WINTER FISH USE OF GLACIAL STREAMS

An Annotated Bibliography

(Annotations Primarily Author Abstracts)

Compiled for the
Region III Forest Practices Riparian Management Committee

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SUMMARY

Glacial streams (water bodies that are fed seasonally by sediment-laden glacial meltwater) are a significant feature of interior Alaska. The use of glacial rivers and streams by salmonids (salmon, char and whitefish) for summer and fall spawning migrations is well known and documented. These migrations are vital for effective harvest in commercial, subsistence, and recreational fisheries. Winter is much less important as a time for fisheries harvest but is a critical period for arctic and subarctic fishes that use glacially-fed waters to survive this difficult period. The purposes of this literature review were to better understand and document the use of glacial streams by fish during winter months, to assist with assessment of vulnerability of overwintering fish use to land use activities, and to provide a background for the development of effective best management practices.

Rivers fed only by glaciers (e.g., braided rivers in Denali National Park) cease to flow during winter and are not viable winter fish habitat. Large glacial rivers with substantial base flows of groundwater (e.g., Tanana River) are essential fish habitat and play a critical role for fish in winter. In these rivers, the onset of winter fish use occurs when cooler fall temperatures cause glacial flow contributions to cease, and water turbidity drops from a summer high of 1000-2000 NTU, to about 150 NTU in October, and finally to about 10 NTU after freeze-up. The amount of DO can decrease in winter with time and distance downstream of open water patches, sometimes reaching minimums that threaten fish survival in March and April just before breakup. The "sealed" nature of some glacial river and stream reaches in winter also gives rise for concerns about the ecological effects of waste discharge in these rivers (Reynolds 1997).

There are three general groups, or life stages, of fish that use glacial streams as overwintering habitat: eggs, alevins (sac fry), and fingerlings of salmonids that spawned during summer and fall; adults of resident species inhabiting clearwater and non-glacial tributaries of glacial streams in other seasons; and all life stages of other resident species that occupy glacial streams year round.

Among salmonids whose eggs or young overwinter in interior Alaska glacial streams, fall chum salmon are best known and most common. For example, radio-tagging studies of fall chum salmon (Barton 1992) documented 18 distinct spawning areas in the mainstem Tanana River between the upper end of Salchaket Slough and the Little Gerstle River. These relatively small spawning areas are collectively more important to chum salmon production in the Tanana River in some years than previously realized. Chum salmon fry migrate to sea during spring discharge and do not spend a second winter in freshwater. King salmon generally spawn in non-glacial tributaries of glacial rivers (e.g., Chena and Goodpaster rivers). Their young usually remain in these tributaries for two winters, first as eggs and alevins, then as fingerlings. A third winter may be spent in a tributary, or in sloughs and other flowing backwaters of glacial rivers before these fish migrate down river as smolts. Dolly Varden, whitefish, and inconnu (sheefish) spawn in the fall and may use braided reaches, or other areas with gravel substrate, in mainstem glacial rivers for spawning (e.g., Brown 2000). Thus, the dependence of early life stages of salmonids on glacial streams for wintering habitat is common. Spawning areas are characterized by gravel with significant interflow for egg incubation. Groundwater or hyporheic upwelling areas and winter ice cover affect flow, temperature, and ice pattern. Fish use ice as cover in areas where there are open leads (Jakober et al. 1998).

Certain resident fish species (e.g., Arctic grayling, northern pike) spend most of the year in clearwater tributaries including their spawning periods. However, adults of these species, having attained enough size to provide them with energy reserves for migration and protection from predation, may seek glacial waters downstream for overwintering habitat. For example, some stocks of adult Arctic grayling spend the winter in the Tanana River before gathering near the mouths of non-glacial tributaries (e.g., Shaw Creek, Goodpaster River) in April, just prior to an upstream spawning migration into the tributary (Clark and Ridder 1988). During autumn, northern pike from sections of Minto Flats move into the mainstem Tanana River to spend the winter in areas between the Tolovana and Kantishna rivers (Burkholder and Bernard 1994). The habitat of these larger fish is not well documented but seems to be “holes” and other deep areas on outer bends where cut banks and bluffs are prevalent.

Some species reside in glacial waters year round. The most common and well known is burbot. Some burbot may enter tributaries for long-distance spawning migrations during winter (Breeser et al. 1988), while others may use various reaches of the mainstem Tanana at different life stages (Evenson 1989). The habitat use of other year-round residents, such as lake chub, longnose sucker and slimy sculpin, is poorly described except during summer (Mecum 1984) but is assumed to include various mainstem and side channel habitats during winter. Small species and life stages have the advantage of burrowing in the substrate or using large woody debris for protection during winter (Reynolds 1997), but larger individuals must move to deeper areas that have adequate flowing water during severe freezing periods (Cunjak 1984).

Two major data gaps were present in the sources we evaluated for this review: the role of woody debris in overwintering habitat (e.g., cover for fish, nutrients and substrate for insect larvae, alterations of depth and flow), and an understanding of the microhabitat needs of overwintering fish.

Annotations in this review are typically author's abstracts. Citations and annotations came from a variety of sources, including an online search by the Alaska Resources Library and Information Services (Water Resources Abstracts, Fish and Fisheries Worldwide, and Arctic and Antarctic Regions databases, key word glacial), reviewers' personal libraries, and the annotated bibliography in ADF&G Technical Report No. 97-1.

REFERENCES

Barton, L. H. 1992. Tanana River, Alaska, fall chum salmon radio telemetry study. Alaska Department of Fish and Game. Fisheries Research Bulletin No. 92-01. Juneau.

A total of 210 Tanana River fall chum salmon was radio tagged in fall 1989 about 11 km below Fairbanks. Previous surveys documented fall chum spawning areas only in those areas where visual surveys could be conducted.

Specific spawning areas were identified for 131 fish. Ninety-seven (74%) of these fish spawned in the floodplain of the Tanana River between upper Salchaket Slough and the mouth of the Little Gerstle River. Six different spawning areas were identified in the mainstem Tanana River between upper Salchaket Slough and the Little Delta River. Specific spawning sites were observed in mainstem channels or sloughs near Salchaket Slough, the mouths of the Little Salcha and Salcha Rivers, Flag Hill, Silver Fox Lodge, and about 5 km below the Little Delta River. Four spawning areas were found between the Little Delta River and Delta Creek.

About 18% of the 131 fish for which spawning areas were determined used the Delta River for spawning. Only three tagged fish (2%) were believed to have spawned above the Gerstle River. The furthest upstream spawner was near the mouth of George Creek. Overall, about 82% of the spawners were tracked to areas upstream of the Little Delta River.

In Barton’s concluding remarks he states that at least in some years, the numerous and relatively smaller spawning areas in the mainstem Tanana River, when taken collectively, contribute more substantially to total Tanana River fall chum salmon spawning escapement than previously realized.

Breeser, S. W., F. D. Stearns, M. W. Smith, R. L. West, and J. B. Reynolds. 1988. Observations of movements and habitat preferences of burbot in an Alaskan glacial river system. Transactions of the American Fisheries Society 117:506-509.

Movements of 21 radio-tagged burbot in the upper Tanana River drainage from the Northway area to Tetlin were recorded from October 1983 to December 1984. The tagged burbot ranged from 50 to 95 cm long. The fish were tracked at three-week intervals. Burbot were relocated up to 68 km downstream and 84 km upstream from release sites. The longest combined upstream and downstream movement of an individual fish was 125 km. The longest upstream movements occurred from November to March, although burbot moved during all seasons. Most tagged burbot apparently preferred the main channels; those fish that moved into clear tributaries did so in late summer after water velocities had dropped and turbidity had decreased.

Brown, R. J. 2000. Migratory patterns of Yukon River inconnu as determined with otolith microchemistry and radio telemetry. Master's thesis. University of Alaska, Fairbanks.

Migratory patterns of Yukon River inconnu *Stenodus leucichthys* were evaluated using otolith aging and microchemical techniques and radio telemetry. Research was conducted each fall between 1997 and 1999, on inconnu captured at a study site 1,200 river km from the Bering Sea. Biological data were collected to establish maturity and spawning condition. Sagittal otoliths were analyzed optically to determine age distribution, and microchemically to determine amphidromy. Inconnu were tagged with radio transmitters and located in upstream spawning destinations. Inconnu captured at the study site were uniformly large, mature fish preparing to spawn. Age estimates ranged from 7 to 28 years. Microchemical analyses suggested that the population was amphidromous rather than freshwater only. Preliminary testing of radio transmitter attachment methods showed that the internal method (pushed through the esophagus into the stomach) was superior to the external method (attached behind the dorsal fin) for use with migrating inconnu. Most radio-tagged inconnu were located during their spawning time in a common region of the Yukon River. Inconnu captured at the study site each fall were mature fish engaged in a spawning migration that originated in the lower Yukon River or associated estuary regions, and continued towards a common spawning destination in the Yukon River, approximately 1,700 river km from the sea.

Buklis, L. S., and L. H. Barton. 1984. Yukon River fall chum salmon biology and stock status. Alaska Department of Fish and Game Division of Commercial Fisheries, Information Leaflet No. 239.

Increasing exploitation by commercial and subsistence fisheries during the period 1974-1983, combined with declining escapement indices, leads the authors to recommend conservative harvest regulation of Yukon fall chum salmon (*Oncorhynchus keta*). While total return showed a moderate increase of 10% for the recent 4-year period (1980-1983) over the previous 4-year period (1976-1979), commercial harvest increased by 30%, subsistence harvest increased by 36%, while the escapement index decreased by 42% and 58% for the Porcupine and Tanana River stocks, respectively. A comprehensive review of information available on the life history, stock composition, exploitation, escapement, and stock status of Yukon River fall chum salmon is presented. Deficiencies in the present data bas are discussed, and recommendations are made for future research.

Burkholder, A., and D. R. Bernard. 1994. Movements and distribution of radio-tagged northern pike in Minto Flats. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Manuscript No. 94-1, Anchorage.

Radio telemetry was used to study the movements of northern pike *Esox lucius* in Minto Flats. Ninety-eight northern pike were surgically implanted with high frequency (150-152 MHz) transmitters during the fall of 1987. Tracking was conducted with a fixed-wing aircraft during 10 tracking periods between September, 1987 and September, 1988. Northern pike radio-tagged throughout Minto Flats during the fall of 1987 segregated into four overwintering groups. About

70% of the radio tags implanted in the fall of 1987 were assumed to have failed prematurely and unexpectedly by April 1988. The highest median velocities for most northern pike for each overwintering group were achieved prior to December, 1987. In general, median velocities progressively decreased throughout the winter (December through April). No differences between the velocities of male and female or small and large radio-tagged northern pike for a given overwintering group were detected. Differences between the velocity of male and female northern pike for a given tracking period were only detected in three of 28 comparisons. Differences between the velocity of small and large northern pike for a given tracking period were only detected in two of 25 comparisons. An additional 20 northern pike were radio-tagged at one of the overwintering sites in March, 1988. Dispersal from this overwintering site was not detected until May. Northern pike located throughout the remaining tracking periods (after May) moved very little.

Calkins, D. J. 1989. Winter habitats of Atlantic salmon, brook trout, brown trout and rainbow trout: a literature review. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Special Report 89-34.

Reviews winter habitat studies of overwintering salmonids in ice-covered streams providing general information on substrate conditions and focal point velocities and depths. Draws attention to various areas as yet inadequately addressed. A review of winter habitat studies in ice-covered streams for four species of salmonid provided some general information on substrate conditions and focal point velocities and depths. All species of fry are found at depths less than 40 cm and at velocities of 10 cm/s or less; juveniles of all species are found at velocities of less than 15 cm/s. A lack of continuous physical, chemical and biological measurements throughout the ice-covered season was a common deficiency of the studies reviewed. The interaction of the ice cover with other physical processes in the stream was rarely addressed.

Chen, L. C. 1968. The biology and taxonomy of the burbot, Lota lota leptura, in interior Alaska. Biological Papers of the University of Alaska No 11.

This study was done on burbot in the Yukon and Tanana Rivers. Taxonomic data on burbot, length and age and length and weight relationships, and reproductive and food habits are presented. Young-of-the-year burbot were seined during high water on flooded grassy beaches in the upper Yukon River. Young-of-the-year burbot were also found in an isolated pond in the upper Chena River. Young-of-the-year burbot were caught in the Tanana River using seines in late July. Small burbot feed primarily on benthic invertebrates, mainly Plecoptera, but change to a diet of fish as they grow. The most abundant species in both the Yukon and Tanana Rivers are longnose suckers, lake chub, and slimy sculpin.

Clark, R. A., and W. P. Ridder. 1988. Stock assessment of Arctic grayling in the Tanana River drainage. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 54. Juneau.

This report describes field studies conducted during 1987 on stocks of Arctic grayling in the Delta Clearwater, Richardson Clearwater, Goodpaster, Chena, Chatanika, and Salcha rivers, Caribou and Shaw creeks, and Fielding and Tangle lakes.

Sampling in the Richardson Clearwater River was conducted between 7 July and 3 August. The Arctic grayling population was estimated to be 2,775 fish larger than 250 mm in the lower 12.8 km of the river. Seventy five of the Arctic grayling sampled in the Richardson Clearwater River were tagged previously in other waterbodies in other years (54 from Caribou Creek, 18 from the mouth of Shaw Creek, and 3 from the Goodpaster River).

The post-spawning migration of Arctic grayling out of Caribou Creek was sampled with a weir from 3 to 11 June. A total of 932 Arctic grayling, of which 315 were considered sexually mature, was captured. Tag returns included 77 Arctic grayling tagged at Caribou Creek in previous years, one Arctic grayling tagged at Clear Creek in 1984, and 4 Arctic grayling tagged 1.5 months earlier at the mouth of Shaw Creek.

Electrofishing at the mouth of Shaw Creek before breakup from April 15 to 23 found Arctic grayling consistently only in two small areas. One area was located 0.8 km above the mouth in a backwater slough approximately 50 m wide, 300 m long, and 3 m deep. The other area was 0.8 km below the mouth in the main channel of the Tanana River. Arctic grayling were holding in a 100 m long and 1 m deep section of water adjacent to the main current. Two hundred eighty eight Arctic grayling were captured during this sampling. Thirty nine Arctic grayling were initially tagged in previous years: 37 at the Caribou Creek weir, 1 tagged at the mouth of Caribou Creek in 1979, and 1 tagged in Clear Creek in 1984. Population estimates for Arctic grayling in Shaw Creek are provided and discussed.

Craig, P. C. 1989. An introduction to anadromous fishes in the Alaskan Arctic. University of Alaska Biological Papers 24:27-54

Overview of Arctic anadromous fishes and of their adaptation to key environmental features. Examines commonly held beliefs that Arctic fish are regulated by limited availability of overwintering habitats and that life history pattern of anadromy allows fish access to abundant food supply in marine environment

Cunjak, R. A. 1984. Habitat utilization by stream fishes overwintering. Paper presented to Ontario Ethology Colloquium, April 18, 1984. University of Waterloo.

A comparison of overwintering strategies used by fish in subarctic rivers and those used in temperate streams showed contrasts. In northern streams, juvenile fish moved into the substrate in autumn and remained buried until the following spring. Larger fish depended on deeper pools in large rivers or lakes to provide overwintering habitat. In temperate areas, there was extensive use of ground water refugia in tributary streams or in the main river channel. These areas provided protection against ice and critically low temperatures and allowed the fish to remain mobile. In both areas, early winter was the period of greatest depletion of body reserves. Data collection involved three field trips to the Koksoak River in northern Quebec. An autumn (late Sept.) sampling period gave data on the start of the winter while a late May visit provided data on the condition of the fish at the end of the winter. A mid-March attempt to get winter data failed because the conditions were too difficult for sampling (6-8 feet of ice and temp. of -40 degrees C). However, considerable experience was gained attempting winter work which may be useful in future projects.

Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53Supplement:267–282.

This paper reviews the habitat characteristics and the behaviour of selected stream fishes during winter in temperate–boreal ecosystems. Emphasis is placed on the salmonid fishes upon which most winter research has been directed. As space is the primary factor regulating stream fish populations in winter, aspects of winter habitat are considered at various spatial scales from microhabitat to stream reach to river basin. Choice of winter habitat is governed by the need to minimize energy expenditure, with the main criterion being protection from adverse physicochemical conditions (e.g., ice, spates, low oxygen). The distance moved to wintering habitats, and the continued activity by many fishes during winter, need to be considered when making management decisions regarding fish habitat. How habitat is affected by land-use activity in stream catchments is discussed with reference to impacts from water withdrawal, varying discharge regimes, and erosion or sedimentation. Even stream "enhancement" practices can deleteriously affect fish habitat if project managers are unaware of winter habitat requirements and stream conditions. Maintenance of habitat complexity, at least at the scale of stream sub-basin, is recommended to ensure the diversity of winter habitats for fish communities.

Dinneford, W. B. 1978. Final report of the commercial fish--technical evaluation study: Tanana and Delta Rivers. Joint State/Federal Fish and Wildlife Advisory Team. Special Report No. 20.

Fall chum salmon escapement, distribution, timing, age class and length trends, fecundity and egg retention were measured in the Delta and Tanana rivers in 1977 as part of studies associated with the construction of the Trans-Alaska Pipeline. Limited data concerning development of chum salmon eggs and juveniles are presented. Fry in the Delta River emerged in early-to-mid April with peak outmigration occurring in early-to-mid May.

Rip rap bank protection on the south bank of the Tanana River at Big Delta caused at least a short term avoidance of the area by spawning chum salmon. Spawner distribution in 1976, the year of construction, indicated that only 20 to 25% of the traditional number of spawners used the disturbed area. The distribution of spawners in 1974 and 1977 was similar, suggesting the cause of the low count in 1976 was sediment-choked spawning gravel from construction activities that was eliminated by normal high water flows before the 1977 run reached the spawning grounds.

It was estimated that a break in the pipeline at Jarvis Creek could kill the entire Delta River chum population of spawners or pre-smolt, while a break over the Tanana River could similarly affect an entire class of migrant adults (fall) and/or pre-smolt juveniles (spring) found below the line for an undetermined distance downstream.

Eiler, J. H., B. D. Nelson, and R. F. Bradshaw. 1992. Riverine spawning by sockeye salmon in the Taku River, Alaska and British Columbia. Transactions of the American Fisheries Society 121:701-708.

Radio telemetry was used to determine the distribution of sockeye salmon *Oncorhynchus nerka* returning to spawn in the glacial Taku River in 1984 and 1986, and to locate and characterize spawning areas used by this species. During the study, 253 sockeye salmon were tracked as they moved upriver; 204 of these were followed to spawning areas. Only 37% of the 204 fish traveled to areas associated with lakes; the remaining 63% returned to "riverine" areas—river areas without lakes (42% to the Taku River main stem, 17% to the Nakina River, and 4% to other rivers). Sockeye salmon spawning in riverine areas used a variety of habitat types, including main-river channels, side channels, tributary streams, and upland sloughs. Most (55%) of the radio-tagged fish that returned to the Taku River main stem were tracked to side-channel spawning areas. Half of the 471 adult sockeye salmon sampled in the main-stem spawning areas had migrated to sea as juveniles before their first winter. This study showed that many sockeye salmon returning to the Taku River do not depend on lakes, and that riverine sockeye salmon make up a major portion of the run in some river systems.

Evenson, M. J. 1988. Movement, abundance and length composition of Tanana River burbot stocks during 1987. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 56. Juneau.

This paper reports the results of field studies conducted in 1987 in the Tanana River from Manley Hot Springs upstream to its headwaters near Northway. In 1987, 4,516 burbot (greater than or equal to 300 mm total length) were captured in hoop traps and tagged. Length frequency, growth, age, and movement data are presented. Population estimates are provided for sections of the Tanana River near Rosie Creek and near Healy Lake.

Tag returns indicated 72% of burbot were recaptured within 8 km of tagging sites, 25% moved upstream greater than 8 km, and 3% moved downstream 8 km or more. The median distance traveled was 27 km, with a maximum distance of 265 km. A greater percentage of movement was documented during summer (June, July, August) and winter (December, January, February) than in fall or spring. Of fish captured in winter, almost 70% had made significant movements (usually in an upstream direction). The winter movements are probably associated with spawning and summer movements may be correlated with feeding.

Evenson, M. J. 1989. Biological characteristics of burbot in rivers of interior Alaska during 1988. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 109. Juneau.

This paper reports the results of field studies conducted in 1988 in six sections of the Tanana River from Manley Hot Springs upstream to near Tok, in one section of the Yukon River, in one section of the Tolovana River, and in one section of the Chena River. In 1988, 2,305 burbot were captured in hoop traps and tagged in the Tanana, Chena, and Tolovana rivers. Length frequency, age, movement, catch per unit effort, and gear selectivity data are presented.

Movement information from tag recoveries indicate burbot are 76% resident (captured within 8 km of the tagging site) to a given area up to a period of 1.5 years. The percentage of burbot remaining resident to an area is lower (48%) after a period of 1.5 years, indicating burbot are not completely resident to an area throughout their lifetime. Movements are predominantly upstream. Downstream movements are infrequent and short ranging. Movements were most frequent in the fall and winter and were likely feeding migrations (fall) in response to prey outmigrations from tributary systems or spawning migrations (winter).

Movement of burbot between the Tanana River and the Tolovana, Goodpaster, and Chena rivers indicated stocks of burbot in these systems are not isolated. Few small (300-449 mm) burbot were captured in the Tolovana River, suggesting that spawning and rearing of burbot may not occur in this system. Migrations of burbot into the Chena River in the fall may be related to feeding, spawning, or both. Tag returns also indicate the Goodpaster River may be used for spawning.

Tag returns also indicated that at least two isolated stocks of burbot exist in the mainstem Tanana River with the boundary lying near the mouth of George Creek (river km 594). The boundary area is characterized by swift current, which may act as a barrier to burbot migration, and relatively low burbot densities.

Evenson, M. J. 1993. Seasonal movements of radio-implanted burbot in the Tanana River drainage. Alaska Department of Fish and Game. Fishery Data Series No. 93-47. Anchorage.

Radio-transmitters were surgically implanted in 40 large (greater than 650 mm) and 15 small (less than 450 mm) burbot in the Tanana and Chena rivers in the vicinity of Fairbanks from 24 August to 4 September 1992. Radio-tracking occurred from September 1992 to July 1993.

Small burbot moved shorter distances than did large burbot between all consecutive tracking periods. Total ranges of small burbot averaged 17 km and were all less than 40 km. Ranges of large burbot averaged 57 km and were between 5 and 255 km. The largest movement downstream from the point of release was 224 km, whereas the largest upstream movement was 85 km.

The high frequency of downstream movements documented in this study were at odds with previously recorded tag returns, which indicated movements, tended to be upstream. This discrepancy may be related to recovery from transmitter implantation, mortality or expulsion of transmitters, or biased tag return data from unequal distribution of sampling effort among river areas.

Mean movements of large burbot were greatest during periods coinciding with river freeze-up and breakup, and were smallest during periods coinciding with spawning. There was substantial interchange of burbot between the Tanana and Chena rivers.

Fourteen general spawning locations were identified in the Tanana and Chena rivers for 33 large burbot. The largest concentration of large burbot was near Whiskey Island where six fish were located throughout the spawning period.

Francisco, K. 1976. First interim report of the commercial fish - technical evaluation study. Joint State/Federal Fish and Wildlife Advisory Team. Special Report No. 4.

The objectives of this study were to determine the distribution, abundance and timing of fall chum and coho salmon spawning above and below the Trans-Alaska Pipeline crossing of the Tanana River at Big Delta that could be affected by the construction and operation of the pipeline, sample chum and coho salmon escapement for age-sex-size information, and to obtain early life history information for Delta River chum salmon (development, emergence, and outmigration timing). The time period of the early life history studies was from November 1974 through May 1975. Distribution studies of adult salmon were conducted from September to December 1975. Studies of chinook and chum salmon juveniles and adults in the Salcha River also were described.

Water temperatures, dissolved oxygen content, flow, and ice conditions were reported for the lower Delta River. Limited data regarding chum salmon fry growth and development and emergence are presented. The distribution and abundance of fall chum and coho adult salmon was incompletely determined because of poor survey conditions.

King salmon fry in the Salcha River were most common in the deep holes, around the brush piles and beaver houses, and in the sloughs. Fry also were found in riffle areas but were not very abundant. The number of fry using beaver food caches increased dramatically in September and were speculated to be important potential overwintering areas. King salmon fry use of tributary streams seemed to be concentrated in the lower mile of the tributaries. Some limited growth data for king salmon fry are presented.

Limited limnological data are presented for the Salcha River and several of its tributaries. Adult king and chum salmon distributions, and age and sex distribution were presented. The peak smolt outmigration for both chum and king salmon occurred during a high water event from May 10 through 15.

Francisco, K. 1977. Second interim report of the commercial fish--technical evaluation study. Joint State/Federal Fish and Wildlife Advisory Team. Special Report No. 9.

This paper reports the results of studies conducted from October 1975 to June 1976 on the early life history of chum salmon in the Delta River. Chum salmon spawning occurred from mid October through November. Hatching began in early February and continued until mid March. Emergence from the gravels began in early April and continued through the third week in April. Downstream migration of the chum smolt began in early April, with very few remaining in the river for rearing before moving downstream. Outmigration peaked on April 28 and on May 17 following increased river flows. Survival to smolt outmigration was estimated to be 2.9 to 4.9% of the potential egg deposition. Total smolt production in the Delta River in spring 1975 was estimated at 72,500 to 191,900 smolts.

A small number of king salmon juveniles, young-of-the-year and age 1 fish, were captured in the Delta River. King salmon are not known to spawn in the Delta River. A small number of coho smolt, age 1, also were caught in the lower Delta River. Limnological data are presented for April and May 1976.

Hallberg, J. E., R. A. Holmes, and R. D. Peckham. 1987. Movement, abundance, and length composition of 1986 Tanana River burbot stocks. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 13. Juneau.

This paper reports the results of field studies conducted in 1986 in the Tanana River from Manley Hot Springs upstream to its headwaters near Northway. [Sections not sampled included the area from Moose Creek upstream to Big Delta]. In 1986, 3,541 burbot (greater than or equal to 300 mm total length) were captured in hoop traps and tagged. Length frequency and age data are presented. A population estimate of burbot in a 6.4 km section of the Tanana River near Rosie Creek near Fairbanks provided an estimate of 2,892 burbot greater than 300 mm.

Tag returns obtained from area anglers and continued sampling indicate that burbot move upstream more than downstream after release. The greatest recorded movement was by a burbot that moved 256 km upstream over a period of 1,244 days. Three burbot were recaptured in the Goodpaster River during winter, suggesting that these fish may have moved into this river to spawn.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly-sedimented Idaho stream. Transactions of the American Fisheries Society 16:185-195.

Summer and winter habitat used by age 0 spring chinook salmon was assessed in the Red River, an Idaho stream heavily imbedded with fine sediment. Chinook salmon used habitats with water velocities less than 20 cm/sec, depths of 20 to 80 cm, and close associations with cover (undercut banks). During summer, 95% of the age 0 chinook salmon were concentrated in pool and glide habitat, predominantly along the sides and tail-ends of this habitat. About 5% of the chinook salmon were in riffles, and these fish were found behind boulders greater than 25 cm in diameter, where water velocities were comparable to velocities used by juveniles in glides and pools. As fish became larger, they selected faster, deeper water. Fish that remained in the study area during winter selected areas where submerged sedges and grasses overhanging undercut banks provided cover and where water velocities were less than 12 cm/sec.

Cobble (mean maximum diameter, 19 cm; range 9 to 37 cm) was piled 26 cm deep on the streambed to evaluate the relationship between sediment and winter habitat selection by juvenile chinook salmon. After cobble substrate was added to the streambed beneath undercut banks and in midchannel in a glide and a riffle habitat, eight times more chinook salmon used the cobble substrate (in November) than in the previous year. Significantly more chinook salmon used cobble placed under banks than any other area.

Jakober, M. J., T. E. McMahon, R. F. Thurow, and C. G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127(2):223-235.

We used radiotelemetry and underwater observation to assess fall and winter movements and habitat use by bull trout *Salvelinus confluentus* and westslope cutthroat trout *Oncorhynchus clarki lewisi* in two headwater streams in the Bitterroot River drainage, Montana, that varied markedly in habitat availability and stream ice conditions. Bull trout and cutthroat trout made extensive (>1 km) downstream overwintering movements with declining temperature in the fall. Most fish remained stationary for the remainder of the study (until late February), but some fish made additional downstream movements (1.1–1.7 km) in winter during a low-temperature (1°C) period marked by anchor ice formation. Winter movement was more extensive in the mid-elevation stream where frequent freezing and thawing led to variable surface ice cover and frequent supercooling (<0°C). Habitat use of both species varied with availability; beaver ponds and pools with large woody debris were preferred in one stream, and pools with boulders were preferred in the other. Trout overwintered in beaver ponds in large (N = 80–120), mixed aggregations. In both streams, both species decreased use of submerged cover following the formation of surface ice. Our results indicate that (1) continued activity by trout during winter is common in streams with dynamic ice conditions and (2) complex mixes of habitat are needed to provide suitable fall and winter habitat for these species.

Jordan, J. L. 1998. Riparian rehabilitation along the north fork of the Bradfield River, stand 29. Prescription for Certification. Wrangell Ranger District, Wrangell, Alaska.

This report presents the abiotic and biotic background data, and management prescription, for restoring and enhancing riparian conditions beside Stand 29 along a glacial outwash channel (North Fork Bradfield River) in southeast Alaska. It is one of the few written references to discuss use of glacial mainstem habitat by juvenile coho and chinook salmon. The objectives for the selected stand were to improve fish habitat and stream and/or riverbank stability, increase the size of snags and crown competition factor for wildlife habitat, maintain or increase aquatic and terrestrial invertebrate populations, and minimize costs of implementation.

Mainstem habitat is used by overwintering coho and chinook salmon, and becomes increasingly important as temperatures and flows drop in winter, dewatering side channels. Large accumulations of wood are associated with greater depth and are important factors in overwintering habitat. Coho juveniles overwinter within these complex debris jams, while juvenile chinook used the less complex margins of these jams, and surrounding rubble.

Off-channel overwintering habitat consists primarily of historic and current beaver ponds, which are used by coho salmon, cutthroat trout, Dolly Varden, and perhaps sockeye salmon. The report suggests that the importance of these areas as overwintering habitat depends on depth and the presence of upwellings.

Lorenz, J. M., and J. H. Eiler. 1989. Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society 118:495-502.

Spawning habitats of sockeye salmon *Oncorhynchus nerka* in the Taku River and its tributaries in British Columbia and Alaska were studied to determine habitat use and redd characteristics in a glacial river system. We used radiotelemetry to track adult sockeye salmon to 26 spawning reaches, and 63 spawning sites were sampled for habitat characteristics. Over 40% of the sockeye salmon in the sampling area had a freshwater age of zero, and most of these spawned in main channels or off-channel areas. The availability of upwelling groundwater influenced habitat use in the main stem of the river; upwelling groundwater was detected in nearly 60% of the sites sampled in main-stem areas. Spawning sites with upwelling groundwater had lower water velocities and more variable substrate compositions than sites without upwelling groundwater. Redds had two to four times more fine sediment than previously reported. The probability of use was greatest when substrate had less than 15% fine sediment, water velocity was between 10 and 15 cm/s, and intragravel temperature was between 4.5 and 6.0C.

Mecum, R. D. 1984. Habitat utilization by fishes in the Tanana River near Fairbanks, Alaska. Master's thesis. University of Alaska, Fairbanks.

This study evaluated summer habitat utilization of fishes and the effects of floodplain developments on fish and aquatic habitat in the glacially-fed Tanana River near Fairbanks, Alaska. Aquatic habitats were quantitatively described on the basis of water velocity, depth, and clarity, and substrate, cover and vegetation. Lake chub and longnose sucker were abundant in all habitats. Whitefishes, juvenile salmon, and northern pike were captured most frequently in areas with high water clarity. Burbot preferred deeper, turbid waters. Young-of-the-year of lake chub and longnose sucker preferred shallow, silty backwaters; juvenile lake chub demonstrated no habitat preferences; and adult lake chub, juvenile longnose sucker, and juvenile/adult slimy sculpin preferred gravel riffles. Bank stabilization activities have significantly modified aquatic habitat and fish communities of Tanana River backwaters. In general, free-flowing sidechannels have become blocked-off sloughs resulting in reduced turbidities and lower flows.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, southeast Alaska. Canadian Journal of Fisheries and Aquatic Science 46:1677-1685.

This research paper reports the results of field studies conducted to determine juvenile salmon use of the lower Taku River in southeast Alaska during summer 1986. Sockeye, coho, and chinook salmon were present within the study area. Chinook salmon were predominantly age 0 (99%) and ranged from 40 to 93 mm FL. Seining was used to estimate fish density. Habitat was classified into two broad categories: river habitats -- main channels, backwaters, braids, channel edges, and sloughs within the active river; and off-channel habitats -- beaver ponds, terrace tributaries, tributary mouths, and upland sloughs on the valley floor.

Mean water velocity was lowest (0-5 cm/s) in sloughs, backwaters, tributary mouths, upland sloughs, and beaver ponds; intermediate (10-21 cm/s) in braids, channel edges, and terrace tributaries; and highest (102 cm/s) in main channels. Main channels, except for channel edges, were assumed too swift (mean, 102 cm/s) to contain rearing salmon. Mean depth ranged from 0.3 m in braids to 1.0 m in beaver ponds and 2.9 m in main channels. Typically, river habitats were turbid (means, 240-400 JTU), whereas off-channel habitats were clear or humic (means, 20-208 JTU). Water temperatures were 2-4°C higher in beaver ponds and upland sloughs than in channel edges, braids, and terrace tributaries.

The distribution of salmon was most closely related to water velocity, and turbidity had a secondary influence. Sockeye and coho densities were highest in still or slow water (<11 cm/s), whereas chinook density was highest in slow-to-moderate current (1 to 20 cm/s). All species were virtually absent from areas with currents greater than 30 cm/s. Differences in water velocity may have masked effects of turbidity. Chinook density was similar in areas of different turbidity.

In the active channel of the lower Taku River, substrate is mostly compacted gravel, sand, and mud, providing little cover from the turbulent flow, and the only suitable habitat occurs along the channel edge. Other studies have shown juvenile chinook salmon can inhabit areas with current as fast as 70 cm/s where coarse substrate (20-40 cm diameter) provided cover from the fast current.

Mean salmon density in the habitat types corresponded to water velocity but also differed between the river and off-channel areas. Chinook primarily were in river habitats with mean velocities of 3 to 15 cm/s, particularly sloughs and channel edges (means, 6-8 fish/100 m^2), and off-channel terrace tributaries and tributary mouths (means, 5-8 fish/100 m^2). Chinook were virtually absent from beaver ponds and upland sloughs (<1 fish/100 m^2).

Murphy, M. L., K V. Koski, J. M. Lorenz, and J. F. Thedinga. 1997. Downstream migrations of juvenile Pacific salmon (*Oncorhynchus* spp.) in a glacial transboundary river. Canadian Journal of Fisheries and Aquatic Science 54:2837-2846.

Migrations of juvenile Pacific salmon (*Oncorhynchus* spp.) in the glacial Taku River (seventh order) were studied to assess movement from upriver spawning areas (in British Columbia) into lower-river rearing areas (in Alaska). Differences between fyke-net catches in the river and seine catches in the river's estuary indicated that many downstream migrants remained in the lower river instead of migrating to sea. In particular, age-0 coho salmon (*O. kisutch*) and chinook salmon (*O. tshawytscha*) moved downriver from May to November but were not caught in the estuary. Age-0 sockeye salmon (*O. nerka*), coho presmolts, and other groups delayed entry into the estuary after moving downriver. We tagged groups of juvenile coho (ages 0-2) from the fyke net with coded-wire to determine when they left the river. One-third of all tags recovered from sport and commercial fisheries occurred 2-3 years later, showing that many coho remained in fresh water for 1-2 years after moving to the lower river. Lower-river areas of large glacial rivers like the Taku River can provide essential rearing habitat for juvenile salmon spawned upriver and are important to consider in integrated whole-river management of transboundary rivers.

Peckham, R. D. 1980. Evaluation of interior Alaska waters and sport fish with emphasis on managed waters, Delta district. Annual performance report. Alaska Department of Fish and Game, Federal Aid in Fisheries Restoration Volume 21 Project F-9-12, Job G-III-I.

This report describes field studies conducted in 1979 that included estimates of angler harvest of Arctic grayling on the Tanana River and Shaw Creek, stream surveys on Shaw Creek and two of its tributaries, and sampling on the Goodpaster River.

An early spring fishery for Arctic grayling and round whitefish occurs in open water on the Tanana River at Big Delta from late March through mid April. An estimated 1,029 angler hours of effort during a 15 day sampling period caught an estimated 309 Arctic grayling and 134 round whitefish. Sampled Arctic grayling averaged 266 mm in length with a range of 203 to 365 mm. Round whitefish averaged 326 mm with a range of 250 to 405 mm.

Highway reconstruction in 1976 altered the Tanana River downstream of Shaw Creek, eliminating the pool that in the past attracted Arctic grayling for a period of two to three weeks before breakup on Shaw Creek. Since highway reconstruction, the concentration of Arctic grayling and the resulting sport fishery have not occurred.

Arctic grayling were observed spawning in the lower four miles of Rapids Creek, a tributary of Shaw Creek, on May 17 and 18. Spawning was observed over sandy-silt bottom and organic debris, usually in flowing water just below beaver dams. No Arctic grayling were seen in the upper four miles of Rapids Creek.

A small downstream weir was installed on September 10 and operated for four days on Caribou Creek, a tributary to Shaw Creek. Eight species were captured: Arctic grayling, humpback whitefish, longnose sucker, slimy sculpin, round whitefish, lake chub, coho salmon, and northern pike. Mean lengths and ranges are provided for each species.

Reynolds, J. B. 1997. Ecology of overwintering fishes in Alaskan freshwaters. Pages 281-302 *in* Milner, A. M. and M. W. Oswood, editors. Freshwaters of Alaska—Ecological Syntheses. Ecological Studies, Vol. 119. Springer-Verlag New York, Inc., New York.

Sixty years have passed since Hubbs and Trautman (1935) made their plea for winter studies of freshwater fishes. They perceived a serious neglect of such investigation and concluded that the state of affairs had resulted because of lack of winter-trained personnel, limited funding for winter research, and--probably most importantly--a preference among biologist for summer field work. The reasons for concern are the same now as they were then: winter may be a critical period controlling or limiting freshwater fish production. Many of the questions posed by Hubbs and Trautman are framed in an ecological context: Do fish experience food shortages during winter? Is ice formation an important factor in fish mortality? Are habitat requirements similar between winter and summer?

Hubbs and Trautman would be pleased to know that winter research in fisheries and freshwater ecology has significantly increased since the 1970s, particularly in Alaska and Canada, where the severity of winter has long been regarded as a significant factor in freshwater fish ecology. In Alaska, this increase occurred because of increased State funds (oil development), changes in priorities (environmental concerns) and improved technology (e.g., biotelemetry). Alaskan winter fisheries studies have centered in three areas of the state: northern or arctic Alaska, including the North Slope and Brooks Range, where winter extractions of gravel and water from streams are needed for site development by the oil and gas industry; central Alaska including the interior and Alaska Range, due to human population growth and its related impacts (e.g., proposed hydroelectric dams on the Susitna River); and southeast Alaska, the coastal rain forest, spurred by potential impacts of mining and timber harvest on salmonid production in coastal streams.

This chapter describes Alaskan freshwaters as winter habitat for fish, and summarizes the results of Alaskan studies of freshwater fish populations during winter. Scientific and common names of fishes referenced in this chapter are listed in Table 11.1. Much of the work by government agencies is excellent, but the resulting reports remain part of the "gray" literature; these sources have been used only when no published source was available to support a particular point. Fortunately, a number of key studies have been published in the peer-reviewed literature; these serve as the primary source of information for this chapter. In addition, relevant studies in Canada, the continental United States, and elsewhere are cited, not as an exhaustive review, but as needed to support and complement the purpose of this review (i.e., to synthesize what is known about overwintering fishes in Alaskan freshwaters).

Rickman, R. L. 1998. Effect of ice formation on hydrology and water quality in the lower Bradley River, Alaska—implications for salmon incubation habitat. U.S. Geological Survey, Water-Resources Investigations Report 98-4191. Prepared in cooperation with the Alaska Energy Authority.

Previous studies of streamflow in the lower Bradley River near Homer, Alaska, have shown that a minimum flow of 50 cfs is required from November 2 to April 20 to ensure adequate habitat for salmon incubation. The flow regime of the lower Bradley River was reevaluated in a U.S. Geological Survey study to determine the effects of ice formation on salmon habitat. The limiting factor for determining the minimal acceptable flow in the lower Bradley River appears to be stream-water velocity. The minimum short-term flow needed to ensure adequate salmon incubation habitat when ice is present is about 30 cfs. For long-term flows, 40 cfs is adequate when ice is present. Long-term minimum discharge needed to ensure adequate incubation habitat--which is based on mean velocity alone--is as follows: 40 cfs when ice is forming; 35 cfs for stable and eroding ice conditions; and 30 cfs for ice-free conditions. The effects of long-term streamflow <40 cfs on fine-sediment deposition and D.O. interchange could not be extrapolated from the data. Hydrologic properties and water quality data were measured in winter only from March 1993 - April 1998 at 6 transects in the lower Bradley River under three phase of icing: forming, stable, and eroding. Discharge in the lower Bradley River ranged from 33 to 73 cfs during all phased of ice formation and ice conditions, which ranged from ice-free to 100% ice cover. Hydrostatic head was adequate for habitat protection for all ice phases and discharges. Mean stream velocity was adequate for all but one ice-forming episode. Velocity distribution within each transect varied significantly from one sampling period to the next. No relation was found between ice phase, discharge, and wetted perimeter. Intragravel-water temperature was slightly warmer than surface-water temperature. Surface- and intragravel-water D.O. levels were adequate for all ice phases and discharges. No apparent relation was found between D.O. levels and streamflow or ice conditions. Fine-sediment deposition was greatest at the downstream end of the study reach because of low shear velocities and tide-induced deposition. D.O. interchange was adequate for all discharges and ice conditions. Stranding potential of salmon fry was found to be low throughout the study reach. Minimum flows from the fish-water bypass needed to maintain 40 cfs in the lower Bradley River are estimated.

Ridder, W. P. 1994. Arctic grayling investigations in the Tok River drainage during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-19. Anchorage.

This study was conducted in April, May, June, and September 1993 to determine the age and size composition of Arctic grayling larger than 149 mm in the Tok Overflow for an initial assessment of the population in this system. Sampling was expanded to include other locations within 21 km of the Tok Overflow when few fish were found in the Tok Overflow. Other areas sampled included the Tok Overflow #2, the Little Tok River, the Tok River, and Mineral Lake Outlet. Stream descriptions and descriptions of each fishery are provided. Length and age composition data are provided.

The Tok River below the Tok Overflow was found to be an overwintering area for Arctic grayling that disperse upstream to at least Mineral Lake Outlet. Water temperatures indicated the Tok Overflow to be the coldest stream in the study area and likely inhospitable as a summer feeding area for Arctic grayling. Daily high stream temperatures ranged from 2.7 to 4.8°C between 15 April and 6 August. Arctic grayling (56 fish between 200 and 300 mm) were found at the mouth of the Tok Overflow only on 22 June (five other surveys were conducted) when the stream temperature at the mouth was 5.9°C.

The Tok River drainage is the only locale in the Tanana River drainage that supports a significant Dolly Varden fishery. Dolly Varden were captured in the Tok Overflow and the Tok Overflow #2. Two Dolly Varden were active on a redd in the Tok Overflow on 13 September. Eighteen Dolly Varden in the Tok Overflow #2 in June averaged 142 mm in length (range = 101 to 191 mm; SD = 20). Five Dolly Varden captured in the Tok Overflow #2 averaged 159 mm (range = 115 to 212 mm; SD = 32).

Ridder, W. P. 1998. Radio telemetry of Arctic grayling in the Delta Clearwater River 1995 to 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-37.

In 1995 and 1996, 110 adult Arctic grayling *Thymallus arcticus* with implanted radio transmitters were released at their summer feeding area in the Delta Clearwater River, a spring-fed tributary to the Tanana River in interior Alaska. The fish were tracked from aircraft and by boat for one year after implanting to locate overwintering and spawning areas and to estimate fidelity to the Delta Clearwater River for summer feeding. The majority of fish overwintered within a 115 mi reach of the Tanana River. Spawning areas were found in eight streams up to 72 mi distant from release. The greatest proportion of radio tagged fish spawning in the Goodpaster (59%, SE = 7%) and Volkmar (20%, SE = 6%) rivers. After spawning, 98%)SE = 3%) of live fish returned to the Delta Clearwater River for summer feeding. A radio tag shedding rate of 25% (SE = 9%) is estimated from recaptures of 24 radio-tagged fish one to two years after release.

Schallock, E. 1966. Investigations of the Tanana River and Tangle Lakes fisheries: migratory and population study. Annual report of progress. Alaska Department of Fish and Game Federal Aid in Fisheries Restoration Project No. F-5-R-7, Job 16-B.

This paper describes field work conducted in summer 1965 on Arctic grayling in the Delta Clearwater, Fielding Lake, and the Tangle Lakes systems. Field work included migration, growth, fecundity, spawning, parasite, and overwintering, and tag loss studies.

Limited data from work conducted in the Delta Clearwater indicated similar results to that described in Schallock (1965). Delta Clearwater Arctic grayling tag recoveries indicated some upstream and downstream movement, and for short tag to tag-recovery intervals, no movement phenomena during the summer. Tag recoveries also indicated immigration from Clearwater Lake and the Goodpaster River.

Netting in the Delta Clearwater - Tanana Slough area in mid October produced 22 Arctic grayling, all of which were located downstream of chum salmon redds. Sixty nine percent of the retained Arctic grayling contained salmon eggs in their stomach contents. One short sampling effort in mid December in the campground area revealed one large school of about 200 fish (several were tentatively identified as Arctic grayling; the remainder were considered whitefish). Several other small schools of unidentified fish also were seen.

Tack, S. L. 1980. Migrations and distributions of Arctic grayling, *Thymallus arcticus* (Pallus), in Interior and Arctic Alaska. Annual performance report. Alaska Department of Fish and Game Federal Aid in Fisheries Restoration Volume 21. Project R-I, Job R-I.

This report describes in detail seasonal migrations and distributions of Arctic grayling for five basic river types in Interior and Arctic Alaska. River types included: unsilted rapid runoff streams (Chena, Salcha); silted rapid runoff streams (Tanana, Yukon); spring-fed streams (Delta Clearwater); bog-fed streams (Shaw Creek, Little Salcha River); and glacier-fed streams (heavy silt load in summer only; generally have little or no fish life). Information presented includes overwintering distribution, prespawning migration, spawning distribution, postspawning migration, summer distribution, fall migration, and miscellaneous short-term movements.

Whalen, K. G., D. L. Parrish, and M. E. Mather. 1999. Effect of ice formation on selection of habitats and winter distribution of post-young-of-the-year Atlantic salmon parr. Canadian Journal of Fisheries and Aquatic Science 56:87-96.

We determined how ice affects selection of habitats and distribution of post-young-of-the-year Atlantic salmon (*Salmo salar*) parr during winter. Night snorkeling surveys were completed between November and April to evaluate parr habitat use and movements. Systematic measurements of water depth and velocity were recorded during ice-free and 55% iced conditions to quantify habitat availability. Ice formation altered the distribution and reduced the abundance of habitats commonly used by parr; differences between parr habitat use and habitat availability were greatest when ice was present. Edge ice formation resulted in the concentration of flows, and areas of high flow were formed in midchannel; few parr were observed in midchannel after ice had formed. Through the winter, most parr were found lateral to high flows on the ice edge boundary or in the post-ice period lateral to the stream midchannel. The correspondence of parr movements during winter to changes in the physical habitat associated with ice formation indicates that movements and redistributions may be important for survival in streams affected by ice.