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DFO Atlantic Fisheries
Research Document 96/47

MPO Pêches de l'Atlantique
Document de recherche 96/47

Ratio of Adults to Experimental Ponds Area Juveniles in a Prediction of Atlantic Salmon (Salmo salar L.) Returns to the Gander River, Newfoundland in 1996

by

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Abstract

Spring population sizes of juvenile Atlantic salmon were determined by Schnabel multiple, mark-recapture methods in two Experimental Ponds Area (EPA) lakes at the headwaters of the Gander River from 1979-95. Juvenile abundance in 1995 was considerably higher than expected as indicated by a previously derived stock-recruit relationship between juvenile abundance and adults returning to the Salmon Brook fishway on a lower river tributary four years earlier.

Total river adult (small salmon <63 cm) returns were obtained over the period 1989-95 at the counting fence near the mouth of the river and the fish angled downstream of the fence. Changes in the ratios of returning small salmon to the juvenile abundance one year earlier were indicative of a more than fourfold (4.8 X) increase in the average marine survival of Gander River salmon following closure of the commercial fishery in 1992. Total river adult returns in 1996 were projected from 1995 juvenile abundance and the post-commercial fishery ratio of returning small salmon to the juvenile abundance one year earlier. Projections indicate that 37,014 small salmon will return to the Gander River to spawn in 1996 and will exceed the current target spawning requirement in 1996.

Résumé

De 1979 à 1995, on a déterminé les effectifs printaniers des jeunes saumons atlantiques par les méthodes de recapture après marquage de Schnable, dans deux lacs de la zone des lacs expérimentaux, aux sources de la rivière Gander. En 1995, l'abondance des jeunes saumons était considérablement supérieure aux résultats attendus à partir du rapport stock/recrutement qui avait été déterminé d'après l'abondance des jeunes saumons et le nombre d'adultes revenant à la passe migratoire de Salmon Brook, dans un tributaire en aval, quatre années auparavant.

La remonte totale d'adultes dans la rivière (petits saumons de moins de 63 cm de longueur) est tirée, pour 1989-1995, des dénombrements à la barrière située près de l'embouchure de la rivière et du nombre de poissons pêchés à la ligne en aval. Les variations du rapport de la remonte de petits saumons à l'abondance des juvéniles un an auparavant indiquent une augmentation de plus du quadruple (4,8 %) de la survie moyenne en mer du saumon de la rivière Gander après la fermeture de la pêche commerciale en 1992. On a extrapolé le nombre total d'adultes de remonte dans la rivière en 1996, à partir de l'abondance des juvéniles en 1995 et du rapport, après la fermeture de la pêche commerciale, de la remonte de petits saumons à l'abondance des juvéniles un an auparavant. D'après les extrapolations, 37 014 petits saumons reviendront frayer dans la Gander en 1996. Ce chiffre excède l'objectif de ponte cible pour 1996.

Introduction

The Gander River (Fig. 1) has insular Newfoundland's largest river basin area that is naturally accessible to sea-run Atlantic salmon (Murray and Harmon 1969). During the past 20 years, commercial marine catches of returning sea-run adults around the mouth of the river in Gander Bay have increased substantially, followed by a marked decline after 1989 (Fig. 2). Concurrently, escapement of spawners to the river, as indicated by freshwater angling success rates, has plummeted (Fig. 3). The minimum or target spawning requirement for the Gander River has been estimated as 21,828 small salmon (O'Connell and Dempson 1991). However, the decreased abundance of adults returning to spawn in the river has, particularly during 1989-91, resulted in an egg deposition of only about 35 % of that requirement (Porter and O'Connell 1992, O'Connell and Ash 1993).

Changes in the fisheries for adult salmon have included, starting in 1992, a closure of the commercial salmon fishery on the island and imposition of a quota in the recreational fishery (with subsequent catch and release fishing) (O'Connell and Ash 1993).

As a result of the changing salmon fisheries and resultant changes in applicable fishing effort statistics, alternate methods to assess the salmon stock in the Gander River system have been explored. One of these was the evaluation of variations in juvenile abundance in two headwater lakes in the Experimental Ponds Area (EPA) (Fig. 4). This evaluation was based upon the assumption that increases in the abundance of juveniles are, unless shown otherwise, indicative of increases in the size of the spawning stock. Previously, it had been shown that the spring population size of juvenile salmon in two EPA lakes prior to 1985 was a strong ($r=0.813$) positive correlate of a catch per unit effort statistic for the subsequent year's angler success (fish/rod/week) in the fishery for returning sea-run adults (Ryan 1986a). After that time, dramatic changes in marine mortality resulted in marked deviations from that relationship (Ryan et al. 1994). Additionally, a recently described stock-recruit relationship, developed from adult escapement to a fishway on a lower tributary of the system (as spawners) and the known abundance of juveniles in the two headwater EPA lakes (as recruits), has served as a means of evaluating management strategies and the attainment of maximum spawner capacity (Ryan et al. 1995).

In this paper we examine two adult-juvenile relationships with data available up to 1995 for the purpose of assessing stock recovery in the Gander River system. Following the methods of Ryan et al. (1995), we update the numerical relationship between adult small salmon (<63 cm) returning to the Salmon Brook fishway (as spawners) and the juveniles in two EPA lakes at the headwaters of the Gander River system (as recruits) four years later. Subsequently, we assess that stock-recruit relationship for current applicability.

Additionally, we update the numerical relationship between the juveniles in the EPA at the headwaters and the adults returning to the entire river system one year later (as determined from a counting fence and angler survey on the main stem of the river since 1989). We then project total river adult small salmon returns in 1996 from the post-commercial fishery ratio of total returning adults to the juvenile abundance one year earlier.

Juvenile Study Areas

Headwater and Spruce ponds are dilute (mean conductance 35 uS · cm^{-1}), brown-water lakes within the Department of Fisheries and Oceans' Experimental Ponds Area (48°19'N; 55°28'W) at the headwaters of the Gander River system (Fig. 4). Their physical and chemical characteristics approximate the average descriptors of water quality in insular Newfoundland (Ryan and Wakeham 1984). Headwater Pond (76.1 ha, maximum depth = 3.3 m, mean depth = 1.1 m) drains 3.5 km to the north into Spruce Pond (36.5 ha, maximum depth = 2.1 m, mean depth = 1.0 m) and the Spruce Pond outlet flows about 155 km northeast to the Atlantic Ocean. The closest known major concentration of salmon spawning substrate is about 12 km downstream of Spruce Pond (Ryan and Wakeham 1984). In addition to anadromous Atlantic salmon, other fishes present in these lakes are the brook trout (Salvelinus fontinalis), the American eel (Anguilla rostrata), and the threespine stickleback (Gasterosteus aculeatus). The history of ecological assessment in the Experimental Ponds Area has been reviewed by Ryan et al. (1994). Reviews of the population dynamics of salmon in the Experimental Ponds Area are available in Ryan (1993a, b) and references therein.

Adult Counting Sites

Detailed maps, analyses, and history of the Gander River fisheries and adult counting facilities (Fig. 1) are available in O'Connell and Ash (1992, 1993), Porter and O'Connell (1992), and references therein. Salmon Brook, a tributary, is downstream of Gander Lake on the main stem of the Gander River. Adult small salmon counted migrating through the fishway there represented 3.8-9.1% of those counted at the Gander River counting fence on the mainstem from 1989 to 1993 (O'Connell and Ash 1994).

An adult counting fence has been operated on the main stem of the Gander River since 1989 (Fig. 1) and total adult small salmon returns to the Gander River system have been calculated as the sum of the number of adults passing through the fence and the number angled downstream of the fence (O'Connell and Ash 1994).

Methods

Juvenile Salmon Abundance

Salmon were censused, concurrently with brook trout, in the spring and fall from 1978-95 in Spruce Pond and from 1979-95 in Headwater Pond using fyke nets and Schnabel multiple mark-recapture techniques as detailed by Ryan (1990). The study was terminated by management in 1988, but subsequently reinstated in 1989. Fish were captured in fyke nets, measured for length, marked with fin holes or clips, released, and recaptured for the computation of population size. Weights and scale samples have been routinely collected as documented by Ryan (1986b).

Following the methods of Ryan (1990), recapture rates during the censuses were compared to the marking rates or expected recapture rates as a test of the validity of census requirements. Recapture rates were calculated simply as the proportion of marked fish in the catch on a given day. The expected recapture rate on a given day was calculated as the number of marked fish in the population at the start of the day expressed as a percentage of the final Schnabel population estimate.

The number of salmon smolts migrating out of the lakes each year up to 1983 has been calculated as the loss in numbers of salmon from each of the age-groups over the spring-to-fall period (Ryan 1986b). Additionally, the calculated number of smolts in those years has been related to the number of salmon present in the lakes in the spring of the year ($r=0.987$) by least-squares regression (Ryan 1986a). Accordingly, we have used spring juvenile abundance here (Table 1) as a readily obtainable index of the smolt migration up to 1995.

Adult (Small Salmon) Abundance

Small salmon (<63 cm) counts at the Salmon Brook fishway in 1974 and from 1978 to 1995 have been documented by O'Connell et al. (1996). Complete fishway counts were not obtained in 1979 but we have used all available data from 1978 to 1995, including the partial count (Table 1).

Total adult small salmon returns to the Gander River system have been calculated as the number of adults passing through the counting fence on the mainstem of the lower river plus the number angled downstream of the fence (O'Connell and Ash 1994). We have used all return counts since installation of the fence in 1989 as updated to 1995 by O'Connell et al. (1996).

Juvenile-Adult Relationships

In order to examine adults as a predictor of subsequent juvenile abundance (stock-recruit), we followed the methods of Ryan et al.

(1995) and compared counts of salmon at the Salmon Brook fishway with juvenile salmon abundance four years later. This reflects the emergence of young the following year plus an average age of pond juveniles in the spring of three years (Ryan 1986b). Successful application of this method requires a proportionality between counts of salmon at the Salmon Brook fishway and adult returns to the total river system but permits a forecast of juvenile abundance four years in advance (Ryan et al. 1995). We then assessed the stock-recruit relationship for its current applicability by a simple examination of deviations from prior trends and by a comparison of Gander River total small salmon returns to the adult count at the Salmon Brook fishway.

In order to examine juveniles as a predictor of adult abundance, juvenile abundance was compared to data on adult returns in the following year to reflect the predominant (94%) one year residence of adults at sea (see O'Connell and Ash 1994). We updated the previously described (Ryan et al. 1995) numerical relationship between the juveniles in the EPA at the headwaters and the adults returning to the entire river system one year later (as determined from the counting fence and angler survey on the main stem of the river since 1989). We then projected total river adult small salmon returns in 1996 from the mean post-commercial fishery ratio of total returning adults to the juvenile abundance one year earlier.

Results

Experimental Ponds Area Juveniles

The expected recapture rates during the last three day's fishing in Spruce Pond averaged 33.4% while the observed recapture rates on those days averaged 29.4%. Similarly, in Headwater Pond, the expected recapture rates during the last three day's fishing averaged 22.8% while the observed recapture rates on those days averaged 25.0%. The differences between expected and observed recapture rates in Spruce and Headwater ponds of 4.0% and 2.2% respectively were similar to the average difference of 3% observed during the censuses of juvenile salmon in the study lakes over the long term (Ryan 1990). The small differences between expected and observed recapture rates are consistent with a close approximation of ideal census requirements during Schnabel multiple, mark-recapture censusing.

The abundance of juvenile salmon in the Experimental Ponds Area has fluctuated during the period 1979 to 1995 (Fig. 5) with a maximum spring population of 4,925 salmon in Spruce and Headwater ponds in 1989 (Table 1). In 1995, the spring juvenile abundance of 4,492 fish was near the high end of the previously recorded range. The pattern of seasonal change continued to be one of comparatively high spring abundance followed by a lower fall abundance after smoltification and the seaward migration.

Current Applicability of the Stock-Recruit Curve

The spring 1995 population size of Experimental Ponds Area juveniles deviated markedly from the previously described (Ryan et al. 1995) stock-recruit relationship between juveniles and adult small salmon returns monitored at the Salmon Brook fishway four years earlier (Fig. 6).

The previously described (Ryan et al. 1995) relationship (with all data prior to 1995 included) between juvenile abundance (Y) and adult returns four years earlier (X) was statistically significant:

Equation 1: $Y = 2167.370 + 0.909X;\ r = 0.619;\ N=12;\ p < 0.05.$

However, the spring juvenile year 1985 had been deleted from that regression for predictive purposes as a result of an hypothesized much lower than expected number of juveniles in the ponds in 1985 due to extreme regional flooding in January of 1983 (Environment Canada 1983) and the fact that the data point (corresponding to the 1981 fishway count) was well outside the range of data used in projections. With the juvenile year 1985 deleted from that regression (Equation 1), seventy-four percent of the variation in juvenile abundance (Y) was accounted for by adult returns four years earlier (X):

Equation 2: $Y = 1468.360 + 1.776X;\ r = 0.859;\ N=11;\ p < 0.01.$

The inclusion of the 1995 juvenile census result in the analysis with all data included did not result in a relationship of statistical significance ($N = 13$; $r = 0.392$; $p > 0.05$). Furthermore, the inclusion of the 1995 juvenile census in the analysis with the juvenile year 1985 deleted did not result in a relationship of statistical significance ($N = 12$; $r = 0.558$; $p > 0.05$). As a result of the dramatic departure of the spring juveniles in 1995 from previously recognized trends, we did not employ the stock-recruit curve in our projections.

Possible reasons for the radical departure of the spring 1995 juvenile population from the previously recognized stock-recruit curve, were explored by a comparison of Gander River total small salmon returns to the adult count at the Salmon Brook fishway (Fig. 7). A strong relationship between the variates was apparent ($r = 0.965$; $p < 0.01$). Accordingly, the departure of the spring juveniles in 1995 from previously recognized trends could not be attributed to the absence of a proportionality between counts of salmon at the Salmon Brook fishway and adult returns to the total river system.

Gander River Adults Related to Juveniles One Year Earlier

Examination of the relationship between the spring estimate of abundance of Experimental Ponds Area juveniles and the total adult small salmon returns to the Gander River system in the subsequent year revealed a distinct separation of data points corresponding to the periods before and after the closure of the commercial fishery (Fig. 8). The mean survival ratio index (ratio of adult returns to EPA juveniles in the previous year) of 1.71 for the two years prior to the closure of the commercial fishery in 1992 increased to a mean of 8.24 for the four years after ($t = -8.05$; $p < 0.01$) (Table 2). This difference was consistent with previously described increases in salmon survival after the closure of the commercial fishery (Ryan et al. 1995) and was indicative of a more than fourfold increase in marine survival rates.

Projected Adult Abundance in 1996

Juvenile abundance in 1995 multiplied by the mean post-commercial fishery ratio of adults to juveniles in the previous year provided a projection of Gander River small salmon returns to 1996 (Table 1, Figure 9). Calculations indicate a high level of adult returns to the Gander River in 1996 with returns in that year calculated as 37,014 small (<63 cm) salmon.

Discussion

Validity of Juvenile Census Data

Juvenile census results of the type employed here have been previously verified by comparisons of calculated frequencies of marked fish in the lakes with observed frequencies in catches and by the relationships between catch per unit effort and census results (Ryan 1990). However, census data do not provide precise point estimates due to the fact that census assumptions of no emigration or immigration are not completely satisfied (Ryan 1990). This shortcoming has been minimized through empirical analysis and design optimization (Knoechel and Ryan 1994). Additionally, the small differences between expected and observed recapture rates during the spring 1995 juvenile census are consistent with a close approximation of ideal census requirements.

Gander River Stock-Recruit Curve

It is evident from Figure 6 that the abundance of adult salmon returning to the Gander River to spawn has been a major determinant of the subsequent abundance of juveniles. However, two distinct departures from the trend described by the stock-recruit curve suggest that marked variations in year-class strength may be too frequent to allow for accurate long-term prediction.

As discussed by Ryan et al. (1995), the outlier in the stock-recruit curve (Fig. 6) corresponding to fishway year 1981 may have resulted from a flooding of the river system in January of 1983 which could have reduced the strength of the 1982 year class. Young salmon produced by the 1981 adult run would have been underyearling fish during that flood and susceptible to high mortality.

Similarly, the conspicuous departure of the 1995 juvenile population from the stock-recruit curve was suggestive of an atypically high freshwater survival rate of one or more year classes occupying the lakes in the spring of 1995.

The close correspondence between Salmon Brook fishway counts and total river adult returns suggests that adult counts at the Salmon Brook fishway will serve as a valid indication of adult escapement to the Gander River. However, since freshwater survival has the potential to be highly variable, juvenile counts are likely to serve as a more accurate predictor of adults than are counts of the preceding generation of adults. Accordingly, censusing of juveniles prior to smoltification can be expected to serve as the more accurate means of evaluating angling management strategy and the attainment of maximum spawner capacity.

Impact of the Fishery Closure

The distinct separation of Figure 8 data points which correspond to the periods before and after the closure of the commercial fishery indicates a dramatic increase in juvenile to adult survival after the fishery closure. These results are indicative of a more than fourfold (4.8 X) increase in the average marine survival of Gander River salmon following closure of the commercial fishery in 1992.

Projected Time of Stock Recovery

The target spawning requirement for the Gander River, or the minimum number of spawners required for sustained production, has been estimated as 21,828 small salmon (O'Connell and Dempson 1991). Projections of the present study, 37,014 small (<63 cm) salmon returning to the river in 1996, are that the number of salmon returning to the Gander River to spawn will exceed that amount.

Use of the present method (ratio of adults to juveniles) to predict the adult returns to the Gander River one year in advance has previously resulted in a conservative projection. The difference of 3,659 salmon between the observed returns in 1995 and the returns projected from the juvenile 1994 data (Ryan et al. 1995) represents 16% of the actual 1995 count, indicative of a slightly faster stock recovery than previously anticipated.

Large fluctuations in the number of adult returns, such as those evident from 1993 to projected 1996 levels, will likely persist due to variations in juvenile year class strength. These fluctuations will be evident during future juvenile assessments and permit updating of potential harvest levels as stocks continue to recover. However, substantial departures of marine survival rates from recent levels will result in deviations from projected adult returns.

Acknowledgements

A large number of Fisheries and Oceans staff and Memorial University students have assisted with data collections in the Experimental Ponds Area over the years. We especially appreciate the assistance of C. E. Campbell, K. Clarke, L. J. Cole, D. P. Riche, and D. Wakeham. Graduate students of Memorial University continue to assist with data collection. N. Cochrane provided invaluable assistance with collection and processing of Gander River adult data. The Newfoundland Region Atlantic Salmon Stock Assessment Committee, especially J. B. Dempson, reviewed the manuscript.

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Table 1. Spring Atlantic salmon juvenile population sizes in the EPA to 1995, Salmon Brook fishway small salmon (<63 cm) counts, and Gander River small salmon returns projected to 1996.

Year of Census	Spruce and Headwater ponds total Atlantic salmon juveniles (no.)	Salmon Brook fishway count (no.)(yr N)* (partial count- '79, adjusted count- '90)	Gander River total small salmon returns (yr N)* (no. calculated 1996 with 95% confidence interval bracketed)
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	7743
1990	3642	345	7740
1991	2362	245	6745
1992	3069	1168	18179
1993	2470	1560	26205
1994	2370	963	18080
1995	4492	1600	22264
1996			37014 (23835 - 50193)
1997			

* From O'Connell, Reddin, and Ash: DFO Atlantic Fisheries Research Document 96/ (in preparation).

Table 2. Ratios of Gander River small salmon returns to EPA juveniles in the previous year with survival ratio indices before and after the closure of the commercial fishery in 1992.

Year of Census	Spruce and Headwater ponds total Atlantic salmon juveniles (yr N)	Gander River total small salmon returns (yr N+1)	Survival ratio index (adults/juveniles)
1989	4925	7740	1.57
1990	3642	6745	1.85
1991	2362	18179	7.70
1992	3069	26205	8.54
1993	2470	18080	7.32
1994	2370	22264	9.39
		Mean ratio	6.06
		Mean pre-closure ratio (S. E.)	1.71 (0.198)
		Mean post-closure ratio (S. E.)	8.24 (0.922)

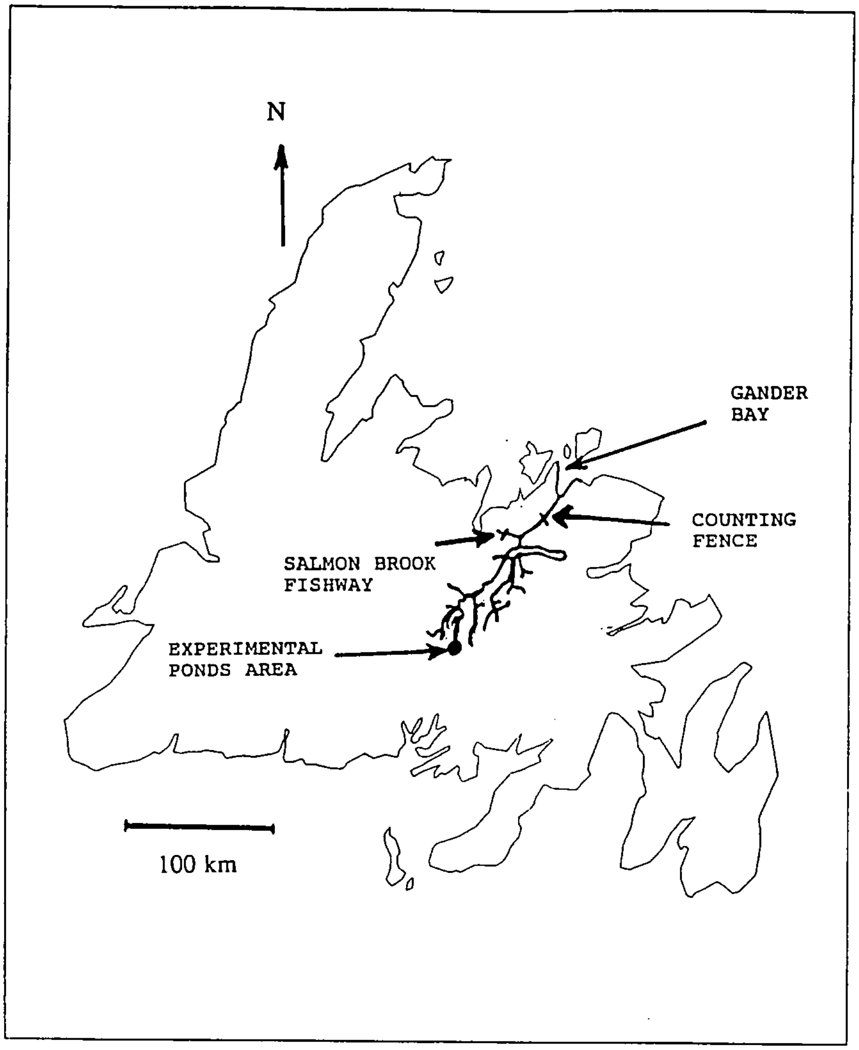
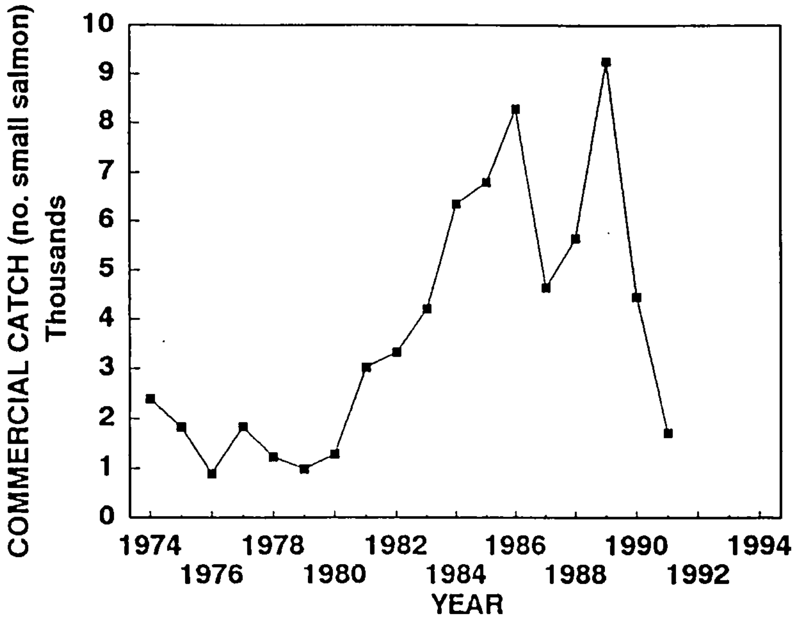


Figure 1. Gander River basin of insular Newfoundland with locations of study sites referred to in the text.

Figure 2. Commercial catch of small salmon (returning sea-run adults less than 63 cm in length) in Gander Bay at the mouth of the Gander River, insular Newfoundland. Small salmon have historically represented in excess of 90% of all adults escaping to the river. For additional numerical detail, see Porter and O'Connell (1992).



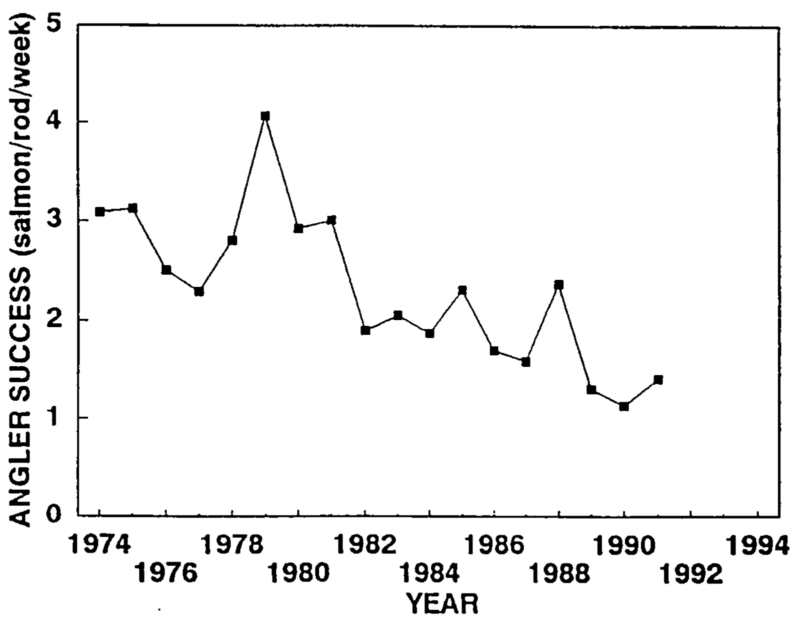
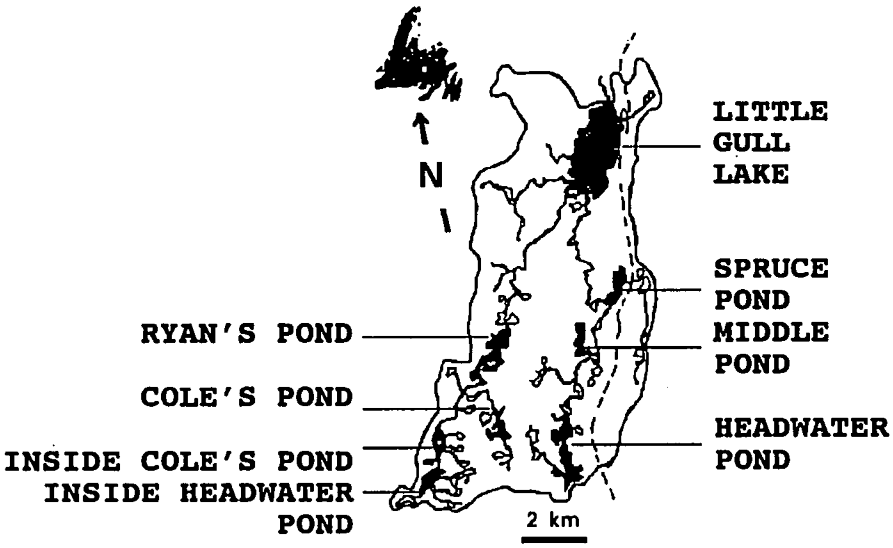


Figure 3. Angler success in the Gander River, insular Newfoundland.

Figure 4. 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 is the Bay D' Espoir highway.



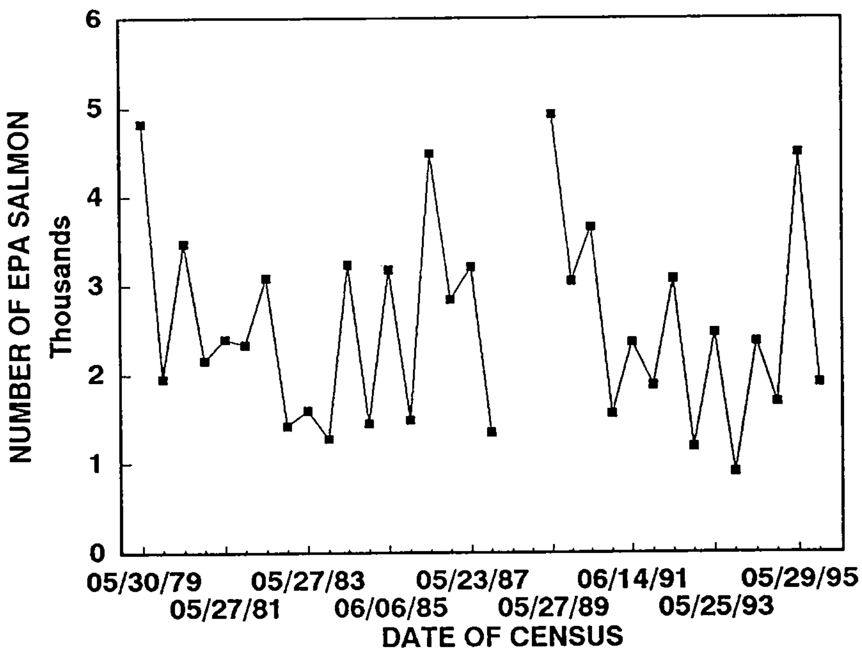


Figure 5. Schnabel population estimates of Experimental Ponds Area (EPA) juvenile salmon (Headwater and Spruce ponds combined) in the spring and fall, 1979-95.

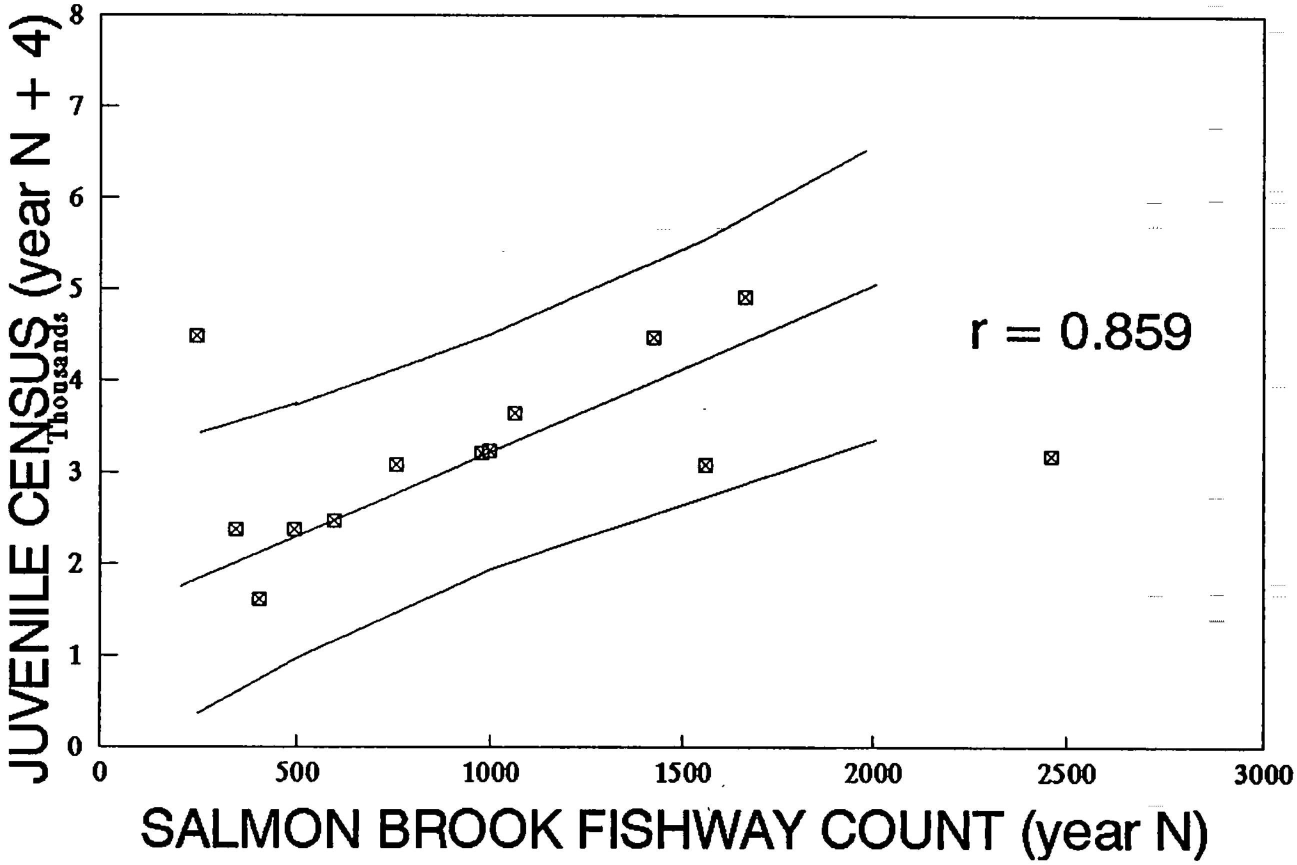


Figure 6. Stock-recruit relationship for the Gander River system based upon counts of small salmon (<63 cm) at the Salmon Brook fishway and the spring census of juveniles in the Experimental Ponds Area four years later. The two obvious outliers are juvenile years 1985 (far right) and 1995 (top left). The regression equation with the 1985 and 1995 juvenile data removed is:

Equation 2: $Y = 1468.360 + 1.776X$; $r = 0.859$; $N=11$; $p < 0.01$

The 95% confidence belt about the regression is shown.

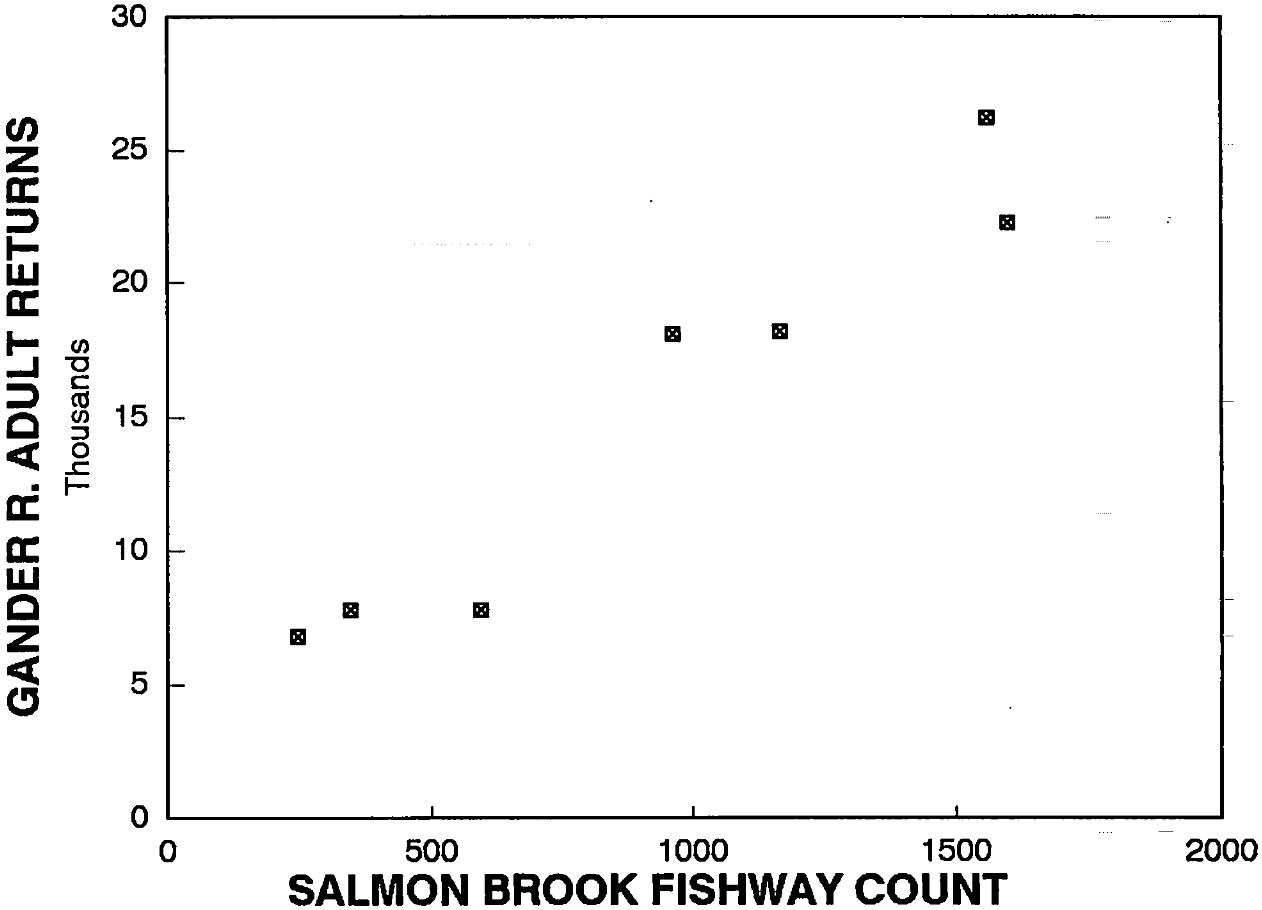


Figure 7. Proportionality between small salmon returns to the Gander River in its entirety (Y) and counts of small salmon at the Salmon Brook fishway (X), 1989-95. The trend between the variates can be described by:

Equation 3: $Y = 2553.541 + 13.753X$; $r = 0.965$; $N=7$; $p < 0.01$

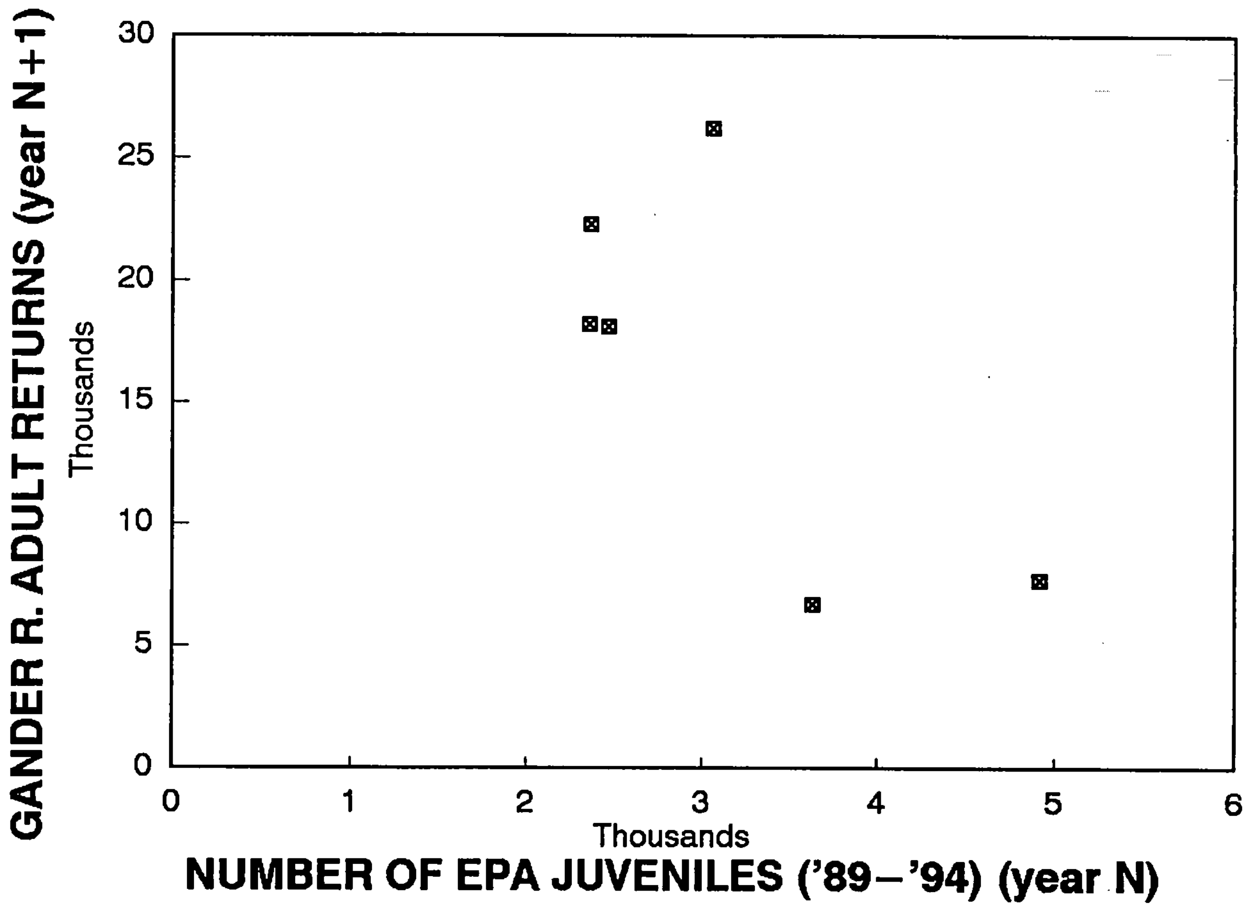


Figure 8. Decreased marine mortality of Gander River Atlantic salmon associated with the closure of the commercial salmon fishery in 1992 as indicated by total Gander River small salmon returns and the spring census of juveniles in the Experimental Ponds Area (EPA) one year earlier. The two data points at the lower right represent adult data from 1990 (far right) and 1991 while the upper four points correspond to the period of no commercial fishery.

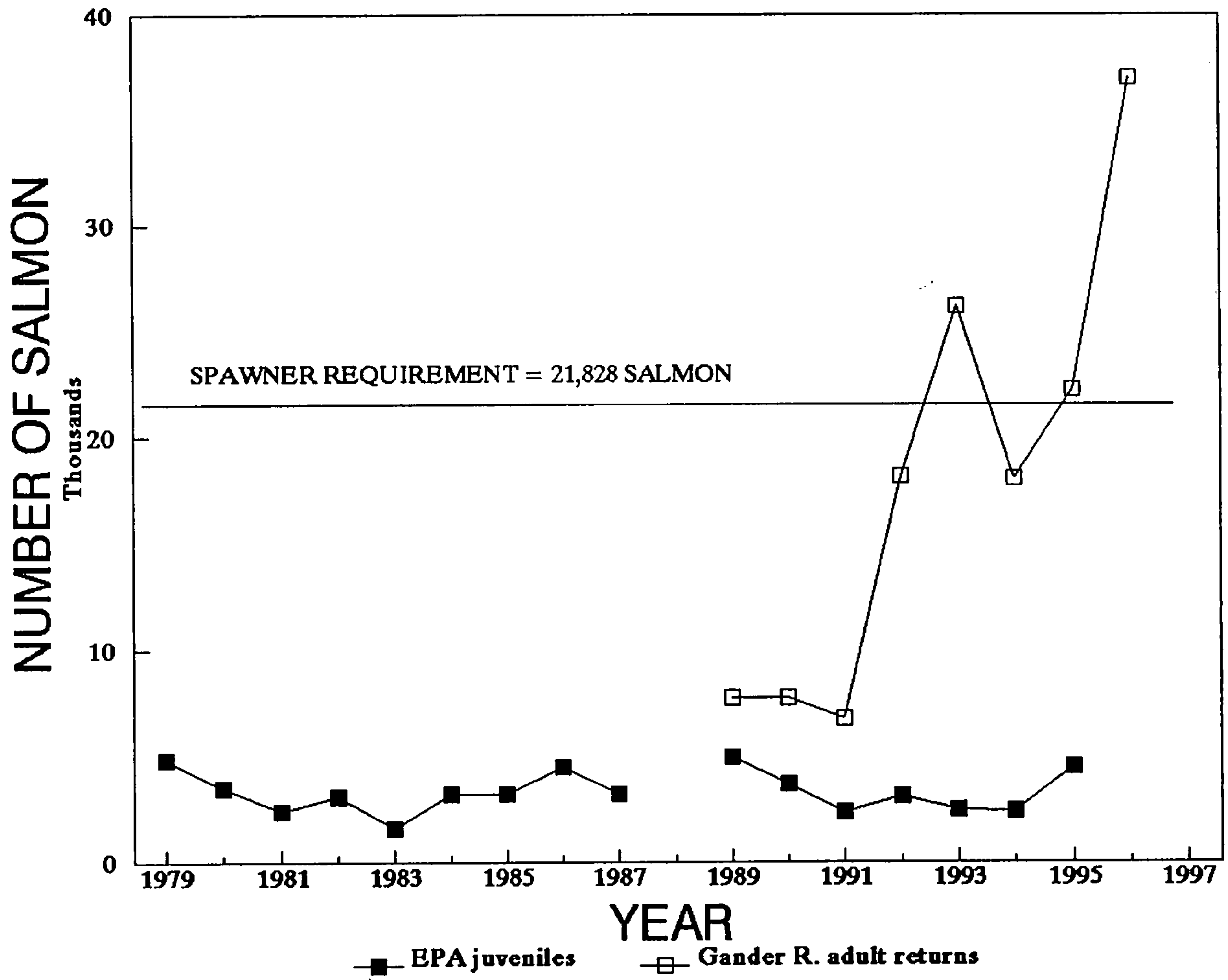


Figure 9. Experimental Ponds Area (EPA) spring juvenile salmon abundance to 1995 and Gander River small salmon returns to 1996. Juvenile numbers to 1995 are from census data. Adult returns to 1995 are actual values while returns for 1996 were calculated from the juvenile numbers and the mean ratio of adults to juveniles in the previous year after the closure of the commercial fishery. Presented for comparison is the estimated target spawning requirement for the Gander River.