# WINTER HABITAT OF ARCTIC GRAYLING IN AN INTERIOR ALASKA STREAM

A

THESIS

Presented to the Faculty
of the University of Alaska Fairbanks
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

By

Brian R. Lubinski, B.S.

Fairbanks, Alaska

May 1995

## Abstract

Placer mining and the lack of information on winter ecology of Arctic grayling *Thymallus arcticus*, has raised concern for this popular sportfish. A study was designed to validate aerial radio telemetry data and to locate and describe overwinter areas (OWA) of Arctic grayling in Beaver Creek, Alaska. Reliance on aerial data alone resulted in overestimation of survival and misidentification of 14 of 26 designated OWAs. Twenty-one Arctic grayling were tracked downstream 12-58 km to 12 OWAs spanning a 31-km section of Beaver Creek. Radio-tagged and untagged Arctic grayling occupied areas with ice thickness of 0.4-1.4 m overlying 0.06-0.52 m of water, flowing at 0.03-0.56 m/s. During winter, discharge, cross-sectional area, velocities, and water width in four OWAs decreased until late March; then, cross-sectional area increased due to an increase in discharge that pushed the ice upward. Adult Arctic grayling overwintered downstream of habitat disturbances, and occupied much shallower winter habitats than expected.

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# Introduction

This study was implemented in response to increasing concerns for the protection of important Arctic grayling *Thymallus arcticus* migration routes and habitats within the upper watershed of Beaver Creek, Alaska. It was intentionally designed in two components, which together provided the means of addressing the above concerns.

The first component of this study focused on validating location techniques and confirming that both radio-tagged fish and untagged fish (adult Arctic grayling) used the same habitat during winter. This validation approach is an integral part of any biological program which seeks to provide information to land managers using techniques that are yet to be validated or are known to produce variable results.

The second component of this study focused on providing much needed information on the winter habitat of adult Arctic grayling. When data gaps are filled, potential impacts to the aquatic ecosystem are often identified. In addition, mitigation measures can be implemented when impacts are identified before a particular disruptive resource use is allowed to occur.

This study provides specific information on the use of radio telemetry in locating adult Arctic grayling overwinter areas. It also represents the first quantitative approach to describing Arctic grayling winter habitats. In addition, new insights were developed concerning the winter ecology of the Arctic grayling which, collectively, will enhance the management and research of this popular sportfish and its habitats.

## Acknowledgements

This study was funded by the U.S. Bureau of Land Management (BLM) and supported by the U.S. Fish and Wildlife Service (USFWS), Fairbanks Fishery Resource Office. I thank Dr. James B. Reynolds and Dr. Jacqueline LaPerriere, Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska Fairbanks (UAF), and Dr. Erich Follmann, UAF Institute of Arctic Biology, for serving on my graduate committee and for their help and guidance during all aspects of this project; Robert Clark, Alaska Department of Fish and Game, and Sharon Wilson, BLM, for reviewing the first chapter of this thesis for publication; Dr. Val Stuve, Aurora Animal Clinic for helping improve surgical techniques; Nathan Collin, BLM, for his assistance in the field as well as map preparation; Stan Bloom, BLM, for his time and expertise in map and slide preparation; Eric Yeager, Jon Kostohrys, Nathan Collin, Tim DuPont, and Collin Cogley, BLM; David Wiswar, USFWS, for their assistance in the field and in making trails to overwinter areas where no trails existed before; and Roy Nieman and Jim Mitchell, for volunteering their time and ideas to this project which lead to some fantastic underwater video. Lastly, I thank my wife, Mary, and two children, Julie and Andy, for supporting me throughout this time-intensive project.

## Use of ground surveys to validate aerial radio telemetry data; Arctic grayling as a case in point.

### Introduction

Radio telemetry is often considered a valid tool for assessing habitats used by stream fishes (Wichers 1978 as cited in Chisolm 1985; Larimore and Garrels 1985). However, it is only as valid as the equipment, techniques, and interpretations allow. If location equipment and techniques provide for only marginal accuracy and telemetric data interpretations are based on false assumptions (e.g., using qualitative indicators, which are unimportant to fish, for determining radio-tagged fish survival), radio telemetry becomes an invalid tool. Furthermore, it is tempting for biologists to forgo validating the assumption that the attachment and presence of radio tags do not alter fish behavior or habitat use. Occasionally, remoteness or harsh climatic conditions prevent validating techniques and assumptions (West et al. 1992). In other cases, reliance on movement data and previous findings are used (Chisolm 1985). However, a number of factors can lead to errors in telemetric data interpretations. In addition, although tagged fish may be alive and carrying transmitters, their behavior or habitat use may have been altered.

In response to these concerns, a validation component was added to a habitat study on Arctic grayling *Thymallus arcticus*. This component focused on identifying the direction and degree of error in interpretations of aerial radio telemetry data and evaluating the assumption that surgically implanted transmitters do not alter habitat use.

From 1991 to 1993, aerial radio telemetry was used to follow the fall migration and locate winter habitats of Arctic grayling within the upper Beaver Creek drainage. Ground surveys were used to validate aerial data. Ground surveys were important in determining which transmitters had been retained by live fish and verifying that habitat use of untagged and tagged Arctic grayling were the same. This information becomes especially important when habitat locations and descriptions obtained using radio-tagged fish are used to establish management prescriptions. This chapter describes the use of ground surveys to validate aerial telemetry data on fish survival, transmitter retention, and habitat use during winter.

## Methods

Adult Arctic grayling were captured by angling from their summer feeding areas in the headwaters of Beaver Creek and surgically implanted with high frequency (152 MHz) radio transmitters. Twenty fish were collected from Little Champion Creek during 30 August-1 September 1991 and 38 from Nome Creek during 3-12 August 1992.

Two types of radio transmitters (Telonics models CHP-2P and CHP-3P, Mesa, AZ)[1] were used for implants. Both types were sealed with polymers and each transmitter was assigned a unique frequency (Table 1). Attempts were made to implant transmitters less than or equal to 2% of fish weight as suggested by Winter (1983), but this was often exceeded, especially in 1992 due to a lack of large fish and an unanticipated increase in transmitter weight caused by thicker polymer coatings. Air weight of the CHP-2P tags ranged from 1.1 to 2.6% of fish weight; 1.8 to 3.4% for the CHP-3P tags.

Surgical Procedures

Surgical procedures in 1991 followed those of West et al. (1992). In 1992, surgical procedures were slightly modified as follows. Immediately after capture, fish were placed in a bucket of river water and weighed. Fish heavier than 300 g were implanted with CHP-2P tags and those over

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[1] Trade names and commercial enterprises are mentioned solely for information. No endorsement is implied.

Table 1. Characteristics of the Telonics transmitters surgically implanted into Arctic grayling captured within the headwaters of Beaver Creek, Alaska.

| Tag | Dimensions | | | | Antenna |
|---|---|---|---|---|---|
| type | length (mm) | width (mm) | depth (mm) | Weight (g) | length (mm) |
| CHP-2P | 30 | 12 | 6 | 6.0-7.0 | 256 |
| CHP-3P | 45 | 12 | 6 | 11.0-13.0 | 256 |

350 g with CHP-3P tags. Fish weight (g) and fork length (mm) were recorded and a scale sample taken according to Brown (1943). Ages were later determined by counting annuli identified according to the criteria established by Kruse (1959). Scale ages are believed to be reliable for Arctic grayling up to age 7 or 8 (Armstrong 1986).

Tricain methanesulfonate (MS-222) was added to the water to make a concentration of 50-100 mg/L. Once opercular movement increased and equilibrium was noticeably affected (stage 3 anesthesia, Summerfelt and Smith 1990), the fish was placed ventral side up in a V-shaped, foam-lined trough soaked in river water. Depending on the stage of anesthesia during surgery, either river water or anesthetic was applied to the gills. All surgical instruments, including transmitters, were sterilized with a cold sterilant (Control III, Maril Products Incorporated, Tustin, California). A 12-18 mm incision through the skin and muscle just anterior to the pelvic girdle along the midventral axis was made with a number 12 stainless steel scalpel. A 127 mm rat-toothed forceps was used to pull the skin and muscle away from the underlying viscera so that the incision could be made into the peritoneal cavity. A water soluble, powdered topical antibacterial agent (Furacin, Smithkline Beecham Animal Health, Chester, Pennsylvania), was squeezed into the peritoneal cavity. The transmitter antenna was threaded through a 115 mm stainless steel cutting edge surgical needle. The needle was carefully inserted into the peritoneal cavity under the pelvic girdle and pushed through the body wall between the pelvic girdle and vent. The transmitter antenna was then gently pulled while lightly pushing the transmitter through the incision and into the peritoneal cavity, slightly posterior to the pelvic girdle. The antibacterial powder was again squeezed into the incision and the incision sutured using monofilament nylon 3-0 suture with a cutting FS needle. A 150 mm Olsenhager stainless steel needle holder was used to complete the four to five, three-knot, simple, interrupted sutures using the instrument tie as described in Summerfelt and Smith (1990). The body wall and skin were sutured together and the suture drawn tight enough to just begin folding the two sides of the incision together. The incision was then blotted dry and Vetbond (Animal Care Products-3M Company, Minneapolis, Minnesota) liquid suture thinly applied. The fish was then placed immediately in the water and held ventral side up, with the incision above the water, for 1-2 min to allow the Vetbond to dry. The fish was then released into a quiet backwater area and monitored until it swam off on its own, usually within 15 min of release. Surgery time ranged from 4 to 15 minutes and averaged 7 minutes.

Aerial Tracking

Aerial relocations of fish were attempted 1-3 times per month during the fall migration and then less frequently after movements decreased substantially, usually by early December. Locations were recorded to the nearest 0.16 km stream length on 1:63,360 USGS quadrangles. Flights were conducted at 200 to 250 m above ground level at an average speed of 148 km/h. Fixed-wing, single-engine aircraft were configured with dual "H" antennas mounted on the wing struts, and antenna reception was manually controlled using a switch box. A Telonics (Mesa, Arizona) TR-2 receiver, TDP-2 advanced digital data processor and TS-1 scanner, programmed for 0.9 frequencies/s (54/min), were used. Locations were determined by monitoring pulse intensity during manipulation of antenna reception. Fish survival and transmitter retention were determined from aerial data based primarily on whether or not the fish had made a significant move, as determined by locations falling outside a 500-m radius circle of the previous location. This distance was selected because it amply exceeded the ± 100 m stream length of the true location documented by West et al. (1992), as well as the ± 160 m for this study. A circle was used as opposed to stream length to account for stream sinuosity. When at least one significant move had occurred, but doubt remained due to the short distance traversed, two other criteria were applied: (1) the timing of fall migration relative to the other tagged fish, and (2) the proximity of open-water leads (spring areas), known deep pools, or aufeis areas (where water erupts through the ice and freezes in layers to form ice fields often several meters thick) at the transmitter location.

The physical characteristics identified under criteria (2) are based on observations of fish associated with these characteristics during winter. These characteristics have been used to locate sources of liquid water in winter (Wilson et al. 1977) and to identify sites for winter fish sampling with some success (Schallock 1980; Van Hyning 1978). Adult Arctic grayling have been documented within open-water leads (spring-fed areas) within the Beaufort Sea drainages of eastern Yukon Territory (de Bruyn and McCart 1974) and the North Slope of Alaska (Craig and Poulin 1975; West et al. 1992), as well as in interior Alaska (Netsch 1975). Similarly, Arctic grayling have been found to overwinter in deep pools of mainstem rivers in Russia (Zakharchenko 1973) and interior Alaska (Tack 1974). Arctic char *Salvelinus alpinus* and subadult Arctic grayling were found to overwinter in areas containing aufeis in the North Slope of Alaska (Furniss 1975; Bendock 1982). Hughes and Burkholder (Alaska Cooperative Fish and Wildlife Research Unit, Fairbanks, personal communication) found many subadult Arctic grayling within an aufeis field in a small interior Alaska stream.

Aerially-determined overwinter areas (OWA) were considered to be those areas where fish were located January-April, and had met either the first criterion (significant movement) or either of the two other criteria (migration timing or proximity of flowing water). Tagged fish within 160 m stream length of each other were considered to be within the same OWA.

Ground Surveys

Overwinter areas 25 to 34 km from the road system were reached by snowmachines during January-April. Transmitter locations were determined using the scanner-receiver and a Telonics RA-1A hand-held paddle antenna. Once the highest pulse intensity had been attained, the coaxial antenna cable was disconnected from the receiver to reduce the range of reception, and the transmitter was relocated. This procedure provided locations within a 1-m radius of the true location (as determined from those situations when a loose transmitter was physically recovered). Chisolm (1985) documented a detection accuracy of 0.6-1.2 m using a bidirectional loop antenna and Custom Telemetry receiver (Athens, Georgia), however, he conducted these tests prior to implant during the summer (I. Chisolm, Minnesota Department of Natural Resources, personal communication). A hole was drilled directly over the transmitter location with a power auger and the transmitter was relocated. Fish survival and transmitter retention were confirmed when the transmitter location, after drilling, fell outside a 1-m radius circle centered around the initial location. This procedure was repeated until fish status was confirmed and often resulted in the physical recovery of the transmitter in cases where the fish had perished or had expelled its transmitter. The assumption that radio-tagged fish select the same winter habitats as untagged fish was validated when untagged and tagged Arctic grayling were observed together.

To measure habitat variables and to observe fish, a series of holes were drilled across the channel directly over the original location of each transmitter. Under-ice observations were made using either a model B underwater periscope or type 6/V801 Fieldcam (Fuhrman Diversified Inc., Seabrook, TX).

# Results

Of the 58 radio-tagged Arctic grayling, 2 were not located aerially after October (possibly due to transmitter failure), and 17 could not be located during ground survey due to inaccessibility, dangerous weather, or time constraints caused by short daylengths. Analysis of the aerial data on the remaining 39 tagged fish indicated that all had survived and retained their transmitters within 26 different OWAs. Subsequent ground surveys however, confirmed that 18 of these fish had actually perished or had expelled their transmitters, reducing the number of OWAs to 12 (Table 2). The 21 fish confirmed alive and with transmitter averaged 348 mm in fork length, 442 g in wet weight, and were from 8 to 10 years of age (Table 3). The 18 fish found to have perished or expelled their transmitters were of similar length, weight, and age (Table 4).

When fish survival and transmitter retention were confirmed, under-ice observations were conducted to confirm that identified OWAs were representative of those used by the untagged portion of the population. Several factors affected these observations. The length and quality of observations at any particular site were quite variable due to constraints inherent in subarctic winter field studies

Table 2. Aerial radio telemetry data interpretations made before and after ground surveys of radio-tagged Arctic grayling in Beaver Creek, Alaska.

| Survey | Status | | |
|---|---|---|---|
| | Alive | Dead/expelled tag | OWA[a] Identified |
| Aerial | 39[b] | 0 | 26[b] |
| Ground | 21[c] | 18 | 12[c] |

[a] OWA = Overwinter area.
[b] Based on the timing of fall migration and aerial views of open leads, aufeis areas, or known deep pool areas.
[c] Based on confirmed movements and direct observation of radio-tagged fish.

Table 3. Summary of radio-tagged Arctic grayling confirmed alive and with transmitter in overwinter areas (OWA) within Beaver Creek, Alaska. Tag-Body weight ratios are based on air weights.

| Fish | Implant date | Implant location (river km)[a] | OWA location (river km)[a] | Arrive OWA | Fork length (mm) | Fish weight (g) | Fish age | Tag-body weight ratio (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 8/5/92 | 488.4 | 465.3 | 10/30/92-11/27/92 | 342 | 405 | 9 | 3.0 |
| 2 | 8/11/92 | 492.9 | 465.3 | 10/16/92-10/30/92 | 343 | 370 | 9 | 3.3 |
| 3 | 9/1/91 | 491.0 | 464.3 | 11/12/91-1/7/92 | 384 | 645 | - | 1.9 |
| 4 | 9/1/91 | 491.2 | 464.3 | 11/12/91-1/7/92 | 376 | 610 | - | 1.8 |
| 5 | 8/4/92 | 476.2 | 464.3 | 11/27/92-1/15/93 | 344 | 410 | 9 | 2.8 |
| 6 | 8/11/92 | 489.1 | 464.3 | 10/16/92-10/30/92 | 334 | 360 | 8 | 3.1 |
| 7 | 8/11/92 | 490.2 | 464.3 | 9/15/92-10/16/92 | 373 | 485 | 9 | 2.4 |
| 8 | 8/4/92 | 479.3 | 461.1 | 9/15/92-10/16/92 | 349 | 440 | 10 | 2.6 |
| 9 | 8/11/92 | 489.7 | 461.1 | 9/15/92-10/16/92 | 325 | 350 | 8 | 3.3 |
| 10 | 9/1/92 | 492.6 | 460.3 | 1/7/92-3/11/92 | 374 | 545 | - | 1.1 |
| 11 | 9/1/92 | 496.6 | 457.4 | 1/7/92-3/17/92 | 363 | 535 | - | 2.1 |
| 12 | 8/4/92 | 488.8 | 451.6 | 12/29/92-3/2/93 | 332 | 355 | 9 | 3.2 |
| 13 | 8/4/92 | 474.0 | 451.3 | 12/29/92-1/15/93 | 311 | 300 | 9 | 2.3 |
| 14 | 8/11/92 | 491.7 | 451.3 | 11/27/92-12-29-92 | 340 | 390 | 8 | 3.1 |
| 15 | 8/11/92 | 488.9 | 450.8 | 11/27/92-12-29-92 | 349 | 420 | 9 | 2.7 |
| 16 | 9/1/91 | 492.6 | 449.5 | 11/12/91-1/7/92 | 347 | 515 | - | 2.2 |
| 17 | 9/1/91 | 492.6 | 448.8 | 9/24/91-9/29/91 | 374 | 550 | - | 2.1 |
| 18 | 8/4/92 | 486.0 | 448.8 | 8/4/92-10/16/92 | 332 | 365 | 8 | 3.2 |
| 19 | 8/4/92 | 486.7 | 448.8 | 8/4/92-10/16/92 | 332 | 360 | 9 | 3.2 |
| 20 | 8/11/92 | 491.8 | 440.2 | 1/15/93-3/2/93 | 329 | 360 | 8 | 3.3 |
| 21 | 8/4/92 | 473.8 | 434.7 | 10/16/92-10/30/92 | 357 | 505 | - | 2.4 |

[a] River km from the Yukon River.

Table 4. Summary of radio-tagged Arctic grayling found to have perished or expelled their transmitter within Beaver Creek, Alaska. Tag-Body weight ratios are based on air weights.

| Fish | Implant date | Implant location (river km)[a] | Final location (river km)[a] | Fork length (mm) | Fish weight (g) | Fish age | Tag-body weight ratio (%) |
|---|---|---|---|---|---|---|---|
| 1 | 8/30/91 | 498.7 | 490.5 | 324 | 355 | - | 1.7 |
| 2 | 8/31/91 | 493.7 | 490.2 | 362 | 590 | - | 1.8 |
| 3 | 9/1/91 | 491.5 | 489.9 | 353 | 495 | | 1.3 |
| 4 | 8/31/91 | 492.8 | 489.9 | 334 | 370 | - | 1.6 |
| 5 | 8/31/91 | 497.3 | 490.5 | 295 | 295 | - | 2.0 |
| 6 | 8/31/91 | 491.0 | 484.6 | 365 | 500 | - | 2.2 |
| 7 | 9/1/91 | 492.6 | 483.8 | 316 | 345 | - | 1.7 |
| 8 | 8/31/91 | 493.6 | 483.3 | 358 | 505 | - | 2.2 |
| 9 | 8/5/92 | 487.1 | 471.5 | 330 | 370 | 9 | 3.2 |
| 10 | 8/4/92 | 482.8 | 467.2 | 351 | 440 | 9 | 2.7 |
| 11 | 8/5/92 | 486.7 | 463.7 | 348 | 440 | 9 | 2.6 |
| 12 | 8/31/91 | 497.2 | 462.0 | 315 | 340 | - | 1.9 |
| 13 | 8/10/92 | 488.8 | 462.2 | 345 | 450 | - | 2.7 |
| 14 | 8/4/92 | 482.8 | 461.2 | 330 | 370 | 8 | 3.1 |
| 15 | 8/31/91 | 492.5 | 459.8 | 336 | 395 | - | 1.5 |
| 16 | 8/31/91 | 492.3 | 454.8 | 347 | 465 | - | 2.4 |
| 17 | 8/11/92 | 491.2 | 450.3 | 348 | 410 | 8 | 2.9 |
| 18 | 8/4/92 | 480.7 | 431.5 | 337 | 400 | - | 2.9 |

[a] River km from the Yukon River.

(i.e., cold temperatures, poor lighting). Underwater visibility varied with the time of day and month, flow depth, ice thickness, and snow depth. Snow removal helped substantially, but could only be accomplished over a limited area due to 0.5-0.8 m snow depths. Furthermore, locations of tagged fish after drilling revealed that noise from drilling displaced fish 3-91 m from their initial location; 14 of 19 displaced fish returned to their initial location after drilling. Of these 14 fish, most returned within 2 to 24 h. Despite these limitations, under-ice observations were conducted in 11 of 12 OWAs; the presence of untagged adult Arctic grayling was confirmed in eight of these areas. Subadult Arctic grayling were present in only 2 of the 11 OWAs and were outnumbered 12 to 1 overall, suggesting a habitat preference of subadults different from that of adults.

No similarities were found among the winter habitats previously described for Arctic grayling (i.e., open-leads, deep pools, and aufeis areas) and the winter habitats documented in this study. Specifically, deep pool areas would be associated with deep flow depths such as the 4-6 m depths documented by Zakharchenko (1973), open-leads with ice-free areas such as those documented by West et al. (1982), and aufeis areas with relatively snow-free areas of thick ice as observed by Bendock (1982). In this study, within the 12 confirmed adult Arctic grayling OWAs, winter low-flow (February-March) depths were 0.03-0.76 m under an ice thickness of 0.03-1.40 m.

## Discussion

This study clearly shows that analyses based solely on aerial radio telemetry data may overestimate survival. Aerial re-locations of 39 transmitters suggested 100% survival, but ground surveys revealed that only 21 of these fish, or 56%, were in live fish. Furthermore, aerial data resulted in the misidentification of 14 of 26 OWAs, because 18 of 39 transmitters were expelled or in dead fish, thus failing to confirm the presence of an OWA. To minimize these errors, it is important to identify the factors that lead to misinterpretations of aerial telemetry data so they can be incorporated into final data interpretations. Adult Arctic grayling in interior Alaska typically exhibit downstream movements in the fall, followed by a long period of inactivity throughout the winter. Therefore, factors that contribute to delayed mortality or transmitter expulsion after the fall migration has begun, would lead to errors in aerial data interpretations.

A potentially large source of mortality is the predation on tagged fish by otter _Lutra canadensis_, and to a lesser extent, mink _Mustela vison_. Of 20 transmitters that were physically recovered, four had otter tooth marks on them and one had those of mink (M. Ben-David, Alaska Cooperative Fish and Wildlife Research Unit, Fairbanks, personal communication). Work conducted by Erlinge (1968) on captive otter and Poole and Dunstone (1976) on captive mink supports my suspicion that tagged fish are more likely to be preyed upon, not just because of their assumed reduced ability to escape, but also because the trailing transmitter antenna and behavioral differences may attract these predators.

Delayed mortality from the stress of surgery and the presence of the transmitter is also suspected, based on the weight loss of radio-tagged fish recaptured 12 months after implantation. Seven fish were recaptured 286-359 d after surgery and were found to have lost from 1 to 120 g (mean 29 g). However, weight loss is normal during winter and no controls were available for an evaluation of weight loss due to radio-tagging.

Natural mortality may also play an important role in making erroneous aerial data interpretations. This is especially true in studies such as this, that must make use of the largest, and therefore older, fish in the drainage to minimize tag-body weight ratios. Of the 14 radio-tagged fish aged in this study, none were younger than 8 years (Table 3).

Finally, transmitter expulsion would also lead to misleading aerial data. One of seven recaptured fish showed signs of transmitter expulsion, with the transmitter visible through a non-ulcerated hole near the midventral axis, anterior to the pelvic fins. This phenomenon has not been studied in Arctic grayling, but has been documented in channel catfish Ictaluras punctatus by Marty and Summerfelt (1986) and in rainbow trout Oncorhyncus mykiss by Helm and Tyus (1992).

When resource uses are modified or eliminated to protect or minimize impacts to misidentified OWAs, management agencies and potential user groups are penalized in management errors. Also, resource managers are sometimes forced to trade-off restrictive management prescriptions for more liberal ones in areas believed to have less crucial habitat at risk. This practice could lead to protecting misidentified habitats and disturbing habitats that are important to the survival and well being of the fish population. Magnifying this problem is the extrapolation of study results, and the subsequent establishment of management prescriptions, to unstudied areas.

In conclusion, ground surveys proved to be a valuable tool in accurately interpreting aerial radio telemetry data on adult Arctic grayling. Factors contributing to erroneous aerial data interpretations included post-surgical mortality and/or transmitter expulsion during migration, combined with the use of habitat features which were assumed, based on the results of previous studies, to be indicators of Arctic grayling winter habitats. Predation, delayed surgical mortalities, and natural mortality are believed to be the primary factors affecting post-surgical mortality. Finally, ground surveys verified the assumption that winter habitat use was the same for tagged and untagged Arctic grayling. This validated the use of radio-tagged adult Arctic grayling to document winter habitat locations and descriptions for the general population.

## Summary

Radio transmitters were surgically implanted in 58 adult Arctic grayling in fall 1991 and 1992 to study habitat use in Beaver Creek, Alaska. Aerial data on fish survival, transmitter retention, and habitat were validated by ground surveys. Of the 39 radio-tagged fish that could be ground surveyed, aerial movement and habitat data indicated all were alive and had retained their transmitters. However, ground surveys confirmed that 18 of 39 had perished or expelled their transmitters. Habitat use was not affected by surgical implants based on the presence of tagged and untagged fish in 8 of 11 OWAs. Arctic grayling occupied OWAs with ice thicknesses of 0.03 to 1.40 m overlying 0.06 to 0.76 m of water; these areas were quite different from the open leads, aufeis areas, or deep pools often considered as indicators of winter fish habitat. Ground surveys were essential in accurately interpreting aerial telemetry data and validated the use of radio-tag implants for habitat studies of adult Arctic grayling.

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# Winter habitat of Arctic graying in Beaver Creek, Alaska

## Introduction

Biologists have long recognized the importance of winter habitat to freshwater fish populations in the Arctic. Some of the first studies to address winter habitat of Arctic grayling *Thymallus arcticus* in Alaska were those of Wojcik (1955), Warner (1957), Nagata and Van Whye (1963), Reed (1964), and Schallock (1965). The importance of winter habitat to arctic fish populations is based on the scarcity and quality of liquid water during this period. Craig (1989) states that one of the most physically significant aspects of the Arctic is the drastic reduction of fish habitat in winter. In addition to these physical factors, fish are physiologically stressed and depend on the physical, chemical, and biological stability of the aquatic ecosystem to successfully overwinter. Craig (1989) provides an excellent overview of the factors affecting the overwintering success of arctic fishes.

Knowledge of the winter ecology of arctic fish populations is important for rational management, especially habitat protection. This information need is expressed in the number of recommendations for additional research on winter fish ecology found in the literature; many of these recommendations are specific to the winter ecology of Arctic grayling (Wojcik 1955; Nagata and Van Whye 1963; Craig and Poulin 1975; Wilson et al. 1977; Stuart and Chislett 1979; Bendock 1980; Tack 1980; Holmes 1983, 1984; Ridder 1985; Reynolds 1989). Management issues related to winter ecology of Arctic grayling include stock separation (Holmes 1984), migration barriers (West et al. 1992), instream flow (Wilson et al. 1977), critical habitat protection (Holmes et al. 1986), and introductions of non-native species (R. Clark, Alaska Department of Fish and Game, Fairbanks, personal communication).

There have been many studies addressing winter habitat of Arctic grayling in Alaska and Canada. Reviews of this work can be found in Tack (1980), Krueger (1981), and Armstrong (1986). However, with few exceptions, these studies focused on qualitative descriptions, either by design or due to technological limitations, time and weather constraints, or reduced access. Review of the quantitative data currently available clearly indicates a need for more detailed winter habitat studies of Arctic grayling.

This study was conducted from 1991 to 1994 within the upper Beaver Creek drainage in interior Alaska. The purpose of this study was to characterize the physical attributes of overwinter areas (OWAs) used by adult Arctic grayling and document the range of these characteristics within microhabitats occupied by individual fish. This study represents the first attempt to quantitatively describe Arctic grayling winter habitat.

## Study Area

The Beaver Creek watershed, located in the eastern interior of Alaska, flows 481 km from its origin in the limestone-rich White Mountains to its confluence with the Yukon River (Figure 1). This area is characterized by forested upland plateaus scattered with 1,200-1,500 m tundra-covered mountains. Beaver Creek has moderate-to-high confinement, moderate gradient and sinuosity, fine gravel to cobble substrate, clear water, numerous springs, and frequent gravel bars. Open leads persist in many areas throughout the winter and can be several kilometers long in the 423 km downstream of Big Bend (lower basin). In the 58 km upstream of Big Bend (upper basin), open leads are small and scattered throughout the drainage and aufeis fields, although present in the mainstem, are common in the five headwater tributaries from which Beaver Creek is formed. This study took place in the upper basin (Figure 2).

The basin lies in the subpolar continental climatic zone characterized by long cold winters and short hot

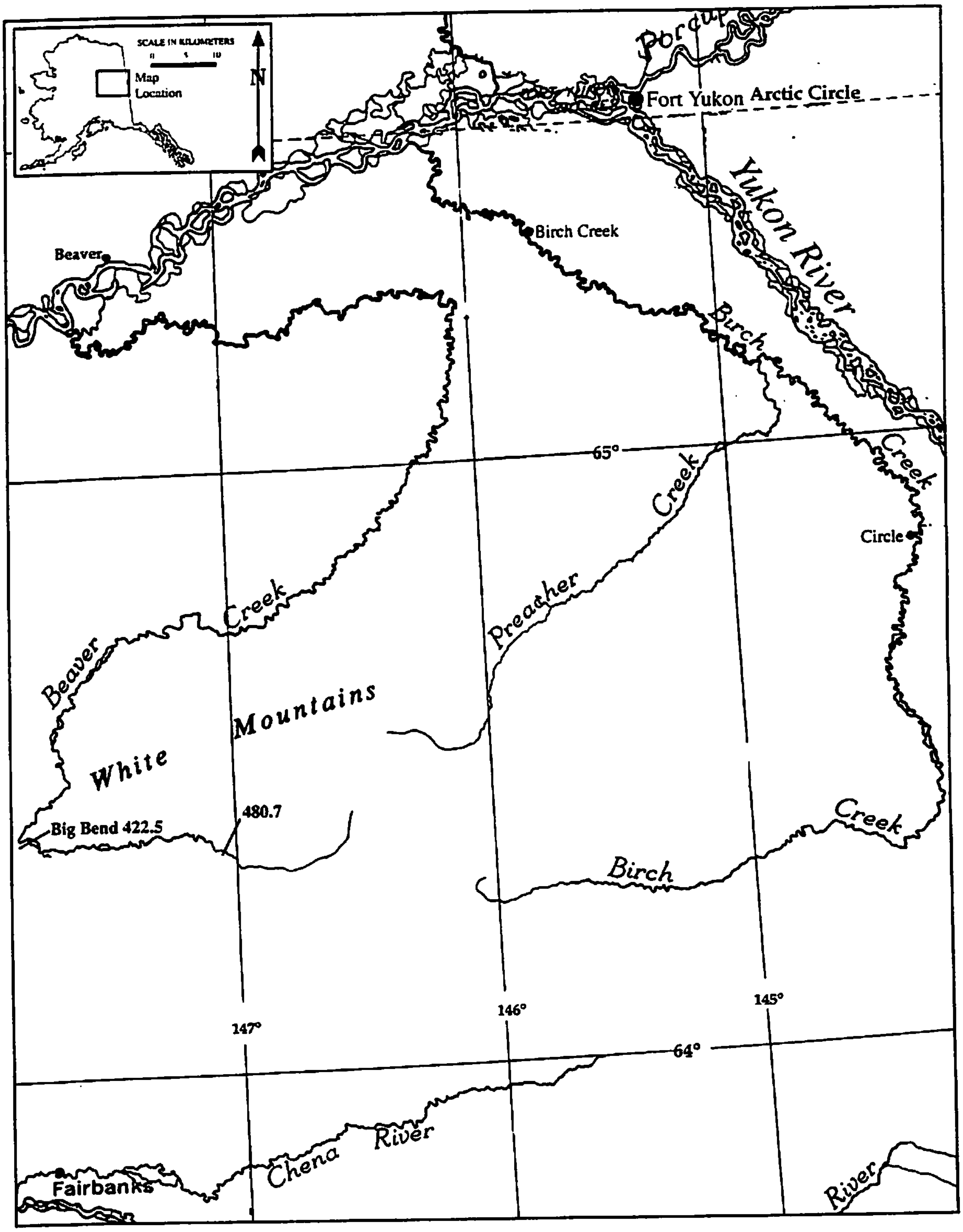


Figure 1. The Beaver Creek watershed, Alaska.

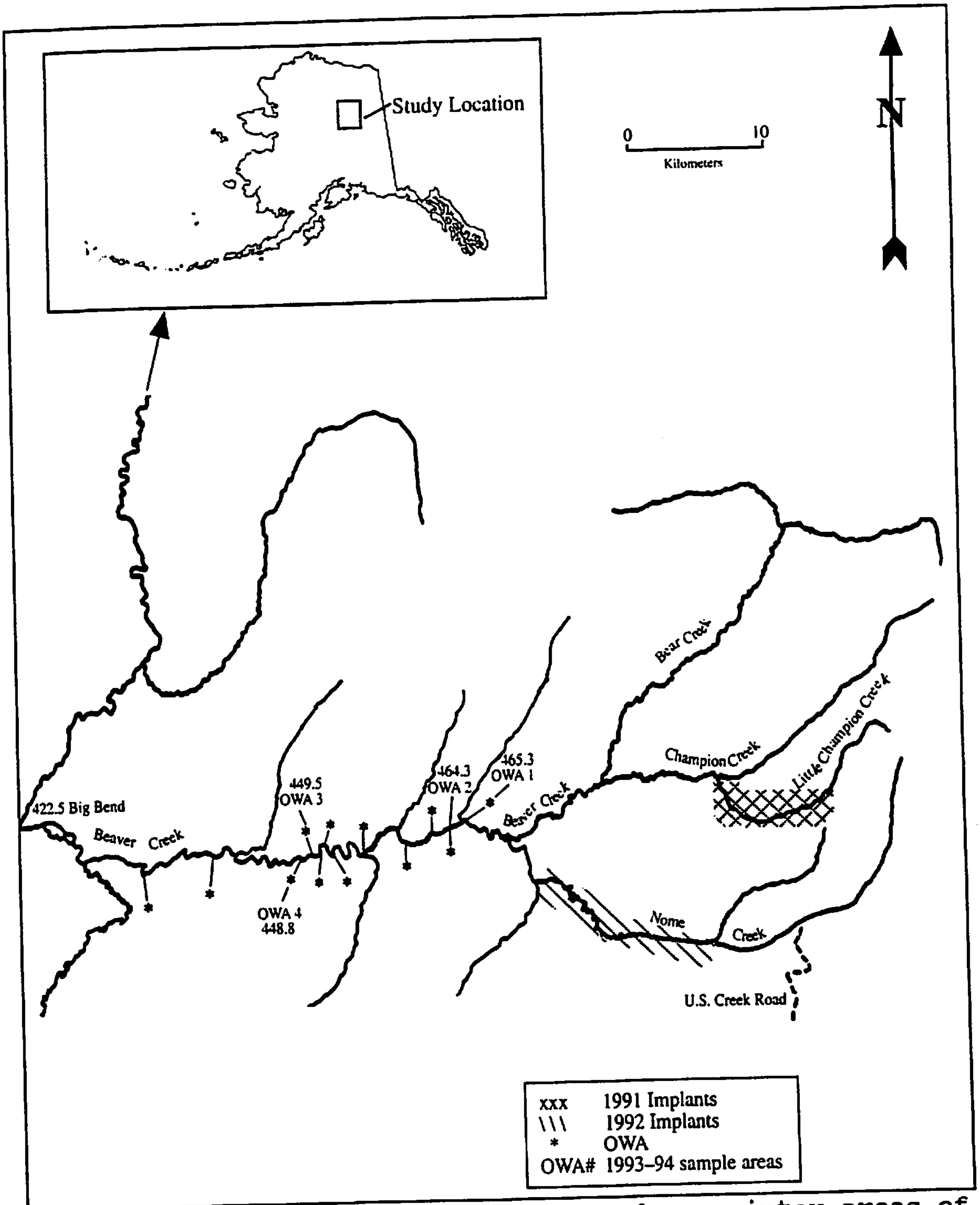


Figure 2. Capture-release locations and overwinter areas of Arctic grayling within the upper mainstem of Beaver Creek, Alaska.

summers (USDC 1968). Day length varies widely with a winter minimum of under 4 h and a summer maximum of over 21 h. Temperature extremes range from -50 $^0$C in winter to +30 $^0$C in summer. Rainfall averages 25-38 cm per year at nearby recording stations, though variations are great due to surrounding topography (Kostohrys and Sterin 1994). Precipitation is generally greater at higher elevations during summer; most occurs as rainfall from late June to early September (USDC 1968). Snowfall averages about 127 cm per year, with about 51 cm remaining on the ground prior to spring break-up (Kostohrys and Sterin 1994). Break-up usually begins in late April to mid-May and high streamflow may persist into June. Freeze-up on streams often begins at higher elevations in mid-September, though some streams lower in the basin remain open until November. Mean monthly discharge above Big Bend (upper basin) ranged from a summer maximum of 43 to 48 $m^3$/s (June) to a winter minimum of 0.40 to 0.99 $m^3$/s (March) during 1988-1992 (Kostohrys and Sterin 1994). Deep pools are present throughout the upper mainstem during summer and may even exceed 3 m within sharp bends of the headwater tributaries.

The relatively flat floodplain varies in width from 60 to 150 m in the upper basin to 800 to 1600 m in the lower basin. Riparian habitats consist of white spruce Picea glauca, balsam poplar Populous balsamifera, black spruce P. mariana, willow Salix spp., alder Alnus crispa, dwarf birch Betula nana and B. glandulosa, grasses, ericaceous shrubs, and herbaceous communities consisting of eriophorum and other sedges Carex spp.. Fish species include Arctic grayling, round whitefish Prosopium cylindraceum, northern pike Esox lucius, burbot Lota lota, sheefish Stenodus leucichthys, king salmon Oncorhynchus tshawytscha and chum salmon O. keta, and slimy sculpin Cottus cognatus.

## Methods

Overwinter areas of adult Arctic grayling were located during the winters of 1991-92 and 1992-93 by tracking adult fish implanted with radio transmitters. Details of this work appear in the previous chapter of this thesis. During the winter of 1991-92 and 1992-93, the focus was on characterizing habitat during the winter low-flow period (February-March) by taking one series of measurements across a single transect established over each radio-tagged fish location. Efforts in 1993-94 focused on characterizing and monitoring trends within OWAs using repeated measurements of multiple transects throughout the winter. February 1994 measurements were used for monitoring trends as well as describing low-flow conditions within OWAs, therefore these measurements were also included in the 1991-92 and 1992-93 winter low-flow analyses.

Winter low-flow measurement

The transect method was selected to describe winter habitat of adult Arctic grayling. Holes (stations) drilled across the entire transect were used to describe available habitat (availability); those stations within 1 m of adult Arctic grayling were used to describe occupied habitat (i.e., microhabitat or use). Chisolm (1985) used whole transects to describe stream habitat use by Brook Trout Salvalinus fontinalis in winter and concluded that variability within these data may have been reduced by using data collected closer to the fish. Therefore, I collected data from both whole transects and within 1 m of fish to compare these two approaches for describing Arctic grayling winter habitat. My intention was to characterize winter habitat when it was most limited, therefore data on available habitat and microhabitat were collected during the low-flow period (February-March).

Transects were established perpendicular to the channel and extended from bank to bank over a radio-tagged fish location. Transects were shoveled out along their entire water width and a series of 15 to 20 stations were drilled.

A station was identified by its distance from a benchmark established on the bank closest to the thalweg (line of maximum water depth) and comprised half the distance between the holes on each side of it. Attempts were made to space stations so that a maximum of 10% of the flow was accounted for within each station (Rantz et al. 1982). This was done by increasing the number of stations as water width increased, but was not always possible due to logistical constraints.

Snow depth, ice thickness, flow depth (water under ice), and water, ice, and channel widths were recorded throughout the transect. Mean velocity of the water column in the vertical was measured at 0.6 depth from the ice bottom and a discharge measurement calculated according to Rantz et al. (1982). Mean velocity for entire cross-sections was calculated by dividing discharge by cross-sectional area. Velocities measured within 1 m of adult Arctic grayling were averaged (Aadland 1993). Velocity was measured with a Scientific Instruments vertical-axis, vane type current meter mounted on a graduated rod. Ice thickness was measured with the rod by hooking the ice with the meter and flow depth determined by subtracting ice thickness from the stream bottom to top of ice value. All widths were measured with a tape stretched across the channel.

Although radio-tagged fish would move 3-91 m out of the area during drilling, 14 of 19 returned to their original location within 2-24 h. Therefore, to avoid biasing microhabitat data, a minimum of 12-24 h (one night) separated transect establishment and the measurement of microhabitat characteristics. Water velocity, ice thickness, and flow depth were recorded at those stations where fish were either located with telemetry or observed within approximately 1 m of the station.

Temperature, dissolved oxygen, total alkalinity (as $CaCO_3$), hardness (as $CaCO_3$), conductivity, pH, and turbidity were collected from most OWAs within transect sections occupied by fish. Water samples, collected by submerging a 250 ml graduated cylinder under the ice by hand or on a string for several minutes, were analyzed on site. Turbidity measurements were made in the laboratory from samples transported in plastic bottles. The conductivity meter was typically calibrated at the beginning and end of each trip, however, standards used in calibrations were not at the same temperature as the samples at the time of testing and may have resulted in a decrease in accuracy.

The HACH wide-range pH test was used for most of the pH measurements and occasionally a pH meter, calibrated prior to each test, was used to support these tests. Titrations were completed using HACH 0.16 N $H_2SO_4$ cartridges (alkalinity) and 0.08 EDTH (hardness) and accuracy tests performed on at least one of the three repetitions by titrating back to the starting point. Water quality equipment included a digital titrator (HACH model AL-36DT), conductivity/total dissolved solids/temperature meter (HACH model 44600), pH meter (HACH model 43800-00) and turbidimeter (HF Scientific model DRTC-15C). During winter 1992-93, dissolved oxygen was measured using a HACH pocket colorimeter and Accuvac ampules.

Monthly overwinter area measurement

Four OWAs were selected for study from December 1993 through March 1994. Two areas were selected from the upper part of the reach and two from the lower section (Figure 2), in an attempt to encompass the range of winter habitat within the upper mainstem of Beaver Creek. Criteria for selection of OWAs included documented use by live radio-tagged fish in winters 1991-92 and 1992-93, and number of tagged and untagged fish observed within them.

Three transects, perpendicular to the channel and spaced 40 m apart, were established within each of the four OWAs. Simonson et al. (1994) investigated the use of transects for evaluating the full range of stream fish habitats in summer (pools, riffles, glides) and recommended measuring habitat variables along approximately 20 transects, spaced two mean stream widths apart. They defined mean stream width as the horizontal distance along a transect, measured perpendicular to stream flow from bank to bank, at existing water surface. Mean stream width for this study was defined as the mean ice width. Because only winter habitat of adult Arctic grayling was being evaluated in this study and the mean ice width was 59 m in the upper section and 77 m in the lower section, the number and spacing of transects was likely sufficient to describe the OWAs.

Transect locations within the four OWAs were determined based on the location of transects used in previous years within each OWA. Two of the OWAs (2 and 4) had two transects established (B and C) from previous work where several radio-tagged fish were located. Within the other two OWAs (1 and 3), two additional transects were established so that they occupied habitat similar to that contained in the initial transect. Selection of similar habitat was based on prior summer and winter surveys and above-ice features at the time of transect establishment. Establishment of transects within similar habitat was done to ensure all three transects fell within the OWA. My intent was not to determine the aerial extent of an OWA, but rather to characterize confirmed OWAs. Therefore, number and spacing of transects represented a balance between workload (number) and representativeness (spacing). Each transect was marked with a tree-mounted reflector which served as a benchmark for subsequent surveys.

Transect measurements during 1993-94 were taken by the same methods used in 1991-92 and 1992-93. Ice thickness and flow depth were measured using a wooden staff graduated in 1-cm increments and fixed with a bolt at 0 cm with which the ice was hooked.

Overwinter areas were described near the end of each month (December, January, February, and March). These months were used to designate the samples, though sampling occasionally extended into the following month. These monthly samples were used to characterize and monitor trends within adult Arctic grayling OWAs. Of the four months sampled, only February 1994 data are considered representative of the winter low-flow period. Because the objective was to characterize available and microhabitat data during the winter low-flow period, only February 1994 data were compared to 1991-92 and 1992-93 low-flow data. March was not included for comparison because discharge and cross-sectional area increased by the time the sample was taken; January was omitted because it did not fall within the low-flow period identified by hydrologic monitoring during 1988-1992 by Kostohrys and Sterin (1994).

During summer 1994, substrate was measured as described by Wolman (1954) and classified according to the modified Wentworth particle-size scale (Orth 1983, Table 5). A tape was stretched at each of the transects measured in winter 1993-94 and 7 m sections sampled uniformly across the channel (usually 20 particles per 7 m). I took small steps across each section and the first particle touched with my pointed finger directly in front of my lead foot was selected for measurement.

Spacing of stations varied among the four OWAs and between months for the same transects due to time and weather constraints. Transect placement each month was either directly over the initial location or offset 0.3 m upstream or downstream to avoid packed snow and ice from the previous sample. When the initial transect was reworked, holes were drilled tangent to the hole from the previous month. Induced ice formation resulting from snow removal,

Table 5. Modified Wentworth classification for substrate particle sizes (Orth 1983).

| Substrate Type | Particle Size (mm) |
|---|---|
| sand/silt/clay | 2 |
| fine gravel | 2-16 |
| coarse gravel | 16-64 |
| rubble | 64-130 |
| cobble | 130-256 |

snow packing, and water upwelling through drilled holes was evaluated at OWA 4 (most downstream OWA) during March. Control transects were drilled 2 m above and below each of the 3 transects and comparisons made using ANOVA model I for fixed factor levels (Steel and Torrie 1980).

## Results

### Winter low-flow measurement

Winter low-flow (February-March) habitat measurements were made within 12 OWAs in 1991-92, 1992-93, and 1993-94. During winter 1991-92 and 1992-93, 21 radio-tagged adult Arctic grayling were used to locate these 12 OWAs over a 31-km section of the upper mainstem of Beaver Creek (Figure 2). Six of these fish were captured in September 1991 from Little Champion Creek and 15 during August 1992 from Nome Creek (Table 6). Of the 12 OWAs, 2 (river km 464.3 and 448.8) were sampled in both winters because both Little Champion Creek and Nome Creek radio-tagged fish occupied them. Five OWAs were inhabited by more than one radio-tagged fish during the same winter, once in 1991-92 and on five occasions in 1992-93. On four of these six occasions, more than one transect was worked because the radio-tagged fish were more than 5 m upstream or downstream of each other. When only one transect was sampled in locations with

Table 6. Distribution of radio-tagged Arctic Grayling throughout the 12 documented overwinter areas (OWA) during winter 1993-94.

| | Area[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 465.3 OWA 1 | 464.3 OWA 2 | 461.1 | 460.3 | 457.4 | 451.6 | 451.3 | 450.8 | 449.5 OWA 3 | 448.8 OWA 4 | 440.2 | 434.7 |
| 1991 Implants | | 2 | | 1 | 1 | | | | 1 | 1 | | |
| 1992 Implants | 2 | 3 | 2 | | | 1 | 2 | 1 | | 2 | 1 | 1 |
| Total | 2 | 5 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 1 |

[a] Area designations are river km from the Yukon River.

two or more radio-tagged fish, or when no transect was established (once), microhabitat data were collected from one station placed within 1 m of each radio-tagged fish using location methods described in the previous chapter.

During February-March 1992, 1993, and 1994, a total of 24 transects were established and 379 stations measured to describe available winter habitat. Of the four months sampled in winter 1993-94, only February data are used to describe winter low-flow habitat availability and use.

Discharge, generally increasing in a downstream direction, ranged from 0.57 to 1.92 $m^3/s$ throughout the period of study while flow area ranged from 1.5 to 12.7 $m^2$ (Tables 7, 8, 9). All OWAs were under complete ice cover, however extensive aufeis formation was not encountered within the OWAs and only 2 of 24 transects had snow-free sections (extensive aufeis formation frequently results in snow free areas visible from the air).

Cross-sectional figures were constructed to display the relative magnitudes of these physical characteristics and assist in identifying similarities between OWAs (Appendix A). All areas were located within either cutbank or glide habitats with the flow generally confined to one side of the

Table 7. Winter 1991-92 stream conditions during the low-flow period within adult Arctic grayling overwinter areas within Beaver Creek, Alaska.

| Area[a] (river km) | Date | Discharge ($m^3/s$) | Water width (m) | Ice width (m) | Bankful width (m) | Flow area ($m^2$) | Mean snow depth (m) |
|---|---|---|---|---|---|---|---|
| 464.3 OWA 2C[b] | 3/13/92 | 0.69 | 9.8 | 47.2 | 50.9 | 1.5 | - |
| 457.4 | 3/19/92 | 1.24 | 21.9 | 32.0 | 35.0 | 4.4 | - |
| 449.5 OWA 3B[c] | 2/27/92 | 0.97 | 29.3 | 91.4 | 106.9 | 5.5 | - |

[a] Area designated by river km from the Yukon River.
[b] Data came from transect C, OWA 2.
[c] Data came from transect B, OWA 3.

Table 8. Winter 1992-93 stream conditions during the low-flow period within adult Arctic grayling overwinter areas within Beaver Creek, Alaska.

| Area[a] (river km) | Date | Discharge ($m^3/s$) | Water width (m) | Ice width (m) | Bankful width (m) | Flow area ($m^2$) | Mean snow depth (m) (range) |
|---|---|---|---|---|---|---|---|
| 465.3 OWA 1B | 2/24/93 | 1.40 | 18.0 | 33.5 | 56.4 | 6.2 | 0.45 (0.30-0.91) |
| 464.3 OWA 2C | 3/3/93 | 1.61 | 32.9 | 60.0 | 69.7 | 4.8 | 0.46 (0.30-0.61) |
| 464.3 OWA 2B | 3/4/93 | 1.43 | 25.6 | 64.0 | 71.9 | 7.1 | - |
| 461.1 | 3/10/93 | 0.95 | 22.6 | 46.0 | 65.5 | 4.9 | 0.78 (0.46-1.22) |
| 461.1 | 3/10/93 | 1.28 | 24.4 | 40.5 | 58.2 | 6.7 | 0.69 (0.37-1.22) |
| 451.6 | 3/18/93 | 1.47 | 41.5 | 73.5 | 75.0 | 9.4 | 0.43 (0.00-0.91) |
| 451.3 | 3/17/93 | 1.79 | 49.7 | 74.4 | 82.8 | 7.9 | - |
| 450.8 | 3/31/93 | 1.73 | 25.3 | 36.3 | 48.8 | 6.6 | 0.47 (0.00-1.07) |
| 448.8 OWA 4A | 3/25/93 | 1.47 | 42.7 | 60.4 | 75.6 | 8.3 | 0.45 (0.31-1.22) |
| 448.8 OWA 4C | 3/24/93 | 1.31 | 35.1 | 60.7 | 76.2 | 4.2 | 0.51 (0.31-0.76) |
| 440.2 | 3/30/93 | 1.76 | 35.1 | 57.0 | 60.2 | 8.5 | 0.42 (0.30-1.07) |
| 434.7 | 3/30/93 | 1.92 | 34.1 | 60.4 | 76.2 | 6.8 | 0.60 (0.37-0.91) |

[a] Area designated by river km from the Yukon River.

Table 9. Winter 1993-94 stream conditions during the low-flow period within adult Arctic grayling overwinter areas within Beaver Creek, Alaska.

| Area[a] (river km) | Date | Discharge ($m^3/s$) | Water width (m) | Ice width (m) | Bankful width (m) | Flow area ($m^2$) | Mean snow depth (m) (range) |
|---|---|---|---|---|---|---|---|
| 465.3 OWA 1A | 3/1/94 | 0.83 | 20.3 | 39.9 | 78.0 | 4.6 | 0.21 0.12-0.40 |
| 465.3 OWA 1B | 3/1/94 | 0.66 | 22.1 | 71.6 | 77.4 | 3.3 | 0.18 0.06-0.43 |
| 465.3 OWA 1C | 3/1/94 | 0.57 | 21.2 | 57.6 | 76.5 | 3.8 | 0.22 0.09-0.40 |
| 449.5 OWA 3A | 3/2/94 | 1.00 | 31.2 | 84.1 | 99.7 | 10.0 | 0.30 0.30-0.40 |
| 449.5 OWA 3B | 3/2/94 | 0.95 | 22.1 | 90.2 | 105.6 | 8.7 | 0.25 0.20-0.40 |
| 449.5 OWA 3C | 3/2/94 | 1.06 | 21.9 | 84.7 | 100.3 | 12.3 | 0.31 0.24-0.41 |
| 448.8 OWA 4A | 3/2/94 | 1.10 | 35.1 | 64.0 | 114.0 | 12.7 | 0.13 0.03-0.34 |
| 448.8 OWA 4B | 3/2/94 | 1.33 | 32.0 | 70.1 | 101.5 | 5.5 | 0.17 0.03-0.43 |
| 448.8 OWA 4C | 3/2/94 | 1.05 | 20.6 | 70.7 | 114.0 | 4.1 | 0.18 0.09-0.37 |

[a] Area designated by river km from the Yukon River.

channel (i. e., point bars were present). Transect sections occupied by adult Arctic grayling were overlaid on these figures and revealed that fish were never observed within thalwegs (line of maximum water depth) running adjacent to the bank (cutbank habitat). However, fish were found within thalwegs located off the bank (glide habitat).

Under-ice observations and radio tracking were conducted in winters 1991-92, 1992-93, and 1993-94 within the 12 OWAs during the low-flow period and confirmed the presence of 151 adult (21 were radio-tagged and 9 of these were observed) and 9 subadult Arctic grayling, as well as 19 adult round whitefish (Table 10 and 11). Adult Arctic grayling were within approximately 1 m of 23% (88 of 379) of all stations used to describe available winter habitat. Water velocity, flow depth, and ice thickness were measured at these stations to describe adult Arctic grayling microhabitats within the upper mainstem of Beaver Creek.

Over all three winters sampled during the winter low-flow period, available (across entire transect, n=379 for each variable) flow depths ranged from 0.03 to 0.76 m (mean 0.23 m), velocities from 0.01 to 0.66 m/s (mean 0.23 m/s), and ice thicknesses from 0.03 to 1.40 m (mean 0.83 m). In contrast, flow depths within 1 m of undisturbed adult Arctic grayling (n=88 for each variable) during this same

Table 10. Winters 1991-92 and 1992-93 results of under-ice observations within 12 Arctic Grayling overwinter areas within the upper mainstem of Beaver Creek, Alaska.

| Area (river km) | Date | Adult AG[a] | Subadult AG | Adult RWF[b] | Slimy Sculpin | Inverts[c] | Drift[d] |
|---|---|---|---|---|---|---|---|
| 465.3 (OWA 1) | 2/19/93 | 3 | 3 | 3 | | | |
| 464.3 (OWA 2) | 3/11/92 | 2* | | 1 | | | |
| 464.3 (OWA 2) | 3/3/93 | 10 | | | 1 | | |
| 461.1 | 3/5/93 | 6 | | | | | |
| 460.3 | 3/11/92 | 2 | | | | | |
| 457.4 | 3/19/92 | 1* | | | | | |
| 451.6 | 3/18/93 | 1* | | | | | |
| 451.3 | 3/17/93 | 3 | | | | | |
| 450.8 | 3/18/93 | 1* | | | | Y | Y |
| 449.5 (OWA 3) | 2/26/92 | 8 | 6 | 12 | 1 | Y | Y |
| 448.8 (OWA 4) | 3/24/93 | 64 | | | | | |
| 448.8 (OWA 4) | 2/26/92 | 1* | | | | | |
| 440.2 | 3/30/93 | 2 | | | | | |
| 434.7 | 3/31/93 | 1* | | | | Y | |
| | Total | 105 | 9 | 16 | 2 | 3 | 2 |

[a] AG = Arctic grayling
[b] RWF = Round whitefish
[c] Stonefly (Plecoptera) and caddisfly (Tricoptera) larva and unidentified adults.
[d] Particulate matter in water column believed to be dislodged epiphytic periphyton.
* Only radio-tagged fish documented.

Table 11. Winter 1993-94 results of under-ice observations within four Arctic Grayling overwinter areas within the upper mainstem of Beaver Creek, Alaska.

| Area (river km) | Date | Adult AG[a] | Subadult AG | Adult RWF[b] | Inverts[c] |
|---|---|---|---|---|---|
| 465.3 (OWA 1) | 3/1/94 | 1* | - | 1 | - |
| 449.5 (OWA 3) | 1/26/94 | 1 | - | 2 | - |
| 449.5 (OWA 3) | 3/2/94 | 6* | - | 2 | - |
| 448.8 (OWA 4) | 12/28/93 | 3 | - | - | - |
| 448.8 (OWA 4) | 1/27/94 | 10 | - | - | Y |
| 448.8 (OWA 4) | 3/2/94 | 39* | - | - | - |
| 448.8 (OWA 4) | 3/30/94 | 161 | - | 4 | Y |
| | Total | 221 | 9 | 16 | 2 |

[a] AG = Arctic grayling
[b] RWF = Round whitefish
[c] Stonefly (Plecoptera) and caddisfly (Tricoptera) larva.
* Winter low-flow observations.

period ranged from 0.06-0.52 m (mean 0.25 m), velocities from 0.03-0.56 m/s (mean 0.21 m/s), and ice thicknesses from 0.40-1.40 m (mean 0.77 m) (Table 12). Although ranges differed slightly between availability and use, similar patterns of availability and use were evident when all three years were combined (Figure 3). A Kolmogorov-Smirnov test was used to test for significant differences between use and availability distributions for ice thickness, velocity and flow depth at alpha 0.05 (Sokal and Rohlf 1981). Ice thickness (P-value 0.13) and velocity (P-value 0.12) tests were not significant, however, flow depth was (P-value 0.04). Use and availability flow depth distributions were likely different as a result of the physical exclusion of adult fish from flow depths less than 0.06 m and the avoidance of thalwegs running adjacent to the bank. These patterns were also observed for each variable when graphed by year (Appendix B).

Although the microhabitat descriptions were confined to February 1994, attempts were made to collect microhabitat data during December-March 1993-94, within OWA 4 (river km 448.8). Unfortunately, under-ice observations were not comprehensive in December and January due to short daylengths so interpretations for these months are limited. Graphical overlays were used to display habitat use with

Table 12. Comparisons of available habitat with microhabitat (use) within the upper mainstem of Beaver Creek, Alaska.

| Winter | Habitat category | Sample size | Flow depth (m) | | | Velocity (m/s) | | | Ice thickness (m) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Max | Mean | Min | Max | Mean | Min | Max | Mean | Min |
| 1991-92 | Available | 49 | 0.37 | 0.20 | 0.03 | 0.66 | 0.31 | 0.01 | 1.40 | 1.02 | 0.76 |
| | Use | 15 | 0.30 | 0.20 | 0.06 | 0.56 | 0.25 | 0.14 | 1.40 | 1.02 | 0.76 |
| 1992-93 | Available | 268 | 0.76 | 0.23 | 0.03 | 0.54 | 0.23 | 0.01 | 0.88 | 0.64 | 0.03 |
| | Use | 54 | 0.49 | 0.26 | 0.09 | 0.41 | 0.21 | 0.06 | 0.79 | 0.68 | 0.40 |
| 1993-94 | Available | 62 | 0.70 | 0.27 | 0.06 | 0.49 | 0.16 | 0.01 | 1.07 | 0.84 | 0.52 |
| | Use | 19 | 0.52 | 0.29 | 0.12 | 0.40 | 0.15 | 0.03 | 1.07 | 0.83 | 0.64 |

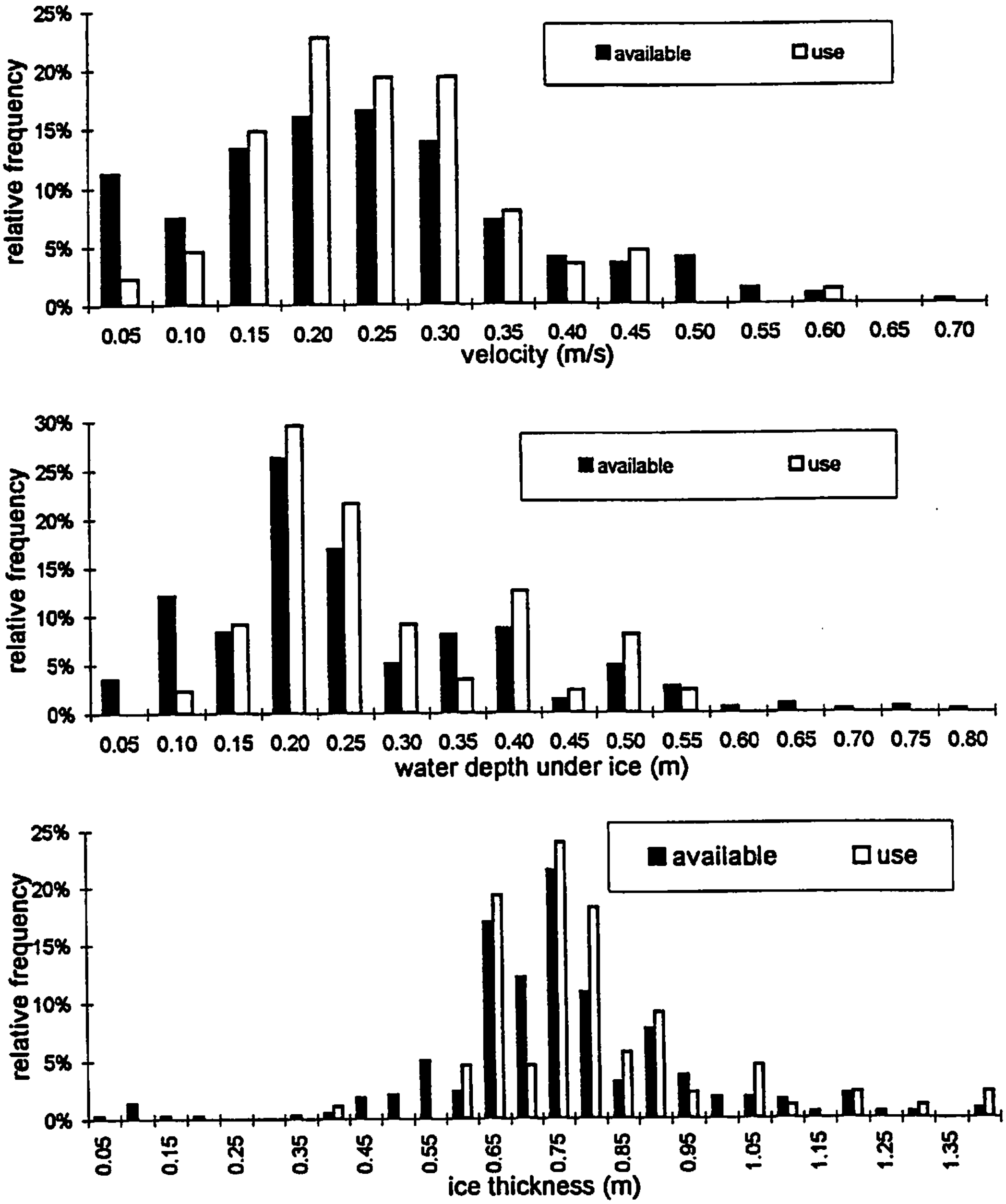


Figure 3. Comparison of under-ice velocities, flow depths, and ice for available habitat (n=379) with those for microhabitat (use, n=88) collected from Beaver Creek, Alaska. Interval designations are maximum values (e.g., depth interval 0.15 ranges from 0.11-0.15).

velocity and flow depth by transect and month. As in winters 1991-92 and 1992-93, fish were not found within thalwegs located along the bank (Figure 4). These areas typically contain slightly higher velocities (Figure 5). Review of the cross-sectional figures of OWA 4 for each month provides useful data for the description of winter habitats and interpretation of use patterns (Appendix C).

Water quality measurements were made within both OWAs and unconfirmed use areas in winter 1991-92 (Table 13) and 1992-93 (Table 14). Turbidity was low (0.08-0.17 NTU), dissolved oxygen remained high (9.4-12.7 mg/L), and pH varied little from neutral (6.5-8.0) throughout both winters. Dissolved oxygen, pH, alkalinity, and hardness were similar to those documented by Chisolm (1985) in ice covered streams of the Snowy Range, Wyoming.

Monthly overwinter area measurement

Efforts in winter 1993-94 to sample three transects monthly within each of the four OWAs (OWA 1, river km 465.3; OWA 2, river km 464.3; OWA 3, river km 449.5; OWA 4, river km 448.8) were not always successful due to overflow and inclement weather (Table 15). Despite these limitations, 463 stations were measured within 37 transects during December-March to characterize and monitor trends within OWAs.

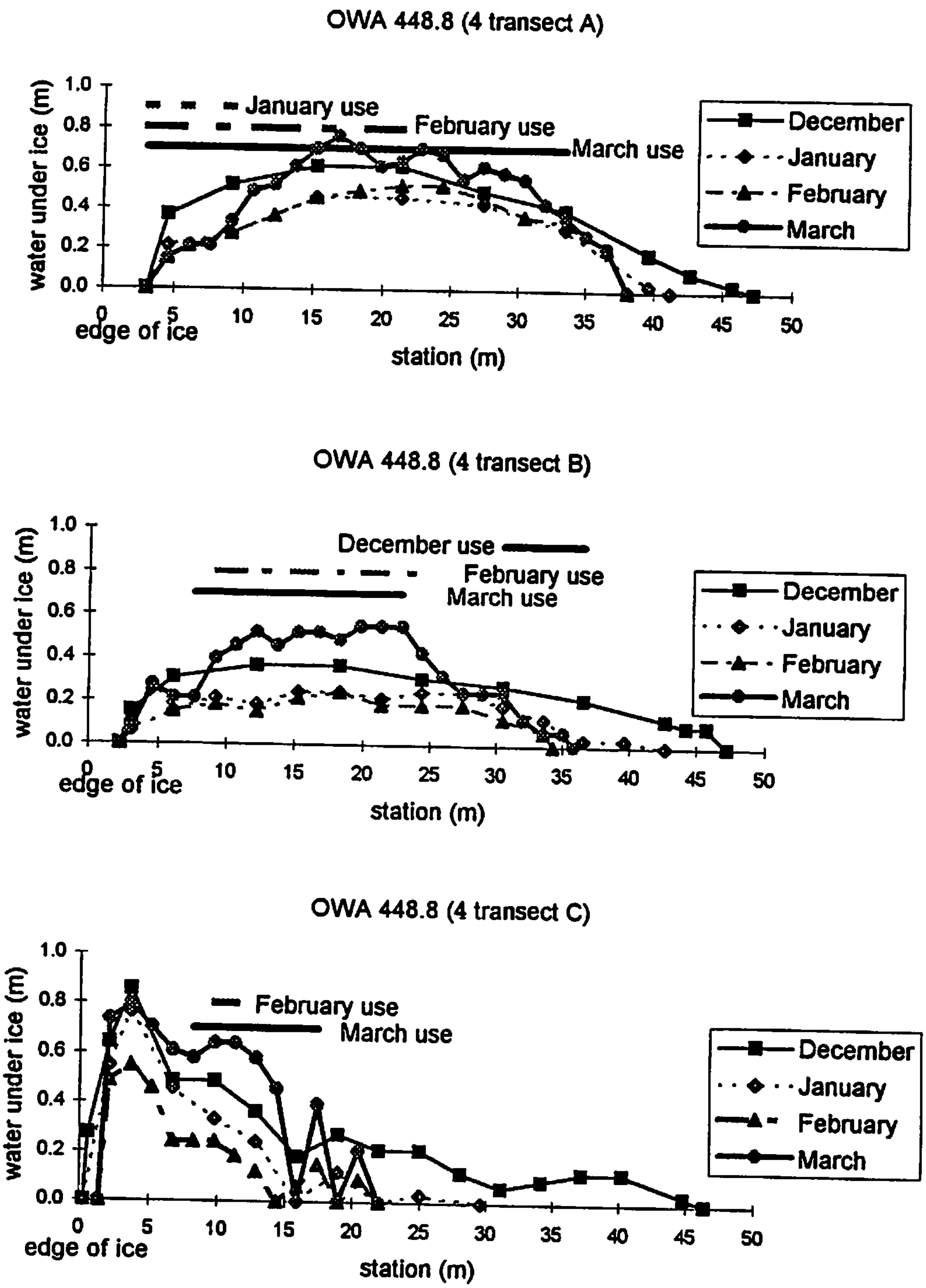


Figure 4. Winter 1993-94 microhabitat (use) and flow depth (water under ice) by station and month within OWA 4 (448.8), Beaver Creek, Alaska.

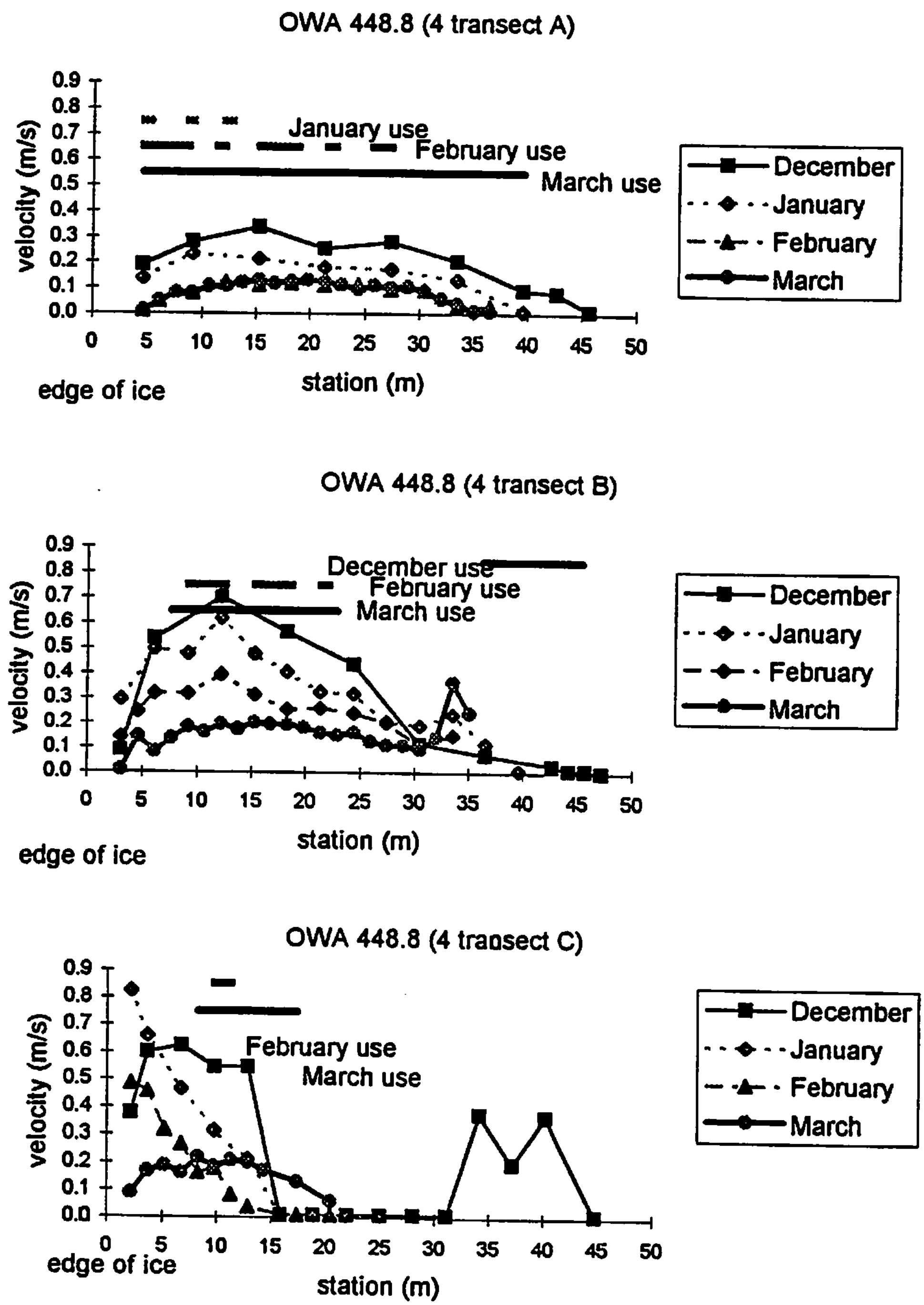


Figure 5. Winter 1993-94 microhabitat (use) and under-ice velocity by station and month within OWA 4 (448.8), Beaver Creek, Alaska.

Table 13. Winter 1991-92 water quality characteristics within the upper mainstem of Beaver Creek, Alaska.

| Area (river km) | Documented OWA[a] (yes/no) | Date | DO[b] (mg/L) | Alkalinity (mg/L) (as $CaCO_3$) | Hardness (mg/L) (as $CaCO_3$) | pH | Turb.[b] (NTU) | Water temp. (°C) | Cond.[c] (μS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 484.4 | N | 2/7/92 | 12.7 | 36.7 | - | - | 0.09 | 0.1 | 120.1 |
| 483.3 | N | 2/13/92 | 12.7 | 41.8 | - | - | 0.08 | 0.1 | 117.2 |
| 457.4 | Y | 3/19/92 | - | - | - | 8.0 | - | 0.2 | 113.4 |
| 454.8 | N | 3/19/92 | 10.2 | 32.1 | - | 8.0 | - | 0.2 | 112.9 |
| 451.6 | Y | 3/18/92 | - | - | - | - | - | 0.1 | 113.8 |
| 449.5 (OWA3) | Y | 2/27/92 | 9.4 | - | - | 8.0 | 0.17 | 0.2 | 102.3 |
| 448.8 (OWA4) | Y | 2/26/92 | - | 26.6 | - | - | 0.10 | 0.2 | 106.4 |

[a] OWA = Overwinter area
[b] DO = Dissolved oxygen
[c] Turb. = Turbidity
[d] Cond. = Conductivity

Table 14. Winter 1992-93 water quality characteristics within the upper mainstem of Beaver Creek, Alaska.

| Area (river km) | Documented OWA[a] (yes/no) | Date | Mean DO[b] (mg/L) | Alkalinity (mg/L) (as $CaCO_3$) | Hardness (mg/L) (as $CaCO^3$) | pH | Turb.[b] (NTU) | Water Temp. (°C) | Cond.[c] (μS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 467.4 | N | 2/26/93 | 10.9 | - | - | 7.0 | - | 0.1 | 13.9* |
| 465.3 (OWA 1) | Y | 2/25/93 | 10.5 | - | - | 7.0 | 0.16 | 0.1 | 126.6 |
| 464.3 (OWA 2) | Y | 3/4/93 | 10.9 | - | - | 6.5 | - | 0.1 | 17.2* |
| 451.3 | Y | 3/17/93 | 10.6 | 23.2 | 64.1 | 6.5 | - | 0.1 | 92.5 |
| 450.8 | Y | 3/31/93 | - | - | - | - | - | 0.1 | 117.5 |
| 448.8 (OWA 4) | Y | 3/25/93 | 10.6 | 31.1 | 56.8 | 6.5 | - | 0.1 | 113.6 |
| 440.2 | Y | 3/31/93 | 10.5 | - | 67.6 | 6.5 | - | 0.2 | 107.8 |
| 434.7 | Y | 3/31/93 | - | - | - | 8.0 | - | 0.2 | 113.4 |

[a] OWA = Overwinter area
[b] DO = Dissolved oxygen
[c] Turb. = Turbidity
[d] Cond. = Conductivity
* Low conductivities may be a result of water freezing inside the probe.

Table 15. Winter 1993-94 monthly sampling effort in Beaver Creek, Alaska.

| OWA | December | January | February | March |
|---|---|---|---|---|
| 1 | 12/21/93 | - | 3/1/94 | 3/29/94<br>A and B |
| 2 | 12/22/93 | - | - | 3/28/94<br>B and C |
| 3 | 12/29/93 | 1/26/94 | 3/2/94 | 3/30/94 |
| 4 | 12/28/93 | 1/25/94 | 3/2/94 | 3/30/94 |

The effects of monthly sampling on ice thickness, which could subsequently result in changes to velocity and flow area measurements, were addressed in March 1994. Nine transects were established: the original three and one 2 m above and one 2 m below each original transect within OWA 4. Assumptions of dependence and normality were checked visually (dependence: spacial plots; normality; comparison of expected values under normality to observed and QQnorm probability plots) and no violations were suggested by these analyses. The assumption of homogeneity of variance was checked both visually and statistically (Hartley's test for unequal variances); variance tests were not significant (Table 16). Based on these results, ANOVA model I for fixed factor levels was used to test for significant differences between mean ice thicknesses. No significant differences between mean ice thicknesses were detected at alpha 0.05 (P-values 0.08-0.10) (Table 17).

Overwinter areas 1 and 2, separated by 1.0 km, are located 16 km upstream of OWAs 3 and 4, which are separated by 0.7 km. In August 1994, measurements were made at each transect within all four OWAs to measure discharge, flow and bankful depths, channel widths, and substrate. Bankful widths ranged from 65.8 m (OWA 2) to 108.7 m (OWA 4), water widths from 27.3 (OWA 1) to 55.7 (OWA 4), and discharge from

Table 16. Results of Hartley's test for homogeneity of variance ($\alpha$=0.05; numerator/denominator degrees of freedom = 3/7) between transect measurements of ice thickness taken March 1994 within overwinter area 4 (448.8).

| Transect | Variance | Test Statistic (H[a]) | H Critical | Result[b] |
|---|---|---|---|---|
| A upper | 0.00360 | | | |
| A original | 0.00225 | 1.596 | 6.94 | NS |
| A lower | 0.00231 | | | |
| B upper | 0.004106 | | | |
| B original | 0.006234 | 2.121 | 6.94 | NS |
| B lower | 0.00869 | | | |
| C upper | 0.00667 | | | |
| C original | 0.00553 | 1.229 | 6.94 | NS |
| C lower | 0.00681 | | | |

[a] Hartley's test statistic calculated by dividing the largest variance by the smallest.
[b] NS = not significant

Table 17. Results of ANOVA model I tests for differences between control (upper and lower transects) and original transects mean ice thicknesses within OWA 4 (448.8), March 1994.

| Transect | Mean[a] | Variance | F Statistic | F Critical | P-value | Result[b] |
|---|---|---|---|---|---|---|
| A upper | 0.922 | 0.00392 | | | | |
| A original | 0.975 | 0.00186 | 2.91 | 3.47 | 0.08 | NS |
| A lower | 0.922 | 0.00206 | | | | |
| B upper | 0.953 | 0.00365 | | | | |
| B original | 0.880 | 0.00596 | 2.59 | 3.47 | 0.10 | NS |
| B lower | 0.872 | 0.00848 | | | | |
| C upper | 1.02 | 0.00635 | | | | |
| C original | 1.06 | 0.00529 | 2.58 | 3.47 | 0.10 | NS |
| C lower | 0.97 | 0.00630 | | | | |

[a] Sample size of 8 per transect.
[b] NS = not significant

6.2 (OWA 1 and 2) to 23.8 $m^3/s$ (OWA 3) (Table 18). Course gravel was dominant in OWAs 2 (47%) and 3 (56%) and nearly equaled the dominant substrate (rubble) in OWAs 1 and 4 (Figure 6).

Substantial differences in mean water velocities (Figure 7), flow depths (Figure 8) or ice thickness (Figure 9) were not evident between OWAs. Nor were there substantial differences in discharge, flow area, or water, ice and bankful widths (Tables 7, 8, 9).

Flow depths, velocities and ice thicknesses were plotted by station, transect, and month for each OWA to identify common trends across each channel and through time. Flow depths decreased in most stations until late March, when all but OWA 1 showed an increase (Figures 10, 11, 12, 13). Water velocities tended to increase with depth and showed a gradual decrease December-March (Figures 14, 15, 16, 17). Ice thickness changed little across the channel for any particular area or month, but exhibited distinct increases each month (Figures 18, 19, 20, 21). It is interesting that flow depth should increase during a time when ice thickness is also increasing, suggesting flow depth is not always a function of ice thickness. Discharge and cross-sectional area decreased December-February and showed

Table 18. August 1994 stream conditions measured within adult Arctic grayling overwinter areas within Beaver Creek, Alaska. Mean and median values calculated for each OWA from the three transects measured each month in winter 1993-94.

| Area | Median discharge ($m^3/s$) | Median water width (m) | Median flow area ($m^2$) | Mean flow depth (m) | Max flow depth (m) | Mean velocity (m/s) | Max velocity (m/s) | Mean bankful width (m) | Winter 1993-94 ice width (m) |
|---|---|---|---|---|---|---|---|---|---|
| OWA 1 | 6.2 | 27.3 | 13.2 | 0.49 | 0.80 | 0.47 | 0.63 | 77 | 53.4 |
| OWA 2 | 6.2 | 36.5 | 15.6 | 0.42 | 0.69 | 0.40 | 0.52 | 66 | 62.0 |
| OWA 3 | 24.0 | 49.9 | 27.6 | 0.51 | 0.87 | 0.87 | 1.12 | 102 | 86.4 |
| OWA 4 | 22.6 | 55.7 | 34.1 | 0.58 | 1.02 | 0.66 | 0.78 | 110 | 68.3 |

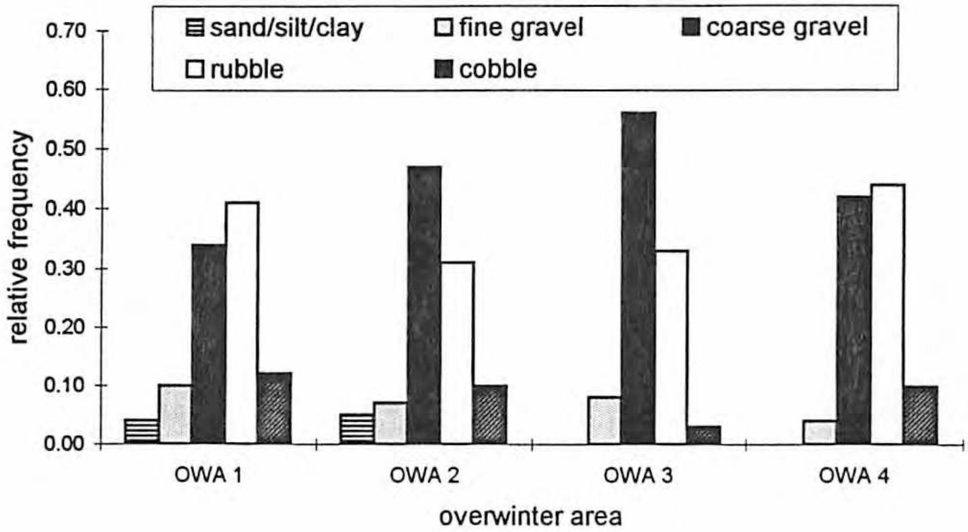


Figure 6. Relative frequency of modified Wentworth particle size categories collected from overwinter areas 1 (n=592), 2 (n=330), 3 (n=571), and 4 (n=537) August 1994 within the upper mainstem of Beaver Creek, Alaska.

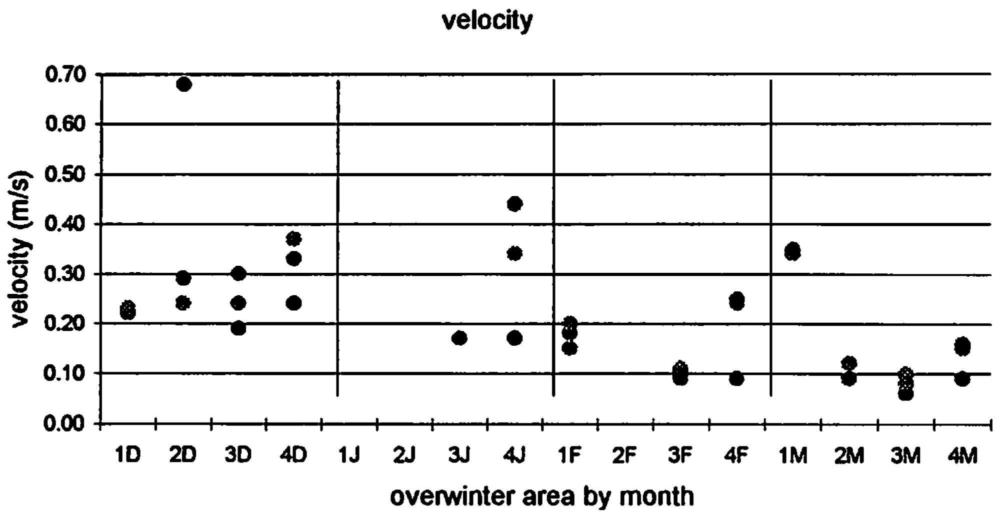


Figure 7. Winter 1993-94 mean under-ice velocities by area, transect, and month measured within overwinter areas within Beaver Creek, Alaska. Abscissa labels are overwinter area number and the first letter of the month sampled. Multiple points per area and month are means for each transect measured.

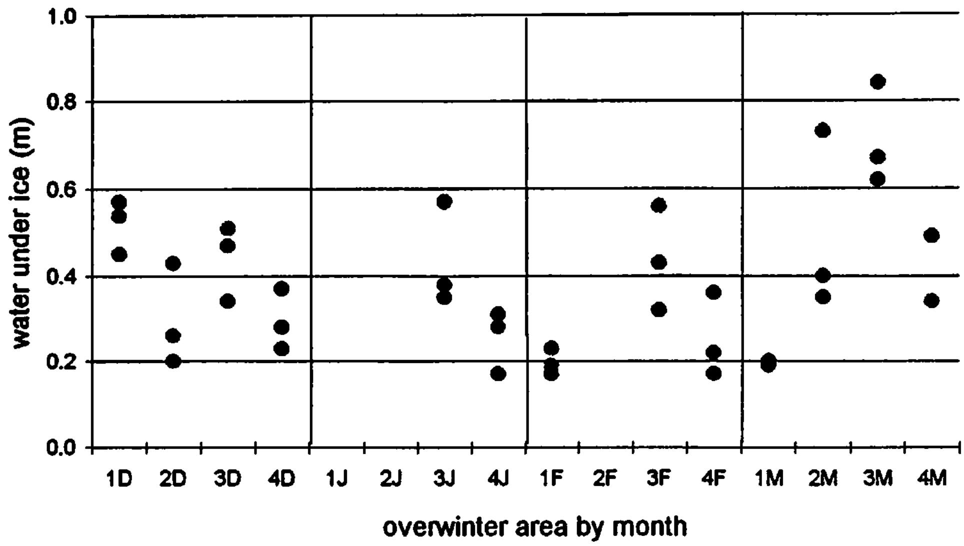


Figure 8. Winter 1993-94 mean flow depths (under-ice) by area, transect, and month measured within overwinter areas within the upper mainstem of Beaver Creek, Alaska. Abscissa labels are overwinter area number and the first letter of the month sampled. Multiple points per area and month are means for each transect measured.

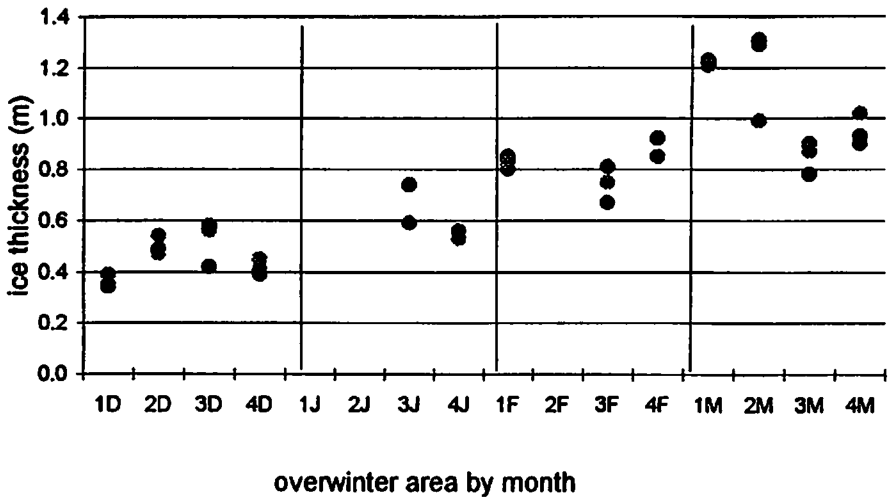


Figure 9. Winter 1993-94 mean ice thicknesses by area, transect, and month measured within overwinter areas within the upper mainstem of Beaver Creek, Alaska. Abscissa labels are overwinter area number and the first letter of the month sampled. Multiple points per area and month are means for each transect measured.

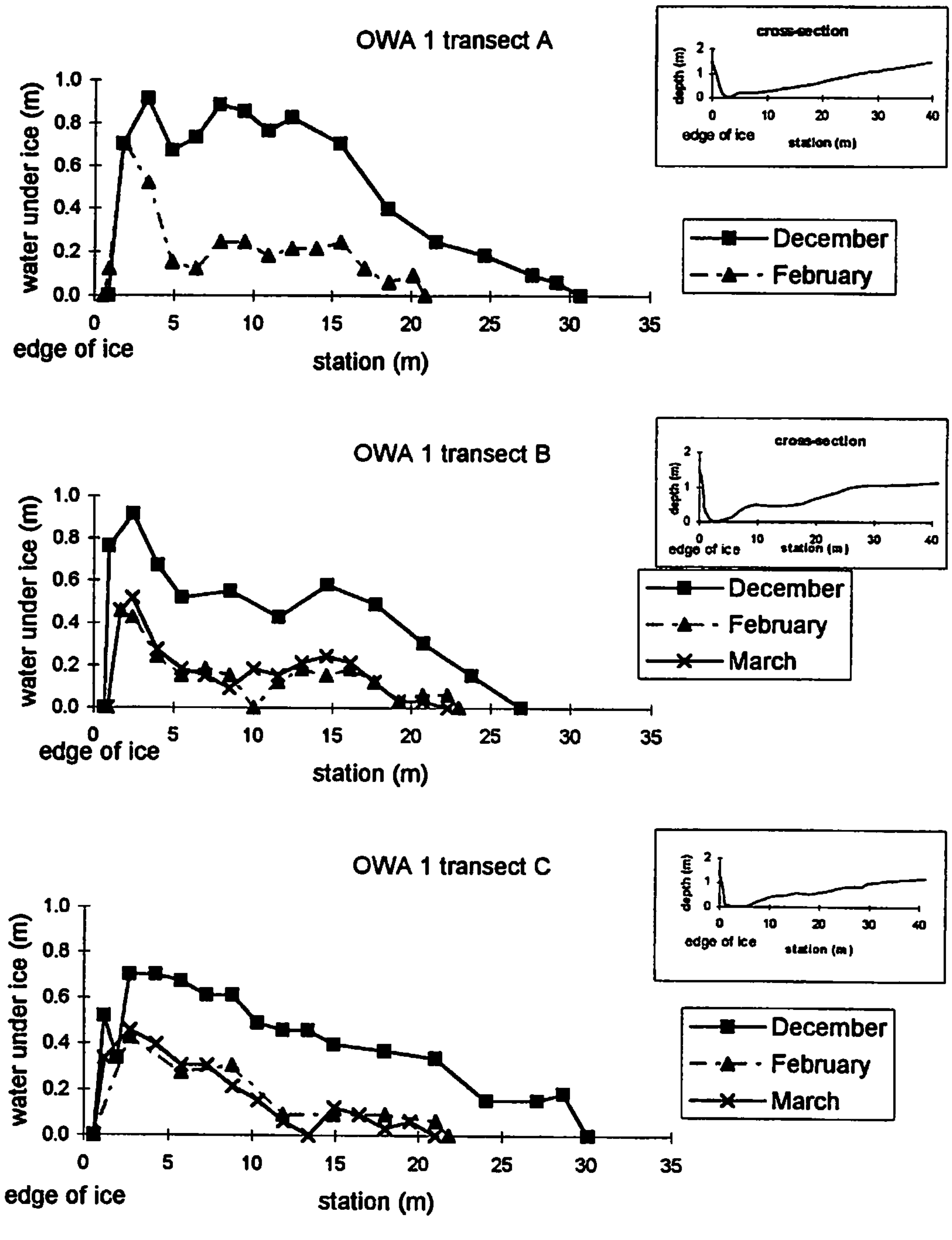


Figure 10. Winter 1993-94 flow depth (water under ice) by station and month within overwinter area 1 (OWA 1) located within the upper mainstem of Beaver Creek, Alaska.

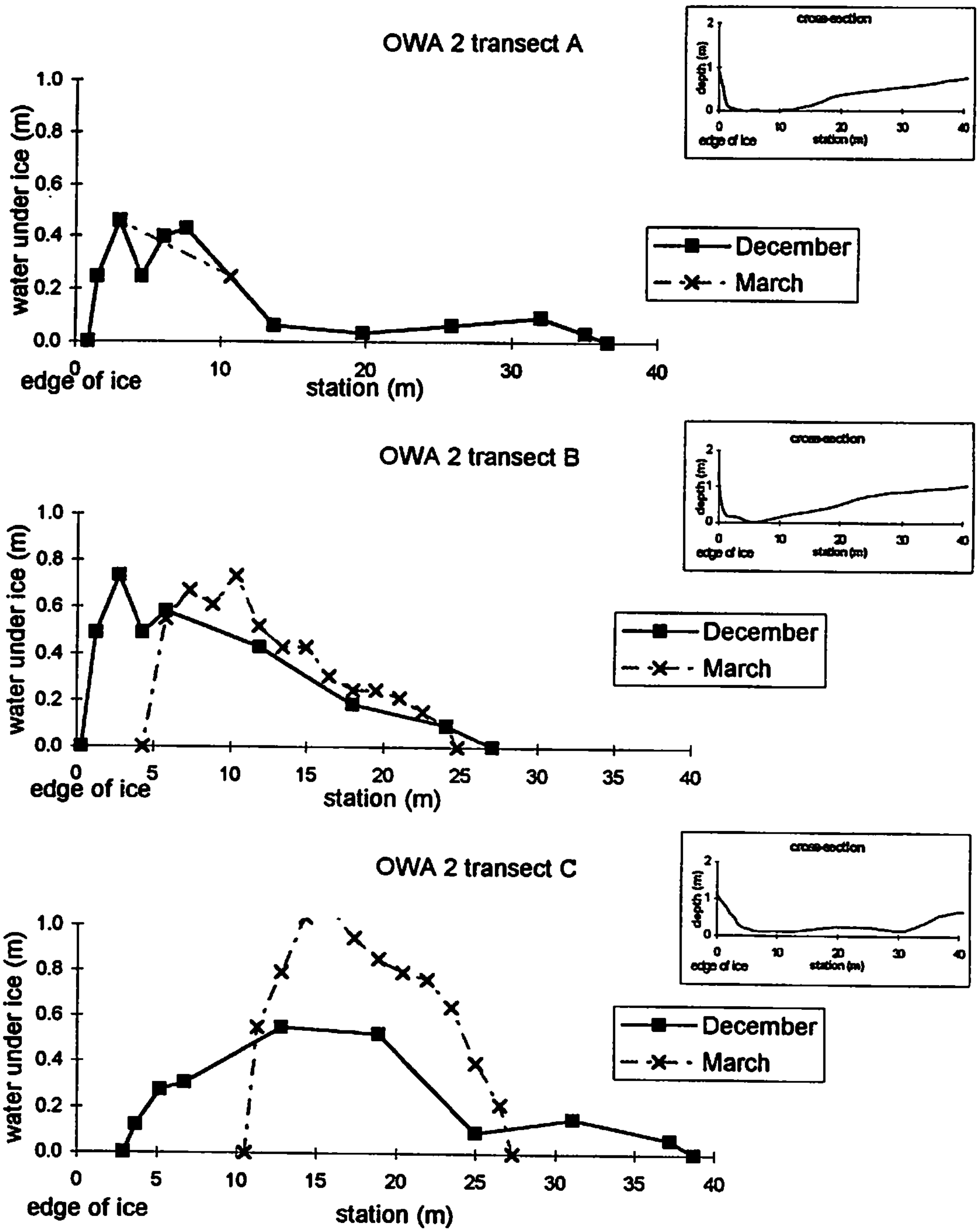


Figure 11. Winter 1993-94 flow depth (water under ice) by station and month within overwinter area 2 (OWA 2) located within the upper mainstem of Beaver Creek, Alaska.

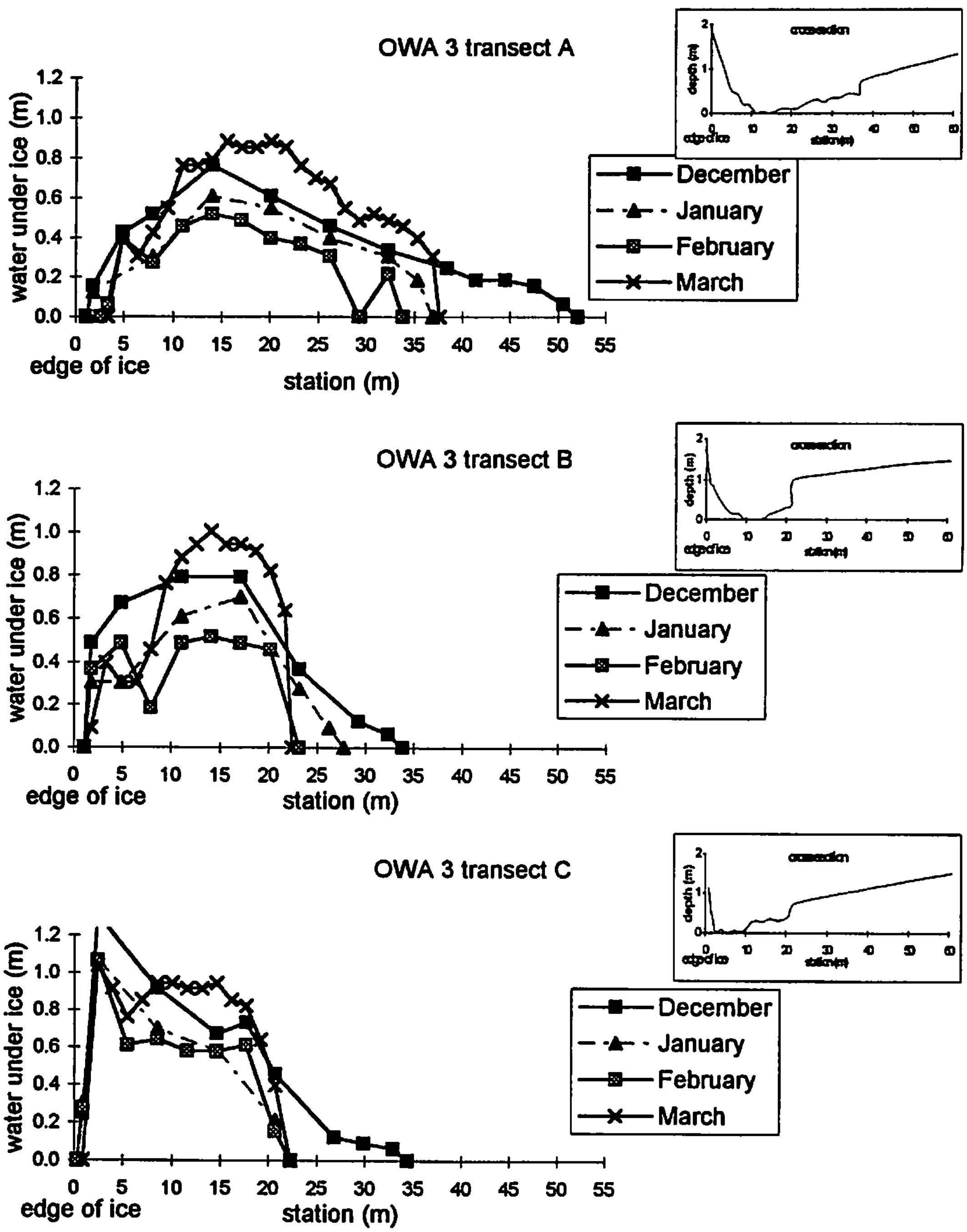


Figure 12. Winter 1993-94 flow depth (water under ice) by station and month within overwinter area 3 (OWA 3) located within the upper mainstem of Beaver Creek, Alaska.

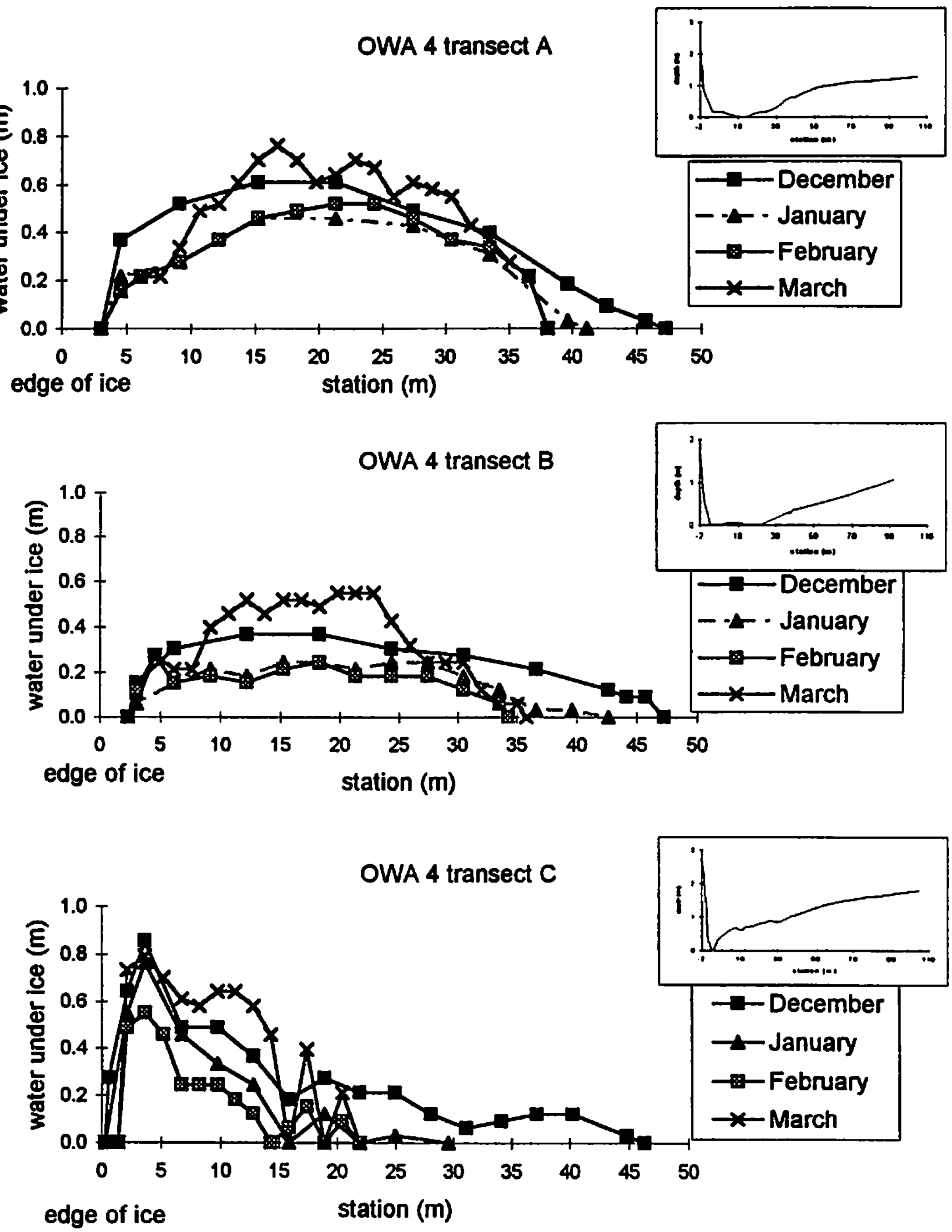


Figure 13. Winter 1993-94 flow depth (water under ice) by station and month within overwinter area 4 (OWA 4) located within the upper mainstem of Beaver Creek, Alaska.

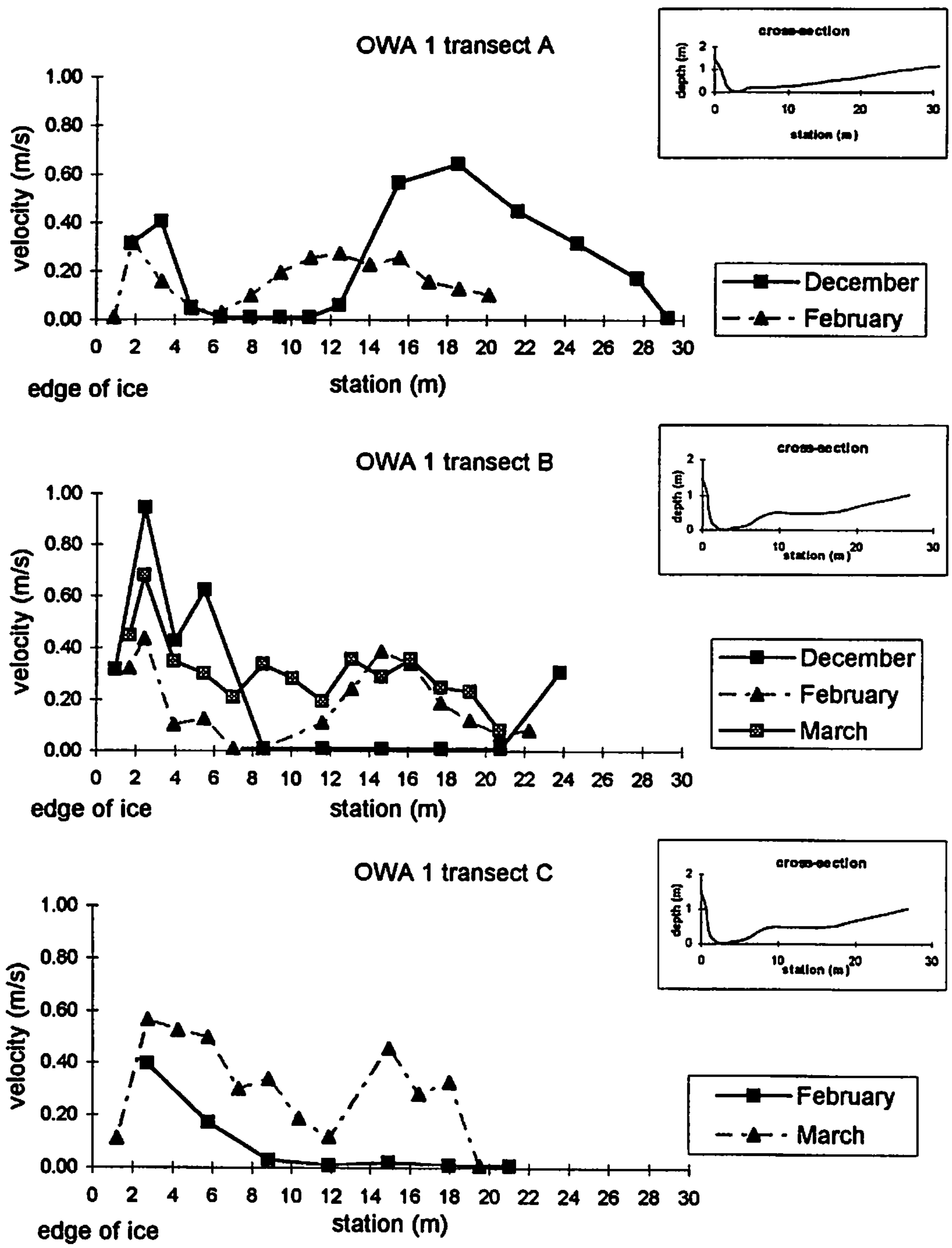


Figure 14. Winter 1993-94 under-ice velocities by station and month within overwinter area 1 (OWA 1), located within the upper mainstem of Beaver Creek, Alaska.

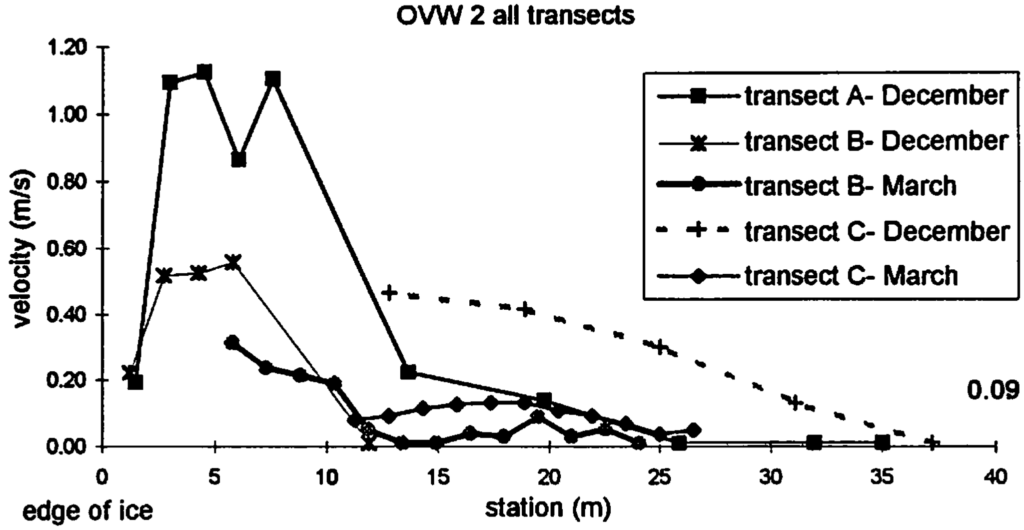


Figure 15. Winter 1993-94 under-ice velocities by station and month within overwinter area 2 (OWA 2), located within the upper mainstem of Beaver Creek, Alaska.

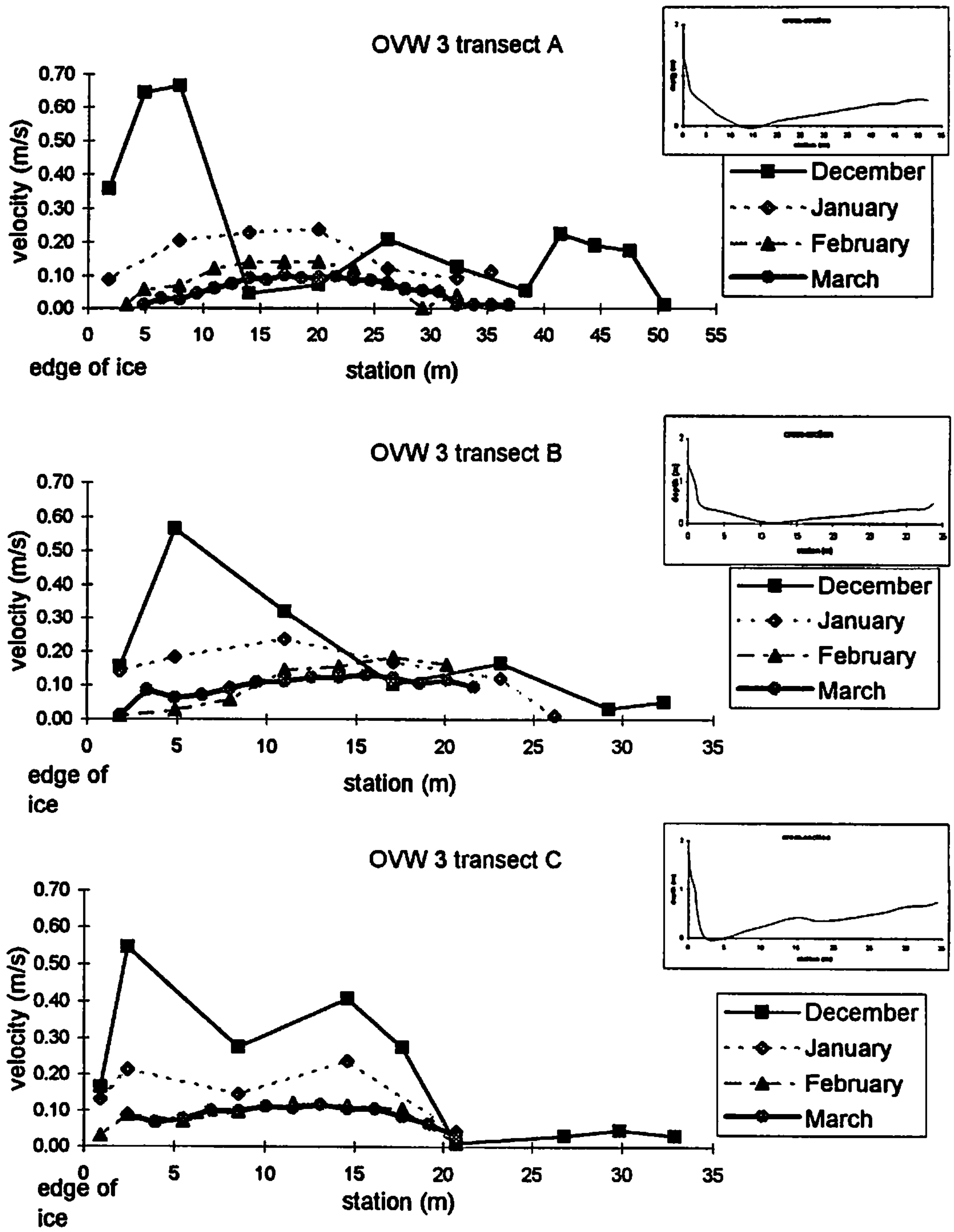


Figure 16. Winter 1993-94 under-ice velocities by station and month within overwinter area 3 (OWA 3), located within the upper mainstem of Beaver Creek, Alaska.

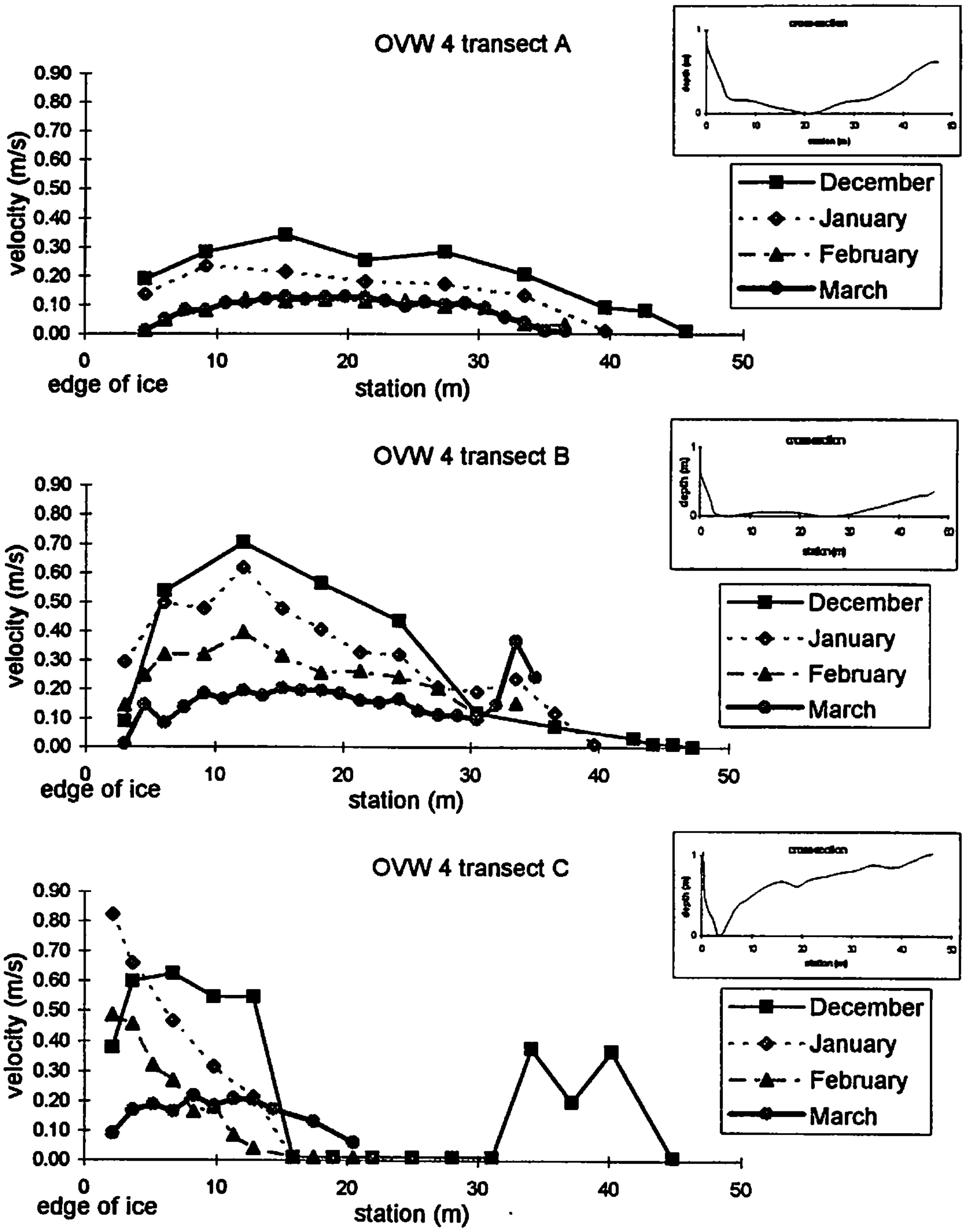


Figure 17. Winter 1993-94 under-ice velocities by station and month within overwinter area 4 (OWA 4), located within the upper mainstem of Beaver Creek, Alaska.

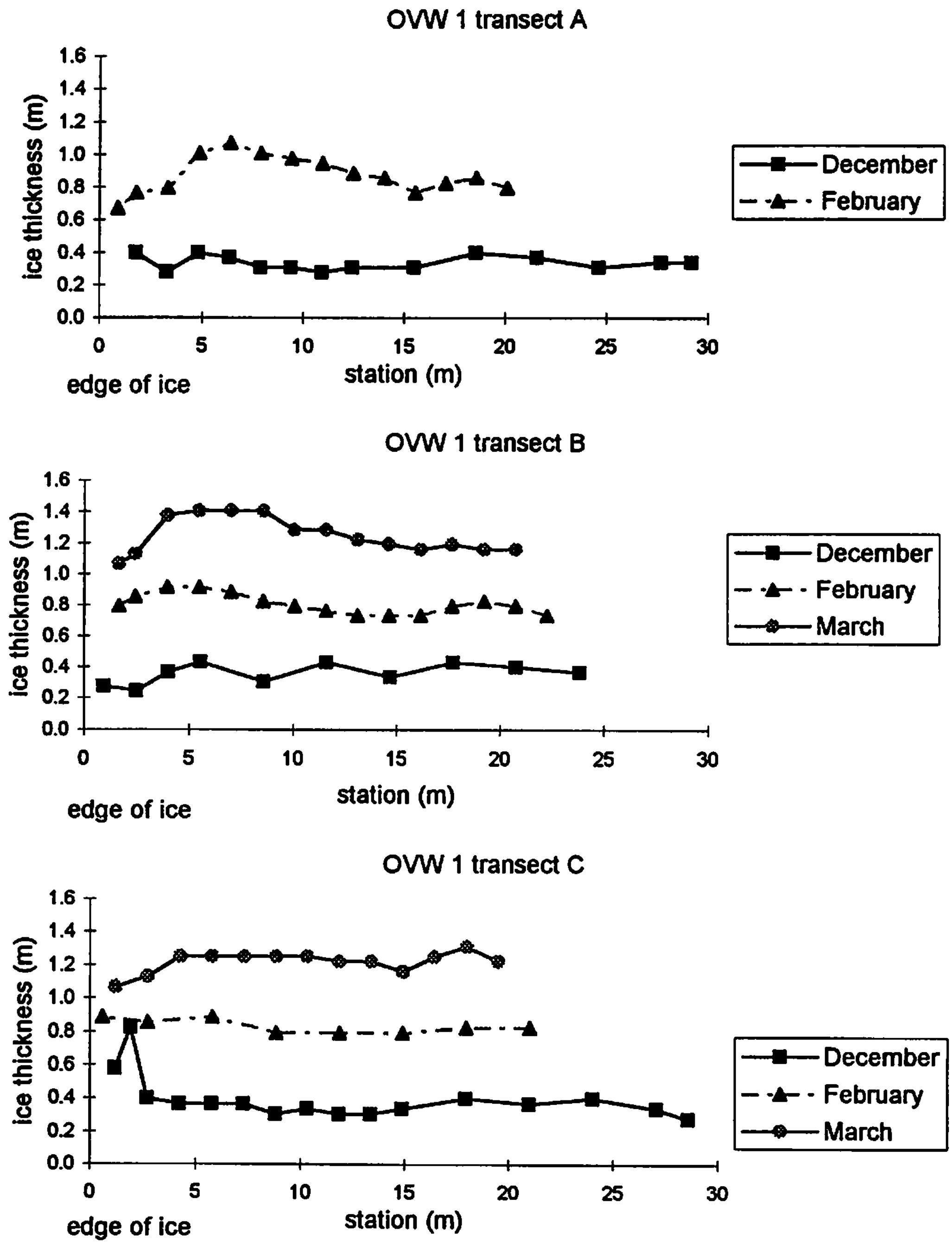


Figure 18. Winter 1993-94 ice thicknesses by station and month within overwinter area 1 (OWA 1) located within the upper mainstem of Beaver Creek, Alaska.

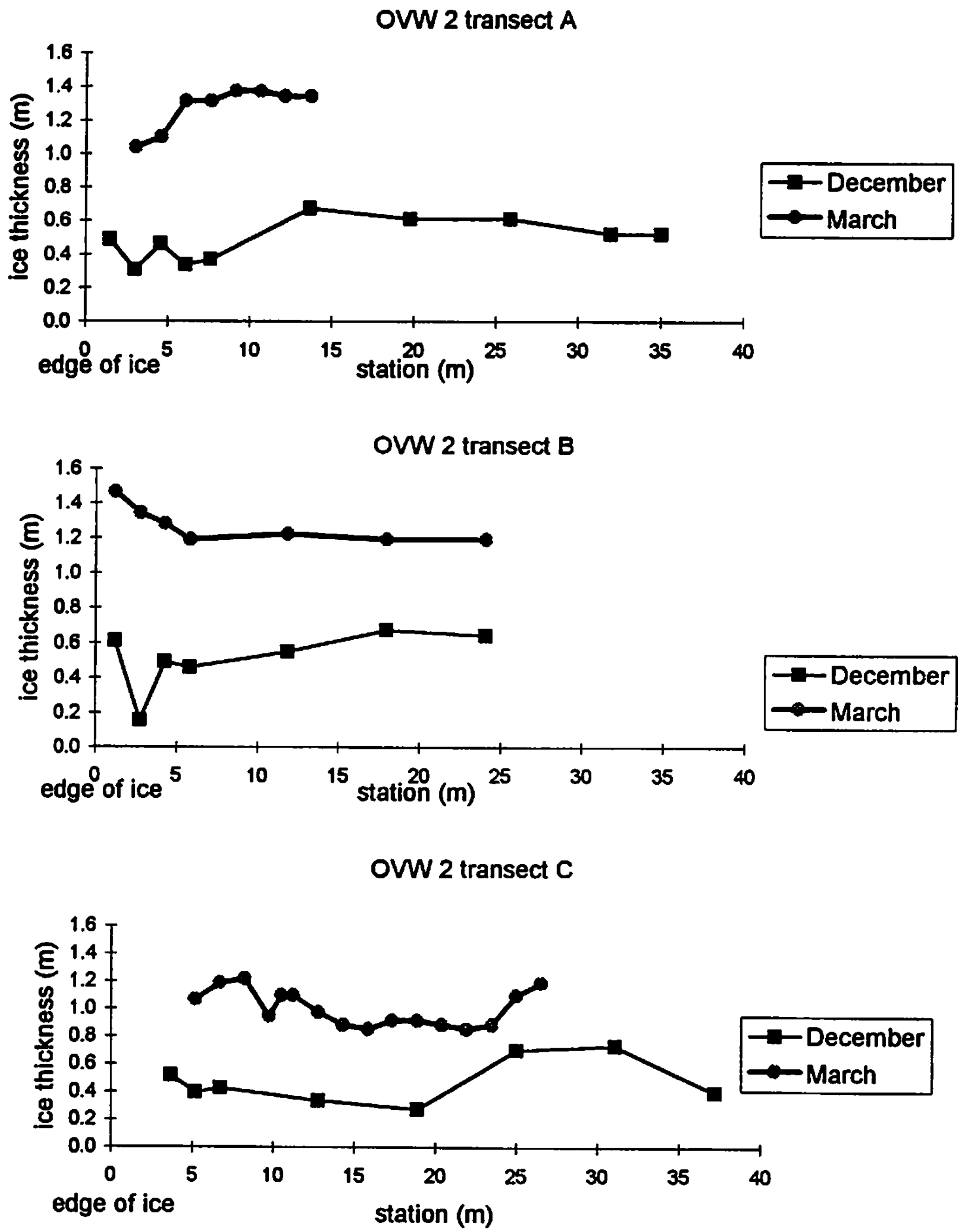


Figure 19. Winter 1993-94 ice thicknesses by station and month within overwinter area 2 (OWA 2) located within the upper mainstem of Beaver Creek, Alaska.

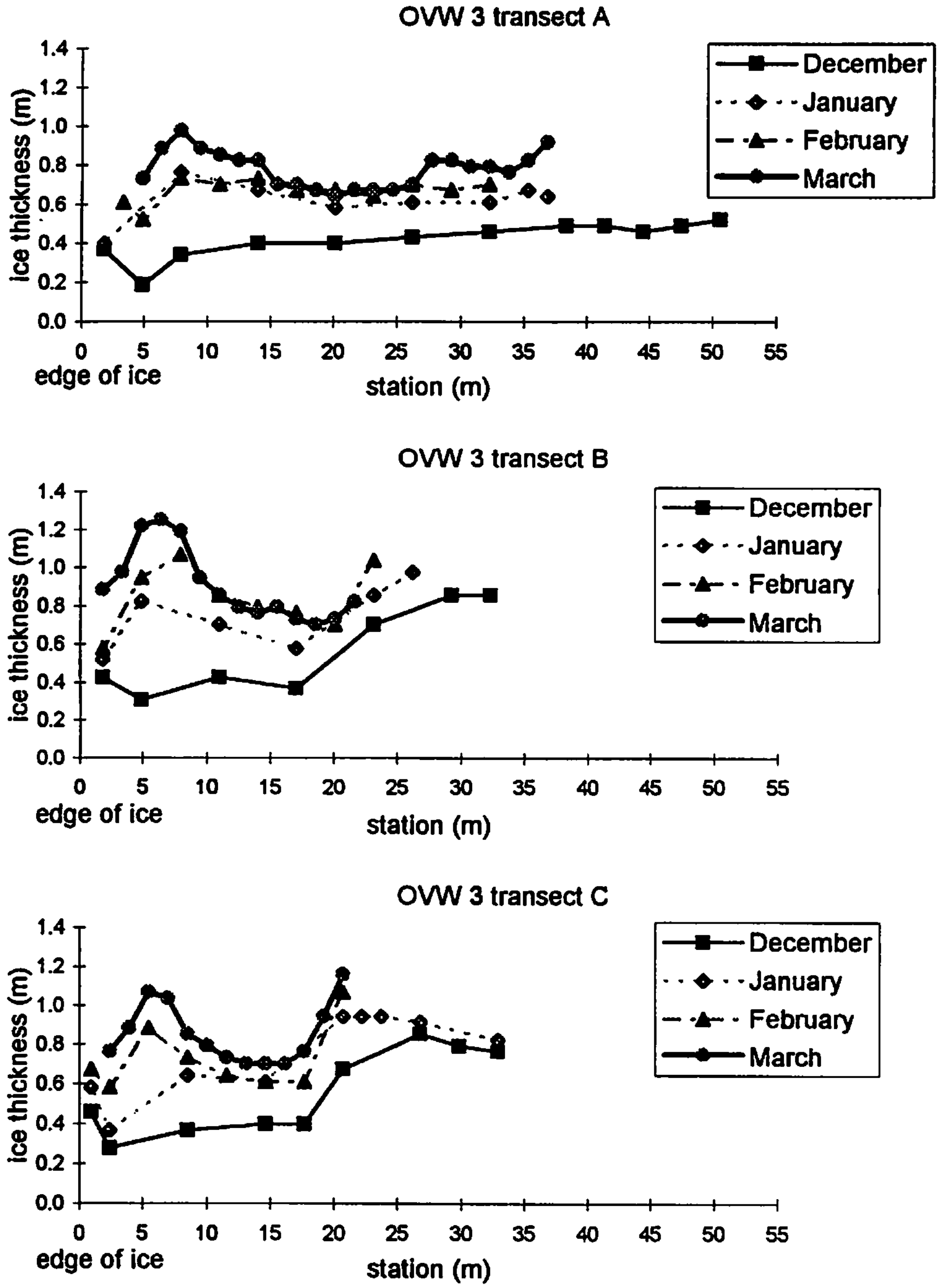


Figure 20. Winter 1993-94 ice thicknesses by station and month within overwinter area 3 (OWA 3) located within the upper mainstem of Beaver Creek, Alaska.

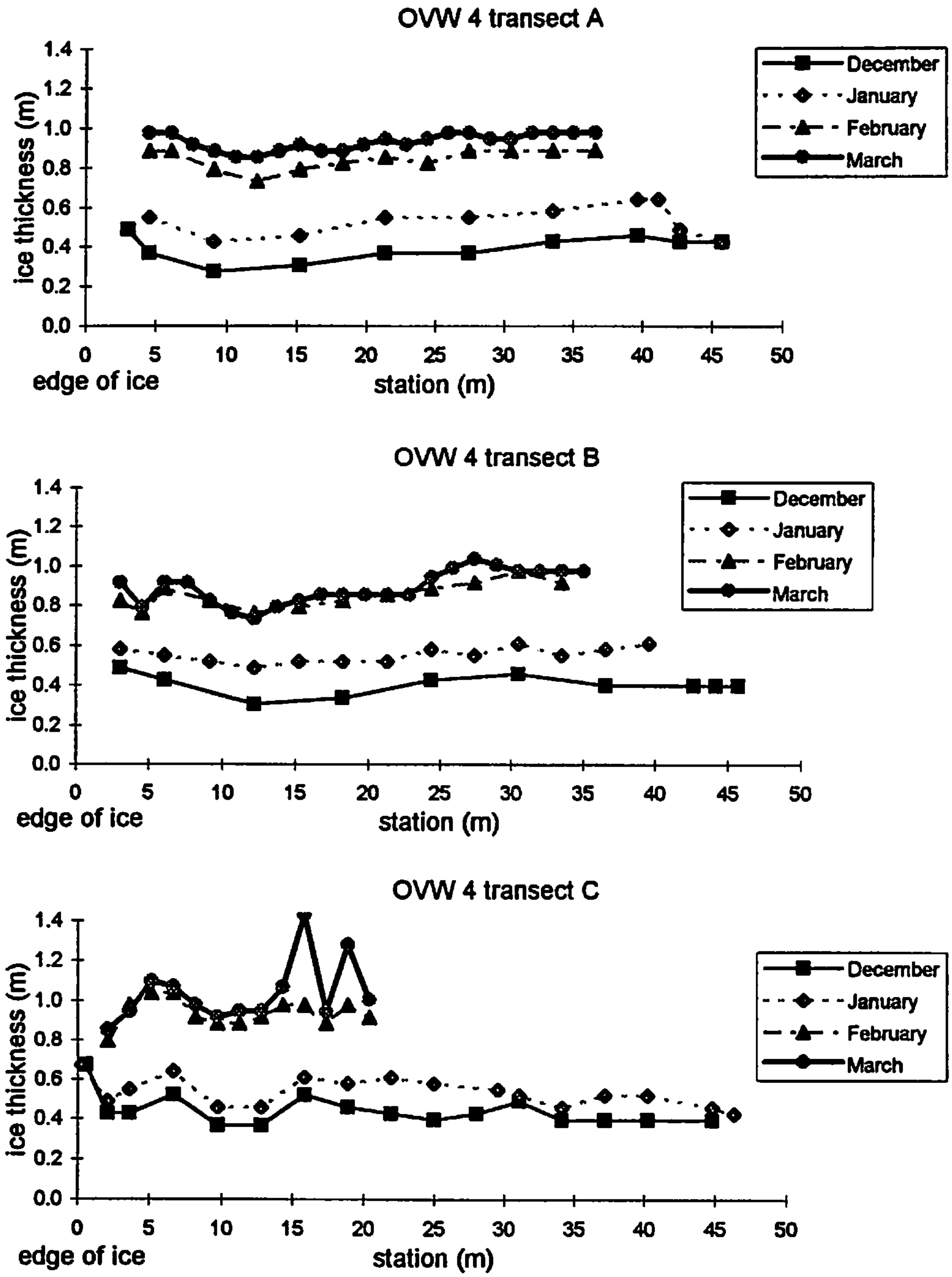


Figure 21. Winter 1993-94 ice thicknesses by station and month within overwinter area 4 (OWA 4) located within the upper mainstem of Beaver Creek, Alaska.

an increase February-March for those transects measured during those months (Figures 22 and 23). Water width decreased through February and by late March had either remained constant or had returned to February levels (Figure 24).

Cross-sectional diagrams were prepared for each transect sampled to illustrate the above physical characteristics and trends (Appendix D).

## Discussion

The results of this study add to our knowledge on the winter ecology of Arctic grayling. Ecological information can lead to the identification of potential impacts of management prescriptions on the aquatic ecosystem and provide avenues for mitigation that may otherwise go unnoticed.

Although biologists have long recognized the importance of winter habitats to arctic fish populations, this study provided empirical evidence of its importance. By the end December, radio-tagged fish movements were confined to stream sections less than 100 m in length. Of 40 ground relocations of radio-tagged fish during February-March 1992, 1993, and 1994, 26 had moved 0-1 m, 8 had moved 1-10 m, and 6 had moved 11-91 m from their initial location. This,

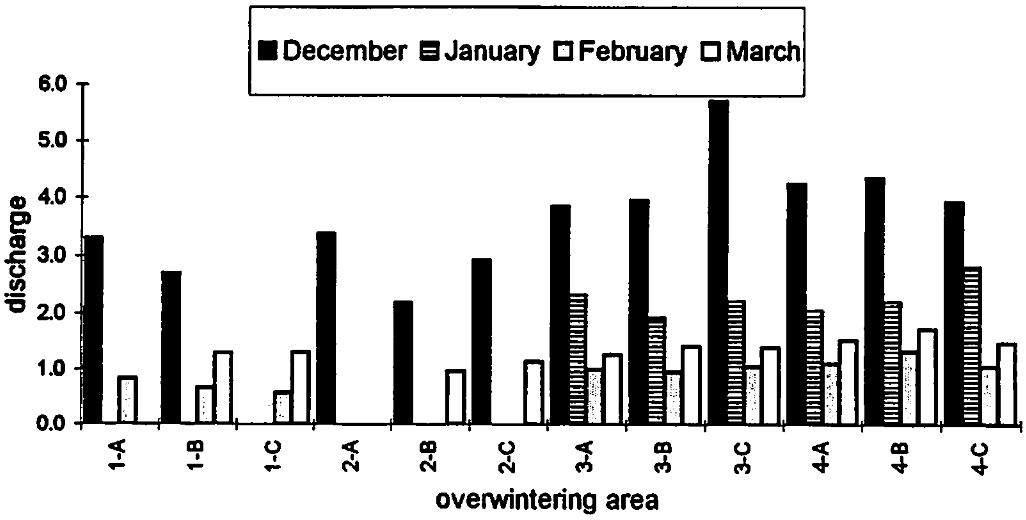


Figure 22. Winter 1993-94 monthly discharge ($m^3/s$) measurements within overwinter areas in Beaver Creek, Alaska.

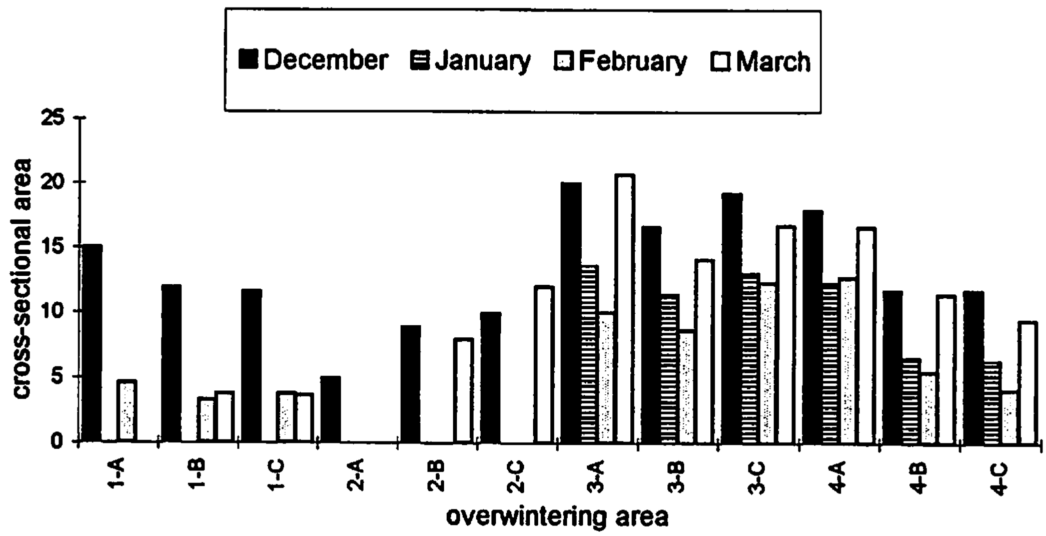


Figure 23. Winter 1993-94 monthly cross-sectional area ($m^2$) measurements within overwinter areas in Beaver Creek, Alaska.

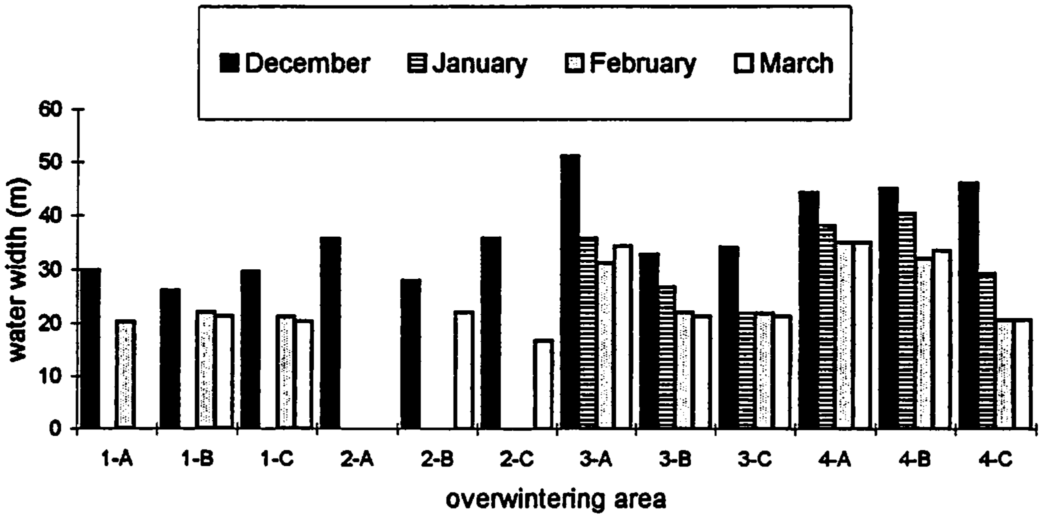


Figure 24. Winter 1993-94 monthly water width measurements within overwinter areas in Beaver Creek, Alaska.

coupled with the documentation of schooled Arctic grayling during under-ice observations, suggests the high value of these habitats. Importance of these habitats is further suggested by the fact that 21 Arctic grayling occupied only 12 OWAs, with two OWAs inhabited by fish tagged and released in different tributaries. In addition, of 3 radio-tagged fish confirmed alive during the second winter of tracking, one returned to a site within several meters of its previous year's location while the other two were within 2 km of theirs.

Why these two fish failed to return to their previous year's OWA may in part be explained by the observations in OWA 2 in winter 1993-94. It should be noted that one of these fish had occupied this particular OWA (OWA 2) the previous year. Although 5 radio-tagged and 8 untagged fish were documented in OWA 2 in winter 1991-92 and 1992-93, none were observed there in winter 1993-94 after many hours of observation. This may have been a direct result of changing flows resulting from large pieces of ice which, during freeze-up, froze as obstructions to flows 15 m above the upper transect (A). These obstructions resulted in restricted flows which maintained an open-lead in an area frozen over the previous two winters. In addition, water velocities in two stations within transect A in March 1994 were 1.50 and 1.65 m/s, more than twice the maximum velocity observed the previous two winters. Changes such as these likely result in displaced fish.

Under-ice feeding, although occurring only occasionally for any particular Arctic grayling, was observed each winter at water temperatures of 0.1-0.2 $^0$C. Under-ice sampling conducted by Alt and Furniss (1976), as cited in Wilson et al. (1977) on the North Slope of Alaska and February-March samples of Arctic grayling in Hodgson Creek, Northwest Territories by McKinnon and Hnytka (1988), revealed that Arctic grayling feed during winter, mostly on insects and fish eggs. In addition, Needham and Jones (1959) reported trout actively feeding at water temperatures between 0 and 1 $^0$C and also found that stream invertebrates in winter were abundant. Under-ice feeding may play an important role in the development of gametes for spring spawners, such as the Arctic grayling. Benefits of feeding to overwintering fish have been questioned due to low consumption and digestive rates (Leonard 1942, Reimers 1957). However, the recurrence of under-ice feeding behavior in Arctic grayling and round whitefish, suggests feeding may be important to at least these two interior Alaska fish species. This may be especially true for subadult Arctic grayling and adult round whitefish, based on the distinctly higher consumption rates observed for these two as compared to adult Arctic grayling. This may place added importance on maintaining the low turbidities documented in this study. Furthermore, reductions in the quantity or quality of the already reduced under-ice invertebrate drift (primarily due to reduced flow rates) could have substantial effects on the productivity of the fish population. Under-ice invertebrate drift is likely a function of velocity and invertebrate abundance on the surface of the streambed (LaPerriere 1983), therefore reductions in velocity or invertebrate productivity could have negative effects on Arctic grayling. Under-ice feeding may also maintain energy reserves for the upstream spring migration to spawning habitats.

In this study, under-ice observations documented adult Arctic grayling closely associated with the stream bottom. This association has also been documented for juvenile brown trout Salmo trutta by Hartman (1963). In addition, fish rely on winter cover for shelter and velocity barriers (Tschaplinski and Hartman 1983). Although fish would move short distances, they were nearly always observed settling back into the substrate. When viewed from an underwater camera at the focal point of the fish, this substrate often towered above the surrounding substrate and hid 50% or more of the fish. Based on substrate measurements within these areas, this substrate was either rubble (16-64 mm) or cobble (64-130 mm). A consideration for resource managers is that availability of this cover can be reduced or eliminated through siltation caused by alterations in the stream hydrology, channel morphology, or both.

Flow depths within OWAs never exceeded 0.76 m and maximum observed water width during winter low-flow (February-March) was only 49.7 m. Also, fish were not observed within thalwegs running adjacent to the stream bank. This suggests that even minimal reductions in under-ice discharge could lead to substantial habitat reductions with resulting impacts to fish populations. Channel disturbances frequently result in the formation of aufeis, and could well result in reductions to downstream fish habitats by reducing flow rates. In interior Alaska, placer mining often occurs in mainstem tributaries believed to contain little if any crucial fish habitat. However, channel modifications resulting in aufeis formation may be an important mechanism in reducing the carrying capacity of the system through reductions in available habitat.

Fish ecology investigations may also provide information on important differences in habitat use for other life stages and fish species. This study documented the presence of subadult Arctic grayling in only 2 of 12 OWAs where they were outnumbered 12 to 1 overall, suggesting a subadult habitat preference different from that of adults. One subadult Arctic grayling OWA was discovered within the mainstem of Beaver Creek at river km 467.4, 1.9 km upstream of the most upstream adult Arctic grayling OWA (OWA 1). This suggests subadult Arctic grayling overwinter in more upstream reaches than adults, perhaps in tributaries historically managed for placer mining. Subadult Arctic grayling were found within the headwaters of Hogdson Creek, Northwest Territories (McKinnon and Hnytka 1988) and in areas with an average of 45 cm of ice overlying an average of 20 cm of flowing water within a tributary to the Sukunka River, British Columbia (Stuart and Chislett 1979). Winter investigations conducted by the Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska Fairbanks (N. Hughes, University of Alaska Fairbanks, personal communication), documented subadult Arctic grayling overwintering within an aufeis covered, isolated pool of a small headwater tributary to Birch Creek in interior Alaska. In contrast to the Birch Creek subadult OWA, upper mainstem Beaver Creek OWAs appeared to be connected. However, migratory routes to upstream spawning habitats may not be open during the winter low-flow period. Arctic grayling begin their pre-spawning migration between mid-April to early June and as early as 18 days prior to spring break-up (Tack 1980). A phenomenon which may open these potentially closed migration routes to under-ice migrants such as the Arctic grayling was documented in this study. From late February to late March, water widths remained unchanged and ice thicknesses increased. This usually implies a reduction in flow area and depth. However, an increase in both were observed, a result of increased discharge observed during this time period. Two points are worth noting here: 1) late winter-early spring increases in discharge increase flow area and depths by lifting the ice cover and 2) flow depth is not necessarily a function of ice thickness. Cross-sectional areas increased with the lifting of the ice. This maintained, and in some areas decreased, mean velocities in the vertical. These reduced velocities may decrease metabolic demands on overwintering fish and perhaps in part explain how overwintering fish can maintain energy levels needed for migration and spawning.

This study described adult Arctic grayling microhabitats and OWAs within an interior Alaska stream. Overwinter area descriptions revealed a similarity between up- and downstream OWAs and that OWAs generally followed the same pattern of change over time.

Available (entire transect) and microhabitat data (use) were similar, suggesting that the less time-intensive transect technique can be used to describe Arctic grayling microhabitat. Winter habitat use studies on brook trout suggest the opposite, that use would be better described by data collected from individual fish locations (Chisolm 1985).

This work identifies the need for several specific areas of research: 1) winter habitat preference based on aerial habitat descriptions; 2) identification and characterization of the natural and man-made factors affecting winter flow regimes with an emphasis on placer mining; 3) significance of winter feeding and factors affecting the abundance of under-ice invertebrate drift; 4) investigate the relationship between otter and Arctic grayling in two specific areas: fish habitat use as a function of predator avoidance, as opposed to preference; and, the perceived increase in vulnerability of radio-tagged adult Arctic grayling to predation.

## Summary

Placer mining and road construction within the headwaters of Beaver Creek, Alaska, and the paucity of information on the winter ecology of Arctic grayling, raised

concern for the protection of crucial habitats for this popular sportfish. A study was designed to locate and describe OWAs of adult Arctic grayling. In 1991 and 1992, 21 radio-tagged Arctic grayling were tracked 12-58 km from summer habitats to 12 OWAs located over a 31-km section of upper Beaver Creek. Eighty-eight stations were established within 1 m of undisturbed fish from which microhabitat variables were measured during the winter low-flow period (February-March) in 1991-92, 1992-93, and 1993-94. Adult Arctic grayling occupied areas with ice thickness of 0.4-1.4 m overlying 0.06-0.52 m of water, flowing at 0.03-0.56 m/s. In winter 1993-94, four OWAs were selected for characterization during December-March. Discharge, cross-sectional area, and water width decreased until late March, when discharge and cross-sectional area increased. Water velocities decreased and ice thicknesses increased. Arctic grayling occupied much shallower winter habitats than previously thought, increasing concern for proper winter water management. Adult Arctic grayling OWAs were not located within areas with the potential for disturbance, however, subadults were absent from adult OWAs, raising a need to also locate these habitats.

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## Conclusion

Resource managers require information on the locations of crucial fish habitats so they can be afforded adequate protection against land-altering activities. In addition, information on fish ecology allows identification of potential impacts which may otherwise go unnoticed (e.g., channel disturbances upstream of shallow overwinter areas may lead to habitat reduction by locking up liquid water in the form of aufeis).

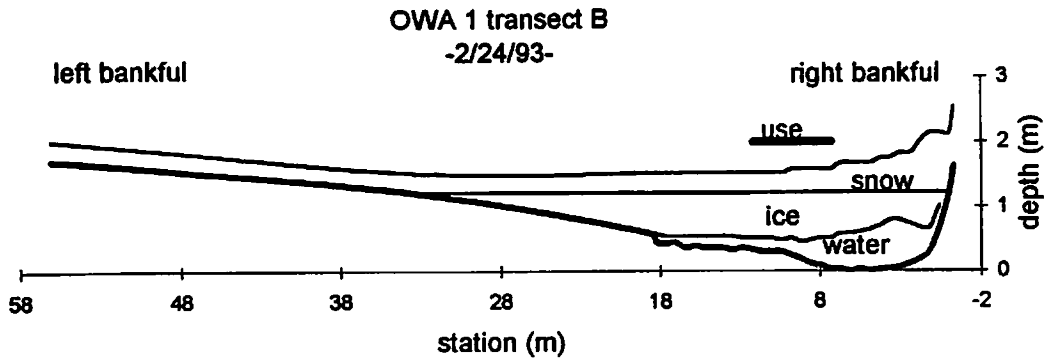
Accurate locations of crucial habitats is imperative to successful resource management. This study confirmed that interpretations based soley on aerial radio telemetry data overestimated tagged fish survival. Factors contributing to erroneous aerial data interpretations included post-surgical mortality and/or transmitter expulsion during migration, combined with the use of habitat features which were assumed, based on the results of previous studies, to be indicators of Arctic grayling winter habitats. Erroneous interpretations resulted in misidentifying 14 of 26 overwinter areas. Having gone unnoticed, resource managers would have made decisions concerning resources uses based on inaccurate information. It is critical that location techniques and interpretations be validated before integration into resource management programs so that informed decisions are made based on accurate information. In addition, scientific credibility and public trust are damaged when these inaccuracies are identified after integration into management programs. As important as validating location techniques is confirming that behavior and habitat use are not affected by the attachment or presence of the transmitter. Biologists must confirm that habitat use of radio-tagged fish is the same as unhandled fish of the same species and life-stage. This often over-looked aspect would invalidate the use of radio-tagged fish for investigating behavior and habitat use. Once location techniques and habitat use have been validated, behavior and habitat investigations can be conducted.

Adult Arctic grayling were found to overwinter 12-58 km downstream from their summer feeding habitats. Winter low-flow (February-March) descriptions of these overwinter areas revealed that these habitats were shallow, ice covered areas with relatively slow velocities. All overwinter areas were located in cut-bank habitats or in glides transitioning into them.

There were no similarities between the habitat descriptions documented in this study and those from previous studies. This is important for two primary reasons. First, this information increases our understanding of the winter ecology of Arctic grayling, which will benefit future research and resource management. Secondly, previous studies found overwintering Arctic grayling in association with open-leads, aufeis areas, and deep pools, which can be used to identify potential overwinter areas. In contrast, there are no physical indicators of adult Arctic grayling overwinter areas in Beaver Creek.

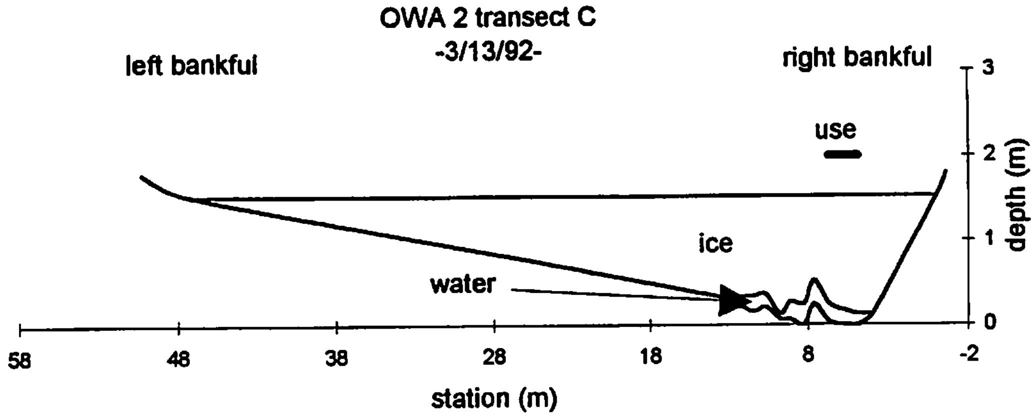
Adult Arctic grayling overwinter areas are similar throughout the upper mainstem of Beaver Creek and exhibit similar patterns of change through winter. Flow depth, water width, cross-sectional area, velocity, and discharge decrease throughout most of the winter. By late winter, water widths and velocities are at a minimum while discharge, cross-sectional area, and flow depth increase.

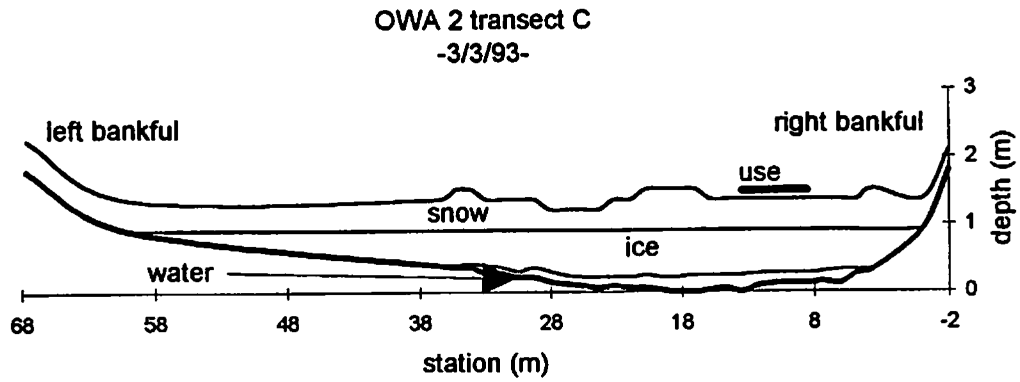
APPENDIX A

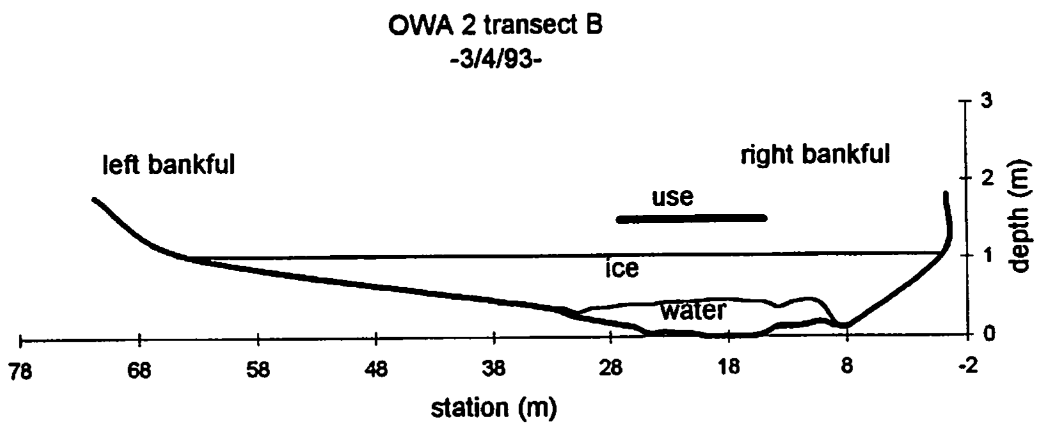



Winter 1991-92 and 1992-93 cross-sectional diagrams of 12 overwinter areas showing areas of use in Beaver Creek, Alaska. Stations are measured from the edge of ice on the thalweg side of the channel.

APPENDIX A (CONT.)

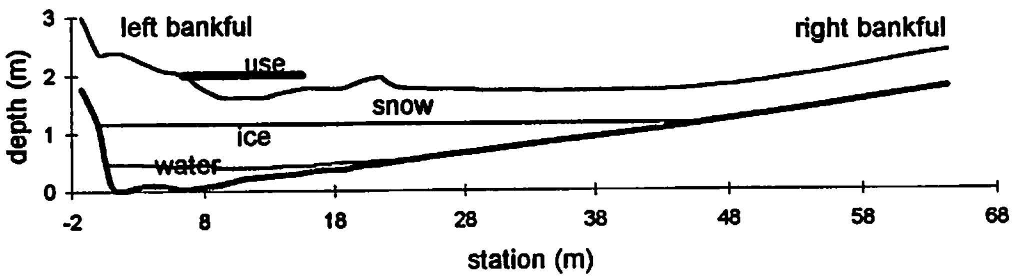


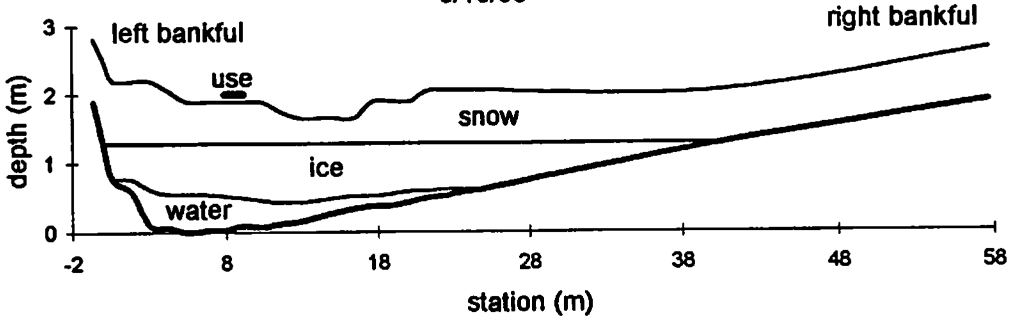



APPENDIX A (CONT.)

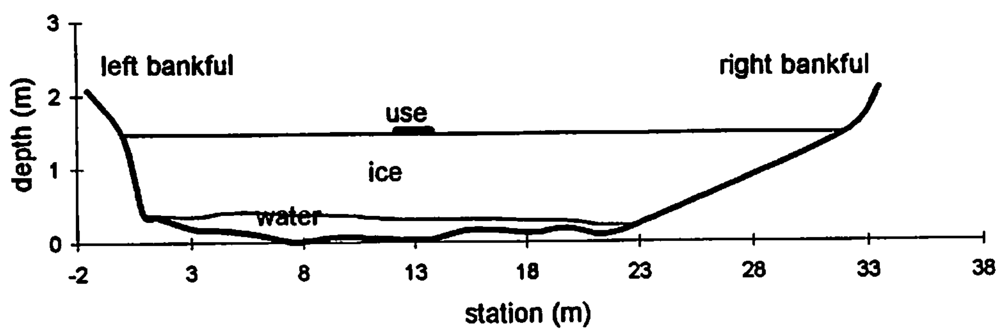
OWA 461.1 (lower transect)
-3/10/93-




OWA 461.1 (upper transect)
-3/10/93-

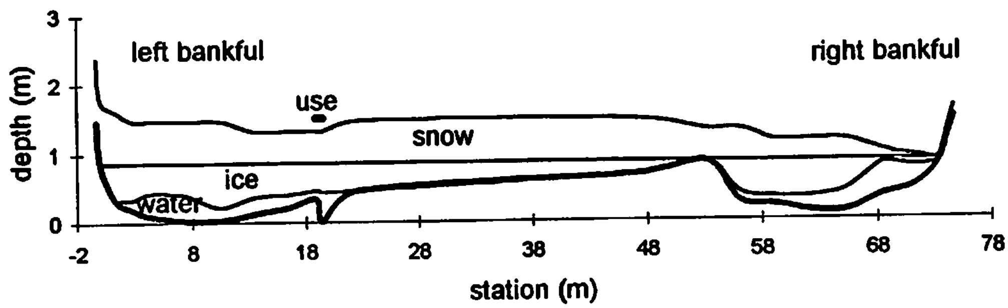



OWA 457.4
-3/19/92-

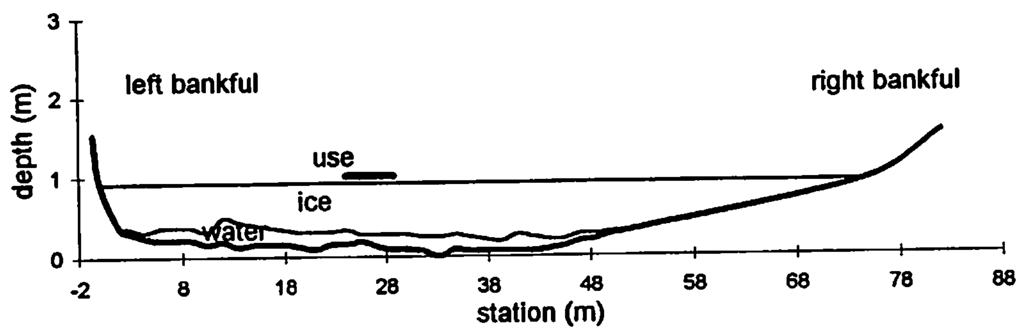


APPENDIX A (CONT.)

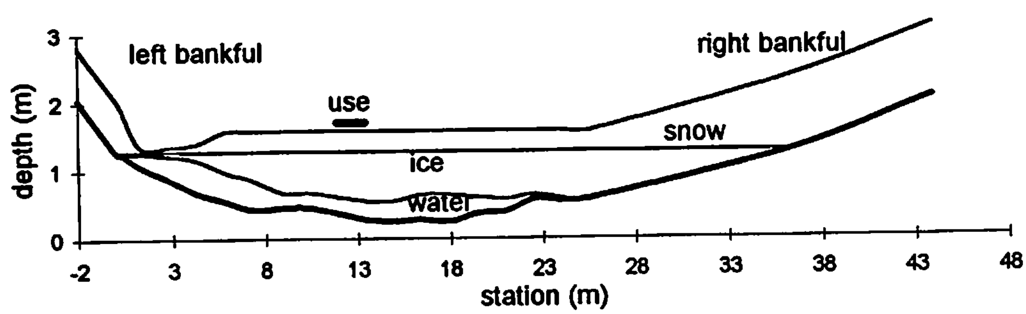
OWA 451.6
-3/18/93-




OWA 451.3
-3/17/93-

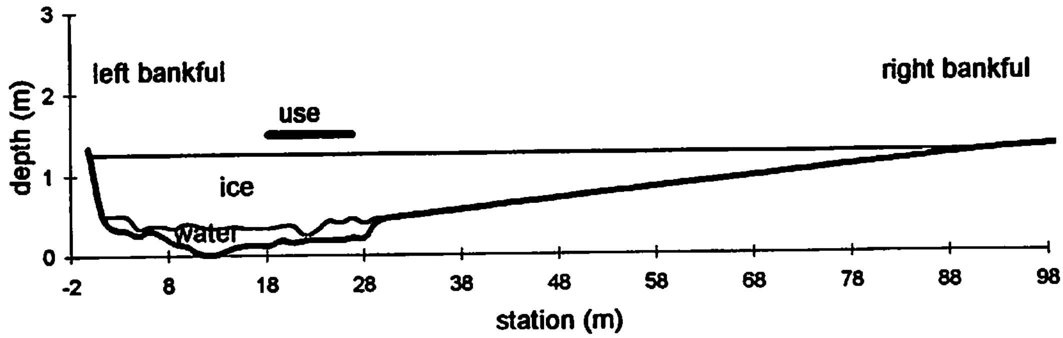



OWA 450.8
-3/31/93-

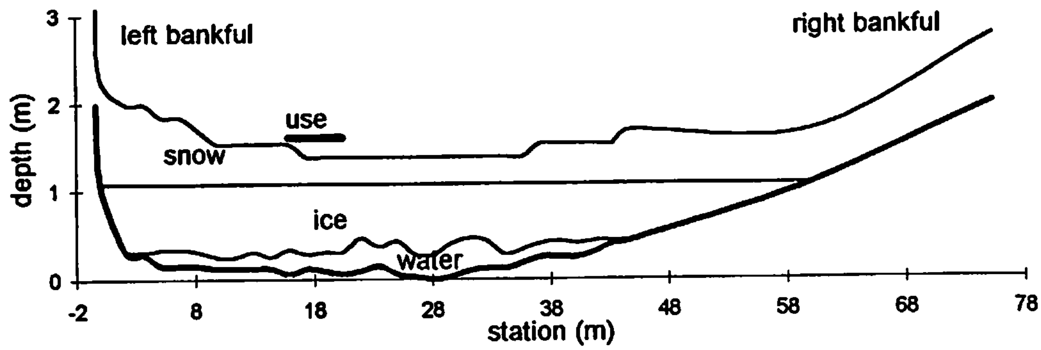


APPENDIX A (CONT.)

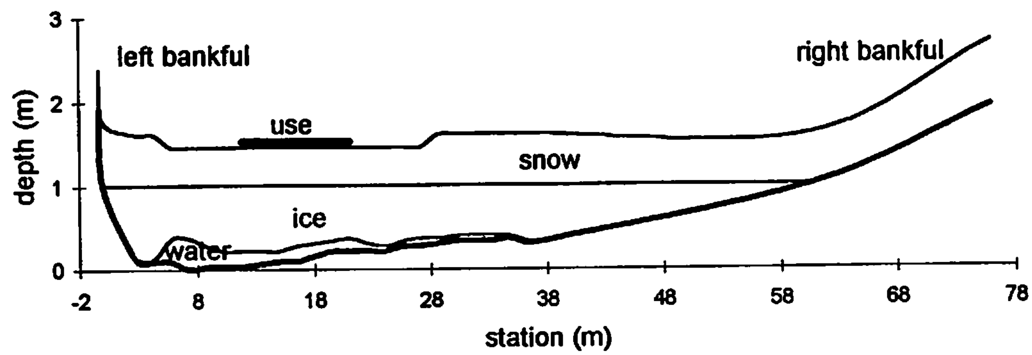
OWA 3 (449.5) transect B
-2/27/92-




OWA 4 transect A
-3/25/93-

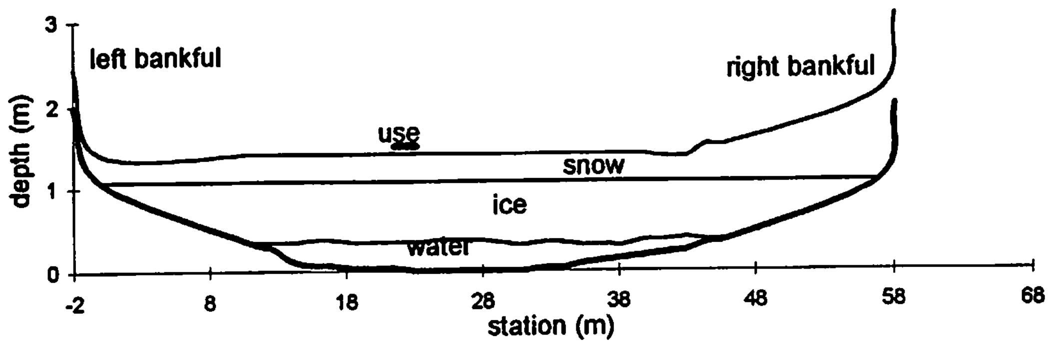



OWA 4 transect C
-3/24/93-

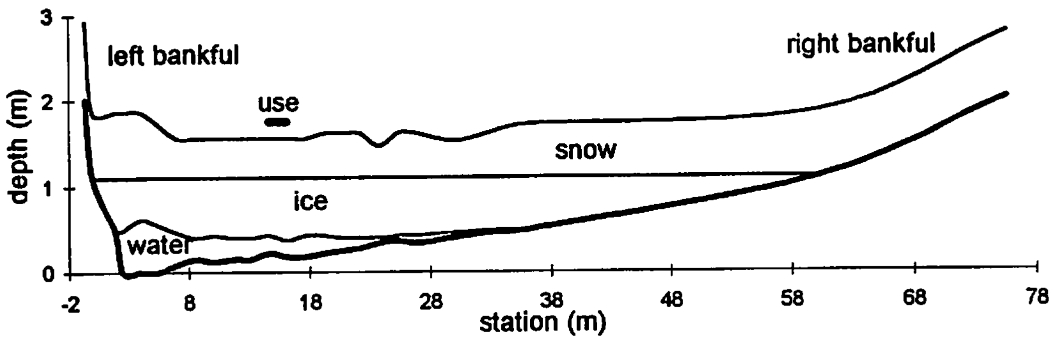


APPENDIX A (CONT.)

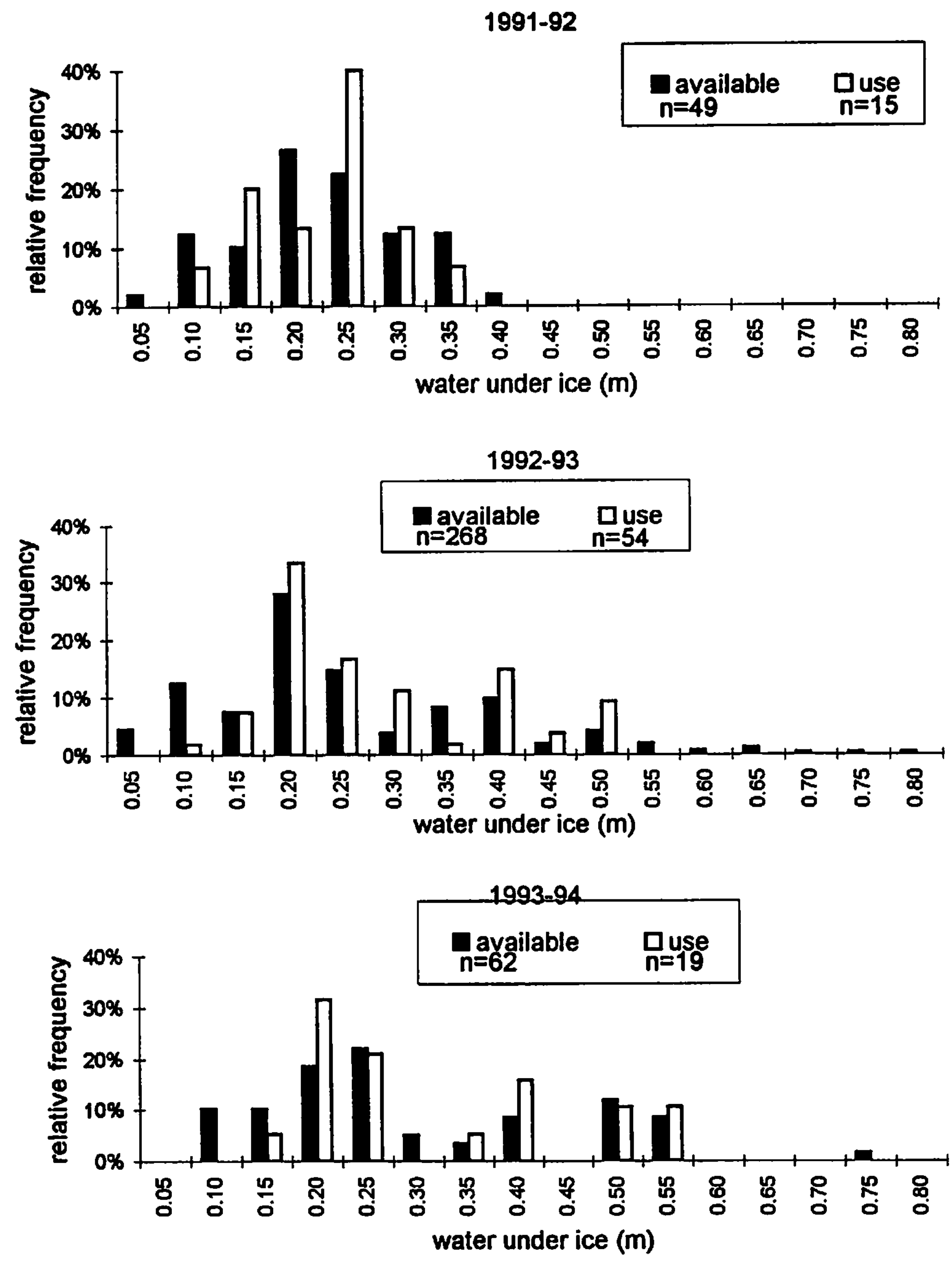
OWA 440.2
-3/30/93-




OWA 434.7
-3/31/93-

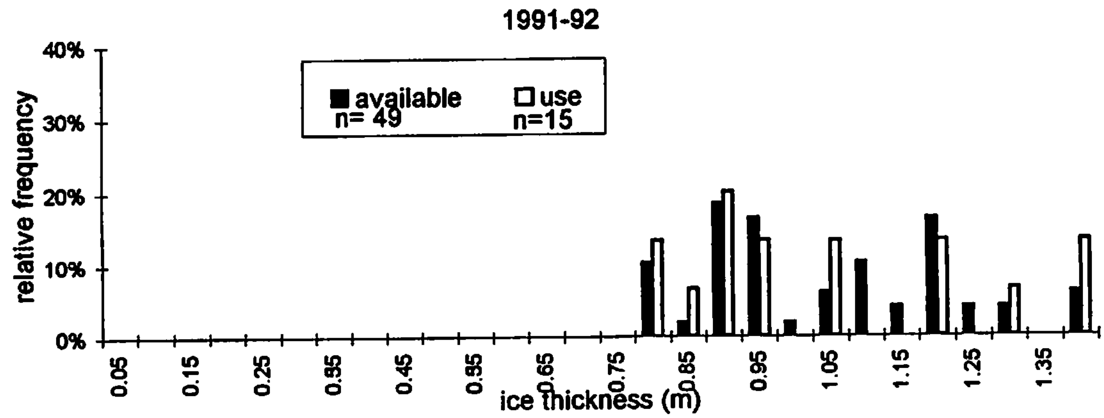


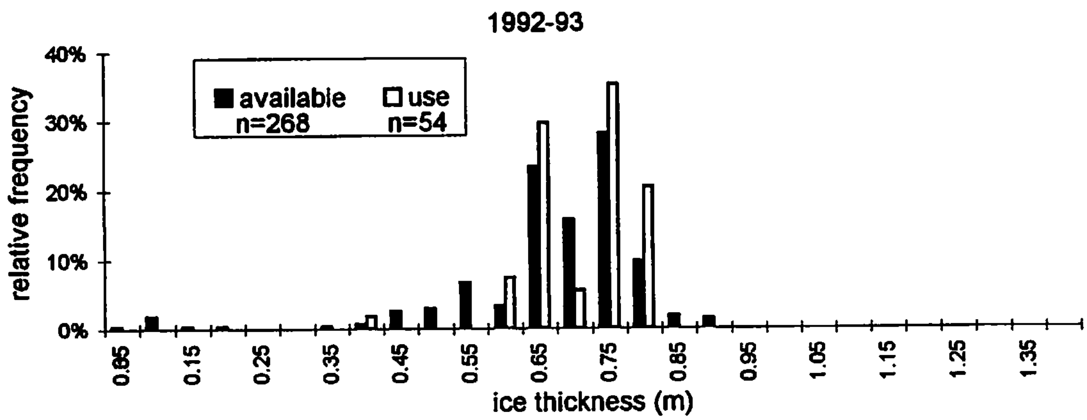
# APPENDIX B

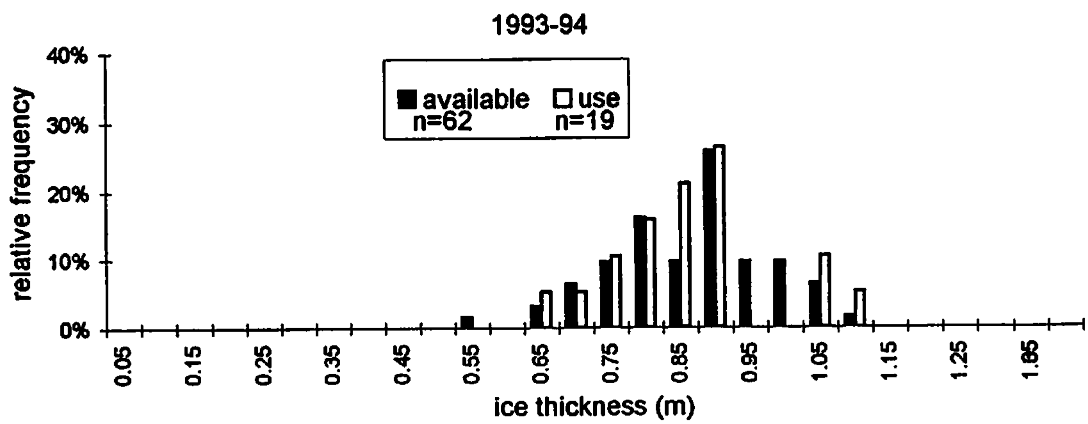



Comparison of available flow depths (water under ice), ice thicknesses, and velocities with those measured within 1 m of undisturbed Arctic grayling in winter within the upper mainstem of Beaver Creek, Alaska.

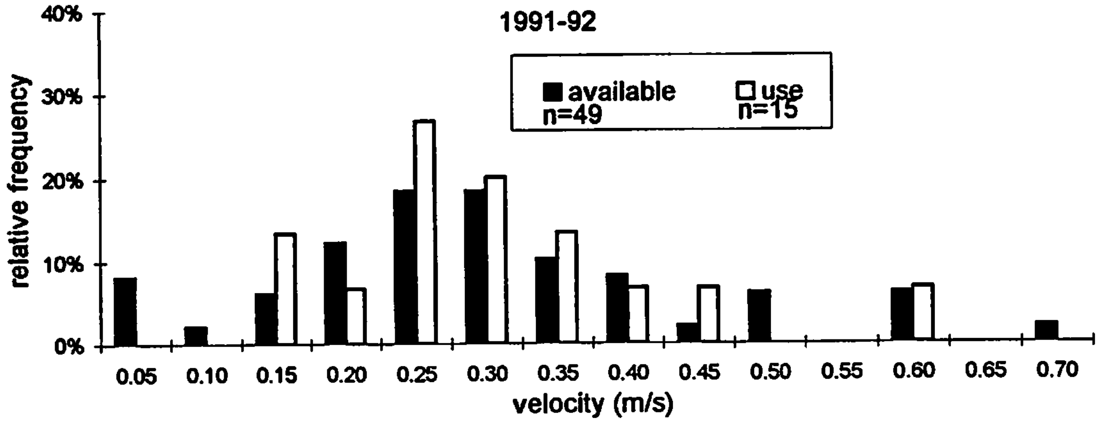
APPENDIX B (CONT.)

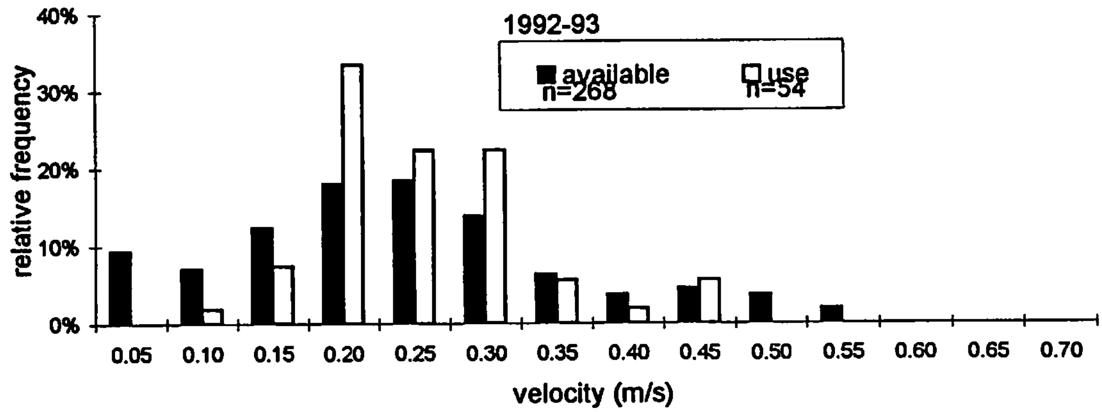


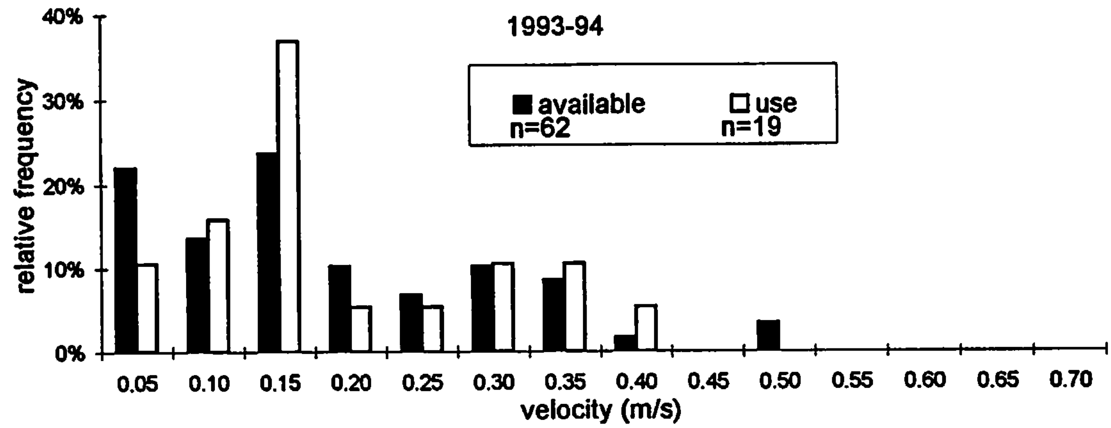



APPENDIX B (CONT.)

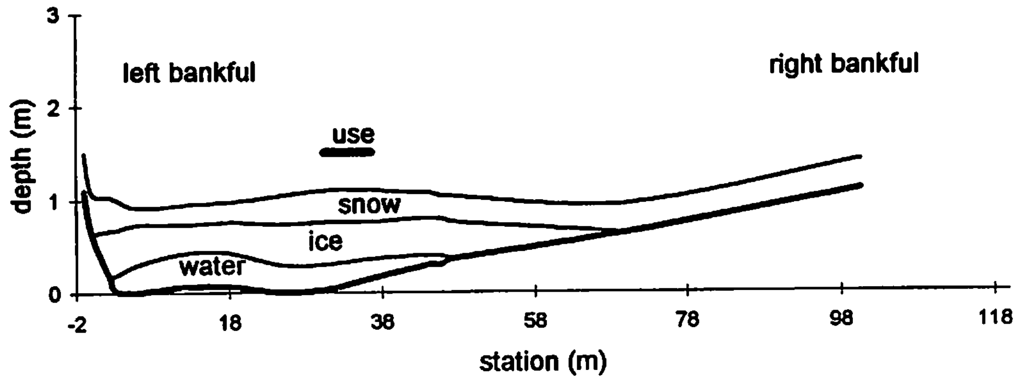


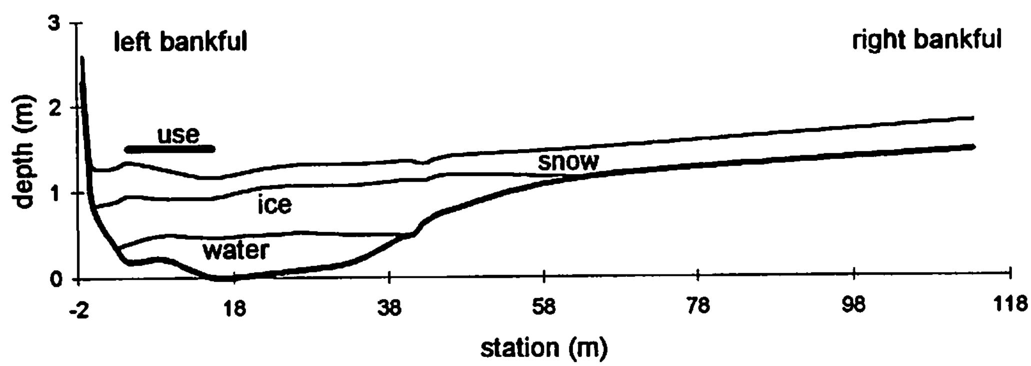



# APPENDIX C

OWA 4 transect B
-December-

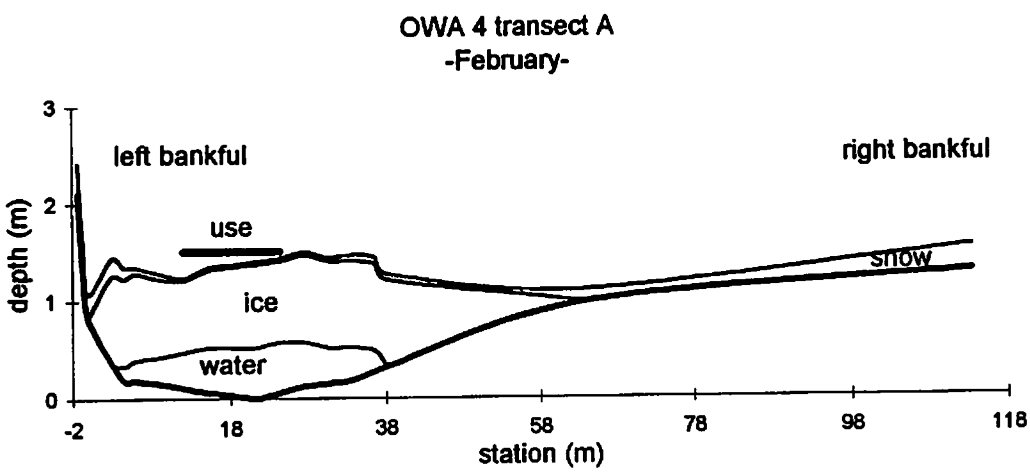


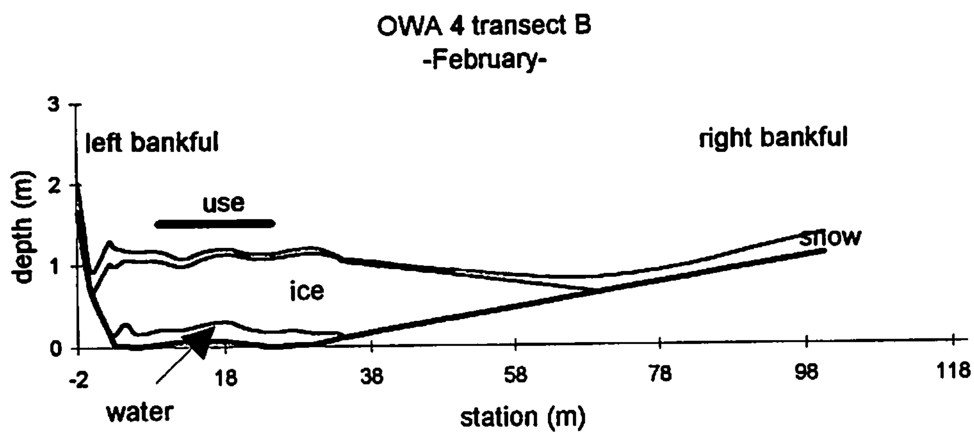

OWA 4 transect A
-January-

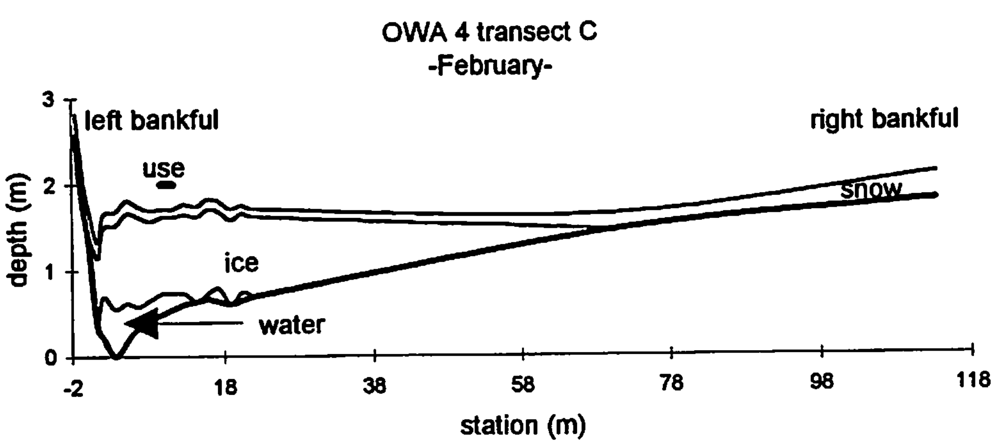



Winter 1993-94 cross-sectional diagrams of those transects within OWA 4 where adult Arctic grayling were observed within the upper mainstem of Beaver Creek, Alaska.

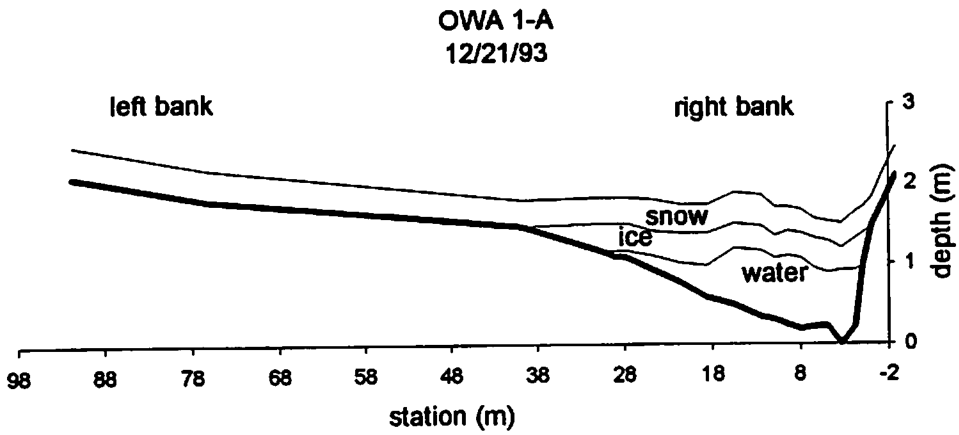
APPENDIX C (CONT.)

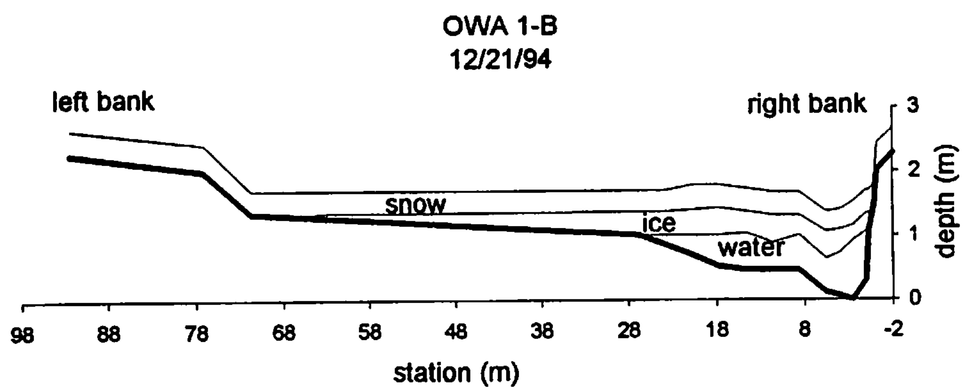


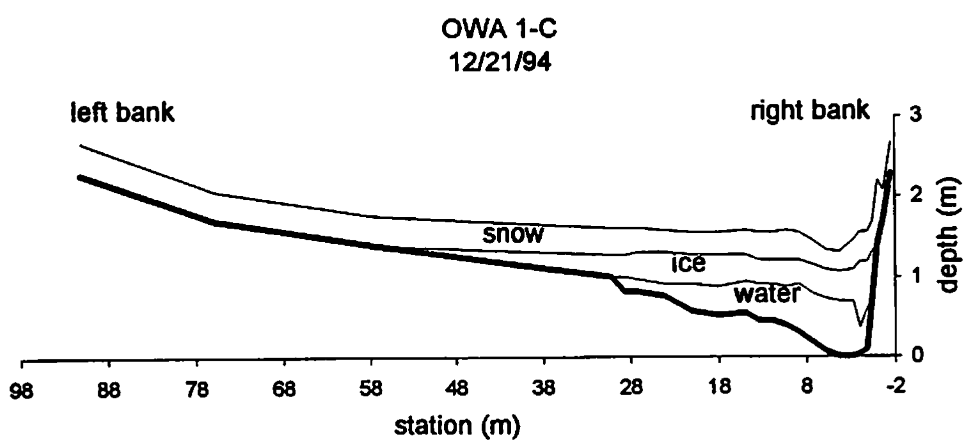



APPENDIX D



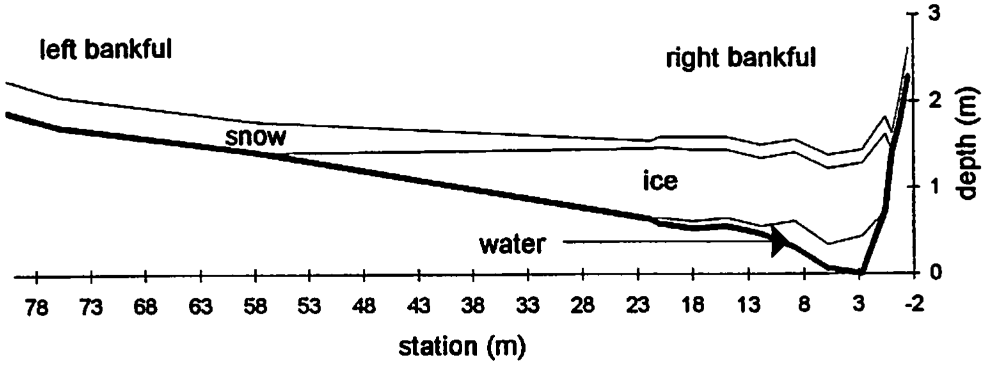



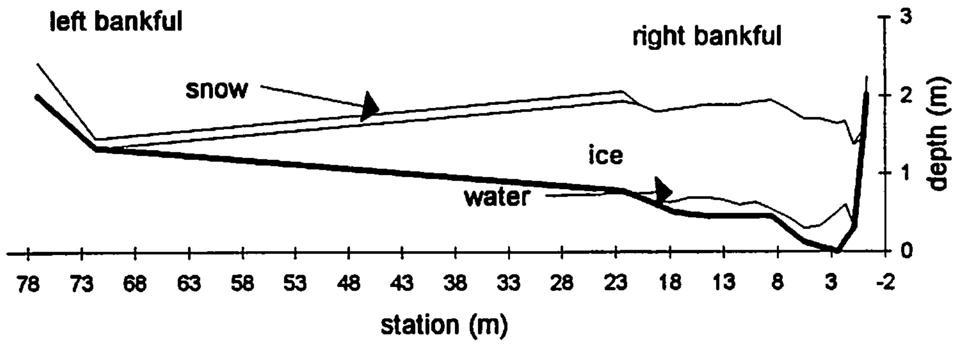

Winter 1993-94 cross-sectional diagrams of adult Arctic grayling overwinter areas (OWA) measured December-March within the upper mainstem of Beaver Creek, Alaska.

# APPENDIX D (CONT.)

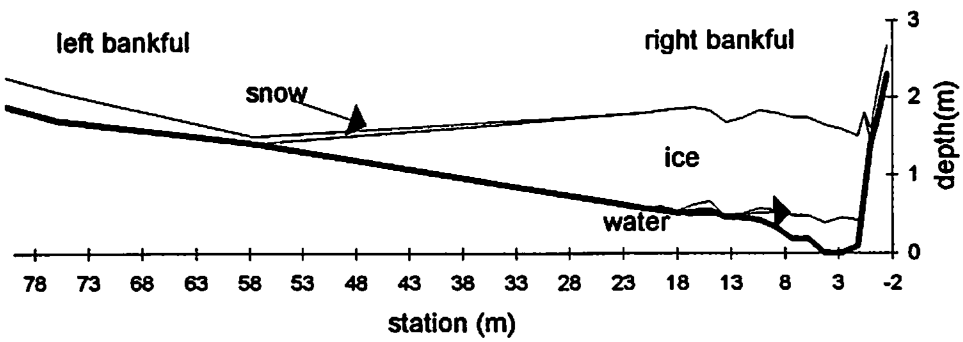
OWA 1-A
03/01/94




OWA 1-B
03/01/94

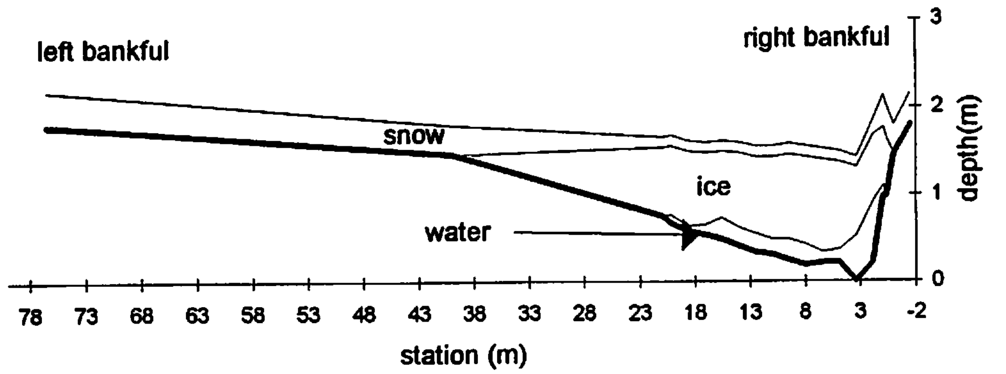



OWA 1-C
03/01/94

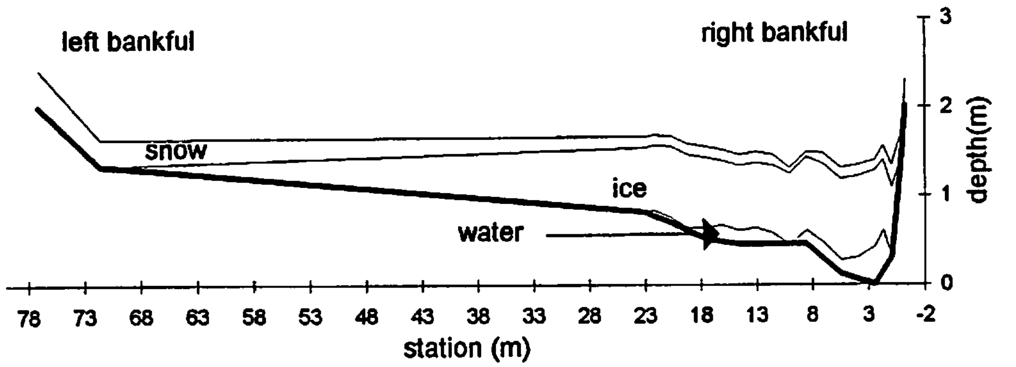


APPENDIX D (CONT.)

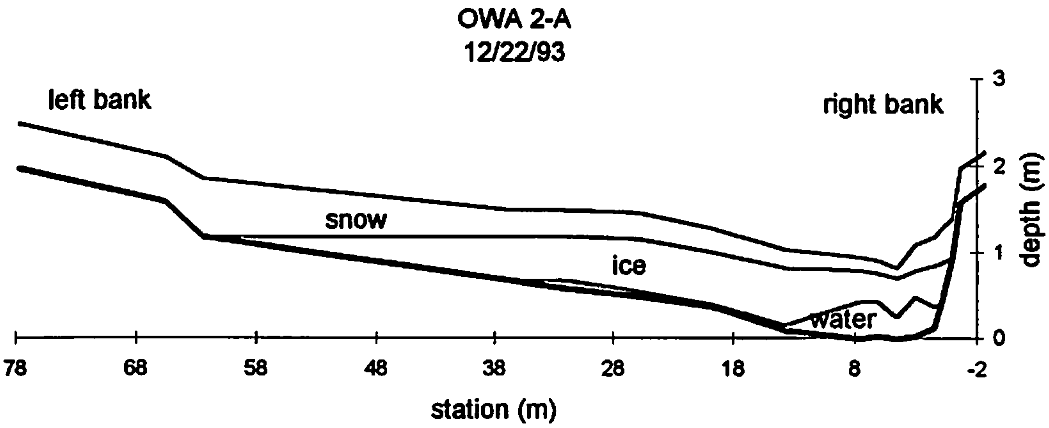
OWA 1-A
03/29/94

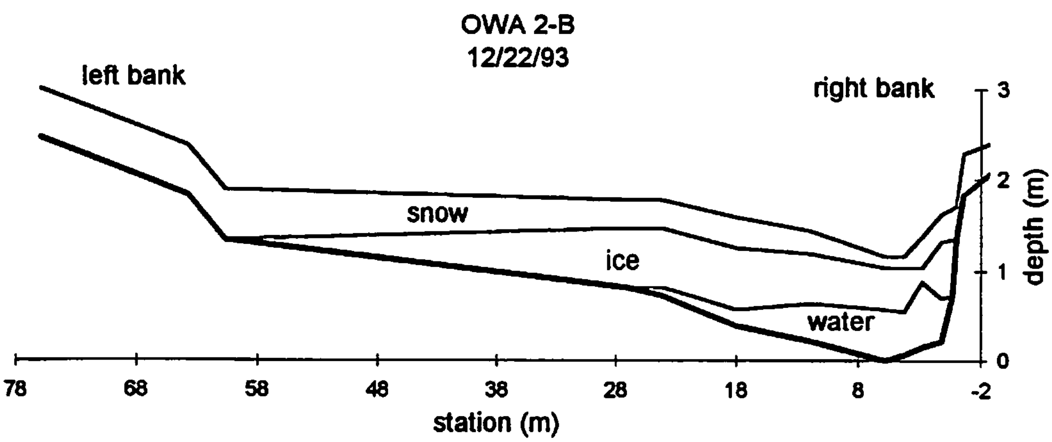


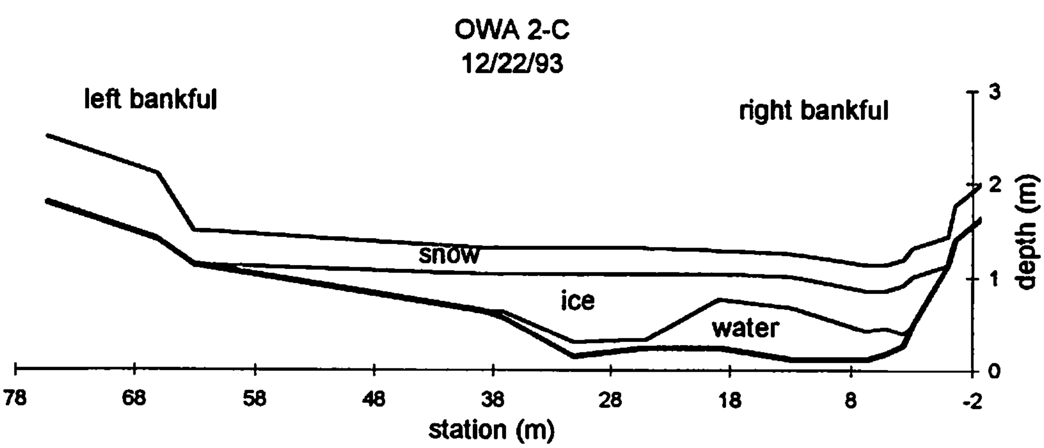

OWA 1-B
03/29/94



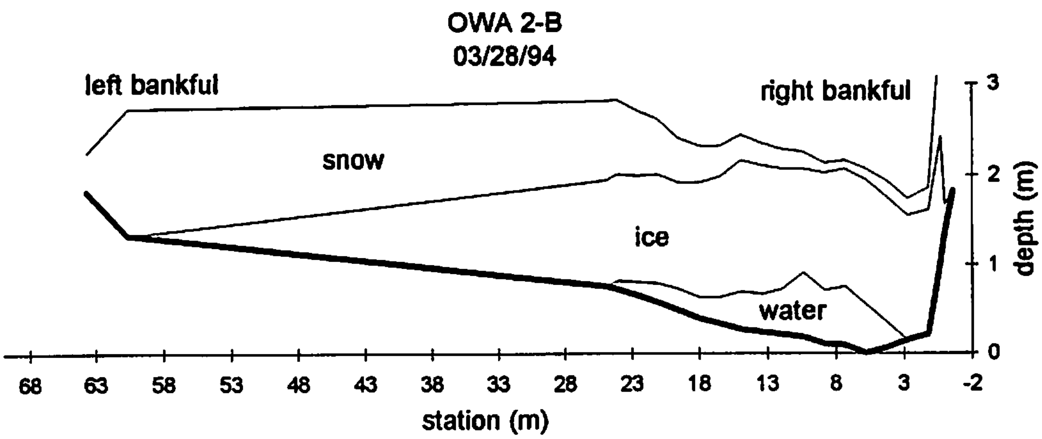
APPENDIX D (CONT.)

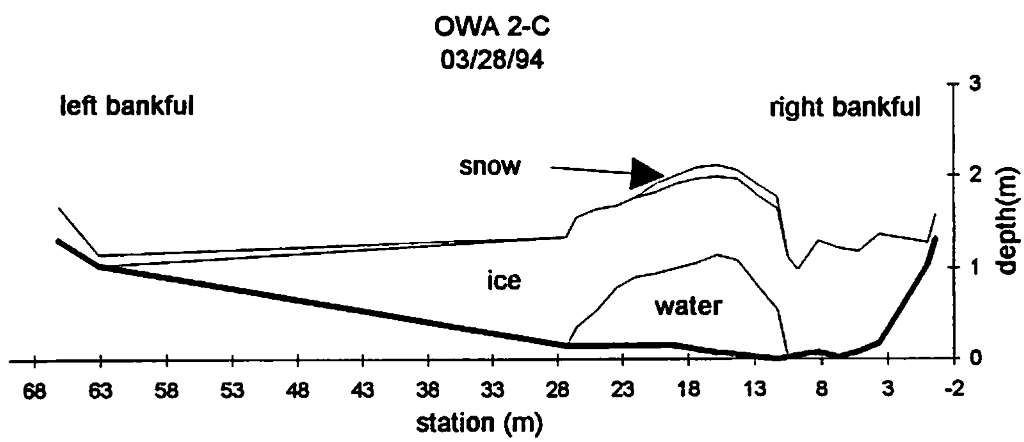


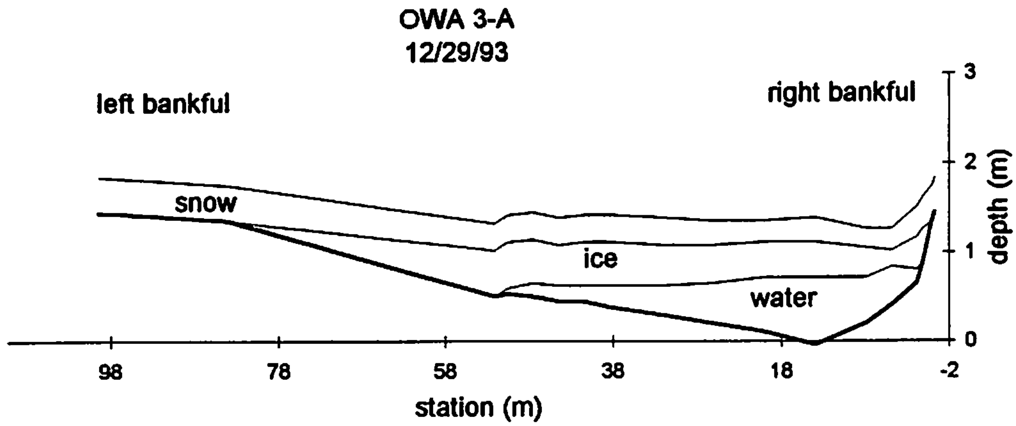



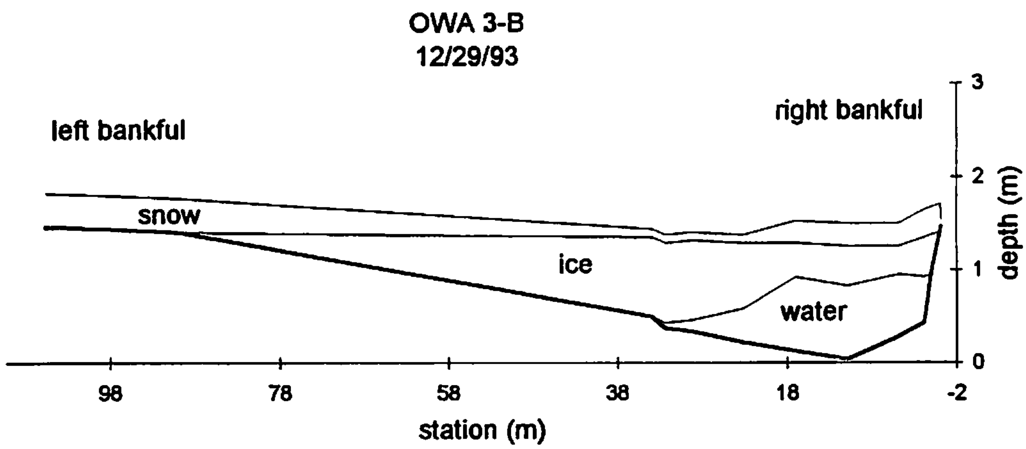
APPENDIX D (CONT.)

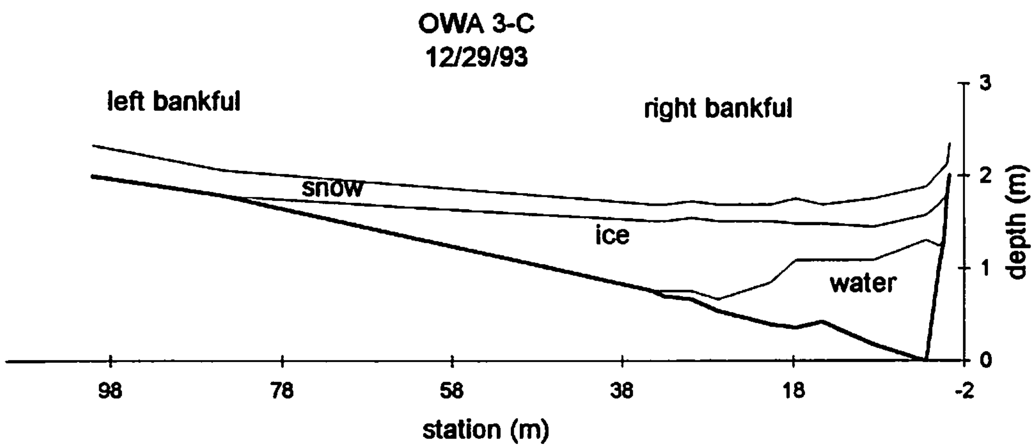


APPENDIX D (CONT.)

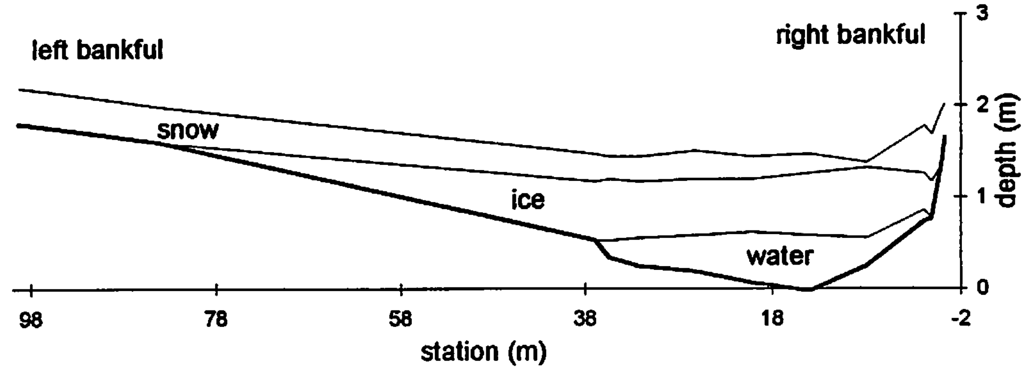


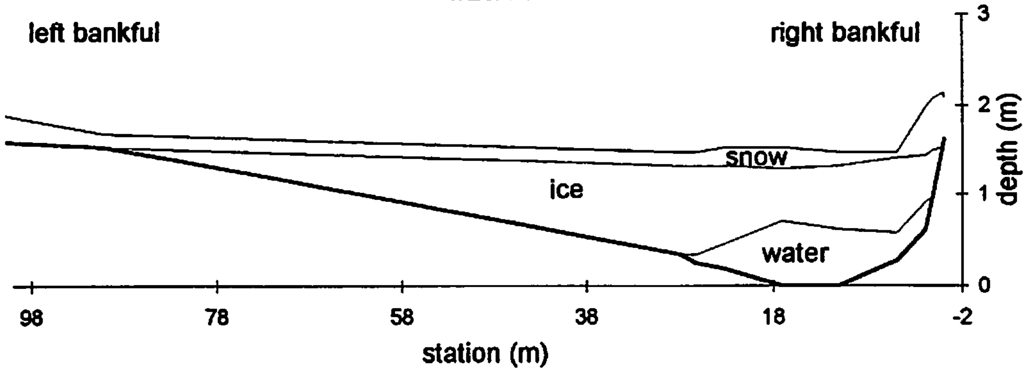



APPENDIX D (CONT.)

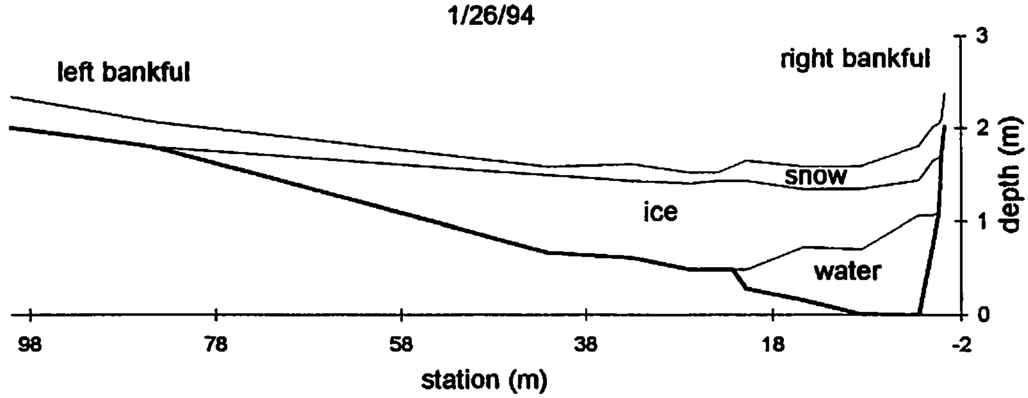
OWA 3-A
1/26/94

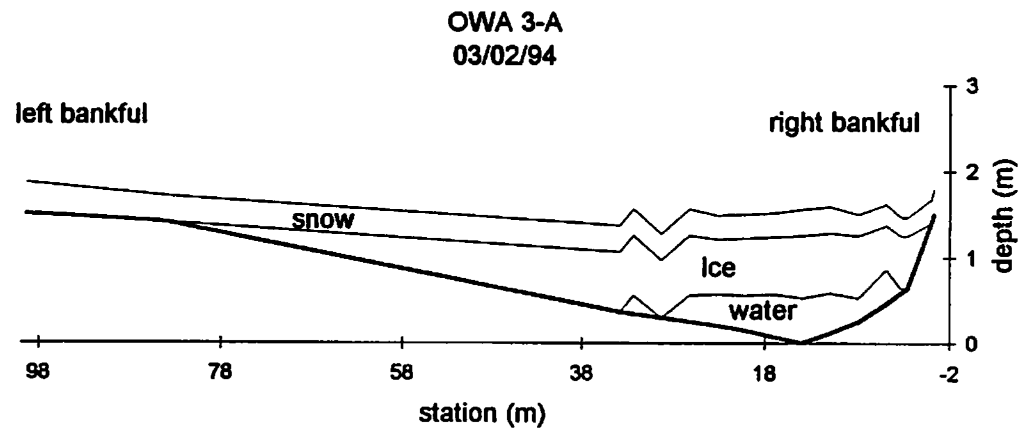


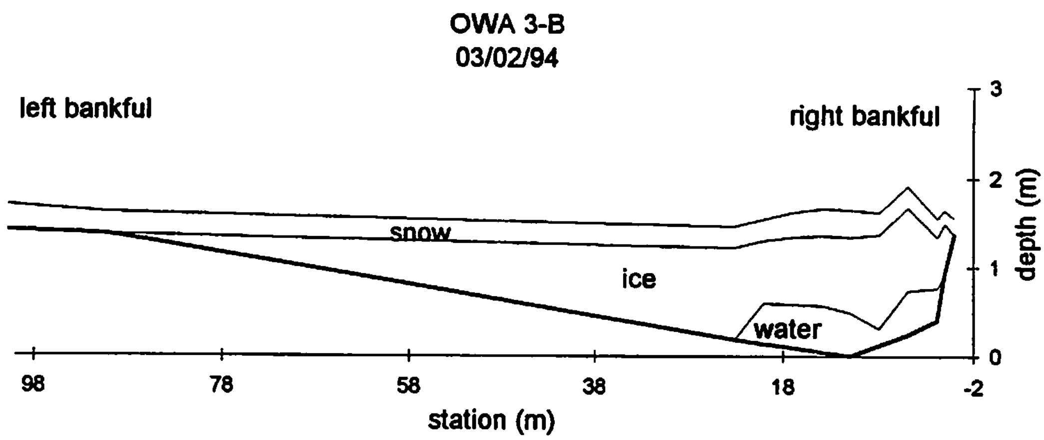

OWA 3-B
1/26/94




OWA 3-C
1/26/94




OWA 3-A
03/02/94
left bankful
right bankful
snow
Ice
water
3
2
1
0
depth (m)
98
78
58
38
18
-2
station (m)


OWA 3-B
03/02/94
left bankful
right bankful
snow
ice
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depth (m)
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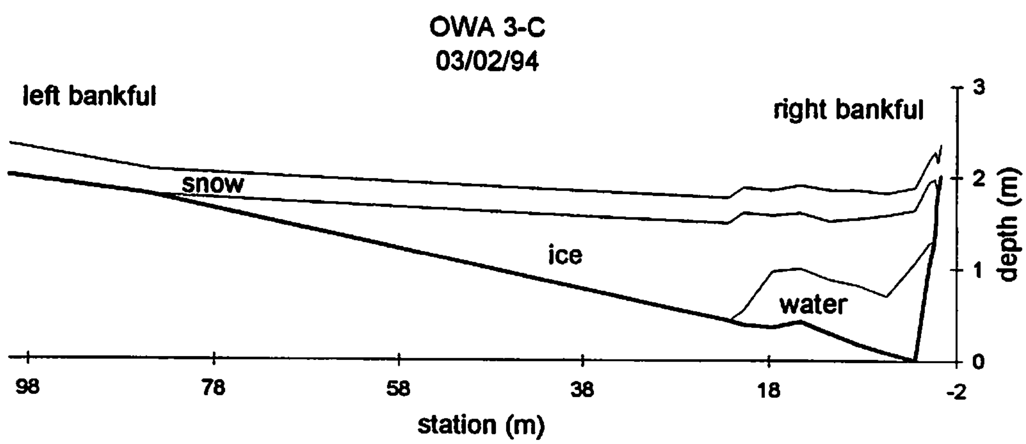
station (m)


OWA 3-C
03/02/94
left bankful
right bankful
snow
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water
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depth (m)
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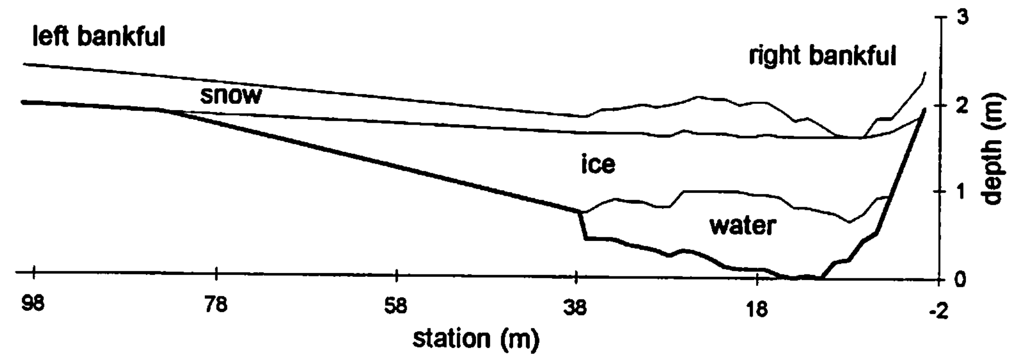
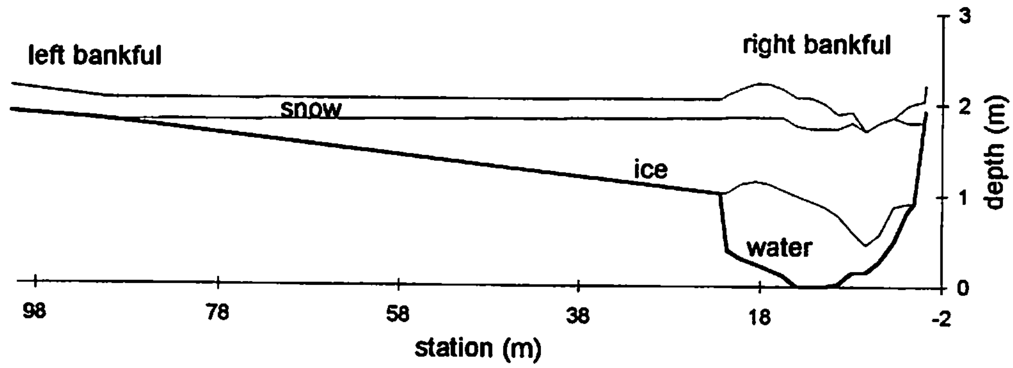
-2
station (m)

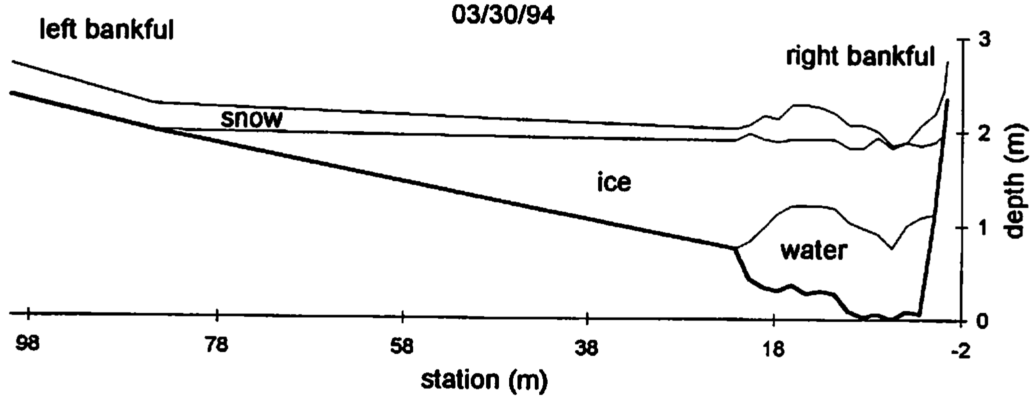
OWA 3-A
03/30/94

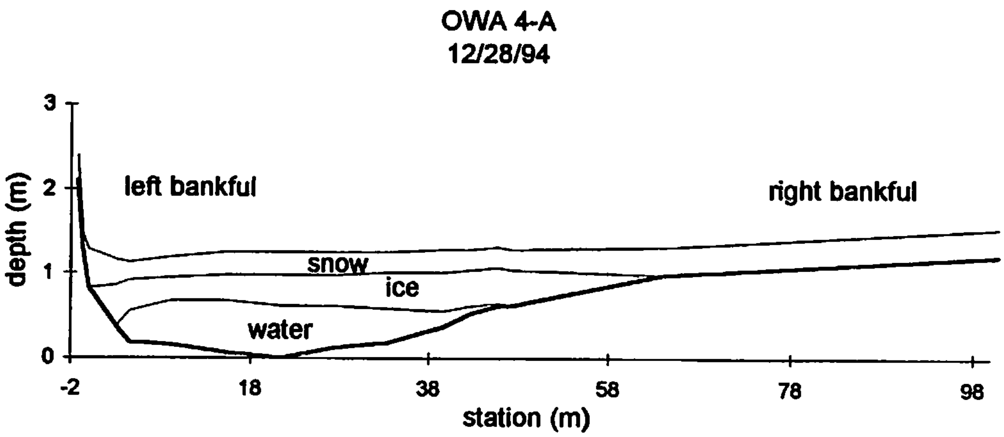


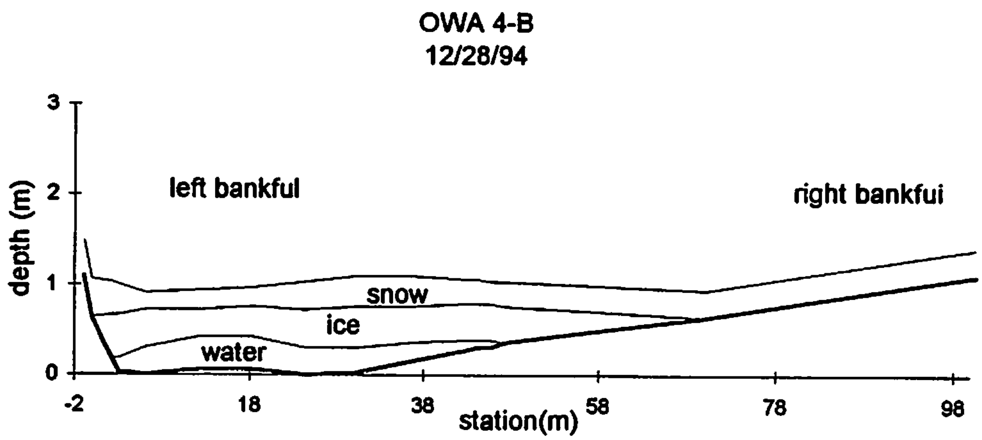

OWA 3-B
03/30/94




OWA 3-C
03/30/94




OWA 4-A
12/28/94
3
2
1
0
depth (m)
left bankful
right bankful
snow
ice
water
-2
18
38
58
78
98
station (m)


OWA 4-B
12/28/94
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depth (m)
left bankful
right bankfui
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water
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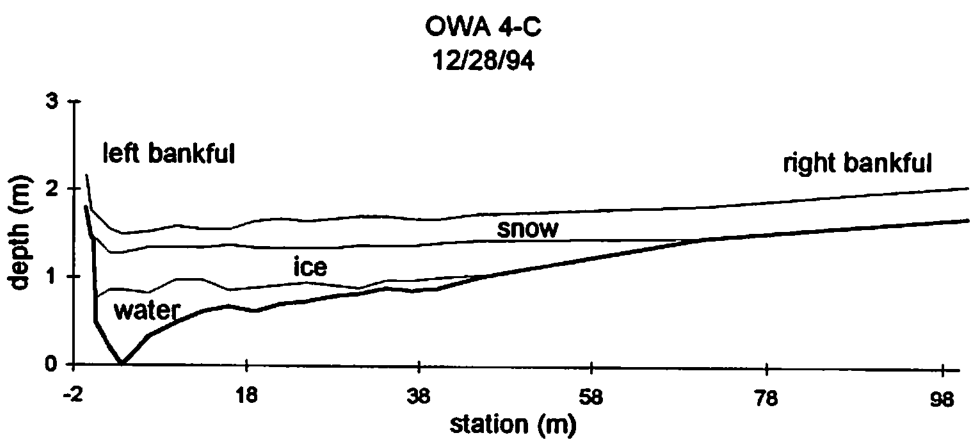
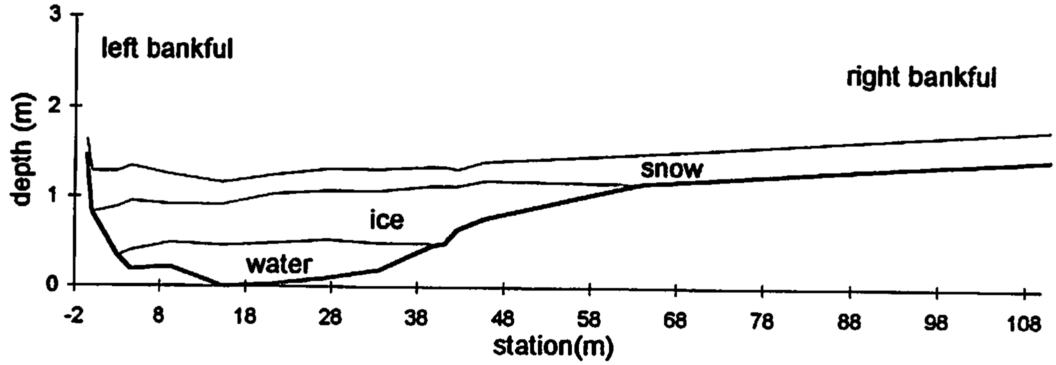
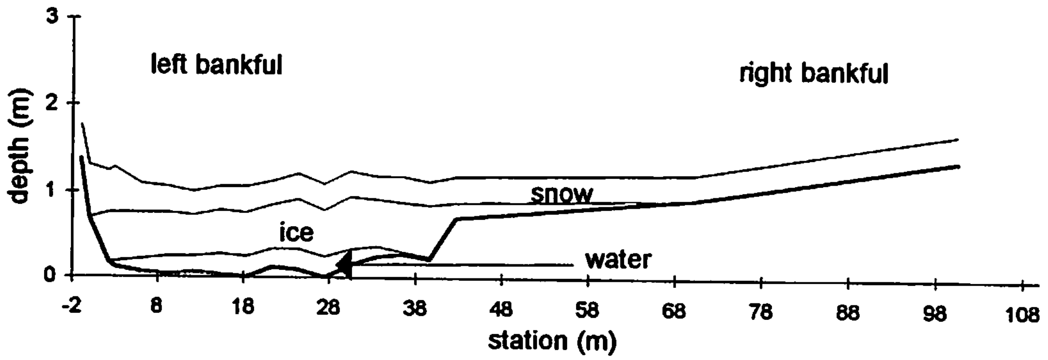
station(m)


OWA 4-C
12/28/94
3
2
1
0
depth (m)
left bankful
right bankful
snow
ice
water
-2
18
38
58
78
98
station (m)

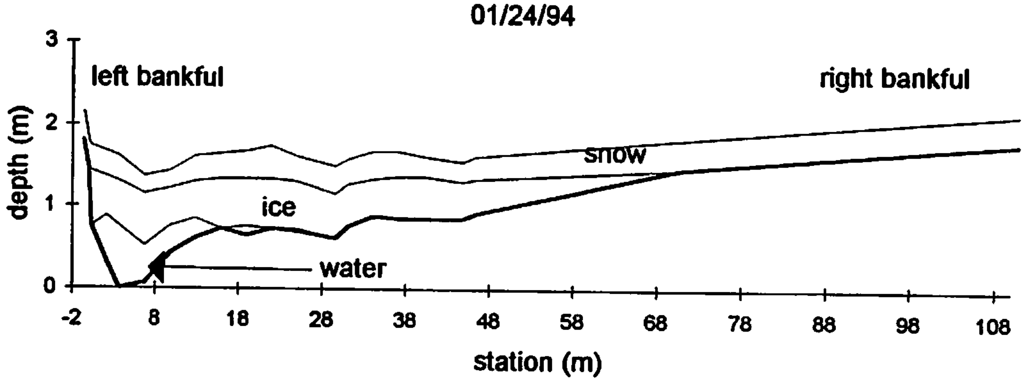
OWA 4-A
01/25/94



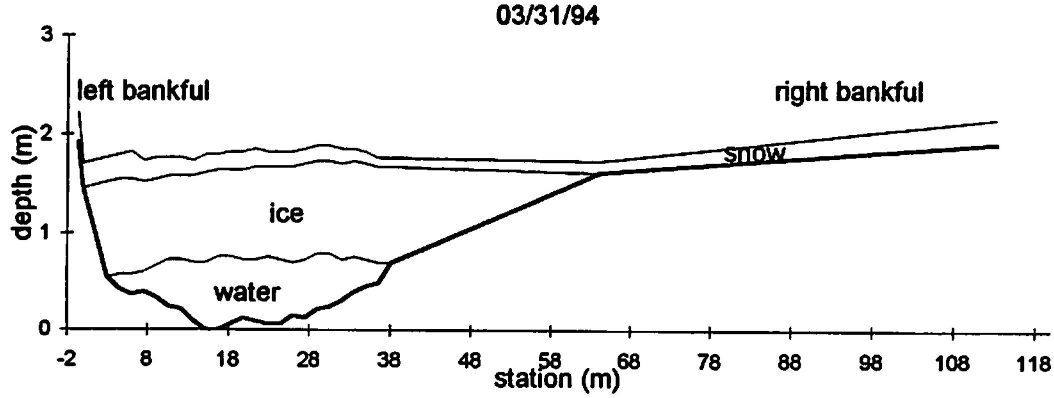

OWA 4-B
01/25/94



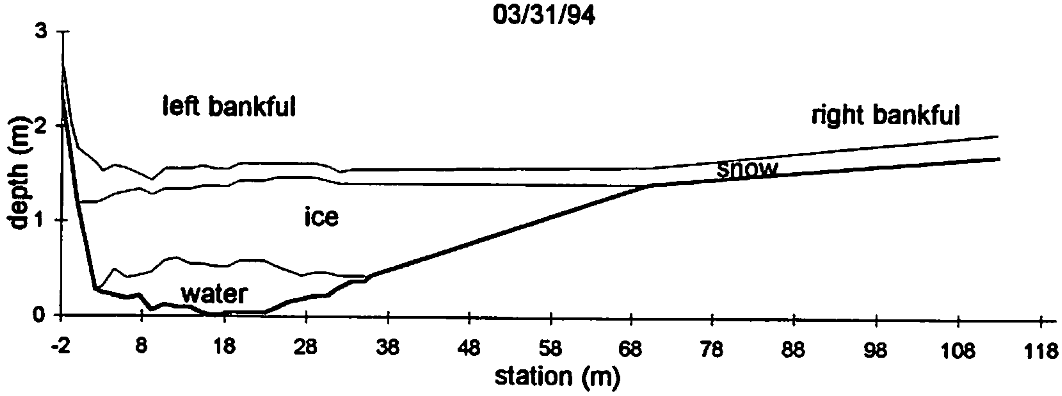

OWA 4-C
01/24/94



OWA 4-A
03/31/94




OWA 4-B
03/31/94




OWA 4-C
03/30/94