Ice conditions in the Southwest Miramichi River and its possible influence on winter movement of post-spawned Atlantic salmon

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ABSTRACT

Despite the importance of winter ecology for Atlantic salmon, very little is known about the distribution and habitat preferences of fish in winter. Surface and frazil ice conditions in rivers could limit suitable areas for overwintering of fish. The objectives of the present study were to a) monitor winter ice conditions in a salmon pool the Southwest Miramichi River, and b) to monitor movements of radio-tagged 1SW (one-sea-winter; grilse) Atlantic salmon kelts in both the Little Southwest Miramichi and Southwest Miramichi rivers in relation to ice.

The surface ice condition increased from early January to late March in winter of 1996/97 while the discharge decreased for the same period. In the monitoring of frazil ice accumulation in the Miramichi this winter, it was observed that salmon pools had variable conditions. In fact, very little frazil ice accumulation was found in Black Brook Pool compared to significant accumulation in Big Hole Pool (Northwest Miramichi River). This contrast in frazil ice accumulation is believed to be due to a combination of river depths, slopes and ultimately water velocities which influence the probability of occurrence of frazil generation zones.

The majority of 1SW Atlantic salmon kelts from the middle and lower reaches of the Miramichi River overwintered below the head of tide and they move here very early in winter prior to river freeze-up. Distances that kelts moved under river ice-cover were six times greater for kelts overwintering below the head of tide in comparison to kelts overwintering above this region of the river. Kelts from the upper study pool in the Southwest Miramichi River were found to move the greatest distances downstream to overwinter in comparison with kelts from the lower study pool. However, 60 % of kelts from the upper pool in contrast to 75 % of kelts from the lower pool overwintered below the head of tide.

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INTRODUCTION

Environmental aspects of river ice are largely unknown despite the acknowledged importance of ice as a critical factor affecting winter habitat and winter survival of fishes (see reviews by Prowse and Gridley 1993; Scrivener et al. 1994; Cunjak 1996). Frazil ice is a form of ice that typically forms in fast-flowing, shallow, open reaches of rivers once the water becomes super-cooled (Beltaos 1995 and Tsang 1982). Such ice shows many unique qualities in winter that can affect the suitability and availability of fish habitat (Power et al. 1993; Brown and Mackay 1995).

Frazil ice is often displaced downstream with the stream current and accumulates in deep main river pools where the velocities are substantially reduced. Changes in stream-flow patterns resulting from frazil ice deposition can potentially affect fish habitat availability. For example, Cunjak and Caissie (1994) observed a "hanging dam" of frazil ice, which occupied >80% of a large pool (maximum depth = 9m) in the Northwest Miramichi River. They speculated on the implications for overwintering fish, but no direct observations of fish behaviour relative to the frazil mass were carried out, and no other pools were investigated to determine the extent of this phenomenon. More recently, Komadina-Douthwright et al. (1997) conducted ice surveys at three pools in the Northwest Miramichi River and found that frazil ice was also a common phenomena in these pools. Their study showed that the majority of radio-tagged Atlantic salmon (*Salmo salar*) kelts moved downstream below head of tide prior to freeze-up.

After spawning in autumn, many Atlantic salmon remain in the river to overwinter before moving seaward in the spring (Scott and Scott 1988). Little is known about the habitat requirements and behaviour of this life-stage (kelt) although significant percentages of multiple spawners are found in Atlantic rivers, particularly since the reduction of commercial fisheries for salmon in 1984 (Moore et al. 1995). In the Miramichi River, multiple spawners represent 30% - 40% of the large salmon returns to the system (Chaput et al. 1994) where they can contribute >40% of the total egg deposition (Moore et al. 1995). Therefore, a further understanding of the physical environmental conditions in winter, habitat use and movements of Atlantic salmon kelts could help to ensure protection of this valuable resource.

The objectives of this study were (1) to quantify temporal and spatial accumulation of surface and frazil ice in one salmon pool in the Southwest Miramichi River, and (2) to monitor movements of radio-tagged Atlantic salmon kelts in both the Little Southwest and Southwest Miramichi Rives.

MATERIALS AND METHODS

Study Area:

Ice surveys were carried out at Black Brook Pool in the Southwest Miramichi River which was selected based on a combination of depth (> 2 m), and winter accessibility. It is also well-

known within the sport fishing community and such physical information was much valued for the overall understanding of ice processes and overwintering of salmon.

Black Brook Pool (47°02.4'N, 65°50.3'W) is believed to be one of the largest and deepest pool in the Southwest Miramichi River (Figure 1). This pool has water depths > 4 m, pool width of approximately 100 m, and an overall length of 600 m yielding, an estimated pool volume of more than 180,000 m^3 with and average depth of approximately 3 m. This pool is also believed by local residents to be an area where Atlantic salmon kelts overwinter. Black Brook Pool is located approximately 10 km upstream of Town of Blackville (Figure 1).

Tracking of radio-tagged Atlantic salmon kelts were carried out with captured, tagged and released fish at two pools in the Southwest Miramichi River (Green Rock Pool and Black Brook Pool) and in the Little Southwest Miramichi River (Catamaran Brook).

Ice surveys:

Four ice surveys were carried out at approximately three week intervals beginning in the middle of January after a stable ice cover and ending at the end of March 1997. Three primary transects were established over the deepest section of the pool and a minimum of ten holes (20 cm diameter) were drilled through the ice at 5 m intervals across the width of the pool. Subsequent surveys radiated 1 meter left, right, upstream and downstream of the primary hole to avoid drilling in the same hole twice. The following measurements were made at each hole on each of the surveys: (1) snow-depth, (2) depth of frazil ice (3), thickness of surface ice, (4) hydrostatic pressure, (5) depth of water beneath ice, (6) water surface elevation, and (7) mid-water velocities.

Snow depth was measured from the top of the snow to the top of the surface ice. Frazil ice measurements were made by using a scooping pole with a flat plate fastened to one end that was lowered into the water. While twisting the pole, the plate would offer resistance when it was lowered through frazil ice. Once resistance was no longer encountered, the depth of frazil was recorded. Surface ice thickness was measured by scraping the plate down the side of the hole until the under-side of the ice was encountered. All measurements were taken in reference to the water surface that upwelled into the holes after drilling. This value, also referred to as the static level, was either a negative or positive value depending on the hydrostatic pressure. A negative value would indicate that the water level was above the elevation of the surface ice. Water depth was measured as the amount of water beneath the ice (surface and frazil). The distance from the water surface to the ice surface was also measured to complete the ice thickness.

In open water situations mean water velocities are normally taken at 0.6 of the total water depth. However, in winter because of frictional forces from both the stream-bed and undersurface of ice, mean water velocity was observed to be at mid-water depth and 0.88 % of measured velocity (Pelletier 1988). In this study we measured maximum water velocity at mid-depth of the water column beneath ice using a model 201D Marsh McBirney meter.

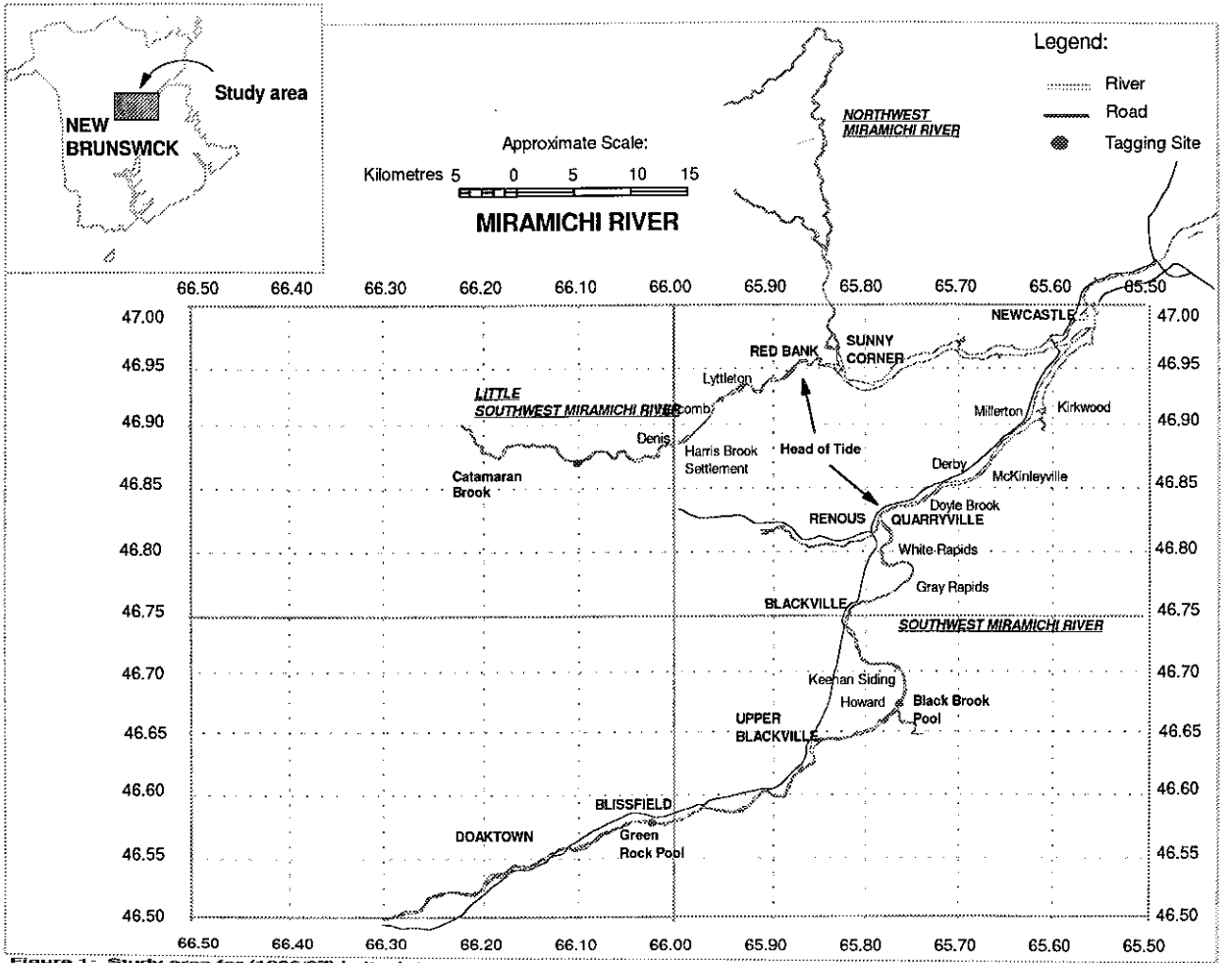

Figure 1 - Study area for (1996/97) kelt winter movement study carried out in the Miramichi River.

In order to investigate the presence/absence of frazil ice at different locations throughout the Southwest Miramichi River system, a survey was carried out on March 19, 1997 from Boiestown (25 km upstream of Doaktown; Figure 1) to above Blackville at Black Brook Pool. During this survey, the information collected was similar to the pool survey, however, to maximize the number of sites visited only three holes were drilled per sites at approximately 1/3 of the river width. In total, 4 sites were visited; Hayesville, Porter Cove, Priceville, and Doaktown.

Radio-tracking of Atlantic salmon kelts:

Radio-tags were purchased from Advanced Telemetry Systems (ATS) and were standard circuit transmitters with frequencies ranging from 150.392 MHz to 150.993 MHz, a pulse rate of 55 pulses per minute (ppm), pulse width of 21 milliseconds (ms), battery life of 300 days, weight of 20 grams (in air), diameter < 2 cm and an overall length of approximately 5 cm, of which the last 2 cm tapered to a diameter of < 1 cm. Tags were powered by a 3 volt lithium battery that was encapsulated in a non-toxic resin which tapered to a 25 cm flexible wire coated antenna. The receiver was a Lotek Engineering Inc. Suretrack STR_1000 Programmable Scanning Receiver configured to operate over a continuous 2 MHz band frequency with a channel spacing of 1 KHz.

In total, 20 (16 grilse, 1SW and 4 multi-sea-winter, MSW) post-spawned, adult Atlantic salmon were given stomach implants of radio-tags with unique frequencies in late autumn of 1996. The radio-tag insertion device consisted of a 40 cm long section of Tygon® tubing (outside diameter 1.25 cm) and a 50 cm long section of rigid metal pipe. The metal pipe was inserted into the Tygon tube, to serve as a plunger to dislodge the tag after insertion into the stomach. The insertion device and radio-tag were dipped in 100% vegetable oil for lubrication. All tagging instruments were sterilized in Wescadine® solution prior to their use. Of the 20 fish tagged, 7 fish (5 grilse and 2 MSW) were tagged and released at Green Rock Pool, 8 fish (6 grilse and 2 MSW) from Black Brook Pool and 5 fish (all grilse) from Catamaran Brook a tributary of the Little Southwest Miramichi River.

RESULTS

Black Brook Pool ice-conditions in winter 1996/97

Data on surface and frazil ice were collected at three transects in Black Brook Pool and the results were presented for both the entire pool as well as for each of the three cross sections. The average snow depth at Black Brook Pool was 18.2 cm on January 15 and increased to 26.5 cm by February 13, then decreased again in March (22.8 cm and 22.2 cm; Table 1). During the winter period of 1996/97 the surface ice at Black Brook Pool increased from 30.7 cm in early winter to 63.6 cm during the last survey (March 25). In contrast to ice thickness, which was greater at the end of the season, the maximum depth of frazil was observed in early winter at 71.0 cm. Frazil was only present during 2 of the 4 surveys at Black Brook Pool (Table 1). Water depth at Black Brook Pool decreased as the winter season progressed and this was largely due to reduced discharge (water level) over the winter period.

Table 1. Average surface ice condition at Black Brook Pool within the Miramichi River basin in winter of 1997.

Date	Snow (cm)	Ice (cm)	Depth of frazil Maximum (cm)	Water Depth (m)
		Black Brook Pool (all sections)		
Jan 15	18.2	30.7	71.0	2.39
Feb 13	26.5	53.8	-	1.42
Mar 04	22.8	59.8	36.0	1.38
Mar 25	22.2	63.6	-	1.29
		Upstream Section		
Jan 15	19.4	33.4	71.0	2.11
Feb 13	28.1	53.2	-	1.22
Mar 04	28.4	54.2	-	1.25
Mar 25	25.7	57.2	-	1.13
		Central Section		
Jan 15	17.4	32.1	35.0	2.37
Feb 13	27.4	54.3	-	1.42
Mar 04	23.3	62.5	36.0	1.32
Mar 25	24.9	68.1	-	1.27
		Downstream Section		
Jan 15	17.8	26.6	23.0	2.69
Feb 13	24.1	54.1	-	1.63
Mar 04	16.7	62.5	-	1.57
Mar 25	16.0	65.5	-	1.48

At the transect level, frazil was only present at the upstream and downstream sections in January (Table 1). The location of frazil ice accumulation for the upstream section was dominant on the TL bank as shown in Figure 2a. For the downstream section, the frazil was present at a few locations in the centre and TR bank (Figure 2c). For the centre cross section, frazil ice accumulation was present both in January and March with similar maximum depth of frazil at approximately 35 cm (Table 1 and Figure 2b). Also for the centre cross section, the snow depth on March 04 was more concentrated on the TR bank (Figure 2b). The maximum depth of water observed at Black Brook Pool was measured at the downstream section at 3.84 m (hole 0+50) on January 15 (Figure 2c).

Discharge at the Blackville gauging station (approximately 10 km below Black Brook Pool) showed decreasing values as the winter season progressed. During the January 15 survey, discharge was estimated at 66.4 m^3/s in comparison to half this value (31.3 m^3/s) on March 25, 1997 (R. Lane, Environment Canada, pers. comm.). These changes in water discharge rates influenced the water velocities in the pool among surveys. For instance, higher velocities were observed in early winter and decrease thereafter. The velocity distribution for each transect showed that maximum mid-depth water velocities occurred in the middle portion of the river (Figure 3). It was observed that the highest water velocities were measured during the early part of the winter on February 13, 1997 (the first survey for which the velocities were carried out). During this survey, maximum velocities of 0.7 m/s were measured at the upstream section and water velocities greater than 0.6 m/s were found in the central section (Figure 3). The downstream section showed the lowest water velocities which was consistent with greater water depth at this location. Water velocities distribution results showed that a similar pattern in velocities was maintained throughout the winter season for each cross section of the pool.

A survey was carried out at Big Hole Pool (Northwest Miramichi River) on January 22, 1997 to compare frazil ice accumulation results to those observed in Black Brook Pool. In contrast to the small amount of frazil ice observed at Black Brook Pool, the conditions at Big Hole were very similar to those observed in previous year with > 5 m of frazil ice in a good portion of the pool (see hole 0+20, 0+30 and 0+40; Figure 4). The maximum depth of frazil was measured at 7.0 m in hole 0+20. At Black Brook Pool the surface and frazil ice accumulation during the January survey represented < 20% of the pool volume while conditions at Big Hole Pool were > 80% of the pool volume during the same month.

Radio-tracking of Atlantic salmon kelts

Before ice-cover

All kelts that overwintered below the head of tide made their way to this region of river early in winter prior to the formation of a permanent winter ice-cover. Kelts after first being released generally held their positions for a number of days (between 2 and 7 days), but on November 11, 1996 (5th tracking event) water levels were elevated as a result of heavy rains in the rivers headwater and all but one kelt (fish #11; MSW ripe female at Green Rock Pool) descended the rivers (Table 2a). Average downstream movement

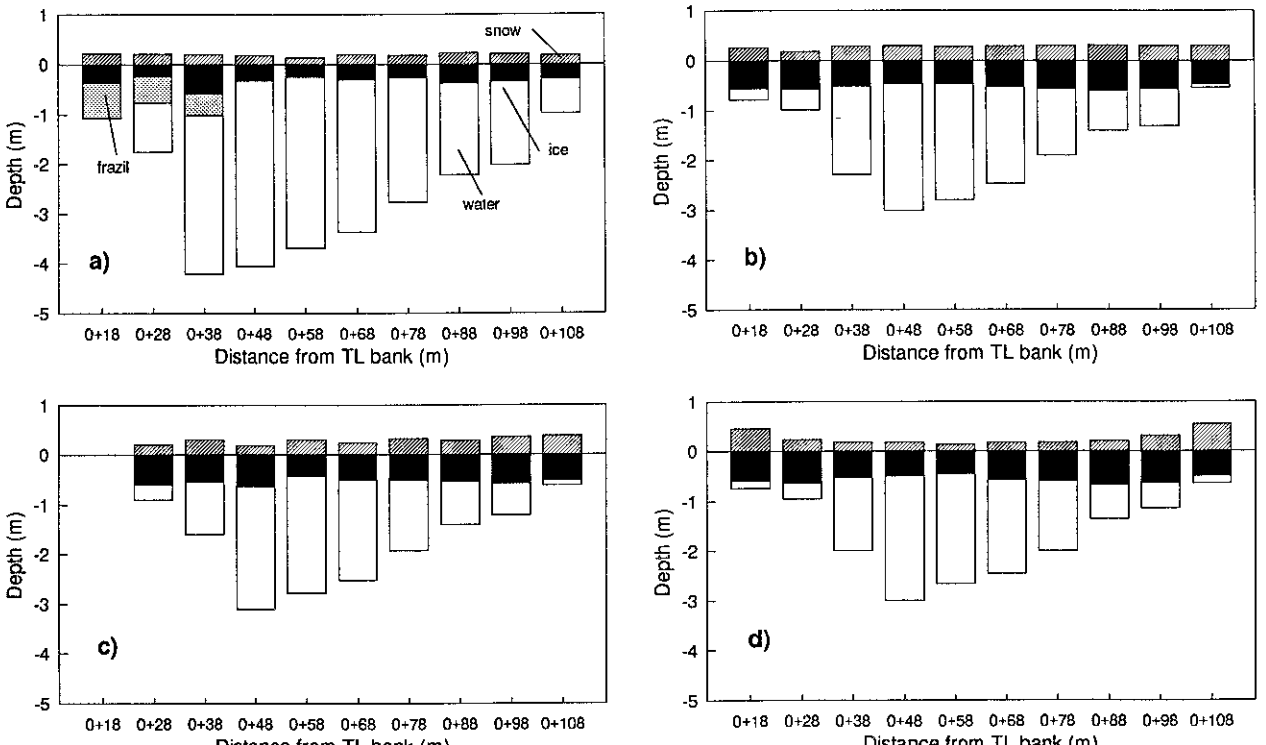

Figure 2a. Distribution of surface and frazil ice at the upstream cross section at Black Brook Pool in winter of 1996/97. a) January 15; b) February 13; c) March 04; d) March 25; TL=True Left

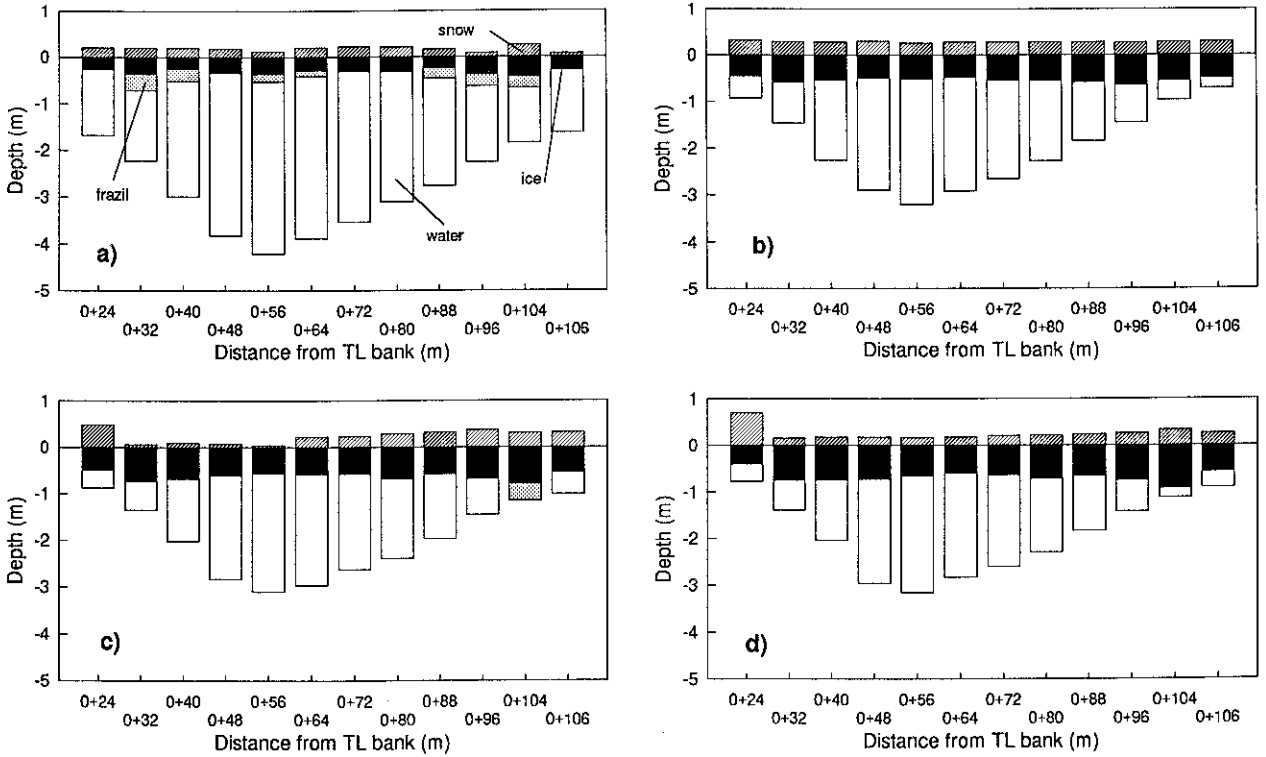

Figure 2b. Distribution of surface and frazil ice at the central cross section at Black Brook Pool in winter of 1996/97. a) January 15; b) February 13; c) March 04; d) March 25; TL = True Left

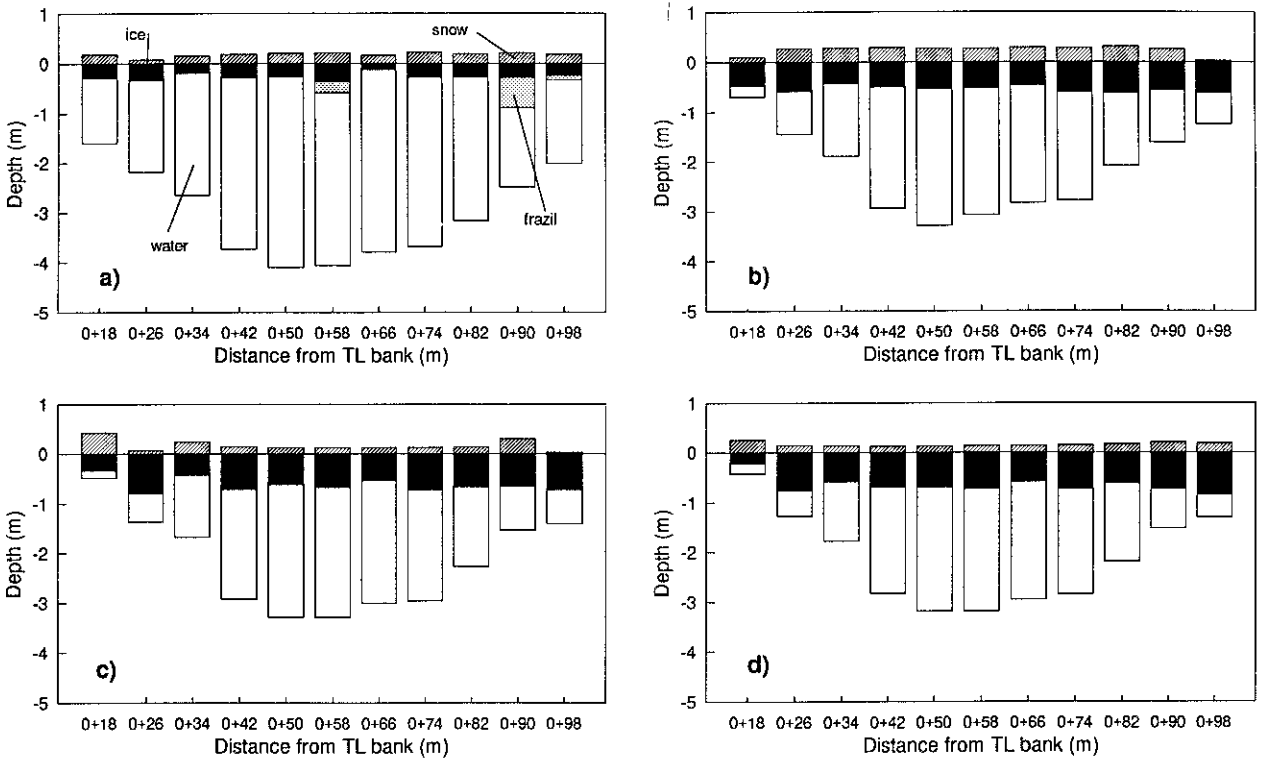

Figure 2c. Distribution of surface and frazil ice at the downstream cross section at Black Brook Pool in winter of 1996/97. a) January 15; b) February 13; c) March 04; d) March 25; TL=True Left

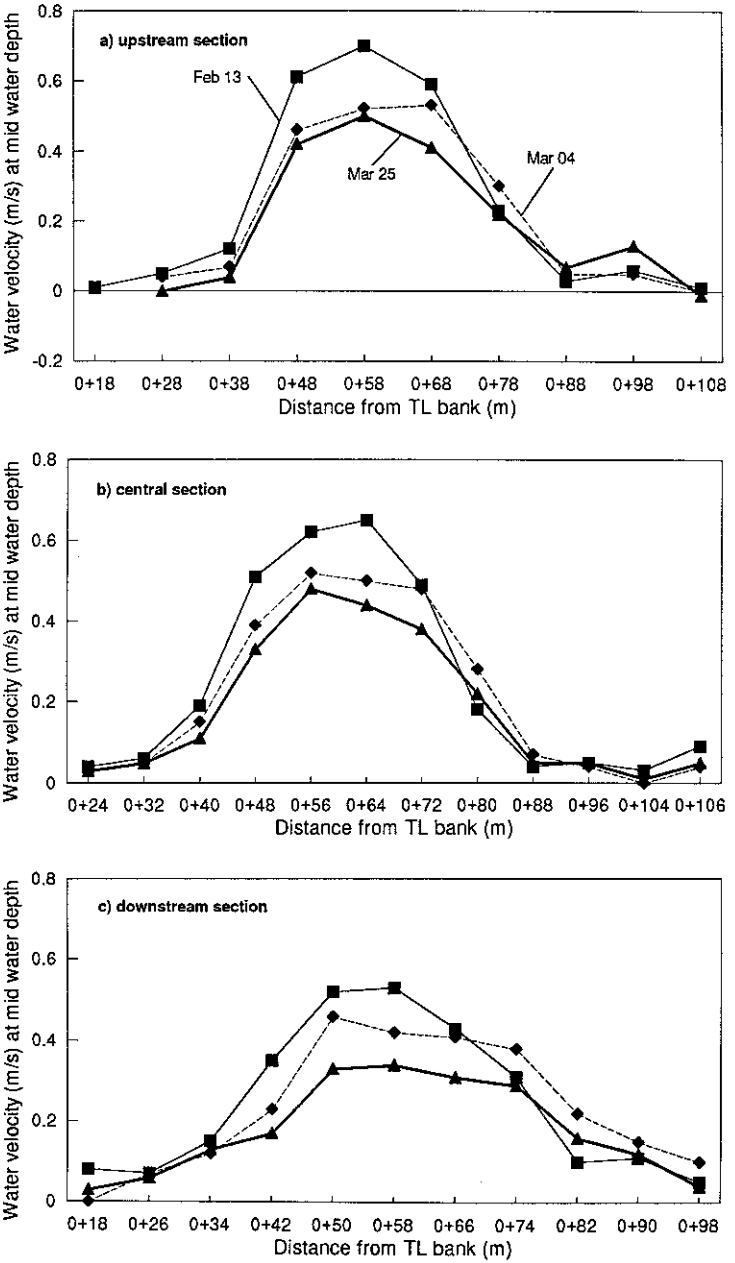

Figure 3. Velocity distribution at mid-water depth under the ice cover at Black Brook Pool in winter of 1996/97

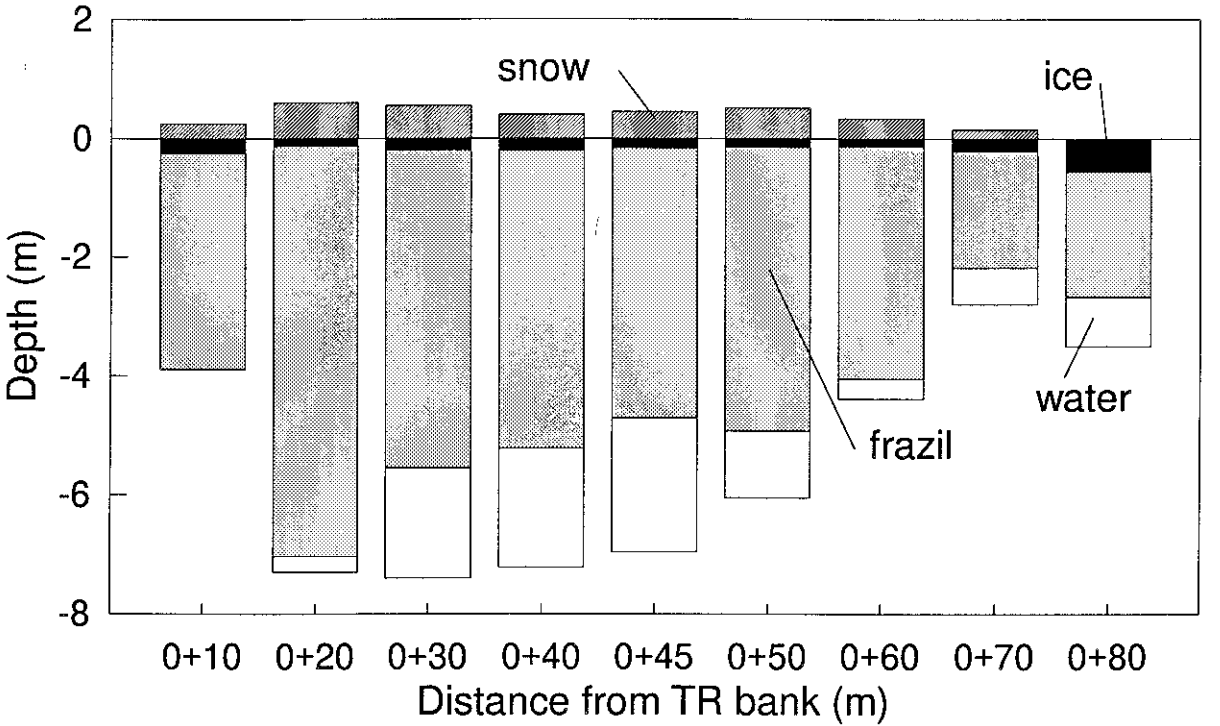

Figure 4. Distribution of surface and frazil ice at Big Hole Pool (Northwest Miramichi River) on January 22, 1997.

Table 2a : Net distance travelled (kilometres) by radio-tagged Atlantic salmon kelts from the Little Southwest and Southwest Miramichi Rivers, N.B. before winter (1996/97) ice-cover. Heavily outlined values indicate when kelts first appeared below the head of tide.

		Tracking event date and date correlated identification number (0-39):															
	Tag	Nov. 5, 1996	Nov. 6, 1996	Nov. 7, 1996	Nov. 9, 1996	Nov. 11, 1996	Nov. 13, 1996	Nov. 15, 1996	Nov. 18, 1996	Nov. 21, 1996	Nov. 25, 1996	Dec. 2, 1996	Dec. 9, 1996	Dec. 16, 1996	Dec. 22, 1996	Dec. 30, 1996	Net movement before
Tagging site	**frequency**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	ice-cover
Catamaran Brook	(1) 150.913	-1.0	0.0			-29.8	0.0	0.0	-2.0		0.5	2.2	1.0	-7.5	-4.5	-3.5	**-44.6**
	(2) 150.813		-2.0			-28.5	-0.3	0.0	-0.6		0.4	0.3	-2.4	-1.4	-2.6	2.1	**-35.0**
	(3) 150.783	-1.2	0.2			-8.2	-6.1	-0.6	-0.1		0.0	0.0	-0.6	0.0	0.0	0.0	**-16.6**
	(4) 150.663	-1.6	0.0			-11.3	-9.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-1.5	**-23.4**
	(5) 150.852	-1.7	0.0			-29.1	-2.5	0.0	0.0		-2.5	-1.0	1.5	-1.7		0.0	**-37.0**
	total	-5.5	-1.8			-106.9	-17.9	-0.6	-2.7		-1.6	1.5	-0.6	-10.6	-7.1	-2.9	
	mean	-1.4	-0.4			-21.4	-3.6	-0.1	-0.5		-0.3	0.3	-0.1	-2.1	-1.8	-0.6	
	std	0.3	0.8			9.6	3.5	0.2	0.8		1.1	1.0	1.4	2.8	1.9	1.9	
Green Rock Pool	(6) 150.573					-42.7	-1.3	0.9	0.0	-8.3	0.6	-0.4	0.0	-0.3	-0.2	0.0	**-51.6**
	(7) 150.993	-0.5	0.0	0.0		-2.2	-1.0	0.0	0.0	0.0	0.0		-20.3	-3.0			**-27.0**
	(8) 150.973	-0.5		-0.7		-3.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0				**-3.7**
	(9) 150.613	-0.1		0.0		-38.6		-15.5	-3.8	0.2	-0.2	-1.8			-4.2	0.1	**-63.9**
	(10) 150.542			-0.7			-9.1	-7.8	1.5	0.0	-1.0	-1.9	-11.1	-13.1	-1.6	-7.2	**-52.0**
	(11) 150.722					0.0	0.0	2.3	-3.5	0.0	0.0	0.0	0.0		0.0	1.2	**0.0**
	(12) 150.892					-26.3		-7.6	0.0		0.0	-1.2	0.0	0.0	-0.7	0.0	**-35.8**
Black Brook Pool	(13) 150.483					-4.4	-4.5	-0.5	-1.0	-1.1	-1.4	-0.5	-10.2	-6.0	0.0	-3.6	**-33.2**
	(14) 150.952						-27.9	-0.7		0.0		-3.0					**-31.6**
	(15) 150.632					-11.6	-1.7	0.0			-0.6	0.0	0.0	-2.2	0.0	2.8	**-13.3**
	(16) 150.831					-3.4		-4.5	-3.0	-0.5	-13.0			-11.7	0.1	-1.0	**-37.0**
	(17) 150.933					-1.4	-0.4	-1.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	**-2.6**
	(18) 150.422					-9.5	0.0	0.0	0.0	0.0	-0.5	-0.8	-13.8	0.2	0.0	-0.6	**-25.0**
	(19) 150.870					-18.3	-5.5	-1.1	-1.6	-3.5		-4.5					**-34.5**
	(20) 150.392					-14.0	-2.3	-0.8	-0.5			-7.7	-2.6	0.0	0.0		**-27.9**
	total	-1.1	0.0	-1.4		-175.4	-53.7	-35.8	-11.8	-13.2	-16.1	-21.7	-56.0	-36.1	-6.6	-8.3	
	mean	-0.4	0.0	-0.4		-13.5	-4.5	-2.4	-0.9	-1.1	-1.3	-1.7	-5.3	-3.6	-0.6	-0.8	
	std	0.2	0.0	0.4		13.7	7.5	4.5	1.5	2.4	3.6	2.2	6.9	4.8	1.2	2.6	
Combined	**TOTAL**	-6.6	-1.8	-1.4		-282.3	-71.6	-36.4	-14.5	-13.2	-17.7	-20.2	-56.5	-46.7	-13.7	-11.2	
	MEAN	-0.9	-0.3	-0.4		-15.7	-4.2	-1.8	-0.8	-1.1	-1.0	-1.1	-3.7	-3.1	-0.9	-0.7	
	STD	0.6	0.8	0.4		13.2	6.6	4.0	1.4	2.4	3.1	2.1	6.3	4.3	1.5	2.4	

during this event was calculated at 15.7 km per kelts with a maximum movement of 42.7 km (fish #6; Green Rock Pool). Three of the five kelts from Catamaran Brook were also located > 3 km below the head of tide on this date.

As the season progressed more and more kelts were observed below head of tide. For instance, on November 13, 1996 the first fish from Black Brook Pool (fish #14) was observed below head of tide. On the next tracking event (Nov. 15) the first fish from Green Rock Pool (fish #9) was observed below head of tide (Table 2a). On this date (Nov. 15, 1996) the Southwest Miramichi River was frozen below Quarryville (Figure 1) and approximately 70% of the river upstream was filled with pancake ice. General movements of kelts decreased over the next tracking events and five more kelts were observed below head of tide by the end of December. Combined kelt movements decreased to < 20 km (mean of 0.6 km) downstream from December 22, 1996 to December 30, 1996 and the last of 12 of 20 kelts were located below the head of tide (fish #10 from Green Rock Pool; Table 1a).

During ice-cover

On the 16th tracking event (January 7, 1997) a permanent winter ice-cover was formed on both rivers (Little Southwest and Southwest Miramichi Rivers). Combined distances (total distance) moved by kelt from the tracking events occurring from January 7, 1997 until March 27, 1997 were < 8 km per tracking event (Table 2b). The majority of kelt movements that occurred during the ice-covered period of winter were from the kelts that overwintered below the head of tide (Table 2b). Range of distances moved by kelts above the tide head were from 0 km to 0.8 km downstream and for kelts below the head of tide were between 2.5 km upstream and 10 km downstream (Table 2b). It was calculated that six times more net movements occurred on average for kelts overwintering below the head of tide in comparison to kelts that overwintered further up river.

During ice-melt and ice break-up in the rivers

From April 4, 1997 until May 3, 1997, kelts moved a combined distances of < 10 km (mean value < 1.2 km), but did increase marginally toward the last few dates of tracking (Table 2c: boxed numbers in this table indicates when kelts were no longer under ice-cover). For example, fish #12, #15 and #17 were among the first fish to be in open water on April 23, 1997. On April 27, 1997, the Southwest Miramichi River was completely open. By the end of the study period, all but one fish was in open water condition. Fish #4 was still under ice-cover at the end of the study period, but it moved into an ice-covered backwater bogan area away from the open water river channel that was carrying large chunks of fast-moving ice.

Location that kelts overwintered in relation to head of tide:

Sixty percent of kelts (3/5) that were radio-tagged and released in Catamaran Brook (approximately 27 kilometres above the head of tide in the Little Southwest Miramichi

Table 2b: Net distance travelled (kilometres) by radio-tagged Atlantic salmon kelts from the Little Southwest and Southwest Miramichi Rivers, N.B. under winter (1996/97) ice-cover.

		Tracking event date and date correlated identification number (0-39):													
	Tagging site and tag	Jan. 7, 1997	Jan. 12, 1997	Jan. 20, 1997	Jan. 27, 1997	Feb. 4, 1997	Feb. 8, 1997	Feb. 12, 1997	Feb. 19, 1997	Feb. 27, 1997	Mar. 5, 1997	Mar. 12, 1997	Mar. 20, 1997	Mar. 27, 1997	Net movement during ice-cover
Tagging site	frequency	16	17	18	19	20	21	22	23	24	25	26	27	28	
Catamaran Brook	(1) 150.913	3.2	-3.2	1.0	lost tag										1.0
	(2) 150.813	0.7	0.4	-2.0	-1.6	0.0		0.4	-0.3		0.6	0.0	-1.9		-3.7
	(3) 150.783				0.2	-0.2		-1.0	0.0	0.0	0.2	0.0	0.0	0.0	-0.8
	(4) 150.663			-0.2	-0.1	0.0		0.0	0.0	0.0	0.0	0.1	0.0	0.0	-0.2
	(5) 150.852		-1.0	-1.5	1.0	0.7		-0.7		3.0	1.0	0.0	-1.0	0.0	1.5
	total	3.9	-3.8	-2.7	-0.5	0.5		-1.3	-0.3	3.6	1.8	0.1	-2.9	0.0	
	mean	2.0	-1.3	-0.7	-0.1	0.1		-0.3	-0.1	1.0	0.5	0.0	-0.7	0.0	
	std	1.3	1.5	1.2	0.8	0.3		0.6	0.1	1.4	0.4	0.0	0.8	0.0	
Green Rock Pool	(6) 150.573	0.4	-1.8	-2.3	0.0	-0.8		-0.2	0.0	0.0	0.2	0.0	0.8	-0.3	-3.9
	(7) 150.993	0.0													0.0
	(8) 150.973	lost tag													0.0
	(9) 150.613	0.0	0.0	0.0	0.0	-0.2	-0.4	-0.8	0.0	0.0	0.0	0.0	0.0	-1.0	-2.4
	(10) 150.542	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	-2.6	2.1	-0.3	0.3	-0.2	-1.7
	(11) 150.722	2.5	lost tag												2.5
	(12) 150.892	0.7	0.0	0.0	0.0	0.0		-0.5	-0.2	-0.2	0.0	0.0	0.0	-0.1	-0.3
Black Brook Pool	(13) 150.483	-0.7	0.0		-1.7	-6.0	0.4	-2.0							-10.0
	(14) 150.952														0.0
	(15) 150.632	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(16) 150.831	-1.0		0.5	0.0	-0.9	-0.9	2.1	0.0	0.8	-1.1	1.1		-1.1	-0.5
	(17) 150.933		0.0	0.0	0.5	0.0	0.0		-0.3	0.0	0.0	0.0	0.0	0.0	0.2
	(18) 150.422	0.2	0.0	-0.2	0.4	0.0	0.0	-0.2	0.2	0.4	0.0	0.2	0.0	0.0	1.0
	(19) 150.870														0.0
	(20) 150.392	-2.8	0.0	0.0	-0.7	1.3		-0.3	-0.3	-0.2	-0.3	-0.6	-0.4	0.0	-4.3
	total	-0.7	-1.8	2.0	-1.5	-7.8	-0.9	1.9	-0.6	-1.8	0.9	0.4	-0.7	-2.7	
	mean	-0.1	-0.2	-0.2	-0.2	-0.8	-0.1	-0.2	-0.1	-0.2	0.1	0.0	0.1	-0.3	
	std	1.2	0.5	0.7	0.6	1.9	0.4	1.0	0.2	0.9	0.8	0.4	0.3	0.4	
Combined	TOTAL	3.2	-5.6	-4.7	-2.0	-7.1	-0.9	3.2	-0.9	1.2	2.7	0.5	-2.2	-2.7	
	MEAN	0.2	-0.4	-0.4	-0.1	-0.5	-0.1	-0.2	-0.1	0.1	0.2	0.0	-0.2	-0.2	
	STD	1.4	1.0	0.9	0.7	1.6	0.4	0.9	0.2	1.2	0.7	0.4	0.7	0.4	

Table 2c: Net distance travelled (kilometres) by radio-tagged Atlantic salmon kelts from the Little Southwest and Southwest Miramichi Rivers, N.B. during the spring of 1997 and total accumulative movements for the 1996/97 study period. Thick division line shows when kelts were no longer under ice-cover.

		Tracking event												
	Tagging site and tag	Apr. 4, 1997	Apr. 9, 1997	Apr. 14, 1997	Apr. 18, 1997	Apr. 21,19 97	Apr. 23, 1997	Apr. 25, 1997	Apr. 27, 1997	Apr. 28, 1997	Apr. 30, 1997	May 3, 1997	Net movement during ice-melt	Total movement during study
Tagging site	frequency	29	30	31	32	33	34	35	36	37	38	39		
Catamaran Brook	(1) 150.913	lost tag											0.0	-43.6
	(2) 150.813	2.0		-1.3	0.1		-0.5	1.5	0.2	0.0	0.0	-0.3	1.7	-37.0
	(3) 150.783	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	-3.2	-3.4	-20.8
	(4) 150.663	0.0	-0.3	0.5	0.1	-0.6	-0.1	-0.2	0.1	0.0	0.0	-0.8	-1.3	-24.9
	(5) 150.852	-0.9	0.0	-0.3	-0.9	0.8	0.6	-1.7	0.4	0.8	-0.2	0.4	-1.0	-36.5
	total	1.1	-0.3	-1.1	-0.7	0.2	-0.2	-0.4	0.7	0.8	-0.2	-3.9		
	mean	0.2	-0.1	-0.3	-0.2	0.1	-0.1	-0.1	0.2	0.2	-0.1	-1.0		
	std	1.0	0.1	0.7	0.4	0.6	0.4	1.1	0.1	0.3	0.1	1.4		
Green Rock Pool	(6) 150.573	1.5	0.0	-1.0	0.3	-0.4	0.1	0.0	-2.7	0.0	0.0	0.0	-2.2	-57.7
	(7) 150.993												0.0	-27.0
	(8) 150.973	lost tag											0.0	-3.7
	(9) 150.613		-0.9	-1.0	-0.9	-0.1	-0.3	-2.7	0.3	-2.5			-8.1	-74.4
	(10) 150.542	-0.6		-0.8	0.8	-2.2	0.0		-2.0	-5.0	-0.3	-3.3	-13.4	-67.1
	(11) 150.722	lost tag											0.0	2.5
	(12) 150.892	-0.1	0.0	0.0	0.0	0.0	-0.3	0.1	-0.5	0.0	0.5	0.2	-0.1	-36.2
Black Brook Pool	(13) 150.483												0.0	-43.2
	(14) 150.952												0.0	-31.6
	(15) 150.632	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-13.3
	(16) 150.831	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-1.0	-0.2	-1.8	-2.7	-40.2
	(17) 150.933	0.0	0.0	0.0	0.0	0.0	0.3	-0.3	-0.1	0.0	0.5	0.4	0.8	-1.6
	(18) 150.422	0.0	0.0	0.0	0.0	-0.2	0.0	-0.2	-0.2	0.0	0.0	-1.2	-1.8	-25.8
	(19) 150.870												0.0	-34.5
	(20) 150.392	0.0	-0.2	0.1	-0.1	-0.5	-0.1	0.0	-1.0	-1.2	0.0	-4.1	-7.1	-39.3
	total	1.0	-1.1	-2.7	0.1	-3.4	-0.0	-3.1	-5.2	-9.7	0.5	-9.6		
	mean	0.1	-0.1	-0.3	0.0	-0.4	-0.0	-0.4	-0.7	-1.1	0.1	-1.2		
	std	0.5	0.3	0.5	0.4	0.7	0.2	0.9	1.0	1.6	0.3	1.6		
Combined	TOTAL	2.1	-1.4	-3.8	-0.6	-3.2	-0.4	-3.5	-5.5	-9.0	0.3	-15.7		
	MEAN	0.1	-0.1	-0.3	-0.0	-0.3	-0.0	-0.3	-0.4	-0.7	0.0	-1.1		
	STD	0.7	0.3	0.5	0.4	0.7	0.3	1.0	0.9	1.5	0.2	1.5		

River) overwintered an average of 12 kilometres below the head of tide in the river (Figure 5). At Green Rock Pool, located approximately 50 kilometres above the head of tide in the Southwest Miramichi River, 3 kelts from this pool overwintered at an average of 16 km below head of tide. At Black Brook Pool, located approximately 25 km above the head of tide, 6 kelts (75 % or 6/8 of the study kelts from this pool) from this pool overwintered at or below head of tide (Figure 5). Combined percentage of the study kelts that overwintered below the head of tide were 65% for both rivers, 60 % (3/5) for Catamaran Brook (i.e. Little Southwest Miramichi River) and 70 % (9/13) of study kelts from the Southwest Miramichi River.

DISCUSSION:

Results of frazil ice accumulation at Black Brook Pool showed that this pool was less affected by frazil ice than those pools surveyed in previous studies in the Miramichi River system, namely Big Hole Pool in the Northwest Miramichi River system (Komadina-Douthwright et al. 1997). In fact, only two of the four surveys carried out at Black Brook Pool during the winter of 1996/97 showed a presence of frazil ice. To make sure that this small accumulation of frazil ice at Black Brook Pool was not due to a mild winter, a survey was carried out at Big Hole Pool (Northwest Miramichi River) on January 22, 1997. The results at Big Hole Pool showed that the winter of 1997 had similar ice conditions that were observed in previous year in that frazil ice accumulation occupied most of the pool (> 80%). In contrast, frazil ice at Black Brook Pool occupied < 20% of the pool volume. This suggest that pools within the Miramichi River basin can be affected differently depending on their locations. Different sites throughout the Southwest Miramichi River were further studied on March 19, 1997 for estimating the extent of frazil ice accumulation in this river.

This survey was carried out from above Boisetown at Hayesville (upper basin of the Southwest Miramichi River) to Doaktown. The results of this survey indicated that frazil ice in the up river was as abundant as Big Hole Pool in the Northwest Miramichi River. For many locations in the upper basin, the frazil ice was grounded (from surface ice to the river bottom) showing similar conditions observed by (Komadina-Douthwright et al. 1997). Also observed in the upper reach of the Southwest Miramichi River, was open water areas with steeper slopes and faster velocities and these areas were presumably frazil ice generation (source) areas. As our survey progressed in the downstream direction near Doaktown, frazil ice accumulation was not as abundant. It can be hypothesized that for larger rivers such as the Southwest Miramichi River, frazil ice is more predominant in the upper basin.

Despite the inter-annual differences in ice formation, our study demonstrated that some salmon pools seemed to be more prone to large frazil ice accumulation (Black Brook Pool, Southwest Miramichi River) than others (Big Hole Pool, Northwest Miramichi River). For those pool where the frazil ice was present, these masses often dominate the volume of these pools and may at times were in direct contact with the pool bottom, especially in the middle, deeper sections and persist throughout the winter (Komadina-Douthwright et al. 1997). The habitat suitability of these pools for overwintering fish such as adult salmon could be directly influenced by such ice. The present study also demonstrated that even when frazil ice was

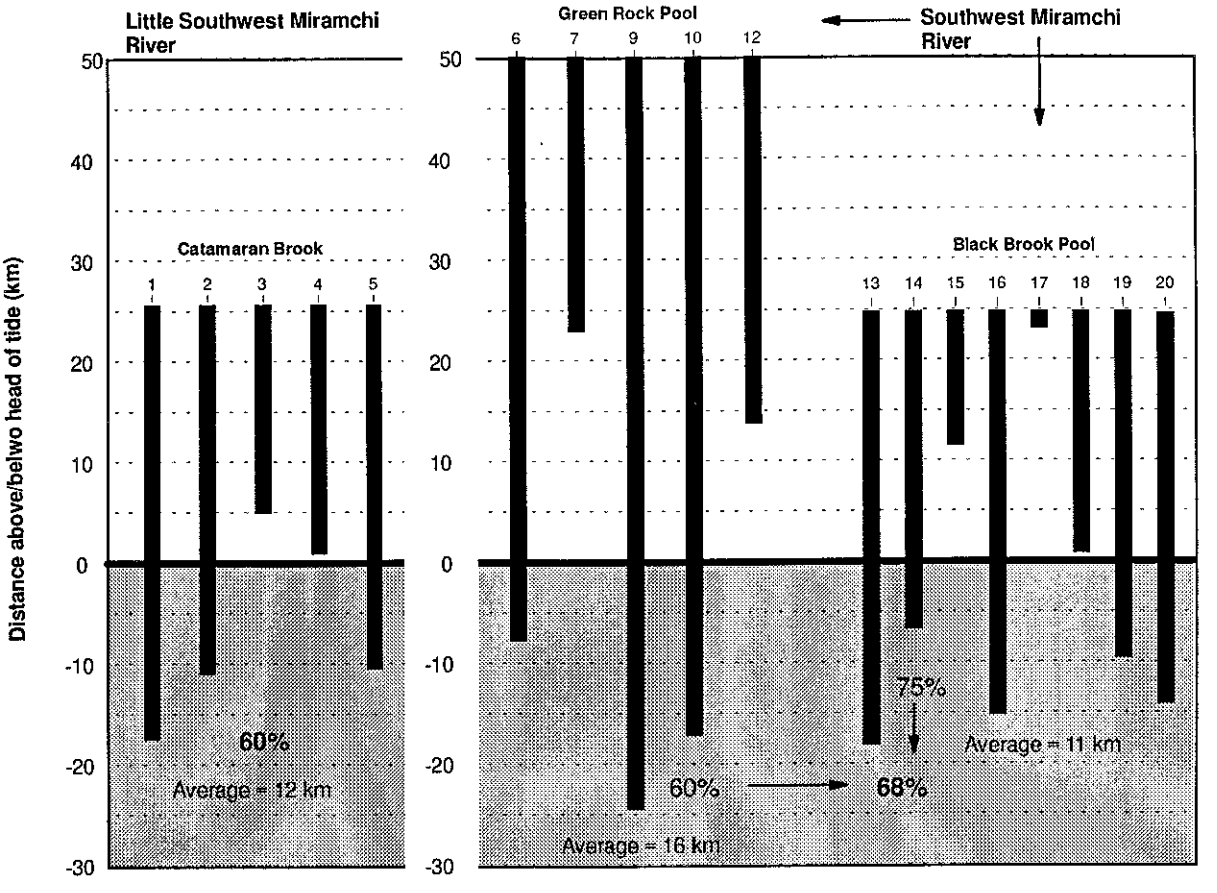

Figure 5: Vertical bars represent distances that kelts moved downstream during winter (1996/97) toward head of tide in the Little Southwest and Southwest Miramichi River in relation to pools where they were captured/radio-tagged and released. Shaded region represents the region below head of tide. Percentages are the portion of kelts that overwintered below head of tide and average values are distances below the head of tide where kelts from each pool overwintered

absent from some pools, such as Black Brook Pool, those pools may not necessarily be more attractive to overwintering kelts.

During the winter of 1996/97 a significant number of kelts moved to overwinter below the head of tide. One of the kelts from Green Rock Pool moved greater than 70 km downriver to overwinter below the head of tide. Apparently, the lower reaches of the river were "preferred" overwintering habitats for many post-spawned salmon in the lower and mid portions of the Southwest Miramichi River, and the timing of the main movement occurs early in winter prior to complete ice cover on the river. Downstream movement of kelts was greatest prior to formation of a complete ice cover in the Southwest Miramichi River. These results were consistent with those observed by (Komadina-Douthwright et al. 1997) although that the frazil ice accumulation was different between the two river branches studied.

The downstream movement pattern is not believed to be the result of post-traumatic stress from tagging as many radio-tagged kelts remained in the same location where they were tagged/released for more than two days. Other studies showed similar results where kelts radio-tagged were found to continue their upstream spawning migration shortly after being released. Studies by Booth (1994) and Shepard from Bangor Hydro Electric, Bangor Maine, USA (pers. comm.) found radio-tagged Atlantic salmon to continue their normal migratory behaviour after being radio-tagged and released. Booth et al. (1995), in studying late-season catch and release angling of Atlantic salmon, measured minimal stress responses when salmon were captured at water temperature $\leq 6°C$. Kelts radio-tagged for the present study were captured at water temperatures within this range.

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