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Sonic tracking of North American Atlantic salmon smolts to sea: correlates of stage-specific survivals and lessons on the migration pathway

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Abstract

Multiple years of sonic telemetry of Atlantic salmon (*Salmo salar*) smolt from five Canadian rivers documented migration patterns and survivals from fresh water river release sites, through estuaries and across the Gulf of St. Lawrence to the Strait of Belle Isle (> 1000 km for some fish). These rivers included four with Greenland migratory 2 SW fish, and one in Newfoundland where the vast majority of fish mature after one year at sea. The study rivers fell on an approximately 600 km latitudinal gradient. Survival patterns of smolts were similar among years for a given river, and differed consistently among rivers over time. Heavy losses occurred in most river estuaries, although in the Miramichi and Restigouche estuaries the fractions of smolt surviving estuary transit increased as smolt run size increased, possibly indicating predator swamping. Travel rates in the Gulf were estimated as 18- 25 km/d, and survivals to the Strait of Belle Isle and travel speeds were not associated with fish body size. Significant numbers of smolts from the Miramichi, Restigouche and Cascapedia rivers passed through the Strait of Belle Isle, showing that this is an important migration pathway for fish from these rivers. The timing of the passage of fish from these rivers through the Strait was synchronized, despite different entry times into the Gulf of St. Lawrence. This may indicate that behavioral aggregation of smolts occurs from multiple populations within the first 30 days of entering the sea.

Introduction

Sonic telemetry is an evolving technology which permits researchers to document fish movement patterns and in some instances provide quantitative estimates of fish survival to various points during their migrations.

We have used sonic telemetry to document movements of North American Atlantic salmon smolts through fresh water, the estuaries of their home rivers, and in some cases across the Gulf of St Lawrence (> 800 km from the home river estuary exits). We have obtained 1-5 years of data from five rivers (the Miramichi and Restigouche Rivers in New Brunswick, the Cascapedia River on Quebec's Gaspé Peninsula, the St. Jean (North Shore) in Quebec on the North Shore of the Gulf of St. Lawrence, and Western Arm Brook (WAB) on the East Coast of Newfoundland). These rivers span an approximately 600 km latitudinal gradient. Four of the rivers have a significant component of their population that mature after two years at sea, and are Greenland migratory. By contrast, in one (WAB), virtually all fish mature after one year at sea and these fish are not believed to migrate to Greenland.

Our work permits us to evaluate if patterns observed for a given river are consistent among years, and whether differences in patterns observed among rivers are also consistent among years. Quantitative estimates of survival have been obtained for smolts from the point of release in fresh water to the start of a river's estuary (head-of-tide), and from the head-of-tide to the exit of the estuary to the sea. For some rivers we have also obtained a minimum estimate of survival from release to the Strait of Belle Isle in the Gulf of St. Lawrence. We are also able to compare the movement patterns of fish from a population that typically matures as grilse, to those from Greenland migratory 2 SW populations.

For two of the monitored rivers (the Miramichi and Restigouche Rivers), annual estimates of smolt run size are available. In one (the Miramichi River), we also have annual estimates of returning adults. We have correlated the estimates of smolt survivals generated by telemetry with these data to gain insights on the factors controlling early smolt mortality. We have also investigated the links between smolt size and: 1) the probability of survival during the ocean migration, and 2) swimming speed.

Methods

Smolts were captured in the study rivers with rotary screw fish traps and surgically implanted with VEMCO V9 sonic tags. They were then released at the point of capture in fresh water and permitted to continue their migration through the fresh water and the estuary and out to sea. Detections were made by VEMCO VR2 receiver units deployed in arrays with overlapping detection ranges across constrictions in the migration route. Arrays were configured such that tagged fish passing by them had a high probability of detection. The head of tide and exit from the estuary of the Miramichi, Restigouche, Cascapedia and Saint Jean (North Shore) Rivers in all years were fitted with arrays. For Western Arm Brook, 2007 was the first year of tagging, and the smolt capture and release site was in close proximity to the head of tide (< 1 km). The WAB estuary does not exceed 3 km in length. No receivers were placed in this river or its estuary.

Equipment was leap-frogged from southern sites to northern sites as the smolt season advanced.

Commencing in 2006, a receiver array was placed across the northern exit to the Gulf of St. Lawrence in the Strait of Belle Isle, between Green Island Cove in Newfoundland, and l'Anse au Loup, Labrador. In 2006, the array was deployed on 10-11 July. In 2007, it was placed on 17 June. For the calculations of travel times of WAB fish to the Strait of Belle Isle array, we included the length of the estuary as part of the marine pathway distance. For the other rivers, this pathway was calculated as the straight-line distance from the midpoint of the estuary-exit array to the midpoint of the Strait array.

Estimates of smolt and adult run sizes for the Miramichi and Restigouche Rivers were obtained through mark-recapture estimates as part of the annual monitoring programs undertaken by the Department of Fisheries and Oceans.

Results

Fresh water and estuary passage

We have obtained five years of data on smolt passage through fresh water and the estuary for the Miramichi River, four years for the Restigouche River, three each for the Cascapedia and St. Jean (North Shore), and one for Western Arm Brook.

Survivals of smolt from fresh water to the head of tide, and through the estuary out to sea, were generally similar among years for a given river. With the exception of the St. Jean

(North Shore) River, mortality rates were always greater in the estuary than in fresh water (Fig. 1).

For the Miramichi and Restigouche Rivers, survival through the estuary appears to be linked to the size of the smolt cohorts (Fig. 2). As smolt cohort size increased, the fraction of smolts surviving to enter the sea increased.

Gulf of St. Lawrence movements

In 2006, three fish from the Cascapedia River and four from the Restigouche River were detected after crossing the Strait of Belle Isle, 885 and 1,036 km respectively from their release points in fresh water. The first detection occurred on 10 July, the first day of receiver deployments, and the last on 20 July. These fish took an average of 33.7 days (range 25.5 – 42.3 days) to cover the 800 km from the exit of their estuary (the Baie des Chaleurs) to the Strait array. Travel rates across the Gulf of St. Lawrence averaged 22.2 km/day (range 18.9 – 31.4 km/day; Table 1), but this value may be low as we could have missed fish that crossed the Strait before the line was placed.

In 2007, deployment schedules for the Strait array were advanced, and all receivers were positioned by 17 June. Subsequently, 44 of the 277 tagged smolts from four rivers (Fig 3) were detected crossing this line. These included fish from the Miramichi, Restigouche, and Cascapedia Rivers, and Western Arm Brook. Fish from the Miramichi, Restigouche and Cascapedia Rivers crossed the line in a 10 day period (10 – 19 July). Western Arm Brook fish were more variable, with the first individual being detected on 2 July, and the last on 22 July. Travel rates for Miramichi River fish crossing the Gulf in 2007 averaged 17.9 km/day, whereas Cascapedia and Restigouche River fish moved at a rate of 22.2 km/day.

In 2007, 15%, 10% and 17% of the fish originally released in fresh water in the Miramichi, Restigouche and Cascapedia Rivers respectively, crossed the Strait of Belle Isle line. These values provide minimum estimates of the portion of fish still alive at this time in the marine migration. Some of the tagged fish from these rivers may have exited the Gulf of St. Lawrence via the more southerly Cabot Strait. An additional portion may mature as grilse and perhaps would never leave the Gulf. By comparison, in 2006, 6% of the fish released in fresh water in both the Restigouche and Cascapedia Rivers crossed the Strait array; however, as previously noted we may have been late in deploying the receivers here and consequently missed some fish.

Arrivals of fish in the Strait of Belle Isle in 2007 were highly synchronous. All detections of smolts from the Greenland migratory populations occurred between 10 and 20 July, and fish from up to four rivers moved through the Strait on the same day (Fig 4). Western Arm Brook fish were the first to log on to the Strait array and remained in the area over a longer time period than did fish from the Greenland group. WAB fish had by far the

shortest distance to cover from their release point to the Strait array (approximately 38.3 km).

Detection patterns of Western Arm Brook fish differed from those observed for the other rivers' smolts. The putative Greenland migratory fish in 2007 did not tarry in the vicinity of the Strait receivers, spending an average of 0.5h (range <0.001 -12.1 h) within detection range. By comparison, WAB fish logged on for an average of 12.6 h (range <0.001 – 75.0 h, $P < 0.04$). WAB fish also tended to be concentrated closer to shore especially on the Newfoundland side of the Strait (distance to shore of 4,827 $\pm$ 3,082 m, range 368 – 17,629 m, 93% on the Newfoundland side of the Strait, N = 14) compared to the Greenland migratory group (average distance to shore of 6,060 $\pm$ 1,805 m, range 3,440-9,518 m, 77% on Newfoundland side, N = 30). However, these differences were not statistically significant.

Fifteen percent of the Miramichi smolts released in fresh water in 2007 logged onto the Strait of Belle Isle array. For the Restigouche River, 6 % and 10% of the smolts released in fresh water were detected in the Strait of Belle Isle in 2006 and 2007, respectively. For the Cascapedia River, 6% and 17% respectively of the 2006 and 2007 fish released in fresh water were detected on the Strait array. These values are minimum estimates of survival for fish from these populations, as some individuals may have exited the Gulf of St. Lawrence via the more southerly Cabot Strait, or perhaps did not exit the Gulf if they will eventually mature as grilse.

Considering only the tagged smolts that survived to exit a given river's estuary, 23% of the survivors from the Miramichi River logged onto the Strait of Belle Isle array. For the Restigouche River, 19 % of the smolts exiting the estuary were detected in the Strait of Belle Isle in both 2006 and 2007. For the Cascapedia River 12% and 33% of the estuary survivors were detected in the Strait in 2006 and 2007, respectively. This indicates that the Strait of Belle Isle is a consistently important migration pathway for Atlantic salmon from Gulf of St. Lawrence drainages.

The mean fork lengths of the tagged smolts that arrived at the Strait of Belle Isle did not differ significantly ($P > 0.05$) from the mean fork lengths of the smolts from the same river and year that were not detected in the Strait (Table 2). This may indicate that size was not an important determinant of survival through this portion of the marine migration.

Smolt size at the time of tagging also did not appear to systematically influence the rate of travel of smolts across the Gulf of St. Lawrence. Fork lengths of the smolts from a given river at the time of release differed by as much as 30%, however, travel times to cover the distance to the Strait of Belle Isle were not correlated with size (Fig. 5).

Calculated minimum swimming speeds for post-smolts that had exited the estuary to cross the Gulf of St Lawrence and reach the Strait of Belle Isle varied from river to river, but was similar between years for the Baie des Chaleurs origin fish. In 2007 fish from the Restigouche and Cascapedia Rivers moved significantly faster than fish from the

Miramichi River (Table 2, $P < 0.05$). Western Arm Brook fish traveled at rates an order of magnitude slower than those from the other rivers. Calculated in terms of fish body lengths per sec (bl/s), mean speeds crossing the Gulf for all post smolts were < 2 bl/s (Table 1), which is well within the sustained swimming capacity determined for smolts in laboratory studies.

Discussion

Patterns of smolt survival through fresh water and the estuary were generally consistent for a given study river among years. In addition, the differences in the survival patterns among rivers were also consistent among years. There was no evidence of a systematic increase or decrease in survival in fresh water and the estuary in rivers at higher compared to lower latitudes. Data from the Miramichi and Restigouche Rivers indicate that survivals through the estuaries were higher for larger smolt classes, possibly indicating predator swamping is occurring during this phase of the migration. It is not known if smaller river systems would show similar patterns.

At this time, we have insufficient information to determine if improved smolt survival through the estuary will translate into increased numbers of returning adults. At one of our sites, the Miramichi River, adult return estimates can be related to the telemetry results. Due to the small number of years of sonic tagging here (5), and the time lags between the year of tagging and fish returns as one or two 2 SW mature individuals, at present we have only three years of returns data for grilse and two for 2 SW salmon that can be correlated back to smolt survivals. Telemetry work needs to continue at these sites to build the data set that will permit these correlations.

Significant numbers of the tagged post smolts from Gulf region, putative Greenland migratory populations were detected in the Strait of Belle Isle. This Strait is the northern exit from the Gulf of St. Lawrence and one of two possible routes for Gulf fish to Greenland (the second is the more southerly Cabot Strait). Between 12 and 33% of the fish known to have survived estuary passage in the Restigouche, Cascapedia, and Miramichi Rivers were detected here in 2006 and 2007, indicating that this is an important salmon migration pathway.

There was a remarkable synchrony in the Strait of Belle Isle arrival for fish from different rivers in both 2006 and 2007. Restigouche, Cascapedia and Miramichi post smolts all logged on within a narrow 10-11 day window, starting on 10 July in both years. However, in 2006, some tagged smolts may have passed the area before the receivers were installed. Considering only results from 2007 where the Strait receiver array was deployed for the full period of the smolt migration, Restigouche, Cascapedia and Miramichi post-smolts came through the Strait together. This is despite the fact that the Miramichi smolts entered the sea earlier than the two more northerly populations. Travel rates for the Miramichi post smolts had to be about 20% slower than the Restigouche and Cascapedia fish to result in this synchronous arrival in the Strait. This may indicate that

the post smolts actively adjusted travel rates to aggregate with conspecifics from other rivers during the ocean migration, and that such aggregation occurred within the first 30 days or so after sea entry. The lack of correlation between post smolt size and smolt travel times that we observed may also indicate that larger and presumably faster fish slow down to accompany smaller slower fish.

Sonic telemetry is proving to be a valuable component of the SALSEA program. It is highly complementary to proposed cruise work, is meeting information requests from NASCO to partition marine mortality to the narrowest geographic scale possible, has permitted us to track some Canadian smolts almost half the distance from the river of origin to Greenland, and is beginning to identify correlates of smolt and post-smolt survival. Sonic telemetry capacity will be extensively increased in North America over the next few years. The Ocean Tracking Network, based at Dalhousie University, will place new telemetry arrays on the continental slope off of Halifax, in the Cabot Strait in the Gulf of St. Lawrence, and eventually in the Gulf of Maine and off of Greenland. These arrays and other innovative technologies which the OTN program is developing should permit the development of quantitative survival estimates for post smolts from rivers south of the Gulf St. Lawrence. This infrastructure is expected to be maintained for at least a 10 year period, providing a long-term platform for marine work on Atlantic salmon post smolts.

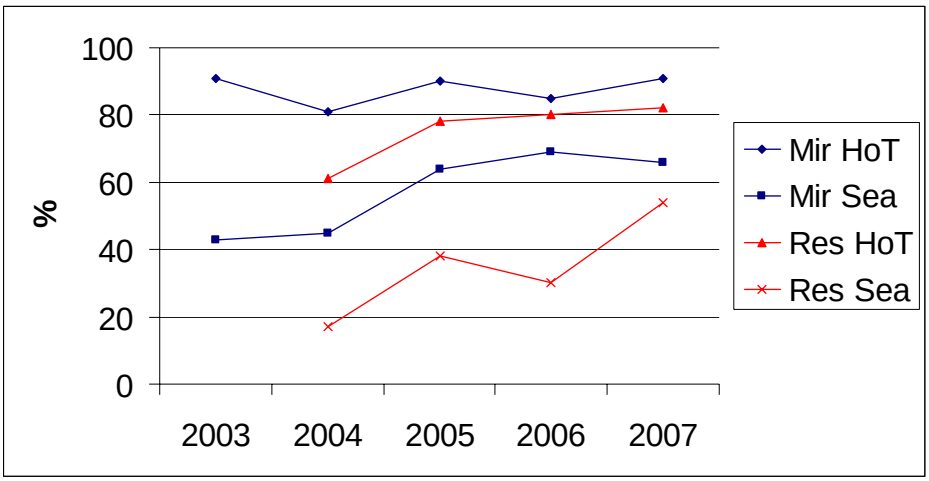
Table 1. Travel rates for fish crossing the Gulf of St. Lawrence after estuary exit. Fish from the Restigouche and Cascapedia Rivers which have a common estuary (the Baie des Chaleurs) have been combined. BL = Body lengths, SD = Standard Deviation, N = number of fish.

Site	Year	km/d	SD	Mean BL/s	SD	N
Miramichi	2007	17.9	1.7	1.4	0.2	12
Baie des Chaleurs	2006	24.6	5.1	2	0.4	5
	2007	22.2	1.4	1.7	0.1	14
Western Arm Brook	2007	1.9	0.6	0.12	0.03	14

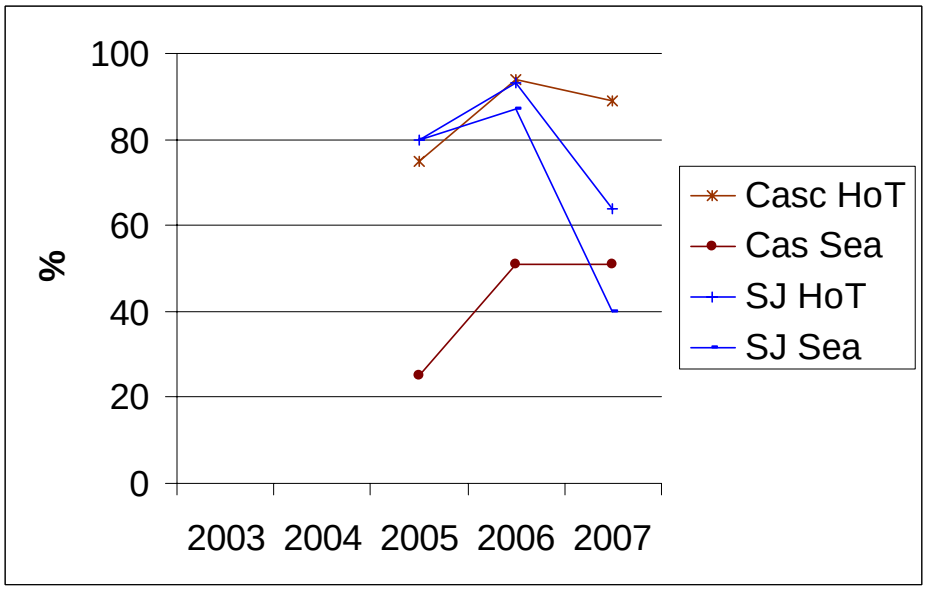
Table 2. Comparisons of mean smolt fork lengths (FL) at the time of release for fish which were detected at the Strait of Belle Isle (SoBI) and those that were not (Others). For a given river within a given year, there were no statistically significant differences in lengths between these two groups (P > 0.05). SD = standard deviation.

		SoBI			Others		
River	Year	FL (cm)	SD	N	FL (cm)	SD	N
Miramichi	2007	14.9	0.7	12	14.8	0.9	28
Restigouche	2006	13.9	0.4	4	14.4	0.8	66
	2007	15.1	0.9	10	14.6	0.7	90
Cascapedia	2006	14.9	0.5	4	15.2	1	46
	2007	14.8	0.8	8	14.6	0.8	39

Figure 1. Percentage of tagged smolts surviving from release sites in fresh water to the start of the river estuary at the head-of-tide (HoT), and also through the estuary to enter the sea (Sea).



a. Miramichi (Mir) and Restigouche (Res) rivers.



b. Cascapedia (Casc) and St. Jean (North Shore) (SJ) Rivers

Fig. 2. Plot of the percent of the sonically tagged smolts exiting the Miramichi and Restigouche rivers versus the midpoint estimate of smolt run size.

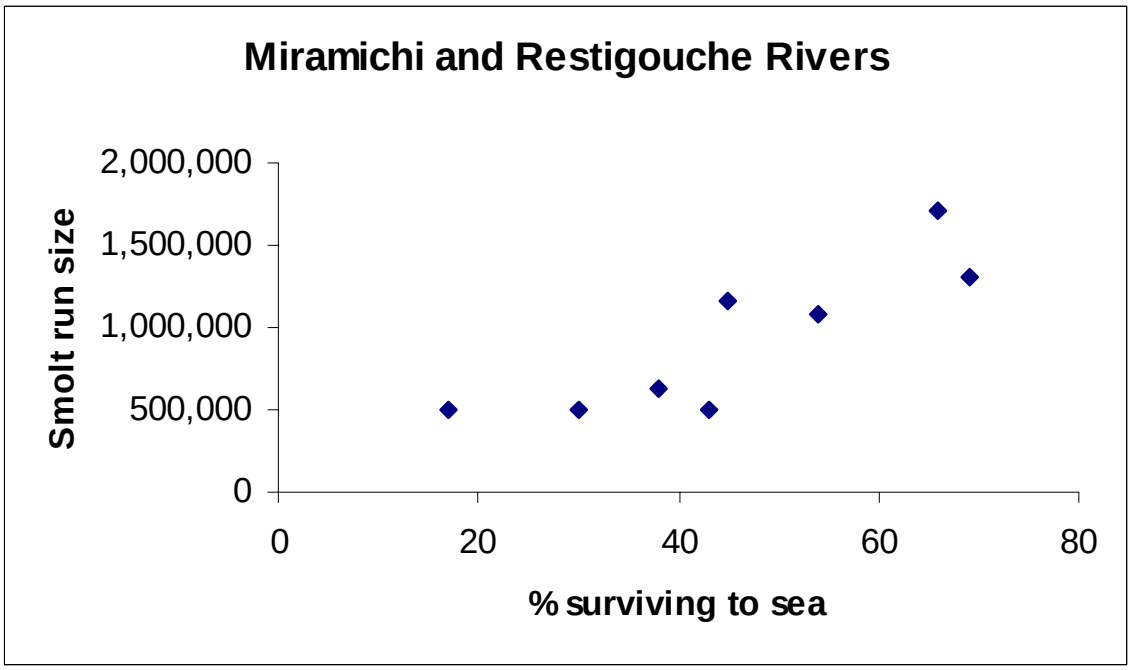
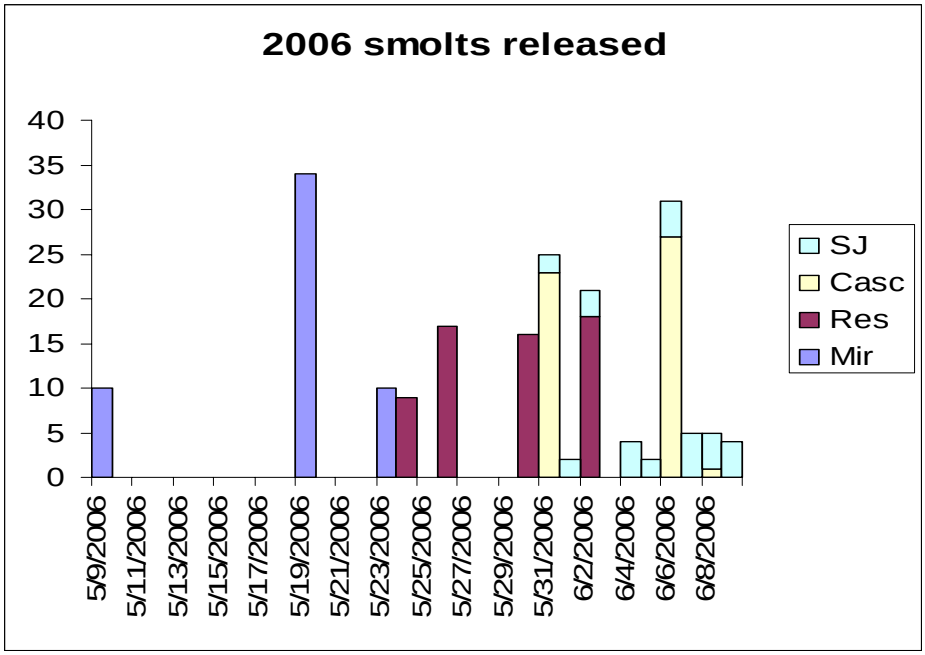


Fig. 3. Numbers and release dates of sonically tagged smolts in 2006 and 2007



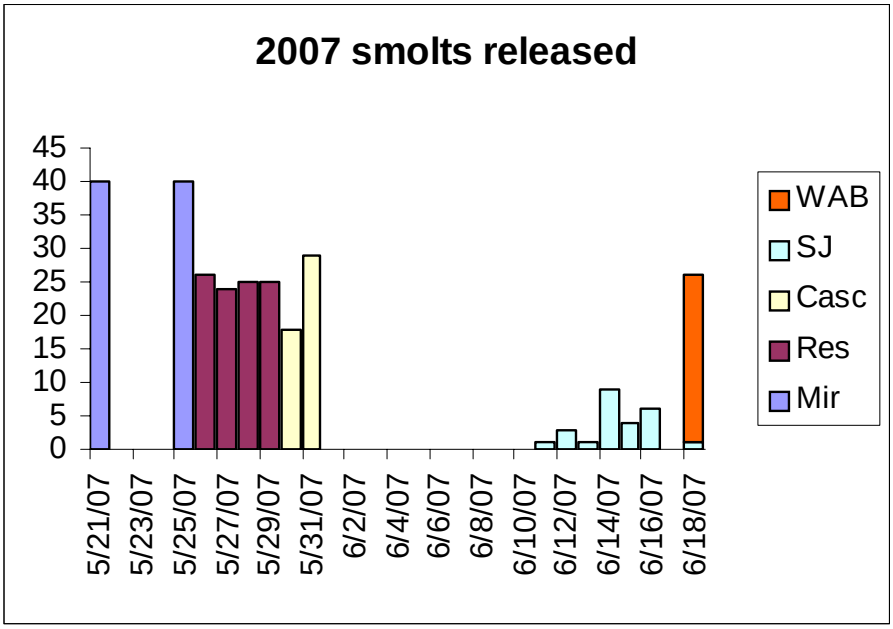


Fig. 4. Detections of sonically tagged smolt on the Strait of Belle Isle (SoBI) array in 2007. SJ = Saint Jean (North Shore), Casc = Cascapedia, Res = Restigouche, Mir = Miramichi, WAB = Western Arm Brook.

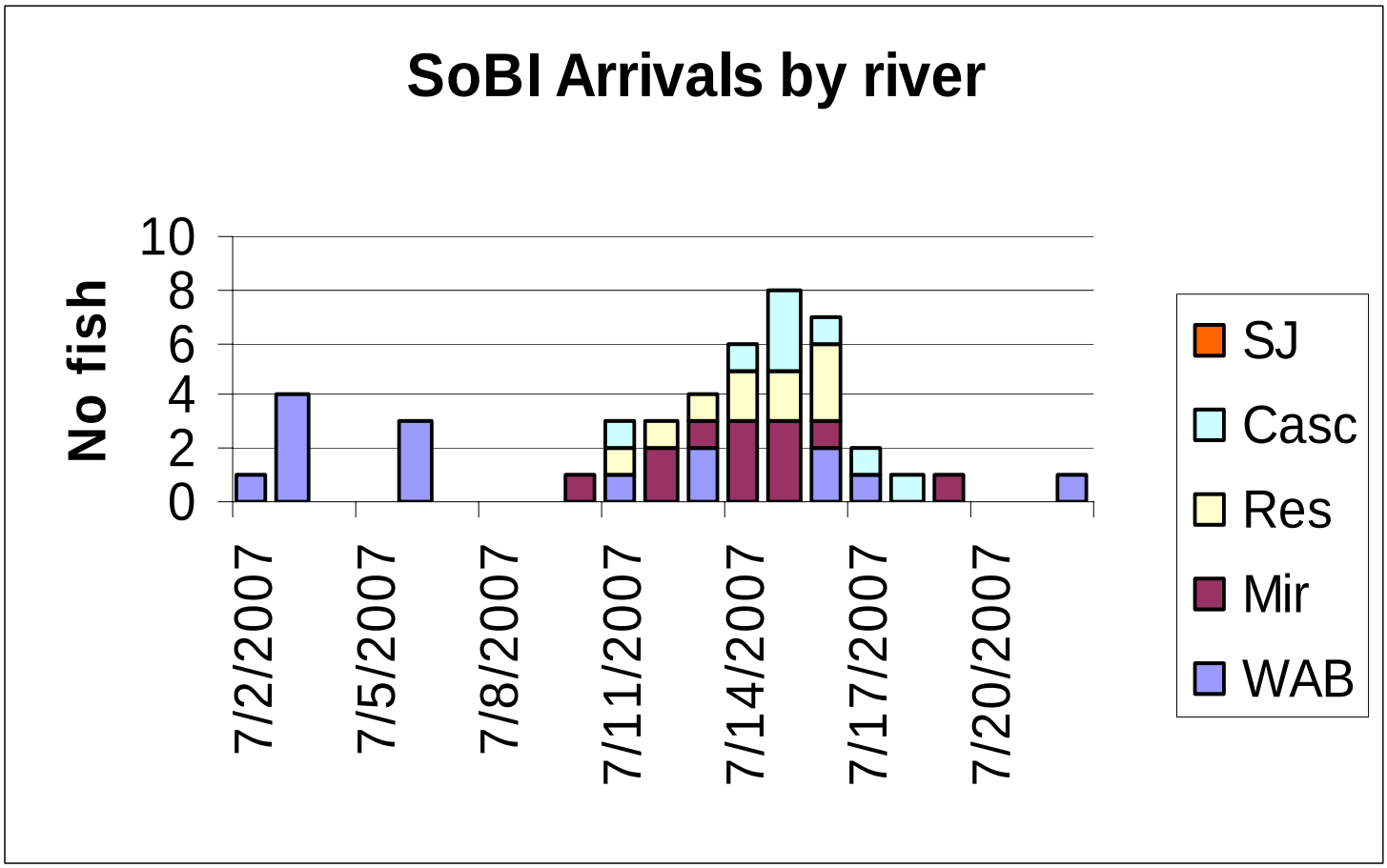


Fig. 5. Relation between fish size and the time it took to cover the approximately 800 km distance from estuary exit to the Strait of Belle Isle. The top panel combines data from smolts tagged in the Cascapedia and Restigouche Rivers in 2006 and 2007, because they share a common estuary (the Baie des Chaleurs). The bottom panel gives 2007 results for Miramichi River fish.