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Influence of Seasonal River Discharge on Survival of Juvenile Atlantic Salmon, *Salmo Salar*

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The effects of winter and summer river discharge on the survival of eggs and underyearlings of Atlantic salmon (*Salmo salar*) were examined in six rivers of Newfoundland and New Brunswick where stock–recruitment relationships were available. There were positive relationships between either winter discharge or temperature and survival of underyearling salmon for five rivers. For all rivers combined, survival and winter discharge were related ($P < 0.05$). The hypothesis that summer discharge was unrelated to survival could not be rejected. However, there was evidence that summer discharge enhances survival in the Miramichi and Northwest Miramichi rivers of New Brunswick.

Les auteurs ont étudié l'incidence du débit fluvial en hiver et en été sur la survie des oeufs et des tacons O+ de saumon de l'Atlantique (*Salmo salar*) peuplant six rivières de Terre-Neuve et du Nouveau-Brunswick pour lesquelles on disposait de relations sur le recrutement du stock. Ils ont noté des relations positives entre, d'une part, le débit hivernal et la température et, d'autre part, la survie des tacons O+ fréquentant cinq rivières. Ils ont aussi relevé une relation ($P < 0,05$) entre la survie et le débit hivernal dans toutes les rivières regroupées. L'hypothèse selon laquelle le débit estival n'est pas lié à la survie n'a pu être rejetée. Toutefois, certains faits prouvent que le débit estival améliore la survie dans les rivières Miramichi et Northwest Miramichi (Nouveau-Brunswick).

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The production of salmonids in rivers is dependent on a number of factors (McFadden 1969), including stability of river discharge (Binns and Eiserman 1979). In addition to regulating prey abundance (Hynes 1970), discharge has direct effects on salmonid production. Wickett (1958) showed that stream discharge had a positive relationship with survival of pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) when spawners were migrating upstream and during early incubation of the eggs, but a negative relationship in the winter, when floods could displace gravel and eggs or alevins. Similarly, Nickelson et al. (1986) suggested that spring freshets reduced survival of early emerging coho salmon (*O. kisutch*), and Cramer et al. (1985) found a negative relationship between survival of spring chinook (*O. tshawytscha*) from egg to fry and winter flows. The commercial catches of coho salmon are positively related to annual stream flows, while juveniles inhabited fresh water (Smoker 1953; Scarnecchia 1981). This higher survival of coho was apparently related to higher summer flow for the fry (Neave and Wickett 1948; Neave 1949; Wickett 1951). However, in contrast with coastal streams, in some British Columbia interior streams, winter precipitation is in the form of

snow, so that lowest flows are in late winter. In these situations, decreases of water reduce overwintering habitat in side channels, causing high mortality of salmonid fry and parr, due to stranding with subsequent suffocation and freezing of juveniles, low dissolved oxygen levels, and predation (Bustard 1986).

In a boreal river in Quebec, Frenette et al. (1984) investigated relationships between abundance of Atlantic salmon (*Salmo salar*) parr and flow conditions. A positive relationship was found between estimates of parr abundance and previous discharges in late winter and late summer, when the juvenile salmon would have been in the alevin (late winter) or in the underyearling (late summer) stages. Using a multiple linear regression analysis over 7 yr of data, a model for populations of 1+ and 2+ parr was obtained. Parr population estimates were made during years of relatively low densities (Gibson 1978) when density-independent mortality may be relatively more important than density-dependent mortality (Elliott 1984a).

However, in the study by Frenette et al. (1984) the same data were used to develop and test the hypothesis; thus, the levels

TABLE 1. Sources of juvenile Atlantic salmon survival and discharge data from six rivers in Newfoundland and New Brunswick.

River	Year-classes	Spawner index	Parr index	Sources of spawner-parr data	Winter discharge index	Summer discharge index
Western Arm Brook, Nfld.	1972-81	Eggs ($\times 10^3$)	3+ parr (derived from 4+ smolts) from counting fence	Chadwick 1987	Mean February discharges, Ste. Genevieve River near Forresters Point	Mean flow July - August, Ste. Genevieve River
Pollett River, N.B.	1955-62	Potential egg deposition ($\times 10^3$)	1+ parr, 100-yd ⁻² from electrofishing	Elson 1975	Mean discharge in February at Lepreau River	Mean flow July - August, Lepreau River
Northwest Miramichi, N.B.	1952-70 ^a	Virtual egg deposition ($\times 10^6$)	1+ parr, 100-yd ⁻² from electrofishing	Elson 1974; Paloheimo and Elson 1974	Mean February discharges for the Little Southwest Miramichi River at Lyttleton	Mean flow July - August, Little Southwest Miramichi River
Miramichi, N.B.	1969-81	Angled kelts	1+ parr, 100-m ⁻² from electrofishing	Chadwick 1985	Mean February discharge Southwest Miramichi River at Blackville	Mean flow July-August, Southwest Miramichi River at Blackville
Restigouche River, N.B.	1971-81	Angled large salmon	1+ parr, 100-m ⁻² from electrofishing	Chadwick 1985	Mean February discharge in the Restigouche River	Mean flow July-August, Restigouche River
Little Codroy River, Nfld.	1954-63	Kelts returning to sea	3+ smolts (plus 2+ smolts $\times 0.4$) from counting fence	Murray 1968a, 1968b; and unpublished data	Minimum mean monthly winter air temperature ($^{\circ}$ F) for St. Andrews, Nfld.	Mean July-August precipitations (in.), St. Andrews, Nfld.

^aThe year-class of 1951 was not included because there were no winter discharge data for that year, nor the year-classes of 1953 and 1954, which suffered heavy mortality from DDT spraying in those years.

TABLE 2. Regression coefficients and probability levels for one-sided tests that slopes (β , γ_w , γ_s) are less than or equal to zero. Also given are the correlation coefficients between the logarithm of the index of summer discharge (D_s) and winter discharge (D_w).

River	$\rho(\ln D_w, \ln D_s)$	Winter flow			$P(\beta \leq 0)$	$P(\gamma_w \leq 0)$	Summer flow			$P(\beta \leq 0)$	$P(\gamma_s \leq 0)$	
		α	β	γ_w			α	β	γ_s			
Newfoundland												
Western Arm Brook	-0.66	6.32	0.46	0.52	0.012	0.011	8.26	0.47	0.54	0.03	0.93	
Little Codroy	0.63	6.79	0.36	0.15	0.17	0.25	7.32	0.34	0.007	0.01	0.50	
New Brunswick												
Miramichi	0.25	-5.82	0.98	0.097	0.0007	0.25	-7.77	1.03	0.50	0.00025	0.05	
Northwest Miramichi	-0.11	1.13	0.88	0.19	0.0014	0.15	0.27	0.90	0.49	0.0008	0.08	
Restigouche	0.79	-3.23	0.65	-0.10	0.002	0.682	-3.50	0.63	0.04	0.0034	0.44	
Pollett	0.19	1.65	0.47	0.10	0.0021	0.26	-1.28	0.44	0.01	0.0039	0.48	

of significance reported are not reliable. We undertook to test the a priori hypothesis that survival of Atlantic salmon eggs and underyearlings is reduced by low river discharge in late winter and late summer.

Methods

We analyzed juvenile salmon survival data from six rivers in Newfoundland and New Brunswick where stock-recruitment relationships were available (Table 1). For each river and for each year-class an index was used of parr abundance, spawner abundance, winter discharge, and summer discharge. The index of spawner abundance was an estimate of egg deposition from fish trap counts when possible, but for some rivers (Miramichi

and Restigouche) we had to rely on indices based upon angling data. The parr index was based upon surveys of 1+ parr when possible, but for some rivers (Table 1) our indices were based upon older parr or smolts. Because we are testing hypotheses concerning survival of underyearlings, we are assuming in our regression analysis that there is no correlation between under-yearling survival and survival rates of older parr. Mean February discharge and the mean July-August discharge obtained from the nearest unregulated river (Environment Canada 1983) were used as indices of winter and late summer discharges, except for the Little Codroy River where only temperature and precipitation data were used as proxy variables (Murray and Harmon 1969).

The following model was used to test the effect of late summer discharge:

$$P = \alpha S^\beta D_s^{\gamma_s}$$

where P is the index of parr abundance, S is the index of spawner abundance, D_s is the index of late summer discharge, and α , β , and γ_s are parameters to be estimated. Our a priori hypothesis was that $\gamma_s > 0$. The model was fitted to the data by log-transforming the three variables and fitting the three parameters by an ordinary least squares regression.

The above a priori regression model was chosen because (i) parr production is a concave increasing function of spawner abundance (Buck and Hay 1984), (ii) the logarithmic transformation helps to stabilize the variance of the model residuals,

and (iii) we believed that survival was more likely to be a concave increasing function of discharge than a linear function.

The appropriateness of the regression model was tested by checking for autocorrelation in the residuals (using the Durbin-Watson test), checking for correlations amongst the regressor variables, and graphing residuals to check skewness and constant variance of the model residuals. The residuals were also plotted against the index of spawners to determine if a Ricker-type curve would be more appropriate.

The above procedure was repeated for late winter discharge, where D_s is replaced by an index of late winter discharge, D_w , and the parameters α , β , and γ_w are reestimated.

The assumptions of an ordinary least squares regression could not always be met; therefore, the analysis was repeated using a nonparametric regression which tests whether the dependent

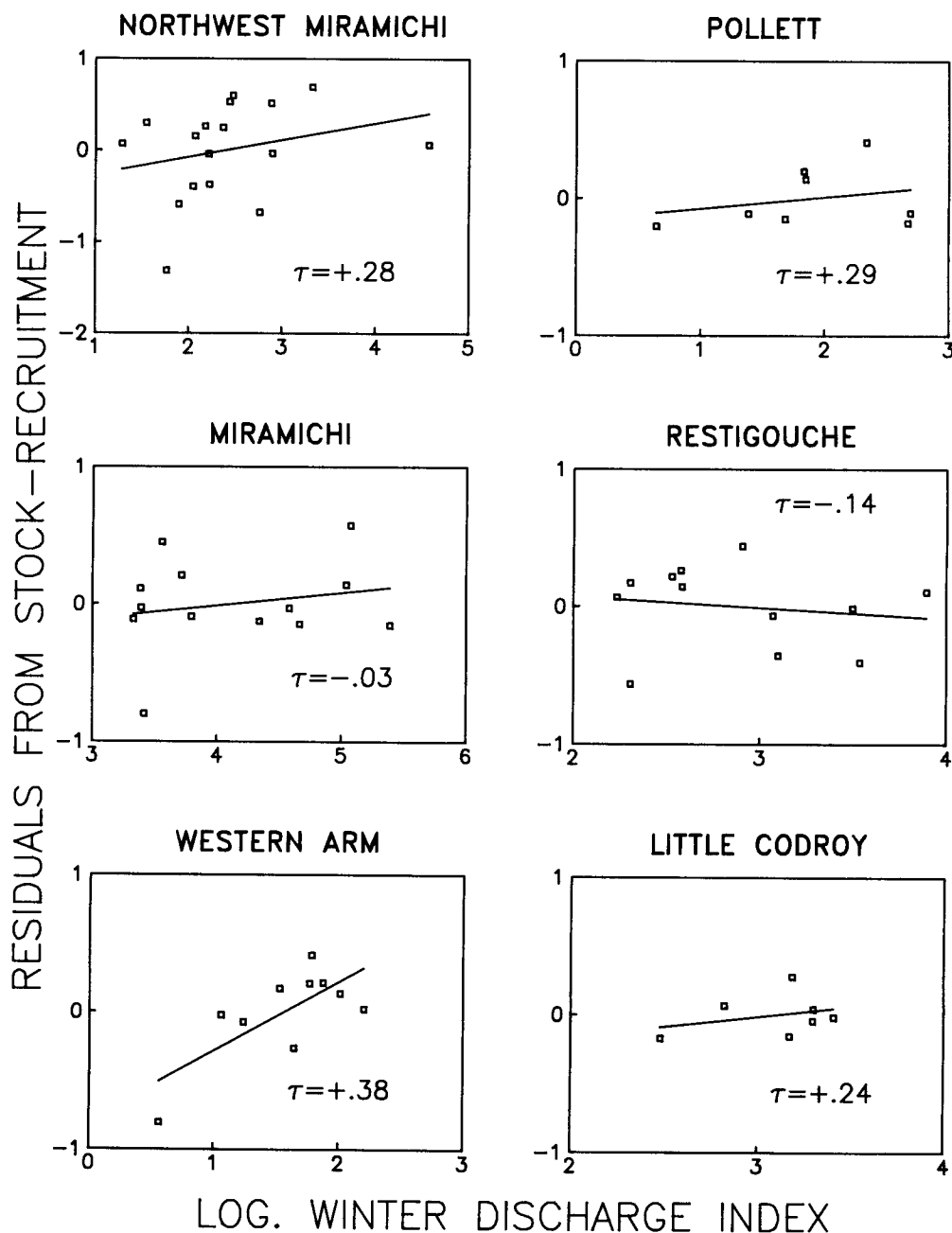


FIG. 1. Residuals from a regression of a stock (spawner index) - recruitment (parr index) relationship. The ordinary least squares regression lines are shown but are sometimes not useful due to heteroscedasticity. Kendall's rank correlation coefficient, τ , is also given.

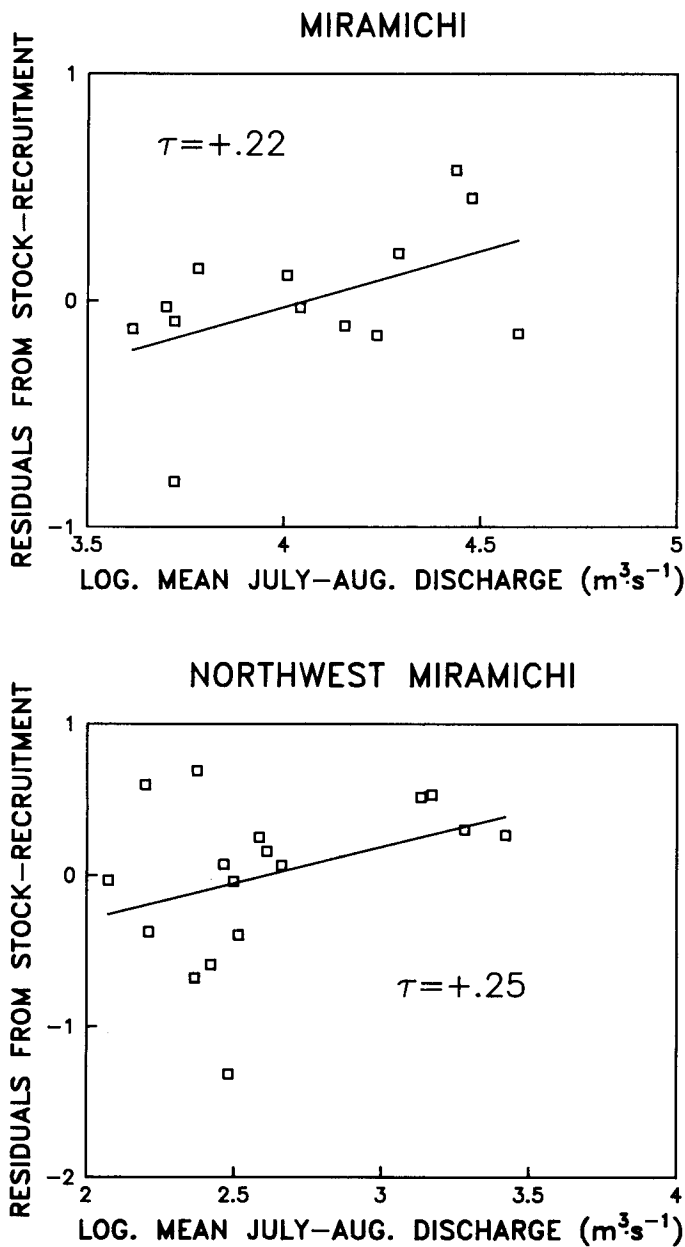


FIG. 2. Same as Fig. 1, except using the summer discharge index.

variable, recruitment, is a monotonically decreasing function of the independent variable, the discharge index. The test we used is the ordering test, which is equivalent to the more familiar Kendall's rank correlation coefficient (Sokal and Rohlf 1981).

We used Fisher's (1954, section 21.1) method of combining probabilities from tests of significance to combine the results for each river to test the above two survival hypotheses. Note that this test is valid only if an a priori decision is made about which significance tests are to be combined. It is also crucial that the individual tests concern the same hypothesis, although the type of data used in the individual tests may vary. See Drinkwater and Myers (1987) for an application of Fisher's (1954) method to a similar problem.

Results

There was no significant autocorrelation among the model residuals, and the logarithmic transformation tended to stabilize

the variance. There were positive relationships between winter discharge and survival of 0+ salmon using ordinary least squares regression for all rivers, except the Restigouche (Table 2; Fig. 1). (We used temperature as a proxy variable for winter discharge for the Little Codroy River because discharge data were not available.) The level of significance of all rivers combined led to a rejection of the hypothesis that survival and winter discharge were unrelated ($P < 0.05$).

We could not reject the hypothesis that summer discharge was unrelated to survival. However, there was evidence that summer discharge generally enhances survival for the Miramichi and Northwest Miramichi rivers (Fig. 2).

There was no consistent correlation between summer and winter discharge (Table 2); however, there were positive correlations between the two discharge indices for the Restigouche and the Little Codroy rivers. These correlations should have little effect on our conclusions because the proposed relationships were not strong for these rivers.

Note that the regressions for winter discharge depend strongly on very poor survival during one year with low discharge in the Northwest Miramichi, the Miramichi, and Western Arm Brook (Fig. 1). A nonparametric analysis based upon ranks shows that these low survivals affect our conclusions for one river, i.e. Kendall's $\tau = -0.01$ for the Miramichi. However, these very low survivals appear to be real and associated with low discharge. One interpretation of the data presented in Fig. 1 is that winter discharge is only important in years in which discharge is low.

We have least confidence in the data source for the spawner indices of the Miramichi and Restigouche rivers, as this is derived from angling data of kelts or large salmon (Table 1) and is therefore dependent to a large extent on water conditions at the time and on the accuracy of creel censuses. We suspect that the poor results for these two rivers may be associated with unreliable data.

Discussion

Except for the Miramichi and Northwest Miramichi rivers, we found little effect of summer discharge. Unlike the other rivers analyzed, except for the Restigouche River, the Miramichi is a large system and unregulated by lakes, so conceivably would be more severely affected by summer droughts. Low summer flows, however, may have more severe effects on survival of young Atlantic salmon in more temperate or southerly regions of the species' range than in boreal regions. Lishev (1959) suggested that in the Eastern Baltic discharges in summer and winter have positive relationships with survival of underyearlings (summer) or developing eggs (winter), but that summer flows were the major factor. Similarly, Havey and Davis (1970) found in Maine that there was a significant positive relationship between summer rainfall and survival of underyearling landlocked Atlantic salmon. Also, studies in Britain have provided evidence that low summer discharge reduces survival of underyearling brown trout (*Salmo trutta*) (Solomon and Paterson 1980; Elliott 1984a, 1984b). Summer drought and temperature conditions may usually be less severe in boreal regions. However, flow regimes vary between river systems, and depend on river basin morphology as well as climate, and may be regulated considerably by gradient, stream order, groundwater, and the influence of lakes and bogs, etc. (Hynes 1970).

The effects of low winter discharges on survival of Atlantic salmon appear, however, to be more severe in boreal regions

of North America than in temperate regions with milder winters, where such effects have not been documented. In boreal rivers, such as those considered in the present study, the winter climate is relatively severe, and lowest discharges occur in late winter (Frenette et al. 1984). Low winter discharges would reduce percolation of water through the redds and, therefore, oxygen transport to developing eggs and alevins, with subsequent changes in survival (Wickett 1954; Chadwick 1982; Becker et al. 1982). This effect seems to be important only in years of very low winter flow. Also, reduced flows may lower temperatures, and mortality of eggs increases at temperatures below 4°C (Peterson et al. 1977). Winter density-independent effects on developing salmon eggs due to low river discharges therefore need to be considered in development of stock-recruitment models.

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