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Juvenile Atlantic salmon (*Salmo salar* L.) abundance in the Experimental Ponds Area relative to subsequent adult returns to the Gander River as an index of marine survival: apparent evidence for density-dependent marine mortality

by

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Abstract

A marine survival ratio index was calculated as the number of adult salmon returning to the Gander River divided by the total juvenile salmon populations in the Experimental Ponds Area (EPA) at the headwaters of the river in the previous spring. This survival index increased more than four-fold in the first four years (1992-95) following closure of the commercial fishery in 1992 but then dropped moderately in 1996 and then precipitously in 1997, suggesting a large decrease in marine survival despite the continued closure of the commercial fishery in insular Newfoundland. The decreases in the marine survival index occurred in the context of increasing juvenile abundance, a pattern consistent with an interpretation of density-dependent mortality. Juvenile abundance declined in 1997 and the marine survival index increased, as would be expected if mortality were density-dependent. The negative correlation between juvenile abundance and the marine survival index leads to a prediction of a dome-shaped relationship between juvenile abundance and subsequent adult returns to the Gander River. This relation suggests that the Gander River conservation requirement of 21,828 small adult spawners will be met when EPA juvenile abundance in the preceding year is in the range of 3000 - 5000 individuals. EPA juvenile abundance in 1998 was 2385 individuals which yields an estimated 1999 return of 19,740 small adults which would be 10% below the conservation requirement. The predicted return would increase to 25,643 small adults if the high marine survival observed during the early post-moratorium years (1992-95) was achieved.

Résumé

Un indice du taux de survie en mer a été calculé sous la forme du rapport entre le nombre de saumons adultes revenant à la rivière Gander et le la population de saumon juvénile totale se trouvant, au printemps précédent, dans la zone des lacs expérimentaux (EPA) située en amont de la rivière. L'indice de survie a plus que quadruplé au cours des quatre premières années (1992-1995) suivant la fermeture de la pêche commerciale en 1992. Il a ensuite diminué de façon modérée en 1996 avant de subir une chute abrupte en 1997, ce qui porte à croire à une importante baisse de la survie en mer en dépit du maintien de la fermeture de la pêche commerciale de l'île de Terre-Neuve. Cette baisse de l'indice de survie en mer s'est produite dans le contexte d'une augmentation de l'abondance des juvéniles, une tendance conforme à l'interprétation d'une mortalité dépendante de la densité. L'abondance des juvéniles a diminué en 1997 et l'indice du taux de survie en mer a augmenté, comme on pouvait le prévoir pour une mortalité dépendante de la densité. La corrélation négative entre l'abondance des juvéniles et l'indice du taux de survie en mer indique l'existence d'une relation de type « normale » entre l'abondance des juvéniles et les remontées ultérieures d'adultes dans la rivière Gander. Cette relation porte à croire que la remontée nécessaire à la conservation dans la Gander, de 21 828 petits géniteurs adultes, sera atteinte lorsque l'abondance des juvéniles dans la zone EPA au cours de l'année précédente sera de l'ordre de 3 000 à 5 000 individus. L'abondance des juvéniles dans cette zone en 1998 était de 2 385 individus et devrait correspondre à une remontée de 19 740 petits adultes en 1999, valeur de 10 %, inférieure aux besoins de conservation. Si le fort taux de survie en mer observé pendant les premières années suivant le moratoire (1992-1995) se maintient, la remontée prévue devrait atteindre 25 643 petits adultes.

Introduction

The number of adult salmon returning to the Gander River should be primarily a function of the number of smolts migrating to sea the previous year and their subsequent mortality rate at sea because the returning adults are largely one-sea-winter fish. A marine survival ratio index has been developed which is calculated as the number of adult salmon returning to the Gander River divided by the total juvenile salmon populations in the Experimental Ponds Area (EPA) at the headwaters of the river in the previous spring. This survival index increased more than four-fold following closure of the commercial fishery in 1992 and has been used to predict adult salmon returns to the Gander River one year in advance (Ryan et al. 1995, 1996, 1997). The survival index provides a metric for estimating changes in mortality during the difficult-to-monitor marine phase of the life cycle. We herein present data suggesting an apparent negative relationship between EPA juvenile abundance and the subsequent marine survival index. This relationship implies that there is an optimum range of juvenile abundance above and below which adult returns decrease.

Methods

Juvenile salmon populations were assessed at the Experimental Ponds Area (EPA) which is located at the headwaters of the Northwest Gander River (Figure 1). Populations were estimated for Spruce Pond and Headwater Pond (Figure 2) using fyke nets and Schnabel multiple-mark-recapture methods as detailed by Ryan (1990). Headwater and Spruce ponds are shallow (mean depth 1.1 and 1.0 m, respectively), dilute (mean conductance 35 uS cm^{-1}), brown-water lakes whose physical and chemical characteristics have been detailed by Ryan and Wakeham (1984).

An adult counting fence has been operated on the main stem of the Gander River since 1989. Total adult small salmon returns to the Gander River system have been calculated as the sum of the number passing through the fence and the number angled downstream of the fence (O'Connell and Ash 1994) except for 1997 and 1998 when the angled catch was not monitored (this catch is a very small portion of the total adult return). We have used adult return counts for the post commercial fishery period of 1992-1997 as updated by O'Connell et al. (1999).

Results and Discussion

The spring salmon population abundance in both Spruce and Headwater ponds combined declined to 2385 in 1998, a level at the lower end of the range observed for the period 1979-1998 (Figure 3). This represents a continued decline from the peak abundance observed in 1996. The juvenile estimate was 25% lower than the predicted abundance (3179) based on the past relationship between EPA juvenile abundance and Salmon Brook adult counts four years previous (for 1982-1994 excluding 1985: juveniles (year N) = (1.776 * Salmon Brook count (year N-4))+ 1468.36, Ryan et al. 1997).

A marine survival index, calculated as the ratio of total Gander River small salmon returns to EPA juveniles the previous year, indicated a major improvement in survival following the commercial fishing moratorium (Table 2). The mean survival ratio index during the first four post-moratorium years was 8.24 as compared to 1.71 in the two pre-moratorium years. Increased EPA juvenile abundances in 1995 and 1996 were followed by declines in the subsequent marine survival index estimates to 5.27 in 1996 and 1.60 in 1997, a level consistent with that observed prior to closure of the commercial fishery. EPA juvenile abundance declined in 1997 and the marine survival index subsequently increased to 6.02. These data illustrate a negative correlation between juvenile abundance and subsequent marine survival (Figure 4). Such a pattern would be consistent with an interpretation of density-dependent mortality. The negative correlation is statistically significant ($r = -0.931$, $p=0.002$, one-tailed test) but is strongly dependent upon the 1996 and 1997 data. The least squares regression equation describing the relationship is:

Survival Index = 12.007 - (0.001564 * EPA Juvenile Estimate)   Equation 1.

Omission of the 1997 data point still results in a significant negative correlation ($r = -0.774$, $p=0.045$, one-tailed test) with little change in the regression equation:

Survival Index = 11.550 - (0.001402 * EPA Juvenile Estimate)   Equation 2.

The apparent relationship between juvenile abundance and the marine survival index (Equation 1) can be used to predict small adult returns over a range of hypothetical EPA juvenile abundances (Figure 5). The predicted pattern is a dome-shaped curve with a broad peak which exceeds the Gander River conservation requirement of 21,828 small adult salmon when EPA juvenile abundance is in the range of approximately 3000 - 4500 individuals. Predicted adult returns fall to zero at EPA juvenile abundances of 0 and 7677 individuals.

Applying Equation 1 to the 1998 EPA juvenile estimate of 2385 fish yields a predicted marine survival index of 8.277 which would result in an expected 1999 return of 19,740 small adult salmon to the Gander River. This estimate is 10% below the conservation requirement.

Continued monitoring of EPA juvenile abundance and Gander River adult returns would allow the apparent negative relationship between juvenile abundance and subsequent marine survival to be further evaluated. For example, the 1995 Salmon Brook count of 1295 small adult salmon yields a predicted EPA juvenile abundance in 1999 of 4310 (using the recruitment relationship described above from Ryan et al. 1997). This increased juvenile abundance should, according to Equation 1, lead to a decrease in the subsequent marine survival index to 5.266 and a resultant small adult return of 22,697 in the year 2000. Estimates of juvenile abundance and adult returns in 1999 and 2000 would provide a means of testing these predictions. If the density-dependent mortality pattern is confirmed, it would provide a scientific basis for refining recommendations regarding river management. The density-dependent mortality model (Equation 1) would provide a means of identifying periods of expected low marine survival which could then be the focus of research efforts into identifying the causes of mortality.

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Table 1. Spring Atlantic salmon juvenile population size in the Experimental Ponds Area (EPA, Spruce and Headwater ponds combined), Salmon Brook fishway small adult (<63 cm) counts, and Gander River small adult count.

Year of Census	Total Count EPA Juveniles	Salmon Brook Fishway Count	Gander River Total Small Salmon Count
1978		755	
1979	4822	404	
1980	3463	997	
1981	2393	2459	
1982	3077	1425	
1983	1603	978	
1984	3226	1081	
1985	3175	1663	
1986	4474	1064	
1987	3199	493	
1988		1562	
1989	4925	596	
1990	3642	345	
1991	2362	245	7743
1992	3069	1168	7740
1993	2470	1560	6745
1994	2370	963	18179
1995	4492	1600	26205
1996	6558	946	18080
1997	3112	465	22264
1998	2385	1295	23665
			10474
			18742

Table 2. Survival ratio indices calculated as the ration of returning Gander River small adult salmon to the EPA juvenile abundance the previous year.

Year of Census	EPA Juveniles	Gander River Return Small Adults (year n+1)	Survival Ratio Index (adults year n / juveniles year n-1)
1989			
1990	4925		
1991	3642		1.57
1992	2362	7740	1.85
1993	3069	6745	7.70
1994	2470	18179	8.54
1995	2370	26205	7.32
1996	4492	18080	9.39
1997	6558	22264	5.27
1998	3112	23665	1.60
		10474	6.02
		18742	
			1.71 (± 0.20)
		Mean Pre-closure Ratio (± S.E. for 1990-1991)	8.24 (± 0.92)
		Mean Post-closure Ratio (± S.E. for 1992-1995)	6.55 (± 2.59)
		Mean Post-closure Ratio (± S.E. for 1992-1998)	

Figure 1. Gander River basin of insular Newfoundland with locations of study sites referred to in the text.

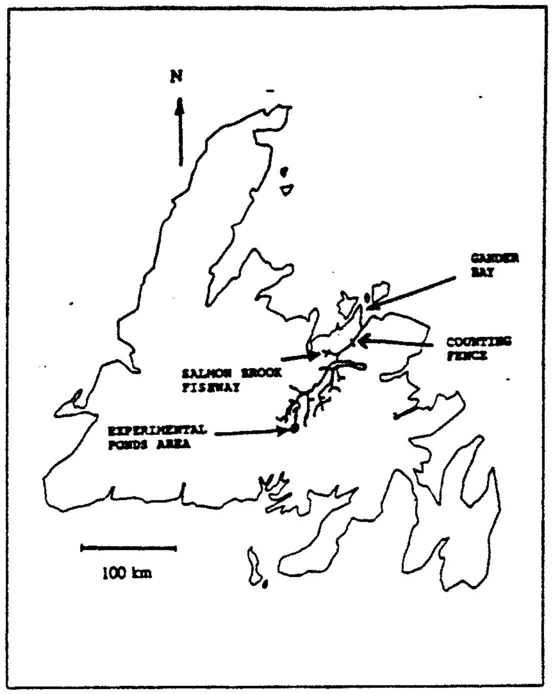

Figure 2. Watershed of the Experimental Ponds Area at the headwaters of the Northwest Gander River, central Newfoundland (inset). The dashed line through the east side of the watershed represents the Bay D'Espoir highway.

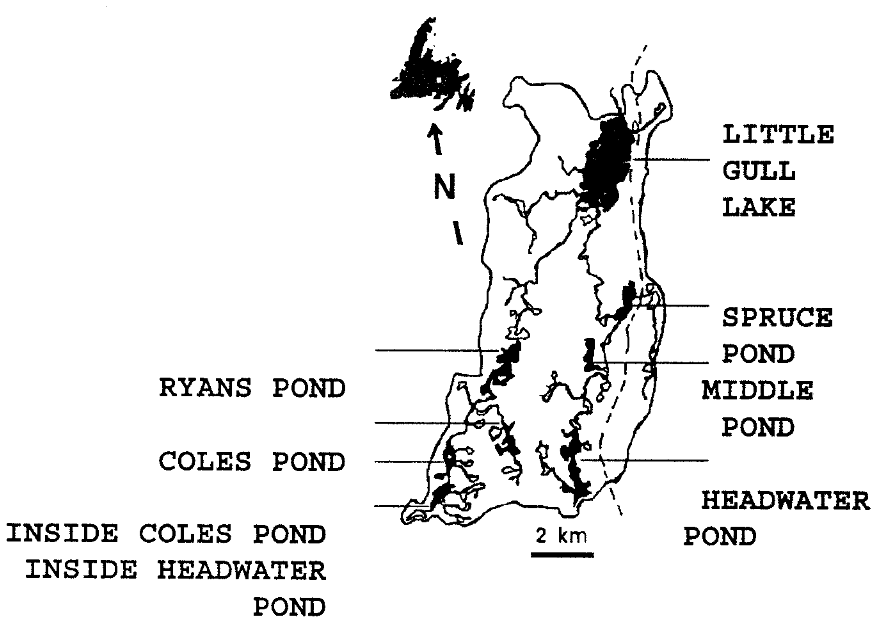

Figure 3. Spring Schnable population estimates of Experimental Ponds Area juvenile salmon (Headwater and Spruce ponds combined) from 1979 through 1998.

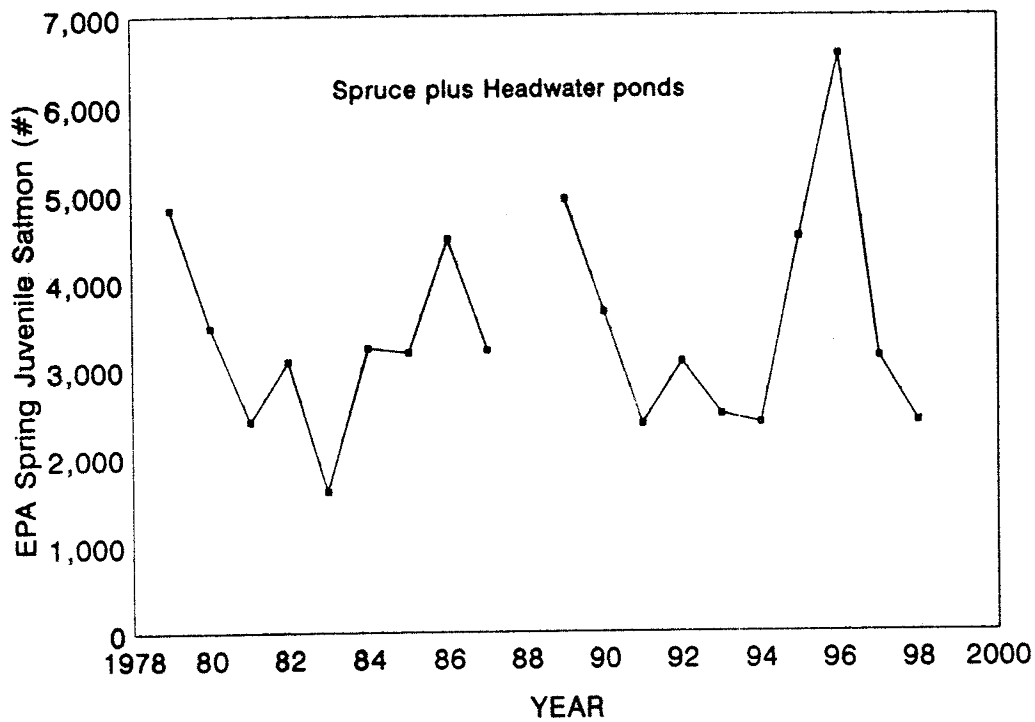

Figure 4. Relationship between estimates of the marine survival index and EPA juvenile abundance the preceding year.

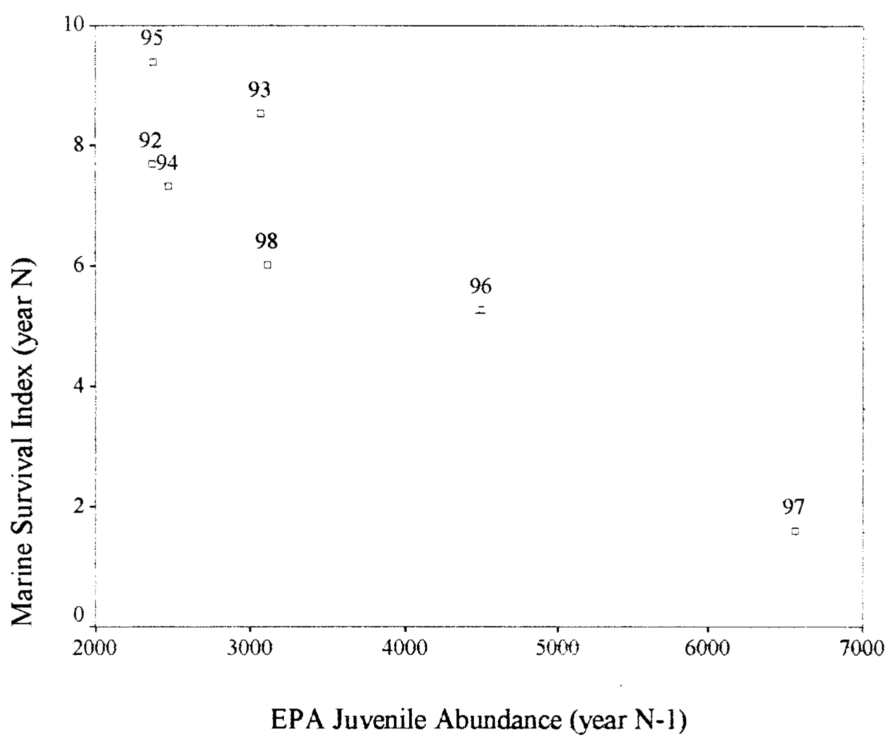

Figure 5. Relationship between small adult salmon returns to the Gander River and EPA juvenile abundance that would be predicted from Equation 1 describing the negative correlation between the marine survival index and juvenile abundance.