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Model development for predicting multi-sea-winter Atlantic salmon (*Salmo salar* L.) returns to Saint John River, New Brunswick

by

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ABSTRACT

A model for predicting multi-sea-winter (MSW) Atlantic salmon returns to the Saint John River was developed by screening the linear relationships of MSW returns with each of grilse returns to the river in the previous year, three biological characteristics of age-designated 1-sea-winter (1SW) salmon returns (one included five alternate measures of length), seven potential measures of MSW recruit losses to the distant fisheries and two indices of marine temperature, and by subsequent application of stepwise regression to the reduced set of candidate variables. The resulting regression is:

$$\log_e \text{MSWS} = 18.113 + 0.128\ \text{GRLS} - 0.304\ \text{YLEN}, \quad \text{where}$$

MSWS = MSW salmon returns to the river in year i, GRLS = grilse returns to the river in year i-1, and YLEN = mean fork length of 1SW salmon returns to the river in year i-1. The regression is highly significant (df = 2, 17; $F = 13.11$; $p < 0.001$), and accounts for 56% of the variance in returns of MSW salmon since 1971. GRLS is interpreted as an index of stock strength and YLEN as an index of shifts in sea-age at first maturity related to fish size and condition during the first sea-winter.

RÉSUMÉ

On a mis au point un modèle de prévision du nombre de saumons de l'Atlantique pluribermarins retournant aux eaux de la rivière Saint-Jean en examinant les relations linéaires entre les remontées de saumons pluribermarins et celles des madeleineaux au cours de l'année précédente, trois caractéristiques biologiques des saumons unibermarins amontants en fonction de l'âge (dont une englobait cinq différentes mesures de la longueur), sept mesures potentielles des pertes de recrues pluribermarines par pêche en haute mer et deux indices de la température de la mer. On a ensuite effectué une analyse de régression par degrés de la série de variables retenues pour obtenir la régression suivante:

$$\log_e \text{MSWS} = 18{,}113 + 0{,}128\ \text{GRLS} - 0{,}304\ \text{YLEN}$$

où MSWS = nombre de saumons pluribermarins amontants au cours de l'année i, GRSL = nombre de madeleineaux amontants au cours de l'année i-1 et YLEN = longueur à la fourche moyenne des saumons unibermarins amontants au cours de l'année i-1. La régression est nettement signficative (dl = 2, 17; $F = 13{,}11$; $p < 0{,}001$) et explique 56 % de la variance des remontées de saumons pluribermarins depuis 1971. L'entité GRLS est considérée comme un indice de l'importance du stock et l'entité YLEN comme un indice des variations du temps d'arrivée à première maturité en milieu marin par rapport à la taille et à la condition du poisson pendant le premier hiver passé en mer.

INTRODUCTION

Predictions of multi-sea-winter (MSW) Atlantic salmon returns (include fish that have spent at least two winters in the sea and most repeat spawners) to the Saint John River, N.B., is required to formulate annual fishing plans. Forecasts are used to identify surpluses to spawning requirements and potential harvests in advance of the fishing season.

During the early 1980s a loglinear regression model was used to predict MSW salmon returns from the previous year's return of grilse (include salmon that have spent one winter at sea and a few small repeat spawners) (Marshall 1987, 1988). Commencing with the MSW salmon returns in 1987, the model deteriorated annually (MSW salmon years 1971 to 1990; df = 1, 18; F = 3.18; p = 0.091).

A lower percentage of MSW salmon in the Saint John River stock from recent smolt classes (Anon. 1990a) coincides with the deterioration in the forecast model. Lower percentage of MSW salmon in recent year returns is common to many North American rivers despite reductions in catches of MSW salmon in Canadian commercial fisheries and of non-maturing 1SW salmon at Greenland (Anon. 1990a). A relationship, indicating that larger size of 1SW salmon of the Saint John River is associated with the return of proportionately fewer MSW salmon, was reported by the ICES Study Group on North American Salmon Fisheries (Anon. 1990a). This relationship supports the hypothesis that the observed variation in the percentage of MSW salmon returns to the Saint John River by smolt class is largely the result of environmentally induced change in age at first maturity.

Although grilse returns and length of age-designated 1SW salmon were expected to be included in the forecast model, the search for potential independent variables was broadened to investigate other factors. This paper details the steps and rationale leading to the development of a forecast model for MSW salmon returns to the Saint John River from wild smolts produced upstream of Mactaquac Dam.

METHODS

Models for predicting MSW salmon returns to the Saint John River were developed by screening the linear relationships of MSW salmon returns with each of 17 potential independent variables, and by subsequent application of stepwise (both backward and forward) multiple linear regression to the reduced set of candidate variables. Correlation analysis was used to determine the relationships between potential independent variables.

Separate stepwise regression analyses were conducted with MSW salmon returns expressed as the number of returns to the river (designated MSWS) and as the natural logarithm of returns (Log_e MSWS). The resultant models are referred to as non-log and semi-log models. The option of logging returns was considered because the distribution of MSWS appears skewed (Fig. 1) and plots of MSWS on some of the potential independent variables (i.e., the different measures of average length of 1SW salmon returns) show curvilinear trends (e.g., Fig. 2).

MSW salmon returns span 20 years, 1971 to 1990 (Table 1). They include counts at Mactaquac Dam plus estimated losses to fisheries during their return migration through the estuary and main river. Returns up to and including 1988, and the method by which later returns were determined, are from Marshall (1989).

All but three of the potential independent variables selected for consideration were measurements that could be secured early enough to permit forecasting of the next year's return of MSW salmon. The three measurements that would be unavailable for forecasting were derived from tag return information. They were included to investigate the potential effects of the marine interception fisheries.

The potential independent variables are:

- Grilse returns to the river in year i-1 (GRLS) (Table 1). This candidate variable was used previously to predict MSW salmon returns (Marshall 1987) and is regarded as an indicator of stock strength. Grilse returns include counts at Mactaquac Dam and estimated losses to fisheries in the estuary and main river (Marshall 1989).

- Mean fork length of returning 1SW salmon in year i-1 (Table 2) for:
  - entire season, all ages (YLEN);
  - June - July, all ages (JJLEN);
  - August, all ages (ALEN);
  - September - November, all ages (SNLEN);
  - entire season, 2-year smolts (Y2LEN).

  Large size of 1SW salmon at return is hypothesized as being associated with earlier age at first maturity (i.e., larger size being the result of larger smolt size and/or improved marine foraging conditions) (Anon. 1990a). Smolt size was expected to vary as a result of annual variation in the number of smolts trapped above hydroelectric dams and experiencing delays in entering the sea by at least one year. Length of 1SW salmon returns was also expected to reflect marine conditions and resultant growth. Since the Saint John River produces no 1-year smolts, length of 1SW salmon from 2-year smolts could not have been affected by river entrapment and therefore was assumed to be the most sensitive of the five length measures to varying marine conditions.

  Mean fork length of 1SW salmon was noted to increase during the season (Fig. 3) and hence consideration was given to mean lengths for different segments of the season. The increase in length during the season is assumed to reflect the amount of plus growth after the sea-winter annulus. Selection of the best indicator of size at the end of the first sea-winter was expected to be complicated by the selectivity of river gillnet fisheries prosecuted by the Indians at the base of Mactaquac Dam, 1974 to 1988, and by the licensed commercial fishery in the lower river in 1970, 1971, 1981, 1982 and 1983. Except for 1974, when sample size was small (108), freshwater ages and length measurements were weighted according to relative abundance during the season, i.e., every tenth grilse was scale sampled and measured, and ages and length measurements included for a subsample taken randomly or, in recent years, for the entire sample.

- Percent females among fall returns of 1SW salmon to Mactaquac Dam in year i-1 (PFEM) (Table 3). The sex ratio of 1SW salmon returns was expected to vary if age at first maturity of returning salmon varied. Estimation of the female component was based on external sexing of 1SW salmon returning after August 31. External sexing earlier in the season was presumed to be less accurate.

- Mean smolt age of returning 1SW salmon in year i-1 (SAGE) (Table 3). Relative returns of MSWS and GRLS were expected to vary with smolt age. Older smolts were expected to be larger and thereby mature moreso as 1SW salmon.

- Catches of small salmon in commercial fisheries along the coasts of eastern Newfoundland (SFAs 3,4,5,6,7 and 8) (ENFLD) and southern Labrador (SFA 2) (SLAB) in year i-1 (Table 4). The term small salmon refers to the size class that is generally comprised of 1SW salmon. Catches of small salmon along the east coast of Newfoundland, 1974 to 1989, were considered because tag recapture data for hatchery smolts of Saint John River origin indicate the east coast to be the main area for their interception, i.e., 72% of tag recaptures in Newfoundland-Labrador fisheries were returned from SFAs 3 to 8 inclusive (Ritter 1989). Catches for SFA 2 were considered because a further 17% of the tag recaptures were from southern Labrador (Ritter 1989), and because the commercial fishery in SFA 2 has experienced few (if any) restrictions compared to insular Newfoundland.

  Consideration was limited to catches of small salmon because virtually all of Saint John River salmon harvested in Newfoundland - Labrador are caught as 1SW salmon, and based on time and location of capture, are non-maturing (Ritter 1989). About 70% of the tagged hatchery fish recaptured in the Newfoundland-Labrador fishery and for which weights were reported by fishermen, were less than the upper bound of 2.6 kg for small salmon. These data suggest that most wild fish, having originated from generally smaller smolts, would have been classed as small salmon.

- Catches of salmon in the Greenland fishery in year i-1, 1970 to 1989 (Table 4), as indicated by total nominal catch (TGLD) and catch of North American 1SW salmon (NAGLD). Tag recapture data indicate that this fishery harvests a significant and annually varying proportion of Saint John River salmon that were destined to first mature as 2SW and older salmon (Ritter 1989).

- Proportions of total tag recaptures as MSW salmon and non-maturing 1SW salmon taken in marine interception fisheries along the Newfoundland-Labrador coast (TGNFLD), at Greenland (TGGLD), and in both fisheries combined (TGMAR) (Table 5). Tag recapture proportions were for native hatchery smolts released from Mactaquac Hatchery, Saint John River, 1970 to 1988. Recaptures as maturing 1SW salmon (usually in the home river) were excluded from the analysis. All recaptures as 1SW salmon in Newfoundland-Labrador and Greenland fisheries were presumed to be non-maturing, based on time and location of recapture. Higher recapture proportions for these marine fisheries were expected to reflect increased exploitation of the wild stock and reduced returns of MSW salmon to the

Saint John River.

- Sea surface temperatures for the Gulf of Maine immediately in advance of (April) and at time of smolt entry (May) to the sea in year i-2 (GOM), and for the Inner Labrador Current in late winter (February to April) in year i-1 (ILC) (Table 6). Warmer GOM was expected to enhance early sea growth and thereby contribute to larger size as 1SW salmon and earlier age at maturity. Similarly, warmer ILC was expected to enhance growth and general condition of 1SW salmon and thereby advance maturity.

  Sea surface temperature data were extracted from the ships-of-chance data base which is derived principally from cooling water intakes of merchant vessels and reported in radio weather messages and logbooks that are transmitted to the U.S. Fleet Numerical Oceanographic Center and the U.S. National Climatic Center for processing and archiving. Analyses of these data, involving screening and computation of monthly averages for each 1^0 X 1^0 quadrangle for which enough data have been reported, were conducted by the Pacific and Environmental Group of the U.S. National Marine Fisheries Service. The Gulf of Maine and Inner Labrador Current are two of 24 areas in the northwest Atlantic for which the ships-of-chance data are assembled (Trites and Drinkwater 1985).

MODEL DEVELOPMENT

An examination of the linear relationships between MSW salmon returns and each of the candidate variables (Table 7) resulted in the elimination of both measures of sea temperature (GOM, ILC), three of the four catch series (ENFLD, TGLD, NAGLD) and two of the tag recapture proportions (TGNFLD, TGGLD) from being included in the stepwise regression process. Retention of a variable was based on $p < 0.5$. Correlation analysis of the five fork length series for 1SW salmon returns indicated these to be highly correlated ($p < 0.01$) and thereby allowed for selection of YLEN as the one reflecting the closest relationship with MSWS and for the elimination of the other four (JJLEN, ALEN, SNLEN, Y2LEN). This preliminary screening process reduced the potential independent variables to GRLS, YLEN, PFEM, SAGE, SLAB and TGMAR.

Both forward and backward stepwise regression processes selected YLEN and GRLS for inclusion in both non-log (Model I) and semi-log (Model II) models (Table 8). Model II accounted for more of the variance in MSW salmon returns (i.e., 56% vs 49%) and predicted returns more accurately at the lower end of the range than did Model I (Table 9).

The first and fourth largest standardized residuals for Model II were recorded for MSW salmon returns in 1983 and 1984. This coincides with suspicion that 1983 harvests of both MSW salmon and grilse in the homeriver commercial fishery were under-reported. Removal of these two years from the analysis (Model III) enhanced the adjusted R^2 (from 0.56 to 0.69) (Table 8), but did not markedly alter the predicted returns of MSW salmon (Table 9). Thus it was concluded that elimination of the 1983 and 1984 MSW salmon returns was unwarranted.

DISCUSSION

The inclusion of GRLS in the model, the only indicator of stock size, is consistent with the original forecast model for the Saint John River population (Marshall 1987, 1988) and models used to forecast MSW salmon returns to other Maritime rivers (Cutting et al. 1987; Randall and Schofield 1987; Randall et al. 1987). The negative coefficient for YLEN compensates for the excessive forecasts of MSW salmon returns in 1987 and 1988 produced by the original model (Marshall 1987, 1988).

YLEN is negatively correlated with MSWS ($r = -0.42$; $p = 0.062$) and positively correlated with GRLS ($r = 0.51$; $p = 0.021$). Weighted regression (Snedecor and Cochran 1967) of MSW salmon as a proportion of total returns from a smolt class on YLEN further confirms the strong association between YLEN and both MSWS and GRLS (df = 1, 18; $F = 30.71$; $p < 0.001$).

A plot of the percent MSWS on YLEN (Fig. 4) highlights the MSW salmon years 1981 and 1987 to 1990 for which YLEN is critical to the model. The tendency for Saint John 1SW salmon to be larger in 1986 to 1989 is consistent with observations on the LaHave River (Table 10). Length and weight measurements for LaHave 1SW salmon indicate that the 1986 to 1989 returns were longer, heavier and of greater condition factor than returns in 1984 and 1985.

Increased length of 1SW salmon returns coincides with longer smolts and proportionately more females among the 1SW salmon returns (Table 11). For two groups of hatchery smolts released into the Saint John River, 1989, the longer smolts (+ 2.6 cm in fork length) yielded returns of 1SW salmon that were longer (+ 2.2 cm). Correspondingly, proportionately more of the group with longer 1SW salmon were female (27.3% vs 2.4%) despite sex ratios for the two groups of smolts at release being similar (57.3% vs 55.5% female). This difference in sex composition is assumed to reflect the difference in sea-age at first maturity of the two groups which can only be confirmed with the 2SW salmon returns in 1991. The greater percentage of females in the 1SW salmon return is presumed to be the result of the difference in smolt size (20.5 vs 17.9 cm) rather than smolt age (2-year vs 1-year). Ritter et al. (1986) concluded that sea-age at first maturity is more likely to be affected by smolt size than smolt age.

Larger mean fork length of wild 1SW fish is believed to be the product of both holdback of the smolts in the system at hydroelectric dams and more favourable marine conditions. Substitution of the mean length of all 1SW salmon (YLEN) with that of 2-year smolts (Y2LEN) reduced the adjusted R^2 from 0.56 to 0.25. Despite this reduction, both regression coefficients remained significant (i.e., GRLS $p = 0.013$; Y2LEN $p = 0.026$), indicating that holdback of the smolts is not solely responsible for the contribution that YLEN makes in the forecast model. Similarly, the evidence that 1SW salmon from the LaHave River, on which there are no hydroelectric impoundments, were larger and of better condition factor in 1986 to 1989 than in either 1984 or 1985 (Table 10), suggests a common cause at sea for the larger size of 1SW salmon returning to the Saint John and LaHave rivers in recent years.

PFEM, an indicator of sex ratio change in returning 1SW salmon, failed to enter into the model because its effects were captured by the first selected variables in the model. The linear relationships between MSWS and each of the 17 potential independent variables indicated PFEM ($p = 0.029$) to be second to SAGE ($p = 0.027$) and of greater singular importance than either YLEN ($p = 0.062$) and GRLS ($p = 0.195$) in accounting for the variance in MSWS (Table 7). PFEM was also hampered by the small sample base for most years (Table 3) and the potential non-representativeness of the annual return by the September to November sample. Significant annual variation in smolt sex ratio, if occurring, would also have complicated the relationship between PFEM and MSWS, e.g., more female smolts should result in both more MSW salmon (>MSWS) and more female 1SW salmon (>PFEM).

Although PFEM did not enter the model, PFEM values for 1986 to 1989 returns are among the highest in the data series (Table 3). Because of small sample size the reliability of PFEM values for returns in the early 1970s and in general, prior to 1984, remains a concern.

SAGE would have been the third variable to enter the regression, and if allowed to enter, would have enhanced the adjusted R^2 from 0.56 to 0.61. The regression coefficient for SAGE would have been significant at $p = 0.096$. Coefficients for both GRLS and YLEN would have remained significant at $p = 0.005$ and $p < 0.001$. The negative sign of the coefficient for SAGE suggested that an increase in the smolt age of the 1SW salmon would be followed by a decrease in MSW salmon returns. Because SAGE explained an additional 5% of the variance in MSW salmon returns and was close to being included in Model II ($p = 0.096$), SAGE should be reconsidered in future efforts to upgrade the forecast model with extended data sets.

Neither of the two indicators of marine temperature conditions (GOM, ILC) entered the model. Correlations of these indicators with year are suggestive of a warming trend since the early 1970s (Table 12, Fig. 5 and 6). Correspondingly, the percent MSW salmon (% MSWS) has decreased while YLEN has increased over the same time period. Cross correlations however, indicate no relationship between % MSWS or YLEN and either GOM or ILC. This indicates that the recent increase in size of 1SW salmon returning to the Saint John (Table 3) and LaHave (Table 10) rivers is not likely the direct result of warmer sea temperatures. Instead, we might expect increased abundance of forage to be responsible for the larger size at return.

The principal distant fisheries could not be implicated in the return of MSW salmon to the Saint John River. This is not surprising considering that the absolute catches (ENFLD, SLAB, TGLD, NAGLD) may not be indicative of exploitation rate, particularly if the size of the North American salmon stock has decreased in recent years, as is suspected. Similarly, the tag recapture proportions (TGNFLD, TGGLD, TGMAR) are for hatchery smolts and therefore may not be representative of the wild Saint John River stock, or of exploitation rates, if reporting rates for tags recovered in the Newfoundland-Labrador and Greenland fisheries have changed. Regardless, the foregoing analysis indicates that much of the variance in MSW salmon returns to the Saint John River (56%) can be accounted for by factors other than the marine interception fisheries.

The forecast model includes GRLS as an index of stock and YLEN as an index of change in sea-age at first maturity. The selection of YLEN to the model provides an explanation for the decrease in MSW salmon returns to the Saint John River in recent years. The mechanism underlying the recent change and expressed by YLEN is consistent with results reported for hatchery-reared smolts of both coho salmon (Oncorhynchus kisutch) (Bilton et al. 1982) and Atlantic salmon (Ritter et al. 1986). Both these investigations indicated a tendency for salmon of larger size to mature at an earlier age. More recently, Thorpe et al. (1990) demonstrated the opportunity to alter maturation in sea-cultured Atlantic salmon by restricting food intake during the winter months. This recent study indicates that age at first maturity varies in relation to body condition or energy stores at the onset of maturation. Greater YLEN is likely to be associated with higher energy stores for those 1SW salmon returns that are longer because of more favourable fall and/or winter marine conditions. Data pertaining to the LaHave 1SW salmon (Table 10) generally indicate a positive association between length and condition factor.

CONCLUSION

Model II is recommended for forecasting MSW salmon returns to the Saint John River (Table 8). The importance of YLEN in Model II implies that a shift to earlier sea-age at first maturity has contributed to the lower than expected returns of MSW salmon to the Saint John River in recent years.

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Table 1. Thousands of MSW salmon (MSWS) and grilse (GRLS) returns to the Saint John River, 1971 to 1990 and 1970 to 1989, respectively.

Year i	MSWS year i	GRLS year i-1
1971	4.715	3.057
1972	4.899	1.709
1973	2.518	0.908
1974	5.811	2.070
1975	7.441	3.656
1976	8.177	6.858
1977	9.712	8.147
1978	4.021	3.977
1979	2.754	1.902
1980	10.924	6.828
1981	5.991	8.482
1982	5.001	5.782
1983	3.447	4.958
1984	9.779	4.309
1985	10.436	8.311
1986	6.128	6.526
1987	4.352	7.904
1988	2.625	5.909
1989	4.072	8.930
1990	3.329	9.522

Table 2. Mean fork length (cm) and sample number of grilse returns to Mactaquac, Saint John River, 1970 to 1989, partitioned by period of return and smolt age.

Year	All smolt ages								2+ smolts	
	June-July		August		Sept-Nov		All year		All year	
	No.	Len. (JJLEN)	No.	Len. (ALEN)	No.	Len. (SNLEN)	No.	Len. (YLEN)	No.	Len. (Y2LEN)
1970	145	54.3	13	52.9	41	56.5	199	54.7	29	54.6
1971	122	54.5	12	55.7	53	58.8	187	55.8	35	56.3
1972	64	56.1	32	57.3	39	58.3	135	57.0	16	53.6
1973	142	53.8	24	55.7	33	57.5	199	54.6	150	54.2
1974	73	56.3	29	54.8	6	60.3	108	56.1	48	56.3
1975	145	55.0	29	56.8	22	57.1	196	55.5	65	55.0
1976	127	54.7	44	56.5	23	57.4	194	55.5	112	55.3
1977	139	55.7	24	56.4	29	57.5	192	56.1	49	55.9
1978	131	55.8	32	56.3	36	58.7	199	56.4	48	56.2
1979	144	56.0	25	55.6	29	59.0	198	56.4	99	56.8
1980	114	56.9	50	58.9	33	61.1	197	58.1	55	57.7
1981	147	56.3	23	55.7	26	57.0	196	56.3	51	56.1
1982	138	54.5	36	57.6	26	57.1	200	55.4	37	55.7
1983	244	54.8	57	55.8	42	58.0	343	55.4	222	55.0
1984	307	55.3	232	55.4	133	56.8	672	55.6	359	55.6
1985	280	55.2	169	55.9	75	57.7	524	55.8	117	55.4
1986	450	57.4	97	57.8	72	58.8	619	57.6	286	57.6
1987	367	57.7	72	58.9	66	59.3	505	58.1	242	57.3
1988	609	58.2	73	59.1	113	60.8	795	58.6	452	58.3
1989	656	58.8	72	58.7	100	61.4	828	59.1	371	58.3

Table 3. Proportion female and mean smolt age of wild 1SW salmon returns to Mactaquac, Saint John River, 1970 to 1989.

Year	1SW salmon			Smolt age	
	Sample no.	Female No.	Female Prop'n (PFEM)	No.	Age[1] (SAGE)
1970	40	4	0.10	194	2.91
1971	54	21	0.39	181	2.90
1972	38	10	0.26	120	2.96
1973	32	2	0.06	197	2.25
1974	7	1	0.14	102	2.53
1975	22	6	0.27	192	2.67
1976	23	1	0.04	191	2.44
1977	29	1	0.03	186	2.74
1978	36	8	0.22	194	2.77
1979	29	3	0.10	193	2.50
1980	33	3	0.09	188	2.76
1981	27	3	0.11	182	2.81
1982	27	7	0.26	183	2.85
1983	43	4	0.09	341	2.35
1984	115	3	0.03	638	2.44
1985	75	8	0.11	484	2.78
1986	77	10	0.13	570	2.51
1987	67	22	0.33	475	2.52
1988	113	17	0.15	770	2.42
1989	100	17	0.17	784	2.56

[1]Mean smolt age.

Table 4. Nominal commercial catches of small salmon in SFAs 3 to 8 (insular Newfoundland) and SFA 2 (Labrador), 1974 to 1989 (O'Connell et al. 1990), and at Greenland, 1970 to 1989 (Anon. 1990b). Greenland catch figures reflect both total harvests and numbers of North American 1SW salmon. Harvest estimates and parameter values used to derive numbers of 1SW salmon of North American origin caught at Greenland are from Anon. (1990b).

Year	Newfoundland-Labrador		Greenland	
	SFAs 3 to 8 (number/1000) (ENFLD)	SFA 2 (number/1000) (SLAB)	Total harvest (tonnes) (TGLD)	North American 1SW salmon (number/1000) (NAGLD)[1]
1970			2146	215
1971			2689	289
1972			2113	208
1973			2341	257
1974	163.7	40.7	1917	225
1975	205.1	70.4	2030	279
1976	152.7	50.9	1175	159
1977	158.4	46.0	1420	
1978	70.2	15.1	984	125
1979	143.6	31.1	1395	198
1980	197.0	76.4	1194	189
1981	181.2	98.4	1264	228
1982	146.9	62.9	1077	177
1983	121.4	36.2	310	36
1984	106.3	15.5	297	42
1985	138.0	28.8	864	141
1986	159.3	51.3	960	174
1987	197.8	71.8	966	175
1988	116.5	64.3	893	118
1989	117.6	39.5	337	62

[1]NAGLD = (TGLD ÷ mean weight of all fish) X 1SW salmon proportion X North American proportion.

Table 5. Numbers of tagged smolts recaptured as MSW and non-maturing 1SW salmon and proportions of total recaptures taken as 1SW salmon in the Newfoundland-Labrador fishery and at Greenland. Smolts were of native stock, hatchery-reared and released from Mactaquac Hatchery, Saint John River, 1970 to 1988.

Smolt year	Recaptures (maturing 1SW salmon excluded) Total no.[1]	Nfld-Lab No.	Nfld-Lab 1SW Prop'n (TGNFLD)	Greenland No.	Greenland 1SW Prop'n (TGGLD)	Nfld-Lab plus Greenland prop'n (TGMAR)
1970	28	2	0.07	12	0.43	0.50
1971	139	4	0.03	19	0.14	0.17
1972	51	3	0.06	16	0.31	0.37
1973	284	35	0.12	93	0.33	0.45
1974	111	28	0.25	23	0.21	0.46
1975	230	29	0.13	41	0.18	0.31
1976	189	55	0.29	7	0.04	0.33
1977	172	29	0.17	23	0.13	0.30
1978	428	26	0.06	86	0.20	0.26
1979	377	73	0.19	31	0.08	0.27
1980	141	11	0.08	23	0.16	0.24
1981	68	10	0.15	13	0.19	0.34
1982	67	10	0.15	1	0.01	0.16
1983	49[2]	6	0.12	3	0.06	0.18
1984	56[2]	10	0.18	8	0.14	0.32
1985	72[2]	5	0.07	14	0.19	0.26
1986	73[2]	20	0.27	17	0.23	0.50
1987	22	0	0.00	8	0.36	0.36
1988	24	6	0.25	3	0.13	0.38

[1]Total recaptures as MSW and non-maturing 1SW salmon in sea fisheries and home river.

[2]Includes unreported 2SW salmon estimated to have been recaptured in an Indian fishery in home river. Estimate based on an assumed exploitation for this fishery equal to the mean of rates derived for MSW salmon in years 1978 to 1982 (Marshall 1985).

Table 6. Sums of mean monthly sea surface temperatures for April-May, Gulf of Maine (GOM) and February-April, Inner Labrador Current (ILC). Mean temperatures were derived from ships-of-chance reportings.

Year i	GOM in year i	ILC in year i+1
1971	11.02	-1.08
1972	12.13	-1.00
1973	10.63	-1.69
1974	13.24	-0.73
1975	11.67	0.71
1976	13.62	-0.89
1977	12.20	2.77
1978	12.52	0.74
1979	12.91	0.60
1980	13.24	2.32
1981	13.32	1.79
1982	14.00	3.74
1983	13.07	1.69
1984	12.20	-1.20
1985	12.49	1.02
1986	15.35	0.32
1987	10.73	0.57
1988	11.33	1.45

Table 7. Results of linear regressions of MSW salmon returns to the Saint John River (MSWS), 1971 to 1990, on each of 17 potential independent variables.

Variable	df	F	p
GRLS	1,18	1.81	0.195
YLEN	1,18	3.95	0.062
JJLEN	1,18	2.79	0.112
ALEN	1,18	3.53	0.077
SNLEN	1,18	1.01	0.329
Y2LEN	1,18	0.70	0.415
PFEM	1,18	5.64	0.029
SAGE	1,18	5.80	0.027
ENFLD	1,14	0.00	0.979
SLAB	1,14	1.42	0.254
TGLD	1,18	0.35	0.562
NAGLD	1,17	0.42	0.528
GOM	1,16	0.02	0.881
ILC	1,16	0.14	0.717
TGNFLD	1,17	0.23	0.637
TGGLD	1,17	0.47	0.501
TGMAR	1,17	1.34	0.264

Table 8. Models for predicting MSW salmon returns to the Saint John River (MSWS). Models I and II were derived from MSW salmon returns 1971 to 1990; Model III was derived with 1983 and 1984 MSW salmon returns excluded.

Source of variation	Coefficient	S. E.	t-value	p
Model I, Dependent Variable = MSWS				
Constant	95.700	22.301	4.29	<0.001
GRLS	0.712	0.193	3.69	0.002
YLEN	- 1.663	0.405	4.11	0.001
Adjusted R^2 = 0.491, F = 10.16, p = 0.001				
Durbin-Watson = 2.05				
Model II, Dependent Variable = Log_e MSWS				
Constant	18.113	3.569	5.08	<0.001
GRLS	0.128	0.031	4.15	0.001
YLEN	- 0.304	0.065	4.70	<0.001
Adjusted R^2 = 0.560, F = 13.11, p < 0.001				
Durbin-Watson = 2.14				
Model III, Dependent Variable = Log_e MSWS				
Constant	18.764	3.044	6.17	<0.001
GRLS	0.132	0.025	5.19	<0.001
YLEN	- 0.316	0.055	5.74	<0.001
Adjusted R^2 = 0.691, F = 20.02, p < 0.001				
Durbin-Watson = 1.86				

Table 9. Comparison of MSW salmon (MSWS) predictions from models I, II and III versus recorded returns to the Saint John River, 1971 to 1990. Corresponding standardized residuals are shown.

		Model I		Model II		Model III	
Year	Recorded MSWS	Predicted MSWS	Standardized residual	Predicted MSWS	Standardized residual	Predicted MSWS	Standardized residual
1971	4715	6911	-1.13	6443	-1.01	6581	-1.31
1972	4899	4122	0.40	3878	0.75	3889	0.91
1973	2518	1556	0.50	2429	0.12	2394	0.20
1974	5811	6374	-0.29	5852	-0.02	5960	-0.10
1975	7441	5010	1.26	4544	1.59	4577	1.91
1976	8177	8288	-0.06	8224	-0.02	8454	-0.13
1977	9712	9206	0.26	9703	0.00	10072	-0.13
1978	4021	5238	-0.63	4735	-0.53	4776	-0.68
1979	2754	3261	-0.26	3312	-0.60	3301	-0.71
1980	10924	6770	2.15	6230	1.81	6336	2.14
1981	5991	5121	0.45	4592	0.86	4609	1.03
1982	5001	6191	-0.61	5616	-0.37	5694	-0.51
1983	3447	7101	-1.89	6645	-2.12		
1984	9779	6639	1.62	6114	1.52		
1985	10436	9157	0.66	9612	0.27	9929	0.20
1986	6128	7553	-0.74	7194	-0.52	7359	-0.72
1987	4352	5541	-0.61	4964	-0.43	5001	-0.55
1988	2625	3288	-0.34	3301	-0.74	3279	-0.87
1989	4072	4608	-0.28	4177	-0.08	4176	-0.10
1990	3329	4199	-0.45	3871	-0.47	3857	-0.58

Table 10. Pair-wise comparisons of fork lengths (cm), weights (kg) and condition factors for 1SW salmon returns to Morgan Falls, LaHave River, N.S., 1984 to 1989. Bars under means indicate non-significant difference determined by analysis of factor effects and the Bonferonni method of multiple comparisons (Neter et al. 1985). Significance of difference is based on 95% confidence intervals.

Variable	Statistic	1984 (137)[1]	1985 (90)[1]	1986 (145)[1]	1987 (207)[1]	1988 (213)[1]	1989 (193)[1]
Length	Mean	53.420	52.907	55.759	54.436	54.630	53.708
	SD	2.531	2.727	2.527	2.259	2.307	2.224
Weight	Mean	1.647	1.590	2.001	1.831	1.835	1.803
	SD	0.276	0.274	0.316	0.243	0.244	0.263
Condition factor	Mean	1.074	1.066	1.147	1.132	1.122	1.158
	SD	0.102	0.097	0.091	0.087	0.092	0.103

[1]Number in parentheses is sample size.

Table 11. Mean fork lengths and sex compositions for two groups of 1SW salmon returns to Mactaquac, Saint John River, 1990, and for the corresponding groups of the 1-year (Mactaquac Hatchery) and 2-year (Saint John Hatchery) smolts from which they originated. Sex of both 1SW salmon and smolts was determined by internal examination. Both groups were from late-run MSW salmon parents that returned to Mactaquac.

Variable	Mactaquac			Saint John		
	Sample	Mean	SD	Sample	Mean	SD
Smolts						
Fork length	450	17.9	1.4	250	20.5	2.3
Sex, % female	119	55.5	-	96	57.3	-
1SW salmon						
Fork length, female	2	56.0	-	15	61.7	2.1
Fork length, male	82	58.9	2.5	40	60.8	3.6
Fork length, all sexes	85	58.9	2.5	56	61.1	3.3
Sex, % female	84	2.4	-	55	27.3	-

Table 12. Correlation matrix for % MSWS, YLEN, GOM, ILC and time (YEAR). Values of p are shown in parentheses.

	% MSWS	YLEN	GOM	ILC
YLEN	-0.71 (<0.001)			
GOM	-0.17 (0.492)	-0.16 (0.526)		
ILC	-0.18 (0.474)	0.05 (0.807)	0.33 (0.180)	
YEAR	-0.80 (<0.001)	0.63 (0.003)	0.23 (0.365)	0.45 (0.064)

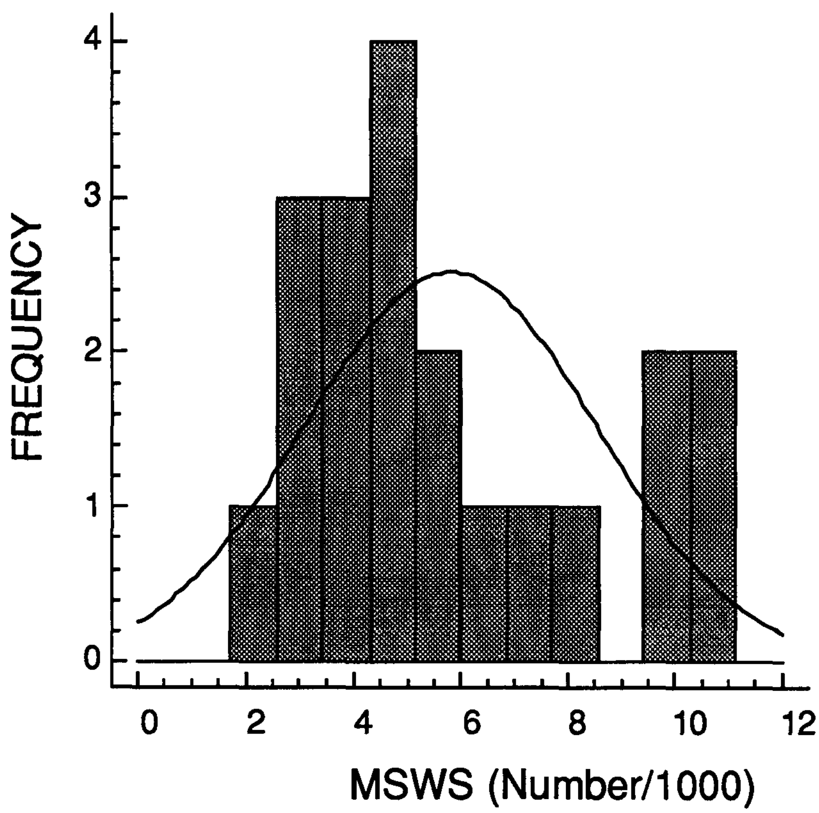


Fig. 1. Histogram of annual returns of wild MSW salmon to the Saint John River (MSWS), 1971 to 1990. Normal distribution is superimposed on histogram.

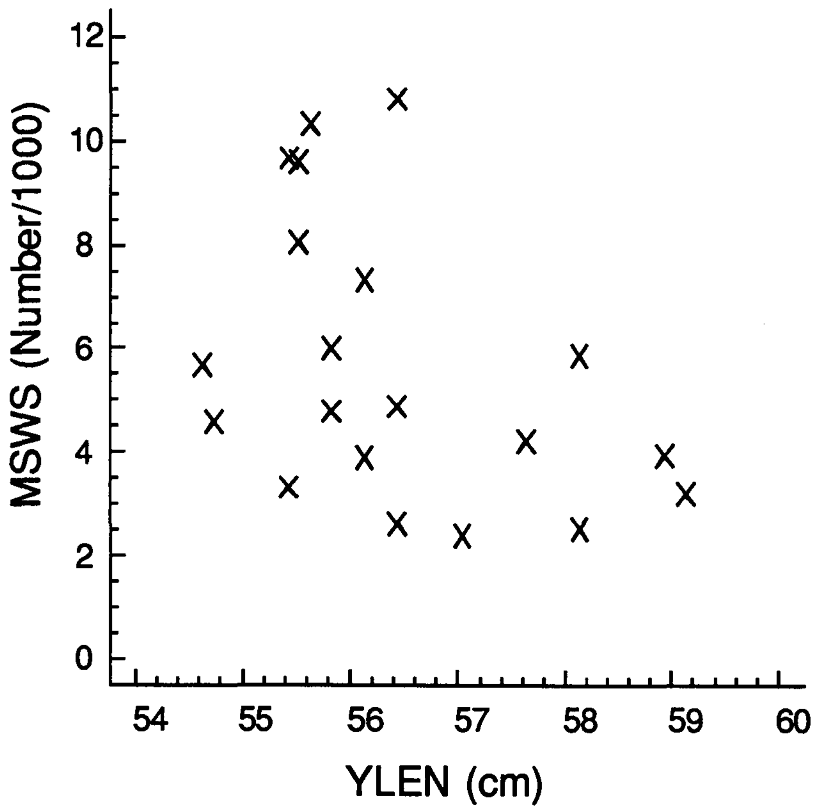


Fig. 2. Evidence of curvilinear trend in relationship between wild MSW salmon returns to the Saint John River (MSWS), 1971 to 1990, and mean fork length of 1SW salmon returning the previous year (YLEN).

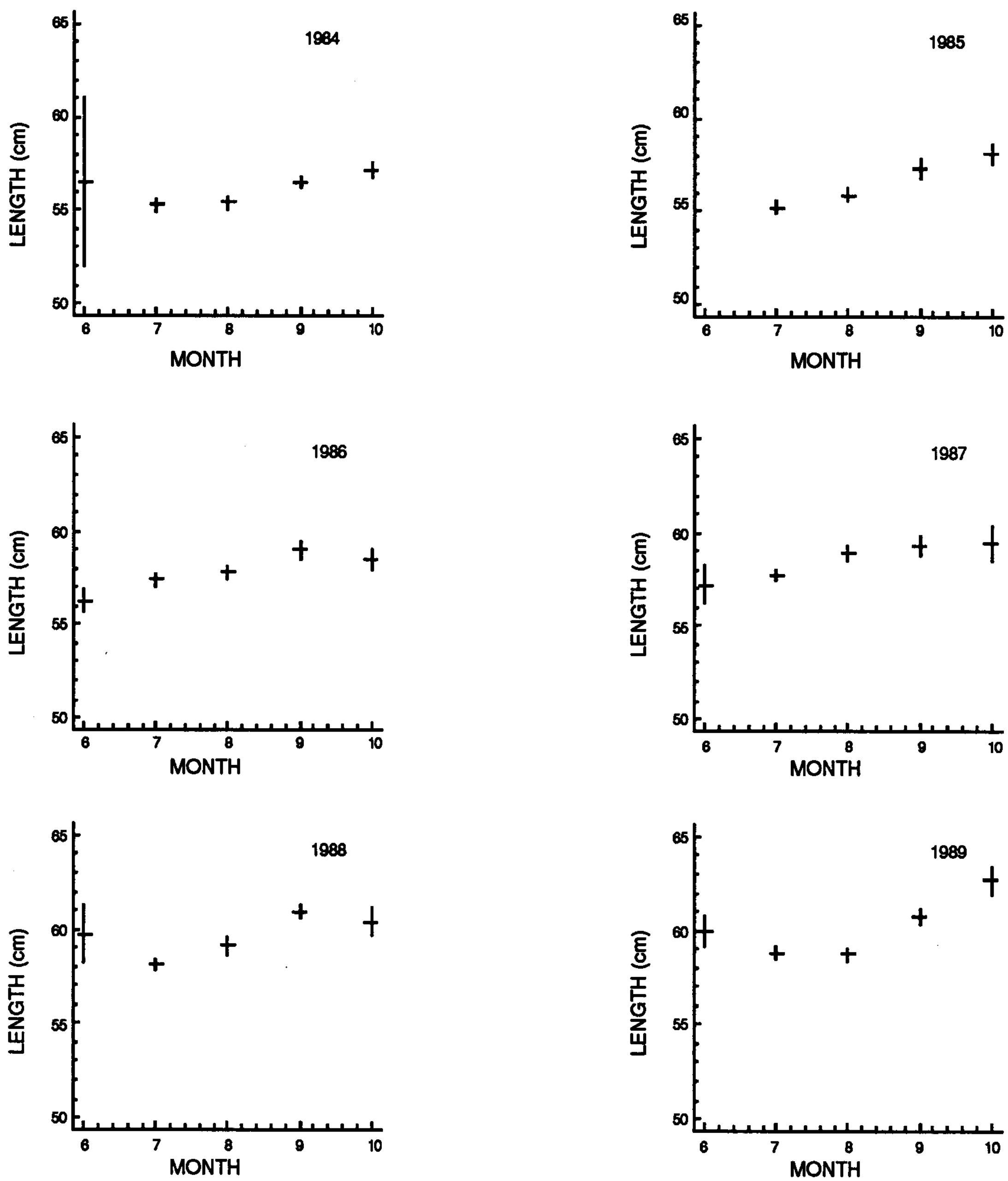


Fig. 3. Monthly mean fork lengths and standard errors for wild 1SW salmon returning to Mactaquac, Saint John River, 1984 to 1989.

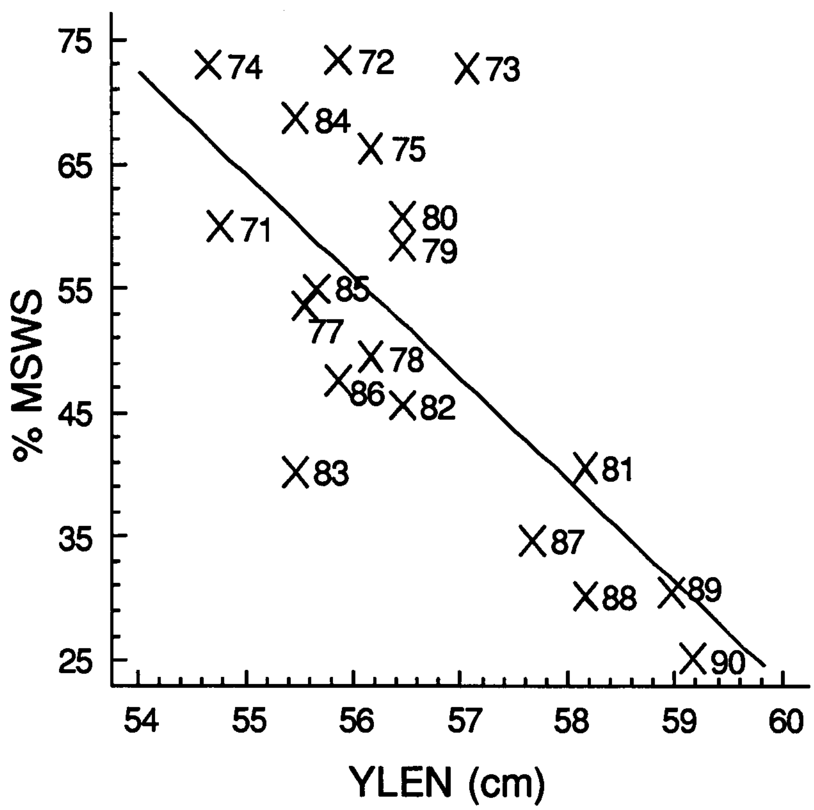
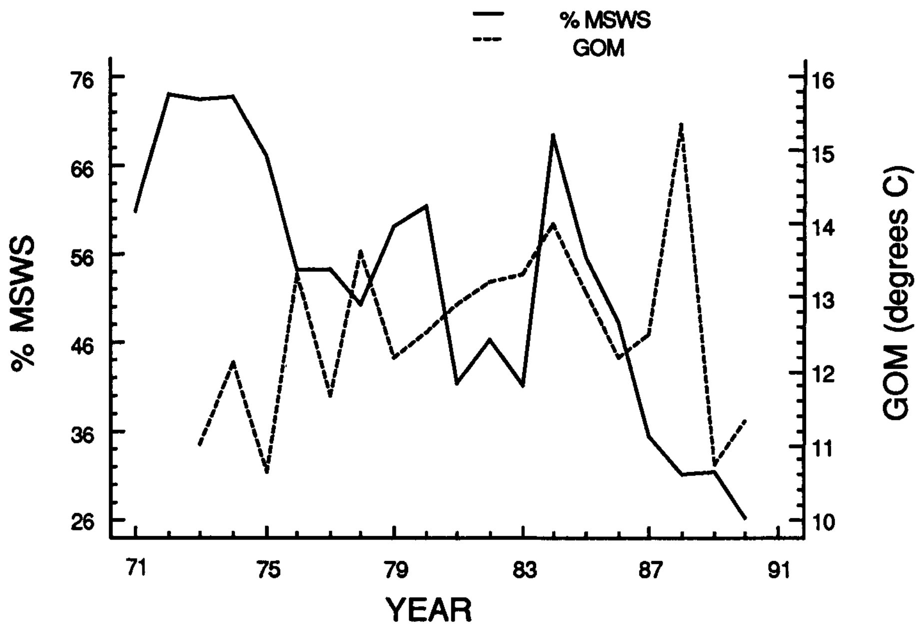


Fig. 4. Plot of percent MSW salmon returns (% MSWS) on mean fork length of previous year's 1SW salmon (YLEN). Year of MSW salmon return is shown for each point.



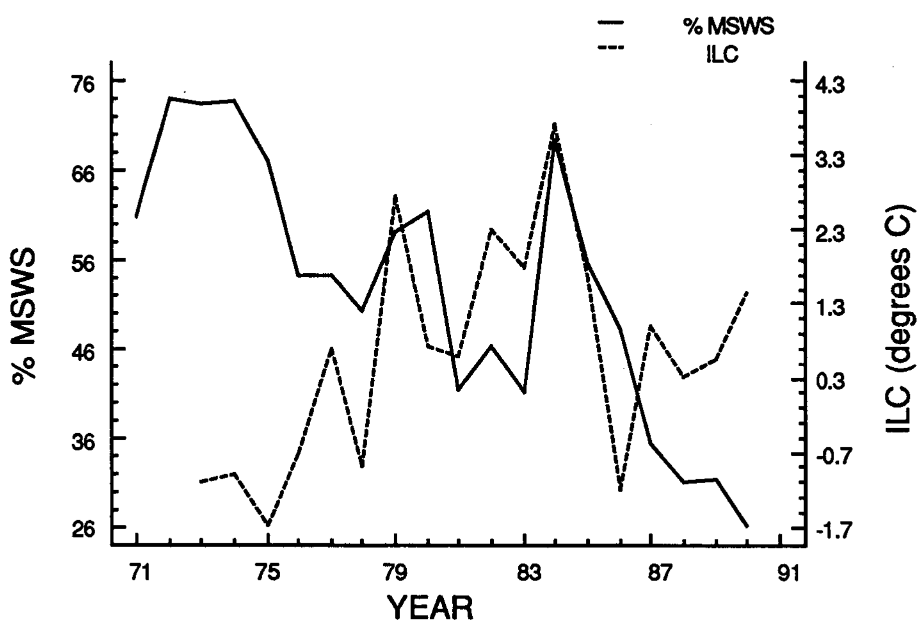
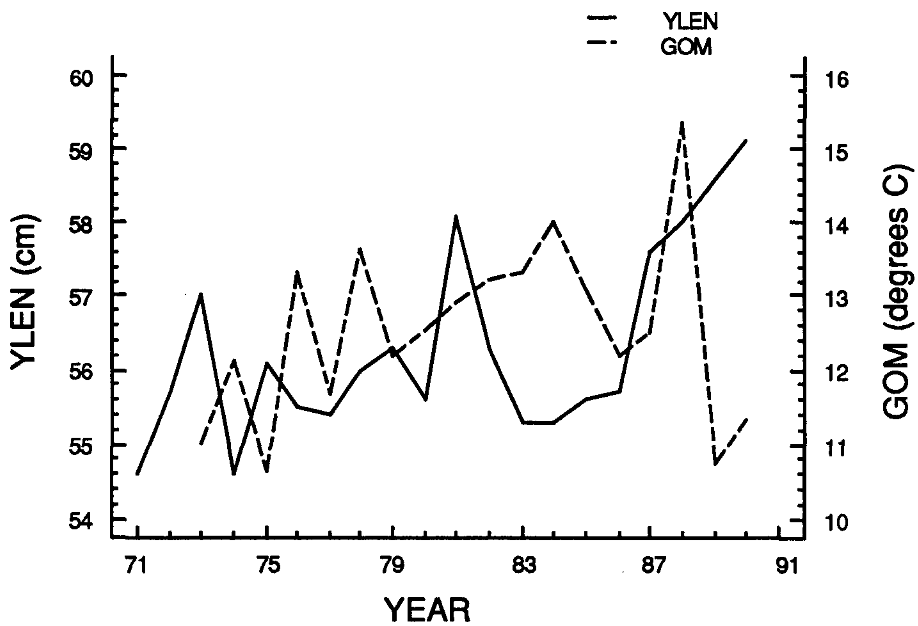


Fig. 5. Plots of percent MSW salmon returns to the Saint John River (% MSWS) and of sums of mean monthly sea surface temperatures for April-May, Gulf of Maine (GOM) and February-April, Inner Labrador Current (ILC). Measurements are referenced to year of MSW salmon return.



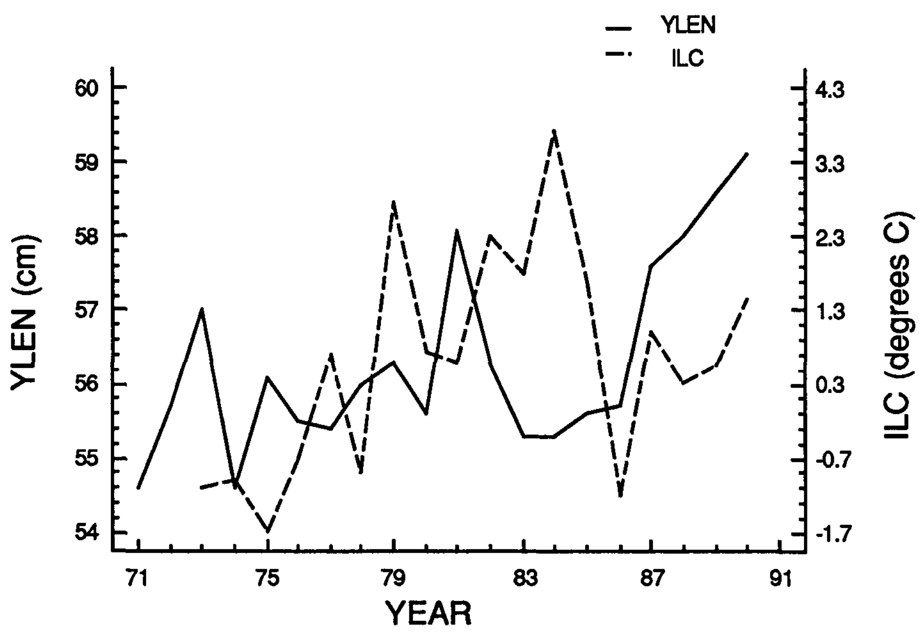


Fig. 6. Plots of mean fork length of 1SW salmon returns to the Saint John River (YLEN) and of sums of mean monthly sea surface temperatures for April-May, Gulf of Maine (GOM) and February-April, Inner Labrador Current (ILC). Measurements are referenced to year of MSW salmon return.