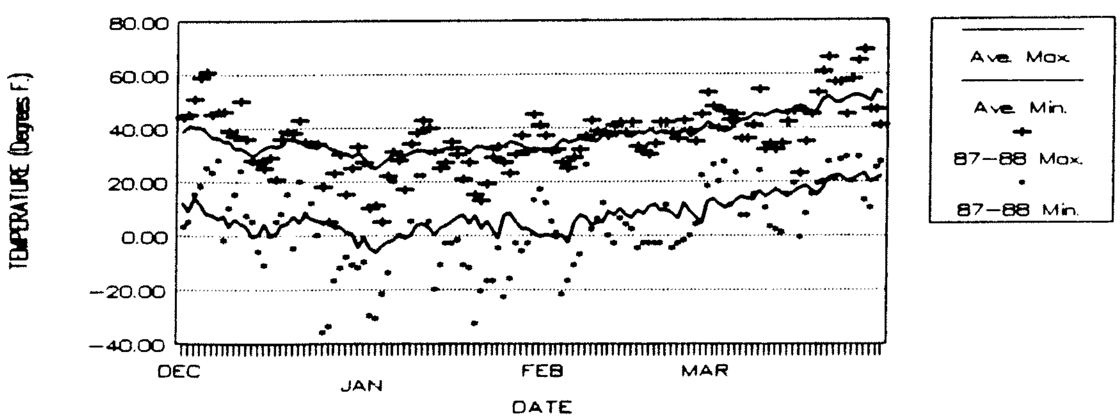


Figure 17. Average daily maximum and minimum air temperatures at Maybell, Colorado from 1958-1985, compared to daily maximum and minimum air temperatures in the winter 1987-1988.

Table 11. Frequency of habitat use within each study area during the fall, winter, and spring, 1987-1988. n = number of observations.

Government Bridge Study Area (n=83)

Date	Backwater	Embayment	Eddy	Pool	Run	Shoreline
Fall (n=49)						
Sep 21-26		2	8			12
Oct 5-9	2				16	
Oct 19-26					4	
Nov 2-7					2	
Nov 16-20	2				1	
Winter (n=29)						
Dec 1-8	2	9			2	
Dec 14-18					4	
Jan 4-10					2	
Jan 19-25					5	
Feb 1-6					1	
Feb 15-20					1	
Feb 29-Mar 4					1	
Mar 14-18					2	
Spring (n=5)						
Apr 19-21			1			
May 18-22	1					
Jun 8-12	3					

Maybell Study Area (n=125)

Date	Backwater	Embayment	Eddy	Pool	Run	Shoreline
Fall (n=61)						
Sep 21-26		4	12	2		
Oct 5-9				3	4	
Oct 19-26			2	3	2	11
Nov 2-7				4	8	
Nov 16-20		4				2
Winter (n=56)						
Dec 1-8		4				7
Dec 14-18		9			6	
Jan 4-10					6	
Jan 19-25		3			3	
Feb 1-6					6	
Feb 15-20		2			5	
Feb 29-Mar 4		2			1	
Mar 14-18					2	
Spring (n=10)						
Apr 5-8			1			
Apr 19-21	1					
May 3-5			2		1	
May 18-22	1		1			1
Jun 8-12			1			1

Table 11. continued.

Lily Park Study Area (n=99)

Date	Backwater	Embayment	Eddy	Pool	Run	Shoreline
<u>Fall</u> (n=36)						
Sep 21-26				4		
Oct 5-9				14		
Oct 19-26		2		8		
Nov 2-7				4		
Nov 16-20			2			2
<u>Winter</u> (n=53)						
Dec 1-8				2		
Dec 14-18				18		
Jan 4-10				9		
Jan 19-25				4		
Feb 1-6				2	4	
Feb 15-20				2	4	
Feb 29-Mar 4			2	4		
Mar 14-18					2	
<u>Spring</u> (n=10)						
Apr5-8			1			1
Apr19-21						1
May 3-5	1				1	
May 18-22			1			1
Jun 7-12			1			1
Jun 27				1		

In contrast to the other study areas, habitats used in Lily Park were mainly pools throughout fall and winter months. This was likely due to the large quantity and high quality of pool habitat available. Very little embayment and no backwater habitat was present in the upper portion of the study area where radiotagged fish were located. Pool habitats were exceptional in that they offered diversity of structure and depths. During the spring habitat use was mainly shoreline and eddy. Some backwater habitat was used in the lower portions of the study area, however this habitat type was not accessible on a regular basis due to fluctuating water levels. Pool habitat was used by one squawfish in late June after runoff flows subsided. Apparently this fish did not migrate to the spawning area.

Depth utilization over time

Depth utilization was analyzed for each bi-weekly trip and habitat group (Appendix D). Both effective depth (ice-free water under all forms of ice cover) and total depth (water plus ice) were compared to determine the extent of ice cover and better evaluate water surface elevation and discharge requirements. Habitats were grouped into backwater and embayment (BA EM), run and shoreline (RU SH), and eddy and pool (ED PO). In many cases it was difficult to distinguish between the two types in each group in the field, especially under ice and snow. For this reason, they were grouped for analysis.

Comparison of depths used between years showed that depths used in all habitat categories decreased in Winter 2, which had lower winter flows (Table 12). The average mean monthly flow during ice cover in Winter 1 was 396 cfs, compared to 241 cfs in Winter 2.

Some effect on depth utilization can be expected from variation in discharge levels between the two years. However, depth utilization was fairly consistent for BA EM and RU SH habitats considering the magnitude of differences in discharge between years. The major differences in discharge between years occurred in the early and latter portions of the winter. Discharges during January through mid-February were on average only 100 cfs higher during Winter 1. This difference could translate into as much as a foot difference in water surface elevation. Depth utilization by squawfish did not reflect this potential difference in BA EM and RU SH habitats. The comparatively high difference in depth utilization in ED PO habitats between years could be misleading. Most data gathered during Winter 1 in eddy habitat were from one fish in a deep eddy at RMI 76.2 and includes no pool habitat. During Winter 2, most pool habitat data were from the Lily Park area where fish used a wide variety of depths in pool habitat. Squawfish utilized shallow pools at the head of riffles and a large pool at RMI 53.3, which had a large, centrally located, submerged, sand bar deposit.

The bi-weekly means of each habitat group from Appendix D were averaged for the winter period with ice cover (Table 12). This approach gives each trip equal weight and reflects depths on average that one would expect squawfish to utilize in each habitat group throughout the period of ice cover for both years combined. Ranges reported in Table 12 are for bi-weekly means, not the overall range of depths utilized. Depth utilization was different between habitat types. Shallowest depths used were in embayments and backwaters and deepest depths used were in eddies and pools. Comparison of differences between mean effective and total depths in each category shows

Table 12. Average effective and total depth used by Colorado squawfish within each habitat group on the Yampa River, Colorado, 1986-1987 (Winter 1) and 1987-1988 (Winter 2).

Habitat Group	Mean Effective Depth (FT)	Range of Effective Depths	Mean Total Depth (FT)	Range of Total Depths
Both winters combined				
BA EM	2.0	(0.5-3.3)	3.2	(2.0-5.0)
RU SH	2.4	(1.1-4.3)	3.9	(2.5-5.1)
ED PO	3.3	(1.0-7.1)	5.7	(2.0-10.5)
Winter 1				
BA EM	2.2	(1.4-2.7)	3.4	(2.7-4.1)
RU SH	2.4	(1.1-4.3)	4.1	(3.2-5.1)
ED PO	6.8	(6.6-7.1)	7.1	(6.6-7.7)
Winter 2				
BA EM	1.8	(0.5-3.3)	3.0	(2.0-5.0)
RU SH	2.3	(1.5-3.2)	3.6	(2.5-5.0)
ED PO	2.7	(1.0-5.5)	5.3	(2.0-10.5)

Habitat Codes:
BA = backwater
EM = embayment
ED = eddy
PO = pool
RU = run
SH = shoreline

that ice thickness (including frazil) was greatest in pools and eddies (mainly pools).

In spite of differences in flow, the maximum normalized value for depth in BA EM habitat was consistent at 2 feet for 8 of 12 trips in which these habitats were used during both winters (Appendix D). This indicates a preference for this depth in these habitat types, especially since a wide range of depths was available. Effective depth tended to remain constant during Winter 2 because as water surface elevation increased with increased discharge, the ice thickened.

Analysis of RU SH data showed that shallower shoreline habitat was used most frequently early and late in the winter. Squawfish moved into the shoreline areas at ice formation, possibly to take advantage of the cover ice provided. The advantage of this behavior may decrease as winter progresses. Use of shallow shoreline areas also increased just prior to ice-out in Winter 1. Fish could have been seeking the comparatively low velocities in response to higher discharges during this time. Depth utilization in run habitat was greater in mid-December than during January and early February.

Velocity utilization over time

Biweekly means for velocity (Appendix E) were averaged for both years for the period during ice cover. This gave equal weight to each trip and reflected average velocities utilized most frequently throughout the winter. Averages were calculated for each habitat group. Therefore, velocities reported in this section differ from overall averages reported previously for each separate habitat type. Negative velocities were converted to positive values for calculation since the negative sign only indicated flow direction.

Comparisons of velocities used between years showed that both means and ranges utilized in run habitat were higher in Winter 1, a higher-flow year (Table 13). Velocities reported for the ED PO category were mostly from eddy habitat in Winter 1 and pool habitat in Winter 2, explaining differences in this category. As mentioned in the discussion of depth, velocity differences between years were not very large considering the magnitude of flow differences.

There were slight velocity differences between habitat groups. Lowest average velocity was observed in BA EM habitats. This is expected since these habitats tend to be off-channel habitats with no velocity inside and only marginal velocity along their interfaces with the main channel. Embayments have larger interfaces with the main channel than backwaters and have more of an eddy effect at their lower ends where velocities are usually slightly above zero. The next highest average velocity was from ED PO habitat. Eddy velocity was mostly negative, but some positive or zero velocity was present along the eddy and run interface. RU SH had higher velocities than other habitat groups. Most of these observations were from run habitat.

Squawfish shifted from run to shoreline habitat in Winter 1 during higher discharges (Appendix E). As discharge increased in Winter 1, the range and means of velocities used increased. In Winter 2, velocities used were much more consistent in RU SH habitats, reflecting the comparatively stable flows in Winter 2. RU SH, in addition to having the highest average velocity, also had the greatest range of velocities on each trip. In general, squawfish showed preference for low-velocity habitat and appeared to prefer a velocity range between 0.2 to 1.0 ft/s in run habitat.

Table 13. Average velocities used by Colorado squawfish within each habitat group on the Yampa River, Colorado, 1986-1987 (Winter 1) and 1987-1988 (Winter 2).

Habitat Group	Mean Velocity	Range of Average Velocities
Both winters combined		
BA EM	0.1	(0.0-0.2)
RU SH	0.5	(0.1-1.0)
ED PO	0.2	(0.0-0.5)
Winter1		
BA EM	0.1	(0.0-0.2)
RU SH	0.6	(0.3-1.0)
ED PO	0.1	(0.0-0.2)
Winter 2		
BA EM	0.0	(0.0-0.1)
RU SH	0.4	(0.1-0.7)
ED PO	0.3	(0.0-0.5)

Habitat Codes:
BA = backwater
EM = embayment
ED = eddy
PO = pool
RU = run
SH = shoreline

Northern pike observations (Winter 1)

During fall and winter of the first year of the study, seven northern pike were radiotagged. Observations were made on these fish only while we were radiotracking squawfish. We did not search for pike until we located a squawfish. Using this procedure we encountered four of the seven northern pike in areas used by squawfish. Northern pike used similar habitat types as squawfish during the winter months. However, northern pike and squawfish were not observed to remain in close proximity (within 5 m) of each other although they were in the same habitat type. Squawfish were observed to remain in very close proximity to each other on several occasions. Like squawfish, northern pike remained in specific river segments during the winter and were locally active (moving about within and between habitats in their preferred river segments). Northern pike used backwater, embayment and shoreline habitat. Mean total depths selected in backwater and embayment habitats were 3.7 and 3.5 feet respectively. This compared to 3.4 foot average total depth selected by squawfish for these habitat types. Mean velocity utilized by northern pike in these habitats was 0.05 ft/s ranging between 0.0 and 0.4 ft/s. This compared to a mean of 0.1 ft/s and a range of 0.0 to 0.2 ft/s. On occasions when squawfish and pike were observed using the same backwater or embayment habitat type, squawfish often used the shallower inside portions with gravel substrates, while the pike remained out in slightly deeper areas with silt and sand substrates.

Radiotracking of northern pike was conducted to add assurance that the behavior and habitat observations made on Colorado squawfish were not being influenced by the presence of northern pike. Our observations indicated that squawfish behaved in a similar manner regardless of the presence of radiotagged northern pike. This requires the assumption that additional northern pike were not present to influence behavior. Intensive fall sampling of study areas made the presence of additional pike unlikely. More detailed information on northern pike behavior and habitat use during the entire study is available from the Colorado Division of Wildlife, Aquatic Research Group, Fort Collins, Colorado.

Winter flow determinations and recommendations

Stage discharge relationships with ice cover

During Winter 2, the relationship between stage and discharge was investigated by comparing water surface elevation change to changes in discharge. Results of main-channel measurements at RMI 81.1 are presented in Figures 18a-g. The lowest discharge measured was 142 cfs on December 15, and the highest was 340 cfs on March 3. As the winter progressed, flows tended to increase, as did water surface elevations until March 15. Discharge decreased only 10 cfs from the previous trip, but water surface elevation dropped 0.4 feet.

Similar comparisons were made for an embayment adjacent to the cross section at RMI 81.1 (Figures 19a-g). Ice thickness increased from 0.85 feet December 15 to 2.12 feet March 15. Water surface elevations increased throughout the winter compensating for the corresponding increase in ice thickness, resulting in relatively stable effective depth. Effective depth

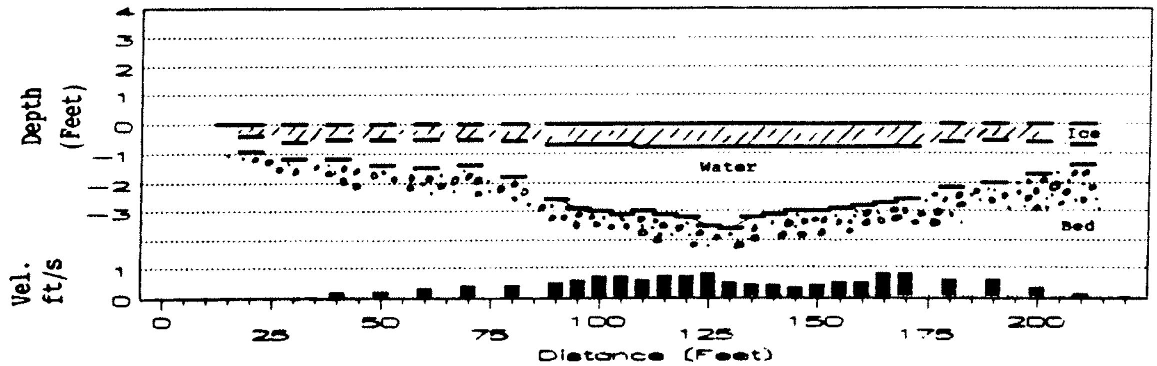


Figure 18a. Main channel transect at RMI 81.1, December 15, 19877. Discharge was 142 cfs. Water surface elevation, based on benchmarks located on site, was arbitrarily established at 0 to coincide with this lowest observed flow level.

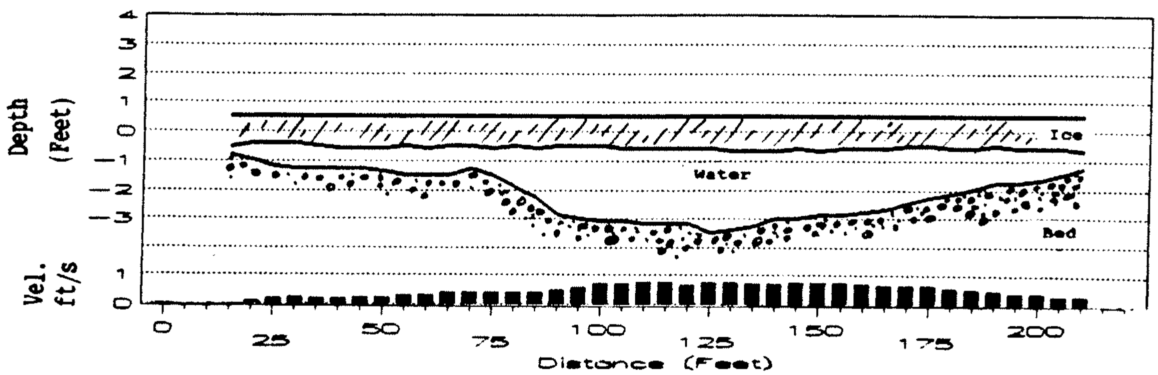


Figure 18b. Main channel transect at RMI 81.1, January 7, 1988. Discharge was 175 cfs. Water surface elevation increased 0.53 feet compared to base level established December 15, 1987 (at 142 cfs).

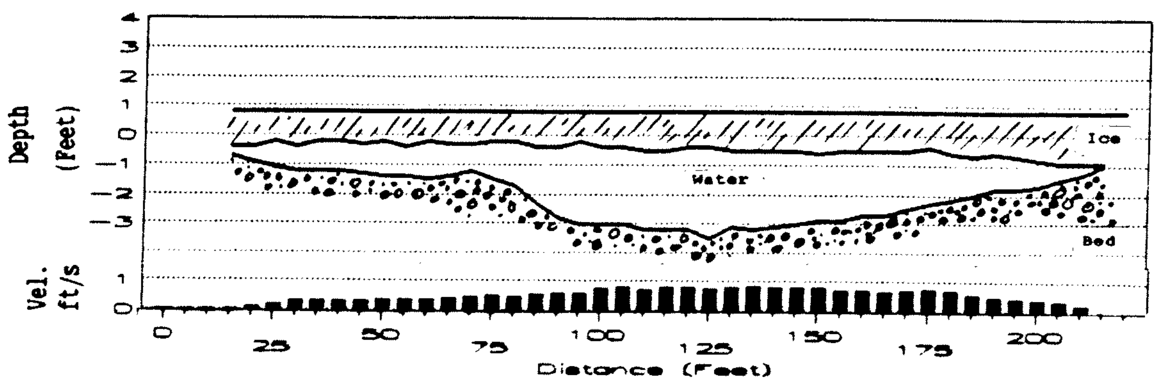


Figure 18c. Main channel transect at RMI 81.1, January 22, 1988. Discharge was 197 cfs. Water surface elevation increased 0.79 feet compared to base level established December 15, 1987 (at 142 cfs).

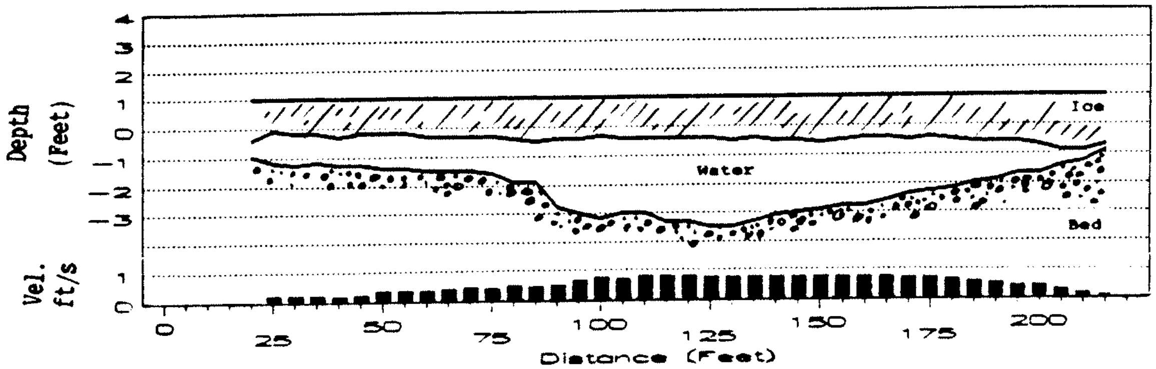


Figure 18d. Main channel transect at RMI 81.1, February 3, 1988. Discharge was 197 cfs. Water surface elevation increased 1.02 feet compared to base level established December 15, 1987 (at 142 cfs).

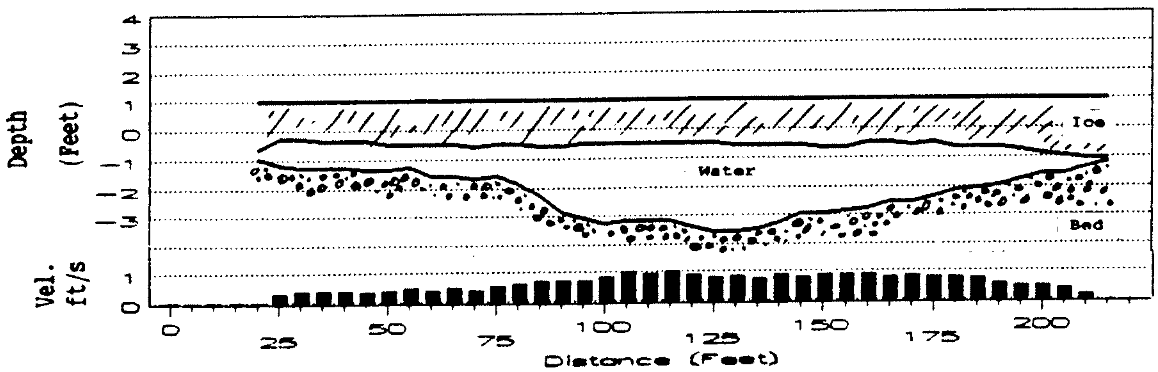


Figure 18e. Main channel transect at RMI 81.1, February 17, 1988. Discharge was 229 cfs. Water surface elevation increased 1.04 feet compared to base level established December 15, 1987 (at 142 cfs).

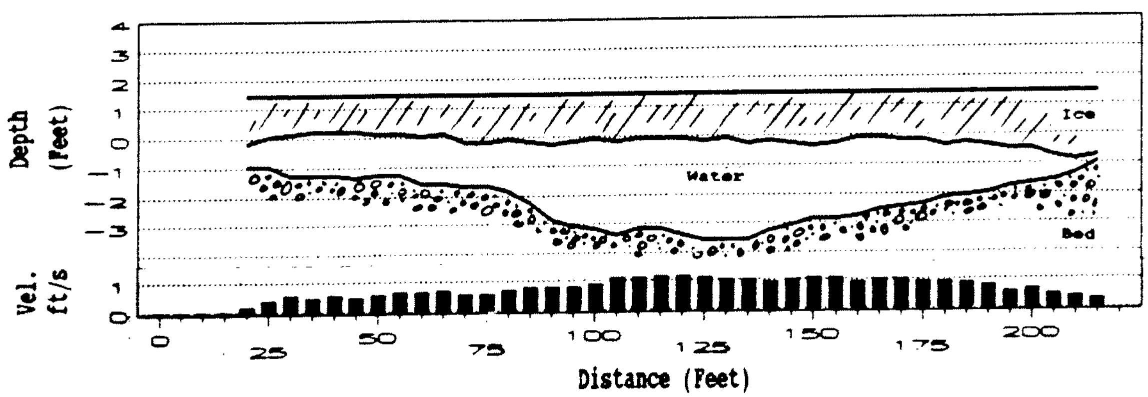


Figure 18f. Main channel transect at RMI 81.1, March 2, 1988. Discharge was 340 cfs. Water surface elevation increased 1.44 feet compared to base level established December 15, 1987 (at 142 cfs).

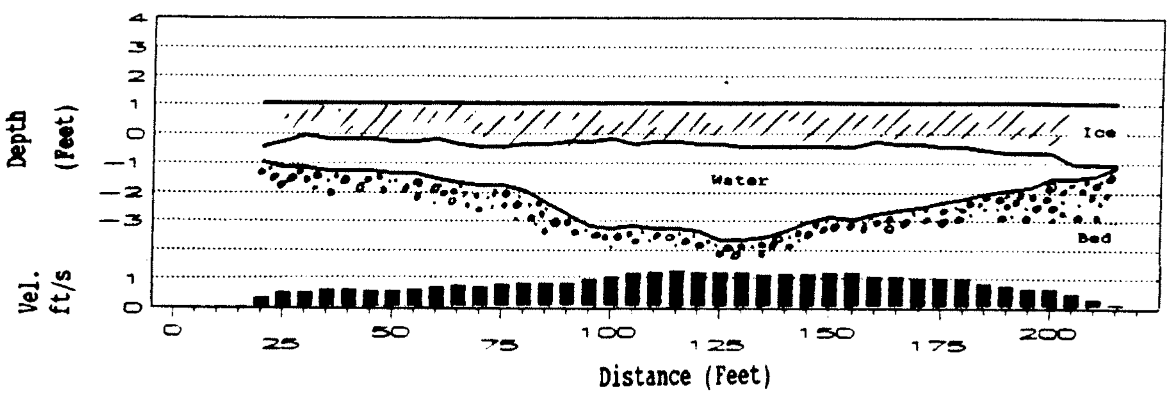


Figure 18g. Main channel transect at RMI 81.1, March 15, 1988. Discharge was 175 cfs. Water surface elevation increased 1.05 feet compared to base level established December 15, 1987 (at 142 cfs).

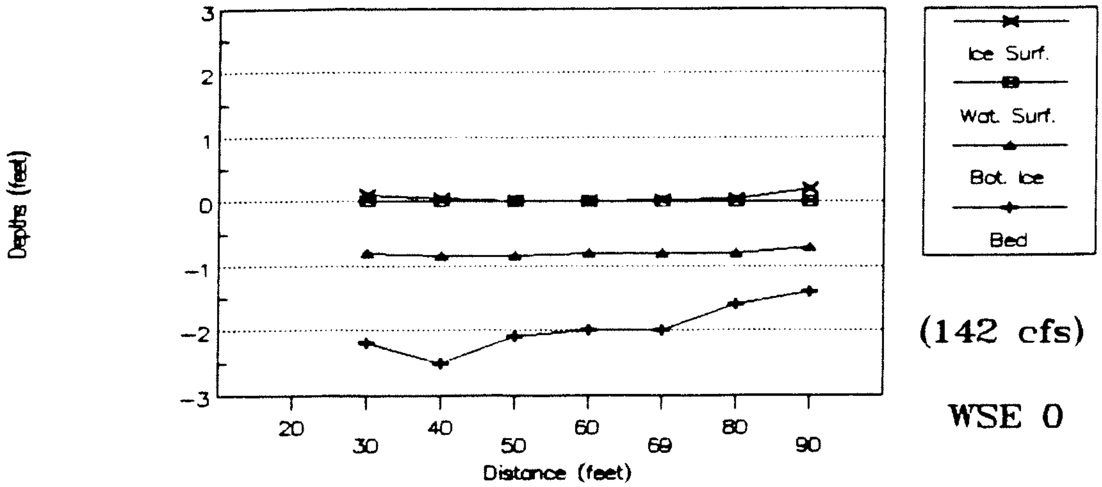


Figure 19a. Transect across embayment mouth at RMI 81.1, December 15, 1987.

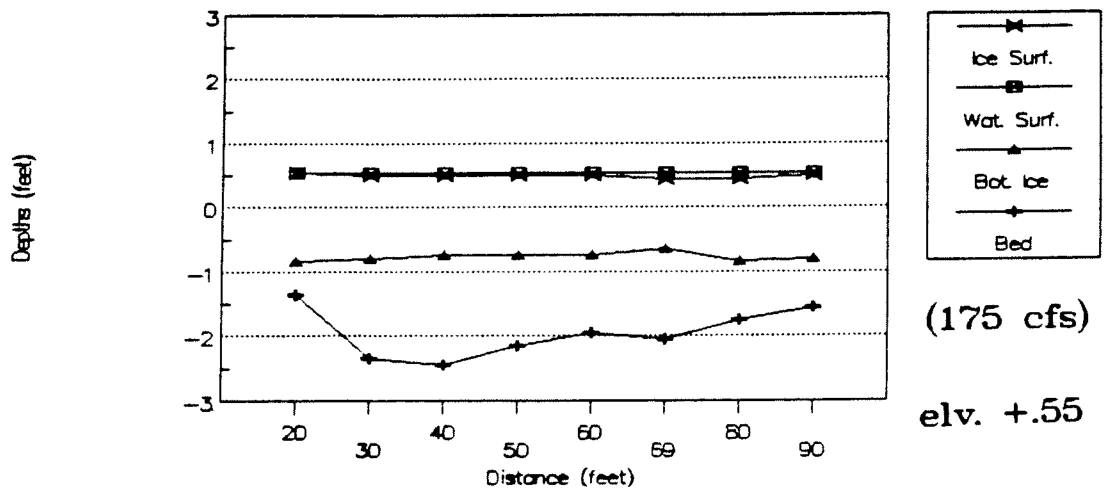


Figure 19b. Transect across embayment mouth at RMI 81.1, January 7, 1988.

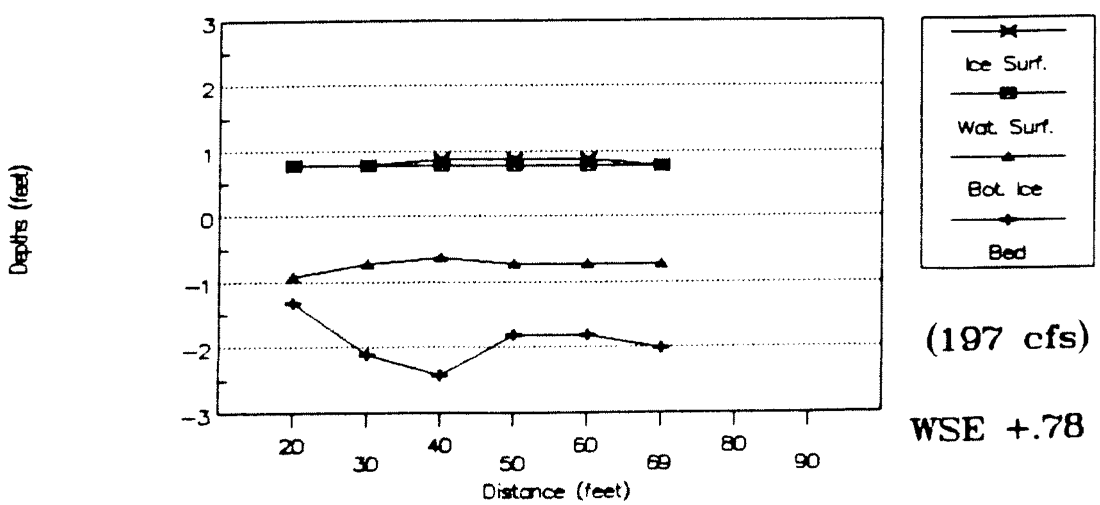


Figure 19c. Transect across embayment mouth at RMI 81.1, January 22, 1988.

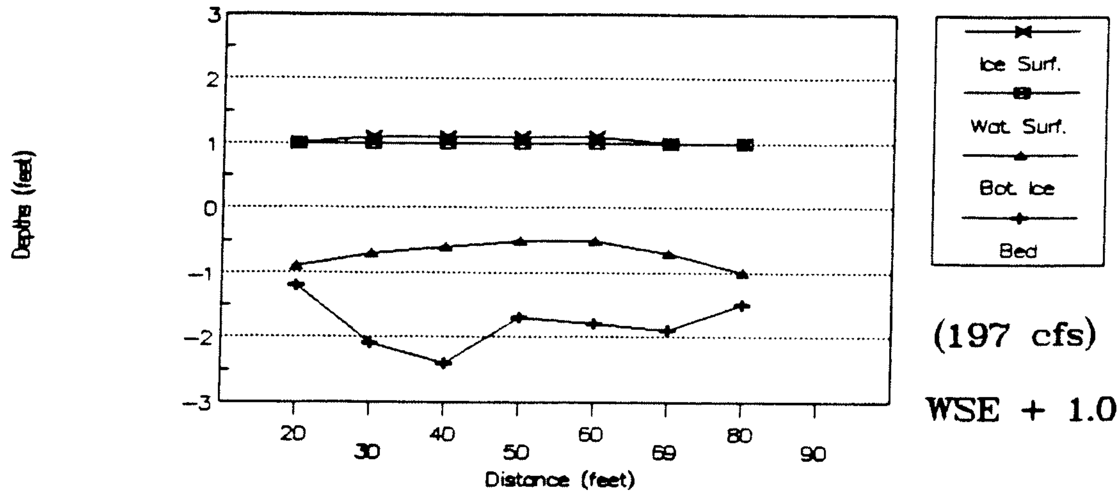


Figure 19d. Transect across embayment mouth at RMI 81.1, February 3, 1988.

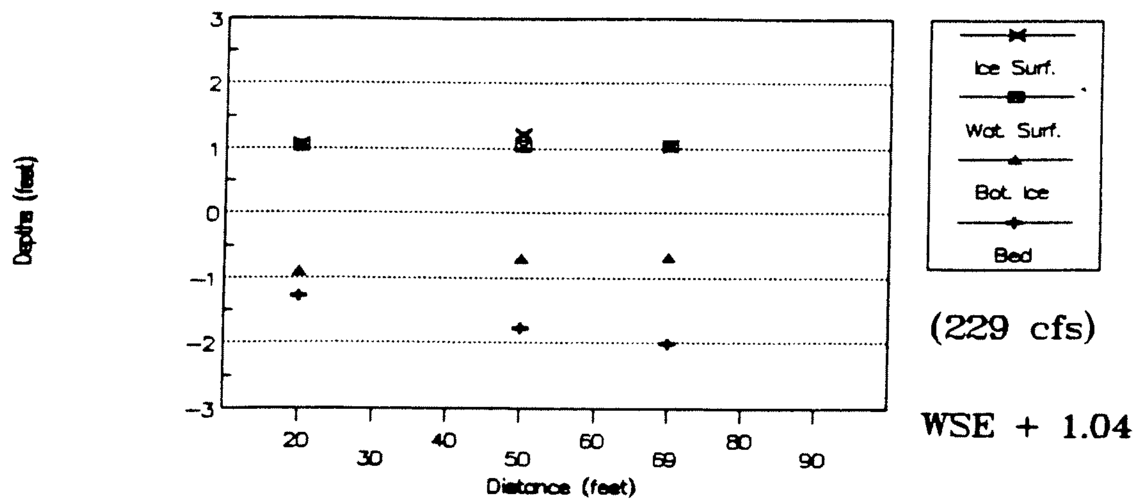


Figure 19e. Transect across embayment mouth at RMI 81.1, February 17, 1988.

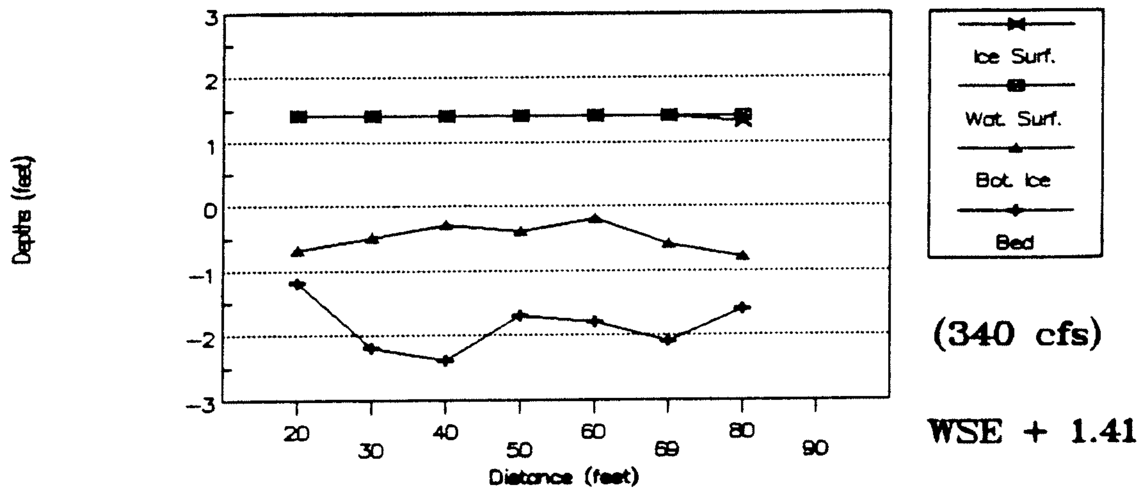


Figure 19f. Transect across embayment mouth at RMI 81.1, March 2, 1988.

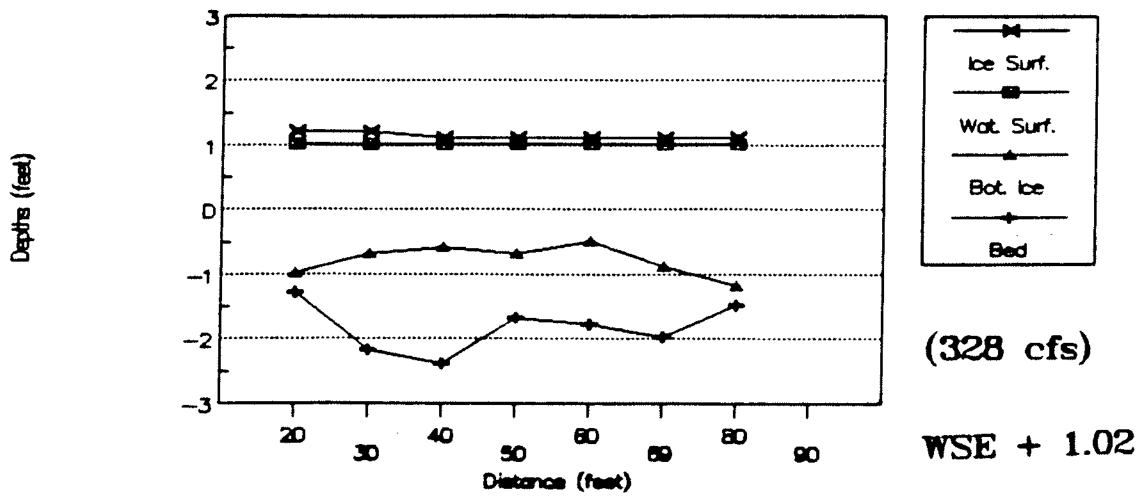


Figure 19g. Transect across embayment mouth at RMI 81.1, March 15, 1988.

varied only 0.1 foot between December 15 and February 17. In early March, effective depth increased 0.3 foot in response to the 340 cfs discharge, then decreased dramatically by March 15, just prior to ice-out. This decrease in effective depth was due to a drop in stage and bed changes resulting from increased water velocities along shorelines.

These stage-discharge relationships demonstrate several interesting effects of different ice conditions throughout the winter period. As initial freeze-up occurs, shoreline ice (Appendix F) forms along the edge of the river. This has the effect of reducing discharge while increasing water surface elevation (because cross sectional area is reduced at controls). For example, the stage height based on the benchmark at RMI 81.1 under ice-free conditions was 90.61 feet at a discharge of 236 cfs. Stage height at the same location under ice conditions on February 7, 1988 was 91.77 feet at 229 cfs (over one foot higher). Another set of measurements showing ice effect was a comparison where stage height was identical for two drastically different discharges. The maximum stage height measured under winter ice conditions was 92.14 on March 2, 1988, at a discharge of 340cfs. On April 6, just after ice-out, an average daily discharge of 1450 cfs resulted in the same stage elevation of 92.14 feet.

As the winter progressed during the second year of the study, both stage and flows increased. The increase in discharge throughout the winter in spite of relatively cold temperatures may have been due to heavy snows in the high country and at lower elevations. Once deep snows build, their insulating effect allows some runoff and maintenance of subsurface flows, thus maintaining winter discharge levels.

Normally, on larger streams like the Yampa, the ice cover is in floatation (Rantz 1982). There is no great buildup of pressure as a result of ice cover. As stage increases or ice thickens, the increased upward force of the water causes tension cracks in the ice, usually near the banks. The ice floats up to a position of equilibrium, and water fills the tension cracks and freezes, again forming solid ice cover. This same procedure occurs if stage drops, the weight of the unsupported ice causes tension cracks along the banks and the ice falls to an equilibrium position with the water. Under extremely cold conditions, heavy surface ice in contact with the stream may resist this state of equilibrium causing flow conditions to more closely resemble a closed-conduit. In mid-February, small increases in discharge (197 to 229 cfs) were not sufficient to raise the level of the ice. The cross sectional area remained fixed like a closed-conduit, resulting only in an increase in velocity. When air temperature warms and discharge fluctuates, ice tensions may increase enough to cause a return to the state of equilibrium. This was observed between January 22 and February 3, when stage increased but discharge remained the same.

Just as the process of ice formation throughout the winter has the effect of increasing stage at a given discharge, the ice-out process can have the opposite effect (Appendix F). This was demonstrated in measurements taken between March 3 and March 15 (Figure 18 a-g). With only a 10 cfs decrease in discharge, stage was reduced by 0.4 feet. This was likely due to loss of shoreline ice at the controls. As air temperatures warm considerably in March and flows increase, ice begins to melt along the banks. This results in an increase in water flowing along the river's edge, loss of the damming effect of the shore ice, and reduction of stage at a given flow.

The ice-out period can be a critical time for some fish because their low-velocity winter habitats are losing effective depth and being invaded by flowing water. Bed changes can also occur as sediments are moved by shifting currents (Figure 19a-g). Fish could be trapped or crushed during this critical time. We noticed that fish appeared to move around more at this time, perhaps as a response to ice-out conditions.

Ice-out can be a violent event. Temporary ice jams can quickly raise water levels several feet. When these jams break up, high flows can sweep through areas changing channel beds. Large slabs of ice tilt up on end and scrape along the river bottom. Severity of ice-out conditions varies considerably between river reaches. Immediately after ice-out in Winter 1, dramatic channel bed changes occurred at the backwater at RMI 95.7. Large amounts of gravel were pushed into the upper end of the backwater, and large pieces of ice were deposited over the gravel bar. All three of the fish that used this backwater during the winter were located downstream after ice-out. However, at the embayment at RMI 81.1 little change was noted and very little ice was deposited in the area. Radiotagged fish remained in the embayment area during ice off.

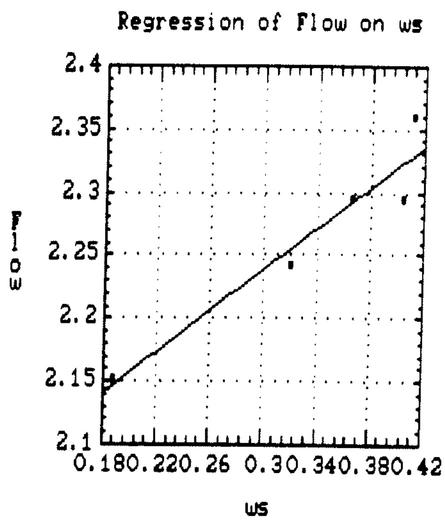
Stage vs discharge predictions with ice cover

Regression analysis was performed on stage (water surface - zero flow elevation) and discharge data according to methods outlined by Bovee and Milhous (1978). Comparisons were made of regressions using two sets of data. Values for the coldest portion of the winter from mid-December until mid-February (Figure 20) were compared to the data set including the warmer, high-discharge period of early March (Figure 21).

Preliminary results using both data sets indicate that the expected loss in stage elevation at RMI 81.1 would be about 0.2 feet for every 20 cfs reduction in discharge (Tables 14 and 15). If discharge were reduced from the lowest measured flow of 142 cfs to 75 cfs, about 0.7-foot reduction of stage elevation would occur. These predictions are based on measurements of the water surface elevation that would occur at zero flow, which would amount to a reduction of stage elevation of 1.54 feet. These relationships are specific to the hydraulic conditions that exist at RMI 81.1. Flow reductions in other river segments could result in different stage elevation changes. As a general rule wider river reaches would have smaller elevation changes than narrow river segments.

Applicability of PHABSIM

At the inception of this project, it was assumed that the Instream Flow Incremental Methodology (IFIM) (Bovee 1981) and Physical Habitat Simulation (PHABSIM) (Milhous et al. 1984) model would be used to determine suitable winter flow regimes. It became apparent that this approach would not be appropriate after observing fish behavior patterns and the complications of ice effect. Since no standardized or proven method for determining adequate winter flows were available, methods used in this report were developed based on recommendations from professional biologists and hydrologists.
Assumptions of the PHABSIM methodology were outlined by Orth (1982): (1) depth, velocity, and substrate are the most important habitat variables affecting fish distribution and abundance when changes in flow regime are considered; (2) the stream channel is not altered by changes in flow regime;



Simple Regression of Flow on ws

Parameter	Estimate	Standard Error
Intercept	1.99582	0.0489216
Slope	0.807316	0.140708

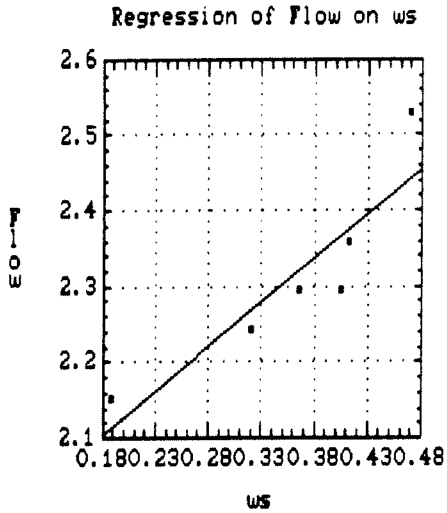
T Value	Prob. Level
40.7964	3.24091E-5
5.73754	0.010513

Correlation Coefficient = 0.957329
Stnd. Error of Est. = 0.0257924

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio
Model	.021[illegible]	1	.021899	32.919375
Error	.0019957	3	.0006652	
Total (Corr.)	.0238952	4		

Figure 20. Regression of log flow on log of water surface elevation minus zero-flow water elevation at RMI 81.1 using bi-weekly flows December 15, 1987-February 17, 1988.



Simple Regression of Flow on ws

Parameter	Estimate	Standard Error
Intercept	1.89359	0.107415
Slope	1.1636	0.289654

T Value	Prob. Level
17.6288	6.08139E-5
4.01722	0.015901

Correlation Coefficient = 0.895193
Stnd. Error of Est. = 0.063528

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio
Model	.065130	1	.065130	16.138067
Error	.0161432	4	.0040358	
Total (Corr.)	.0812733	5		

Figure 21. Regression of log flow on log of water surface elevation minus zero-flow water elevation at RMI 81.1 using bi-weekly flows December 15, 1987-March 2, 1988.

Table 14. Stage discharge data for embayment habitat Yampa River, RMI 81.1 during ice cover.

Date	Discharge (cfs)	WSE(S) (feet)	Log Discharge	Log (S-Z)	WSE Change from 142 cfs
Sep 30, 88	0(Sim)	89.19(Z)			-1.54
Dec 15, 87	142	90.73	2.152	.1875	0.0
Jan 7, 88	175	91.28	2.243	.3201	+.55
Jan 22, 88	197	91.51	2.294	.3654	+.78
Feb 3, 88	197	91.73	2.294	.4048	+1.0
Feb 17, 88	229	91.77	2.360	.4116	+1.04
Mar 2, 88	340	92.14	2.531	.4698	+1.44
Mar 15, 88	328	91.75	2.516*	.4065*	+1.02
Apr 6, 88	1450**	92.14			+1.44
Sep 30, 88	236**	90.61			-.12

WSE = Water surface elevation
SIM = Simulated
Z = Water surface elevation at zero flow, measured at lowest point on bed of crossing bar 0.5 miles below transect.
* = These data not included in regression analysis because of the loss of ice along shoreline.
** = Measurements made under ice free conditions.
cfs = cubic feet per second.

Table 15. Predictions of stage at reduced discharge on the Yampa River at RMI 81.1

	Dec 15- Feb 17 Data		Dec 15- Mar 2 Data		
Discharge (cfs)	WSE (feet)	Elevation change from 142 cfs	WSE (feet)	Elevation change from 142 cfs	Average Elevation change from 142 cfs
120	90.45	-0.28	90.64	-0.19	-0.19
100	90.20	-0.53	90.42	-0.31	-0.42
75	89.90	-0.83	90.14	-0.59	-0.71
50	89.62	-1.11	89.87	-0.86	-0.99
25	89.37	-1.36	89.56	-1.17	-1.27
5	89.21	-1.52	89.28	-1.45	-1.49

142 cfs =lowest measured discharge used as stage base 0.
WSE = Water surface elevation.
WSE is based on benchmarks established at transect site RMI 81.1.

(3) depth, velocity, and substrate are independent in their influence on habitat selection by fishes (this assumption allows one to calculate the composite weighting factor as the product of individual weighting factors); (4) the stream can be modeled on the basis of one or more representative sample reaches; and (5) there is a positive, linear relationship between weighted usable area and fish standing stock or habitat use. Major criticisms of PHABSIM have concentrated on the lack of evidence that fish biomass responds to the weighted usable area (WUA) component in the model (Mathur et al. 1985). If this is true, population responses in terms of standing crop or biomass cannot be predicted based on flow alterations (Orth 1987). Due to the complexity and irregularity of natural stream ecosystems, inability to make accurate predictions using a model should not be surprising (Behnke 1987).

Attempts to apply PHABSIM to quantify flow requirements of various life stages of Colorado squawfish have not met with great success. A major problem is that habitats used by Colorado squawfish are difficult to model. Backwaters, embayments, and eddies are slackwater or reverse-current habitats. These habitats have to be included in the modeling process for meaningful predictions to be made. This has not been done because of the high cost of placing multiple transects at a large number of sites based on habitat use patterns for various life stages at different times of year.

Perhaps the main objective of applying Instream Flow Incremental Methodology (IFIM) should be to quantify flows needed to maintain specific habitats important to Colorado squawfish at critical times of the year. The PHABSIM model of IFIM should be used with caution. The WUA calculation assumes that various combinations of depth, velocity, and substrate provide adequate habitat regardless of the habitat type in which they are located. For large streams, Moyle and Baltz (1985) recommended that field data be weighted to reflect proportional habitat composition of the stream reach. Because Colorado squawfish utilize a high percentage of zero velocity water at shallow depths, WUA is often maximized at extremely low flow levels if only depth, velocity, and substrate variables are used without some type of habitat qualification. A given amount of WUA in the main channel is not necessarily the ecological equivalent of the same area in backwater habitat - even if depth, velocity, and substrate are the same. These problems relate to this study because the IFIM site at Government Bridge does not represent the high percentage of backwater and embayment habitats used during winter months. In addition to the above difficulties in recommending flows, complex problems created by different forms of river ice negate the possibility of standard application of PHABSIM techniques.

USGS winter flow records

Winter discharge measurements recorded at the USGS gaging station near Maybell, Colorado, were used during Winter 1 to provide a record of flow conditions during the study period. Close examination of these records indicated that these data were not accurate enough to establish a reliable stage-discharge relationship for the purposes of this study. The relationship between gage height and discharge established during open water conditions is compromised during the winter. Accuracy of discharge readings at gaging stations is decreased considerably because the stage discharge relationship becomes indeterminate. Various forms of ice at downstream controls, including periodic ice jamming and release, act to raise or lower water surface elevations at the gage. These elevation changes caused by ice effect can translate into either higher or lower discharges than are actually occurring. Ice-affected flow readings were adjusted by USGS hydrologists by comparing various data sources. Actual flow measurements were made near gaging stations at least twice each winter, usually at initial ice formation in December and again in February. These known discharges were compared with weather data (air temperature and precipitation) and flow data collected at other gaging stations to correct discharge data for the winter period. Adjusted discharge data for the winter were as accurate as possible given the extremely variable ice conditions present when it was collected. Accuracy could be improved by more frequent actual field discharge measurements. However, at the present time neither the funds nor demand exists for more accurate winter discharge data. Because the total water discharged in the winter is small compared to the rest of the year, any flow calculation error during winter is relatively small. We worked closely with USGS during the second year of the study to insure that our discharge measurements were made correctly. Our data was incorporated into the USGS data base in 1988 to aid in correcting final winter discharge records. If additional winter flow impacts are expected in the future as a result of dam construction, funding should be made available to increase field flow measurements during the winter to improve the accuracy of winter discharge records. For greater accuracy, gaging stations should be checked at least twice monthly to correct for ice effect. The only way to be certain of discharge and water surface elevation relationships at a particular time is to make actual discharge and water surface elevation measurements. This relationship will change as the winter progresses and ice thickness changes.

<u>Ecological considerations of winter stream flow</u>

In planning strategy to determine winter flows, consideration should be given to all the primary factors that influence the structure and function of the stream ecosystem (Orth 1987). Karr and Dudley (1981) outlined the following primary factors: (1) energy source (sediment inputs, particulate organic matter, and nutrients); (2) water quality; (3) temperature; (4) physical habitat structure (channel form, substrate distribution, and riparian vegetation); (5) flow regime; and (6) biotic interactions.

Obviously, detailed analysis of all these factors could not be undertaken in this study. However, consideration of these factors is helpful in determining which habitats may be important to maintain. Micro-habitat use patterns of squawfish should be examined in light of these factors to determine additional beneficial aspects to the system of a particular habitat type. Other logical criteria that could be used to prioritize habitats that should be examined for effects of altered flow include: (1) vulnerability to low flows, (2) natural availability in the ecosystem, and (3) stability of habitat.

Recommendations regarding winter flows

A key flow consideration during the winter should be maintaining natural conditions of annual variability and steady discharge with little fluctuation during the mid-winter period. Flows levels may be different from year to year going into the winter period depending on the snowpack the previous winter and fall precipitation. However once winter sets in, flows have been historically stable during mid-winter (Figure 22). In addition, any proposed alterations in flows during the winter should be analyzed with respect to the portion of the winter in which they may occur. Effects will be different due to current ice conditions, air temperature, precipitation, and discharge. Reductions below natural baseflow at initial ice formation should be avoided. At this time actual discharge is already decreasing because water is being tied up in ice formation. Maintaining natural flows during the initial freeze period in late November or early December would insure that ice cover forms over the maximum amount of usable winter habitat in a given flow year. A key flow consideration during mid-winter is maintaining the natural conditions of steady discharge with little fluctuation. Flows normally do not fluctuate more than 140 cfs above or below the annual mean during the period from mid-December through February (Figure 22). It is important to avoid unnatural discharge fluctuations that could remove natural ice cover. Overall system productivity will probably be best maintained by providing adequate water levels in a variety of low-velocity habitats (embayments, backwaters, pools and runs) that squawfish utilize during the winter. During Winter 2, this diversity appeared to be best maintained in the 200-300 cfs flow range during the mid-winter period. Flows below this range would result in less than optimum depth in preferred embayment habitat, while higher flows flood and eliminate these habitats. The ice-out period, which usually occurs in March, can be the most critical part of winter. During this time, water surface elevations and effective depth decrease even though discharge is maintained. Therefore, any reductions in flow should be avoided until ice is completely out.

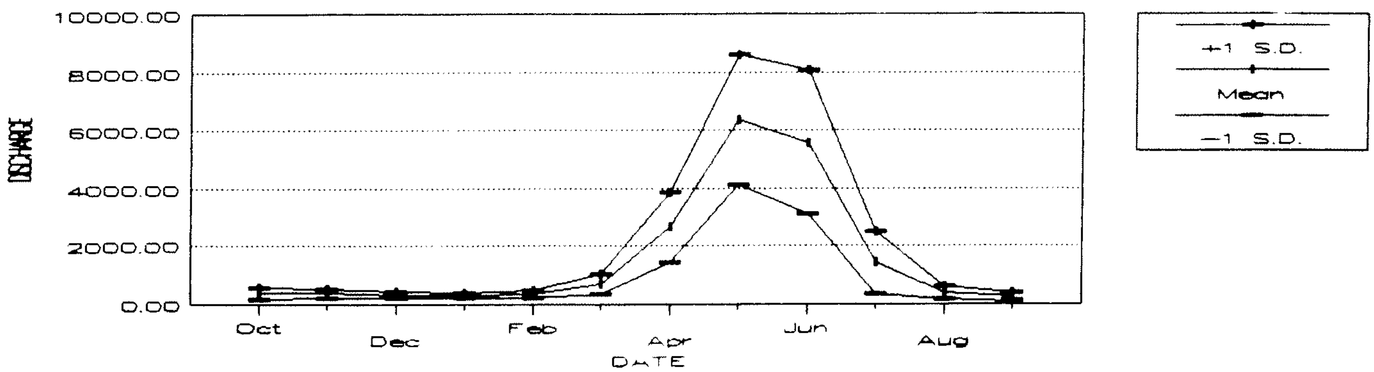


Figure 22. Mean monthly discharge and standard deviations on the Yampa River at Maybell, Colorado from 1917-1988 (USGS).

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Appendix A. Definitions of habitat types used by adult Colorado squawfish during the winter on the Yampa River 1986-1987.

Appendix A. Definitions of habitat types used by adult Colorado squawfish during the winter on the Yampa River 1986-1987. Definitions are modified from Arnette (1976) and Wick et al. (1981) for special application to winter conditions with ice cover.

Habitat type (Code)	Definition
Main channel (MC)	The primary river course that carries the major water flow.
Side channel (SC)	A secondary channel, often in a braided river reach that may carry appreciable flow during high water but reduced flow during low water when it may provide low velocity or backwater habitat.
Backwater (BA)	A body of water with no measurable velocity, created by a drop in water level which cuts off flow through a secondary channel or a portion of the main river channel. Access to the main river channel is not blocked. Backwaters ice over early and are one the of first habitats to form solid ice cover.
Embayment (EM)	An elongated pocket of low velocity water adjoining the main river. Distinctive in appearance at initial ice formation because of wide bands of ice along shore. This habitat forms immediately behind point bars created as a result of large eddys at high runoff flows.
Run (RU)	A stretch of relatively deep, moderately fast flowing water with the surface smooth and non-turbulent. Slow moving run areas freeze shortly after pools. Faster portions of runs freeze just prior to riffle areas.
Eddy (ED)	A whirlpool or back-current created by obstructions in a channel or projections of rock jutting out from shore. Eddies usually ice over early because velocities are relatively low during the winter.
Riffle (RI)	A shallow rapidly flowing section of river where the water surface is broken into small waves by irregular substrate, wholly or partially submerged. Usually the last portion of the river channel to ice over. Some riffle areas remain open the entire winter.
Pool (PO)	A portion of stream that is deep and quiet relative to the main current. One of the first areas to ice over in the main river channel.
Shoreline (SH)	The shallow, low to negligible velocity waters next to shore. Ice forms in narrow bands along the bank.

Appendix B. Fields and definitions used in the database for the Colorado squawfish winter habitat study, Yampa River, Colorado, 1986-1988.

Appendix B. Fields and definitions used in the database for the Colorado squawfish winter habitat study, Yampa River, Colorado, 1986-1988.

Field	Type	Format	Description
#obs	integer	2	Number of 15 minute observations associated with the record.
After	numeric	4.1	The amount of time within the field HOURS that occurred in the afternoon between 1200 - 1800 hours.
Comments	text		Free-form comments.
Cover	text	1	Cover type - main hole. Cover codes: B = Brush D = Organic debris N = None O = Overhang R = Rock S = Shade T = Turbulence V = Vegetation
CTime	integer	2	Time interval of observation. Actual time receiver was on and monitoring the fish.
Date	date	8	Date of observation (mm/dd/yy)
Depth	numeric	4.1	Depth of water in main hole = Effective depth (feet, 0.1 foot increments).
Dist.moved	text	3	Distance fish moved from one map location to another (meters).
ETime	integer	4	Time that observation at a map location ended (military).
Even	numeric	4.1	The amount of time within the field HOURS that occurred in the evening between 1800 - 2400 hours.
Fish ID	text	3	Unique fish identification number.
Habitat	text	4	Habitat at fish location. Habitat codes: Primary Habitat types: CC = Chute channel MC = Main channel SC = Side channel TS = Tributary stream

Appendix B. continued.

Field	Type	Format	Description
Habitat (continued)			Specific Habitat types: BA = Backwater ED = Eddy EM = Embayment PO = Pool RA = Rapid RI = Riffle RU = Run SH = Shoreline
Habitat2	text	4	Reclassified habitat for compatability with Green River studies. See Habitat for codes.
Hours	numeric	4.1	Total time fish was observed at a given map location (hours, 0.1 increments).
Ice Cover	text	1	Is there ice covering the fish location (Y or N)?
Ice Thick	numeric	3.1	Thickness of the ice at fish location (feet, 0.1 foot increments).
Incov	text	1	Cover type - inner hole. See Cover for codes.
Indep	numeric	4.1	Depth - inner hole (feet, 0.1 foot increments).
Insub	text	4	Substrate - inner hole. See Substrate for codes.
Invel.6 (Invel)*	numeric	4.1	Velocity at 0.6 depth - inner hole (feet/second).
Julian	integer	5	Julian date of observation.
MapID	integer	1	Map identification. Letter code that corresponds to code on map sketch.
Morn	numeric	4.1	The amount of time within the field HOURS that occurred in the morning between 0600 - 1200 hours.

Appendix B. continued.

Field	Type	Format	Description
Move.type	text	1	Type of fish movement. Move.type codes: A = Active I = Intial radio contact L = Local M = Moving S = Stationary U = Unknown
Night	numeric	4.1	The amount of time within the field HOURS that occurred in the night between 2400 - 0600 hours.
Outcov	text	1	Cover type - outer hole. See Cover for codes.
Outdep	numeric	4.1	Depth - outer hole (feet, 0.1 foot increments).
Outsub	text	4	Substrate - outer hole. See Substrate for codes.
Outvel.6 (Outvel)	numeric	4.1	Velocity at 0.6 depth - outer hole (feet/second).
RMI	numeric	5.1	River mile location. Starting at the confluence with the Green River at RMI 0.
Slush	numeric	3.1	Depth of slush (Frazil ice), (feet, 0.1 foot increments).
Spp1	text	3	Species of nearby radiotagged fish.
Spp1dist (Site1)	integer	3	Distance to SPP1 (meters).
Spp2	text	3	Species of nearby radiotagged fish.
Spp2dist (Site2)	integer	3	Distance to SPP2 (meters).
Spp3	text	3	Species of nearby radiotagged fish.
Spp3dist (Site3)	integer	3	Distance to SPP3 (meters).
Spp4	text	3	Species of nearby radiotagged fish.

Appendix B. continued.

Field	Type	Format	Description
Spp4dist (Site4)	integer	3	Distance to SPP4 (meters).
STime	integer	4	Start time of observation (military).
Sub	text	4	Substrate type - main hole. Substrate codes: BO = Boulder CL = Clay CO = Cobble GR = Gravel SA = Sand SI = Silt
Time	integer	4	Time at start of observation (military).
Totdep	numeric	4.1	Total depth, calculated field (Depth + Ice Thick + Slush)
Trip	integer	2	Sampling trip number.
Type	text	3	Type of sample. Type codes Winter 1: AN = 2.5 hour - Non-target time AT = 2.5 hour - Target time AW = 2.5 hour - Target fish, unscheduled time AX = 2.5 hour - Extra data BA = 24 hour - 2.5 hour quality BT = 24 hour - Target time BX = 24 hour - Extra data BAX = 24 hour - Extra data 2.5 hour quality BB = first 2.5 hours in 24 hour (BA or BB) data. Type codes Winter 2: STM = Short Term, 30 minute duration. LTM = Long Term, 2 hour duration.
Vel.2	numeric	4.1	Velocity at 0.2 depth (feet/second) - main hole.
Vel.6	numeric	4.1	Velocity at 0.6 depth (feet/second) - main hole.
Vel.8	numeric	4.1	Velocity at 0.8 depth (feet/second) - main hole.
W.temp	integer	2	Water temperature (C) - main hole.

* = fields in parenthesis the name change of the field during the second year.

Appendix C. USGS flow and temperature records for Oct 1986 - Sep 1988.

Appendix C1. Discharge measured at the USGS gage near Maybell, Colorado on the Yampa River, October 1986 to September 1987. From Ugland et al. (1988).

WATER-DISCHARGE RECORDS

PERIOD OF RECORD.--April 1904 to October 1905, June 1910 to November 1912, April 1916 to current year. Monthly discharge only for some periods, published in WSP 1313. No winter records prior to 1917.

GAGE.--Water-stage recorder. Datum of gage is 5,900.23 ft above National Geodetic Vertical Datum of 1929. See WSP 1733 for history of changes prior to Mar. 9, 1937.

REMARKS.--Estimated daily discharges: Oct. 7, 8, 18-29, Dec. 8-9, 13, Feb. 10, and Feb. 15 to Mar. 5. Records good except for estimated daily discharges, which are poor. Natural flow of stream affected by transbasin diversions, numerous storage reservoirs, and diversions upstream from station for irrigation of about 65,000 acres upstream from, and about 800 acres downstream from station.

AVERAGE DISCHARGE.--71 years (water years 1917-87), 1,588 ft^3/s; 1,151,000 acre-ft/yr.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 25,100 ft^3/s, May 17, 1984, gage height, 12.42 ft; minimum daily, 2.0 ft^3/s, July 17-19, 1934.

EXTREMES FOR CURRENT YEAR.--Peak discharges greater than base discharge of 7,000 ft^3/s, and maximum (*):

Date	Time	Discharge (ft^3/s)	Gage height (ft)	Date	Time	Discharge (ft^3/s)	Gage height (ft)
May 2	1330		*6.49	No peak greater than base discharge.			
May 6	0000	*6,140	6.45				

Minimum daily, 124 ft^3/s, Aug. 22.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1986 TO SEPTEMBER 1987
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	933	859	539	275	300	300	569	5500	2400	640	440	196
2	951	900	399	275	300	325	941	5970	2520	950	502	181
3	853	850	423	250	300	350	1320	5560	2450	891	475	162
4	754	774	514	300	300	400	1350	4420	2250	693	385	175
5	745	700	529	300	275	750	1720	3770	2200	566	334	173
6	779	708	544	325	275	1330	2120	3580	2260	456	287	188
7	775	718	620	300	275	1620	2250	3810	2210	410	273	193
8	775	707	500	275	275	1990	2390	4270	2510	376	285	185
9	779	647	400	250	300	2210	2360	4460	2770	336	279	191
10	797	583	305	250	400	1920	2350	4690	3210	300	349	195
11	827	642	234	275	672	1620	1790	4890	3180	250	325	190
12	895	561	304	275	715	1710	1960	4680	2720	294	293	189
13	824	656	398	300	1280	1800	1820	5220	2370	366	227	202
14	734	583	450	275	1380	2300	1440	5410	2020	684	227	215
15	689	611	475	250	1100	2030	1230	5520	1850	646	212	219
16	643	767	500	250	800	1540	1470	5670	1690	506	200	251
17	623	826	450	250	700	1170	2270	5890	1650	418	212	251
18	625	796	450	250	500	921	3050	5790	1470	347	192	249
19	625	854	425	250	400	921	3540	5610	1270	328	199	262
20	650	911	400	250	350	1130	3890	5110	1140	368	182	247
21	650	1110	400	250	325	1020	3470	4590	1020	312	155	219
22	700	918	400	275	300	772	2700	4380	946	250	124	253
23	800	874	375	275	325	807	2740	3980	864	220	127	253
24	850	767	350	300	300	775	3450	3630	764	206	161	225
25	800	638	325	300	300	697	4250	3500	700	189	193	170
26	750	693	300	300	325	625	4750	3290	625	181	238	147
27	700	650	325	300	275	630	4860	3100	569	178	355	151
28	700	564	300	300	275	642	4980	2860	526	252	297	143
29	700	477	325	275	---	554	5630	2610	501	377	216	143
30	713	525	325	275	---	508	5690	2510	515	399	187	148
31	752	---	300	275	---	487	---	2420	---	374	188	---
TOTAL	23391	21869	12584	8550	13322	33854	82350	136690	51170	12763	8124	5966
MEAN	755	729	406	276	476	1092	2745	4409	1706	412	262	199
MAX	951	1110	620	325	1380	2300	5690	5970	3210	950	502	262
MIN	623	477	234	250	275	300	569	2420	501	178	124	143
AC-FT	46400	43380	24960	16960	26420	67150	163300	271100	101500	25320	16110	11830

CAL YR 1986 TOTAL 863211 MEAN 2365 MAX 10400 MIN 234 AC-FT 1712000
WTR YR 1987 TOTAL 410633 MEAN 1125 MAX 5970 MIN 124 AC-FT 814500

Appendix C1. Discharge measured at the USGS gage near Maybell, Colorado on the Yampa River, October 1987 to September 1988. Data from USGS field station Meeker, Colorado.

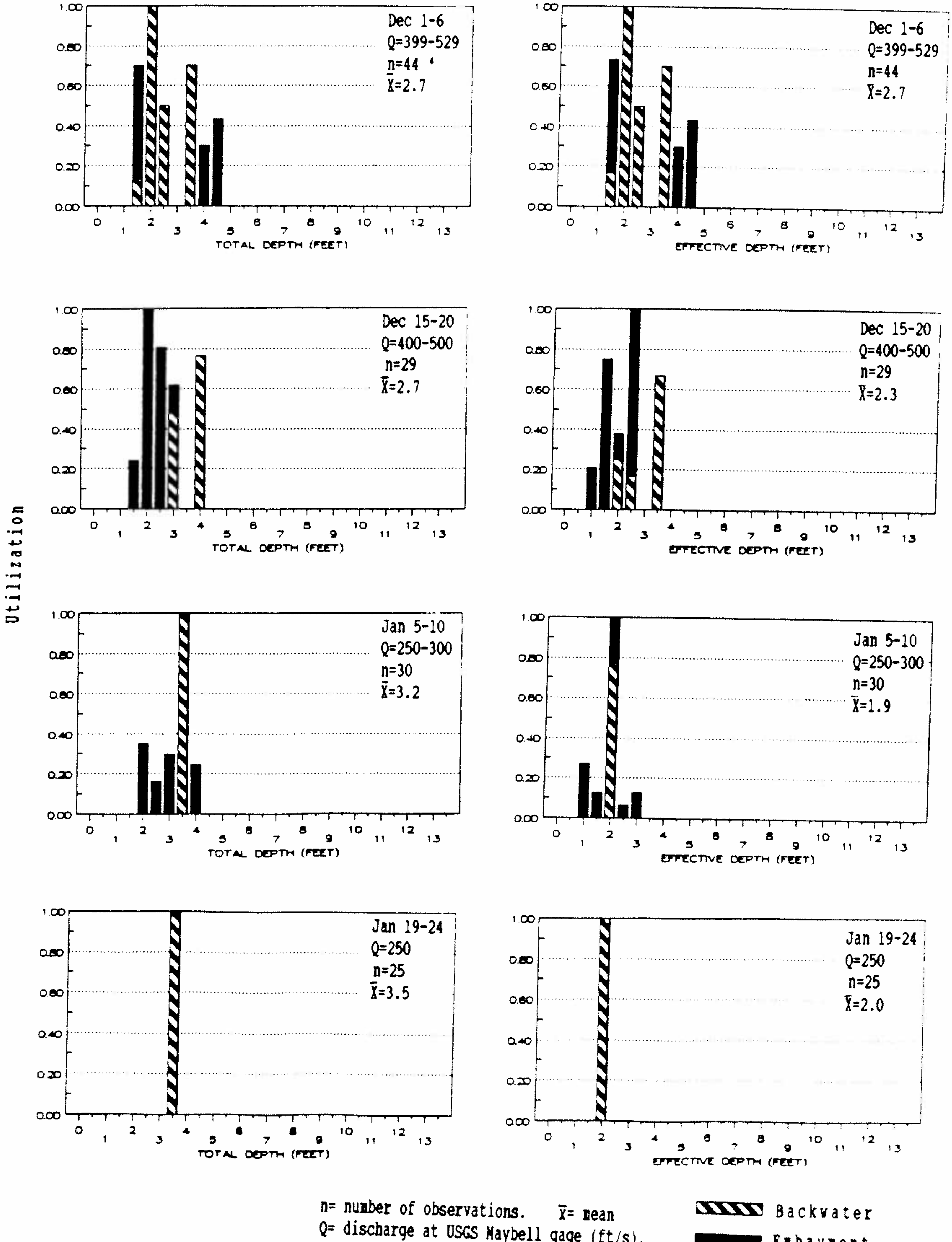
UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - CO DATA 10/07/88

STATION NUMBER 09251000 YAMPA RIVER NEAR MAYBELL, CO. STREAM SOURCE AGENCY USGS
LATITUDE 403010 LONGITUDE 1080145 DRAINAGE AREA 3410.00 DATUM 5900.23 STATE 08 COUNTY 081
PROVISIONAL DATA FROM THE DCP SUBJECT TO REVISION
DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1987 TO SEPTEMBER 1988
MEAN VALUES

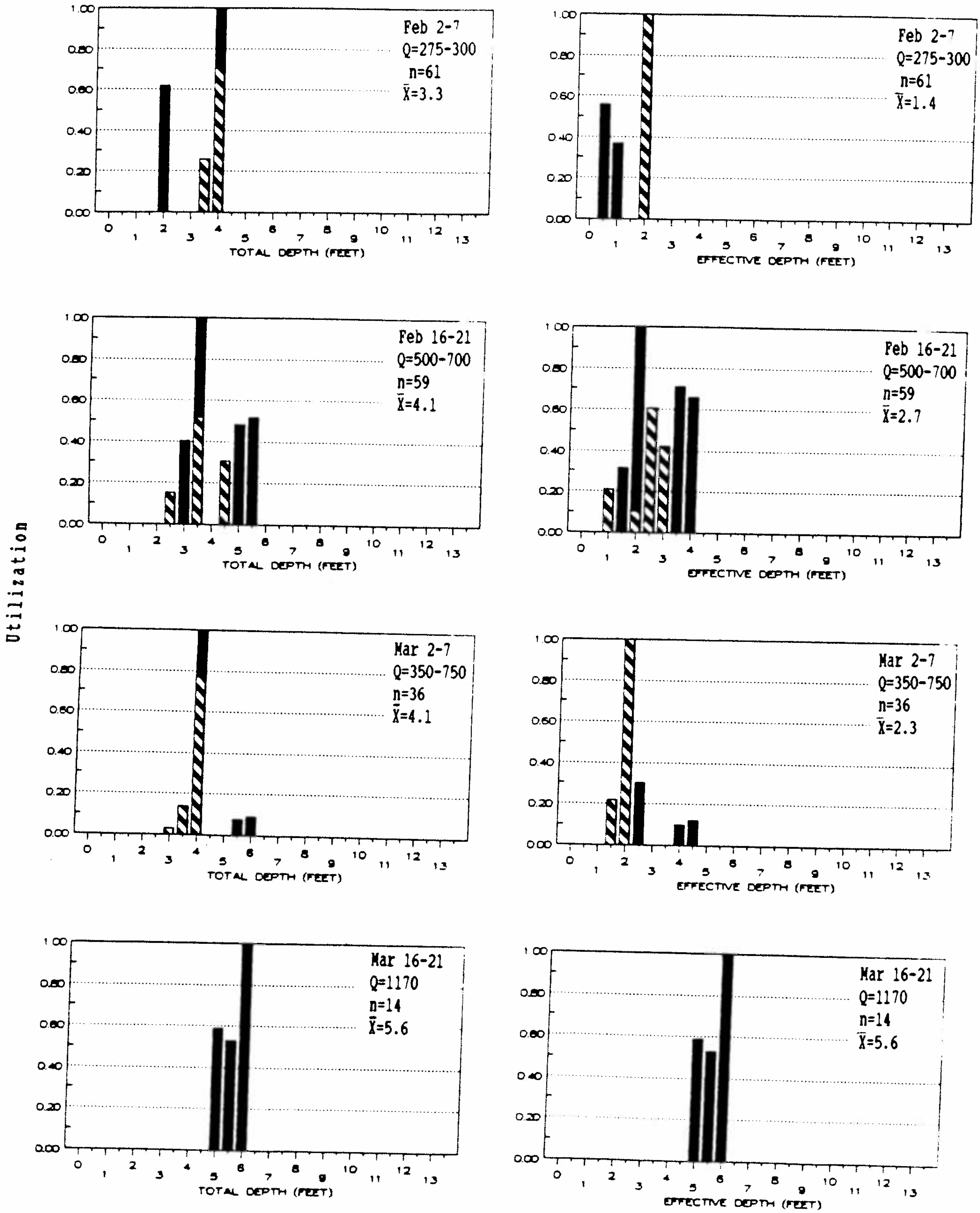
DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	140	369	200	185	240	320	708	3830	5370	1980	283	54
2	137	402	190	190	240	330	695	4700	4590	1630	275	39
3	136	403	190	190	240	340	798	3980	4430	1380	262	37
4	140	434	180	190	250	340	1160	3440	5250	1260	268	37
5	141	425	170	200	240	330	1490	3320	6390	1210	269	37
6	143	405	170	210	230	320	1450	3680	7250	1170	262	37
7	128	393	170	215	230	300	1490	4130	7130	1070	264	37
8	117	394	160	215	230	290	1880	3370	7100	958	266	44
9	128	398	160	215	225	300	2040	3070	6820	831	261	49
10	165	379	150	220	220	320	1560	2880	6430	731	259	37
11	176	364	150	230	220	350	1280	2920	6130	664	221	37
12	174	371	150	230	220	330	1350	3310	5800	621	189	37
13	167	390	140	230	225	320	2020	4380	4980	618	167	69
14	173	370	140	240	230	320	2870	5760	4630	579	153	236
15	190	350	140	230	230	330	3640	7160	4240	520	160	318
16	212	340	130	230	235	320	4250	7210	4130	474	182	291
17	264	290	135	230	240	330	4850	7650	3980	447	170	245
18	272	210	140	230	245	320	5140	8350	3880	419	174	237
19	265	215	140	235	240	310	4550	9800	3660	377	170	232
20	250	220	145	230	235	300	5120	9590	3730	332	160	230
21	238	230	150	230	240	300	4850	7430	3620	371	163	214
22	253	230	150	225	245	300	4730	5680	3490	299	153	222
23	257	220	160	225	240	310	4020	4860	3300	289	146	222
24	262	220	160	230	235	320	3300	4660	3110	269	152	220
25	322	220	160	230	240	340	2890	5120	2750	261	142	227
26	365	225	165	240	250	380	2850	5730	2480	260	128	213
27	424	225	170	230	260	420	2630	5820	2360	260	113	208
28	386	230	175	230	280	500	2420	6270	2520	260	96	214
29	353	220	180	230	300	440	2450	6610	2200	251	83	227
30	336	215	180	235	---	400	2760	6930	2240	252	73	238
31	341	---	180	240	---	450	---	6850	---	280	65	---
TOTAL	7055	9357	4980	6890	6955	10580	81241	168490	133970	20273	5729	4545
MEAN	228	312	161	222	240	341	2708	5435	4466	654	185	151
MAX	424	434	200	240	300	500	5140	9900	7250	1980	283	318
MIN	117	210	130	185	220	290	695	2880	2200	251	65	37
AC-FT	13990	18560	9880	13670	13800	20990	161100	334200	265800	40210	11360	9020

WTR YR 1988 TOTAL 460085 MEAN 1257 MAX 9800 MIN 37 AC-FT 912600

Appendix D. Bi-weekly total and effective depth utilization (normalized) in each habitat by radiotagged Colorado squawfish during each winter.



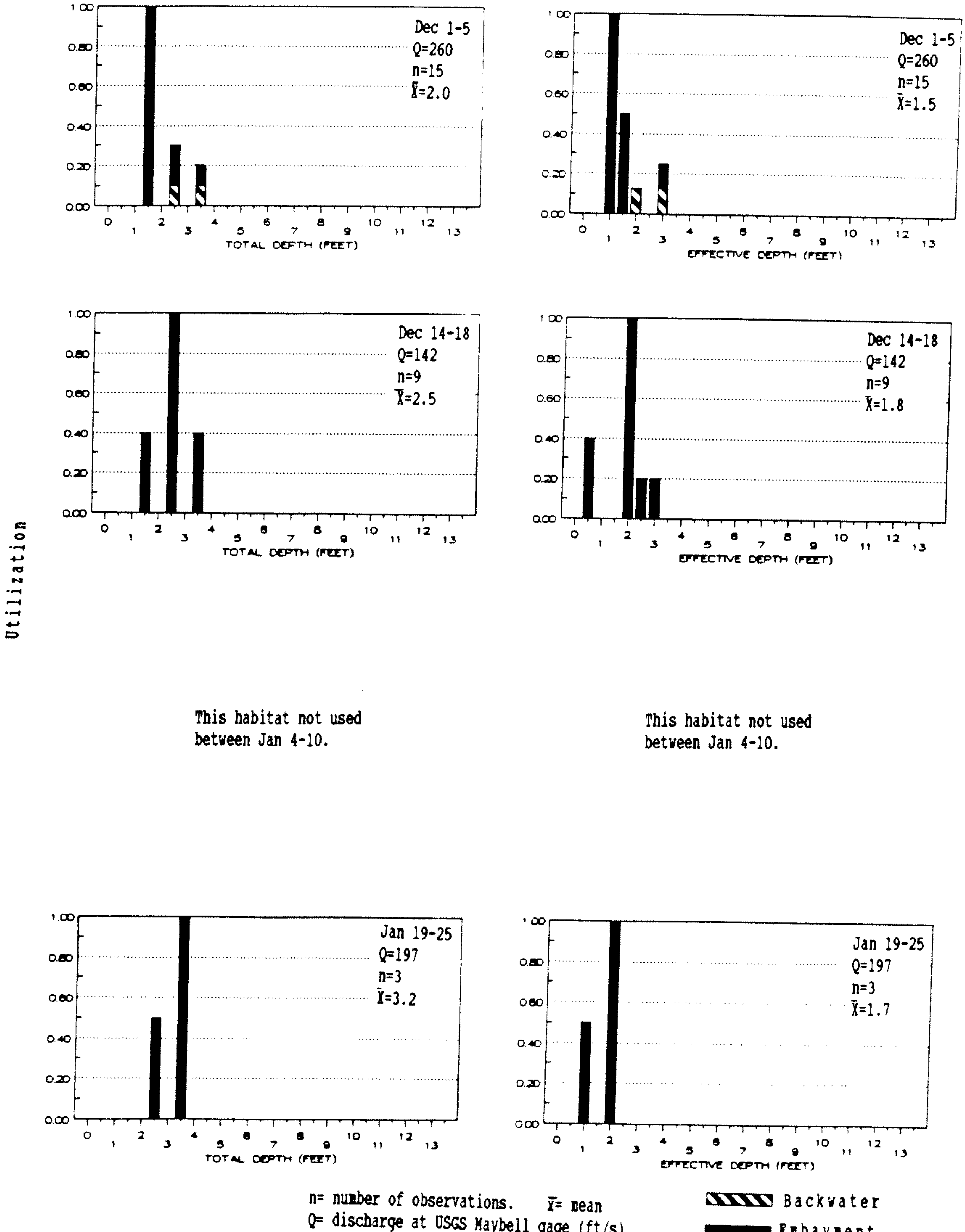
Appendix D1. Bi-weekly total and effective depth utilization (normalized) of backwater and embayment habitats by radiotagged Colorado squawfish from December through January during the winter of 1986 to 1987 on the Yampa River.



n= number of observations. X̄= mean
Q= discharge at USGS Maybell gage (ft/s).

Backwater
Embayment

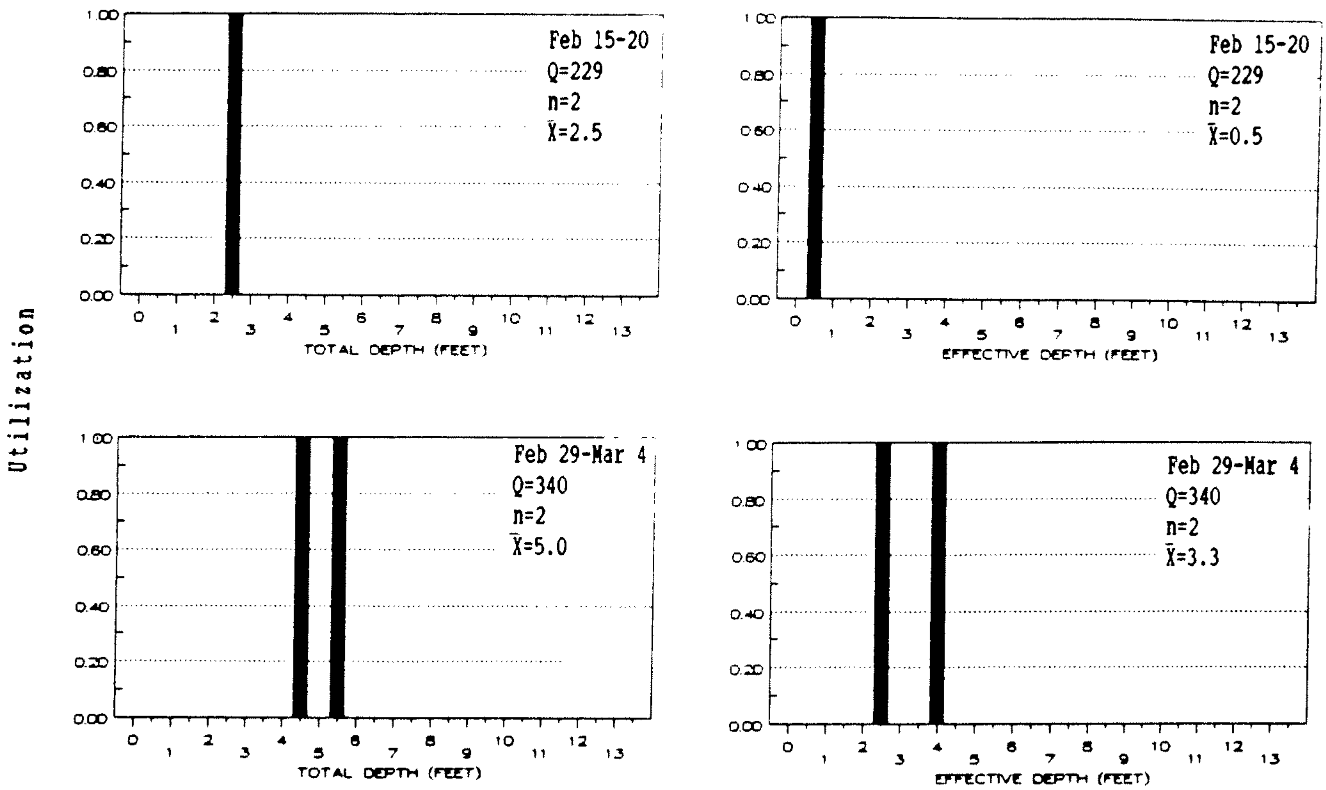
Appendix D2. Bi-weekly total and effective depth utilization (normalized) of backwater and embayment habitats by radiotagged Colorado squawfish from February through March during the winter of 1986 to 1987 on the Yampa River.



Appendix D3. Bi-weekly total and effective depth utilization (normalized) of backwater and embayment habitats by radiotagged Colorado squawfish from December through January during the winter of 1987 to 1988 on the Yampa River.

This habitat not used
between Feb 1-6.

This habitat not used
between Feb 1-6.



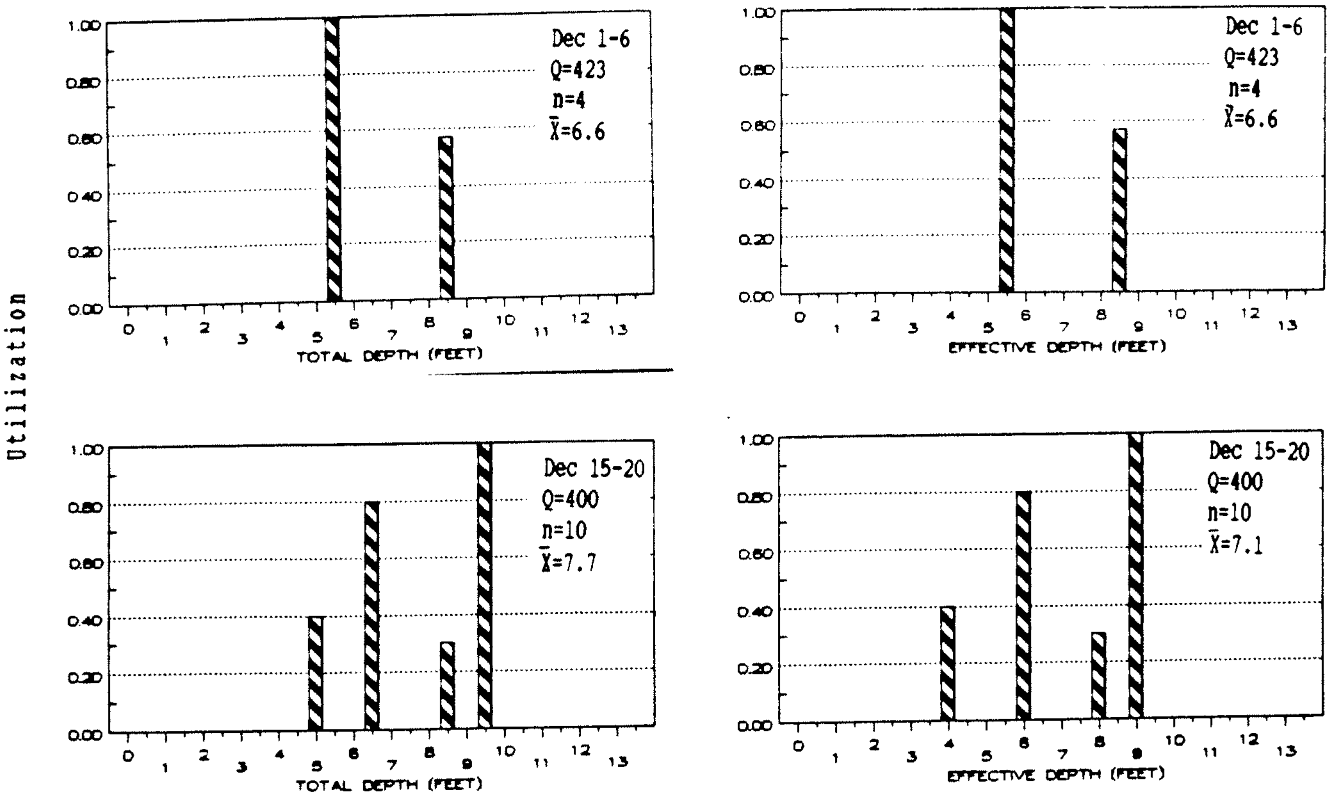
This habitat not used
between Mar 14-18.

This habitat not used
between Mar 14-18.

n= number of observations. X̄= mean
Q= discharge at USGS Maybell gage (ft/s).

Backwater
Embayment

Appendix D4. Bi-weekly total and effective depth utilization (normalized) of backwater and embayment habitats by radiotagged Colorado squawfish from February through March during the winter of 1987 to 1988 on the Yampa River.



This habitat not used between Jan 5-10.

This habitat not used between Jan 5-10.

This habitat not used between Jan 19-24.

This habitat not used between Jan 19-24.

n= number of observations. $\bar{X}$= mean
Q= discharge at USGS Maybell gage (ft/s).

Eddy
Pool

Appendix D5. Bi-weekly total and effective depth utilization (normalized) of eddy and pool habitats by radiotagged Colorado squawfish from December through January during the winter of 1986 to 1987 on the Yampa River.

This habitat not used
between Feb 2-7.

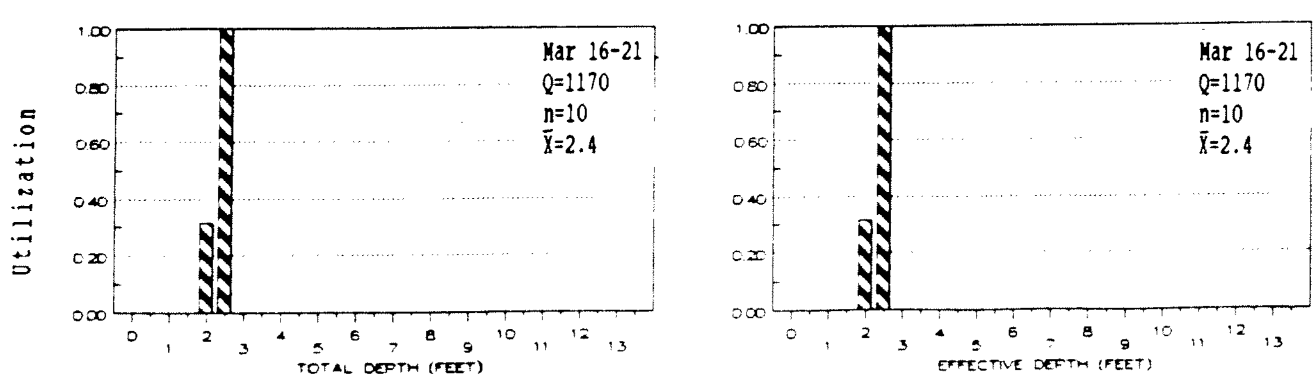
This habitat not used
between Feb 2-7.

This habitat not used
between Feb 16-21.

This habitat not used
between Feb 16-21.

This habitat not used
between Mar 2-7.

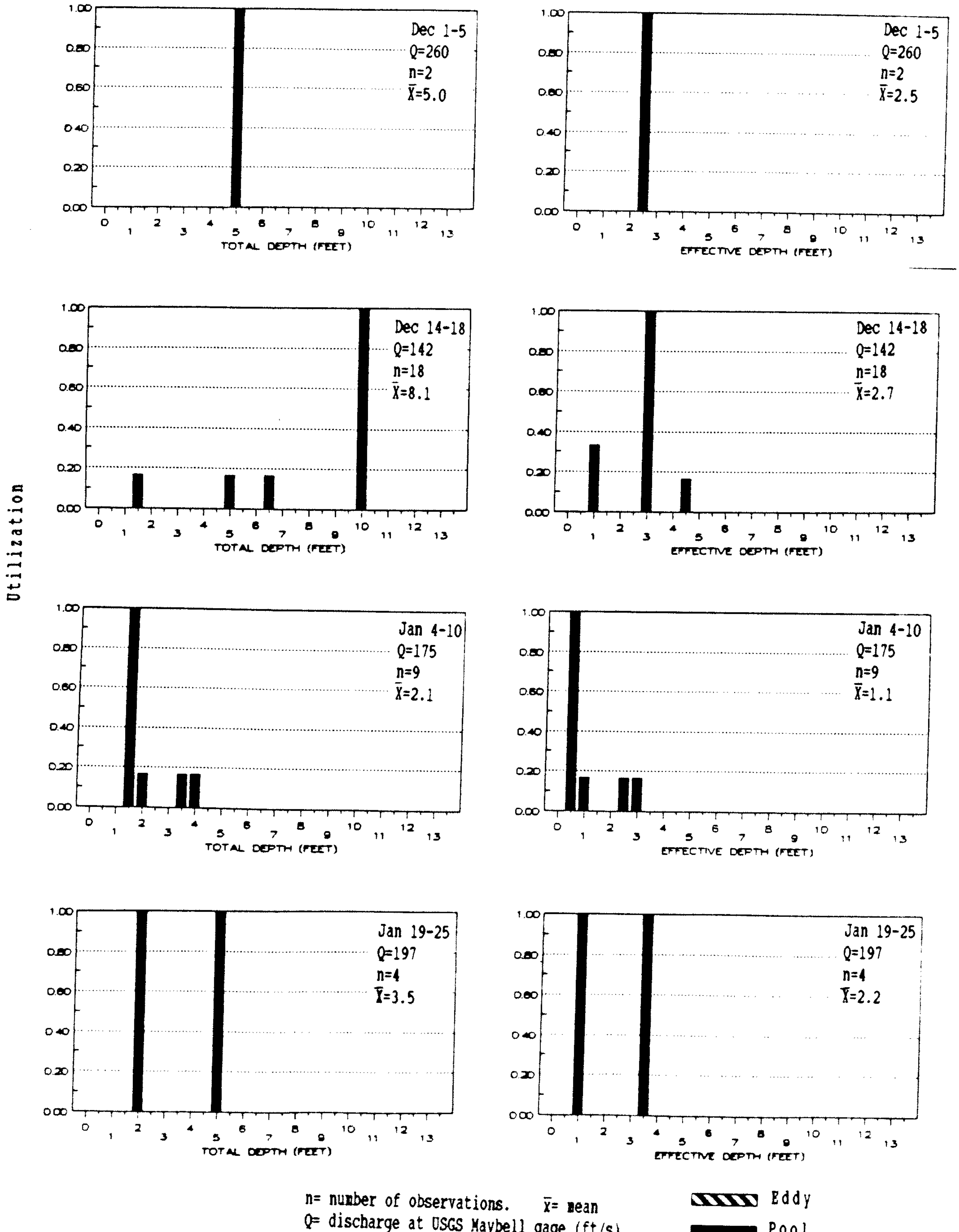
This habitat not used
between Feb 2-7.



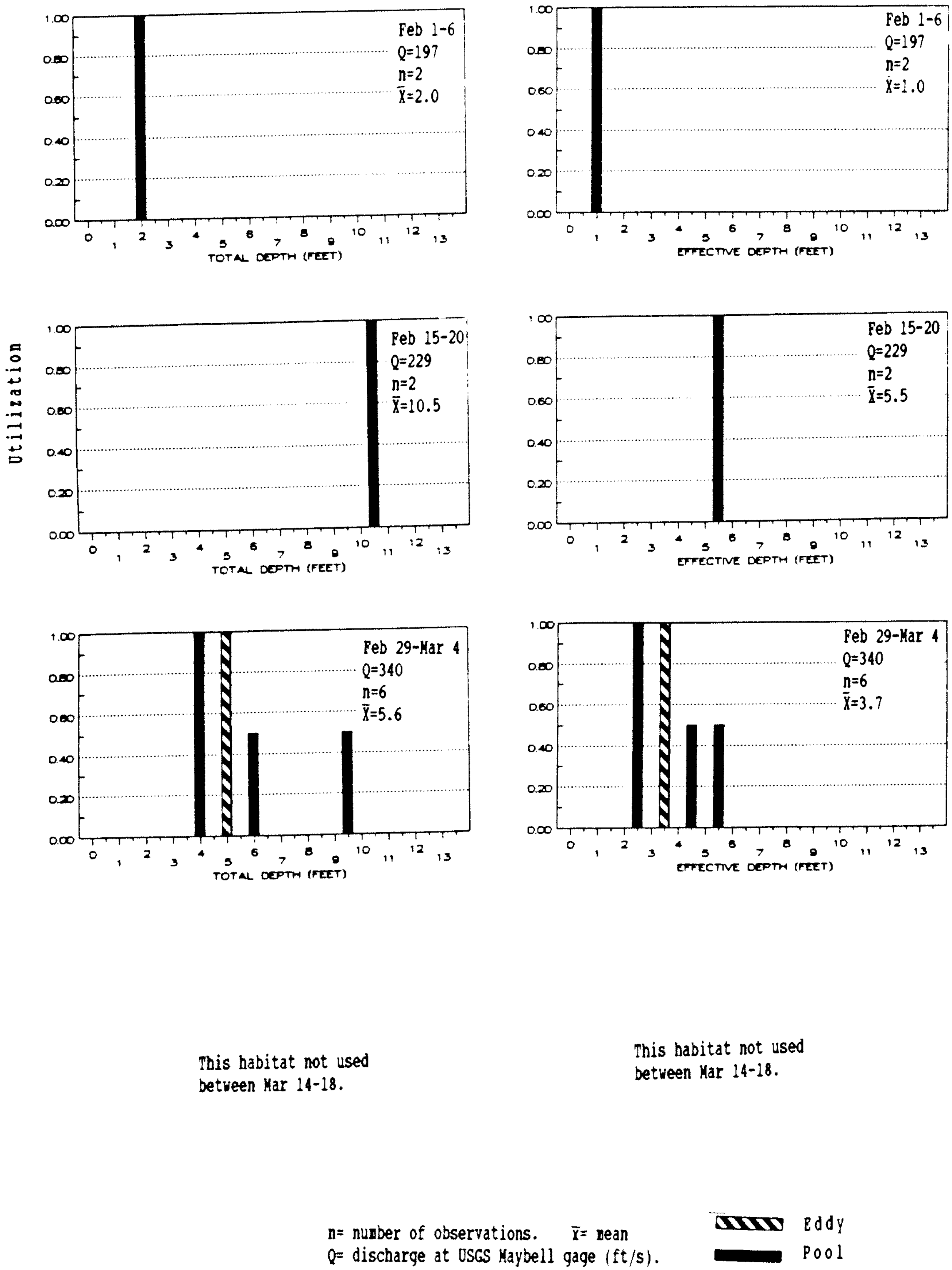
n= number of observations. $\bar{X}$= mean
Q= discharge at USGS Maybell gage (ft/s).

Eddy
Pool

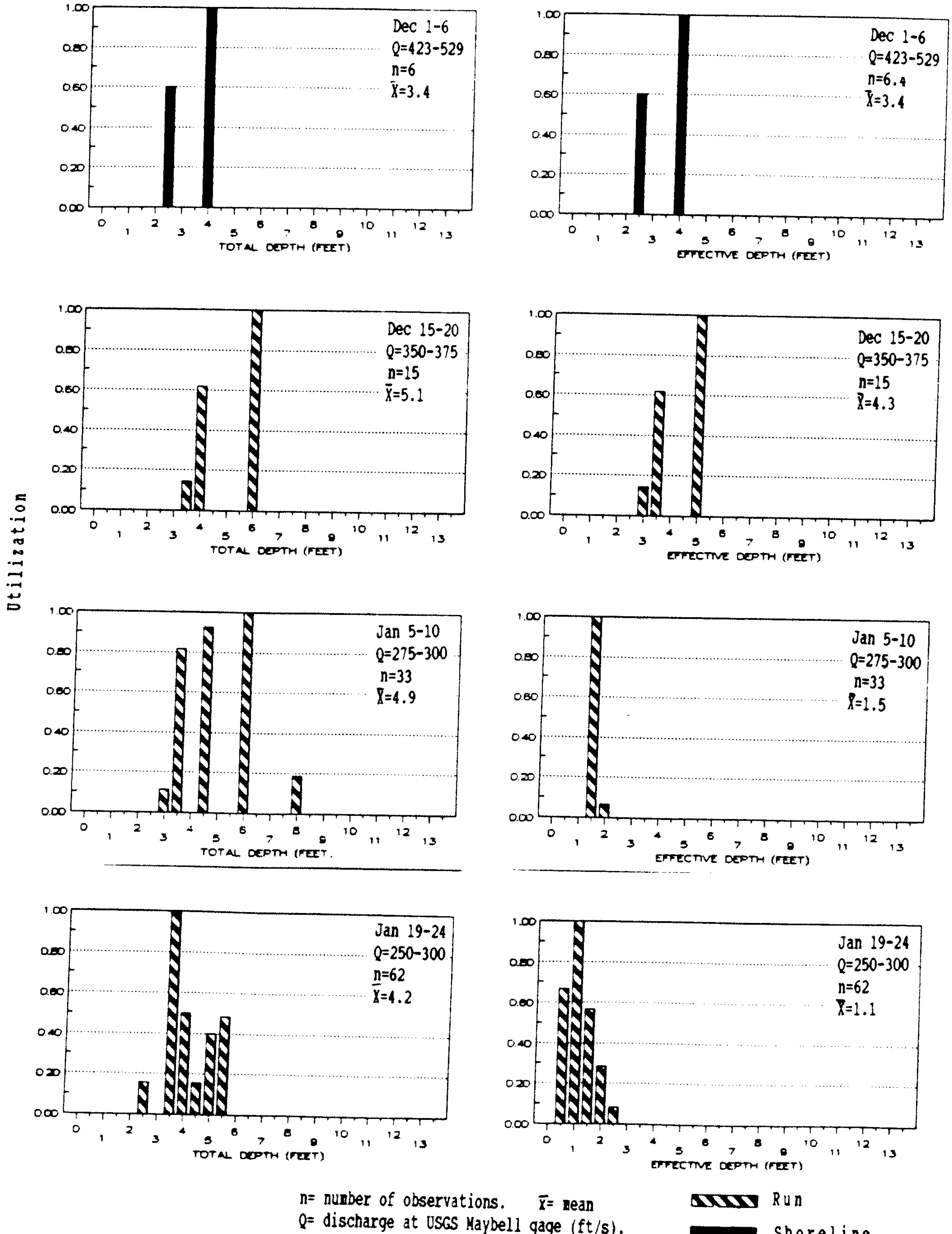
Appendix D6. Bi-weekly total and effective depth utilization (normalized) of eddy and pool habitats by radiotagged Colorado squawfish from February through March during the winter of 1986 to 1987 on the Yampa River.



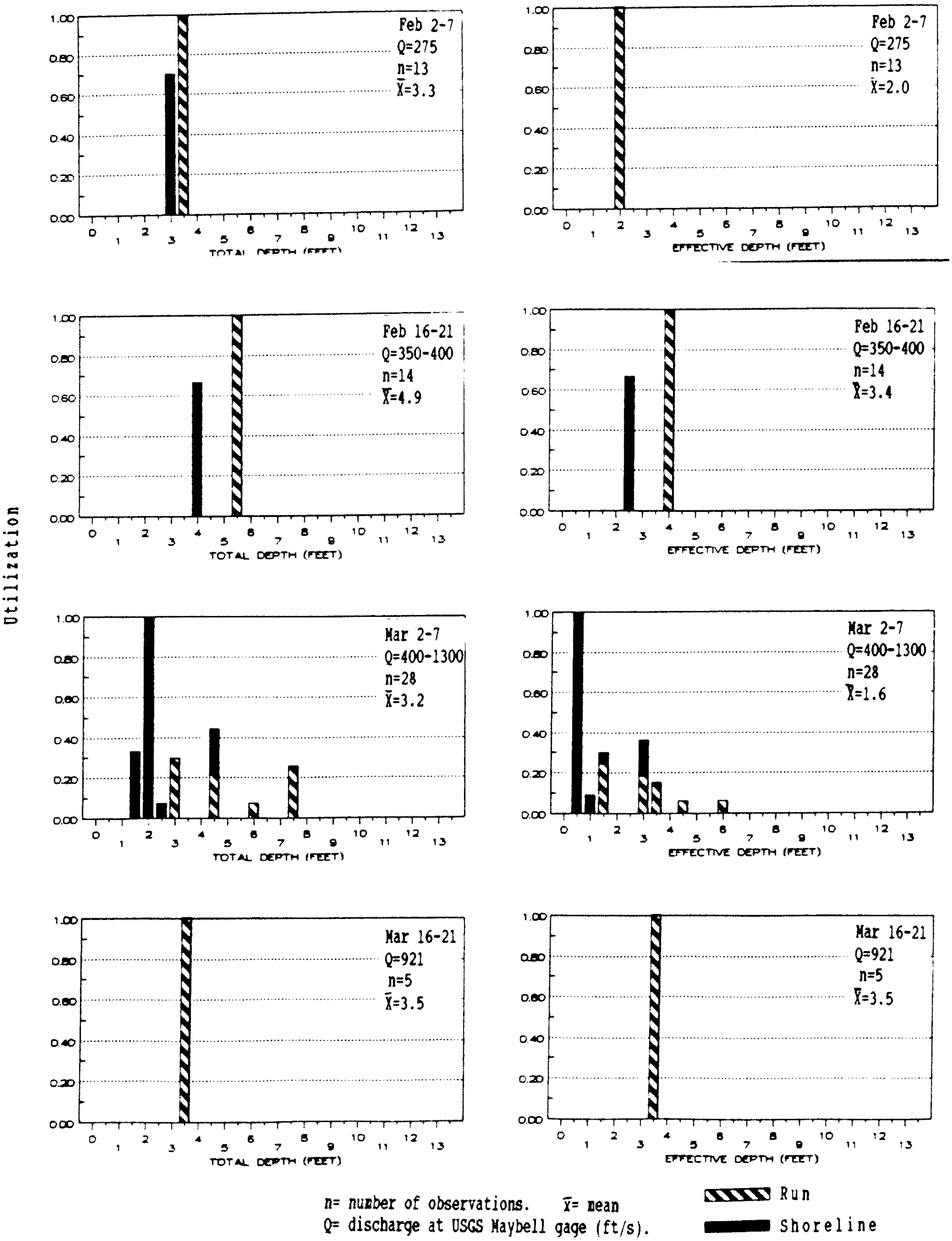
Appendix D7. Bi-weekly total and effective depth utilization (normalized) of eddy and pool habitats by radiotagged Colorado squawfish from December through January during the winter of 1987 to 1988 on the Yampa River.



Appendix D8.. Bi-weekly total and effective depth utilization (normalized) of eddy and pool habitats by radiotagged Colorado squawfish from February through March during the winter of 1987 to 1988 on the Yampa River.



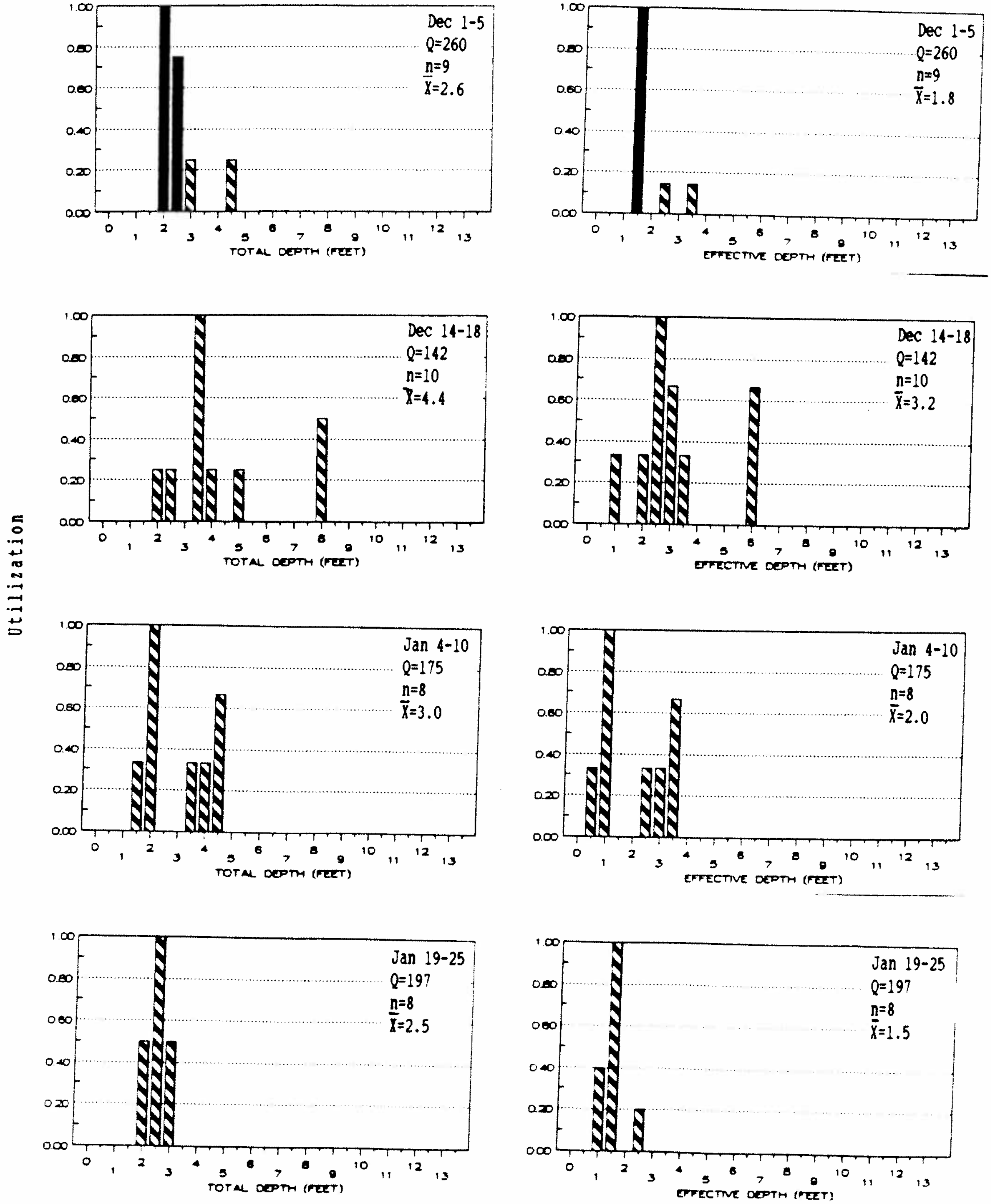
Appendix D9. Bi-weekly total and effective depth utilization (normalized) of run and shoreline habitats by radiotagged Colorado squawfish from December through January during the winter of 1986 to 1987 on the Yampa River.



n= number of observations. X̄= mean

Q= discharge at USGS Maybell gage (ft/s).

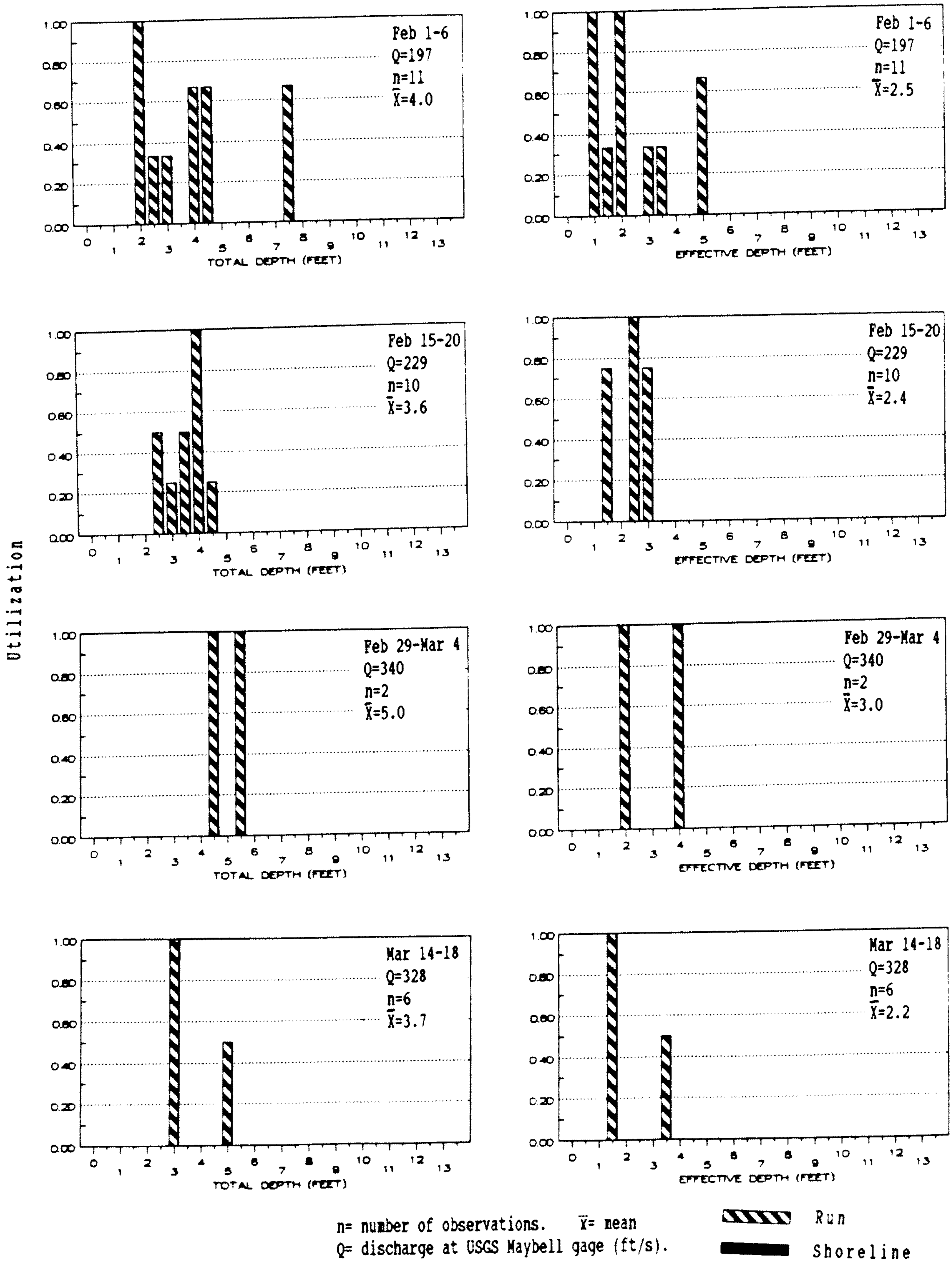
Appendix D10. Bi-weekly total and effective depth utilization (normalized) of run and shoreline habitats by radiotagged Colorado squawfish from February through March during the winter of 1986 to 1987 on the Yampa River.



n= number of observations. X̄= mean
Q= discharge at USGS Maybell gage (ft/s).

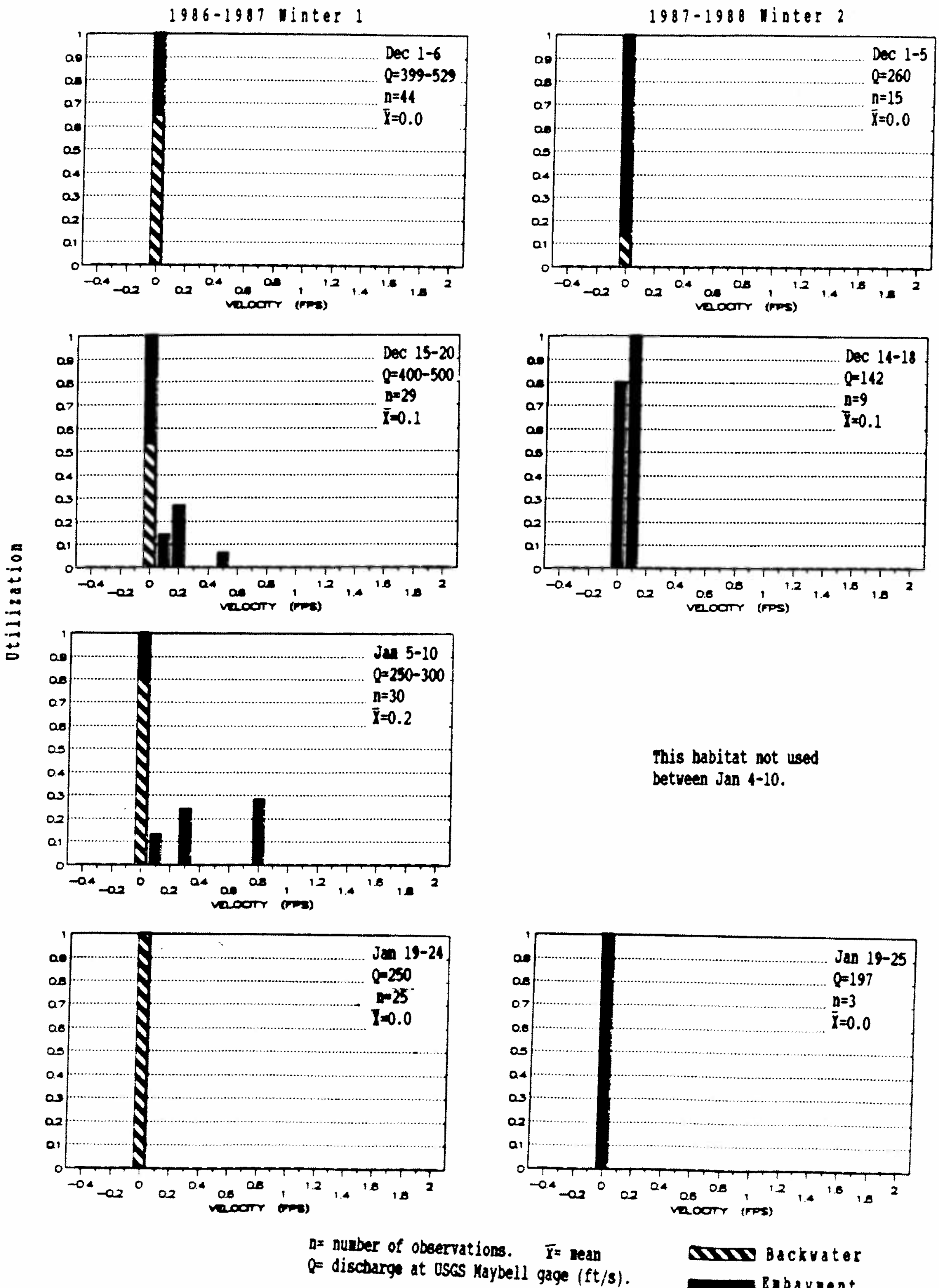
Run
Shoreline

Appendix D11. Bi-weekly total and effective depth utilization (normalized) of run and shoreline habitats by radiotagged Colorado squawfish from December through January during the winter of 1987 to 1988 on the Yampa River.

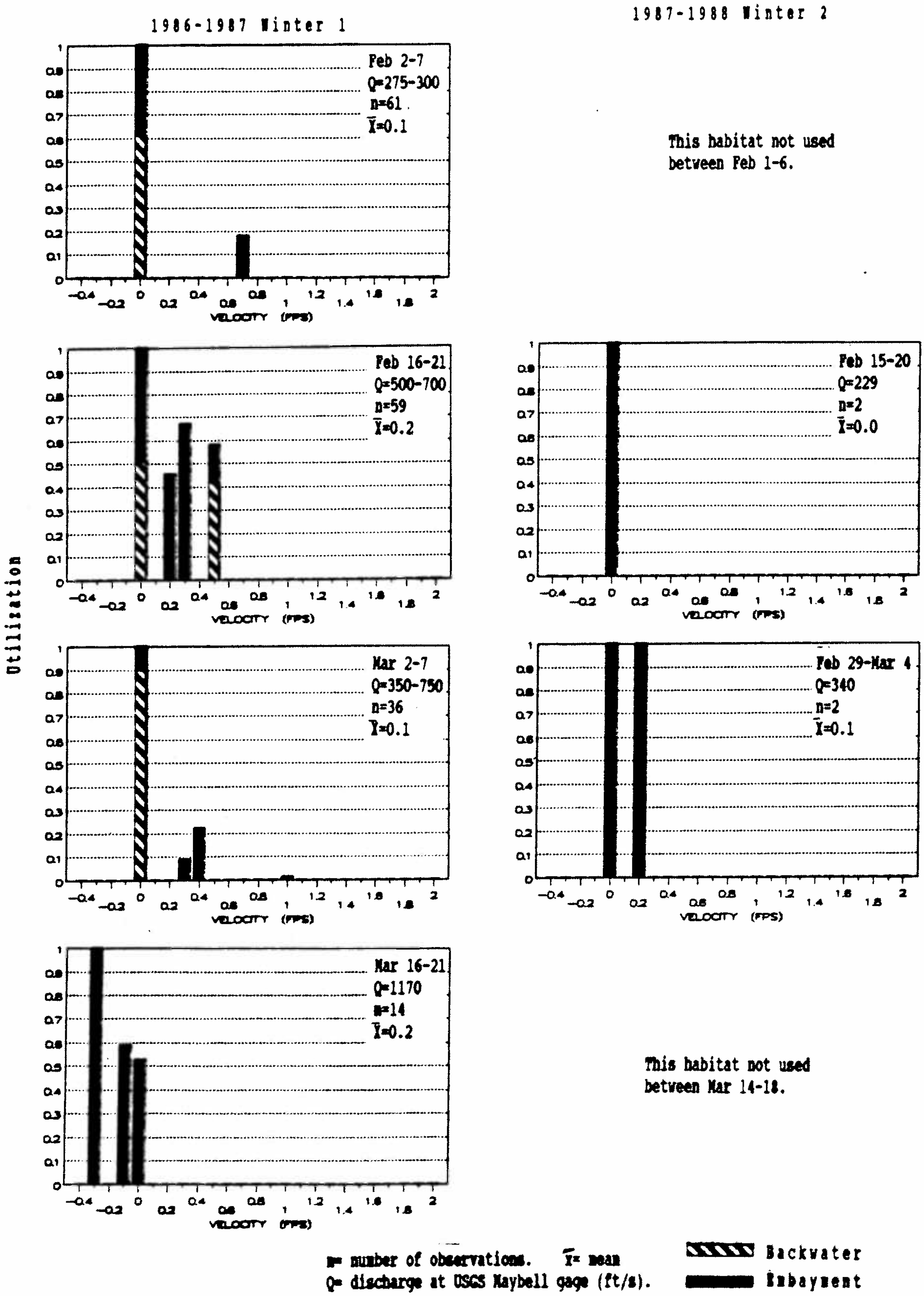


Appendix D12. Bi-weekly total and effective depth utilization (normalized) of run and shoreline habitats by radiotagged Colorado squawfish from February through March during the winter of 1987 to 1988 on the Yampa River.

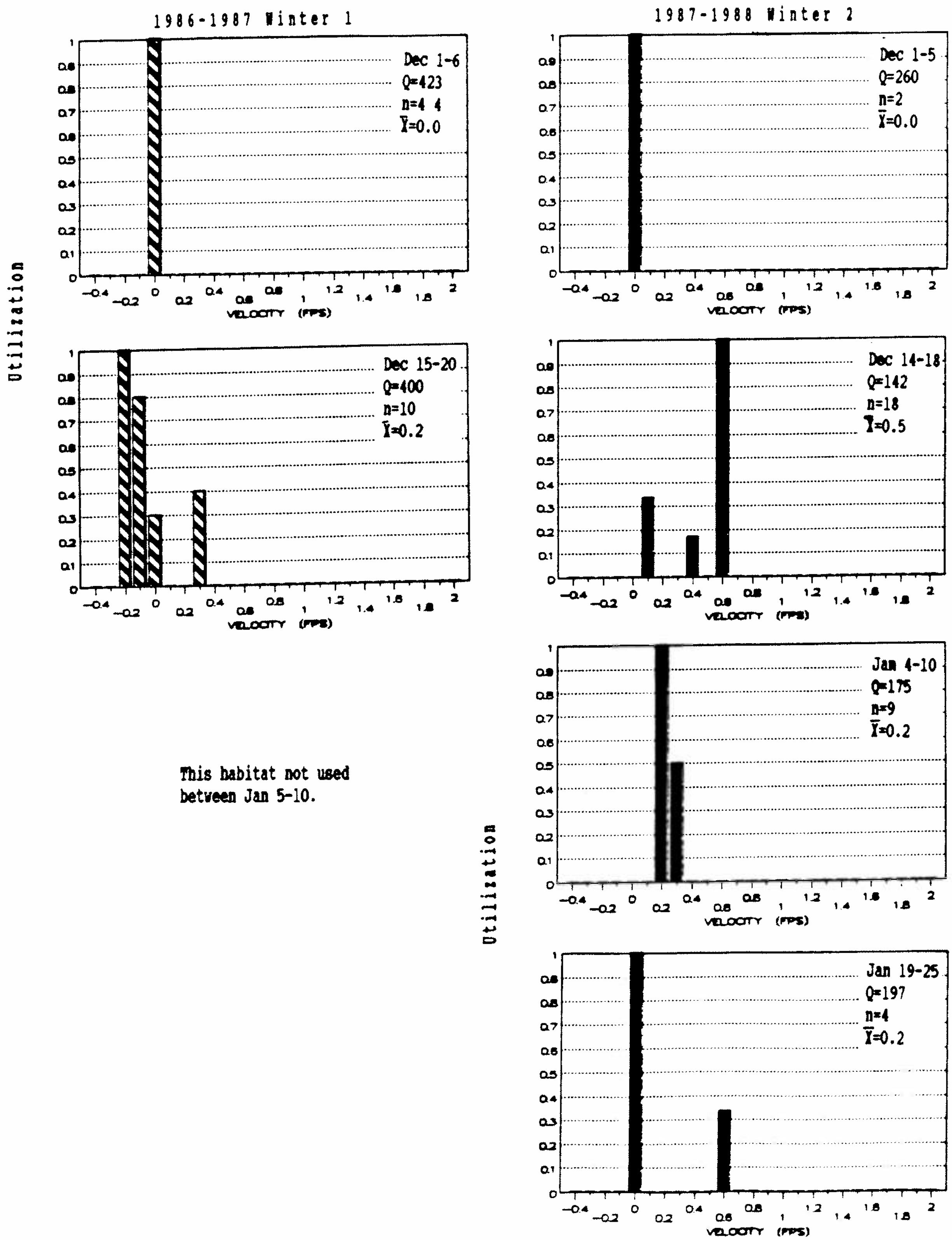
Appendix E. Bi-weekly velocity utilization (normalized) in each habitat by radiotagged Colorado squawfish during each winter.



Appendix E1. Bi-weekly velocity utilization (normalized) of backwater and embayment habitats by radiotagged Colorado squawfish from December through January during two winters (1986-1987 and 1987-1988) on the Yampa River.



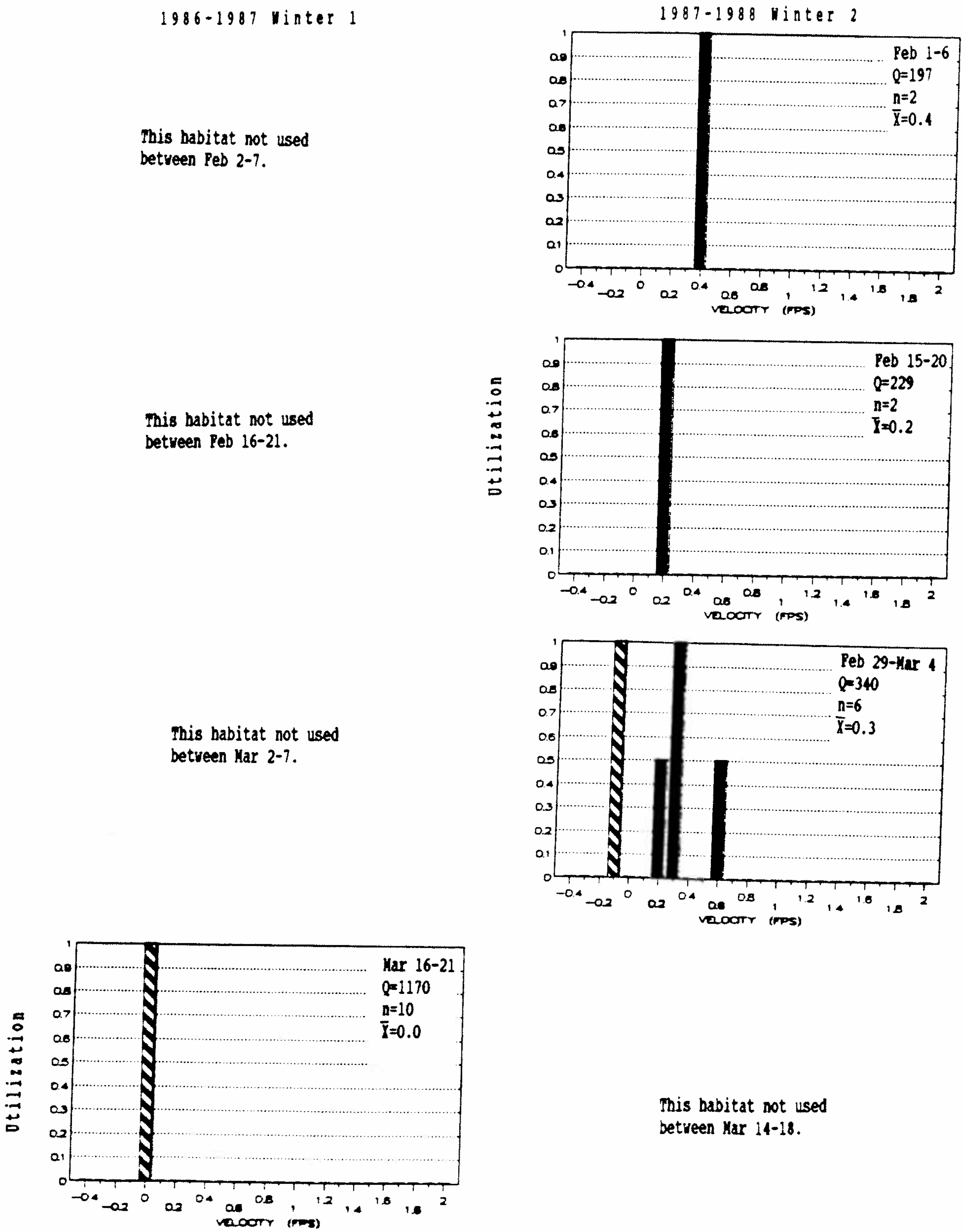
Appendix E2. Bi-weekly velocity utilization (normalized) of backwater and embayment habitats by radiotagged Colorado squawfish from February through March during two winters (1986-1987 and 1987-1988) on the Yampa River.



n= number of observations. Ȳ= mean
Q= discharge at USGS Maybell gage (ft/s).

Eddy
Pool

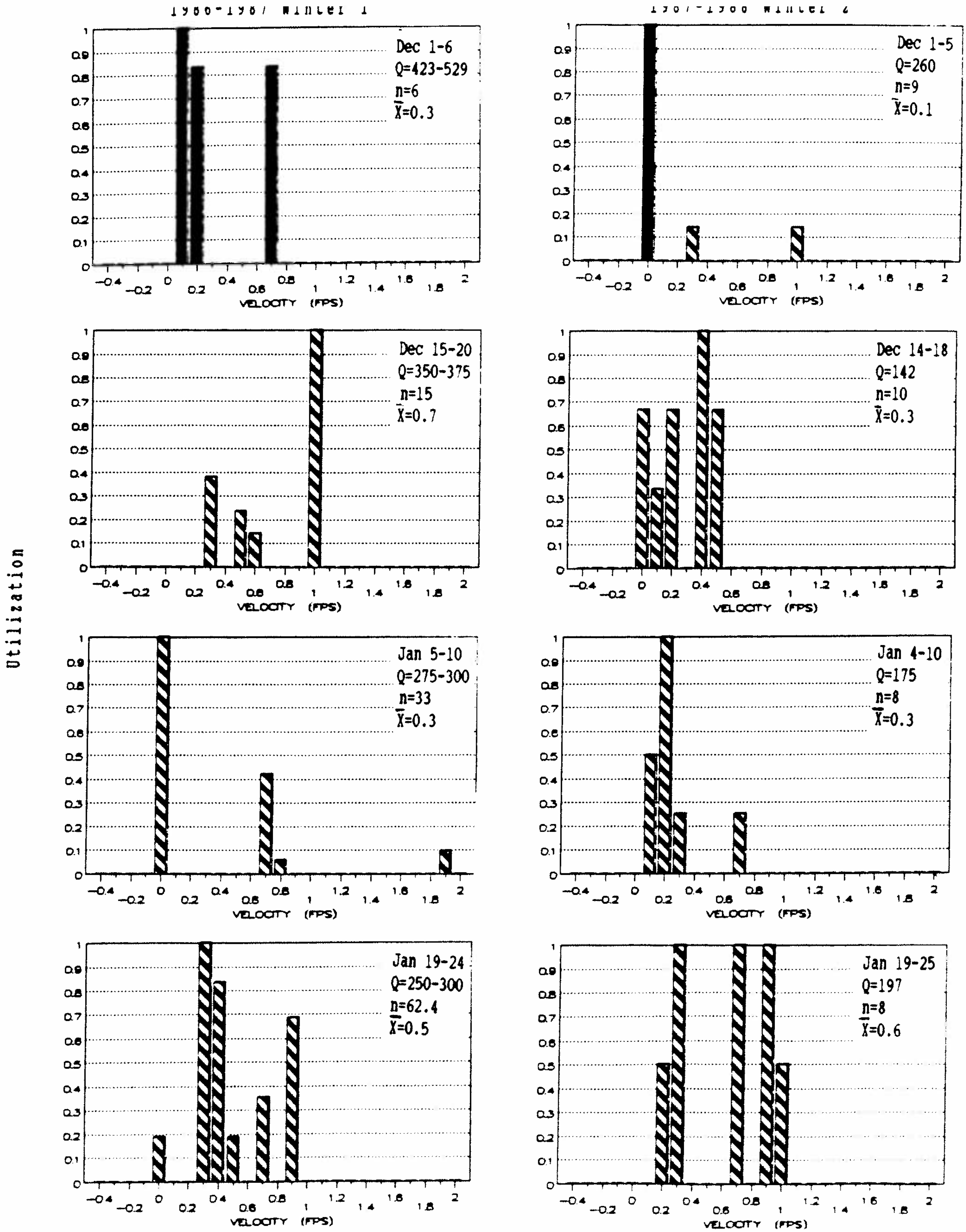
Appendix E3. Bi-weekly velocity utilization (normalized) of eddy and pool habitats by radiotagged Colorado squawfish from December through January during two winters (1986-1987 and 1987-1988) on the Yampa River.



n= number of observations. X̄= mean
Q= discharge at USGS Maybell gage (ft/s).

Eddy
Pool

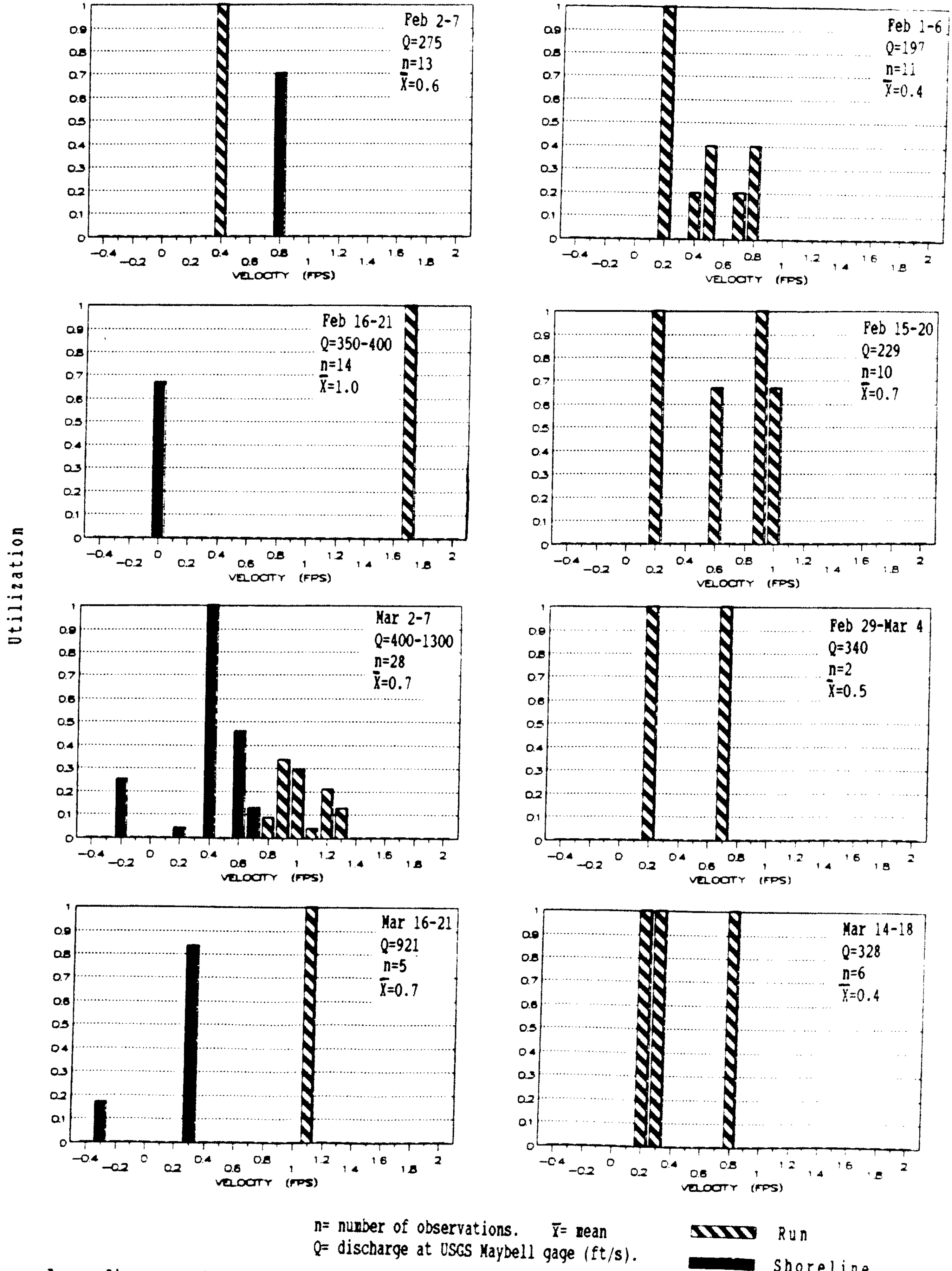
Appendix E4. Bi-weekly velocity utilization (normalized) of eddy and pool habitats by radiotagged Colorado squawfish from February through March during two winters (1986-1987 and 1987-1988) on the Yampa River.



n= number of observations. X̄= mean
Q= discharge at USGS Maybell gage (ft/s).

Run
Shoreline

Appendix E5. Bi-weekly velocity utilization (normalized) of run and shoreline habitats by radiotagged Colorado squawfish from December through January during two winters (1986-1987 and 1987-1988) on the Yampa River.



Appendix E6. Bi-weekly velocity utilization (normalized) of run and shoreline habitats by radiotagged Colorado squawfish from February through March during two winters (1986-1987 and 1987-1988) on the Yampa River.

Appendix F. Types of river ice, their formation, and their effect on water surface elevation.

Appendix F. Types of river ice, their formation and effect on water surface elevation.

Surface ice

Surface ice forms initially on the water surface in areas of zero or low velocity. As surface ice thickens along the shore and at section controls, cross-sectional area is decreased and stage (water surface elevation) will increase for a given discharge (Rantz 1982). In effect, during early and mid-winter, water depths in ice-covered winter habitat are maintained with less discharge.

Anchor ice

Anchor ice is an accumulation of slush adhering to the rock of the stream bed. It is mainly responsible for daily fluctuations in discharge/stage relationships. Anchor ice forms on the stream bed or section controls in late evening or early morning as frazil ice suspended in turbulent currents adheres to rocks or as super-cooled water crystallizes on nucleating agents on the streambed (Rantz 1982). The effect would be an increase of stage at a given discharge. Usually by 1000 hrs, the streambed has warmed, anchor ice is released and floats to the surface, and the stage begins to fall. For a few hours, the stream will be full of floating slush. Small increases in actual discharges in the late afternoon can result from water being released from channel storage as anchor ice upstream goes out and from the melting of snow and ice during the warmer part of the day (Rantz 1982). The effects of anchor ice can be detected on discharge graphs. Discharge and stage measurements can be timed to avoid its effects.

Frazil ice

Frazil ice appears as fine elongated needles, small thin sheets, or cubical crystals that form at the surface of turbulent water at air temperatures of -8 or -9 C (Shen 1985). Turbulence prevents crystals from forming extensive surface sheet ice. When these crystals float into slower water they surface and form masses of floating slush. Floating slush or frazil ice in open water has no effect on the stage discharge relationship. However, floating slush or frazil ice can be carried under surface ice sheets. It can attach to the bottom of surface ice, increasing ice thickness, or accumulate under the ice as thick masses of floating slush. This can reduce the effective depth of water available to fish in pools and runs. Massive under-ice accumulations of consolidated frazil ice or slush ice, termed hanging dams, have been reported in large and small rivers and can lead to large changes in water level (Shen 1985). Channel velocities can increase or shift because water flow is routed around slush-packed areas.