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Indices of marine habitat for Atlantic salmon (*Salmo salar*) and trends in survival of hatchery-origin smolts

by

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[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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Abstract

The variability of marine habitat indices for Atlantic salmon (*Salmo salar*) and correlation with annual return rates of hatchery-reared smolts is examined. Marine habitat indices for the months of January to April were used as independent variates in regression of annual survival rates of one-sea-winter grilse and two-sea-winter salmon for the Saint John, LaHave and Liscomb rivers. Covariate techniques were required to de-trend return rates and identify significant partitioning of data into pre- and post-1984 Salmon Management Plan which closed or reduced interception of salmon. "Plan" effect was not significant (p>0.05) in grilse or salmon returns to Saint John River and return rate had a significant negative trend for both grilse and salmon. Return rates for both grilse and salmon were significantly correlated with maximum habitat area of January to April in the grilse winter-at-sea , but did not account for as much of the variation as the temporal trend. "Plan" was not significant for Liscomb River grilse return rates and was marginally significant (p=0.049) for the salmon return rates. Negative trends in Liscomb return rates were marginally signifcant (p=0.051) for grilse and significant (p=0.005) for salmon in the post-plan years. January habitat index in the return year accounted for more of the variation in return rates than temporal trend for Liscomb data. "Plan" effect for Lahave River return rates was significant for grilse but not for salmon and January habitat accounted for about the same amount of variation as marginally-significant negative temporal trends in return rates. The analysis indicated that even though the plan reduced interception and caused a significant increase in marine survial in some stocks and ages, a decline in marine survival continued. Marine survival for these hatchery stocks was better associated with indices of marine habitat than simple negative linear trend. The possibe causes of these associations are discussed as well as suggestions for improved forecast models of both hatchery and wild returns to rivers.

Resumé

Nous examinons la variabilité des indices de l'habitat marin pour le saumon atlantique (*Salmo salar*) et sa corrélation avec les taux annuel de retour de smolts d'élevage. Nous avons employé les indices de l'habitat marin pour les mois de janvier à avril comme variables aléatoires indépendantes dans la régression des taux annuels de survie des grilses unibermarins et des saumons dibermarins pour les rivières Saint-Jean, LaHave et Liscomb. Le recours à des techniques de covariation a été nécessaire pour éliminer les tendances des taux de retour et faire ressortir le découpage marqué des données avant et après le Plan de gestion du saumon de 1984, qui a interdit ou réduit les interceptions de saumons. L'effet du Plan n'était pas significatif (p > 0,05) au chapitre des retours de grilses ou de saumons dans la rivière Saint-Jean, et le taux de retour présentait une tendance négative marquée tant pour les grilses que pour les saumons. Les taux de retour tant pour les grilses que pour les saumons présentaient une corrélation significative avec la superficie maximale d'habitat de janvier à avril pendant l'hiver en mer des grilses, mais n'expliquait pas la variation de façon aussi nette que la tendance temporelle. L'effet du Plan n'était pas significatif pour les taux de retour des grilses de la Liscomb, et était marginalement significatif (p = 0,49) pour les taux de retour des saumons. Les tendances négatives des taux de retour de la Liscomb étaient marginalement significatifs (p = 0,051) pour les grilses et significatifs (p = 0,005) pour les saumons dans les années qui ont suivi la mise en oeuvre du Plan. L'indice de l'habitat en janvier pendant l'année de retour représentait une plus grande part de la variation des taux de retour que la tendance temporelle dans les données sur la Liscomb. L'effet du Plan sur les taux de retour de la rivière LaHave était significatif pour les grilses mais non pour les saumons, et l'habitat en janvier expliquait à peu près la même part de la variation que les tendances temporelles marginalement significatives des taux de retour. L'analyse indique que, même si le Plan a réduit les interceptions et causé une augmentation significative de la survie en mer chez certains stocks et à certains âges, le déclin de la survie en mer s'est poursuivi. La survie en mer de ces stocks d'élevage était mieux associée aux indices de l'habitat marin que la simple tendance linéaire négative. Nous analysons les causes possibles de ces associations et faisons des suggestions pour l'amélioration des modèles prévisionnels pour le retour vers les rivières tant des poissons d'élevage que des poissons sauvages.

Introduction

Accurate pre-season forecasts of returning adult Atlantic salmon (*Salmo salar*) may allow fisheries managers sufficient time to adjust fisheries to harvest levels closest to conservation level spawning escapements. Implicit in achieving spawning escapement is maintaining long-term stability from the biological, economic and social perspectives. While predicting the future may be a very uncertain and risky business, the benefits of accurate predictions are great.

Three basic methods are presently used to forecast returns to Canadian rivers: 1) trends (mostly moving averages applied to grilse returns and hatchery returns), 2) first-to-second year recruit models (grilse-to-salmon models) and 3) stock and recruitment models. Problems associated with stock and recruit models used to predict returns are the rather large error associated with even medium risk confidence limits (say, a 50% probability) and the almost useless (to the manager), but statistically common, low risk 95% limits. High risk confidence limits (say, 25%) may yield ranges acceptable to the manager but the risk to the resource may be unacceptable. Regression models based on grilse-to-salmon relationships perform somewhat better and often utilize a second variable to reduce errors to useable levels. The stability of these additional variables, usually maturity proportions or size (length) of first recruits, is still in the research stage and mechanisms for their functions are poorly understood and require further investigation. Forecasting the average, while adequate in the long term, does not allow the manager to prepare for significant declines or increases in returns and therefore does not confer public confidence. While in-season adjustment models can ensure conservation through reactive management, mid-season changes seldom instill public confidence in fisheries science or management.

The sensitivity of yield of Atlantic salmon stocks to perturbations in marine survival has long been speculated and estimated (Korman *et al.* 1994). Reasons for these perturbations in marine survival have been examined for hatchery smolts (Farmer 1992) and wild smolts (Scarnecchia 1984; Ritter 1989). Smolt condition, length, and timing of migration have all been examined with little consistent improvement in reducing forecast confidence limits. Reports from Russian fisheries scientists indicate that marine environmental conditions alone can predict returns to specific stocks (A. Zubchenko[1], pers. comm.).

Investigations of the post-smolt migration and habitat preferences (Reddin and Friedland 1993) in the North Atlantic and relationships between abundance at Greenland and subsequent returns to North American fisheries (Reddin 1988b) led to a new method to estimate pre-fishery abundance in the South Labrador Sea (Reddin *et al.* MS 1993). This work, using the techniques of time series and regression analysis, examined the utility of marine habitat area (weighted by temperature preference) in the North Atlantic to account for the Greenland pre-fishery abundance. Because the models used habitat in January to April prior to the fishery, advice to managers on the probability of achieving spawning escapements in North American rivers for given levels of exploitation allowed managers to plan alternatives to the fishery for given levels of risk.

Based on the previously-published relationship between abundance in Greenland and subsequent abundance in Canadian and North American returns (Reddin 1988a), acceptance of this analysis implies that the earliest non-stock-recruitment indication of two-sea-winter (2SW) salmon returns to North American rivers is available a full fourteen months before river entry. This analysis begs the question of whether environmental variables in the North Atlantic could improve stock-specific forecasts of returns. Marshall *et al.* (MS 1993) examined the impact of these habitat variables on changing proportions of one-sea-winter (1SW) salmon in returns to the Saint John River and found that the number, size, and proportion of 1SW fish were positively correlated with most of the monthly habitat indices and few significant relationships with 2SW returns. Negative relationships were interpreted as not biologically meaningful and therefore ignored.

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[1] A. Zubchenko, Polar Institute of Marine Fisheries and Oceanography, Murmansk, Russia.

In this paper we examine the variability and similarity of habitat indices for January to April as reported by Reddin *et al.* (MS 1993). The effect of the Salmon Management Plan of 1984 on return rates of hatchery fish is tested. Temporal trend or trends (depending on the significance of the Management Plan) in return rates to three rivers are tested. This analysis leads to regression of annual return rates of hatchery 1SW (grilse) and two-sea-winter (2SW) salmon on habitat indices. The analysis is performed with the intention of testing the hypothesis that habitat indices can contribute to improved forecasts of hatchery returns and, by inference, wild salmon returns.

Methods

Annual indices of habitat area obtained from D. Reddin[2] are summations of 2^0 arc squares of the North Atlantic where temperatures are between 0 and 14^0 C weighted by a habitat preference probability distribution derived from research drift-netting (Reddin and Friedland 1993). Pearson correlations among monthly indices for January, February, March, and April, 1974 to 1995 were examined. Where significant correlations were encountered, regressions were performed between index pairs and post-hypothesis tests of slope and intercept were conducted. Slopes significantly different from 1 and/or intercepts significantly different from 0 indicated variables that could be treated separately in further analyses. Months with slopes not significantly different from 1 and intercepts not significantly different from 0 would not be expected to provide statistically different input to forecast models.

To further explore the habitat effect, we drew two new sets of annual habitat values by selecting the lowest monthly value of January to April in each year for one variable and the highest value for the other variable. We lagged variables to allow habitat years to align with pre-smolt migration, post-smolt winter/year of return (depending on age at maturity), and year of return for salmon. Habitat variables were standardized for plotting purposes.

Annual hatchery smolt-to-grilse and smolt-to-salmon survival rates for Saint John River, LaHave River and Liscomb River were those reported in Cutting *et al.* (MS 1994; Table 1).

To test whether a change in habitat was coincidental with the instigation of the Management Plan, habitat indices were first tested through analysis of covariance for the effect of the Management Plan, after accounting for the significant temporal trend. Analysis of covariance was then used to determine whether there were differences in mean hatchery survival rates between pre- and post-Management Plan years after adjusting for linear trend in survival rates over all years. The Management Plan variable consisted of 0s (zeros) for years during the fishery (up to and including 1984) and 1s (ones) for years after the close of the interception fishery (1985 onward). The simple metric value for the smolt year was used as the covariate (ie. 1975, ...). Separate regressions for pre- and post-"Plan" years of hatchery survival rate on year were derived for rivers with a significant Management Plan effect. Regressions over all years were derived for rivers with non-significant Management Plan effects.

We used forward stepwise multiple regression of hatchery survival rates on habitat and Management Plan in SYSTAT[3] with significance limits of $\alpha = 0.15$ to enter and $\alpha = 0.15$ to remove variables and a tolerance of 0.72 for variable rejection due to autocorrelation of variables. Durbin-Watson values were calculated as an indication of serial correlation. A natural logarithm transformation of dependent variables was performed when examination of residuals from significant linear models indicated it was warranted. A model that could be used in February of the year of return was preferred because this infomation could be conveyed to managers before consultations with co-managers and stakeholders.

[2] D. Reddin, Department of Fisheries and Oceans, Newfoundland Region, P.O. Box 5667, St John's, Newfoundland, Canada A1C 5X1.

[3] SYSTAT for Windows, Version 5.02, SYSTAT, Inc., Evanston, Ill.

Results

Bonferroni-adjusted (penalty for the number of comparisons made) probabilities of correlations among annual indices of Atlantic salmon habitat in the North Atlantic ocean (Table 2; Figure 1) for January, February, March, and April indicated that all months were significantly correlated with each other ($p<0.0005$). Regressions between pairs of monthly indices indicated slopes not significantly different from 1 and intercepts not significantly different from 0 for all pairs of February to April indices and for the January and April pair of indices (Bonferroni-adjusted $p>0.0083$). Therefore, statistically different input to environmental models was expected for either of January or April and either of February or March, but not among February to April inputs. Models accepting any two months from February to April would have to differ in the sign of the slope. We calculated the average of February to April and included these values as another variable in model selection.

Hatchery smolt survival (relative to return year)

Hatchery smolt-to-grilse survival for Saint John, Liscomb and LaHave rivers varied considerably among rivers and no significant correlation ($p>=0.082$) was found between rivers (Figure 2). A similar result was found for smolt-to-salmon survival ($p>=0.360$; Figure 3).

Survival rates of grilse and of salmon (aligned on the return year) were correlated for the Saint John ($p<0.0005$) and the Liscomb ($p=0.016$) data but not correlated for the LaHave data ($p=0.501$).

Analysis of covariance indicated non-significant ($p>0.116$) "Plan" effects for each of the habitat indices (Table 3). All sets of residuals from significant regressions of survival rate on year and survival rate on habitat indicated that a natural logarithm transformation of the dependent variables were required.

Saint John River

Analysis of covariance indicated non-significant "Plan" effects for both smolt-to-grilse and smolt-to-salmon survival rates ($p=0.623$ and $p=0.289$, respectively), after adjusting for linear trend over the years 1976 or 1977 to 1995. A significant regression of smolt-to-grilse survival rate on year was found and accounted for 68% of the variation in hatchery grilse survival (Table 3). The equation was:

$$\text{Ln(grilse survival)}_i = 192.213 - 0.0968 * \text{return year}_i \qquad i = 1976, ..., 1995$$

A similarly significant regression was found for hatchery smolt-to-salmon survival rate on year. The equation, accounting for 73% of the variation in hatchery salmon survival (Table 3), was:

$$\text{Ln(salmon survival)}_i = 211.417 - 0.107 * \text{return year}_i \qquad i = 1977, ..., 1995$$

Stepwise regression of hatchery grilse survival on habitat variables in the smolt and return years selected a positive coefficient with the January-to-April maximum habitat in the return year (Table 3; Figure 4). The adjusted R^2 indicated 62% of the variation was accounted for in this model. A variable designating pre- and post-Management Plan was not selected in the stepwise procedure. The equation was:

$$\text{Ln(grilse survival)}_i = -4.011 + 0.00237 * \text{maximum habitat}_i \qquad i = 1976, ..., 1995$$

Stepwise regression of hatchery salmon survival on habitat variables in the smolt, grilse, and return years selected a positive coefficient with the January-to-April maximum habitat in the grilse year (Table 3; Figure 4). The adjusted R^2 indicated 48% of the variation was accounted for in this model. A variable designating pre- and post-management plan was not selected in the stepwise procedure. The equation was:

$$\text{Ln(salmon survival)}_i = -4.638 + 0.00217 * \text{maximum habitat}_{i-1} \qquad i = 1977, ..., 1995$$

Liscomb River

Analysis of covariance indicated a non-significant "Plan" effect for the smolt-to-grilse survival rate (p=0.124) and a significant "Plan" effect for the smolt-to-salmon survival rate (p=0.049), after adjusting for linear trend. A marginally significant (p=0.051) regression of hatchery smolt-to-grilse survival rate on year was found and accounted for 18% of the variation in hatchery grilse survival (Table 3). The equation was:

$$\text{Ln(grilse survival)}_i = 127.816 - 0.0644^*\text{return year}_i \qquad i = 1979, ..., 1995$$

For the pre-"Plan" years, a non-significant regression was found for hatchery smolt-to-salmon survival rate on year (p=0.680). For the post-"Plan" years, a significant regression was found. The equation, accounting for 41% of the variation in hatchery salmon survival (Table 3), was:

$$\text{Ln(salmon survival)}_i = 374.266 - 0.189^*\text{return year}_i \qquad i = 1985, ..., 1995$$

Stepwise regression of hatchery grilse survival on habitat variables in the smolt and return years selected a positive coefficient with the January habitat in the return year (Table 3; Figure 5). The adjusted R^2 indicated 39% of the variation was accounted for in this model. A variable designating pre- and post-Management Plan was not selected in the stepwise procedure. The equation was:

$$\text{Ln(grilse survival)}_i = -3.979 + 0.00241^*\text{January habitat}_i \qquad i = 1979, ..., 1995$$

Stepwise regression of hatchery salmon survival on habitat variables in the smolt, grilse, and return years selected a positive coefficient with the January habitat in the return year (Table 3; Figure 5). The adjusted R^2 indicated 46% of the variation was accounted for in this model. A variable designating pre- and post-Management Plan was not selected in the stepwise procedure. The equation was:

$$\text{Ln(salmon survival)}_i = -6.908 + 0.00284^*\text{January habitat}_i \qquad i = 1980, ..., 1995$$

LaHave River

Analysis of covariance indicated a significant "Plan" effect for the smolt-to-grilse survival rate (p=0.034) and a non-significant "Plan" effect for the smolt-to-salmon survival rate (p=0.256), after adjusting for linear trend over years. For the pre-"Plan" years, a non-significant regression was found for hatchery smolt-to-grilse survival rates on year (p=0.531). For the post-"Plan" years, a marginally significant (p=0.070) regression was found and accounted for 24% of the variation in hatchery smolt-to-grilse survival (Table 3). The equation was:

$$\text{Ln(grilse survival)}_i = 271.478 - 0.136^*\text{return year}_i \qquad i = 1985, ..., 1995$$

For all years, a marginally-significant (p=0.084) regression was found for hatchery smolt-to-salmon survival rates on year. The equation, accounting for 14% of the variation in hatchery salmon survival (Table 3), was:

$$\text{Ln(salmon survival)}_i = 140.250 - 0.0709^*\text{return year}_i \qquad i = 1980, ..., 1995$$

Stepwise regression of hatchery grilse survival on habitat variables in the smolt and return years selected a positive coefficient with the January habitat in the return year (Table 3; Figure 6). The adjusted R^2 indicated 23% of the variation was accounted for in this model. A variable designating pre- and post-Management Plan was not selected in the stepwise procedure. The equation was:

$$\text{Ln(grilse survival)}_i = -2.591 + 0.00188^*\text{January habitat}_i \qquad i = 1979, ..., 1995$$

Stepwise regression of hatchery salmon survival on habitat variables in the smolt, grilse, and return years barely selected (p=0.064) a positive coefficient with the January habitat in the return year (Table 3; Figure 6). The adjusted R^2 indicated 17% of the variation was accounted for in this model. A variable designating pre- and post-Management Plan was not selected in the stepwise procedure. The equation was:

$$\text{Ln(salmon survival)}_i = -4.001 + 0.00210 * \text{January habitat}_i \qquad i = 1980, \ldots, 1995$$

Discussion

There is little statistical difference among the February to April habitat values, yet models did not select the average. This is because usually one particular month will explain more of the variation than the average and be selected in the stepwise regression procedure. The inter-correlation among months infers that trends in the amount of habitat area persist for at least quarterly periods of the year, namely the late winter. The differences found between early (January) and late winter (February to April) suggests that the timing of the reduced habitat period may provide a better predictor for the change in annual marine survival of hatchery smolts. These features remain to be tested.

Smolt-to-grilse survival was more highly correlated than smolt-to-salmon survival among the rivers examined. This observation suggests that habitat area is critical for post-smolt survival and directly affects the number of grilse returning. Salmon, on the other hand, spend an additional year at sea and may utilize different distribution strategies among stocks which could result in survival differences among stocks within years.

After accounting for temporal trend in survival, which was always negative, the Salmon Management Plan was significant for only the Liscomb salmon (p=0.049) and LaHave grilse (p=0.034) survival rates. Suprisingly, trends in survival were negative in the post-"Plan" periods where the "Plan" was significant. This result implies that even though interception was reduced (interception has been previously documented in these stocks from tagging programs), marine survival, which increased significantly in the post-"Plan" period, continued to trend negatively.

We examined the hatchery survival data to explore the similarity of effects over three different stocks with known differing migration routes and ages at maturity. Marine survival of hatchery smolts was generally positively related with maximum habitat area. Habitat area accounted for almost as much of the variation in survival as the temporal trend in the Saint John River data. This observation suggests that habitat may be used to forecast hatchery returns accounting for 68% of the variation in grilse survival and 48% of the variation in salmon survival. Forecasts using temporal trends are of little value in forecasting because they do not forecast turnarounds in annual survival. Where there was a significant or nearly significant "Plan" effect, for Liscomb and LaHave rivers, habitat area accounted for at least as much, if not more, of the variation in annual survivals than simple trends.

Models to forecast returns of hatchery grilse and salmon to these rivers could easily be constructed from the number of smolts stocked or migrating, the number of returning adults and the January or maximum habitat value. In order for these models to be valuable to managers as pre-season forecasters, habitat data would have to be available by at least February of the year of return. Improvement (increase in the amount of explained variance) in hatchery survival models may come from adjustments (inclusion of factors or variables) for smolt quality, age, size, release date, location, etc. but at the cost of discreteness. Conversely, adjusting survival for changes in marine habitat may allow improved assessment of rearing techniques. A calibration with wild stocks would provide much expanded opportunity for different approaches to assess the freshwater portion of the life cycle using adult returns of marked hatchery and unmarked wild fish.

While much is known in general about the marine migration and habits of migrating Atlantic salmon, many details of timing, distribution, feeding behaviour and preferences are yet to be uncovered. Hatchery tagging programs and high seas fisheries, directed, commercial and incidental, have indicated that some similarities in marine strategies exist for specific stocks and some very different strategies for others. An extreme case might be the Bay of Fundy stocks. The Saint John River stocks migrate long distances and have a consistently higher age-at-maturity than the inner Bay of Fundy stocks. Differences also exist among migration of two-sea-winter fish; e.g., Saint John vs. LaHave. It is therefore not surprising that marine habitat may affect different stocks in different ways.

The variables used here to infer habitat in the marine environment may equally be interpreted as energy variables in an ecological sense or predator/prey opportunity. With all these possibilities, it is not wise to accept only positive effects and reject negative ones we can not explain. We do not know the cause and effect underlying any of these possibilities and present here only association. One could speculate and support almost any scenario.

These analyses indicate that significant improvements in predicting Atlantic salmon returns can result from inclusion of marine habitat variables. The effect is widespread throughout the stocks explored. Analyses with the hatchery smolt survival data indicate that significant models for wild stocks, where little is known about smolt production, are not spurious relationships and can be used without assuming intolerable risk. Models using these variables provide forecasts where nothing but the average could previously be expected. These analyses suggest further investigation in habitat effects on marine survival are warranted.

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Table 1. Estimated percent return rate of hatchery smolts to grilse and salmon in the LaHave, Liscomb and Saint John rivers, 1975 to 1994.

Smolt year	Return rate per smolt (%)					
	LaHave River		Liscomb River		Saint John River	
	Grilse	Salmon	Grilse	Salmon	Grilse	Salmon
1975					2.80	0.84
1976					2.35	0.85
1977					1.04	0.40
1978	1.44	0.71	1.02	0.11	1.95	1.52
1979	1.54	1.06	1.61	0.08	4.42	1.12
1980	1.93	0.38	0.90	0.15	2.42	0.76
1981	2.04	0.32	1.95	0.15	1.61	0.58
1982	0.98	1.29	1.36	0.10	0.91	0.56
1983	1.27	0.39	0.57	0.08	0.97	0.55
1984	1.46	1.08	0.35	0.22	0.92	0.35
1985	4.84	2.95	2.59	0.18	0.87	0.45
1986	2.41	0.26	2.75	0.23	1.57	0.35
1987	3.93	1.08	1.38	0.23	0.67	0.33
1988	1.65	0.41	0.60	0.05	0.76	0.17
1989	1.94	0.29	1.56	0.08	0.40	0.17
1990	0.42	0.23	0.79	0.05	0.65	0.26
1991	3.60	0.48	0.50	0.05	0.69	0.12
1992	0.84	0.26	0.42	0.03	0.41	0.21
1993	0.56	0.23	0.56	0.03	0.39	0.21
1994	1.05		0.34		0.64	

Table 2. Pearson correlation coefficients and their Bonferroni-adjusted probabilities of annual indices of Atlantic salmon habitat in the North Atlantic ocean for January, February, March, and April, 1974 to 1995.

Pearson Correlation Matrix

	January	February	March	April
January	1.000			
February	0.917	1.000		
March	0.800	0.906	1.000	
April	0.855	0.926	0.881	1.000

Bartlett Chi-square statistic: 100.313, DF = 6, Prob = 0.000

Matrix of Bonferroni Probabilities

	January	February	March	April
January	0.000			
February	0.000	0.000		
March	0.000	0.000	0.000	
April	0.000	0.000	0.000	0.000

Frequency Table

	January	February	March	April
January	22			
February	22	22		
March	22	22	22	
April	21	21	21	21

Table 3. Summary of analyses for examination of habitat indices and indices of hatchery smolt-to-grilse and smolt-to-salmon survival rates (%) to the Saint John, Liscomb and LaHave rivers.

Variables: Dependent	Variables: Independent	Return years	Adjusted R^2	P-value	N
Habitat indices					
January	Management Plan	1974 - 1995		0.311	22
February	Management Plan	1974 - 1995		0.313	22
March	Management Plan	1974 - 1995		0.622	22
April	Management Plan	1974 - 1995		0.116	21
February-April average	Management Plan	1974 - 1995		0.294	21
Minimum	Management Plan	1974 - 1995		0.368	22
Maximum	Management Plan	1974 - 1995		0.410	22
Saint John River					
Grilse survival	Management Plan	1976 - 1995		0.623	20
Ln(grilse survival)	Return year	1976 - 1995	0.680	0.000	20
Ln(grilse survival)	Max habitat (return year)	1976 - 1995	0.617	0.000	20
Salmon survival	Management Plan	1977 - 1995		0.289	19
Ln(salmon survival)	Return year	1977 - 1995	0.732	0.000	19
Ln(salmon survival)	Max habitat (grilse year)	1977 - 1995	0.479	0.001	19
Liscomb River					
Grilse survival	Management Plan	1979 - 1995		0.124	17
Ln(grilse survival)	Return year	1979 - 1995	0.179	0.051	17
Ln(grilse survival)	Jan habitat (return year)	1979 - 1995	0.388	0.004	17
Salmon survival	Management Plan	1980 - 1995		0.049	16
Ln(salmon survival)	Return year	1980 - 1984	0.000	0.680	5
Ln(salmon survival)	Return year	1985 - 1995	0.566	0.005	11
Ln(salmon survival)	Jan habitat (return year)	1980 - 1995	0.462	0.002	16
LaHave River					
Grilse survival	Management Plan	1979 - 1995		0.034	17
Ln(grilse survival)	Return year	1979 - 1984	0.000	0.531	6
Ln(grilse survival)	Return year	1985 - 1995	0.244	0.070	11
Ln(grilse survival)	Jan habitat (return year)	1979 - 1995	0.232	0.029	17
Salmon survival	Management Plan	1980 - 1995		0.256	16
Ln(salmon survival)	Return year	1980 - 1995	0.141	0.084	16
Ln(salmon survival)	Jan habitat (return year)	1980 - 1995	0.169	0.064	16

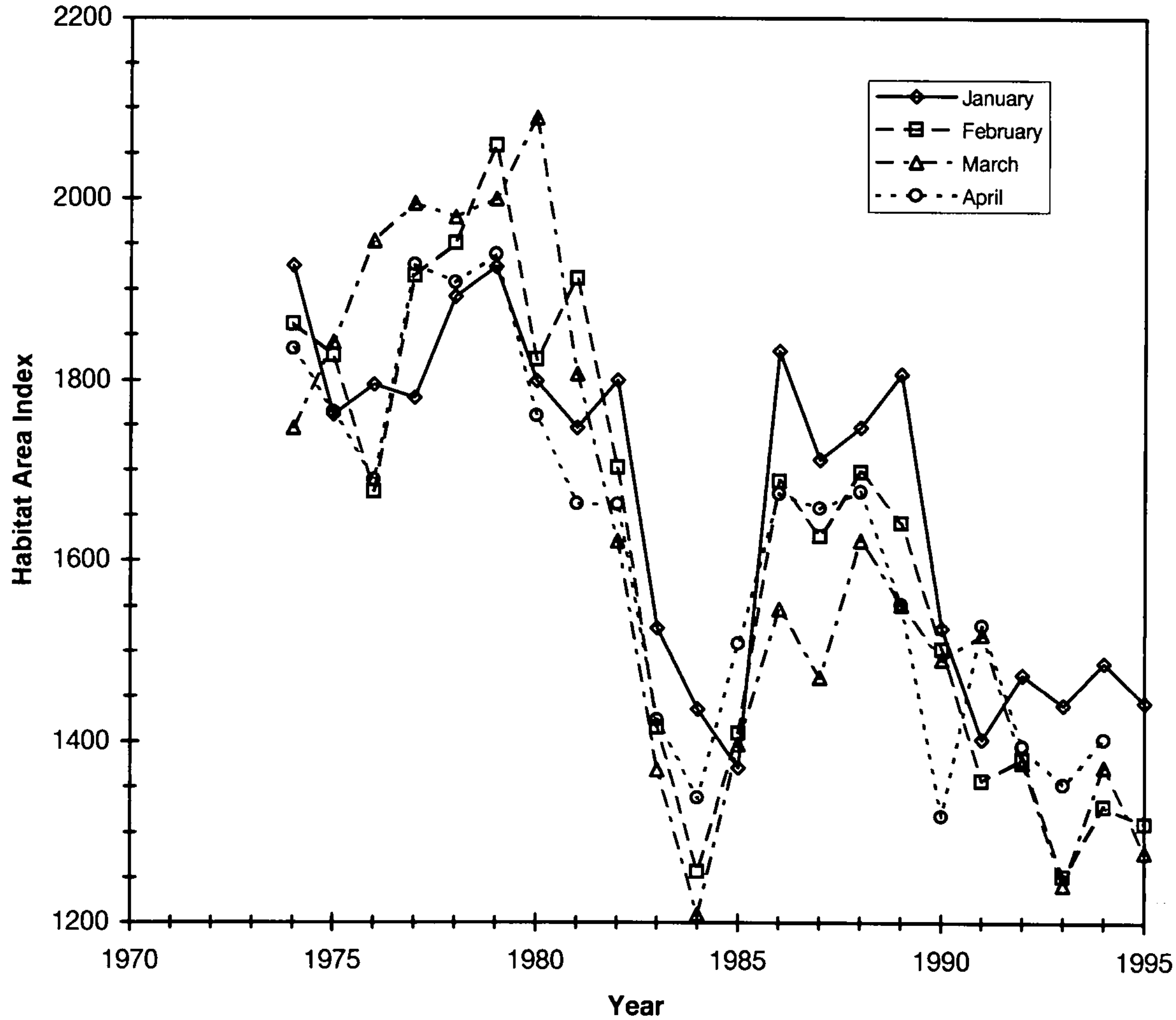

Figure 1. Annual indices of Atlantic salmon habitat area in the North Atlantic ocean for January, February, March and April, 1974 to 1995.

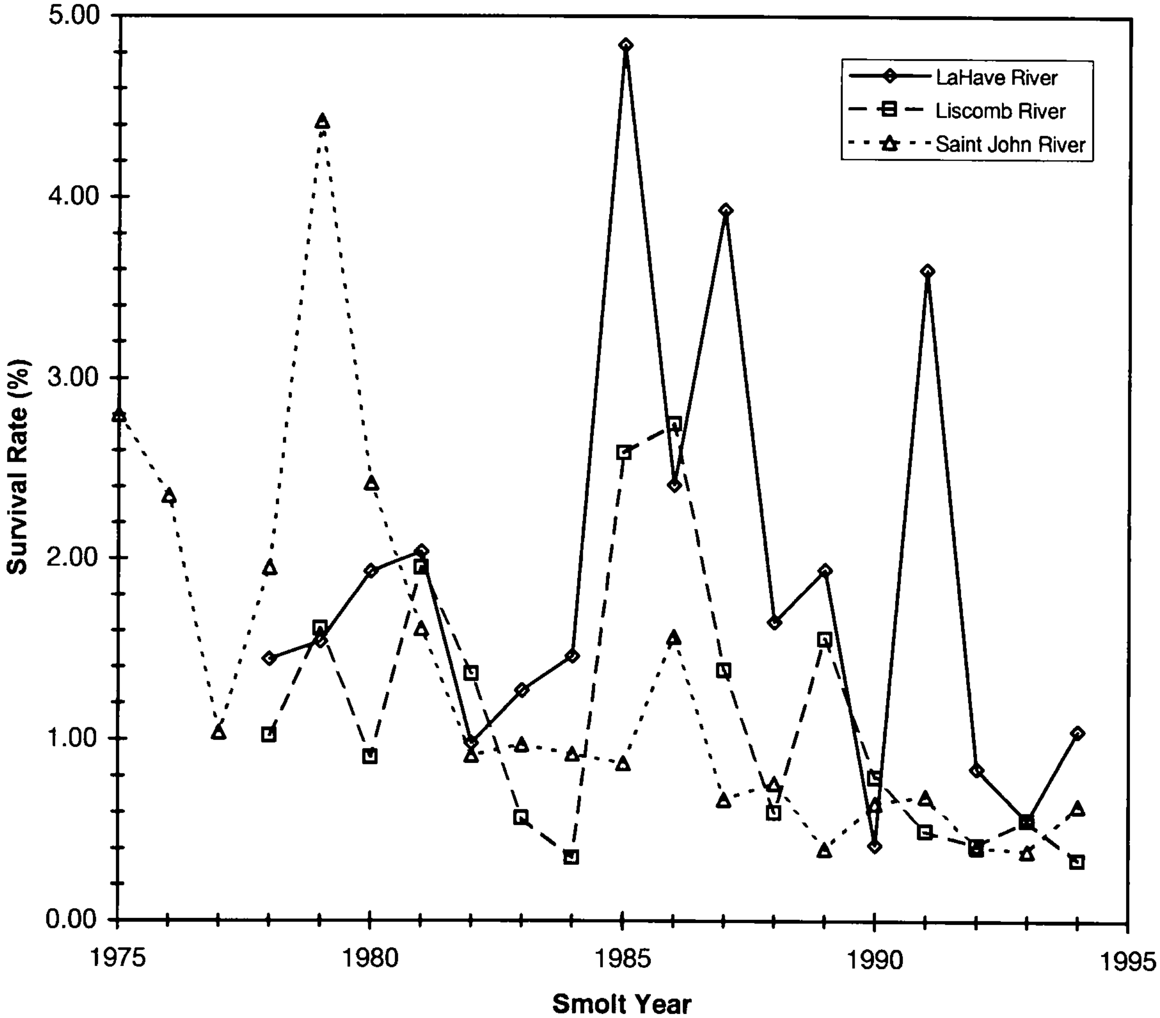

Figure 2. Atlantic salmon hatchery smolt-to-grilse survival rates (%) for LaHave River, Liscomb River and Saint John River, 1975 to 1994.

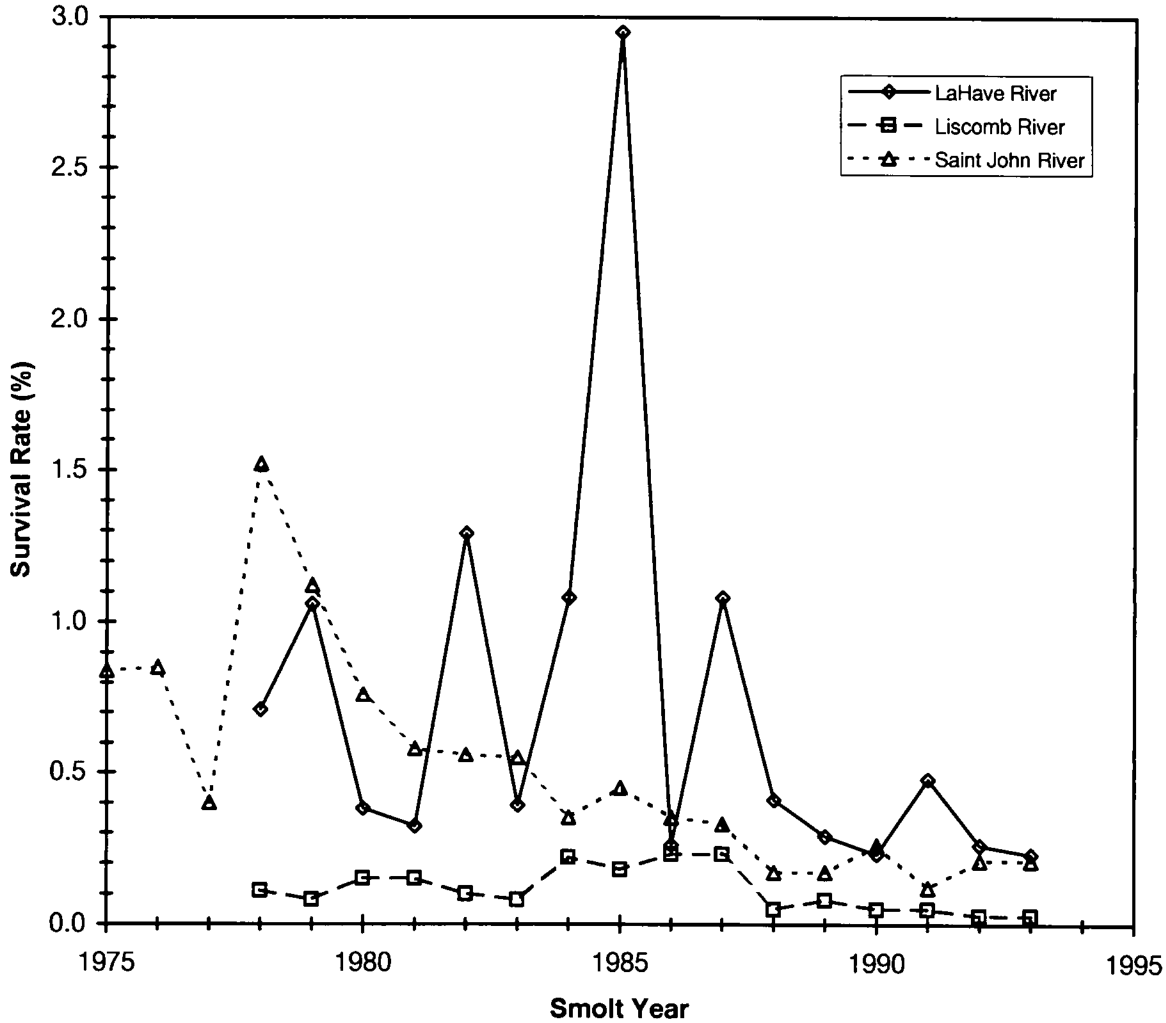

Figure 3. Atlantic salmon hatchery smolt-to-salmon survival rates (%) for LaHave River, Liscomb River and Saint John River, 1975 to 1993.

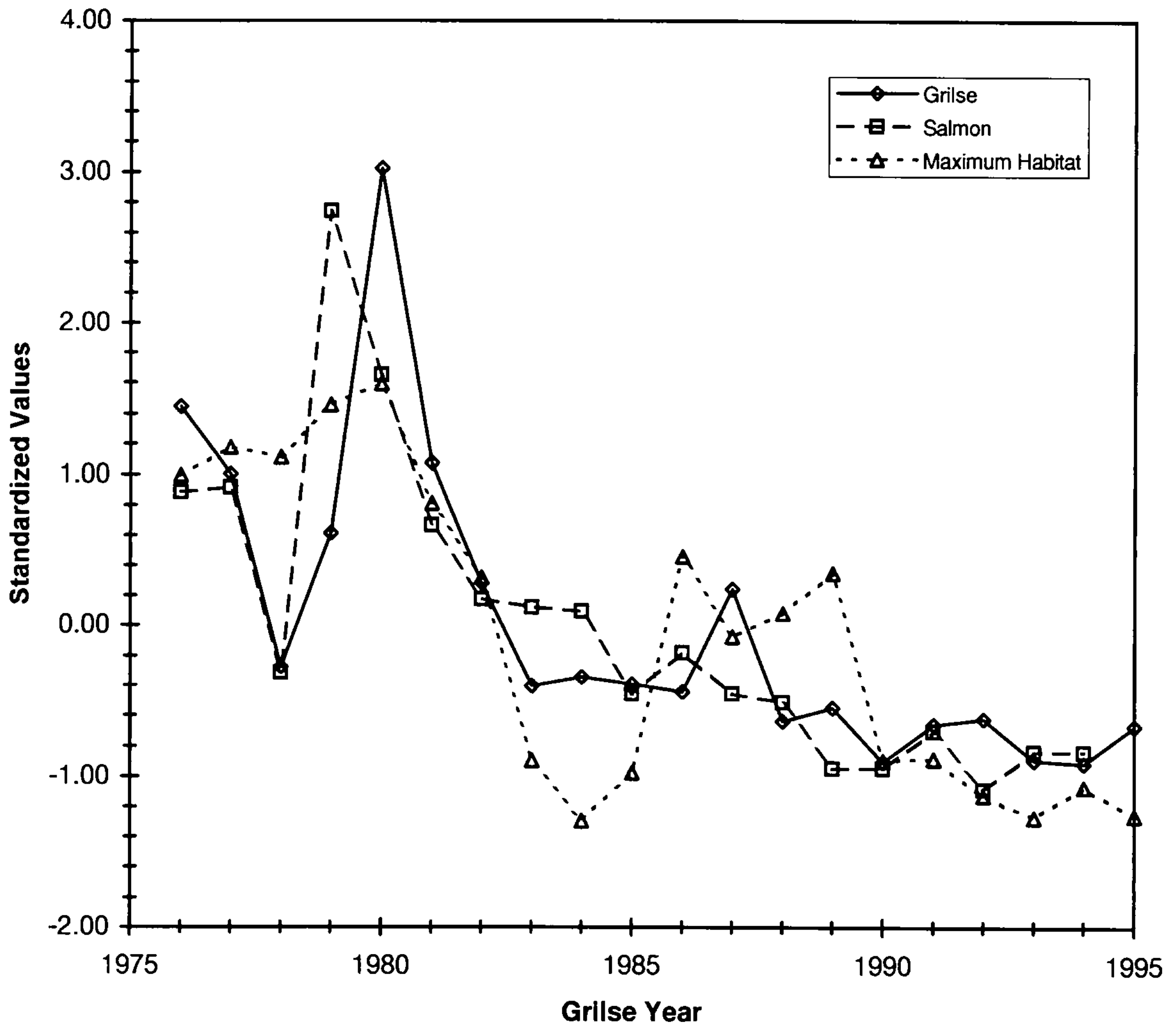

Figure 4. Standardized values of percent Atlantic salmon hatchery smolt-to-grilse and smolt-to-salmon survival rates for the Saint John River and the maximum January-to-April index of Atlantic salmon habitat area in the North Atlantic for the grilse years 1976 to 1995.

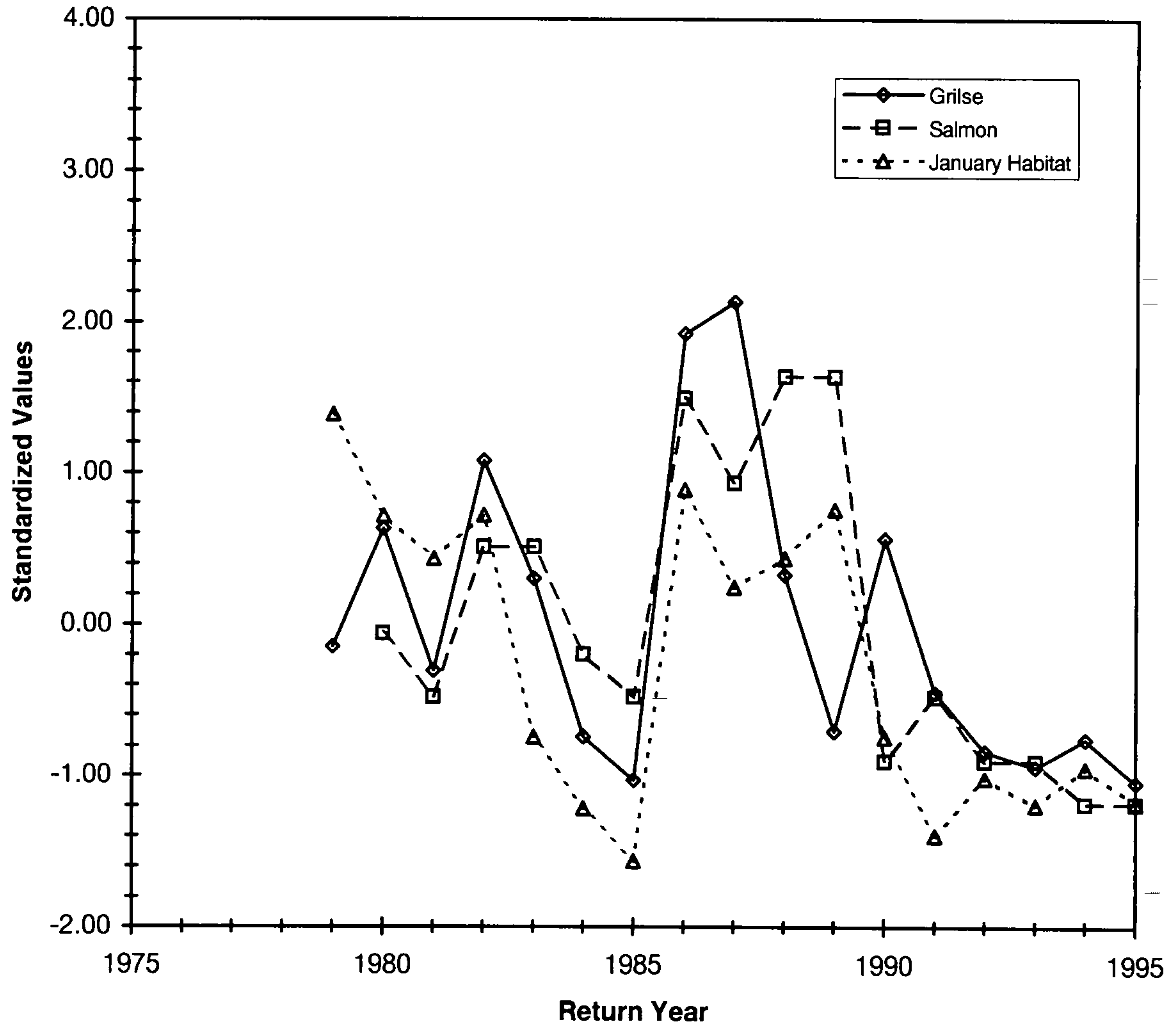

Figure 5. Standardized values of percent Atlantic salmon hatchery smolt-to-grilse and smolt-to-salmon survival rates for the Liscomb River and the January index of Atlantic salmon habitat area in the North Atlantic for the return years 1979 to 1995.

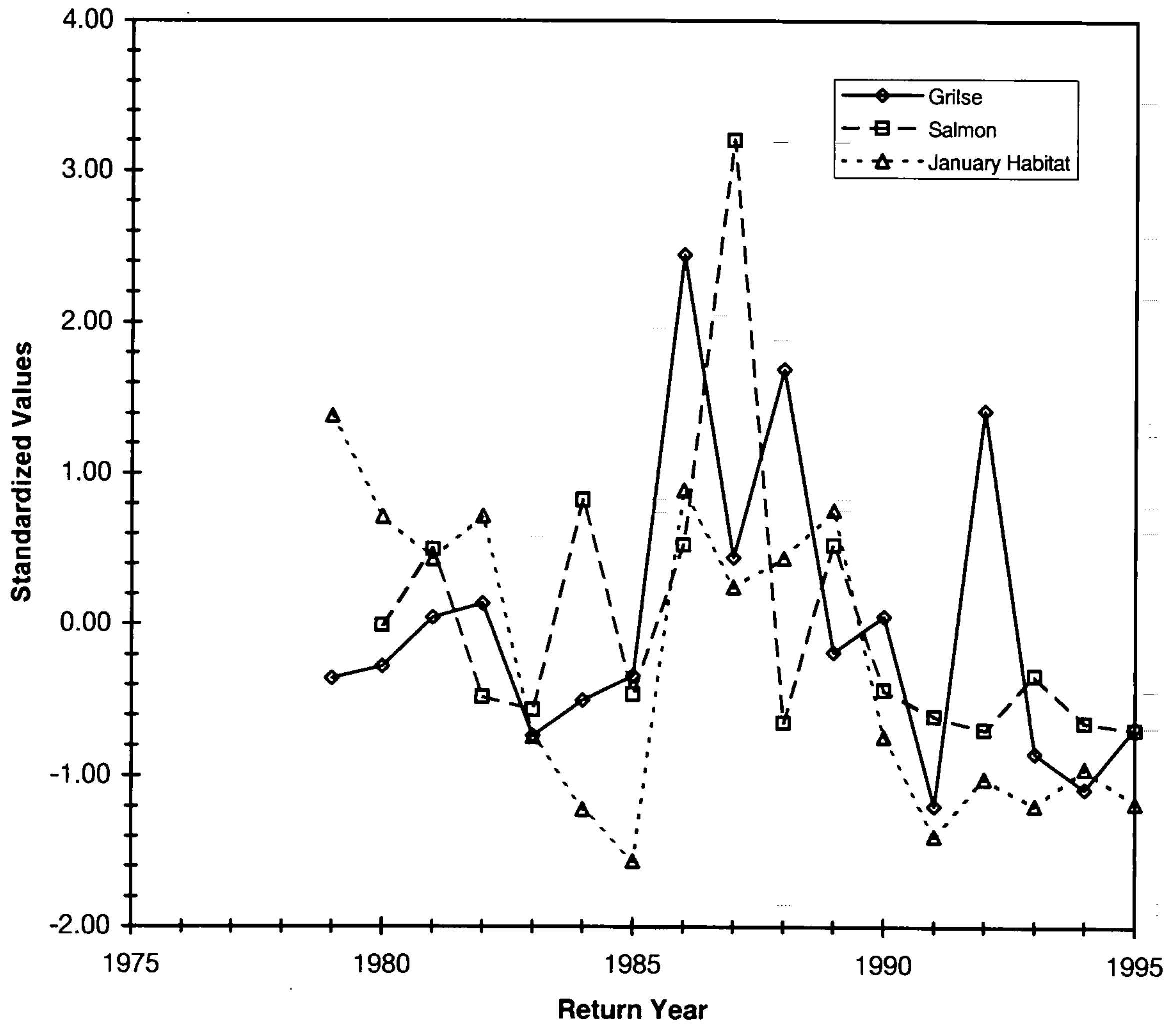

Figure 6. Standardized values of percent Atlantic salmon hatchery smolt-to-grilse and smolt-to-salmon survival rates for the LaHave River and the January index of Atlantic salmon habitat area in the North Atlantic for the return years 1979 to 1995.