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DFO Atlantic Fisheries Research Document 95/95

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MPO Pêches de l'Atlantique Document de recherche 95/95

Atlantic Salmon (Salmo salar L.) Stock Recovery in the Gander River, Newfoundland With Projections to 1999

by

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Abstract

A significant stock-recruit relationship was documented between the spring population sizes of juvenile Atlantic salmon in two Experimental Ponds Area (EPA) lakes at the headwaters of the Gander River from 1979-94 and counts of adult small salmon (<63 cm) at the Salmon Brook fishway four years earlier. Total river adult returns to 1999 were projected from juvenile abundance estimated for 1995 to 1998 from the stock-recruit relationship and the post-commercial fishery ratio of small salmon returning to the entire river system and the EPA juvenile abundance one year earlier. Results indicate that the number of salmon returning to the Gander River to spawn will not exceed the estimated spawning requirement in 1995 or 1996 but should exceed the requirement from 1997-99. Maximum returns over that period are calculated as 33,276 small salmon in 1998.

Résumé

On a documenté une relation significative stock-recrues entre l'effectif de la population printanière de saumons de l'Atlantique juvéniles dans deux sites expérimentaux de lacs situés dans le cours supérieur de la rivière Gander de 1979 à 1994 et les dénombrements de petits saumons adultes (<63 cm) à la passe migratoire du ruisseau Salmon quatre ans auparavant. On a établi une projection du nombre total de remontées de saumons adultes jusqu'en 1999, à partir de l'abondance des juvéniles estimée pour la période 1995-1998 selon la relation stock-recrues et la proportion de petits saumons revenant dans tout le réseau hydrographique postérieurement à la pêche commerciale, ainsi que l'abondance des juvéniles dans les sites expérimentaux un an auparavant. Les résultats révèlent que le nombre de saumons remontant dans la rivière Gander pour frayer n'excédera pas les besoins estimés de frayeurs en 1995 ou en 1996, mais que cela devrait être le cas en 1997-1999. Le nombre maximal de remontées serait de 33 276 petits saumons en 1998.

Introduction

Atlantic salmon returning as adults to spawn in the Gander River system of insular Newfoundland have been in low abundance, particularly during 1989-91; resulting in an egg deposition of only about 35 % of that required for the river (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).

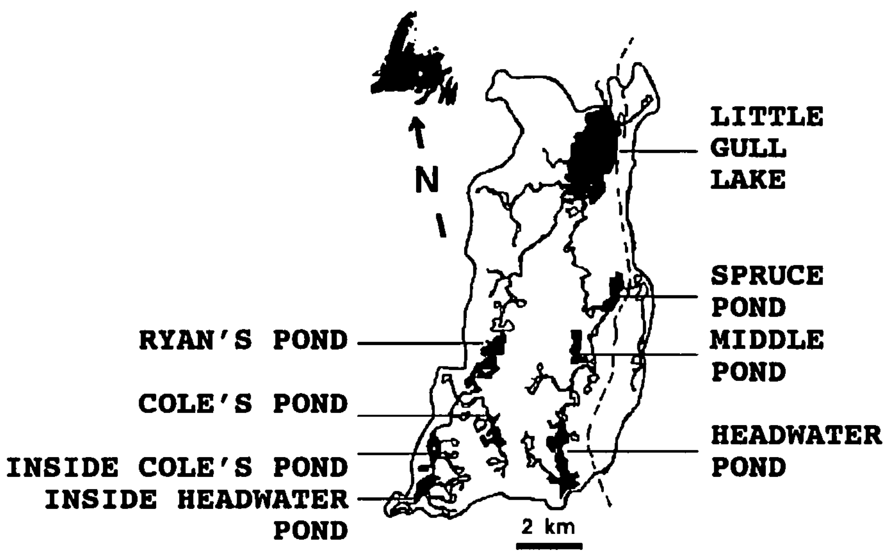
As a result of the changing salmon fisheries and resultant changes in applicable fishing effort statistics, alternate methods to assess the salmon stock in the Gander River system have been explored. One of these was the evaluation of variations in juvenile abundance with the assumption that increases 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 lakes at the headwaters of the Gander River 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) (Ryan 1986a). After that time, dramatic changes in marine mortality resulted in marked deviations from the positive relationship between the abundance of young and the abundance of adults escaping to the river (Ryan et al. 1994). However, it was expected that 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 lakes (as recruits), would serve as a means of evaluating management strategies and the attainment of maximum spawner capacity (Ryan et al. 1994).

In this paper we examine two adult-juvenile relationships with data available up to 1994 for the purpose of assessing stock recovery in the Gander River system. Following the methods of Ryan et al. (1994), we update the numerical relationship between adult small salmon (<63 cm) returning to the Salmon Brook fishway and the juveniles in two lakes at the headwaters of the Gander River system (as recruits) four years later. For the first time we examine the numerical relationship between those juveniles 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). Subsequently, we estimate juvenile abundance from 1995 to 1998 from the stock-recruit relationship and then project total river adult small salmon returns from 1995 to 1999 from the post-commercial fishery ratio of total returning adults to the EPA 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. 1). 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.

Figure 1. 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.



Adult Counting Sites

Detailed maps, analyses, and history of the Gander River fisheries and adult counting facilities 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 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 1978-94 in Spruce Pond and from 1979-94 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).

The age composition of the population during each census up to 1983 has been calculated from the ages and lengths of subsampled fish, the lengths of released fish, the computed population size, and their relative proportions using age-length keys (Ricker 1975). Age-specific migrations to and from the lakes were calculated as the differences, by age-group, between censuses. Thus, 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). 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 1994.

Adult (Small Salmon) Abundance

Small salmon (<63 cm) counts at the Salmon Brook fishway in 1974 and from 1978 to 1994 have been documented by O'Connell et al. (1995). Complete fishway counts were not obtained in 1979 but we have used all available data from 1978 to 1994, 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 1994 by O'Connell et al. (1995).

Juvenile-Adult Relationships

Comparisons between the number of juvenile salmon in the study lakes in spring and adult returns were made with linear regression analyses. In order to examine adults as a predictor of subsequent juvenile abundance (stock-recruit), we 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). 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). Confidence limits (95%) about projected adult returns were obtained from the t distribution (1995 projection) and 20,000 Monte Carlo realizations (1996-99 projections).

Results

Juveniles Related to Salmon Brook Adults Four Years Earlier

The abundance of juvenile salmon in the Experimental Ponds Area has fluctuated during the period 1979 to 1994 (Fig. 2) with a maximum spring population of 4,925 salmon in Spruce and Headwater ponds in 1989 (Table 1). The pattern of seasonal change has been one of comparatively high spring abundance followed by a lower fall abundance after smoltification and the seaward migration.

The spring population size of Experimental Ponds Area juveniles demonstrated a strong stock-recruit relationship with adult small salmon returns monitored at the Salmon Brook fishway four years earlier, except for two notable outliers (fishway years 1981 and 1988) (Fig. 3). With all data included, the relationship between juvenile abundance (Y) and adult returns four years earlier (X) was statistically significant:

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

Anomalous environmental conditions, in the form of extreme regional flooding, are known to have occurred in January of 1983. In that month, precipitation at Bay D'Espoir was 325% of normal and 238.5 mm of rain were recorded on January 12-13, 1983. Precipitation on those two dates represented 77% of the total for the month (Environment Canada 1983). Travel by road to the Experimental Ponds Area was not possible due to road washouts.

It was hypothesized that the January 1983 flooding may have been associated with an atypically high mortality of underyearling salmon during the winter of 1983 thereby resulting in a much lower than expected number of juveniles in the ponds in 1985. Additionally, the data point corresponding to the 1981 fishway count was obviously atypical within the 12 year trend. The data point was well outside the range of data we wished to use in our projections. Accordingly, we deleted fishway year 1981 from the regression for predictive purposes.

We are not aware of any unusual environmental circumstances associated with fishway year 1988 and we retained the associated data point for predictive purposes.

With the 1981 salmon count at the fishway (corresponding to juvenile year 1985) deleted from the stock-recruit curve (Fig. 3), seventy-four percent of the variation in juvenile abundance (Y) was accounted for by adult returns four years earlier (X):

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

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. 4). 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 7.85 for the three years after ($t = 9.37$; $p < 0.01$) (Table 2). This difference was indicative of a more than fourfold increase in marine survival rates.

Projected Juvenile Abundance to 1998 and Adult Abundance to 1999

The regression equation 2 of Figure 3 provided calculated values of juvenile abundance in the Experimental Ponds Area for 1995-1998 (Table 1, Fig. 5). Use of those calculated juvenile abundance values and the mean post-commercial fishery ratio of adults to juveniles in the previous year provided a first projection of Gander River small salmon returns to 1999 (Table 1, Figure 5).

Calculations indicate a high level of variability in future adult returns but our projections do indicate a more than quadrupling of pre-moratorium returns to the Gander River by 1998 with returns in that year calculated as 33,276 salmon.

Discussion

Validity of Juvenile Census Data

The validity of census results for stock assessments has been previously verified by comparisons of calculated frequencies of marked fish in the lakes on the next-to-last sampling days with observed frequencies in the final census samples 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).

Accordingly, census results have provided a practical way of monitoring the juvenile stock. Additionally, it is apparent from the internal consistencies in the results herein (i.e. correspondence of juvenile densities to counts at the fishway and adult returns) that valuable inferences can be drawn concerning the status of the Gander River salmon.

Gander River Stock-Recruit Curve

It is evident from Figure 3 that the abundance of adult salmon returning to the Gander River to spawn has been the major determinant of the subsequent abundance of juveniles. The outliers in the stock-recruit curve (Fig. 3) likely resulted from one or more unusual environmental factors during the four-year interval between adult return and the subsequent assessment of juveniles, thereby resulting in a dramatic variation in year-class strength. It seems probable that flooding of the river system in January of 1983 was the cause of the reduced strength of the 1982 year class. Young salmon produced by the 1981 adult run would have been underyearling fish during the flood of January 1983.

Generally, it has been observed that salmon parr survival is positively related to stream discharge in both summer and winter. However, mortality rates of parr tend to be highest among underyearlings and, where suitable habitats are lacking, survival over winter is expected to be poor (Symons 1979, Gibson 1993). Young salmon may obtain higher survival rates by entering lakes but in insular Newfoundland the first lakeward migrations of salmon from streams typically occur after the first year of life (Ryan 1993b). Underyearling salmon in the stream environment during January of 1983 would have been subjected to displacement due to flood conditions and physical habitat disruption due to ice scour.

It appears that adult counts at the Salmon Brook fishway will serve as an indication of adult escapement to the Gander River but, since that fishway is located on a tributary well downstream on the river system, it may not provide an indication of recovery of the Gander stock in its entirety. The Salmon Brook tributary could be adequately seeded in the future while the remainder of the Gander River system remained below carrying capacity. Should this occur, it should become apparent in the form of radical deviations from the existing stock-recruit curve (Fig. 3). We expect that, if the Salmon Brook fishway counts continue to be a representative measure of adult escapement, the stock-recruit curve being developed from Experimental Ponds Area data will serve as a means of evaluating angling management strategy and the attainment of maximum spawner capacity.

Impact of the Fishery Closure

The distinct separation of Figure 4 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 provide the first indication of the expected substantial increase in the 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 number of spawning salmon required for maximum production, has been estimated as 21,828 small salmon (O'Connell and Dempson 1991). From 1989 to 1991, low numbers of salmon returning to spawn in the Gander River system resulted in an egg deposition of about 35 % of that required for the river (Porter and O'Connell 1992, O'Connell and Ash 1993). Results of the present study suggest that the number of salmon returning to the Gander River to spawn will not exceed the estimated spawning requirement in 1995 or 1996. Our projections indicate that the estimated spawning requirement should be exceeded from 1997-99.

Large fluctuations in the number of adult returns, such as those evident from 1993 to projected 1999 levels, will likely persist due to variation in juvenile year class strength. These fluctuations will be evident in advance during future juvenile assessments and permit updating of potential harvest levels as stocks continue to recover. At this time, projected stock levels, by themselves, should not be used as a basis for stock management due to the fact that only 3 years of post-commercial fishery data are available. Substantial departures of freshwater and marine survival rates from recent levels may result in deviations from projected adult returns. Accordingly, the projections should, without corroboration, only be considered as first estimates and as a documented test of the methods employed for comparison with subsequent assessments.

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 assist with current data collections. The Newfoundland Region Atlantic Salmon Stock Assessment Committee reviewed the manuscript.

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Table 1. Spring Atlantic salmon juvenile population sizes in the EPA projected to 1998, Salmon Brook fishway small salmon (<63 cm) counts, and Gander River small salmon returns projected to 1999.

Year of Census	Spruce and Headwater ponds total Atlantic salmon juveniles (no. calculated '95-'98)	Salmon Brook fishway count (no.)(yr N)* (partial count- '79, adjusted count- '90)	Gander River total small salmon returns (yr N)* (no. calculated '95-'99 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	1903		18605 (12231 - 24978)
1996	3543		14942 (3390 - 27687)
1997	4239		27810 (15053 - 42310)
1998	3179		33276 (18479 - 49859)
1999			24952 (12805 - 38836)

* From O'Connell, Reddin, and Ash: DFO Atlantic Fisheries Research Document 95/ (in preparation).

Table 2. Ratios of Gander River total adult 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
		Mean ratio	5.40
		Mean pre-closure ratio (S. E.)	1.71 (0.198)
		Mean post-closure ratio (S. E.)	7.85 (0.625)

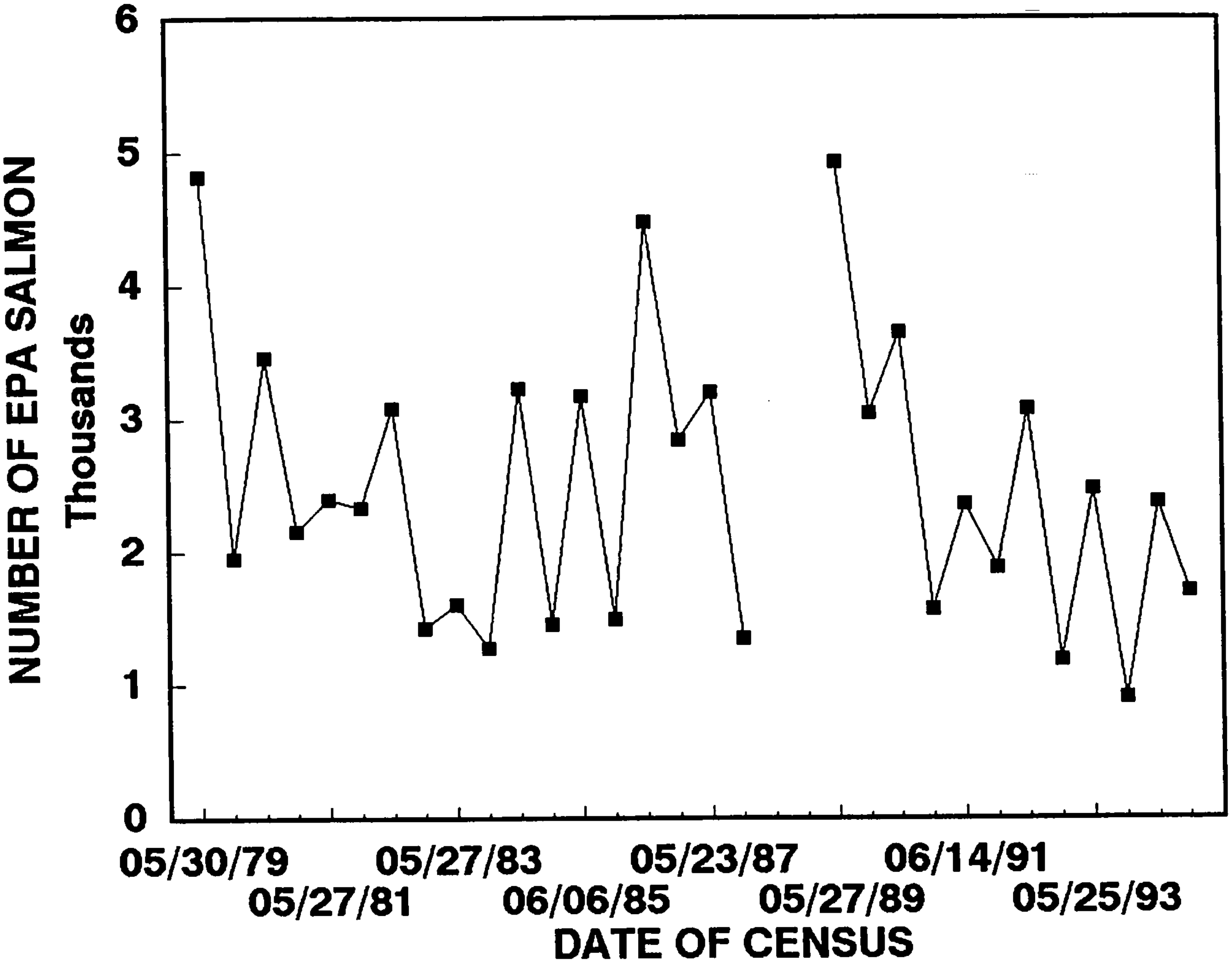

Figure 2. Schnabel population estimates of Experimental Ponds Area (EPA) juvenile salmon (Headwater and Spruce ponds combined) in the spring and fall, 1979-94.

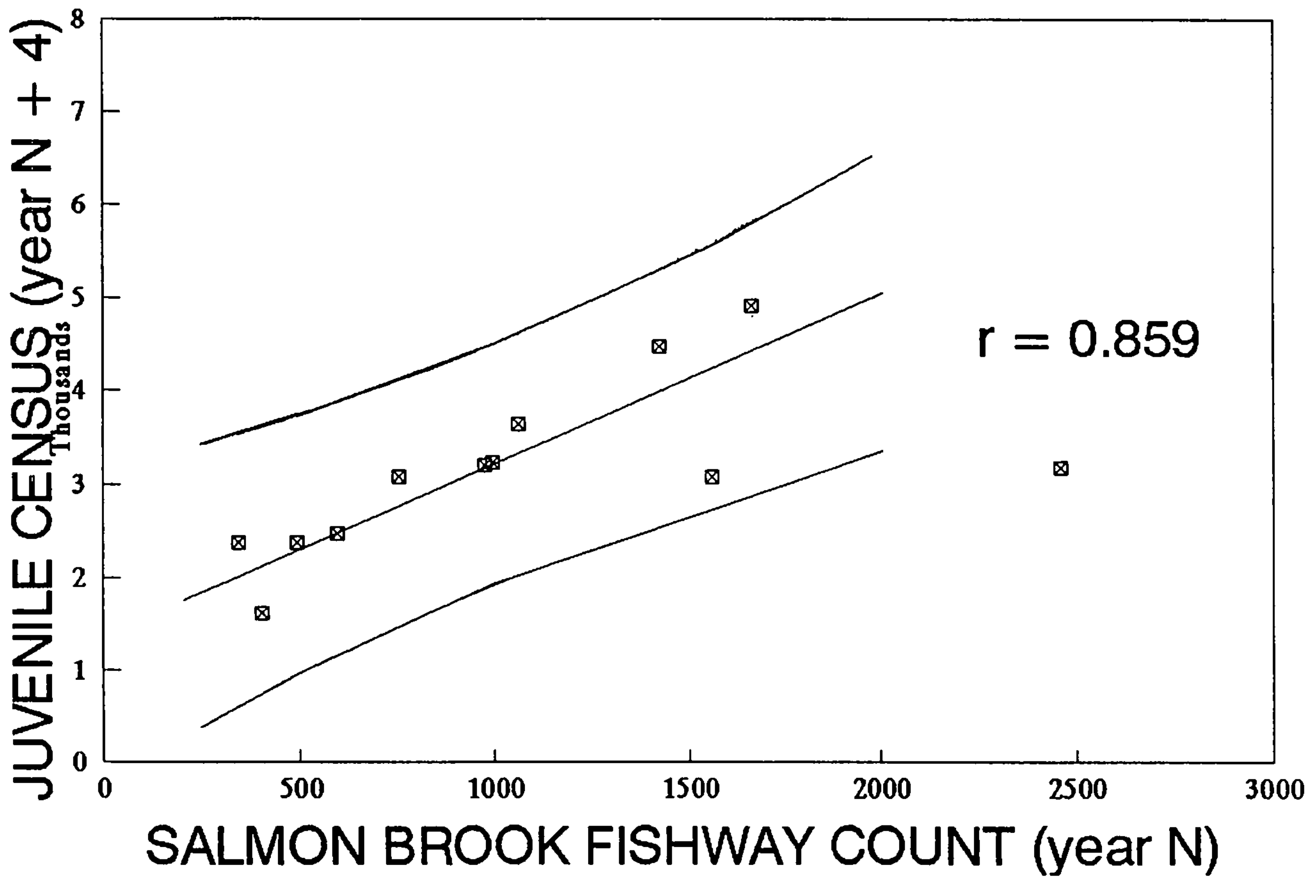

Figure 3. Stock-recruit relationship for the Gander River system based upon counts of small salmon (<63 cm) at the Salmon Brook fishway and the spring census of juveniles in the Experimental Ponds Area four years later. The two obvious outliers are fishway years 1981 (far right) and 1988. The regression equation with the 1981 fishway 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.

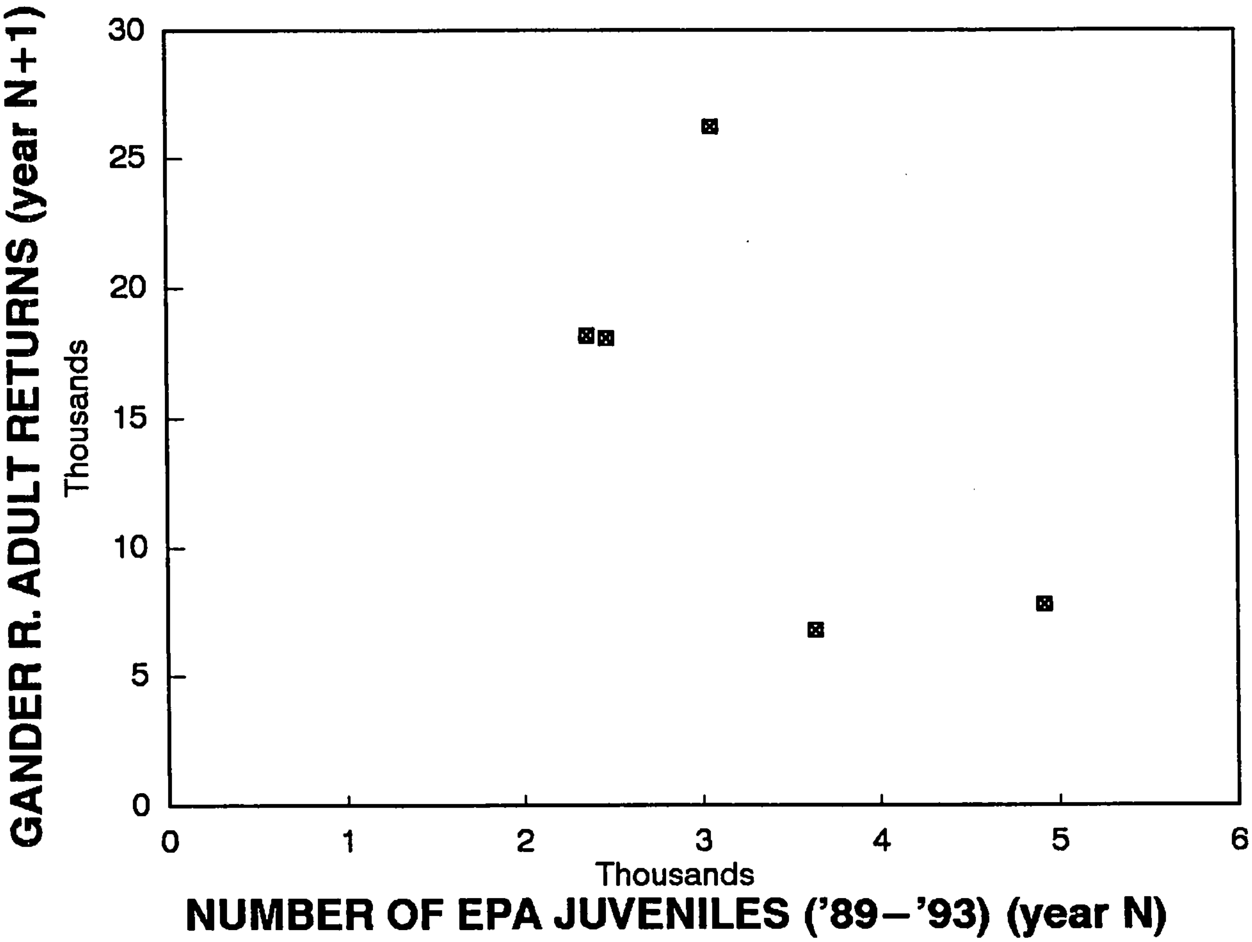

Figure 4. Decreased marine mortality of Gander River Atlantic salmon associated with the closure of the commercial salmon fishery in 1992 as indicated by total Gander River small salmon returns and the spring census of juveniles in the Experimental Ponds Area (EPA) one year earlier. The two data points at the lower right represent adult data from 1990 (far right) and 1991 while the upper three points correspond to the period of no commercial fishery.

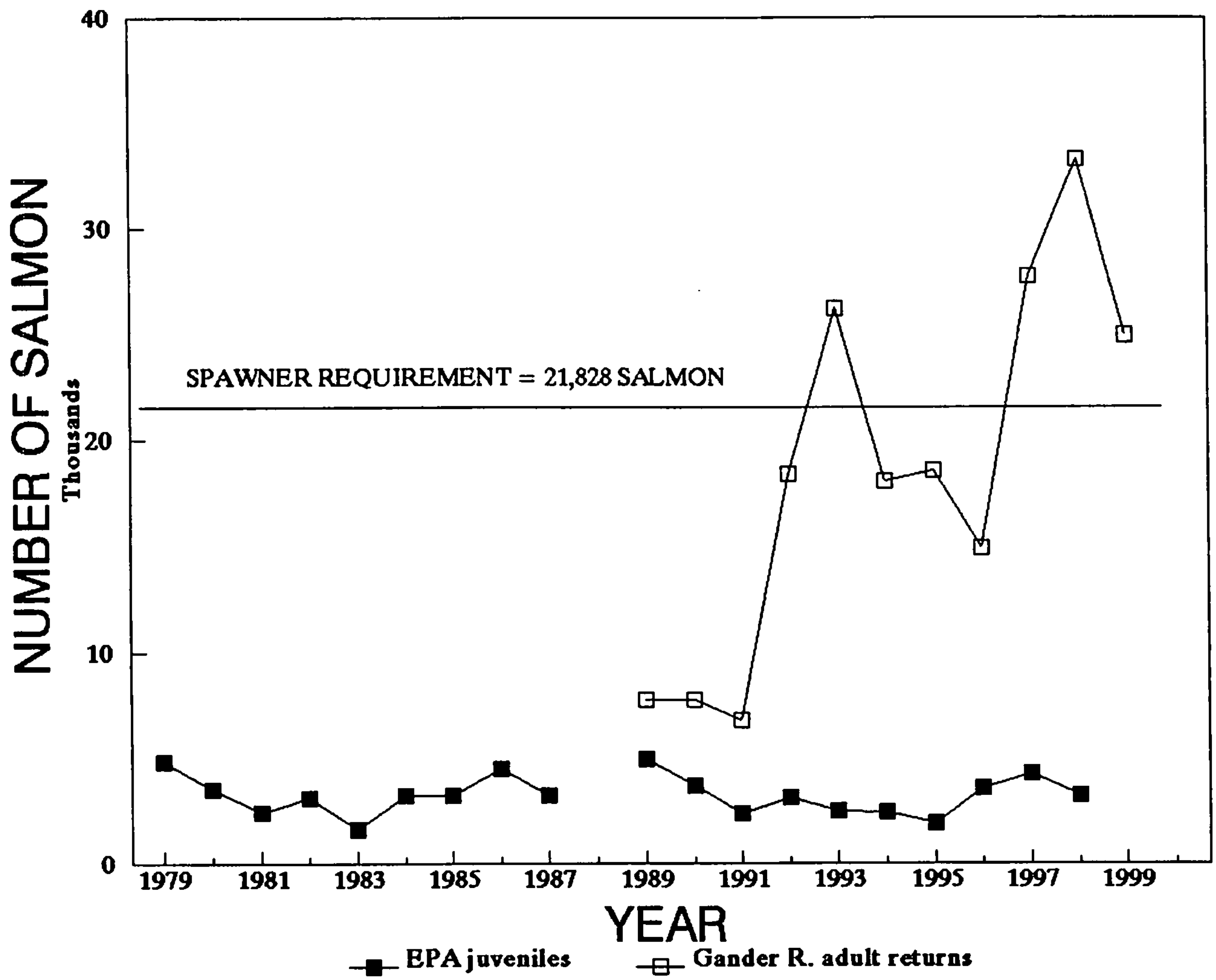

Figure 5. Experimental Ponds Area (EPA) spring juvenile salmon abundance to 1998 and projected Gander River small salmon returns to 1999. Juvenile numbers for 1995-98 were calculated from equation 2 of Figure 3 while data from other years are measured values. Adult returns to 1994 are actual values while returns for 1995-99 were calculated from the estimated juvenile numbers (from equation 2) 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.