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Status Assessments – Some Consequences of Using Different Salmon Indices

by

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ABSTRACT

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At the eleventh annual meeting of the North Pacific Anadromous Fish Commission in 2003, the Working Group on Stock Assessment discussed the possibility of assembling data other than catch to assess the status of salmon. In this report we apply a consistent analytical approach to several data types frequently used to index Pacific salmon in Canada. We compare results using different data types by examining the influence of three recent regime shifts. Conclusions from our evaluation of effects from the 1977 and 1989 regime shifts depended on which of three salmon abundance indices (catch, escapement, and total returns) and two survival indices (marine survival and recruits per spawner) were used. For instance, abundance shifts did not necessarily correspond with changes in survival, and regional variations existed, at least for coho. Results from our analysis confirm that different interpretations of salmon "status" may result, depending on which index is used.

Introduction

At the eleventh annual meeting of the North Pacific Anadromous Fish Commission (NPAFC), the Stock Assessment Working Group discussed the possibility of assembling different types of information to assess the status of salmon:

> "*There was consensus that aggregate catch statistics do not necessarily provide the best indication of salmon health because of regional variations in productivity. A template was distributed and discussed that included, in addition to catch, estimates of spawning escapement, recruits per spawner and marine survival. The possibility of developing reference points as bench marks for various status classifications was also considered. The Working Group acknowledged that while assembling these types of data would be useful, there were limited sources of data such as these and assembling these would be a major task. The Working Group agreed to continue this discussion by e-mail and discuss it more fully at the next CSRS meeting.*" (NPAFC 2003, pg 103).

In this report we present results from the analysis of several types of information that have been used to evaluate the status of Canada's Pacific salmon (*Oncorhynchus spp.)*. Our objective was to determine whether results would vary when a consistent analytical approach was used with several different data types, or indices. Since overwhelming evidence exists that significant changes in oceanographic conditions can take place over relatively short time periods, we tested for differences resulting from recent regime shifts in 1977, 1989 (Hare and Mantua 2000), and 1998 (Peterson and Schwing 2003) using these indices.

Abundance Indices

We used three abundance estimates for BC salmon: 1) the total catch by species in British Columbia (BC) of chinook, coho, sockeye, pink, and chum salmon caught in commercial, recreational, and aboriginal fisheries. (In general, commercial catches were much higher than recreational and aboriginal catches); 2) aggregate escapement estimates by species for all streams in BC; and 3) total returns by species (i.e. the sum of annual estimates of catch and escapement).

Annual Canadian salmon catch estimates are available in NPAFC reports (e.g. Irvine et al. 2003) and escapements are found at http://pisces.env.gov.bc.ca/. Catches included non-BC fish caught by Canadian fishermen and excluded catches of Canadian salmon outside of BC. All data were adjusted to correspond to smolt ocean entry years assuming that pink and coho salmon spent one winter at sea, sockeye two winters, and chum and chinook each three winters.

Survival Indices

We assembled and analyzed two types of survival estimates, productivity measured as recruits per spawner, and marine survival. In contrast with abundance estimates that were for the entire province, survivals were for individual stocks. Our intent was to compare time series of reasonably precise survival estimates by species. We updated and expanded estimates from Research Documents published by the Canadian Stock Assessment Secretariat (CSAS) (http://www.dfompo.gc.ca/csas/Csas/English/Publications/Research_Doc_e.htm) by contacting various individual researchers (see Acknowledgements).

Productivity was measured as $y_t = log\ (R_t / S_t)$ where S_t is the number of spawners in year *t*, and R_t is the corresponding number of mature salmon (recruits) produced from those fish that spawned in year *t* and consequently included effects occurring in freshwater as well as the ocean. In contrast, marine survival estimates only included ocean effects. Data were categorised into two regions, north and south of the north tip of Vancouver Island.

ANALYSIS

Marine abundance and survival data

Abundance (catch, escapement, and total returns) data were log transformed while marine survival data were logit transformed. Two dummy variables (T_1 and T_2) partitioned data into three regimes (R_1, R_2, and R_3):

Regime	T_1	T_2
R_1 ($\leq$1976)	1	0
R_2 (1977 - 1988)	0	0
R_3 (1989 - 1997)	0	1

The time series was too short to evaluate the significance of the 1998 shift. To test whether differences in abundance (A) or marine survival (MS) resulting from the 1977 and 1989 shifts were significant, we constructed a linear model with T_1 and T_2:

$$F(A/MS) = a_0 + a_1 T_1 + a_2 T_2 + \varepsilon \qquad \text{(Model 1)} \qquad (1)$$

where $F(A/MS) = \begin{cases} \log(\text{Abundance}) \\ \text{logit}(\text{Marine Survival}) \end{cases}$. With this formulation of (1), it can be seen that

during R_1, $\quad F\ (A/MS) = a_0 + a_1 \quad (2)$
during R_2, $\quad F\ (A/MS) = a_0 \quad (3)$
and during R_3, $\quad F\ (A/MS) = a_0 + a_2 \quad (4)$

Therefore, if the 1977 and/or 1989 regime shifts were significant, a_1 and/or a_2 should be significantly different from zero.

Initially we used multiple regression analysis and found that the residuals for some data series were temporally correlated. To incorporate this time series structure of the residuals and adjust for its parameter estimation, ε_t in equation 1 was modelled using auto-regressive, moving-average (Box and Jenkins 1970) with order (*p*, *q*), i.e.

$$\varepsilon_t - \phi_1 \varepsilon_{t-1} - \cdots - \phi_p \varepsilon_{t-p} = e_t - \theta_1 e_{t-1} - \cdots - \theta_q e_{t-q}; \qquad (5)$$

where e_t is a white noise process; that is, the e_t are uncorrelated and have zero mean and constant variance, σ^2.

The parameter vector (a_0, a_1, a_2, b) from equation (1) along with the time series parameters $(\phi_1, \cdots \phi_p, \theta_1, \cdots \theta_q)$ were fit by maximum likelihood estimation. We compared a series of models with different combinations of (p, q), e.g., (1,0), (2,0), (3,0), (1,1), (0,1), (0,2), (0,3), (2,1), (2,2), etc. The first-order auto-regressive model, AR(1) was the most statistically significant, i.e. equation (5) with $\varepsilon_t = \phi_1 \varepsilon_{t-1} + e_t$.

Stock-recruitment data

To analyse stock-recruitment data we used the Ricker model extended to incorporate environmental variables (Hilborn and Walters 1992, Chen and Ware 1999, Chen and Irvine 2001). The mathematical formulation corresponding to equation (1) is:

$$y = log\left(\frac{R}{S}\right) = \alpha - \beta S + a_1 T_1 + a_2 T_2 + \varepsilon \qquad (6)$$

where α is the parameter measuring fish stock reproductive performance at low stock size with exp (α) the maximum recruits per spawner, and β is the parameter representing density-dependence during pre-recruitment. Residuals were modelled as in (5).

RESULTS

Abundance

Chinook and coho abundances generally exhibited significant autocorrelation (i.e. AR(1) <0.05). Nevertheless, the first regime shift significantly affected coho escapements and the second shift was significant for chinook escapements. For these species, changes in catch and the sum of catch and escapement were never significant, even though differences between regimes sometimes appeared large (e.g. declining chinook and coho catches following the 1989 regime shift, Fig. 1, Table 1).

Sockeye, pink, and chum abundances were not autocorrelated and the first regime shift was significant for eight of nine abundance measures (Table 1). Abundances increased between the first and second regimes (Fig. 1). In contrast, the second regime effect was only significant for pink salmon catches.

Marine Survivals and Recruits per Spawner

Our marine survival time series were long enough to test for the significance of the first regime shift for sockeye and pink salmon (Table 1). This shift significantly affected the marine survival of Skeena sockeye and Fraser River pink salmon, in spite of significant autocorrelation. The effect of the second regime shift was not significant for pink salmon although it was for one of three chinook, three of nine coho, one of three sockeye, and two of ten chum salmon populations. Interestingly, the significant survival shifts for the two southern coho populations following the second regime shift were negative, while it was positive for northern coho.

Recruits per spawner time series were generally long enough to evaluate the effects of both regime shifts (Table 1). Significant autocorrelation occurred five times out of 24. The first shift was significant only for one Fraser River sockeye population and Fraser River pink salmon. The second shift was significant for two northern pink populations, two sockeye populations, and Skeena chinook.

DISCUSSION

We were fortunate to have multiple indices of salmon abundance and survival. Since we plan to repeat these analyses using a more extensive dataset, we do not focus on specific results here. What is important is that the 1977 and 1989 regime shifts affected BC salmon, but measured effects varied depending on the index that we used.

The estimates in our time series were often autocorrelated. Fréon et al. (2003) also found that many of the apparent synchronies among their catch data occurred by chance because of autocorrelated time series. Researchers should test for autocorrelations as seeming significant results may not be. For instance, although chinook and coho salmon catches declined rapidly following 1989 (Fig. 1), autocorrelations were significant, and differences between regimes were not significant (Table 1).

Catches, escapements, and run sizes for sockeye, pink, and chum salmon increased after the 1977 regime shift, but increases were not abrupt and there was much interannual variability (Fig.1). In contrast, the 1977 shift had no significant effect on chinook salmon and the only significant response for coho was a decline in escapements. Beamish and Noakes (2002) also found more pronounced abundance patterns for sockeye, pink, and chum salmon than for chinook and coho.

The only significant abundance effects from the 1989 shift were declines in pink catches and increases in chinook escapements. However, this may have been partly due to the relatively short time series of abundances following 1989. Recent spawner estimates, which were probably biased low, exceeded catch estimates for each species (Fig 1). Catch therefore is not an adequate estimate of recent abundance for BC salmon.

Abundance shifts did not necessarily correspond with changes in survival. For example, while sockeye, pink, and chum abundances increased following the 1977 regime shift, changes in recruits per spawner following this shift were significant only two of 21 times. The most likely explanation for this apparent discrepancy is that relatively few numerically dominant populations drove our aggregate abundance estimates. Aggregate abundance estimates, including the catch and escapement statistics in our study, should therefore be interpreted cautiously.

Salmon assessments in BC usually occur at the stock or watershed level since most fisheries operate at these levels, and managers need to understand regional differences in productivity. Regime effects were highly variable when we examined regional patterns in marine survival and recruits/spawner. For instance, the effect of the second regime shift was not significant for pink salmon although it was for one of three chinook, three of nine coho, one of three sockeye, and two of ten chum salmon populations. In general, these findings support Pyper et al. (2001, 2002) and Mueter et al. (2002a, b) who successfully demonstrated regional variations in stock productivity and survival using a multi-stock approach.

Different oceanographic domains may explain the opposite patterns in marine survival that we found for coho from northern and southern BC. Significant negative survival shifts occurred for two southern coho populations following the second regime shift, while the survival shift for northern coho was positive. BC coho display considerable variability in productivity (Chen and Holtby 2002) that is presumably related to the different ecosystems the fish live in. Coho from northern and southern BC probably live in different oceanographic domains since they do not usually migrate long distances in the ocean.

These results confirm that aggregate catch statistics are not necessarily the best index of the health of salmon populations. While analyses of national catch data can enable an understanding of effects of major fisheries, catch data may not be an adequate measure of population abundance or status. Regional variations in productivity can also limit the utility of national catch information. Total returns and spawning escapements are potentially useful abundance indicators but need to be contrasted with a reference point if they are to be used to assess status. Survival indices allow one to better understand mechanisms responsible for regime shift and climate change effects than abundance; however understanding mechanisms also requires a good knowledge of the influence of physical oceanographic conditions on the distribution and life history of the salmon. We encourage the NPAFC and other agencies to be clear on their objectives when assessing status and salmon, choose appropriate indices of abundance or survival, and recognise the limitations of whatever data types are used.

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Table 1. Significant differences in abundance (N = no, Y = yes) and survival (number of times significant/number of populations tested) for Canadian chinook (Cn), coho (Co), sockeye (So), pink (Pi) and chum (Ch) salmon between regimes 1 and 2 (T1) and regimes 2 and 3 (T2). NA is not applicable.

Index		T1					T2				
		Cn	Co	So	Pi	Ch	Cn	Co	So	Pi	Ch
Abundance	Escapement	N	Y	Y	Y	N	Y	N	N	N	N
	Catch	N	N	Y	Y	Y	N	N	N	Y	N
	Run Size	N	N	Y	Y	Y	N	N	N	N	N
Survival	Mar. Surv.	NA	NA	1/3	1/1	NA	1/3	3/9	1/3	0/1	2/10
	Rec/Spaw	NA	0/2	1/13	1/7	0/1	1/1	0/2	2/13	2/7	0/1

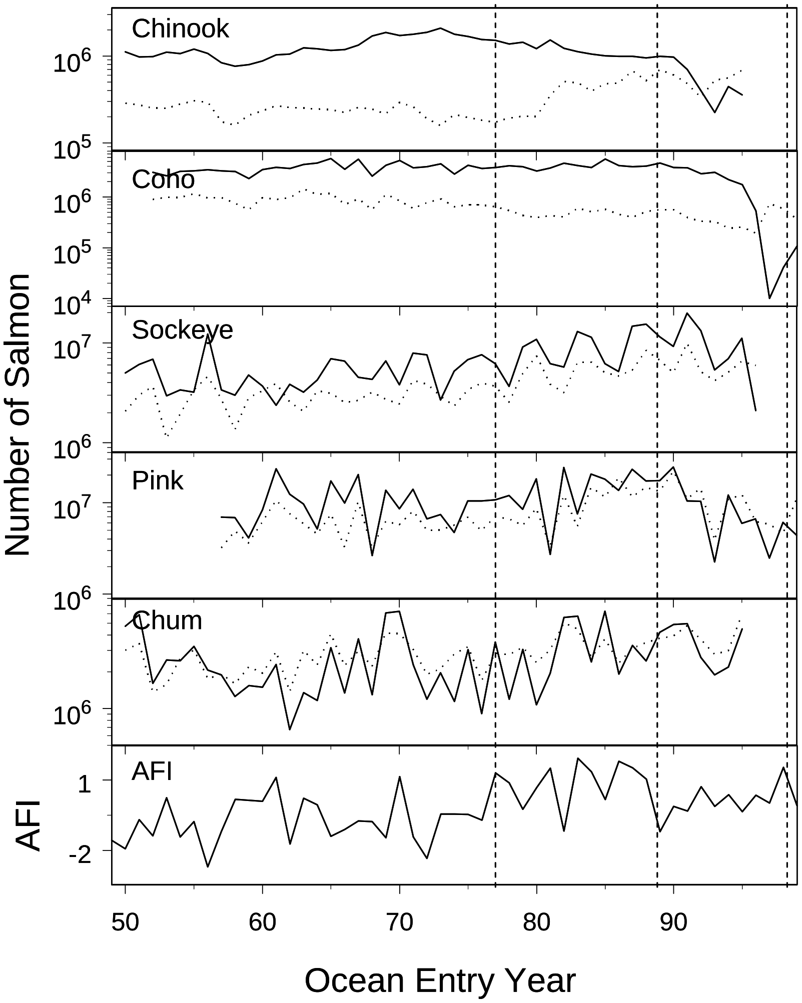

Figure 1. Time series of salmon abundance estimates (top five panels, solid lines depict catch and dotted lines depict escapement, the sum of catch plus escapement is not shown) arranged by year of entry into the ocean for young salmon. Note log scale for salmon abundance. Vertical dashed lines separate the regimes. Values for the atmospheric forcing index (AFI) are also provided.