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Counts of 1SW and MSW salmon returns as an index of marine survival

by

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ABSTRACT

Counts of 1SW and MSW Atlantic salmon returns are often accurate and may have considerable value in assessment and management. Using a simple model, it may be possible to make predictions about future returns or to assess processes such as survival at sea. In this paper previous work on assessing the performance of the 1984 Salmon Management Plan is extended and the assumptions examined. In addition, a randomization test is introduced to analyse return data as an alternative to ANOVA. It is suggested that the conclusion that the Plan led to a significant improvement in survival of MSW salmon is dependent on the assumption that the proportion of the original number of smolt that return as 1SW fish remains constant and that the years immediately prior to the introduction of the Plan are included in the analysis.

RÉSUMÉ

Les dénombrements de saumons de l'Atlantique unibermarins et redibermarins sont souvent justes et peuvent s'avérer extrêment utiles pour l'évaluation et la gestion. À l'aide d'un simple modèle, on pourrait faire des prévisions sur les remontées futures ou évaluer des phénomènes comme la survie en mer. Dans le présent document, on pousse plus avant l'évaluation de rendement du Plan de gestion du saumon de 1984 et on examine les hypothèses sur lesquelles il est fondé. De plus, on présente un test d'échantillonnage au hasard pour analyser les données sur les remontées, comme méthode substituable à l'ANOVA. Il apparaît que la nette amélioration des redibermarins attribuée à la mise en oeuvre du Plan repose sur deux hypothèses : l'invariabilité de la proportion du nombre initial de saumoneaux qui remontent les rivières à l'état d'unibermarin et l'intégration à l'analyse des données portant sur les années immédiatement antérieures au plan.

1. INTRODUCTION

An attractive feature of research on Atlantic salmon is the ability in some rivers to count 1SW (one sea winter) and MSW (multi-sea winter) fish with relatively small error when they return to their natal rivers to spawn. A simple relationship between these two quantities such as

$$MSW_{t+1} = b \ \ 1SW_t$$

may have utility for prediction if the residual error is sufficiently small. Alternatively, changes in the parameter b may provide useful information on changes in processes such as survival. Both applications have recently been documented. Claytor and Chaput (1988) used returns of 1SW salmon in year t to predict the returns of MSW salmon in year $t+1$ for the Margaree River stock, and Chadwick (1989) examined the effect of the 1984 Salmon Management Plan on the relationship between $1SW_t$ and MSW_{t+1} counts for several rivers in the Gulf of St Lawerence. We examine the latter application further here.

The 1984 Salmon Management Plan prohibited commercial catches in SFA 12 and restricted catches in SFAs 1-11 to after week 22 (June 4), thereby shortening the season by three weeks. There was also a reduction in the number of licensed fisherman and in the amount of licensed gear (O'Connell et al. 1990). The objective was to reduce the mortality caused by the Newfoundland and Labrador commercial fishery on MSW salmon returning to the Gulf of St. Lawrence Rivers, i.e. to increase spawning escapement.

The Plan resulted in significant changes in the commercial fishery for large salmon in the Newfoundland Region, particularly catch timing, magnitude of catches and proportion of large salmon in the catches, all of which are consistent with the objectives of the Plan (O'Connell et al. 1990), but do not, in themselves, show that the Plan resulted in an increase in MSW returns. To examine this, Chadwick (1989) calculated $1/b$, the ratio of the count of $1SW_{t-1}$ to multi-seawinter salmon MSW_t (early and late seasons separately) for seven rivers opening into the Gulf of St Lawrence for the period 1975-88. He found evidence that there had been a significant improvement in spawning escapement by MSW salmon as a result of the Plan. In this paper we extend the study by using a simple salmon model to look at the assumptions under which the ratio is a useful index. We also examine the sensitivity of the result to omitting the data for some years. Finally, we introduce a simple randomization test to compare pre and post Plan values of $1/b$.

2. A SIMPLE SALMON MODEL

If it is assumed that there is no natural mortality, that all returning grilse die after spawning and that all remaining fish from a smolt class return as MSW after two years at sea, then

$$S = 1SW_h + 1SW_r + MSW_h + MSW_r$$

where

S = number of smolt in year t -2
$1SW_h$ = harvest of $1SW$ salmon in year t -1
$1SW_r$ = number of grilse returns in year t -1
MSW_h = harvest of MSW salmon in year t and potential MSW salmon in year t -1
MSW_r = number of MSW returns in year t

If $MSW_r = b\ 1SW_r$
then $1/b = 1SW_r / MSW_r$

This model is illustrated diagrammatically in Fig. 1.

Consider three examples with S = 100:
(1) $1SW_r = 60$, $1SW_h = 20$, $MSW_r = 10$, $MSW_h = 10$, $1/b = 6$
(2) $1SW_r = 10$, $1SW_h = 20$, $MSW_r = 60$, $MSW_h = 10$, $1/b = 0.167$
(3) $1SW_r = 10$, $1SW_h = 20$, $MSW_r = 10$, $MSW_h = 60$, $1/b = 1$

These three examples demonstrate that the value of the index 1/b can decrease when MSW_h stays constant (2) or even increases (3). A decrease in the value of the index is only a reliable indication of decreased mortality of MSW fish if the proportion of the original number of smolt that return as $1SW$ fish remains constant. Other factors that will reduce the reliability of the index include mixing between rivers or between early and late run fish, variable natural mortality and the presence in the MSW component of fish that have spent three or more years at sea. The sensitivity to some of these factors will be considered in a future study.

3. TESTING FOR A MANAGEMENT PLAN EFFECT

3.1 Multiplicative model approach

If the index $1/b$ is assumed to be reliable, the efficacy of the management plan can be examined by determining whether, within each separate river-season combination, there was a significant change after 1983. Alternatively, if one river is expected to yield an index that is a fixed proportion higher or lower than another for all years and, equivalently, if one season is expected to give an index that is a fixed proportion higher or lower than the other for all years, then, if year effects are also taken into account, a multiplicative model for a three-way classification without interaction can be specified. If the residual error is assumed to be log normally distributed then the index can be log transformed and the resulting additive model can be fitted by least squares multiple regression analysis of the index on classification variables of river, season and year (i.e. ANOVA). This approach is similar to that of Gavaris (1980) who incorporated years as a variable into the multiplicative model developed by Robson (1966) for obtaining relative fishing power to standardize fishing effort. The log transformation procedure gives biased estimates of the back-transformed dependent variable, but Gavaris (1980) provides unbiased estimators for both the mean and the variance.

Chadwick (1989) adopted the multiplicative model approach, grouping the years into pre- and post-management plan. For this analysis he eliminated two of the rivers from the data set (Madeleine and Upsalquitch) for which a trend in the residuals was found, and one data point which had a large negative residual ($1SW_r$ in 1985 and MSW_r in 1986 for late season at Millbank). He found that pre- and post-management plan coefficients were significantly different and, based on these results, concluded that the Plan had been effective. This result is valid, but depends on the inclusion of the years immediately prior to the institution of the Plan.

Re-analysis of the logged index values, omitting the late season at Millbank in 1986 and early season at Margaree in 1980 (outliers) as well as Madelein and Upsalquitch (trend in residuals), shows that 57% of the variance in the index can be explained by river and season effects (Table 1, Model 1). The parameter estimated for Margaree in the model was not significantly different from zero ($P > T = 0.66$ [probability of getting a value greater than T if the parameter was zero]), and this river was omitted in subsequent ANOVAs. A plot of the residuals against years shows that high values predominated between 1981 and 1983 (Fig 2). Including pre- and post-plan as explanatory variables gave an estimated plan parameter that was significantly different from zero ($P = 0.03$) and the model was able to explain 61% of the variance in the index (Table 1, Model 2). If the data for 1983 are omitted, the estimated plan parameter is no longer significantly different from zero at the 95% confidence level (($P = 0.226$, Model 3). Analyses omitting 1982 and 1983 together, and 1981 to 1983 inclusive, similarly gave estimated plan parameters which are not significantly different from zero (Table 1, Models 4 and 5).

3.2 Randomization test approach

Randomization tests (Edgington 1987, Noreen 1989) provide an alternative method that is independent of the assumptions of parametric methods (randomly drawn samples, normality and homogeneity of variance). A randomization test involves permuting the data repeatedly to compute a distribution of psuedostastistic values from which the probability that the test statistic for the experimental data was achieved by chance can be determined directly. The probability is given by $P = (NGE + 1)/(NS + 1)$ where NS is the number of permutations and NGE is the number of permutations in which the test statistic value was as large or larger than the actual value obtained in the experiment. When all possible permutations are carried out to assess the P value, the test is called an "exact randomization" test. In practice it is more convenient to perform a large number of random shuffles, in which case the test is called an "approximate randomization" test. Randomization tests are therefore computer-intensive, but, besides the advantage of being relatively assumption free, are largely transparent to the user, as the computation is carried out directly rather than read from a table.

In the case of the salmon return data there is reason to believe that the value of the index may not be independent of river or season (Chadwick 1989), and therefore values should not be indiscriminately shuffled across rivers and seasons. Instead stratified shuffling within each river-season combination must be performed. The test statistic is simply the difference between mean values of the index for pre- and post-Plan years and the probability is determined from the proportion of the total number of shuffles that gave a psuedostatistic at least as large or larger than the test statistic from the unshuffled data.

Results of stratified approximate randomization tests on the unlogged values of the index for pre- and post-Plan year are given in Table 2. In Test 1 all data were used and the difference between the mean index for pre- and post-plan years was found to be significantly different ($P = 0.009$). In Test

2 the two outliers (late season at Millbank in 1986 and early season at Margaree in 1980) were omitted without any change to the P value. In Test 3 data for 1983, the year immediately preceding the imposition of the plan, were also omitted and P =0.012 was obtained. Omitting data for both 1983 and 1982 gave P =0.081, i.e the null hypothesis of no difference could not be rejected at the 95% confidence level (Test 4). Omitting the three years with high index values (Test 5) gave P = 0.8.

4. Discussion

Both ANOVA and randomization tests showed that the significant change in the index between pre- and post-plan periods found by Chadwick (1989) is dependent on inclusion of one or more of the three high index years immediately prior to the introduction of the plan. The ANOVA gave an estimated plan parameter that was not significantly different from zero at the 95% confidence level when 1983, 1982 and 1983, or 1981-1983 were omitted from the analysis. The randomization tests showed no significant change in the average index for pre- and post-Plan years when either 1982 and 1983 or 1981-1983 were omitted. The importance of the years immediately prior to the plan in obtaining a significant change in the index from pre- to post-Plan years suggests that alternative explanations, other than that the Plan was effective, should not be discarded. For example, the years immediately prior to the Plan coincided with homewater commercial fisheries.

With regard to the two methods used, randomization tests are less dependent on assumptions than parametric methods and allow full use to be made of the data. Chadwick (1989) correctly omitted two rivers, for which there was a trend in the residuals, from the ANOVA, thereby reducing the data available for analysis, whereas the randomization tests could be applied to the complete data set.

The utility of the simple salmon model from which the index is derived needs to be examined carefully, particularly if the model is going to be used as a predictive tool or to evaluate processes such as survival sea. Future work will include simulations which examine the assumptions and determine the effect of error.

5. REFERENCES

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Table 1. Results of analysis of variance performed on logged index values, omitting certain data and applying three different models (see text for details).

Model	r^2	Model SS	Error SS	Model df	Error df	F	Pr>F	Plan parameter estimate	Pr>T
1	0.57	69.14	53.18	5	92	23.92	0.0001	-	-
2	0.61	46.44	29.38	5	65	20.55	0.0001	0.366	0.034
3	0.65	44.77	24.29	5	58	21.39	0.0001	0.217	0.226
4	0.64	36.04	20.38	5	51	18.03	0.0001	0.217	0.282
5	0.68	30.60	14.00	5	46	20.11	0.0001	-0.077	0.696

Table 2. Results of the randomization tests on pre- and post plan index values (see text for details). The phi value gives an estimate of the significance level for an exact randomization test.

Test	Statistic	P	phi≤0.01	phi<0.05	phi≤0.10	Number of data points	Number of shuffles
1	5.123	0.009	0.667	1.000	1.000	128	999
2	5.146	0.009	0.667	1.000	1.000	126	999
3	0.942	0.012	0.302	1.000	1.000	114	999
4	0.615	0.081	0.000	0.000	0.982	102	999
5	0.079	0.800	0.000	0.000	0.000	92	999

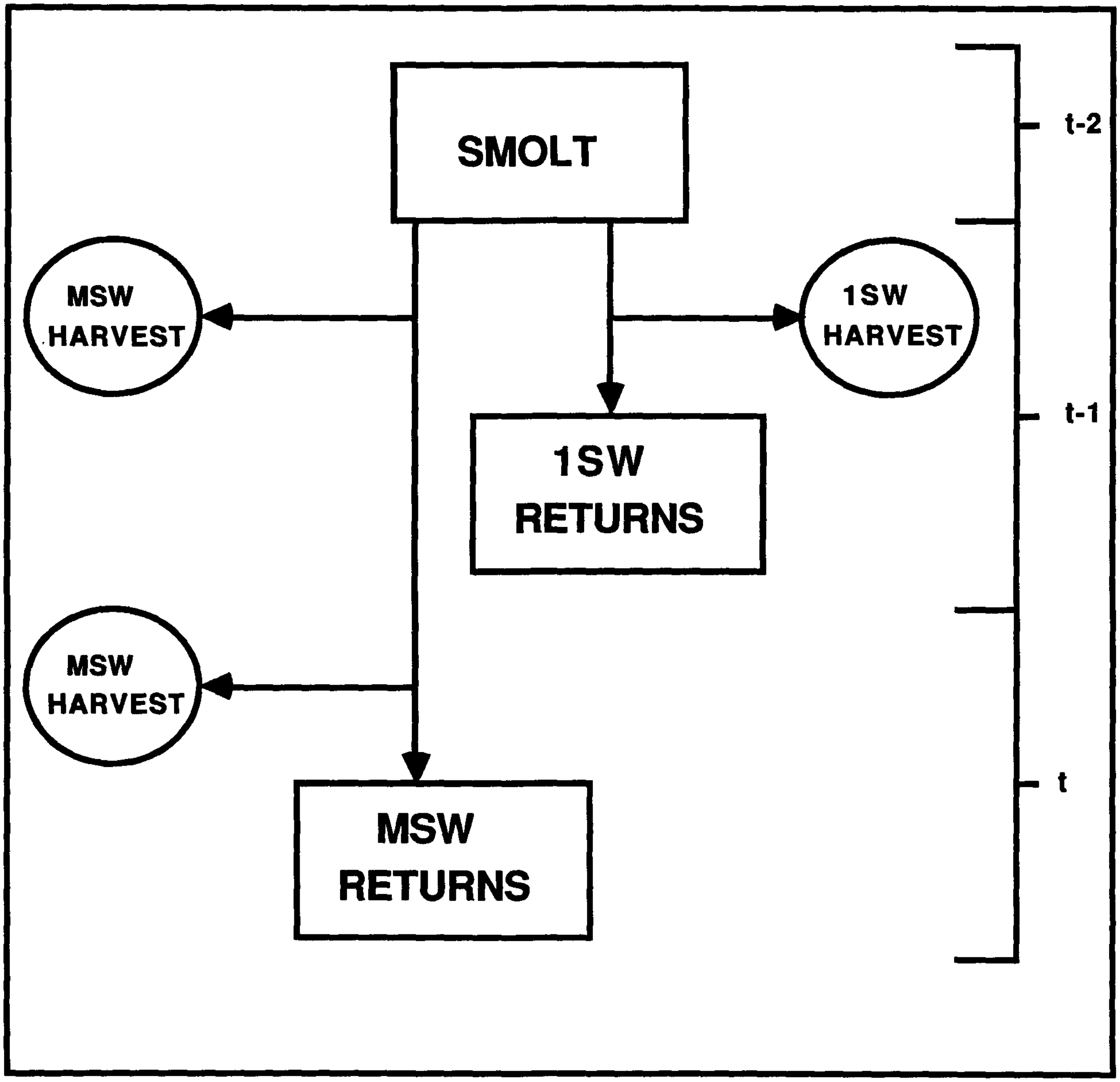

Fig. 1 Diagram of the simple salmon model used to explore the utility of the index.

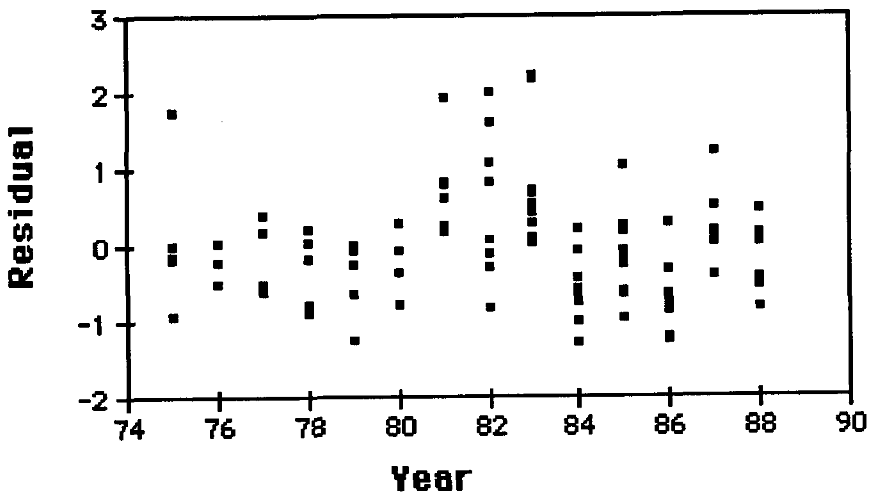

Fig. 2 Residuals after removing river and season effects from the logged index values for seven rivers opening into the Gulf of St Lawrence. Original data from Chadwick (1989), results from Model 1, Table 1.