FRAZIL ICE ACCUMULATION IN A LARGE SALMON POOL IN THE MIRAMICHI RIVER, NEW BRUNSWICK: ECOLOGICAL IMPLICATIONS FOR OVERWINTERING FISHES

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ABSTRACT

One of the largest pools (13,375 m^2 surface area) in the Northwest Miramichi River, and a popular angling pool for Atlantic salmon, was visited at three week intervals from December until the end of March. During each visit, 16 holes along 4 transects were drilled to measure thickness of frazil and surface ice, and depth of water to the pool bottom. The maximum depth of water in the pool was 8.9 m. Average thickness of surface ice increased from the initial to the last survey (0.3 - 0.8 m); average snow depth on the ice followed a similar trend. Frazil ice was present beneath the surface ice during all site visits, with greatest accumulation (8.0 - 8.5 m thickness) occurring in the deepest section of the pool where it extended to the pool bottom. As a percentage of pool volume, frazil ice occupied ≈83% of the pool in December compared with ≈73% by late March. Frazil began to disappear first from the shallow, littoral sections of the pool whereas it persisted to the pool bottom in the deepest section. Water velocities measured near the bottom of the pool were relatively greater in winter than in summer. Implications to overwintering fishes of velocities through frazil laden pools are discussed. Such dynamic ice conditions may affect habitat availability and suitability for overwintering fishes seeking to minimize energy expenditure, and for winter-spawning species (e.g. tomcod).

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INTRODUCTION

In early March of 1991, as a result of investigating the effects of a spill of untreated mine water into the Miramichi River of New Brunswick, we encountered substantial amounts of frazil ice in a large salmon pool. During a subsequent visit to the pool the following year (1992), we found a similar hanging dam of frazil ice which suggested that the accumulation was not an isolated phenomenon. These observations led us to speculate as to the extent and duration of such ice in the pools of the main Miramichi River, and the effect of such ice on the winter habitat of stream fishes.

The Miramichi River (drainage area ≈ 14,000 km^2) is the most productive Atlantic salmon (*Salmo salar*) river in the world. Angling for this highly prized sports fish has a current value of approximately $14 M per annum for New Brunswick (Loftus et al. 1993), with an estimated annual value of $8.5 M the Miramichi region alone. Consequently, a significant amount of resources, financial and human, are devoted to the management of this species. Despite its acknowledged importance, little is understood about the habitat conditions of the salmon during the winter.

Unlike their Pacific cousins, the Atlantic salmon does not die after spawning in the autumn. Instead, they move to deep, main river pools to overwinter. Indeed, this fact permits them to be exploited by a limited, but locally significant, recreational fishery in the spring. Ice conditions in the pools during winter could alter flow dynamics and, hence, habitat availability and suitability which could affect survival. Understanding such processes is, therefore, vital to sound species management.

The main objective of our research was to measure the spatial and temporal changes in ice formation and accumulation in a large salmon pool in the Miramichi River. Based on the results, we sought to estimate the potential impacts of ice to fishes overwintering in the pool, specifically post-spawned, adult Atlantic salmon.

STUDY AREA

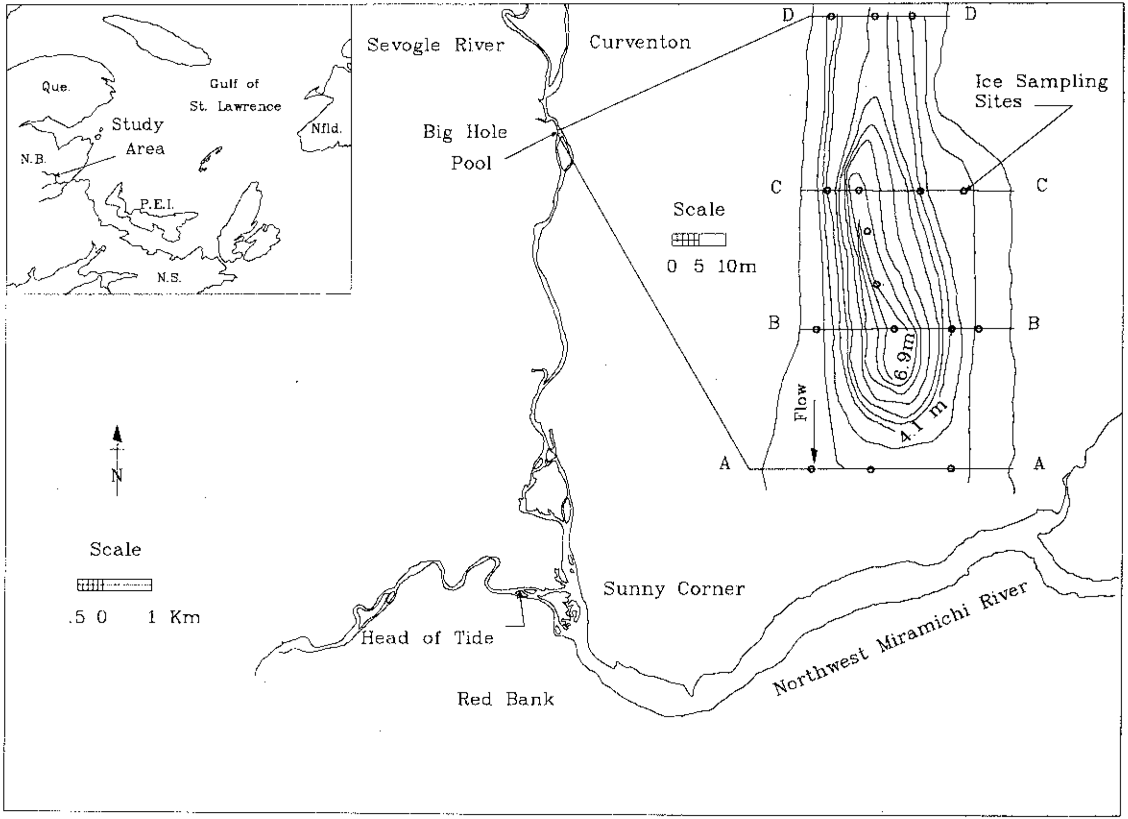
The Big Hole Pool (47° 02.4' N, 65° 50.3' W; Figure 1) is considered by local residents to be the largest salmon pool in the Northwest Miramichi River and an important holding pool for adult Atlantic salmon. Located approximately 10 km above the head of tide, it measures >150 m in length with an average width of 75 m. A complete ice cover generally covers the pool by late December with ice break-up often occurring in mid-April in association with a spring spate. Mean annual flow at the Big Hole site is 30.7 $m^3 \cdot s^{-1}$ with a drainage area of 1390 km^2. This area receives approximately 1100 mm of precipitation annually in which about 300 mm fall in the form of snow.

MATERIALS AND METHODS

During October, 1992, one site visit was made to establish bench-marks along the shoreline and to measure the bathymetry of the pool. To calculate bathymetry, four cross sections were selected and depth were measured every 5 m. Following freeze-up, 5 site visits were made to the pool between December 22, 1992 and March 23, 1993. During these visits, 16 holes were drilled through the surface ice with a 200 mm diam. auger along four transects (Figure 1). At each hole, measurements were taken of snow depth, hydrostatic pressure, thickness of surface and of frazil ice, and depth of water beneath ice to the bottom of the pool. The hydrostatic pressure was measured as the distance from the water surface elevation (or the hydraulic gradient line) to the top of the surface ice. To avoid potential bias of repeated measures at same locations, holes were selected 1 metre away (north, south, east and west) from the initial drill-hole on subsequent visits.

A rod with a cone-shaped device at the end was pushed through the frazil ice, and when the frazil offered no more resistance, the depth of frazil was noted. The rod was then lowered to the bottom of the pool to measure the depth of water beneath ice. Attached perpendicularly to the rod, was a nail of approximately 150 mm in length

Figure 1. Map showing location of Big Hole Pool in New Brunswick. Blow up of study area depicts bathymetry and sampling sites along transects of pool.



which served to establish the underside of the surface ice as the rod was pulled up. This information provided the depth of surface ice to the water surface elevation. Hydrostatic pressure and snow depth were measure using a meter stick. It should be noted that the hydrostatic pressure was either positive or negative depending on if the water surface elevation was below or above the top of the surface ice.

Water velocity ($cm.s^{-1}$) was measured with a Marsh-McBirney meter during two site visits: once in winter (December), and once during the summer (July 1993) for a seasonal comparison. The cone type device mentioned above was used during winter to push away the frazil in order for the velocity meter to be easily lowered below frazil. Measurements were taken at mid-distance between the bottom of the frazil ice mass and the pool bottom, and 50 cm from the pool bottom when possible. This latter measurement was assumed to represent the "focal water velocity" which would be experienced by fish overwintering along the river bottom.

To investigate possible dependence among parameters such as depth of frazil, depth of ice, and depth of snow, a regression analysis was carried out using SAS (SAS Institute Inc. 1985). The selected model for the regression was a simple linear model. For this particular analysis, the data for all the holes and surveys were pooled together which provided a data set of 80 observations. A paired sample t-test was used to compare seasonal measurements of mean water velocity near the pool bottom, at each sampling site.

RESULTS

The maximum depth of water measured in the pool was 8.9 m. Despite this significant depth, frazil ice was similarly thick, often in contact with the pool bottom. Of special note is the measurement of maximum frazil thickness in both early winter (December) and late winter (March; Table 1) suggesting constancy of the frazil mass over the course of the winter. In contrast, thickness of the sheet ice and the snow cover increased between December and March (Table 1). Average minimum and maximum ice thickness was 34 cm and 79 cm, respectively. The ice thickness was highly variable during each survey with a coefficient of variation in the range of 0.35. The maximum depth of ice recorded was during the last survey (late March) at 1.14 m.

TABLE 1. General physical characteristics measured at Big Hole Pool, Northwest Miramichi River, N.B., during the winter of 1992/93.

Sample Date (dd/mm)	% of water column occupied by ice [1]	Maximum (m)		Avg. Thickness (m)	
		Pool Depth[2]	Frazil Depth	Sheet Ice	Snow Cover
22/12	82.8	8.51	8.45	0.34	0.15
20/01	76.8	8.45	7.95	0.49	0.22
09/02	77.1	8.32	8.15	0.64	0.21
02/03	74.9	8.74	8.45	0.72	0.54
23/03	72.8	8.85	8.28	0.79	0.54

[1] includes both sheet and frazil ice.
[2] measured from water surface to bottom of pool.

The ice mass (mainly frazil) occupied a significant percentage of the volume of Big Hole Pool (73% - 83%) throughout the winter of 1992/93 (Table 1). This mass is especially impressive when considering the actual pool volume which is 55,105 m^3. The average volume declined from early to late winter (Table 1) although this was not the trend at all drill-holes (Figure 2) where much temporal variability was measured. There was, however, some evidence of spatial trends in ice accumulation which led us to divide the data among three groups (left-bank, right-bank, and mid-pool). For example, ice occupied most of the water column at those holes situated near midstream, regardless of sample date (Figure 2) or water depth (Figure 1).

The spatial heterogeneity of ice accumulation is better visualized in Figure 3. Frazil ice thickness was greatest in the mid-pool section where water depth was greatest. Despite the depth of water, average water 'space' beneath ice (i.e. usable fish habitat) was < 0.5 m in the mid-pool section; in many cases, frazil ice was in

Figure 2. Differences in the percentage of the water column occupied by ice (surface and frazil) among the different sampling holes in Big Hole Pool during the winter of 1992/93. Uppercase letters refer to transect lines (see Figure 1).

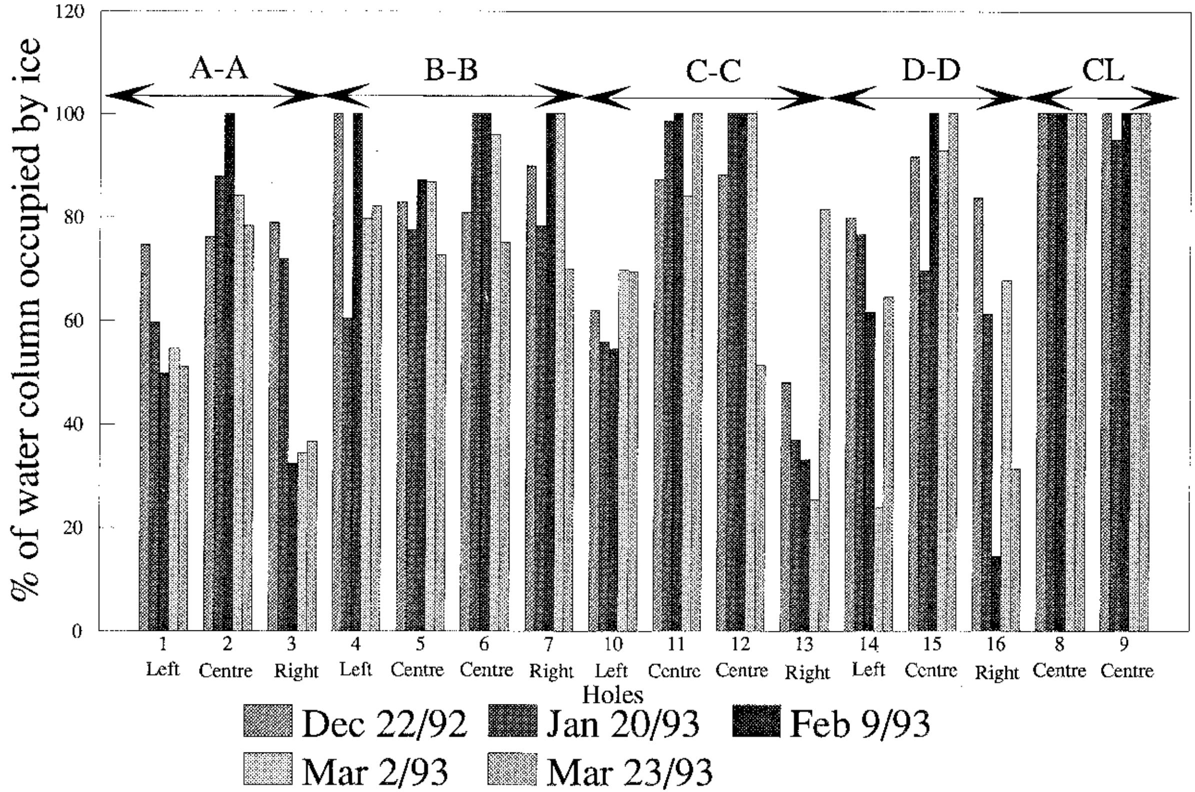
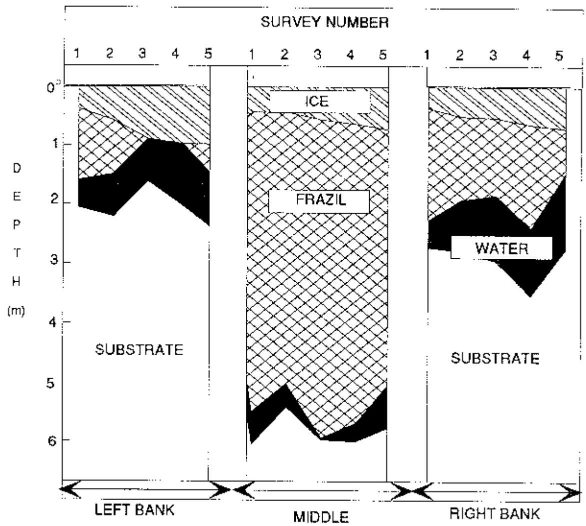


Figure 3. Relative differences in the average depth of surface and frazil ice, and water, in different sections of Big Hole Pool for the five survey dates during the winter of 1992/93.



SURVEY NUMBER	DATE
1	DECEMBER 22, 1992
2	JANUARY 20, 1993
3	FEBRUARY 9, 1993
4	MARCH 2, 1993
5	MARCH 23, 1993

contact with the pool bottom. For example, at the two holes with the greatest depth of water, frazil ice was in contact with the pool bottom during all five winter surveys. *In contrast, in the shallower, littoral margins of the pool, the water space beneath* frazil ice was relatively greater than in the middle of the pool (Figure 3), and never was found to be in contact with the pool bottom.

In both the left and right sides of the pool, frazil accumulation was greatest during the first survey (Dec. 22) and generally declined thereafter (Figure 3). During the February and early March surveys, no frazil ice was detected in any of the drill-holes along the left-side of the pool (Figure 3). It should be noted that water flow through Big Hole Pool is strongest in mid-stream with a large, slow back-eddy current on the left-side (i.e. where frazil accumulation was least).

The results of the regression analysis showed a high dependence between depth of frazil and depth of water ($r^2 = 0.93$, $p < 0.0001$). This shows that deeper areas of the pool also have more frazil ice. Depth of frazil was also significantly, and inversely, related to thickness of surface ice ($p < 0.0001$). That is, frazil tended to accumulate less in the shallower pool margins where, concurrently, surface ice thickness was greatest (see Figure 3). However, the regression did not account for much of the variability in the data ($r^2 = 0.37$). The regression between thickness of surface ice and depth of snow was not significant ($r^2 = 0.012$, $p = 0.32$).

Water velocity along the bottom of Big Hole Pool where fish would be overwintering was generally lower in summer than in winter (Table 2) although the difference was not statistically significant ($p = 0.26$). The fastest velocities (15 $cm \cdot sec^{-1}$) were recorded in winter despite the 35% higher flow measured in summer when velocities were measured (Table 2). The mean, near-bottom water velocity (all sections combined) in August and December was 2.9 $cm \cdot sec^{-1}$ and 5.6 $cm \cdot sec^{-1}$, respectively.

TABLE 2. Seasonal measurements of river discharge ($m^3 \cdot sec^{-1}$) at Big Hole Pool, Northwest Miramichi River, and near-bottom, mean (± std) water velocities ($cm \cdot sec^{-1}$) in different sections of the pool.

Sampling Date	Section of Pool			River Discharge
	Left-side	Middle	Right-side	
Dec. '92	5.8±7.23	6.8±6.83	3.3±5.77	9.3
Aug. '93	3.3±2.35	2.0±2.76	3.8±4.35	14.4

DISCUSSION

The massive hanging dam of frazil ice in Big Hole Pool was a persistent and predictable winter phenomenon. Frazil ice was identified soon after freeze-up in December and throughout the winter until late March. Personal observations in the previous two winters confirmed the presence of frazil ice as a regular occurrence in Big Hole Pool. As frazil must be generated in super-cooled water, often in open reaches of a river (Beltaos et al. 1993), we investigated sections of the Northwest Miramichi River upstream of the study area. Approximately 0.5 km upstream, we found a shallow riffle which was largely uncovered by surface ice for most of the winter of 1992/93. Discussions with local residents indicated that this riffle remained free of ice throughout the winter except for brief periods during the coldest winters. Based on these observations, we speculated that this location was the source of the frazil ice which accumulated in Big Hole Pool.

The ice situation during the winter of 1992/93 may have been excessive relative to previous years, as a consequence of the low water conditions and colder temperatures. During our study, 73-83% of the pool volume, on average, was occupied by ice with >90% in the deep, mid-pool section. A single survey of drill-holes along the thalweg of the pool the previous year (March 1992) found frazil ice throughout the pool (Figure 4) but relatively less than found in the winter of 1992/93. A comparison of the winter hydrographs for the previous three years (Figure 5) shows that discharge was markedly reduced during the winter of 1992/93. Such deficient flows would probably be unable to displace the frazil mass out of the pool. The

Figure 4. Longitudinal profile of Big Hole Pool showing snow, ice, and water depth measurements recorded during a site visit March 04, 1992. All measurements are given in cm. Tomcod eggs were found in the frazil mass at survey hole 4.

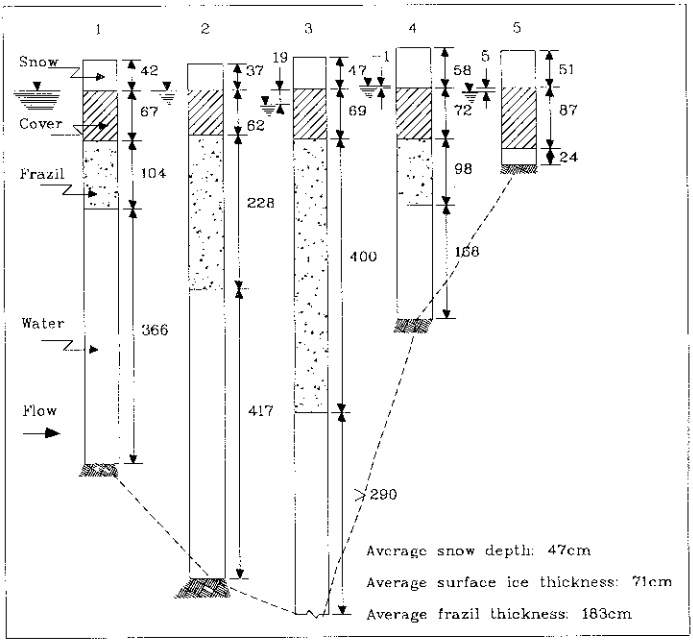
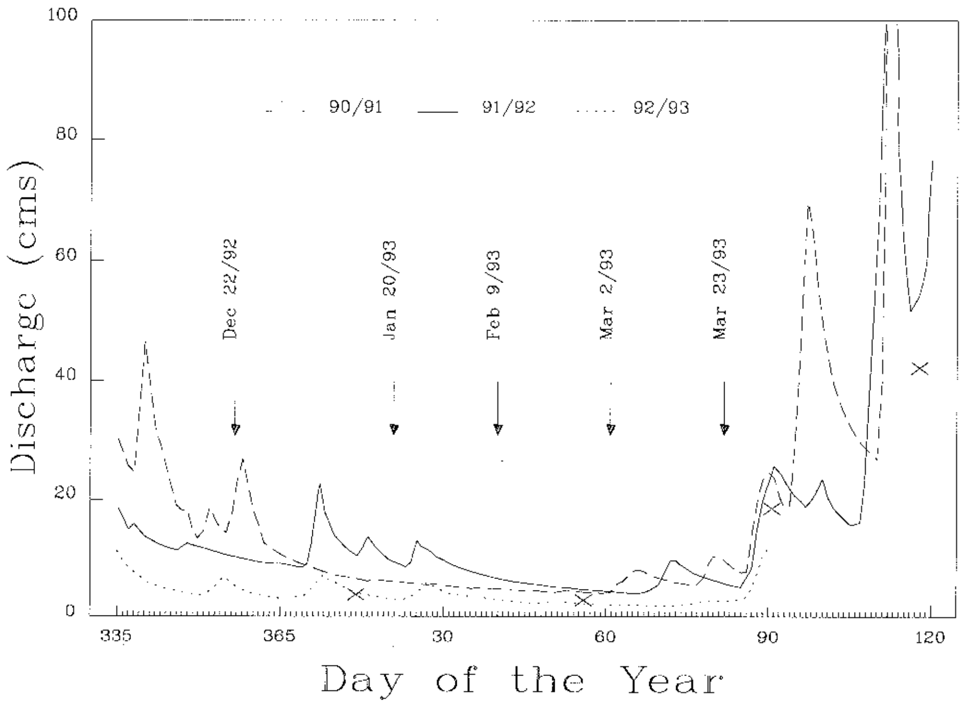


Figure 5. Winter hydrographs of the Northwest Miramichi River for 3 years. Arrows denote sampling dates at Big Hole Pool in 1992/93. The hydrograph of 1992/93, after julian day 01 was derived from prorated discharge values taken from the gauge station on the nearly Southwest Miramichi River; X-points are manual daily discharge measurements in the Northwest Miramichi River for the same year.



winter of 1992/93 was also relatively cold. Mean monthly air temperatures were all below normal for January, February and March as recorded at the Chatham meteorological station approximately 30 km from Big Hole Pool (Environment Canada 1993) and, therefore, conducive to ice formation. The most severe month in 1993 was February with a mean monthly air temperature of -13.7 °C, 4.6 °C colder than the long term average for this month (-9.1°C). Together, these circumstances are believed to be responsible for the large volume of frazil ice found in Big Hole Pool during the winter of 1992/93.

What are the consequences of such extreme ice conditions for the overwintering fishes? Unfortunately our ability to answer this question remains largely speculative because of the dearth of research on this topic (see review by Power et al. 1993). A recent study of the winter behaviour of salmonids in an Alberta stream (Brown et al. 1993, these proceedings) demonstrated an avoidance to frazil ice and the tendency to aggregate in microhabitats where ice accumulation was precluded, similar to the observations by Cunjak and Power (1986). Certainly the extensive frazil accumulation in Big Hole Pool would severely limit habitat availability. Contrary to what one might hypothesize, the deepest section of the pool did not provide the most suitable habitat. Indeed, our data suggest that the shallower, littoral margins of the pool provide more 'free water' space (i.e. habitat) than the deeper, mid-pool.

The ability to move within, or out of, the pool to more suitable microhabitats should conditions change may be an important factor for winter survival. Cunjak and Randall (1993), in studying the winter movements of juvenile salmonids in small streams, suggested that during very cold winters with low discharge, instream movement may be precluded where ice conditions are severe. The precise response by adult salmon to changing ice conditions remains unknown but certainly warrants further investigation.

In March of 1992, eggs of tomcod (*Microgadus tomcod*) were found within the interstitial spaces of the frazil ice (see Figure 4). This species typically spawns in December -January in the lower reaches of tidal rivers, releasing the eggs in the water column to incubate and develop within frazil ice (Fortin et al. 1992). The absence of tomcod eggs during any of the 1993 surveys may provide further evidence of the environmental effects of river ice. The low water levels and ice accumulation during December of 1992 and January of 1993 could have precluded spawning tomcod from reaching pools so far above the head of tide.

It is commonly assumed that water flow through a frazil mass is negligible (S. Beltaos, pers. comm.). Instead, most of the flow is deflected through the water channel with a consequent increase in water velocity because the available volume for the water to pass through has been reduced by the ice. Such a scenario may explain the general, albeit small, increase in water velocities which we measured near the bottom of Big Hole Pool in winter. However, the relatively few points of measurement along a transect do not permit an accurate quantification of the flow pattern. Flow 'conduits' through the frazil mass are possible (G. Tsang, pers. comm.) which could account for a substantial portion of the flow. More frequent measurements along a transect line are required to determine if water velocity increases significantly along the bottom of a pool filled with frazil ice.

Potential increases in water velocity, especially along the river bottom where most fishes overwinter, has important energetic implications. Most stream fishes occupy positions in winter where energy expenditure will be minimized (Cunjak and Power 1986) because of the physiological demands of acclimating to declining water temperatures and freezing conditions (Cunjak 1988). Any increase in water velocity could reduce habitat suitability. During the survey at Big Hole Pool in March of 1991, a diver observed few adult salmon beneath the ice in an estimated 30 m area. However, these few salmon were all positioned on the pool bottom and out of the main current where water velocity was negligible.

In conclusion, this study has yielded many more questions than answers. However, it has established that frazil ice in the Big Hole Pool of the Northwest Miramichi River is a common phenomenon throughout the winter, with greatest accumulation occurring in the main flow, deepest sections of the pool. The implications of such ice events on the overwintering fishes, and the biological community in general, remain largely speculative at present. Further research to elucidate the environmental aspects of frazil ice dams in pools is sorely needed to assure proper management and protection for those species overwintering in such habitats.

ACKNOWLEDGMENTS

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DISCUSSION

Rick Cunjak:

Regarding the 1987/88 freeze-up at Nicola outflow, was there any attempt to follow-up and determine impact by sampling area to establish emergence survival of eggs in redds.

Reply:

No, but a good idea for future work and follow-up studies.