# USE OF RADIOTELEMETRY TO EVALUATE OVERWINTERING OF LANDLOCKED ATLANTIC SALMON (*Salmo Salar*) IN RELATION TO TWO HYDROELECTRIC DEVELOPMENTS IN NEWFOUNDLAND, CANADA

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## ABSTRACT

Landlocked Atlantic salmon (*Salmo salar* or ouananiche), associated with the Bay d'Espoir and Upper Salmon hydroelectric developments in Newfoundland, Canada, were surgically implanted with radio-telemetry tags to evaluate pre- and post-spawning migrations and winter habitat use. Individuals were radio tagged with 6 to 18 month, unique transmitters, with temperature sensing capability, and habitat use and migration were monitored by aerial tracking at key life history stages over the life of the radio-tags. Results identified spawning areas and association of adults with both fluvial habitats and lake shorelines suggested both lacustrine (shoals) and riverine spawning. Individuals dispersed from spawning grounds (primarily in a downstream direction) in the late fall or early winter, likely to their place of origin for overwintering. The tracking data also determined that ouananiche utilized two types of habitats for overwintering; i) deep, warm water areas in large lakes and reservoirs and ii) open water (no ice cover), flowing reaches, at the inlets and outlets of lakes and reservoirs. Utilization of open water, super chilled, flowing reaches in winter was unexpected and raises questions concerning energetic costs of this habitat selection for poikilotherms.

## INTRODUCTION

Hydroelectric development influences the aquatic environment and fish populations, however little attention has been paid to the movement, reproductive strategy, and seasonal distribution of resident and migrating fish affected by development. Conventional sampling methods are of limited application for these types of investigations as they can be consumptive, may only provide site specific information, frequently cannot be deployed in preferred locations (*e.g.*, at hydroelectric intakes, in high velocity areas), and are often labour intensive and costly. Advances in radio telemetry have allowed for the collection of data on the location, behaviour, and physiology of fish in the wild, all in real time. This technology can permit the study of the migratory behaviour of fish relative to environmental conditions, allow investigation of reproductive strategies and other aspects of life history and, when habitat inventory is available, can be used to investigate habitat selection and temporal and spatial variation in habitat use.

Radio telemetry can be particularly valuable in the study of fish during the winter period, where conventional sampling methods are constrained by severe weather and environmental conditions related to ice formation. The difficulty in sampling under these conditions is considered the major constraint in the study of the winter ecology of salmonids in cold regions (Swales et al., 1986). Consequently, relatively few studies have been conducted on the winter biology of salmonids and this is particularly true of adult landlocked Atlantic salmon (*Salmo salar* or ouananiche) in the province of Newfoundland and Labrador. Winter is considered a critical period for fish populations and research is sorely lacking on physiological adaptations, behaviourial strategies, and habitat selection affecting winter survival of fishes (Power *et al.*, 1993; Thorpe 1994).

The results discussed in this paper are from extended monitoring of fish at two hydroelectric facilities that were initially radio tagged in studies for other purposes (Figure 1). Fish tagged in the Upper Salmon Hydroelectric Development were part of a research and development study, sponsored by the Canadian Electrical Association, into merging hydroacoustic and radiotelemetry technologies into a combined remote data acquisition system. Studies on the Granite Canal-Meelpaeg Lake system, within the existing Bay d'Espoir Hydroelectric Development, were undertaken as part of an environmental assessment of a proposed hydroelectric project to address fish passage concerns related to the project. These two hydroelectric developments resulted in alteration of the quantity and quality of available fluvial and lacustrine habitats and access to these habitats. The Canadian Department of Fisheries and Oceans (DFO) and Newfoundland and Labrador Hydro (NLH) undertook cooperative monitoring programs to investigate the effects of these developments, and habitat alteration, on resident populations of ouananiche. In both studies, long life radio tags (6 to 18 month battery life) afforded the opportunity to conduct extensive monitoring of migrations and movements for spawning purposes and seasonal habitat use, in particular for overwintering.

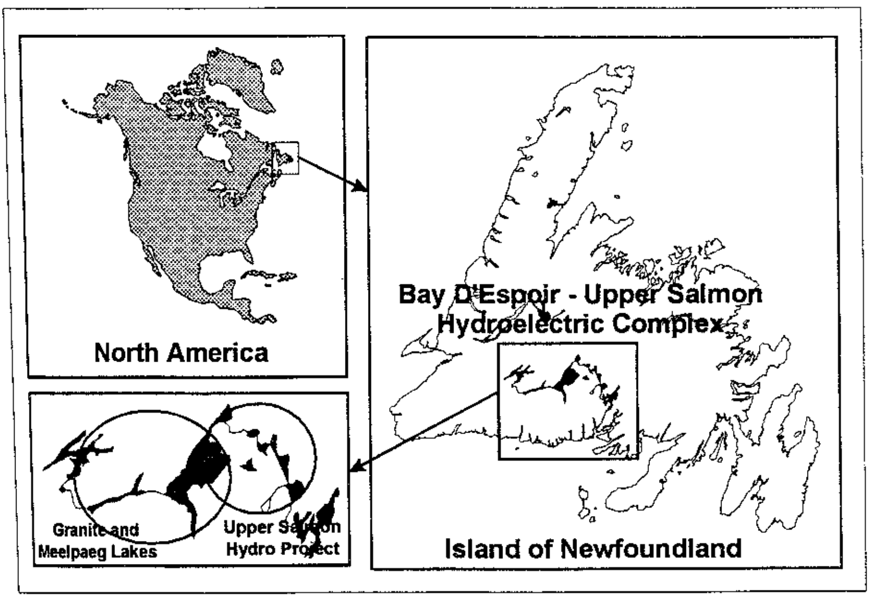


**Figure 1.** Location of the Bay D'Espoir - Upper Salmon Hydroelectric Complex in insular Newfoundland, Canada.

*Upper Salmon*

The Upper Salmon Hydroelectric Development, located in central Newfoundland, was conceived to utilize the head between Meelpaeg Reservoir and Round Pond, taking advantage of the existing reservoir and diversion systems of the previously constructed Bay D'Espoir development (Figures 1 and 2). A dam was constructed on the North Salmon River, flows were diverted into Cold Spring Pond, resulting in flooding of Crooked and Great Burnt Lakes. A dam on the West Salmon River impounded Cold Spring Pond and essentially isolated upstream areas (Cold Spring Pond, Great Burnt and Crooked Lakes) from the downstream reaches (Godaleich, Round, Long Ponds and the Salmon River). Pre-development studies determined the West Salmon River was being used for spawning by fish originating from throughout the watershed (Beak, 1980a; 1983). Fluvial habitats joining these lakes were flooded, channelized, and flows were substantially increased (approximately 10 fold from pre-development levels) and regulated.

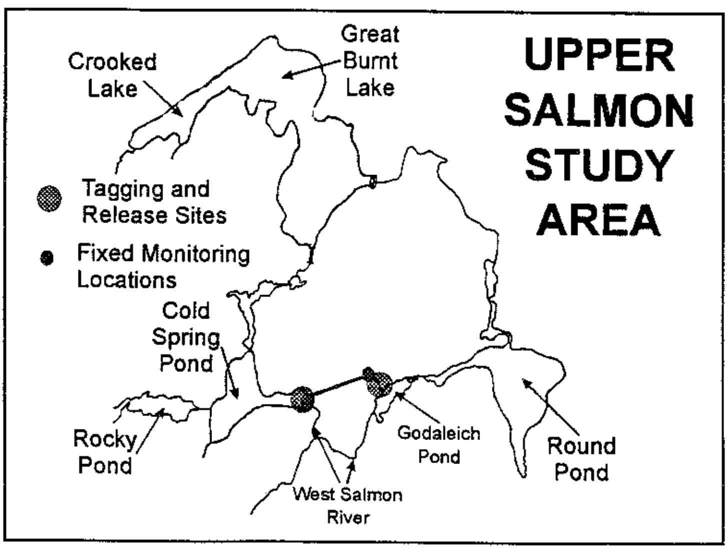


**Figure 2.** The Upper Salmon Hydroelectric Development including sites described in the text.

Twenty-nine adult ouananiche were captured by angling using barbless hooks in August and September 1991. Twenty fish (11 ♂, 9 ♀; 37 to 53 cm [mean=44.6]; 0.6 to 1.8 kg [mean=1.01 kg]) were released above the spillway at Cold Spring Pond dam while 9 fish (5 ♂, 4 ♀; 37.2 to 52.6 cm [mean=43.4]; 0.52 to 1.30 kg [mean=0.85 kg]) were released at the tailrace in Godaleich Pond (Figure 3). Transmitters (55 mm length by 18 mm diameter; 6 month battery life; with temperature sensors; broadcasting at 10 kHz with an operating band of 49.000 to 51.999 MHz) were surgically implanted in the body cavity of the fish. Transmitters weighed less than 1% of the body weight of the experimental animals. Surgical implantation involved opening a 2 cm incision, inserting the transmitter through this incision and pushing it anteriorly, inserting the antennae through the body wall, and then closing the incision with three independent sutures (Ethicon 2/0). Fish recovered from the surgery and were allowed to disperse by their own volition. Tags were implanted from 1.5 to 2 months prior to the spawning period to ensure fish would have recovered from surgery.

Fixed monitoring stations, consisting of Yagi antenna connected to a LOTEK Model SRX-400 receiver/data logger, were set up at the intake (end of the power canal) and at the dam/spillway on Cold Spring Pond. Active monitoring, consisting of ground level and boat tracking, was conducted over the period September 11 to October 17, 1991. Aerial monitoring flights were conducted on October 22 and December 3, 1991 and January 10 and February 5, 1992. Aerial monitoring used 2 programmable radio receiver/data loggers connected to a dipole antenna on the landing strut of a helicopter. The search routine involved following a pre-determined flight pattern at fixed altitude (200 m) across the large lakes at constant speed (100 km $hr^{-1}$) and then following the various major tributary streams. The monitoring routine involved signal detection, halting the automatic search routine, and recording the signal frequency, location, date and time, and temperature (if possible). To maximize the searching efficiency, the detected frequencies were subsequently deleted from memory before restarting the automatic search routine.

Granite Canal

Granite Canal is part of the Bay d'Espoir Hydroelectric Development which was constructed from 1964 through to 1970 and included runoff from a total drainage basin area of 5,254 km$^2$ involving three major diversions (Figures 1 and 3). Granite Lake was part of the headwaters of the White Bear River and was flooded and diverted through the Granite Canal into Meelpaeg Reservoir. Granite Lake and Meelpaeg Reservoir are joined by the Granite Canal and this reservoir system is isolated by Burnt dam (upstream end) and the Ebbegumbaeg control structure (downstream end). Consequently fish populations would need to have all life requisites met within this closed system. The telemetry study described in this paper was undertaken to determine if there was directed movement between Granite Lake and Meelpaeg Reservoir to establish whether a fish passage system was required, if a proposed hydroelectric project was developed, and also to investigate the biological imperative for any migration.

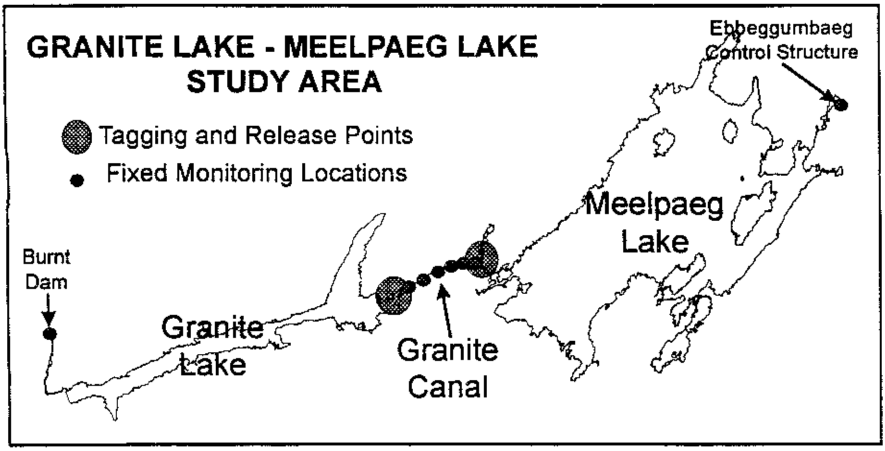


**Figure 3.** Location of the Granite Lake - Meelpaeg Lake study sites.

Thirty-nine adult ouananiche were captured by angling using barbless hooks in the first two weeks of September 1993. Twenty-five fish (10 ♂, 15 ♀; 40 to 45 cm [mean=42.7]; 1.0 to 1.3 kg [mean=1.12 kg]) were captured and released at the downstream end of Granite Canal while 14 fish (6 ♂, 8 ♀, 40 to 46 cm [mean=42.6]; 1.0 to 1.5 kg [mean=1.13]) were captured and released at the upstream end of Granite Canal and in Granite Lake. Transmitters (similar to those used on the Upper Salmon project except with 18 month battery life) were surgically implanted in fish. Tags weighed less than 2% of the body weight of the experimental animals. The surgical procedure was as described for the Upper Salmon study.

Fish were monitored through a combination of fixed monitoring stations, mobile tracking from a boat, and aerial tracking. Five fixed stations, consisting of a programmable radio receiver/data logger with antenna (stripped coaxial underwater cable or Yagi antenna) powered by a 12 volt gel battery charged by solar panel, were located along Granite Canal, and monitoring was conducted during the ouananiche migration and spawning period from September 12 to October 26, 1993. Mobile tracking by boat, with an underwater antenna attached to a receiver/data logger, was conducted within a 6 km radius of both the entrance and exit of Granite Canal. Aerial tracking from helicopter was conducted from October 25, 1993 to November 18, 1994; a total of 11 monitoring flights. Aerial monitoring involved the same search strategy and protocol as described for the Upper Salmon project.

## RESULTS

The two studies consisted of two distinct monitoring phases: i) an initial intense monitoring period using a variety of approaches (*e.g.*, ground level monitoring, fixed stations, aerial tracking) during the migratory and spawning period immediately after tagging and ii) an extended period of aerial tracking at key points in the ouananiche life history until the tag battery life had been exhausted. This paper focuses on the results and observations during the post-spawning and overwintering periods.

Upper Salmon

A synopsis of migration and winter habitat use revealed in this study is provided in Figure 4. Seventeen spillway released fish were subsequently re-located. By late October (post-spawning), fish either remained at the intake or had dispersed to Rocky Pond River and Cold Spring Pond (near the spillway or the north end). In December 1991, fish previously located in the intake area had either (i) passed through the generation station, (ii) moved into Cold Spring Pond, (iii) moved to the west end of Crooked Lake, or (iv) had moved back out into the power canal. In January and February 1992 fish remained close to where they had been observed in October or had moved out into the diversion canal north of Cold Spring Pond, into Crooked Lake, or into Cold Spring Pond. The tailrace released fish either remained in the tailrace or demonstrated extensive movements until remaining relatively immobile during the overwintering period. Seven of 10 tailrace released fish were subsequently located in the initial monitoring phase; three of seven fish were in Godaleich Pond and four in the West Salmon River. Several of these fish were not subsequently re-located in the extended monitoring phase suggesting extensive post-spawning migrations.

During winter (January and February 1992) fish were observed to be resident in two distinctly different habitat types; i) in the middle of the large lakes and reservoirs, presumably at depths where temperatures were warmer (1.1 to 2.4 $^{0}$C), and ii) in open water, fast flowing reaches, characterized by very cold (super chilled) temperatures (0.6 to 1.3 $^{0}$C). Open water locations included the tailrace canal, below Ebbegumbaeg Canal, the channelized high water volume area at the inflow to Round Pond and the Round Pond outflow into Long Pond. Mean water temperatures, obtained from the tags during the aerial tracking surveys in December, January and February, decreased from December (1.23 $^{0}$C), through

January (0.81 $^{\circ}$C), to February (0.74 $^{\circ}$C).

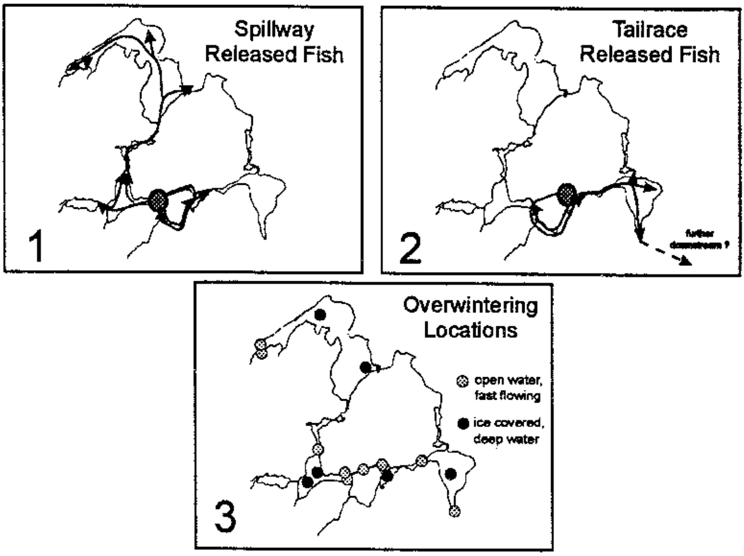


**Figure 4.** A synopsis of migration and habitat use of fish at the Upper Salmon Hydroelectric Development. Panel (1) is for fish tagged and released at the spillway; (2) for fish tagged and released at the tailrace; and (3) identifies overwintering locations in 1993.

Granite Canal

A synopsis of migration and winter habitat use is provided in Figure 5. Nine of 14 fish released above the canal, entered the canal in September/October 1991 while the others remained in the vicinity of their tagging location or dispersed into Granite Lake. Individuals in the canal demonstrated a back and forth movement, possibly seeking refugia from the high velocities in the canal or seeking spawning substrates. Five fish moved downstream through the canal and remained in the area below the outflow for the duration of the initial monitoring period. The majority of the downstream tagged fish remained within the vicinity of the end of the canal throughout the intensive monitoring period. Direct observations and the abundance of radio signals indicated that the region immediately below the outflow of the Granite Canal was a major spawning area.

Construction of redds and spawning activity was observed in the last week of October over a three day period (October 19 to 22). Aerial monitoring in late October 1993 indicated fish had started to disperse into Meelpaeg Lake.

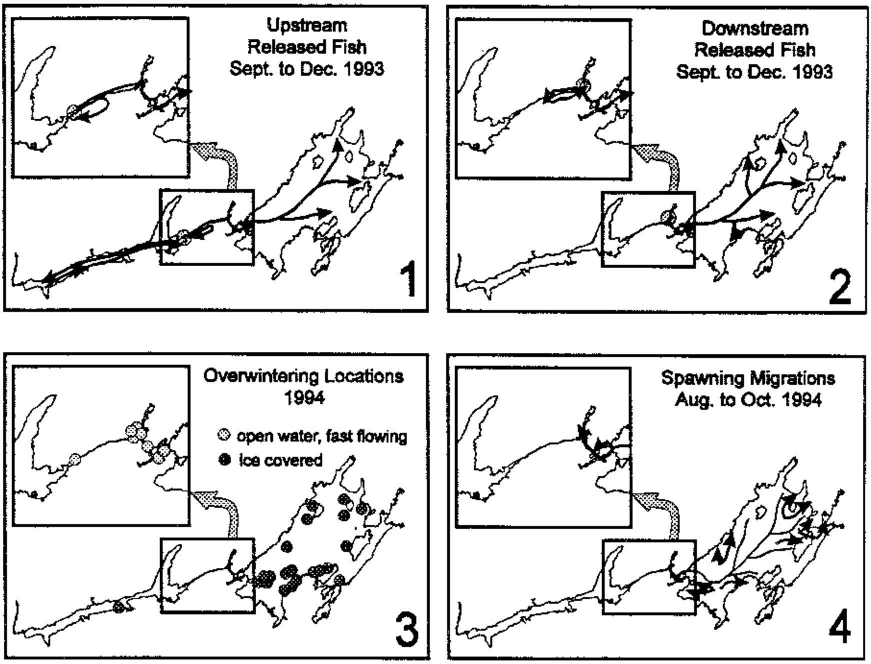


**Figure 5.** A synopsis of migration and habitat use of fish in Granite Lake - Granite Canal - Meelpaeg Lake system. Panel (1) is for the intensive monitoring period (September and October 1993), panel (2) for post-spawning and overwintering period (November 1993 to June 1994), panel (3) for the summer and pre-spawning migrations (July to August 1994) and panel (4) for the fall 1994 spawning period (September to November 1994).

Aerial monitoring flights during the long term monitoring phase, including the number of fish located, were as follows: November 18, 1993 (6 fish); November 30, 1993 (9 fish); December 21, 1993 (33 fish); January 27, 1994 (31 fish); May 5, 1994 (31 fish); June 8, 1994 (29 fish); July 13, 1994 (10 fish); August 15, 1994 (19 fish); September 16, 1994 (23 fish); October 28, 1994 (22 fish); and November 18, 1994 (20 fish). In the post spawning period in 1993 (November and December) most fish dispersed from the spawning congregations below the canal to downstream lotic reaches or out into Meelpaeg Lake. Fish remained in these areas in the late December 1993 and January and May 1994 surveys, a period during which there was full ice cover on the reservoirs. As in the Upper Salmon study, fish utilized both ice covered, deeper waters in Meelpaeg Lake as well as fast flowing, open water in fluvial areas below the spawning area. In June and July 1994, after ice out on Meelpaeg Lake, fish were distributed throughout the lake as well as the fluvial habitats below the canal. By August, fish were again congregating below the canal. These observations continued in September, October, and November 1994 with many fish located below or on the spawning grounds. During this period, fish located in Meelpaeg Lake were close to the lake shorelines suggesting association with spawning shoals.

## DISCUSSION

This study confirms extensive migratory patterns demonstrated by fish in the Upper Salmon development area during migration and tagging studies completed in the early 1980's (Beak, 1980a; 1983). Movements of adult fish in September and October are considered directed movements to preferred spawning habitats. Upstream tagged fish distributed to fluvial reaches suggesting these areas may be used for spawning, including Rocky Pond River which contains pockets of good spawning habitat and quantities of juvenile rearing habitat (Beak, 1980a). This study also confirmed that ouananiche and brook trout are spawning in the regulated West Salmon River which pre-development studies had determined had been used extensively by both upstream and downstream populations for spawning prior to development (Beak, 1980a; 1983). After spawning, all fish had moved from fluvial spawning habitats to return to deep water areas of the lakes and reservoirs and/or regulated, fast flowing fluvial reaches, to overwinter.

The Granite Canal telemetry study indicated migration from throughout the study area to a major spawning area at the outflow of the canal, including movement from upstream areas. The origin of the upstream tagged fish is unknown, however many subsequently moved downstream not to return to the Granite Lake, suggesting they may have originated from Meelpaeg Lake. Few upstream tagged fish were relocated in the Granite Lake or canal area. In the fall of 1994, fish were observed to be utilizing two habitat types for reproduction; the fluvial habitats and possible shallow spawning shoals in Meelpaeg Lake. During winter, fish were observed to be distributed throughout Meelpaeg Lake in deeper areas as well as the regulated, fluvial reach between the canal and the lake.

Landlocked salmon in Maine (Warner and Havey, 1985) and elsewhere have been shown to demonstrate both migratory (upstream) and emigratory (downstream) behaviour either in relation to accessing rearing/feeding areas or in relation to spawning. In Maine, migration distances have been shown to be as much as 38 km with post-spawning fish migrating to their 'home' lakes for overwintering (Warner and Havey, 1985). Conventional tagging studies on the Upper salmon development determined fish had migrated as much as 65 km from the primary spawning area of the West Salmon River (Pope 1984). Watersheds in the Rangley Lake chain in Maine demonstrated primarily a summer run (primarily June-July) of fish from the lakes to streams in advance of spawning, with no evidence of fall run fish (de Sandre *et al.*, 1977). Observations from the telemetry studies, and previous migrations studies (Beak, 1980a; 1983), suggest ouananiche in Newfoundland migrate to spawning areas in September and October, spawn primarily in late October and early November, and then move off the spawning grounds to overwintering areas in late November and December, prior to formation of stable ice cover on lakes and/or reservoirs.

Visual observations from the tracking helicopter and temperature data received from the transmitters in both study areas indicated that ouananiche preferred over-wintering conditions either in an ice free, fast water environment, or in deeper water in the reservoirs. Open water habitats were ice free by virtue of the large volumes of water flow at these points a result of upstream impoundments and regulation that prevented surface ice formation. Observation of fish in these ice free, fast water locations was unexpected as these areas are super cooled in the winter months and it is speculated there would be a metabolic cost to fish to maintain position in these habitats. Interestingly, these areas did not exist prior to development and winter months in fluvial habitats in Newfoundland are characterized as low flow periods (Newfoundland Department of Environment and Lands, 1991). As salmonids are poikilotherms, the low temperatures would control (lower) metabolic rates. Food requirements and appetite of salmonids are reduced at lower temperatures although fish have been observed to feed during winter (Ridell and Leggett, 1981). Declining condition and depletion of energy reserves generally typify physiological changes to salmonids during winter and the selection and use of habitats that would minimize these changes would be important in determining overwinter survival (Cunjak 1988; Metcalfe and Thorpe, 1992).

Fish would also require energy expenditure to hold position at these high velocity sites. Rimmer et al. (1985) determined that the swimming performance of juvenile Atlantic salmon declined sharply below 8 $^{0}$C and suggested that this was, in part, why juvenile salmon seek sheltered, low velocity areas for overwintering. Under winter conditions, where both food availability and swimming performance is reduced, and the ability to hold position against a water current requires energy, one would expect the optimal strategy would be to conserve energy. Early winter is a stressful period for Atlantic salmon undergoing acclimatization to changing environmental conditions (Cunjak 1988) and this is a period of relatively high discharge when coupled to declining water temperatures, depletion of energy for reproduction, and the requirement to migrate from spawning habitats to overwintering areas, would impose considerable energetic demands on adult ouananiche. The Granite Canal study, involving monitoring during two spawning periods, determined that fish that overwintered in these areas survived and 'apparently' exhibited normal spawning behaviour in the subsequent fall.

The biological significance of occupying these super cooled, fast flowing areas requires further study. As fish do little feeding or growing through the winter, it is unclear if they could take advantage of the high biological productivity associated with these areas (Ward, 1976). Without a knowledge of the microhabitat conditions associated with fish holding positions, and the biological productivity and food resources of these habitats, it is difficult to speculate on the benefits and/or metabolic cost of this habitat selection.

## CONCLUSIONS

The observations from these two studies have documented how fish populations have adapted to habitat modifications related to hydroelectric development, particularly in relation to movements and migrations for spawning and overwintering. At the Upper Salmon development, populations upstream of the Cold Spring Pond dam are utilizing available fluvial habitats for reproduction. Downstream populations appear to be making extensive migrations from throughout the Salmon River watershed to utilize the high quality spawning habitats in the West Salmon River, as they did prior to development. In the Granite Lake-Meelpaeg Lake system, fish appear to be using fluvial habitat below the Granite Canal and shallow shoals in Meelpaeg lake for spawning. It is likely that these habitats had not existed prior to hydroelectric development, consequently fish have adapted to utilization of available habitats for reproduction. Neither spawning success nor how current populations compare with pre-development numbers is known.

Radio telemetry technology has permitted monitoring of adult movements and habitat use after spawning and overwinter and throughout a complete annual cycle. Adult ouananiche are using the deep water areas in the large lakes and reservoirs during the winter period. Several fish were observed to be present in fast water, ice free fluvial habitats and the significance of the use of these areas in winter was not apparent.

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## DISCUSSION

**T.D. Prowse, NWRI, Saskatoon, SK**

During the main ice-covered period, did you observe any preferential use of fast flowing open water areas?

**Reply:** The results of both studies indicated there was apparent preferential use, by a major component of the radio tagged individuals, of fast flowing and open water areas during the ice covered winter months. It is unclear, at present, what advantage use of this habitat would provide with respect to over winter survival.