Evaluation of the Reliability of In-Season Run Size Estimation Techniques Used For Southern British Columbia Chum Salmon (*Oncorhynchus keta*) Runs

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A number of models were examined for their ability to estimate in-season the run size of chum salmon stocks returning to Johnstone Strait to the Fraser River area in southern British Columbia. The in-season run size techniques rely upon two basic data sources for the independent variable; test fisheries and commercial fisheries in Johnstone Strait. Both of these fisheries occur in the ocean migration pathway. The dependent variable run size is determined from the combination of all catch (commercial, sport, aboriginal, etc.) and escapement to the spawning grounds. Regression models are developed utilizing various combinations of catch, effort and catch per effort in order to predict total returning run size. The different models were evaluated based upon the criteria of minimizing the residual mean square. Estimates from the individual models were pooled using an inverse weighting technique. Pooled estimates generally resulted in more accurate forecasts of the returning run strength than those produced by individual models. Also the models tended to under-estimate the run size early in the season. This reversed to an over-estimate of true run size by the end of the season. Implications to fishery management are discussed.

INTRODUCTION

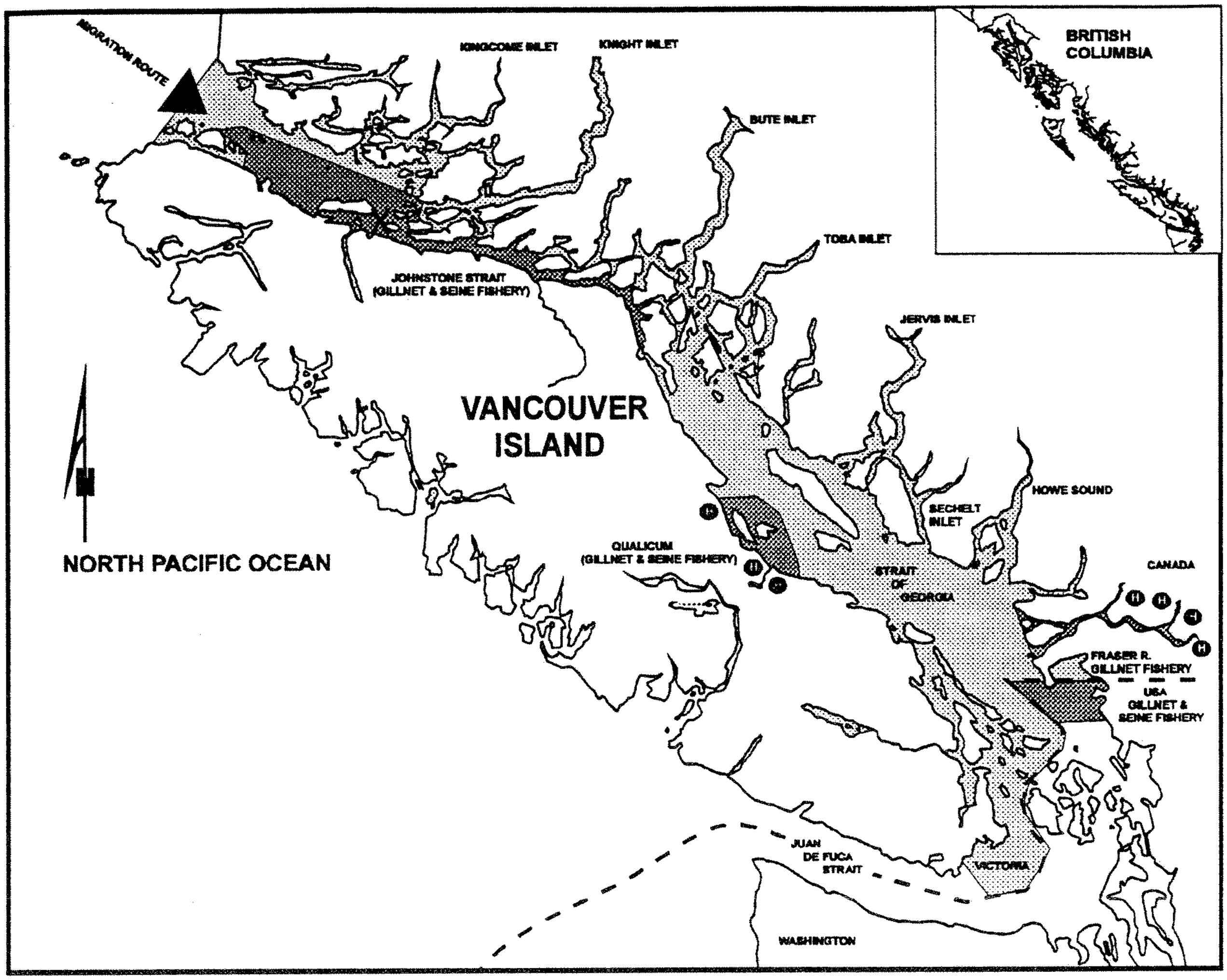
One of the most important components of an in-season salmon fishery management system is the estimate of returning run size. This figure then determines the total number of salmon available for harvest. Managers rely upon these figures to schedule fishery openings, to ensure that catch is allocated among various user groups and to meet specified harvest rate targets or escapement goals. Errors in the process of estimating the run size can trigger or postpone commercial openings, which may lead to under or over-escapement to spawning grounds and/or subsequent fisheries. Pre-season forecasts and in-season run size estimates are also used by fishermen to make decisions regarding how they will allocate their effort among various fishing opportunities.

Many models have been developed for estimating returning run abundance. Run size estimates can be obtained from pre-season forecasts, commercial fisheries (catch and catch per unit effort (CPE)), test fisheries and spawning escapement monitoring. The process of estimating run strength occurs over the length of migration producing an array of run size estimates. The manager must then combine these estimates to produce a "best" estimate. Managers generally consider in-season estimates more reliable than pre-season estimates (Walters and Buckingham 1975). A number of authors (Fried and Hilborn 1988; Fried and Yuen 1987; Henderson et al. 1987) have proposed and evaluated various techniques to both estimate run size and how to combine several independent indicators of run strength.

The purpose of this report is to:

1. Describe the models currently used for assessing the returning strength of chum salmon to the inside waters of southern British Columbia (Fig. 1).
2. Determine whether one model performs with more consistent accuracy than any of the others.
3. Finally to determine whether run size estimation can be improved by pooling results from independent models.

Fig. 1 Map of 'Study Area' ▨ chum salmon stocks and vicinity. X denotes the location of the Johnstone Strait test fishery; Ⓗ are locations of major enhancement facilities; and ▩ are locations of major commercial fisheries on the 'Study Area' chum salmon stock.



METHODS

'Study Area' Chum Salmon Stocks

The region from Johnstone Strait to and including the Fraser River is called the 'Study Area' in terms of DFO chum management (Fig. 1). After an ocean residence of 3 to 5 years chum salmon from the 'Study Area' return, mainly through Johnstone Strait to spawn. Numerous stocks with a wide range of productivity's contribute to this migration; with the largest contributor the Fraser River system. In addition to the many other river systems contributing wild stocks (Mainland Inlets, east coast of Vancouver Island and Puget Sound) there is a significant enhanced component of about 25% of the total returning run size (Gould et al. 1991). The enhanced component is mainly produced at seven major facilities; four in the Fraser River and three on the east coast of Vancouver Island. The main migration route for these chum salmon stocks is through Johnstone Strait and then into the Strait of Georgia (Anderson and Beacham 1983). Along this pathway the chum salmon are potentially harvested by three major Canadian fisheries and one American fishery. The first fishery and single largest producer is a commercial fishery in Johnstone Strait. Both purse seine and gill net gear have participated, with purse seine gear harvesting the largest share (about 80%). This fishery harvests chum stock from the entire 'Study Area' (wild and enhanced). An other major fishery, focuses upon the enhanced returns to mid-Vancouver Island. This fishery was developed to harvest surplus production from hatcheries and spawning channels in the area. Next, there is the Fraser River fishery focusing upon returning Fraser River chum stocks (wild and enhanced). This a gill net only fishery. Then there is a American fishery near the mouth of the Fraser River which harvests mainly Fraser River chum stocks. Finally, there are a number of terminal single stock fisheries that occur when abundance exceeds escapement requirements.

The management strategy governing 'Study Area' chum stocks is known locally as the 'Clockwork'. It was so named due to a set of rules dictating management of the 'Study Area' chum salmon. The Clockwork management plan (Hilborn and Luedke 1987), which was introduced in 1983, outlined the objectives and strategy by which the Johnstone Strait and other chum fisheries in the 'Study Area' would be managed. The main objectives of the strategy are to: (1) achieve a wild escapement of 2.5 million chum in 3 to 4 cycles; (2) allow fishing at low stock sizes; (3) stabilize the annual catch; and (4) learn about the stock productivity by allowing for escapements above 2.5 million in years when stock sizes permitted.

In order to achieve the above objectives, commercial fishing is limited to a variable harvest rate, set according to the magnitude of the returning chum run. Currently there are four steps starting at a 10% harvest rate for runs sizes under 3.0 million, increasing to 20% for run sizes between 3.0 million and 3.9 million, 30% for run sizes between 3.9 million and 5.3 million and finally a 40% harvest rate for run sizes greater than 5.3 million.

Data Sources

Data used in the following analyses are estimates of catch, escapement, fishing effort and age structure. Commercial catch statistics are derived from DFO and Washington Department of Fish and Wildlife sale slips records. Aboriginal catches are also included in the total run estimate and these are obtained from a variety of sources including Bijsterveld and James (1986) and MacDonald (1987). Escapement estimates are obtained from more than 175 streams within the 'Study Area' (Fig. 1). Of these 175 streams, only 36 streams have consistently had more than 5,000 wild spawners. There is also an enhanced component from seven major facilities; three on Vancouver Island and four in the lower Fraser River (Fig. 1). The majority of the escapement estimates are visual estimates provided by stream walks, aerial or float surveys. Escapement into enhanced systems are generally determined with much greater accuracy and are obtained from fence counts and occasionally mark-recapture studies. Fish scales used to determine age structure are derived from catch (commercial and test fisheries) and escapement samples. Fish age was determined from annular ring counts. For example a chum salmon scale with three annular rings would be classified as a 4-year old fish. In the European system this fish would be designated as a 0.3.

Effort information is recorded as boat days for commercial fisheries and number of sets for the test fisheries. Effort counts were obtained visually via overflights during the operation of the commercial fishery.

The final primary source of data used in this report was obtained from two seine vessels operating under charter to DFO within Johnstone Strait (Fig. 1). The program was initiated in 1965, primarily in years of low expected abundance. Starting in the late 1970's the program has begun in late September and continued through until early November. Each vessel is required to make six test sets per day among 40 possible locations within Johnstone Strait. Full descriptions of this operation can be found in HopWo et al. (1993) and are not repeated here.

Model

Six models, one pre-season and five in-season, were constructed to forecast total stock size. The pre-season wild stock prediction for each year *i* from 1988 to 1994 was calculated by determining the average proportion of 3-, 4- and 5-year olds in the returning stock over the period 1980 to 1994. These proportions were based upon chum salmon scales collected from test and commercial fisheries in Johnstone Strait and the Fraser River. Next, the expected total return from years *i*-3, *i*-4 and *i*-5 was calculated by taking the product of the escapement and the return rate per spawner. The average proportion of age 3, 4 and 5's in the recent 15 years has been 19%, 70% and 11%, respectively. The average return per spawner over the same 15 years was 2.1:1.0. Finally, returns from each brood year were summed to produce the predicted wild run size for year *i*. For the enhanced component contribution to the total returning run size, run size was estimated by applying survival rates for each type of enhancement facility and the average return by age group, to the number of fry released by the facilities. The total return was then the sum of the wild and enhanced components.

The five in-season models all had the same structure of the form:

$$LN(\hat{Y})_{i,j} = LN\alpha + \beta LN(X)_{i,j}$$

where $\hat{Y}_{i,j}$ equals the predicted total run size estimated from data source *i* and time *j*, α = the y-axis intercept, β = slope of the regression line, and $X_{i,j}$ = data from data source *i* for time period *j*. The five data sources for the in-season model are: (1) test fishing CPE by week or cumulative CPE; (2) total commercial catch (seine and gill net) in a Johnstone Strait fishery; (3) commercial seine gear catch in a Johnstone Strait fishery; (4) commercial seine gear CPE; (5) pooled estimate combining a test fishery estimate with one of the other model estimates. Pooling was based upon the residual mean square error (RMS) (Hilborn and Walters 1992).

$$\bar{R}_j = \sum_{i=1}^{2} [R_{i,j}\ x(1/\ RMS_{i,j})]\ / \sum_{i=1}^{2} (1/\ RMS_{i,j})$$

where $\bar{R}_j$ = weighted mean run size for time j; $R_{i,j}$ = estimated run size for time j and method i; and $RMS_{i,j}$ residual mean square error from the linear regressions for time j and method i derived in equation (1).

A hindcasting procedure was used to examine the predicative capabilities of the various models. Only data prior to the year of interest was used to calculate the predictive equations. Simulations were conducted for the years 1988 to 1994. Run size estimates are classified into pre- and early-season, mid-season and final. The pre- and early season includes the pre-season forecast, test fishing results in the fourth week of September (9/4) and a commercial fishery held the same week. Mid-season includes cumulative test fishing CPE from the fourth week of September to the second week of October (10/2) and any commercial fisheries held during the second week of October. The final estimate is derived from cumulative test fishing CPE from the fourth week of September up to and including the third week of October (10/3) and any commercial fisheries held after the second week of October. Predictive regressions were only used if F-tests for the model were significant at the 95% level.

Three methods of comparing run size estimates were used: (1) annual percent error, (2) mean percent error (MPE); and (3) mean absolute percent error (MAPE). Annual percent error was calculated as:

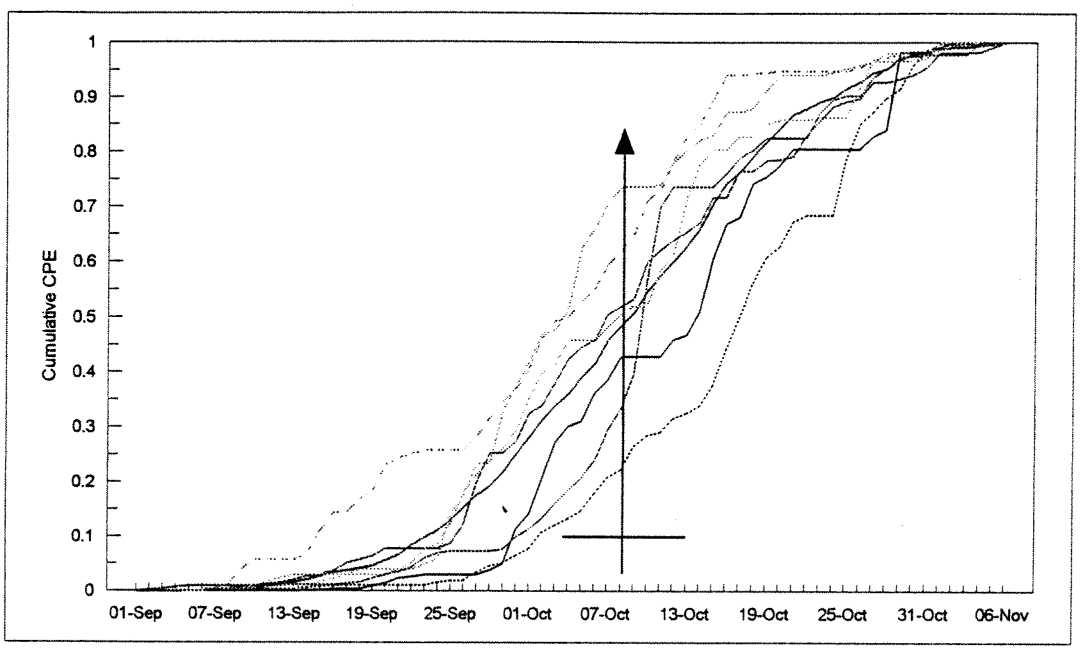
$$[\ -(A_k - R_{i,j,k})\ /\ A_k]\ x\ 100$$

where A_k= actual run size in year k and $R_{i,j,k}$= predicted run size for time i with model j and in year k. MPE provides for a measure of bias in any of the methods used; examining for persistent over- or under-estimates of run size. To assist in examination of the range and distribution of underforecasting (negative MPE) and overforecasting (positive MPE) bar charts were constructed. MAPE yields a measure of overall model performance with over- and under-estimates in run size treated equally.

RESULTS

The size of the chum salmon run varied from a low of 1,815,000 in 1989 to a high of 4,377,000 in 1992. Escapement did not vary as much , ranging from a low of 1,023,000 in 1989 to over 1,931,000 wild spawners in 1994. The run timing as measured by cumulative test fishing CPE in Johnstone Strait varied considerably among years, with the 1989 run arriving the earliest and 1994 the latest (Fig. 2). The actual dates when 50% of the run passed the Johnstone Strait test fishery ranged from October 4 in 1989 to October 17 in 1993.

Fig. 2 'Study Area' chum salmon run timing through Johnstone Strait calculated from cumulative CPE test fishing catch and effort data; years 1988-94. Arrow marks the 50% date and the horizontal line is the 95% confidence interval.



Pre- and Early Season

The accuracy of the various models tested (Pre-season, Test Fishing CPE, Total Catch, Seine Catch and Seine CPE) varied greatly both among and within years (Fig. 3). The Pre-Season forecast had the largest deviation from the true run size during the Pre- and Early Season time frame. Both the Pre-Season and Test Fishing CPE model's produced the largest errors from the true run size; accounting for six out of the seven years between them. There was an overall tendency for the Test Fishing CPE, Total Catch, and Seine CPE models to under-estimate the true run size. With respect to overall model performance there was no single model that outperformed all the others. The MAPE's for all models ranged from a low of 21.3% for the Total Catch model to a high of 28.5% for the Test fishing CPE model. Finally, though, the weighted model estimates were always more accurate than the least accurate of its components.

Mid-Season

Overall, the individual models improved in their forecasting ability from the earlier time frame as evidenced by a reduction in their MAPE values. This improvement in forecasting ability was evidenced by large decreases in the RMS over the course of the season (Fig. 4). There was also a reversal from earlier in the season when the commercial models (Total Catch, Seine Catch and Seine CPE) tended to under-estimate the true run size to a significant over-estimate later in the season as evidenced by their positive MPE values. The Test Fishing CPE model did not exhibit any consistent bias with equal number of under- and over-estimates of run size. As in the Pre- and Early Season time frame the weighted models were always more accurate than its individual components.

End of season

Once again no single model performed consistently better than any of the others. Overall though, the weighted estimates performed better than their individual components. In addition, there was a reduction in MAPE values from the Pre-, Early- and Mid-Season time frames. Also though there was a tendency for the MPE values to be positive (though slightly larger in magnitude from the Mid-season values) indicating a tendency to over-estimate the returning run size by the commercial models (Total Catch, Seine Catch and Seine CPE). The Total Catch model had five out of six years and both the Seine Catch and CPE model's had four out of six years that over-estimated the true run size.

DISCUSSION

The present paper describes the current technique used to estimate the run strength of chum salmon returning to the 'Study Area'. The results show that no one single model examined in this paper outperformed any of the others. It did show though, that pooling of the individual estimates generally improved the overall accuracy and reduced the bias (as measured by MPE) of the run size estimates produced. This result is in agreement with results of Fried and Yuen (1987) who examined a similar pooling methodology for forecasting the returning sockeye salmon run strength to Bristol Bay, Alaska. Fried and Hilborn (1988) also examined Bayesian probability theory to produce in-season estimates for sockeye salmon returning to Bristol Bay, Alaska. They also found that while the Bayesian method was not always more accurate than the most accurate individual method, it was always more accurate than the least accurate individual method.

A number of findings in the present study have some results of interest to management of the 'Study Area' chum salmon fishery. Firstly, there was the noted result of early in the season to under-estimate the actual size of the returning chum salmon run size. This has the effect of delaying any additional harvest until more information from test fishing becomes available. The net result is to reduce the risk of over-harvesting the "Study Area' chum salmon stocks. However, this tendency is actually reversed later in the season when the models tend to over-estimate the run size. This is particularly noticeable in 1989 when the run timing 50% date was October 4 (Fig. 2). The mean 50% date is about October 8 (95% C.L. of 4.6 days). While this explains the initial over-estimation early in the season it does not explain the continuing over-estimation of run size throughout the fishing season. The second important finding from this analysis is that while the amount of error averaged 15-20% by the end of the season there was still 1 year out 7 that over-estimated the run size by 50-60% (1989). Due to the harvest management regime in place for the 'Study Area' chum salmon that places a ceiling upon the harvest rate; this tendency to over-estimate the run size may be ameliorated.

All the models examined in the present study require estimates of catch and escapement. Naturally the reliability of these models will depend upon the quality of these data. While the catch statistics are reasonably easy and consistently collected, the same cannot be said for the escapement data. As pointed out earlier there are a large number of streams contributing to the 'Study Area' chum salmon and a wide variety of escapement methodologies applied.

Fig. 3. Percent error of various models used to predict total run size of 'Study Area' chum salmon. TF CPE9/4 = hindcasting based upon test fishery CPE from week 9/4; Total Catch = Hindcasts based upon total commercial catch (purse seine and gill net gear); Seine Catch = hindcasts based upon total purseseine catch; Seine CPE = hindcasts based upon purse seine CPE; Wt. Mean = estimated based upon models pooled together by their individuals RMS.

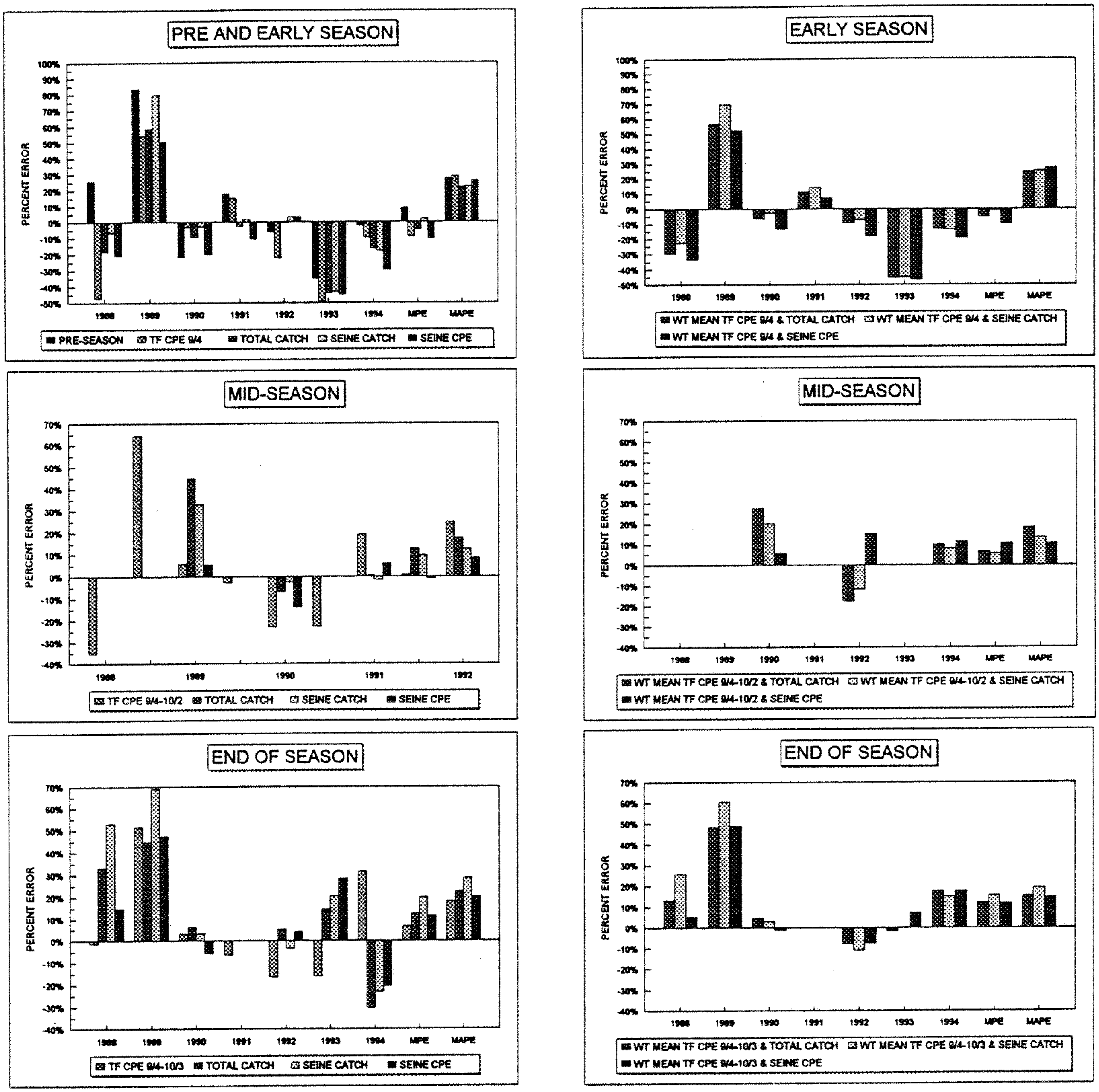
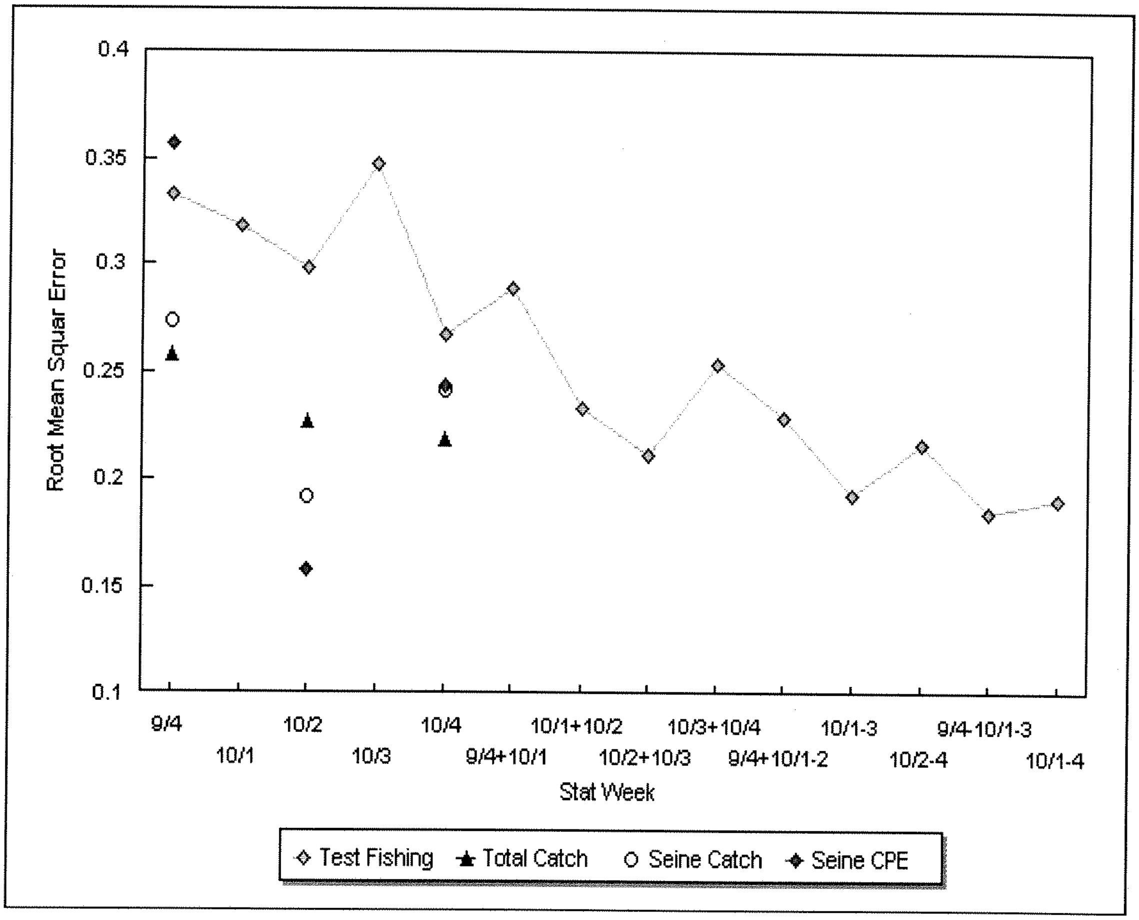


Fig. 4 Residual mean square error associated with four of the models used to predict run size estimates in-season. Test fishing RMS is shown for individual weeks and various cumulative weeks' CPE models.



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