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Area of ice over the northern Newfoundland and southern Labrador shelves as a variable to reduce the variance of inseason forecasts of Atlantic salmon at Morgan Falls, LaHave River

by

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Abstract

This document examines the potential for mean monthly ice areas over the northern Newfoundland and southern Labrador shelves to explain a significant portion of the variation in run timing of Atlantic salmon counted at Morgan Falls, LaHave River. An end of season population estimate, based on cumulative counts to a date, can be made as the season progresses using a linear regression model. An estimate can be made as early as July 1 while maintaining an assumed minimum level of precision of 25% coefficient of variation. Inclusion of the mean March ice area in the model allows an end of season population estimate to be made as early as June 15, with a 20% loss of precision over the July 1 estimate. Inclusion of the mean May ice area improved the proportion of variation explained by the regression from $R^2_{adj} = 0.82$ to $R^2_{adj} = 0.88$ and increased the precision by 12% using cumulative counts to July 6.

Résumé

Le présent document traite de la possibilité d'utiliser les moyennes mensuelles des superficies de glace du nord du plateau de Terre-Neuve et du sud du plateau du Labrador pour expliquer une partie significative de la variation du moment de la remontée des saumons de l'Atlantique dénombrés à Morgan Falls, sur la rivière LaHave. Une estimation de population de fin de saison, fondée sur les dénombrements cumulatifs peut être faite en cours de saison à l'aide d'un modèle de régression linéaire. Une telle estimation peut être obtenue dès le 1er juillet tout en conservant une niveau d'exactitude minimum supposé de 25 % du coefficient de variation. L'ajout de la superficie moyenne de glace en mars permet d'obtenir une estimation de population de fin de saison dès le 15 juin, mais avec une perte d'exactitude de 20 % par rapport à l'estimation faite au 1er juillet. L'utilisation de la superficie moyenne de glace en mai permet d'accroître la proportion de la variation expliquée par la régression de $R^2 = 0{,}82$ à $R^2 = 0{,}88$ et l'exactitude de 12 % de par les dénombrements cumulatifs jusqu'au 6 juillet.

Introduction

Based on cumulative counts to a date, an end of season estimate of the population of Atlantic salmon (*Salmo salar*) can be made as the season progresses. This method requires that the portion of the population observed at any chosen date be estimated with a known error. Inseason estimates provide valuable information to managers for adjusting in-river exploitation rates in order to meet an accepted risk of achieving any pre-determined target escapement of salmon. The value of these adjustments is increased when performed earlier in a season and particularly when conducted without loss of accuracy or precision.

Counts of salmon at Morgan Falls fishway on the LaHave River provide essential data for an inseason forecast. End of season counts can be estimated from simple linear regression of total end of season count on cumulative count to date for the years 1980 to 1996 (Amiro *et al.* MS 1996). To be useful to a fisheries manager we assumed that the chosen regression model must provide a forecast of end of season count at the earliest possible date while maintaining a standard error of the estimate of, at most, one-quarter of the 1980-1996 average end of season count of 2,328 fish, or 582 fish.

The simple cumulative model can provide estimates with this precision on July 6, when on average about 45% of the count has passed the fishway. Most of the angling fishery takes place before July 6. To advance this date, co-variables such as discharge and cumulative discharge-to-date were not successful in reducing the variance; i.e., meeting the precision criterion. The monthly time series of areal extent of the ice over the northern Newfoundland and southern Labrador shelves was noted in the report of marine conditions of the North Atlantic in 1996 (Drinkwater *et al.* MS 1997). This area of the North Atlantic is noted for over-wintering of Atlantic salmon (Ritter 1989, Reddin 1988a). Extremes in the areal ice data were noted to coincide with extremes in the date of the 50^{th} percentile count at Morgan Falls. This observation suggested that the ice data may account for variation in the timing of the return to Morgan Falls.

This document examines the potential for mean monthly ice areas to account for the variation in run timing of salmon counted at Morgan Falls, LaHave River, in order to estimate end of season counts earlier in the season at the assumed precision target.

Methods

Forecast dates examined were June 15, July 1, July 6, July 15, August 1, and August 15 for the years 1980 to 1996. Cumulative total counts for these dates were regressed with and without extent of areal ice (Table 1; Figure 1) in the general model forms:

$$\text{End of season count} = \beta_0 + \beta_1 * \text{Count to date} + \text{error}$$

and

$$\text{End of season count} = \beta_0 + \beta_1 * \text{Count to date} + \beta_2 * \text{Ice area} + \text{error}$$

Six variables quantifying the mean monthly ice area (1000 km^2) on the northern Newfoundland and southern Labrador shelves, one each for December (of the year previous to the forecast year) to May (of the forecast year), were examined at each of the forecast dates using forward stepwise regression analysis (SYSTAT V7.0 1997) with significance limits of $\alpha = 0.05$ to enter and $\alpha = 0.05$ to remove variables.

The occurrence of significant ($p<0.05$) regressions but with significant outliers, in either the x or y direction, prompted the application of an iteratively reweighted least squares (IRLS) robust regression procedure (Neter *et al.* 1996). This procedure is one method to reduce the influence of outliers on the regression parameters. Provided there are few outliers, the method provides more stable parameter estimates, thereby increasing the accuracy and precision of the forecasts.

The IRLS procedure employs weights that vary inversely with the size of the residual and the leverage value. The weights are revised at each iteration from the new residuals and leverage values, until convergence of the independent variable regression coefficients is obtained. Convergence is interpreted as a change of less than 0.5% in the parameter values (tolerance < 0.5%).

A brief outline of this procedure follows:

1. The weighting function chosen is the Huber function given as:

$$weight_i = \begin{cases} 1 & \text{if } |u_i| \leq 1.345 \\ \dfrac{1.345}{|u_i|} & \text{if } |u_i| > 1.345 \end{cases}$$

where u_i is the i^{th} scaled residual calculated as:

$$u_i = e_i * 0.6745 / \text{median}\{|e_i - \text{median}\{e_i\}|\}$$

and e_i is the i^{th} residual from the least squares regression, i=1,...,17. These weights are multiplied by

$$\sqrt{1 - h_i}$$

where h_i is the leverage of the i^{th} case.

2. Starting weights are obtained for all cases by using the initial residuals and leverage values obtained from an ordinary least squares fit.

3. Weighted least squares is performed using the starting weights.

4. The residuals and leverage values from the fitted regression function in step 3 and the weighting function in step 1 are used to obtain revised weights.

5. Iterations continue until convergence is obtained, measured by observing the change in estimated independent variable regression coefficients (tolerance < 0.5%).

Results

Without an ice variable, July 1 was found to be the earliest date from which forecasts of end of season counts could be made, while maintaining a standard error of the regression estimate less than 582. The regression equation is:

$$\text{End of season count} = 926.539 + 1.709 * \text{Count to July 1} \quad (R^2_{adj}=0.73; p<0.0001; n=17)$$

This model forecast an estimated 1996 end of season count of 2,003 salmon (95% C.I. 1012-2994) from 630 salmon counted by July 1. The actual 1996 end of season count was 1327.

With the inclusion of March ice area as an independent variable (Table 1; Figure 2), June 15 was found to be the earliest date from which forecasts of end of season counts could be made, while maintaining a standard error of the regression estimate less than 582 (Figure 3). The regression equation is:

End of season count = -1356.982 + 9.659*Count to June 15 + 8.049*March ice area (R^2_{adj}=0.551; p=0.001; n=17)

This model forecast an estimated 1996 end of season count of 1401 salmon (95% C.I. 210-2592) from 118 salmon counted by June 15 and a March ice area value of 201. The model without the March ice variable is:

End of season count = 1435.847 + 6.659*Count to June 15 (R^2_{adj}=0.37; p=0.005; n=17)

This model has a standard error of the regression estimate greater than the desired criterion but, for the purposes of comparison, this model is used to estimate a forecast. The estimated 1996 end of season count is 2,222 salmon (95% C.I. 617-3827), forecast from 118 salmon counted by June 15. Bayesian (Box and Tiao 1973) probability distributions were estimated for the two models involving cumulative counts to June 15 to illustrate the difference in precision of the forecast, using models with and without March ice area (Figure 4). The model with March ice area estimates a forecast of end of season counts with a narrower confidence interval.

The inclusion of the mean May ice area significantly improved the fit of the inseason estimator model using cumulative counts to July 6 (Table 1; Figures 5 and 6). The regression equation is:

End of season count = -72.028 + 1.722*Count to July 6 + 4.407*May ice area (R^2_{adj}=0.88; p<0.001; n=17)

This model forecast an estimated 1996 end of season count of 1,729 salmon (95% C.I. 1000-2459) from 1,013 salmon counted by July 6 and a May ice area value of 13. The model without the May ice variable is:

End of season count = 730.898 + 1.448*Count to July 6 (R^2_{adj}=0.82; p<0.001; n=17)

The estimated 1996 end of season count from this model is 2,198 salmon (95% C.I. 1366-3030), forecast from 1,013 salmon counted by July 6.

Discussion

Addition of an ice variable advanced the possible forecast date by 15 days from July 1 to June 15 with a 20% loss in precision, while maintaining a standard error of the regression estimate within the acceptable margin. This advanced date is beneficial to the management of conservation escapements and to the provision of exploitation advice with a variety of harvest options. The addition of May ice to the July 6 estimate improved the proportion of variation explained by the regression by 7.32% from $R^2_{adj} = 0.82$ to $R^2_{adj} = 0.88$, and increased the precision by 12%.

These models suggest that the end of season count will be higher than the average June 15 or July 6 counts indicate in years when the March or May ice area is larger; i.e., the run will be later. The biological mechanism for this effect can only be speculated from these data. These run time models support growth and maturity models which are based on temperature and food availability (Thorpe 1994). These growth and maturity models suggest that fish mature and begin homeward migration as the result of achieving some growth threshold. Growth may therefore be influenced by temperature and/or food availability and the areal extent of ice as a signal of that influence. The result is a change in run timing to the rivers.

Acknowledgments

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Table 1. Cumulative counts of Atlantic salmon to Morgan Falls fishway on the LaHave River by date and the mean March and May ice areas on the northern Newfoundland and southern Labrador shelves, 1980-1996.

Year	Date							Ice area (1000 km^2)	
	June 15	July 1	July 6	July 15	August 1	August 15	Season end	March	May
1980	276	1173	1420	1943	2425	2430	2802	255	62
1981	335	1415	1817	2365	3066	3298	3647	58	68
1982	126	778	1058	1380	1390	1774	1918	245	86
1983	95	331	342	455	878	914	1459	247	183
1984	83	736	1145	1487	1941	1985	2715	388	199
1985	36	323	659	1101	1747	1920	2158	396	171
1986	65	809	1182	1517	1964	2229	2384	316	30
1987	308	1822	2234	2684	2776	2782	3660	206	79
1988	145	509	1409	1891	2829	3306	3974	221	73
1989	219	1460	1868	2406	2688	2688	3177	311	47
1990	97	917	1498	2177	2479	2673	2950	409	112
1991	92	101	108	111	111	113	928	289	216
1992	79	898	1249	1677	2131	2150	2844	348	154
1993	11	413	618	860	1070	1231	1364	329	171
1994	80	285	296	388	391	391	1095	325	139
1995	49	402	627	821	1039	1039	1177	299	60
1996	118	630	1013	1120	1236	1252	1327	201	13

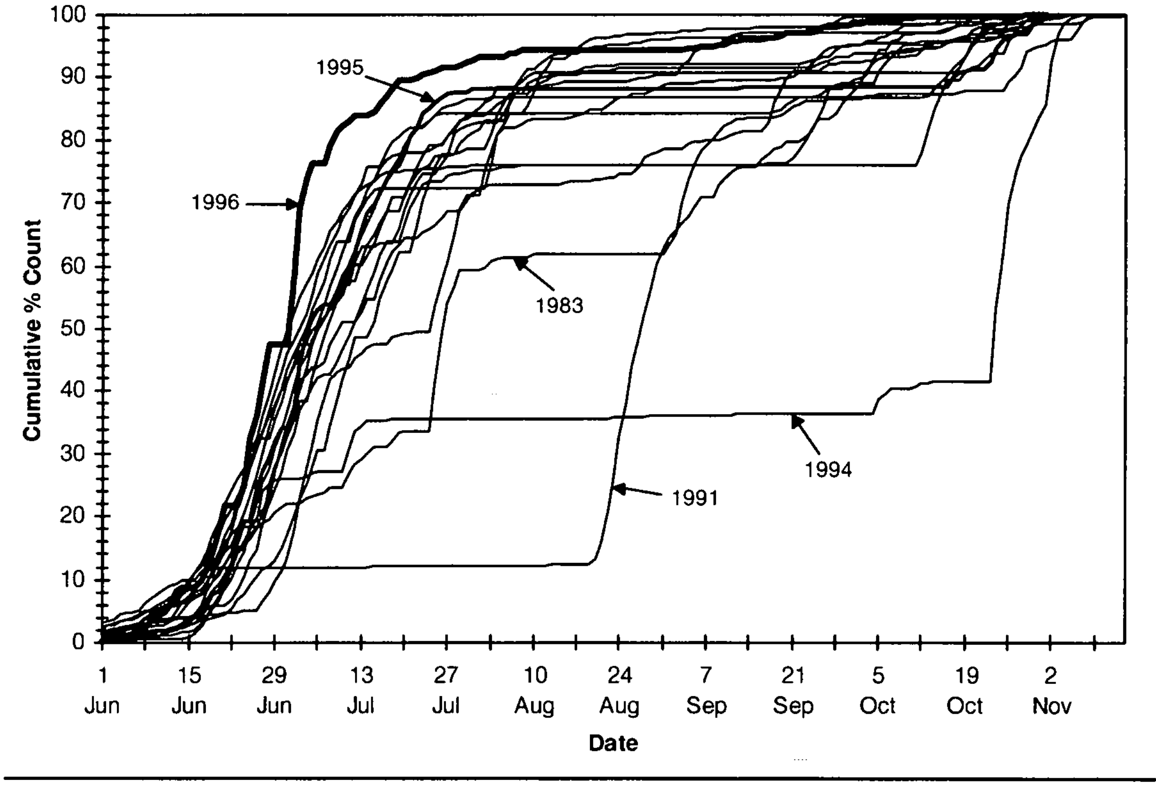

Figure 1. Cumulative percent count of salmon by date at Morgan Falls, LaHave River, 1980-1996.

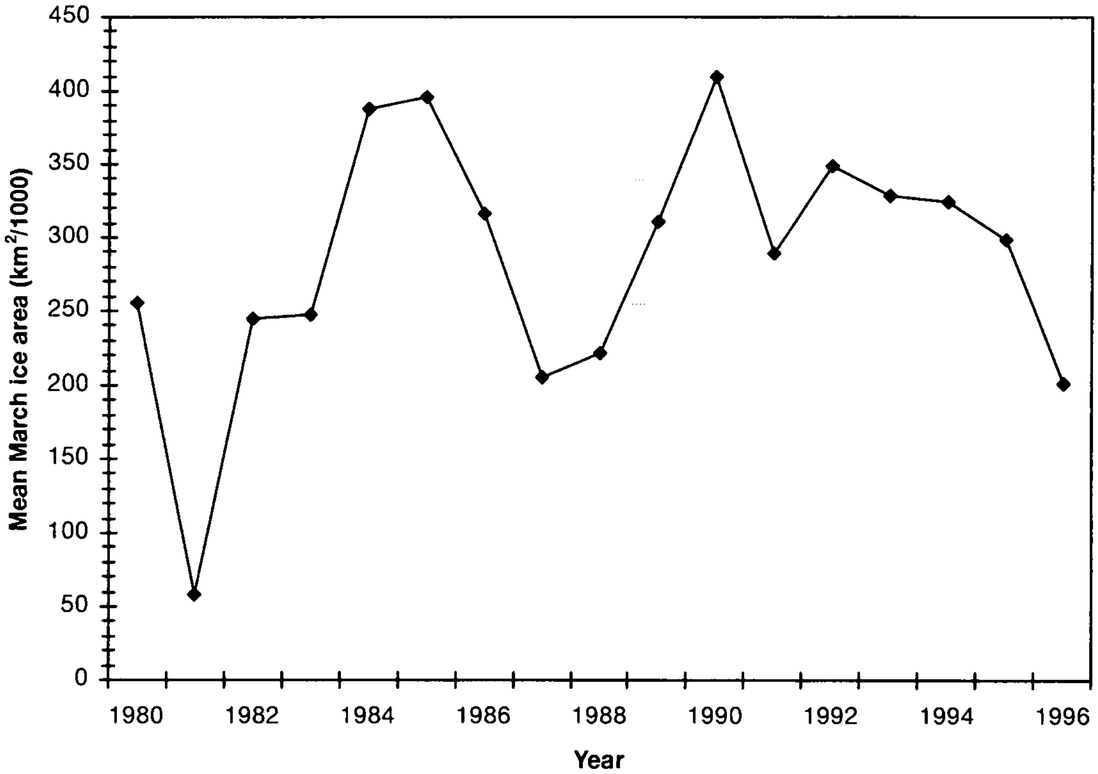

Figure 2. Mean March ice area on the northern Newfoundland and southern Labrador shelves, 1980-1996.

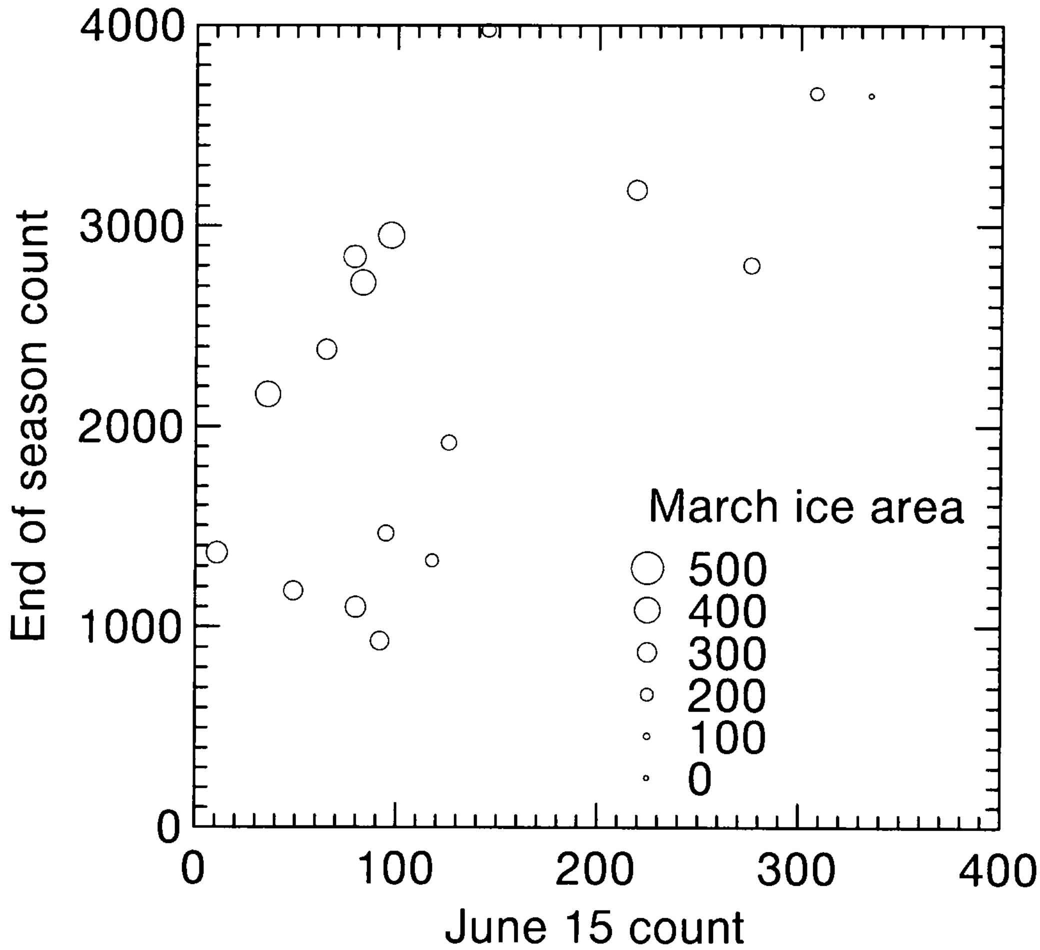

Figure 3. Plot of Morgan Falls, LaHave River, end of season salmon counts against cumulative counts by June 15, 1980-1996. Symbol size represents March ice area coverage on the northern Newfoundland and southern Labrador shelves.

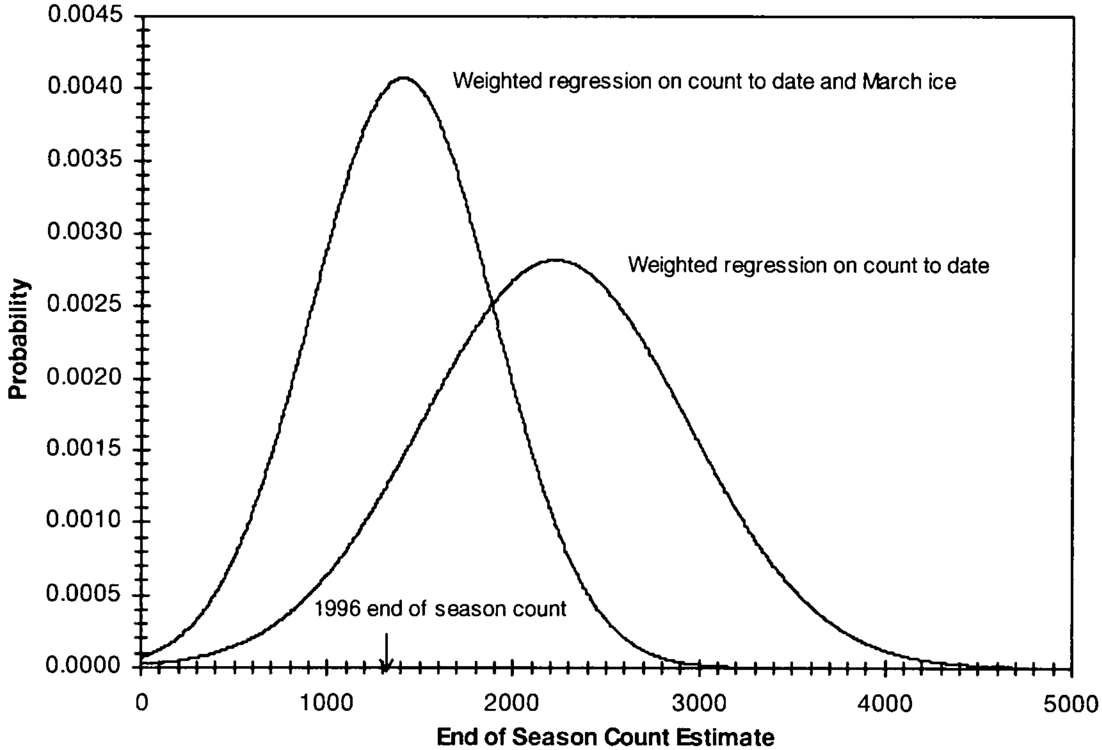

Figure 4. Bayes probability distributions of estimates of 1996 Morgan Falls, LaHave River, end of season salmon counts based on the weighted regression of end of season count on cumulative count to June 15, with and without March ice coverage, 1980-1996.

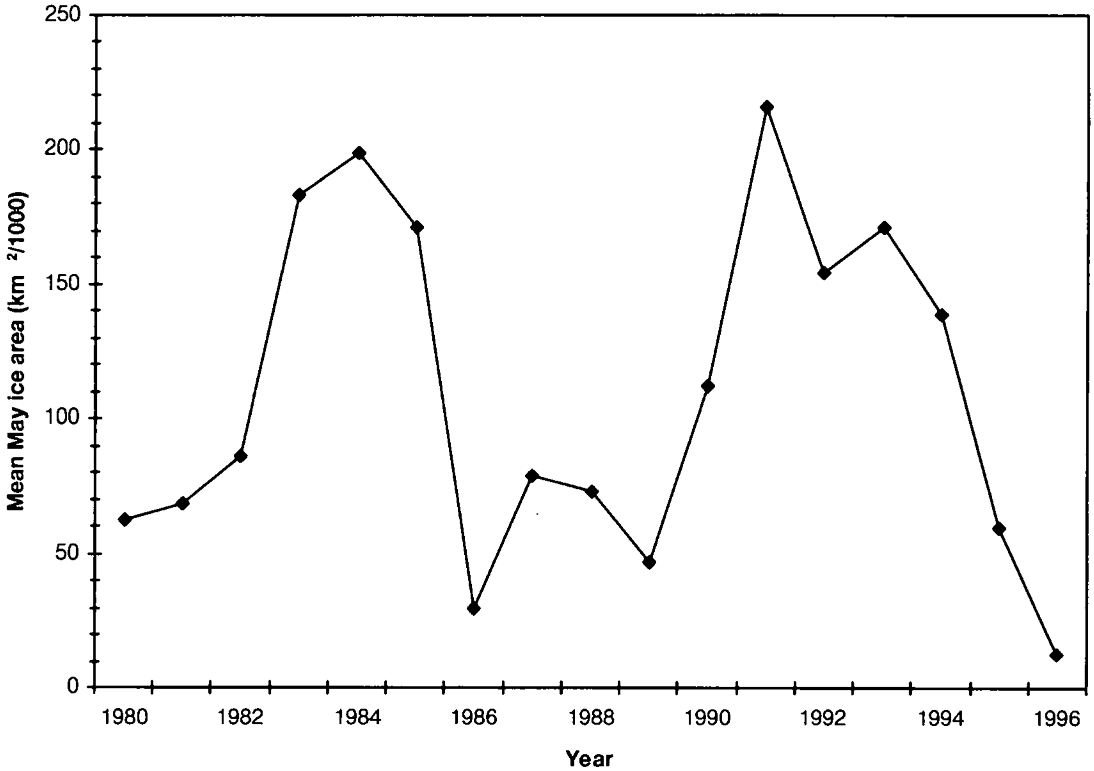

Figure 5. Mean May ice area on the northern Newfoundland and southern Labrador shelves, 1980-1996.

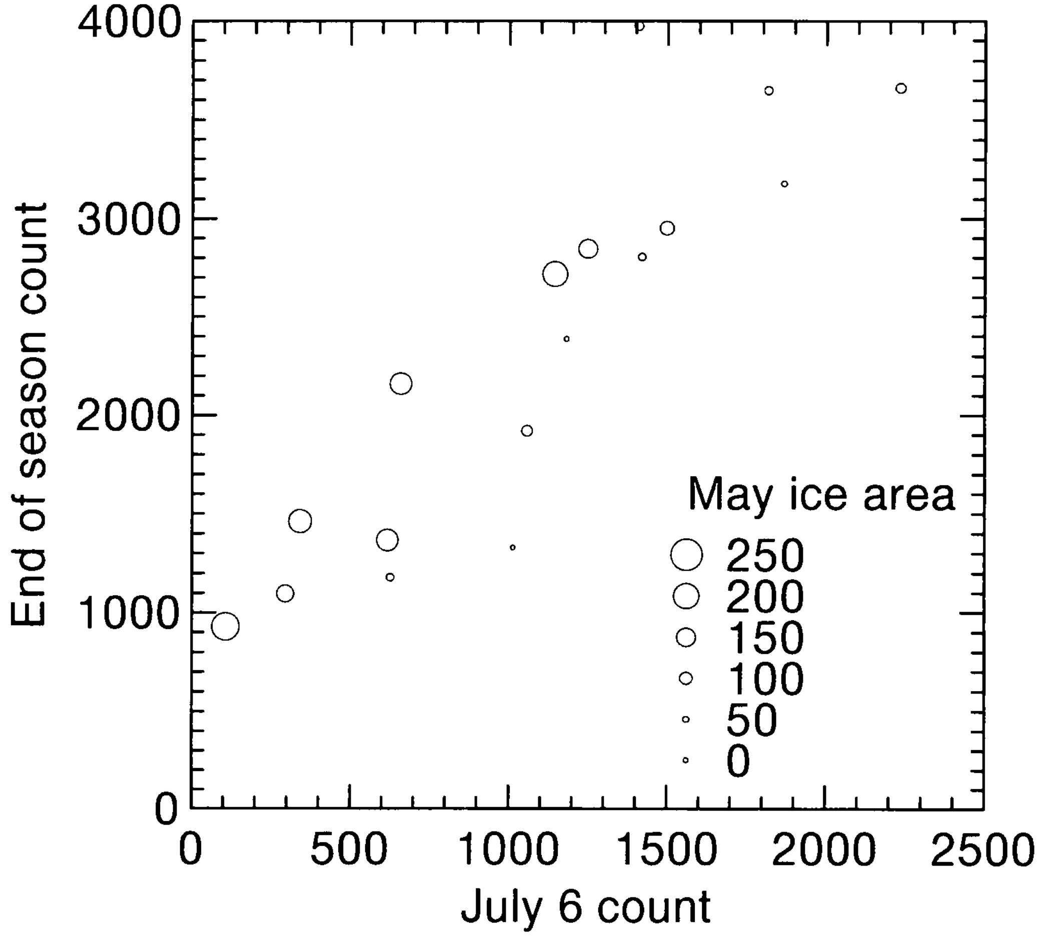

Figure 6. Plot of Morgan Falls, LaHave River, end of season salmon counts against cumulative counts by July 6, 1980-1996. Symbol size represents May ice area coverage on the northern Newfoundland and southern Labrador shelves.