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An Intraseason Forecasting System for Commercial Marine Fisheries

Erik J. Barth
Old Dominion University

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by

Erik J. Barth

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Phillip R. Mundy (Director)

ABSTRACT

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by Erik J. Barth

Chairperson of supervisory committee: Dr. Phillip R. Mundy
Department of Oceanography,
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The reliability of an intraseason yield estimation technique which is commonly used by Pacific salmon harvest managers is evaluated for applicability to a variety of commercial finfish and crustacean fisheries. The estimation technique is known as the average timing or the average performance model. The method is not easily related to standard statistical models, but does show some similarity to both a single parameter linear regression model and the ratio estimator of sampling theory. A comparison of these models, a two parameter linear model, and a regression estimator is made to determine if the precision of forecasts of performance can be improved.

Forecasts by all methods are calculated on each successive time interval of the season. For a yield estimate by the average timing estimator, the cumulative catch of the current year is divided by the corresponding expected cumulative proportion of total yield. The time series of expected proportions is calculated from historical data. The linear model regresses annual yield on cumulative catch. Forecasts of period catches, by similar methods, have also been presented. Use of

the estimation techniques has been extended to other measures of fishery performance, including catch per unit of effort (CPUE) data and abundance data.

Stratification of historical data, performed on the basis of statistical criteria, is used to select annual data series that have patterns similar to the current year. Such stratification is done in conjunction with the ratio estimator.

Six different estimators of annual performance were applied to fifty-six years of data from six different commercial fisheries. Two methods of forecasting performance for each time interval within a season were also used. The estimators were evaluated on the basis of the mean absolute percentage deviation (MAPD); where percentage deviation is the forecasting error expressed as a percentage of the forecast.

A simple linear regression model of annual performance versus cumulative performance for each time interval of the season proved to be more accurate than all other methods. In general, estimates improve as the season progresses but for all methods except the linear regression model are unreliable prior to the midpoint of the season. The overall precision of the linear regression forecasts are correlated with the variability of annual performance. Fisheries which exhibit conservative seasonal patterns of performance are well suited for this type of forecasting regime.

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CHAPTER 1

INTRODUCTION

During the operation of a commercial fishery it is imperative that a manager anticipate the timing (abundance per unit time) of the target species in order to make timely harvest decisions. The simplest measure of abundance for a fishery is catch, therefore forecasts of total annual catch and period catches are critical to harvest management. In many situations this forecasting problem is treated in a subjective manner, meaning that the forecasting process depends on the manager's personal judgement. However a branch of research which is directed at this forecasting problem has evolved from the management procedures for Pacific salmon harvests. A primary goal of the work is the objective definition of the timing of a salmon fishery on the basis of catch and fishing effort data (Vaughan 1954; Roberson and Fridgen 1974; Walters and Buckingham 1975; Mundy 1979; Brannian 1982; Mundy 1982).

Accurate timing information can then be used to predict annual yields during the season. A typical forecast of annual yield is calculated for each time interval by dividing the catch of the current year to date by the corresponding expected cumulative proportion of total yield. The time series of expected proportions, termed a time density by Mundy (1979), is traditionally based on historical patterns of catch and effort (Wright 1981; Mundy 1982). Another method used for intraseason forecasts of yield involves the use of a simple linear regression of total yield on cumulative catch. This method will be presented as a simple alternative to the timing model.

An unfortunate characteristic of the intraseason yield estimators is that the error of estimation is inversely proportional to the cumulative level of catch (Matylewich 1982; Mundy and Schaller 1983). This means that both the error of estimation and the utility of the forecasts decreases as the season progresses.

Guidelines for the developement of a forecasting system as presented by Jenkins (1979) are in Table 1. The purpose of this study is to discuss the application of these guidelines to intraseason forecasting of commercial fisheries data. Specifically, this will entail the evaluation of the average timing model, the linear regression model, and two related sampling theory methods. The forecast methods will be applied to time series of catches and CPUE from commercial finfish and crustacean fisheries.

The relative importance of the methods is not necessarily dependent on their ability to accurately forecast fishery statistics. The desirable attribute of the forecasting system also includes the capability to characterize the seasonality of a fishery and its data. The use of these models forces a careful look at the intraseason variability in the fisheries data and most importantly a logical search for the sources of variability. Since the operations are relatively simple, they are more understandable than a purely statistical procedure such as modern time series analysis (Jenkins 1979), which seeks to optimize statistical criteria. Unfortunately, typical time series models have reached an amazing level of sophistication yet have not greatly increased accuracy of forecasts (Beeston 1983). The sacrifice of the understanding and interest of the regulators and scientists who are close to the data is not compensated for by the increased accuracy or precision of the sophisticated models. For the commercial fishing industry, a highly decentralized entity, it is important that simple, effective alternatives are not ignored.

Table 1. Some guidelines for the developement of a forecasting system (Jenkins 1979).

1. Analyze decision taking system served by forecasts
2. Define forecasts needed to serve decision taking system
3. Develop conceptual model describing mechanisms influencing forecasts
4. Define data available and not available
5. Develop method for generating forecasts
6. Conduct experiments to assess accuracy of forecasts
7. Determine how judgements are to be incorporated into forecasts
8. Implement forecasting system
9. Appraise retrospectively its effectiveness

Forecasting Fishery Dynamics

Forecasting fishery dynamics is a relatively new area of research in commercial fisheries management. Consequently, forecasting methods which have been developed for other industries are being investigated for their applicability to fisheries data. To complement such research intuitive forecasting techniques which are currently used by fisheries managers should be analyzed to assess their accuracy and to allow comparisons with alternative methods.

Fishery dynamics is solely concerned with understanding the behavior of a time series of catch statistics. The goal of fishery forecasting is to determine if accurate forecasts of catch statistics can be based on historical patterns of catch statistics (Saila et al, 1980). This approach stands in direct contrast to traditional fisheries research which has sought to model the dynamics of the population from which catch has been removed.

Forecasting on the basis of historical data has brought research into the realm of statistical analysis where the frequency of past events is used to estimate the probability of future events. Such methods of analysis are more familiar to the fisheries manager since his evaluations of a regulatory situation are dependent on experience. In effect, experience is a compilation of past events, a record of historical performance, which is most useful for predicting future events. Although statistical methods and a manager's experience function in the same manner, statistics have the advantage of being quantifiable and reproducible. Statistics are calculated by an established set of rules which are easily documentable.

Forecasting techniques used by managers need to be quantified. The quantification may involve searching for statistical models which fit the managers' ideas or simply the construction of a narrative of the rules followed by managers. Not only do the methods need to be documented but also the historical results. Fishery predictions have a tendency to be forgotten when they are inaccurate, while they are vividly recalled when accurate. The actual level of accuracy of such predictions tends to become somewhat obscure as the years pass.

Annual yield is the most frequently forecasted catch statistic. The time frame in which annual yields are forecasted will determine the nature of the forecasting process. In practice, annual yield is often estimated as a function of past annual yields (Roff 1983; Kirkley et al 1982; Stocker and Hilborn 1981). Borrowing from the terminology of business forecasting, these can be referred to as medium to long range forecasts (Eby and O'Neill 1977). A medium range forecast (pre-season) is projected one year ahead whereas long term forecasts are projected two or more years into the future. Such forecasts are desirable since the adoption of extended jurisdiction by most nations has necessitated international agreements on allocation of fisheries resources. Successful allocations are dependent on accurate estimates of supply (ie. yield).

Stocker and Hilborn (1981) offer a comparison of several methods of medium term forecasting of catch per unit of effort (CPUE) data. A drawback of predicting annual CPUE is that estimates of annual yield can only be calculated by multiplying by corresponding predictions of annual fishing effort. Ironically, annual effort is as troublesome to predict as annual yield. Regardless of this difficulty, Stocker and Hilborn (1981) provide one of the first attempts to evaluate fishery forecasting techniques. The paper compares several methods which can be roughly classified into three groups: stock-production models; simple auto-regressive models; and time series models.

Stock-production models (eg. Schaefer 1954, 1957; Gulland 1961) are products of classical fisheries research which rely on broad assumptions concerning the reaction of a fish stock to fishing effort. The theory of these models will not be covered, but there seems to be a consensus in the literature that they are oversimplified and best suited to long term forecasting (Saila et al 1980; Mendelssohn 1980).

The autoregressive models relate the future levels of catch or CPUE to the past values by simple numerical models. The two simple models suggested by Stocker and Hilborn (1981) were of the form $C_{t+1}=CPUE_t\ E_{t+1}$ and $C_{t+1}=\bar{C}$. In words the forecast of next year's catch (C_{t+1}) is this year's catch per unit of effort ($CPUE_t$) multiplied by next year's effort (E_{t+1}) and a forecast of next year's catch is an average of all past year's catches. Roff (1983) posed a model similar to the former; C_{t+1} was regressed on $CPUE_t\ E_{t+1}$ and the following predictive model was used:

$$C_{t+1} = A + B\ CPUE_t\ E_{t+1} \qquad (1.1)$$

Where A and B are the regression coefficients calculated from historical data. This autoregressive model was shown to predict catch consistently better than several forms of the stock production model.

The time series model proposed by Stocker and Hilborn (1981) was very simple and only included as another alternative to stock production models. Although the model did not perform well in relation to the others tested, the authors felt that better model developement would improve its results.

Perhaps due to the necessity of tailoring time series and multiple regression models to individual fisheries, Stocker and Hilborn (1981) omitted multiple regression models and failed to validate their time series model. Multiple regression models seem to be one of the more common pre-season forecasting tools of fisheries mangagers, although the results usually remain unpublished. The advantage of using these models is that external factors such as climatic variables can be easily incorporated into a model. Unfortunately, generality is not achieved without a great deal of cooperation from managing agencies of specific fisheries.

Two important concepts are brought out in the work of Stocker and Hilborn (1981) and Roff (1983): 1) there is a need for very simple intuitive models by which the relative accuracy of more sophisticated models can be judged; and 2) the analysis of catch scaled by effort (CPUE) defeats the large variability in catch data. Although the latter statement is valid, reliable measures of annual fishing effort are difficult to obtain because of the seasonal nature of many fisheries. As a simple example consider a salmon fishery in which the probability of capture was approximately normally distributed throughout the season. If one thousand gillnet hours are expended at the tails of the migration, the annual catch would be much less than if the same effort had been expended at the peak of the run. Similarly the CPUE would be much less and would no longer be a proper index of annual performance. Two approaches to this problem are to improve the measurement of effort or to analyze catch and effort data on a smaller time scale.

Improvement of measures of fishing effort has been a major area of research in fisheries, yet logistic problems associated with compiling and adjusting commercial effort data still are unavoidable. Therefore it may be advisable to move towards short range forecasting and the use of data recorded for time increments smaller than a year.

Short range forecasting may also be used to predict annual yield. The models are developed for short time scale data and as each time increment passes the most recent data can be incorporated into the forecasting process, enabling increasingly accurate recalculation of annual forecasts on each time interval.

Empirical models for seasonal data are well developed in business forecasting (Eby and O'Neill 1977; Lewis 1982) and may be roughly classed as either econometric or time series models. Of the two types, only time series analysis has recieved much attention in fisheries. Recent papers by Saila et al (1980) and Mendelssohn (1980) present applications of Box-Jenkins time series models to monthly fisheries data.

The important aspects of the work of Saila et al (1980) are the exclusive use of CPUE data and the comparison of time series results to a relatively simple econometric model utilizing monthly averages of CPUE. The monthly average (MA) model projected a time trend in twelve years of monthly CPUE data. The seasonal variability of the data was accounted for by averaging residuals for each month for the twelve years. Forecasts of monthly CPUE were calculated by predicting future time periods by means of the regression line. The average residual for the corresponding month was then added for the final estimate of monthly CPUE. Annual forecasts were calculated as the sum of monthly forecasts.

The results of the MA model were then compared to an auto-regressive integrated moving average (ARIMA) model fitted to the same data. Saila et al (1980) concluded that the ARIMA model performed better than the monthly average model. Although the average absolute errors of monthly forecasts by the two methods for 1975 did not differ greatly, (MA-23%; ARIMA-18%), the forecasts of annual CPUE by the ARIMA model were noticeably better (MA-22%; ARIMA-10%). Interestingly, Saila et al (1980) made no attempt to relate CPUE values to actual values of catch.

In a recent study, by Mendelssohn (1980), which did forecast monthly catches the average absolute error for twelve monthly catch forecasts was over 100 percent. Mendelssohn (1980) examined the relationship of monthly catch and effort for a Hawaiian skipjack tuna fishery by means of detailed Box-Jenkins models. The goals of the study were to forecast monthly catches, particularly during the summer months, and to estimate annual yield. A univariate model of monthly catches performed as well as transfer function models of catch and effort data. Mendelssohn (1980) noted that the source of error in the transfer function models was due to inability to predict monthly efforts accurately. The inability to effectively forecast fishing effort in Mendelssohn's (1980) study and in general, in fisheries research, is not surprising since effort is dependent on a variety of ill-defined, interacting economic and climatic factors and since many fisheries operate under unlimited public access.

The alternative to effort estimation is short range forecasting which is based, for the sake of simplicity, on incremental catch statistics. Estimates of the precision of forecasts would necessarily reflect the unknown variability due to effort but should also provide a realistic range of expected yields.

The review of these recent papers provides a basis for techniques to be used in research of short-range forecasting in fisheries. Most importantly, there is a need to describe and understand the seasonal dynamics of the fishery. Information on the seasonal fishery dynamics can then be used to forecast annual yield and period yields (ie. monthly catch, weekly catch, etc.). In addition to the point estimates, methods for examining their precision are necessary. The ability to update forecasts as new information accrues is also vital to the utility of an intraseason forecasting process.

Intraseason Forecasting for Salmon Harvest Control

Forecasting approaches which fit these conditions have been developed for Alaskan salmon fisheries. The models rely on simple principles and are based on historical patterns of catch and effort (Wright 1981). The most basic intraseason forecasting models used by salmon harvest managers is the timing model. The seasonal behavior of a fishery is defined by a time series of percentage indexes describing the expected proportion of harvest on a given time interval. The expected proportion for a time interval is the fraction of the harvest which has been historically taken on the time interval. The methodology has been used to define the characteristics of salmon migrations and is often referred to as ′run timing′, or ′entry pattern′ (Mundy 1979). However in a general sense such time series are only particular manifestations resulting from the approximation of the underlying form of the time distribution of abundance of the migration by the actions of the fishery.

The method may be extended beyond fisheries which exclusively target spawning migrations under the requirement that the annual performance curves of the fishery display similar behavior from year to year (Mundy 1983). When such is the case, forecasting on the basis of average performance may be a useful harvest control technique regardless of the dependency of harvests on the behavior of the target species, the harvesters, or both. The term ´similar behavior´ can be objectively defined; however, the actual definition depends upon requirements of the regulatory program.

Before the general case for performance curves can be considered, the origin of the methods in the Alaskan salmon fisheries must be understood. Early in the history of Alaskan salmon fisheries managers evaluated their performance by comparing current annual yield to average annual yield. When salmon stocks declined, managers realized that in order to perpetuate the stocks they had to create a balance between fish caught and those which escaped to spawn. The White Act (U.S.) of the 1920´s required an even division of the migration into catch and escapement for all fisheries. During the 1950´s this led to a management policy which called for certain minimum escapements for each river to be well distributed throughout the spawning season.

Contemporary control of salmon harvests retains the need for a reference point by which to judge the progress towards harvest control objectives. Average performance is a convenient reference of proven durability. The current standard replaces the single data point, ie. average annual yield, by a season long time series of average values of catch and, when available, escapement. For example, if the time series of escapement in the current year is below average and the catch series is above average, then managers have good reason to become concerned about over-harvesting. Another use of average performance information is yield forecasting. As an example, in Bristol Bay, Alaska, July 4 has been considered the mid-point of the sockeye salmon migration since at least the 1930´s. Catch plus escapement up to July 4 is often doubled to produce a forecast of total sockeye returns for the year (Royce

1965). It is upon this grossly defined, intuitively compelling approach that empirical timing research seeks to build and improve.

In all migratory timing work it is assumed that the time of arrival in the fishery is an inherited trait which is mediated by exogenous factors. The expression of arrival behavior in commercial catch data can be modulated by the time distribution of effort (Leggett 1977) as well as the time distribution of climatic factors. It must also be assumed that interannual fishing behavior does not shift dramatically. Fishing should not seriously affect the migratory timing of future stocks by overexploiting any particular segment of migrating spawning population.

Walters and Buckingham (1975) presented some of the first considerations of this type of thinking and, unfortunately, concluded that it was too coarse a method. Mundy (1982) published the first thorough application of empirical migratory timing work. In doing so he showed that useful information could be derived from historical performances. He also introduced a standardization of methods by which to operate.

The two primary objectives of migratory timing research are the characterization of the distribution of fish through time and the utilization of that knowledge for harvest control. Since catch is approximately proportional to abundance, a distribution of catch information is a reasonable reflection of the time of migration. The daily proportion of total catch with respect to time has been called a time density (Mundy 1979). The time density is an empirical probability density function of the variable t_i, the date of capture. The mean date of capture and the variance of capture dates, $\bar{t}$ and s_t^2, are used as the estimates of the mean date and the variance of the migration. These provided convenient numerical representations of annual migrations which can be correlated with external factors.

Average performance is expressed as the average cumulative proportion of catch up to a given time increment. The dynamic estimator which relates total yield to the average performance is:

$$\hat{N}_t = C_t / Y_t \qquad (1.2)$$

where,

$\hat{N}_t$ is the estimated annual yield on time interval t.

C_t is the cumulative catch on time interval t.

Y_t is the average cumulative performance on time interval t, $0 \leq Y_t \leq 1$

Typically the estimates are poor early in the season and steadily improve as the season progresses. Absolute percentage errors in early estimates are usually in the range of 50% to 200%. By the mean date of capture, errors of estimation may be in the 10%-50% range and the corresponding cumulative catch at 40%-60% of the season total.

It is obvious from these generalizations that the yield estimator frequently is less than a spectacular forecasting tool. The past success of the technique seems to be the subjective adjustment of forecasts by the manager in response to perceived discrepancies between the pattern of the current year's fishery and historic performance. It is these types of adjustments which need to be quantified, but further development can only occur after a full knowledge of the strengths and limitations of the basic average timing model is attained.

CHAPTER 2

INTRASEASON FORECAST METHODS

Intraseason Annual Forecasts

The object of this study is to determine if historical patterns of commercial fisheries data are useful for forecasting future patterns. The data falls into several categories: commercial catch; commercial CPUE; and in one circumstance total estimated abundance. All data are species specific. Each source of the data is referred to as a fishery which is defined by arbitrary boundaries in space and time.

In most cases the geographic region which is the source of the data is a management area or statistical area. The length of the fishing season is dependent on the distribution of catches through the year. As an example, the critical segment a commercial sockeye fishery on the Copper River delta, Alaska, extends from the middle of May to the middle of July. Although commercial fishing continues into August, the pattern of catches in this latter period are unrelated to that of the earlier period. It is therefore more suitable to define the period from May 15 to July 15 as a separate season. The data are recorded by coded date, ie. for the Copper River May 15 equals Day 1, for each year of record.

To simplify the explanation of the forecasting methods the data are structured as an array with dimensions equal to the number of time increments in the season (n) and the number of years in the data base (y). Also, since all methods relate directly to the cumulative performance of the data the following conventions will be used:

$c'(i,j)$ = catch on time interval i, year j.

$c(i,j)$ = cumulative catch on time interval i, year j.

$p'(i,j)$ = proportion of catch on time interval i, year j.

$p(i,j)$ = cumulative proportion of catch on time interval i, year j.

where i = 1,...,n; j = 1,...,y. Each method will be described for catch data but the same procedures are also followed for other data categories.

The average timing model (ACP) which serves as a foundation for the other models relates the cumulative performance of catch in the current season to the average cumulative percentage performance in past seasons. The estimator is as follows:

$$\hat{C}(i,j)_{ACP} = c(i,j) \,/\, \bar{p}(i,j-1) \qquad (2.1)$$

where,

$\hat{C}(i,j)_{ACP}$ = estimate of total catch for year j on time increment i by the average cumulative proportion model.

$\bar{p}(i,j-1)$ = Average of cumulative proportions of catch on time increment i for all years prior to year j.

An important consideration is the calculation of $\bar{p}(i,j-1)$ for the initial portion of a season. The date on which fishing begins will vary from year to year, consequently some time intervals will contain no information. Therefore, note that average cumulative proportions are arithmetic means of only nonzero cumulative proportions ($p(i,k) > 0$, where k=1,...,j-1).

Ratio (RAT) and regression (REG) estimators are methods used in survey sampling statistics which are similar to the average timing model. These estimators attempt to increase the precision of estimation by taking advantage of the correlation of the variable in question with another auxillary variate which is more fully known (Cochran 1977). A full developement of Cochran's (1977) original equations for ratio and regression estimators and their relationship to the forecasting problem are in Appendix A.

The variable used in the forecasting problem is c'(i,j). If we consider the time series of these values as a statistical population then the value to be estimated is the population total C(j), or the sum of c'(i,j) for i=1 to n. The basic concept of the ratio estimator is frequently encountered in fisheries, especially in Petersen mark-recapture population estimation. The ratio of average historical total yield, $\bar{C}$, to average historical cumulative catch at time i, $\bar{c}_i$, is the same as the ratio of this year's total catch, C, to the current cumulative catch at time i, c_i.

$$\frac{\bar{C}}{\bar{c}_i} = \frac{C}{c_i} \qquad (2.2a)$$

Of course this year's total yield is the quantity of interest, so solving Equation 2.2a for C, and subscripting in i and j,

$$\hat{C}(i,j)_{RAT} = [\ c(i,j)\ /\ \bar{c}(i,j\text{-}1)\ ]\ \bar{C}(j\text{-}1) \qquad (2.2b)$$

where,

$\bar{c}(i,j\text{-}1)$ = average of cumulative catches on time increment i for all years prior to year j.

$\bar{C}(j\text{-}1) = \bar{c}(n,j\text{-}1)$ = average of total catches for all years prior to year j.

Note that Equation 2.2b is similar to Equation 2.1 in that average cumulative catch on time interval i divided by average total catches is approximately equal to the average cumulative proportion of catch on time interval i.

$$[\ \bar{c}(i,j-1)\ /\ \bar{C}(j-1)\ ]\ \approx\ \bar{p}(i,j-1) \qquad (2.3)$$

Cochran (1977) states that the ratio estimator will work the best when the relationship between $c'(i,j)$ and $\bar{c}'(i,j-1)$ is linear and passes through the origin. Essentially this means that the ratio of these two variables is constant for each time interval. The premise is that the ratio estimated by comparing cumulative catch to average cumulative catch, $c(i,j)\ /\ \bar{c}(i,j-1)$, is an estimate of the population ratio, $C(j)\ /\ \bar{C}(j-1)$. To put it simply, if the current catches are averaging twenty percent higher than average historic catches up to some point in the season then the forecasted total catch at that point would be twenty percent higher than the average annual yield of past seasons.

In certain situations the regression of $c'(i,j)$ on $\bar{c}'(i,j-1)$ will not pass through the origin. If this is the case Cochran (1977) suggests the use of a regression estimator (see Appendix A). The estimate of population total by a regression estimator is as follows:

$$\hat{C}(i,j)_{REG} = (N/i)\ [\ c(i,j) - b'(i)\ \bar{c}(i,j-1)\ ] + b'(i)\ \bar{C}(j-1) \qquad (2.4)$$

where,

N = number of time increments in the season
$b'(i)$ = slope of the regression of $c'(i,j)$ on $\bar{c}'(i,j-1)$ as of time interval i.

The final method relates the cumulative catch on a time interval to the total yield for that season by simple linear regression (LIN). The linear regression estimator is:

$$\hat{C}(i,j)_{LIN} = a(i) + b(i)\ c(i,j) \tag{2.5}$$

where a(i) and b(i) are the least squares estimators of the intercept and slope of the regression of C(j) on c(i,j). Each time interval has a regression line whose parameter estimates, a(i) and b(i), are calculated from j-1 pairs of data. As the season progresses the coefficient of determination of the regression lines steadily increases until reaching one on the final time interval of the season since c(n,j) equals C(j).

Thus far the models underlying each of the estimators has not been mentioned. The formal developement of the models corresponding to the ratio and regression estimators is a rather technical subject and will not be discussed. Such considerations for these models can be found in Cochran (1977). A careful examination of the remaining methods reveals that each could be expressed by first order linear regression models. Formally stated the two basic models are:

$$Y(k) = B(i)\ X(i,k) + \epsilon(i,k) \tag{2.6}$$

$$Y(k) = A(i) + B(i)\ X(i,k) + \epsilon(i,k) \tag{2.7}$$

Where,

Y(k) = C(k) = annual yield on year k.
X(i,k) = c(i,k) = cumulative catch on time interval i year k.
ϵ(i,k) = forecasting error on time interval i year j
k = 1,..., j-1

In either case the model is developed from a linear regression of annual catch on the cumulative catch for time interval i. Equations 2.6 and 2.7 correspond, respectively, to the ACP model and the LIN model. The ACP model is posed as a regression through the origin. Where the parameter, B(i), is the slope of the regression line and is estimated by the quantity, [1 / $\bar{p}(i,j-1)$]. The slope parameter when estimated by the least squares methods is;

$$b = \sum_{k=1}^{j-1} [\ C(k)\ c(i,k)\ ] \quad / \sum_{k=1}^{j-1} c(i,k)^2 \qquad (2.8)$$

Forecasts using the parameter estimate of 2.8, will be referred to as adjusted linear estimates (ADJ LIN).

In the linear regression model, Equation 2.7, the parameters, A(i) and B(i), are estimated by least squares methods. A cursory examination of these models seems to indicate that the LIN model will be more appropriate early in a fishing season. Since a regression line of total yield on cumulative catch will seldom pass through the origin until late in the season.

Intraseason Period Forecasts

Projections of future catches for future fishing periods can be derived from average performance information or by a variation of the linear regression model. By the average performance model, period forecasts could be:

$$\hat{c}'(i+m,j) = \hat{C}(i,j)_{ACP} \quad \bar{p}'(i+m,j-1) \qquad (2.9)$$

where,

$\hat{c}'(i+m,j)$ = projection of catch for time increment i+m, as calculated on time interval i.

m = number of time periods projected ahead.

However Eby and O'Neill (1977) suggest projecting only one time interval ahead, and restricting the method to the use of cumulative proportions in the following manner,

$$\hat{c}(i+1,j)_{ACP} = \hat{C}(i,j)_{ACP} \quad \bar{p}(i+1,j-1) \tag{2.10}$$

where,

$\hat{c}(i+1,j)_{ACP}$ = projection of cumulative catch for time increment i+1, as calculated on increment i.

The estimated period catch is the projection of cumulative catch on time increment i+1 minus the the observed cumulative catch on increment i or,

$$\hat{c}'(i+1,j)_{ACP\ PF} = \hat{c}(i+1,j) - c(i,j). \tag{2.11}$$

Eby and O'Neill's (1977) method (Equation 2.11) is used to project period catches by the average performance model.

Forecasts of cumulative catch on a future time interval can be estimated by linear regression in the same manner as total yield. The projection of period yield is derived from the following estimator:

$$\hat{c}(i+m,j)_{LIN} = a(i) + b(i)\ c(i,j) \tag{2.12}$$

where a(i) and b(i) are derived from the regression of c(i+m,j) on c(i,j). Projections by this linear model were also only calculated for the next time interval in the season, therefore m equals one and,

$$\hat{c}'(i+1,j)_{LIN\ PF} = \hat{c}(i+1,j) - c(i,j) \tag{2.13}$$

Assessment of Accuracy

Ultimately the accuracy of the estimators should be judged by their ability to predict the value being forecasted. In the evaluation of forecasts by Saila et al (1980) the criteria for judgement were the residuals, [$C(j) - \hat{C}(j)$], and a measure of the fit of the modeled data to observed data. The latter is analogous to the coefficient of determination in linear regression. In the described forecasting process it is difficult to compare the effectiveness of models by these criteria. Another statistic which is frequently used in business forecasting is the absolute percentage error (APE). The residual, $\epsilon(i,j)$, or in forecasting terminology, the forecasting error, is expressed as a percentage of the observed value;

$$APE(i,j) / 100 = | \epsilon(i,j) | / C(j) = | C(j) - \hat{C}(i,j) | / C(j) \tag{2.14}$$

where,

$APE(i,j)$ = absolute value of the percentage error of the forecast of annual yield on time increment i, year j.
$\epsilon(i,j)$ = forecasting error (residual)

Roff (1983) used the mean absolute percentage error (MAPE) of several years of forecasts to evaluate medium term forecasts of annual yield. Although MAPE is a good indicator of the success of an estimator, it can not be used to make approximate precision bounds on a forecast. Therefore it is more informative to use a statistic which relates forecasting error as a percentage of the forecast instead of as a percentage of the observed value. As such the mean absolute percentage deviation can be defined as:

$$MAPD(i) = [\ 100\ /\ (n-1)\ ] \sum_{j=1}^{n} |\ \epsilon(i,j)\ |\ /\ \hat{C}(i,j) \qquad (2.15)$$

The interpretation of MAPD, like MAPE, is straightforward in that smaller values indicate successful forecasts and large values indicate inaccurate forecasts. Since the forecast models are usually judged on their empirical performance, it is desirable to express the relative error as statistics which are easily understood and which also allow comparisons of accuracy between fisheries.

Of immediate interest is the relative accuracy of the estimators as the fishing season progresses. The annual data sets for each fishery were divided into two groups and the annual yield was forecasted for each year in the recent group. The number of years to be forecasted was calculated by taking the integer value that resulted from dividing the total number of years in the data base by two. For example, if there were twenty-one years of data, then the most recent ten years were forecasted. Forecasts were based on data from all years prior to the year being forecasted. For example, the tenth year was forecasted on the basis of the previous nine years, the eleventh from the previous ten, etc. A mean absolute pecentage deviation (MAPD) was then calculated for each time interval of the season. The resulting time series of relative errors will provide a important measure of the utility of a forecasting method.

The coefficients of variation of the average cumulative proportions are also indicators of the precision of the ACP model as the season progresses. The coefficient of variation, [$(s/\bar{p}(i,j-1))\ 100$], can be directly related to the absolute percentage error on a time interval by analogy to Chebyshev's Inequality. First it is necessary to express the absolute percentage error in terms of the expected cumulative proportion, $\bar{p}(i,j-1)$, and the observed cumulative proportion, $p(i,j)$. From Equations 2.1 and 2.14:

$$APE(i,j)/100 = \mid (c(i,j) / \bar{p}(i,j-1)) - C(j) \mid \ / \ C(j) \qquad (2.16)$$

Since $C(j) = c(i,j) / p(i,j)$,

$$\frac{APE(i,j)}{100} = \frac{[\ c(i,j) \mid (1/\bar{p}(i,j-1)) - (1/p(i,j)) \mid\ ]}{c(i,j) / p(i,j))} \qquad (2.17)$$

$$APE(i,j)/100 = \mid (p(i,j) - \bar{p}(i,j-1)) / \bar{p}(i,j-1) \mid \qquad (2.18)$$

By Chebyshev's Inequality,

$$P(\{ p(i,j): \ \mid p(i,j) - \bar{p}(i,j-1) \mid > ks \}) \leq [\ 1 / k^2\ ] \qquad (2.19)$$

Where,

s = standard deviation of $p(i,k)$ for $k = 1,\ldots, j-1$.

Multiplying the inequality inside the brackets by [$100/\bar{p}(i,j-1)$],

$$P\left(\frac{100 \mid p(i,j) - \bar{p}(i,j-1) \mid}{\bar{p}(i,j-1)} > \frac{100\ ks}{\bar{p}(i,j-1)} \right) \leq [\ 1 / k^2\ ] \qquad (2.20)$$

$$P(APE(i,j) > k\ CV) \leq [\ 1 / k^2\ ] \qquad (2.21)$$

or approximately, the probability that the absolute percentage error is greater than k times the coefficient of variation is less than $1/k^2$. For example, if k equals two and the CV equals 50 then the probability that the absolute percentage error is greater than 100 is less than or equal to 0.25. If the p(i,j) are approximately normally distributed then this probability would be closer to 0.05. Notice that these inferences can not be extended to a forecast in future years unless it is assumed that the standard deviation of p(i,j) is approximately the same as was calculated for past years.

Prediction intervals can be calculated for forecasts when they are posed as linear regression estimates. Such prediction intervals are more satisfactory as measures of precision since they are more statistically appropriate. Consult standard regression texts for interval formulas. The methods of Neter and Wasserman (1974) were followed for this study.

MAPD's, MAPE's, CV's and the correlation coefficients of the regression models will all serve as useful indicators of the accuracy of both annual and period forecasts on a given time interval for a specific fishery. An overall comparison of the methods which summarizes the accuracy of each estimator for each fishery can be achieved by two statistics, the MAPD of forecasts on the mean date of the fishing season, and the MAPD of all forecasts made on or before the mean date. The mean date of the fishing season is a standard reference point within a fishing season which is frequently the half-way point for a season. Intraseason forecasts are the most useful during the first half of a season, therefore these measures of forecast accuracy for the early portion of a season should be a good measure of a method's utility as a forecasting tool.

It would be informative to compare the results for intraseason forecasts and for pre-season forecasts. But, unfortunately it was not feasible to obtain pre-season forecasts from the management agencies. As a simple alternative a five year moving average (MA) was used as a pre-season estimate of annual performance,

$$C(j+1) = (1/5) \sum_{k=j-4}^{j} C(k) \qquad (2.22)$$

Incorporation of Judgements

The phrase 'incorporation of judgements' can take many meanings in a forecasting problem; judgement may entail complex adaptive forecasting techniques or common sense adjustments of the data. The methods presented here will take the latter approach. The methods will be rather simple practices which selectively restrict the set of historical data used to estimate model parameters.

Upon first inspection of the data base atypical fishing seasons should be isolated. If a clear reason for the aberrant behavior can be found it may be wise to exclude that year of data. Typical causes of abnormal fishing seasons include protracted strikes and natural disasters. However, in fisheries where strikes or other unusual events are not that unusual it may be advisable to include atypical data sets in the analysis.

Each of the methods is dependent on the similarity of the time distribution of the catches in the current year to the catch distributions of past years. As an extreme example, if the catches for a fishery are identically distributed for every year then the regressions of $c'(i,j)$ on $\bar{c}(i,j-1)$ as well as $C(j)$ on $c(i,j)$ will be perfectly linear. Forecasts using this data would be perfect regardless of the method. However, in reality patterns of catch vary a great deal, and the problem then becomes the resolution of systematic variability.

It may be possible in some fisheries to isolate characteristic patterns of catch which can be used to increase forecasting accuracy. Such a procedure is contingent on the ability to correctly determine the type of pattern to be used during the forecast year.

Patterns can be isolated by stratifying the data base so that years of data with similar distributions are grouped together. Mundy and Schaller (1983) showed that seasonal patterns of daily chinook salmon catch in the Yukon River are very dependent on factors related to spring air temperature at Nome, Alaska. They were able to stratify a twenty-three year data set into three categories, cool year patterns, warm year patterns, and average year patterns. In doing so they were able to reduce forecast errors by the ACP model. Results of forecasts made under their stratifications will be presented and compared to forecasts based on unstratified data. The key to this type of stratification is the identification of a factor which is a consistent covariate of each characteristic distribution of catches and can be measured before a season begins.

An additional method of stratification which is based on the statistical behavior of the data has been tested in conjunction with the ratio estimator. The theory of the ratio estimator holds that if the relationship between $c'(i,j)$ and $\bar{c}'(i,j)$ is linear the method will be more successful. For this reason if the average cumulative catches are calculated from the years of data which individually correlate well with the catches in the forecast year then the forecasts may improve. Forecasts by this method will be referred to as censored ratio estimates (CR).

A coefficient of correlation was calculated between the current year's catches, up to time interval i, and each of the corresponding series of catches for past years. If the correlation coefficient exceeded 0.8 then the data from that year was included in the calculation of $\bar{c}(i,j-1)$ and $\bar{C}(j-1)$. Preliminary testing showed that data from a single past year did not necessarily provide a good basis for forecasts, regardless of correlation. Therefore, an average of several well correlated years was tested in an attempt to improve the forecasting performance of the censored ratio estimator.

Since a useful coefficient of correlation can only be derived after enough time intervals have accrued to provide a sufficient sample size, the following criterion of inclusion was used during the initial time periods of a season. The standard deviation of catches on a given time interval was calculated for all of the years included in the forecast procedure. If the catch of a past year was within one standard deviation of the catch on the same interval in the current year then the data from that year was included in the calculation of $\bar{c}(i,j-1)$ and $\bar{C}(j-1)$.

CHAPTER 3

FORECAST RESULTS

The forecasting system has been tested for over sixty years of fisheries data from six commercial fisheries which span the globe. The forecasted data included: chinook salmon (Oncorhynchus tschawytsha) catch data from the Yukon River, Alaska; sockeye salmon (O. nerka) abundance data from Bristol Bay, Alaska; sockeye salmon catch data from Copper River, Alaska; sockeye salmon catch and CPUE data from Lynn Canal, Alaska; rock lobster (Jasus edwardsii) CPUE data from Gisborne, New Zealand; blue crab (Callinectes sapidus) catch data from Virginia, USA.

Because there are many years of forecasts it is not feasible to present the results for each individual year. However, the application of the forecast estimators to the 1983 Yukon River chinook season will be partially worked through as a demonstration of typical annual results.

The Yukon chinook salmon data set was obtained from the Alaska Department of Fish and Game (ADF&G). Initially, the unstratified data for the years, 1961-1982, was used for the forecasts of 1983 catch data. In 1983, no catches were reported during the first three intervals of the season, therefore no forecasts were made. Forecasting was initiated on the fourth interval; the recorded catch was 22,292 fish (see Table 2).

Each of the six forecasts of annual yield for the fourth time interval were calculated as follows:

$$\hat{C}(4,1983)_{ACP} = [\ 1/\bar{p}(4,1982)\ ]\ c(4,1983)$$
$$= [\ 1/.164\ ]\ 22,292$$
$$= 135,901$$

$$\hat{C}(4,1983)_{RAT} = [\ \bar{C}(1982)\ /\ \bar{c}(4,1982)\ ]\ c(4,1983)$$
$$= [\ 75,385\ /\ 13,522\ ]\ 22,292$$
$$= 124,278$$

For the censored ratio estimator only two years had catches on time interval four which were within one standard deviation of the 22,292 fish. The years 1969 and 1981 were selected.

$$\hat{C}(4,1983)_{CR} = [\ \bar{C}(1982)_{CR}\ /\ \bar{c}(4,1982)_{CR}\ ]\ c(4,1983)$$
$$= [\ 85,251\ /\ 17,917\ ]\ 22,292$$
$$= 106,068$$

$$\hat{C}(4,1983)_{REG} = N/i\ [\ c(4,1983) - b'(4)\ \bar{c}(4,1982)\ ] + b'(4)\ \bar{C}(4,1982)$$
$$= 15/4\ [\ 22,292 - (3.4261)\ 13,522\ ] + (3.4261)\ 75,385$$
$$= 168,142$$

$$\hat{C}(4,1983)_{LIN} = a(4) + b(4)\ c(4,1983)$$
$$= 67,085 + (.6314)\ 22,292$$
$$= 81,159$$

$$\hat{C}(4,1983)_{ADJ\ LIN} = b(4)\ c(4,1983)$$
$$= (2.9990)\ 22,292$$
$$= 66,850$$

Note that the catch of 22,292 fish was the highest ever recorded on the fourth time interval. Based on this information a manager probably would discount the adjusted linear estimate as being too low. Notice also that the average timing (ACP), ratio (RAT) and regression (REG) estimates are very high in regard to the historic average of 72,196 fish (Tables 2 and 5). Even though the actual catch was very

Table 2. Catches of chinook salmon from District Y-1, Yukon River, Alaska. Catch data are grouped in three day intervals; first interval begins on June 1.

Year Time Interval	1963	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
c'(i,j)																							
1	0	0	22	0	0	0	4355	1	2117	0	0	0	0	214	0	0	0	0	0	0	0	0	0
2	638	0	693	0	0	0	15765	72	4046	9	0	0	267	4081	0	0	0	0	5820	0	11117	0	0
3	2937	0	4012	0	589	0	15292	1329	3894	241	0	7	2498	6757	0	0	0	2593	4602	1755	15615	0	0
4	10547	3393	12153	0	3495	606	10520	9874	17530	1885	28	68	4427	14594	210	0	0	923	18836	8488	14483	0	22292
5	32508	4553	16534	4	8381	4206	16932	14417	14314	1074	402	1384	6187	11046	467	95	41	9818	7236	22100	18304	5643	12678
6	1660	4594	13155	241	22433	18268	3612	3549	6672	6639	2351	3089	9475	13959	1102	1829	2583	13889	4459	14669	28519	12395	28669
7	14121	14980	7169	9256	16833	11660	16969	12923	10495	21855	3336	17019	8617	6282	5666	1555	10324	7463	15763	26161	0	19925	12641
8	4183	14353	10492	27460	18019	13383	14580	15104	8094	6525	13796	16345	11086	1732	13383	12121	18016	14600	3657	4441	4157	7103	4698
9	8153	17145	9087	11498	7476	10823	6310	13967	2282	10904	20176	7073	10219	7186	12565	12549	12173	5051	5943	3017	2901	0	0
10	4238	3243	9751	4886	5840	7812	0	6626	1968	3142	34597	18924	0	4197	1464	13817	16248	1512	4373	1245	1550	18173	4824
11	2414	2810	1936	6367	6202	4025	0	1588	0	4155	9061	4401	0	0	6152	14205	6897	632	1535	2862	1178	7504	4690
12	3007	2001	0	6273	0	0	0	0	0	0	0	0	1387	662	1142	2773	1825	867	1325	3109	661	1920	1310
13	0	0	0	1570	0	0	0	0	0	0	0	0	1281	234	1445	1247	639	558	385	838	342	1237	1256
14	0	0	0	0	0	0	0	0	44	0	114	915	605	215	598	251	449	457	449	690	0	287	1371
15	0	0	0	0	0	0	0	0	34	58	901	614	365	119	121	924	236	271	223	390	186	85	632
c(i,j)																							
1	0	0	22	0	0	0	4355	1	2117	0	0	0	0	214	0	0	0	0	0	0	0	0	0
2	638	0	715	0	0	0	20120	73	6163	9	0	0	267	4295	0	0	0	0	5820	0	11117	0	0
3	3575	0	4727	0	589	0	35412	1402	10057	250	0	7	2765	11052	0	0	0	2593	10422	1755	26732	0	0
4	14122	3393	16880	0	4084	606	45932	11276	27587	2135	28	75	7192	25646	210	0	0	3516	29258	10243	41215	0	22292
5	46630	7946	33414	4	12465	4812	62864	25693	41901	3209	430	1459	13379	36692	677	95	41	13334	36494	32343	59519	5643	34970
6	48290	12540	46569	245	34898	23080	66476	29242	48573	9848	2781	4548	22854	50651	1779	1924	2624	27223	40953	47012	88038	18038	63639
7	62411	27520	53738	9501	51731	34740	83445	42165	59068	31703	6117	21567	31471	56933	7445	3479	12948	34686	56716	73173	88038	37963	76280
8	66594	41873	64230	36961	69750	48123	98025	57269	67162	38228	19913	37912	42557	58665	20828	15600	30964	49286	60373	77614	92195	45066	80978
9	74747	59018	73317	48459	77226	58946	104335	71236	69444	49132	40089	44985	52776	65851	33393	28149	43137	54337	66316	80631	95096	45066	80978
10	78985	62261	83068	53345	83066	66758	104335	77862	71412	52274	74686	63909	52776	70048	34857	41966	59385	55849	70689	81876	96646	63239	85802
11	81399	65071	85004	59712	89268	70783	104335	79450	71412	56429	83747	68310	52776	70048	41009	56171	66282	56481	72224	84738	97824	70743	90492
12	84406	67072	85004	65985	89268	70783	104335	79450	71412	56429	83747	68310	54163	70710	42151	58944	68107	57348	73549	87847	98485	72663	91802
13	84406	67072	85004	67555	89268	70783	104335	79450	71412	56429	83747	68310	55444	70944	43596	60191	68746	57906	73934	88685	98827	73900	93058
14	84406	67072	85004	67555	89268	70783	104335	79450	71456	56429	83861	69225	56049	71159	44194	60442	69195	58363	74383	89375	98827	74187	94429
15	84406	67072	85004	67555	89268	70783	104335	79450	71490	56487	84762	69839	56414	71278	44315	61366	69431	58634	74606	89765	99013	74272	95061

Table 3. Yukon River chinook salmon catch forecasts for 1983. Observed yield was 95,061 fish. Average timing (ACP); Ratio estimator (RAT); Censored Ratio (CR); Regression estimator (REG); Linear Regression (LIN); Regression through origin (ADJ LIN); Average timing period forecast (ACP PF); Linear regression period forecast (LIN PF).

Time Int	c(i,j)	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP* PF	LIN* ACP
4	22292	135901	124276	106068	168138	81159	66850	10990	12948
5	34970	142740	129794	95351	137052	81378	73264	16147	10303
6**	63639	177708	165083	166910	166961	89109	109744	28664	11731
7	76280	146862	140207	114143	140177	89269	111469	24068	6400
8	80978	118519	115835	98388	122724	89015	104970	15301	---
9	80978	99681	98793	87651	106239	86407	94456	10043	2993
10	85802	93965	93256	87308	99489	88874	92104	4211	10733
11	90492	93413	93140	---	98088	91500	92805	1038	706
12	91802	93066	92906	92539	95792	92125	92760	658	87
13	93058	93668	93609	93496	95451	93286	93554	333	78
14	94429	94709	94692	94586	95641	94578	93554	281	149
15	95061	95061	95061	95061	95061	95061	95061	---	---

Years selected for the censored ratio estimates***

4 1969, 1981
5 1962(.86), 1963(.83), 1968(.83), 1969(.98), 1970(.99), 1974(.91), 1979(.9)
6 1962(.89), 1963(.81), 1965(.82), 1970(.87), 1973(.89), 1974(.9), 1975(.84)
7 1963(.81), 1973(.81), 1974(.88)
8 1974(.87)
9 1974(.83)
10 1974(.83)
12 1974(.81)
13 1974(.81)
14 1974(.82)
15 1974(.82)

* Observed period catches are in Table 2.
** Mean Date
*** Number in parentheses is the correlation coefficient between 1983 period catches to date and the corresponding catches from the selected year.

Table 4. Yukon River chinook salmon catch forecast results for 1983. Observed yield was 95,061 fish. Each column represents the percentage deviation of the forecast on that interval. Average timing (ACP); Ratio estimator (RAT); Censored Ratio (CR); Regression estimator (REG); Linear Regression (LIN); Regression through origin (ADJ LIN); Average timing period forecast (ACP PF); Linear regression period forecast (LIN PF).

Time Int	p(i,j)	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP* PF	LIN* ACP
4	0.24	-30.1	-23.5	-10.4	-43.5	17.1	42.2	15.4	-2.1
5	0.37	-33.4	-26.8	-0.3	-30.6	16.8	29.8	77.6	178.3
6**	0.67	-46.5	-42.4	-43.1	-43.1	6.7	-13.4	-55.9	7.8
7	0.80	-35.3	-32.2	-16.7	-32.2	6.5	-14.7	-80.5	-26.6
8	0.85	-19.8	-17.9	-3.4	-22.5	6.8	-9.4	-100.0	-100.0
9	0.85	-4.6	-3.9	8.5	-10.5	10.0	0.6	-52.0	61.2
10	0.90	1.2	1.9	8.9	-4.5	7.0	3.2	-10.2	128.9
11	0.95	1.8	2.1	---	-3.1	3.9	2.4	-20.7	85.4
12	0.97	2.1	2.3	2.7	-0.8	3.2	2.5	91.0	1340.8
13	0.98	1.5	1.6	1.7	-0.4	1.9	1.6	311.7	1649.5
14	0.99	0.4	0.4	0.5	-0.6	0.5	0.4	125.1	321.8
15	1.00	0.0	0.0	0.0	0.0	-0.0	-0.0	0.0	0.0
MAPD up to mean		36.7	30.9	21.7	39.1	13.5	28.4	54.5	62.7

Years selected for the censored ratio estimates***

4 1969, 1981
5 1962(2.1), 1963(-.1), 1968(.1), 1969(-.4), 1970(5.5), 1974(-.3), 1979(-.3)
6 1962(2.6), 1963(.2), 1965(.7), 1970(2.8), 1973(0.7), 1974(-.1), 1975(15.7)
7 1963(.3), 1973(.4), 1974(0.0)
8 1974(.04)
9 1974(-.08)
10 1974(-.08)
12 1974(-.03)
13 1974(-.02)
14 1974(-.00)
15 1974(0.00)

* Observed period catches are in Table 2.
** Mean Date
*** Number in parentheses is the error, (PE/100), if the selected year was used as basis for a ratio estimate.

high, these estimates would be suspect since the maximum harvest over the time period 1961-1983 was 104,335. The only reasonable estimates were made by the censored ratio estimator (CR) and the linear regression estimator (LIN).

The period forecasts for time interval five are as follows:

$$\begin{aligned}\hat{c}'(5,1983) &= [\ \bar{p}(5,1982)\ \hat{C}(4,1983)_{ACP}\ ] - c(4,1983) \\ &= [\ (.2449)\ 135,901\ ] - 222,292 \\ &= 10,990\end{aligned}$$

$$\begin{aligned}\hat{c}'(5,1983) &= [\ a(4) + b(4)\ c(4,1983)\ ] - c(4,1983) \\ &= [\ 4897 + (1.3612)\ 22,292\ ] - 22,292 \\ &= 12,948\end{aligned}$$

A review of the remainder of period forecasts in 1983 reveals that the forecasts made on time interval four were uncharacteristically accurate (Table 4).

Further examination of 1983 results reveals the characteristic error patterns of the different estimators (Tables 3 and 4). In particular the errors of the average timing, ratio and regression estimators are very similar in that they tend to be large and variable at the outset of the season while decreasing as the season progresses. The censored ratio estimates often behave in the same manner, but in some cases errors are drastically reduced [$\hat{C}(5,1983)$] and in other cases the errors are greater than or equal to the ratio and average timing estimates [$\hat{C}(6,1983)$]. The adjusted linear estimator is also similar in patterns of absolute error but surprisingly is not well correlated with the average timing estimator. The linear regression forecasts follow the same error pattern, but usually have lower errors relative to the other estimates.

Similar observations are evident in the summarization of the forecasting system for the last eleven chinook seasons on the Yukon River (Table 5). As indicated the linear regression estimates proved to be the most reliable. In all criteria it surpassed the other estimators. An average absolute percentage deviation (MAPD) for all forecasts prior to the mean date for the eleven years was only 14.5 percent. The rest of the estimators averaged greater than 50 percent. For forecasts made on the mean date the MAPD for the linear model was 13 percent and for the others greater than 20 percent. Notice also that the five-year moving average of annual yields provided, on the average, a better estimate (19%) than all models except the linear regression (14%).

As mentioned in chapter two, stratification of the Yukon data base by spring air temperature was used by Mundy and Schaller (1983) to reduce forecasting error. The stratifications are as follows: cool years, 1964, 1971, 1972, 1975, 1976, 1977, 1982; average years, 1961, 1962, 1963, 1968, 1970, 1973; warm years, 1965, 1967, 1969, 1974, 1978, 1979, 1980, 1981, 1983. For 1983, using data from the warm stratification, the MAPD of forecasts, by the ACP estimator, on or before the mean date was reduced to 22% (error from unstratified data was 37%, see Table 4). Overall the average error of forecasts was reduced by using these stratifications (Table 6). As an example, the MAPD for the average timing model was reduced by more than half (unstrat. 145%, Table 5; strat 64%, Table 6). However, the linear regression model using either unstratified or stratified data still performed better than the other models. The MAPD up to the mean date for the linear model increased slightly to 16.3 percent and the MAPD at the mean date decreased to 12.1 percent.

Table 5. Summarization of the forecasting results for unstratified chinook salmon catch data from the Yukon River, Alaska, 1973-1983.

Time Int*	p̄(i,j)**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
					MEAN ABSOLUTE PERCENTAGE DEVIATION				
1	1.5	496.4	535.8	95.3	—	4.1	—	—	472.4
2	5.5	267.5	32.0	92.1	—	13.3	101.1	420.5	84.3
3	9.2	105.1	117.6	64.1	71.0	15.9	208.4	118.2	71.7
4	16.4	56.5	60.3	44.8	66.8	19.4	123.5	111.8	60.2
5	24.5	60.0	62.0	35.3	55.1	14.8	105.2	63.3	100.1
6	35.8	263.5	199.1	125.5	192.0	12.7	33.8	170.4	53.8
7	51.9	126.9	130.2	88.7	144.7	11.7	68.8	191.9	35.2
8	68.3	37.9	38.1	15.1	64.4	11.6	38.8	98.6	39.6
9	81.2	21.2	21.1	18.8	45.9	12.6	20.8	123.4	53.9
10	91.3	8.2	8.4	8.8	25.5	6.4	8.7	138.6	82.7
11	96.9	2.6	2.8	3.0	12.0	2.1	3.1	71.5	89.5
12	98.6	1.6	1.7	2.4	7.4	1.3	1.9	161.0	74.9
13	99.3	0.7	0.8	1.0	3.7	0.6	0.8	211.5	85.3
14	99.7	0.3	0.3	0.3	1.5	0.3	0.3	117.3	122.4
15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}}(i,j)$**				STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION				
1	1.7	0.0	0.0	0.0	—	0.0	—	—	0.0
2	6.1	450.3	18.4	0.0	—	8.4	73.0	348.9	69.1
3	10.1	108.2	126.1	0.0	73.8	10.2	216.3	79.9	53.7
4	15.7	41.2	46.5	0.0	75.1	9.0	151.4	169.0	58.5
5	22.4	73.4	85.0	29.6	65.7	8.7	177.9	90.9	57.3
6	25.7	382.2	333.5	155.5	319.1	10.2	45.9	243.3	35.4
7	25.7	231.5	241.4	189.8	259.3	9.3	104.8	270.2	22.0
8	19.7	45.5	47.2	19.8	78.2	8.1	57.5	74.2	33.0
9	15.4	22.2	22.7	19.7	41.9	7.2	26.3	97.2	33.8
10	7.7	10.5	10.7	10.5	23.8	5.8	11.2	157.1	50.8
11	3.2	2.2	2.2	3.1	8.7	1.5	2.3	63.8	120.1
12	1.5	1.5	1.5	1.4	5.8	1.1	1.5	261.4	90.4
13	0.7	0.6	0.6	0.6	3.4	0.6	0.6	242.0	73.2
14	0.4	0.4	0.4	0.2	1.5	0.4	0.4	183.1	149.9
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Yield:	72,195	S.D. of Yields:	17,020
Grand Mean Date:	7.3	S.D. of Mean Dates:	1.6
MAPD for 5 Yr MA Estimates:	19.9	S.D. of 5 Yr MA MAPD:	14.9

Relative Error Summary Statistics:	Up to Mean Date		At Mean Date	
	MAPD	S.D.	MAPD	S.D.
Average Timing (ACP)	145.9	119.8	33.1	17.5
Ratio Estimator (RAT)	124.4	102.2	31.6	16.4
Censored Ratio (CR)	62.4	65.5	23.6	15.9
Regression Estimator (REG)	123.9	124.3	42.4	19.9
Linear Regression (LIN)	14.5	7.7	13.3	8.1
LIN Through Origin (ADJ LIN)	99.1	62.2	21.1	11.3
ACP c'(i+1,j) - (ACP PF)	157.4	104.7	106.8	160.0
LIN c'(i+1,j) - (LIN PF)	72.0	28.7	76.7	73.5

* Catch data is grouped in 3 day intervals - Interval 1 starts June 1
** Calculated from all years of record, 1961-1982

Table 6. Summarization of forecasting results for temperature-stratified chinook salmon catch data from the Yukon River, Alaska, 1973-1983.

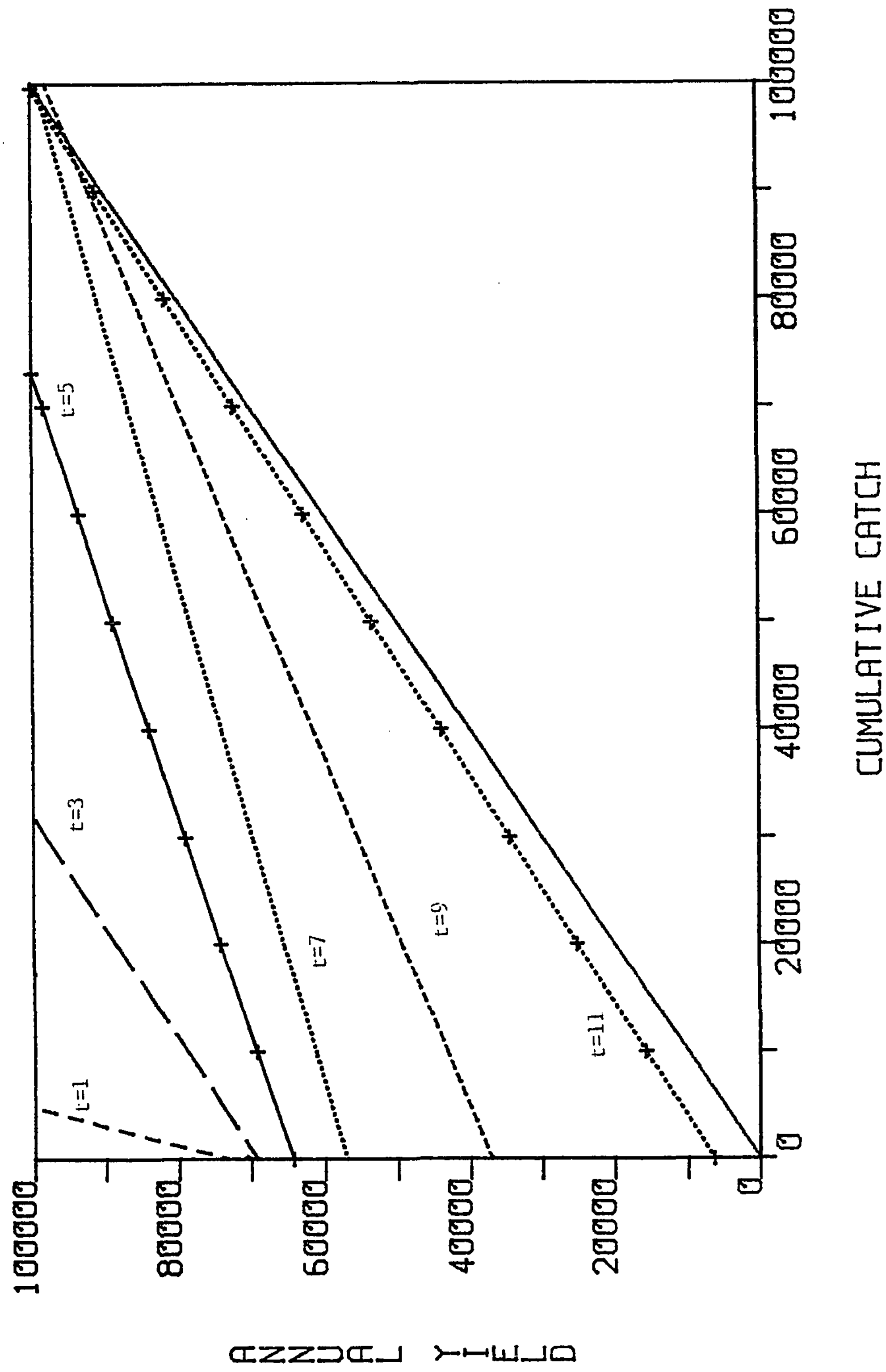
Time Int*	p̄(i,j)**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
				MEAN ABSOLUTE PERCENTAGE DEVIATION					
1	1.5	—	—	886.3	—	12.5	—	555.2	0.0
2	5.5	48.4	52.0	43.1	—	14.5	98.2	255.0	64.9
3	9.2	161.2	175.6	9.3	148.2	18.3	148.7	104.7	51.0
4	16.4	96.9	96.8	7.3	96.9	21.2	124.5	124.8	48.4
5	24.5	90.8	87.5	84.8	93.6	17.3	137.9	70.0	131.0
6	35.8	22.1	21.4	25.4	34.9	15.8	27.8	52.1	55.1
7	51.9	33.8	32.7	16.4	60.1	9.4	41.3	71.7	47.7
8	68.3	14.3	14.3	16.5	34.9	8.6	13.4	55.3	43.7
9	81.2	8.6	8.7	14.3	32.7	11.3	8.6	61.0	46.6
10	91.3	5.8	5.8	7.5	21.1	4.9	5.7	81.9	78.5
11	96.9	2.7	2.8	4.2	10.5	3.5	2.7	143.6	141.4
12	98.6	1.7	1.7	2.3	5.8	1.3	1.6	102.2	173.4
13	99.3	0.8	0.8	1.1	3.2	0.8	0.8	182.9	221.5
14	99.7	0.4	0.4	0.4	1.3	0.6	0.4	262.1	276.6
15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**	STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION							
1	1.7	—	—	0.0	—	0.0	—	0.0	0.0
2	6.1	58.1	69.6	0.0	—	7.9	67.9	414.2	36.8
3	10.1	237.6	260.8	0.0	215.1	10.6	220.9	95.1	41.8
4	15.7	135.3	135.8	0.0	133.0	9.0	192.4	169.1	43.1
5	22.4	170.6	156.3	156.0	132.8	10.0	292.5	69.4	217.9
6	25.7	23.2	23.5	23.1	33.2	12.1	23.1	33.4	29.0
7	25.7	59.7	57.4	23.4	86.8	11.9	81.6	42.9	28.5
8	19.7	22.2	20.5	19.4	30.6	13.2	24.6	34.2	34.0
9	15.4	11.9	10.7	12.1	36.5	16.1	10.7	29.3	41.2
10	7.7	6.4	6.8	10.9	20.5	5.4	7.3	60.6	57.8
11	3.2	1.4	1.6	2.5	9.2	4.2	2.0	190.4	251.7
12	1.5	1.2	1.2	1.2	4.1	1.2	1.4	121.4	259.3
13	0.7	0.5	0.5	0.6	2.2	0.6	0.5	233.5	284.1
14	0.4	0.3	0.3	0.2	1.0	0.5	0.2	325.3	288.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Yield:	72,196	S.D. of Yields:	17,020
Grand Mean Date:	7.3	S.D. of Mean Dates:	1.6
MAPD for 5 Yr MA Estimates:	19.8	S.D. of 5 Yr MA MAPD:	11.7

Relative Error Summary Statistics:	Up to Mean Date MAPD	Up to Mean Date S.D.	At Mean Date MAPD	At Mean Date S.D.
Average Timing (ACP)	64.4	63.4	16.3	11.3
Ratio Estimator (RAT)	65.6	64.3	16.7	11.0
Censored Ratio (CR)	48.7	58.3	14.3	11.1
Regression Estimator (REG)	68.9	72.6	28.5	28.5
Linear Regression (LIN)	16.3	10.6	12.1	15.6
LIN Through Origin (ADJ LIN)	79.0	87.1	14.9	9.6
ACP c'(i+1,j) - (ACP PF)	95.9	81.6	74.5	55.8
LIN c'(i+1,j) - (LIN PF)	69.2	51.9	127.0	218.2

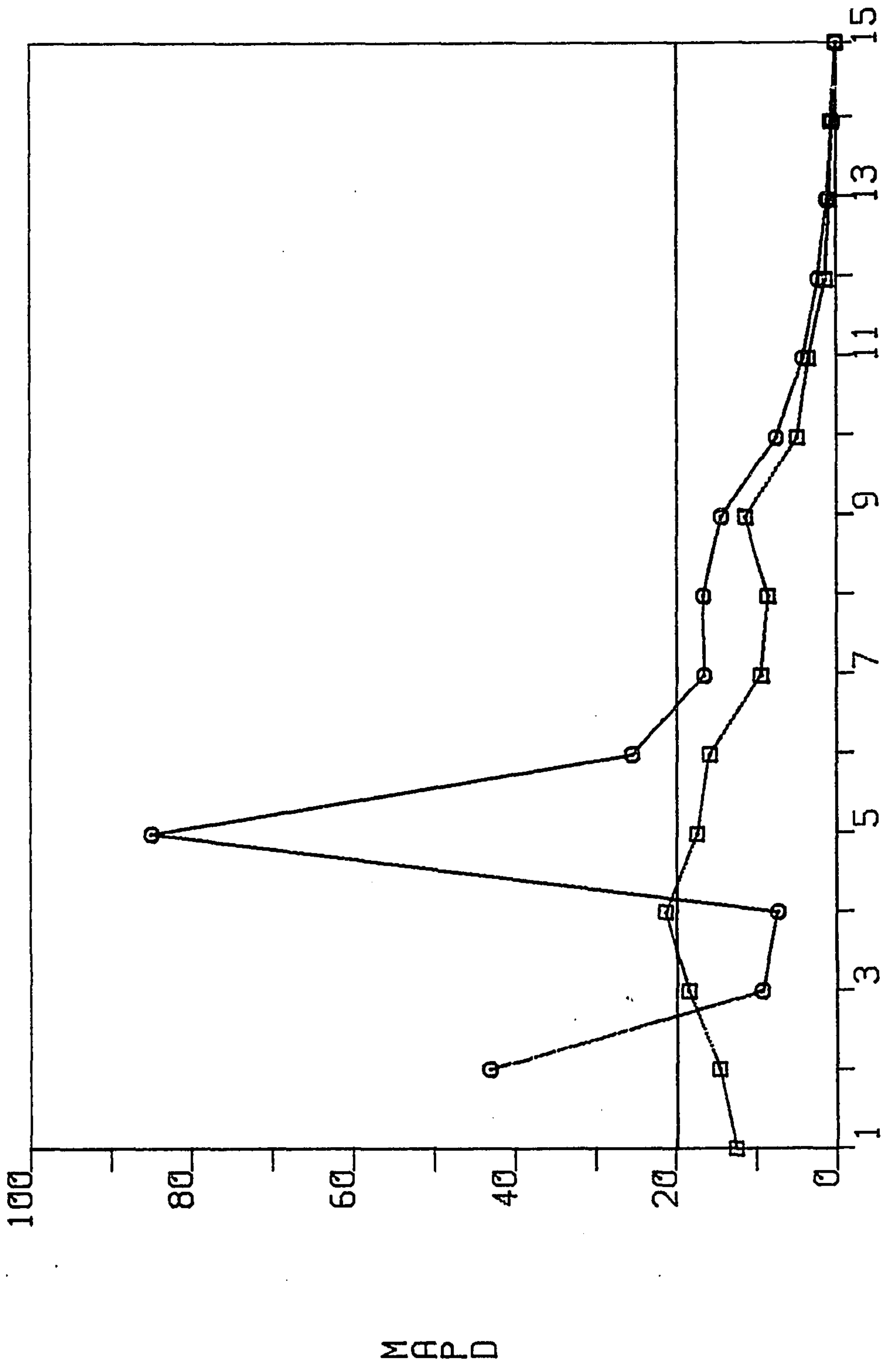
* Catch data is grouped in three day intervals - Interval 1 begins June 1
** Calculated from all years of record, 1961-1982

Figure 1. Behavior of the predictive regression lines for the linear model (LIN) for the Yukon River chinook fishery, calculated from catch data for the years, 1961-1982 (t=1; r^2=.17, t=3; r^2=.37, t=5; r^2=.47, t=7; r^2=.52, t=9; r^2=.65, t=11; r^2=.98)



ANNUAL YIELD
CUMULATIVE CATCH
0
20000
40000
60000
80000
100000
t=1
t=3
t=5
t=7
t=9
t=11

Figure 2. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the censored ratio estimator (o), and the five year moving average (—). Calculated from Yukon River stratified chinook catch forecasts for the years, 1973-1983 (Table 6).



MAPD
TIME INTERVAL
0
20
40
60
80
100
1
3
5
7
9
11
13
15

The series of regression lines used for the 1983 estimates are plotted in Figure 1. The linearity of the relation between the cumulative catches and annual yields increases as the season progresses and is reflected in the increasing correlation coefficients (see Figure 1).

A 95% prediction interval for $\hat{C}(4,1983)_{LIN}$ by standard methods is (55806,106754). The observed yield, 95,061, is within the interval.

Bristol Bay sockeye salmon abundance data was derived by adding commercial catches and lagged escapement counts (Mundy 1979). The annual data which was not published was obtained from Phil Mundy (personal communication). The total annual abundances for the years, 1956-1975, had the highest variability of any of the fisheries data investigated. The coefficient of variation for total abundances was 75. In comparison, the CV for the Yukon annual yield data was only 19.

The errors of estimation were also large. For all estimators of annual abundance the MAPD of forecasts on or before the mean date exceeded 50 percent (Table 7); the lowest MAPD was achieved by the linear regression model (52%). For forecasts on the mean date the censored ratio estimate had the smallest MAPD (27.6%). Period forecasting errors were high by both the linear regression and the average timing methods.

Sockeye salmon catch data from the Copper River was obtained from ADF&G for the years, 1969-1983. Two years of data, 1979 and 1980, were excluded from the forecasting procedures due to extended closures of the fishing area.

Annual yields were variable (CV=50). The adjusted linear model had the lowest MAPD up to the mean date (19.9%) and the lowest MAPD at the mean date (12.8%). The average errors by the rest of the estimators were comparable to the ADJ LIN model (Table 8). Notice that the coefficient of determination for the LIN model on the first time interval was only 0.01 and that the average error on that interval was greater than 50% (Table 8, Fig. 5). By the third interval $r^2 = 0.70$ and the MAPD had been cut in half (21%). The period forecasts were again inaccurate (LIN PF - 61%, ACP PF - 51%).

Lynn Canal sockeye salmon catch and CPUE data for 1969-1981 were obtained from ADF&G. 1975 data was excluded because of an extended closure. Both annual catch and total CPUE were variable during the years forecasted; the coefficients of variation are respectively 41 and 26.

The Lynn Canal fishery was investigated in order to see if there was any significant increase in accuracy when working with CPUE data. As seen in Tables 9 and 10, forecasts of annual CPUE were slightly better than for annual yield. The LIN estimator performed much better on the average than the other estimators, but still error averaged 40% for annual yield and 30% for annual CPUE (Tables 9 and 10). In the early portion of the season the CV's for $\bar{p}(i,j)$ were very high and the r^2 were very low (Tables 9 and 10, Figs. 7 and 9). Notice that in both cases a five-year moving average estimate was better than any of the estimates.

Monthly lobster CPUE data from the Gisborne area, New Zealand is from Saila et al (1980). The data has been rearranged so that the annual cycle begins in June, which has been described as the start of the season by Annala (1981).

The annual CPUE data was very stable over the six years

Table 7. Summarization of the forecasting results for sockeye salmon total abundance data from Bristol Bay, Alaska, 1966–1975.

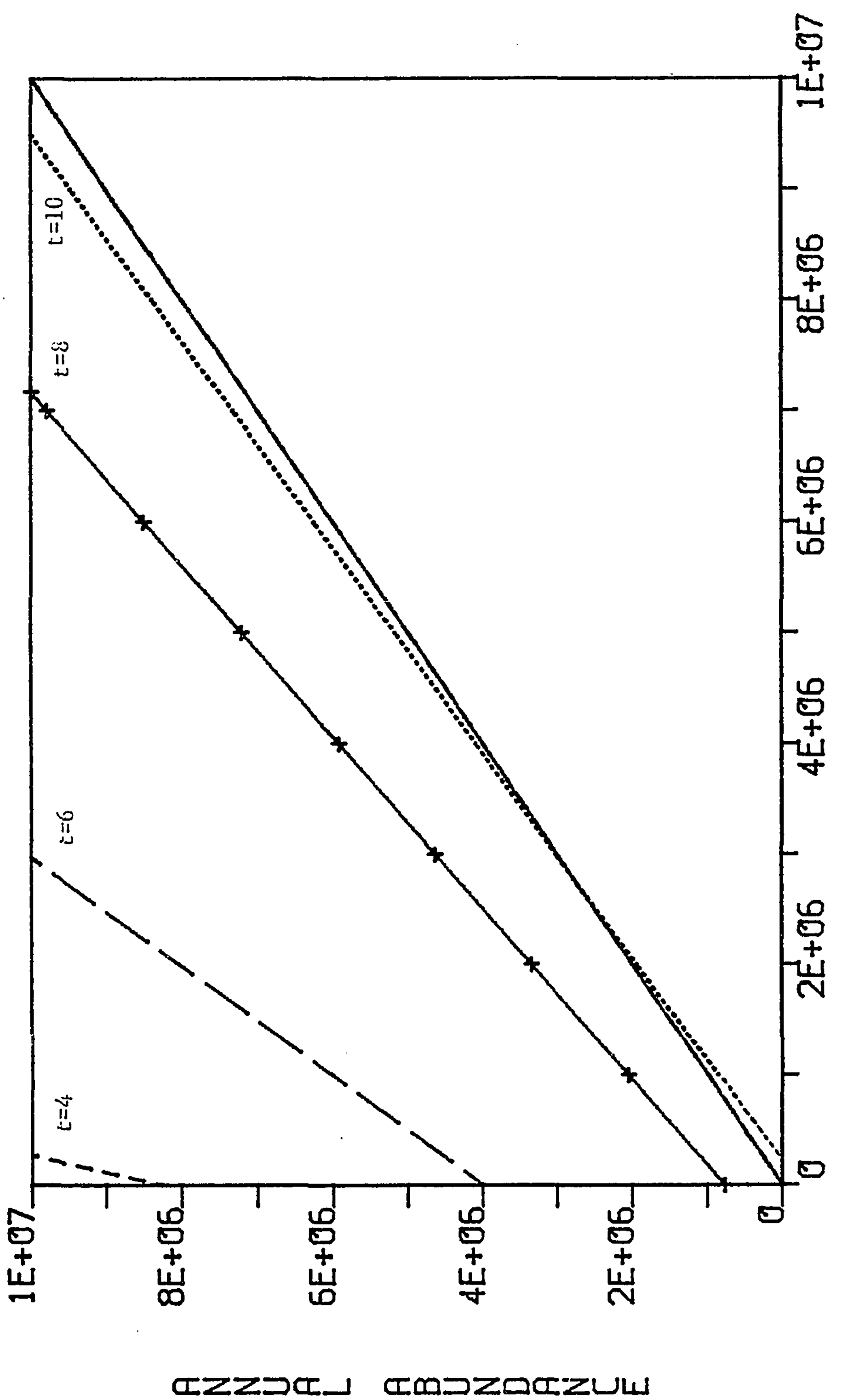
Time Int*	$\bar{p}(i,j)$**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
					MEAN ABSOLUTE PERCENTAGE DEVIATION				
1	0.0	226.1	130.2	83.0	—	80.5	250.6	80.9	92.9
2	0.0	127.1	179.7	235.9	—	53.8	290.4	254.3	80.9
3	0.2	98.4	94.2	178.8	110.0	58.4	145.7	99.7	83.8
4	8.6	109.0	94.8	71.1	84.4	44.4	128.0	58.6	46.3
5	20.1	79.7	76.5	77.7	74.1	44.6	96.8	52.7	41.6
6	40.2	52.4	52.6	50.1	51.5	44.7	53.2	48.9	37.1
7	60.6	32.7	34.5	27.4	37.3	36.7	33.3	50.0	51.8
8	77.4	20.4	22.5	13.7	27.5	25.7	22.1	77.7	74.5
9	88.5	9.4	11.5	6.2	15.2	11.0	12.2	75.6	77.2
10	94.7	4.2	4.9	3.0	9.7	5.2	5.4	86.8	83.8
11	97.8	1.7	1.7	1.5	7.5	1.9	1.9	77.6	87.4
12	99.3	0.5	0.4	0.2	5.3	0.7	0.4	50.4	53.2
13	99.9	0.2	0.2	0.1	3.1	0.3	0.1	89.7	97.9
14	100.0	0.0	0.0	0.0	1.4	0.0	0.0	79.5	60.9
15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**	STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION							
1	0.1	286.8	149.1	73.1	—	139.4	258.0	54.5	77.9
2	1.0	73.9	292.0	267.2	—	38.7	201.3	316.4	50.4
3	2.8	96.2	76.3	209.4	111.7	28.5	166.3	125.9	75.0
4	7.3	178.2	150.8	35.9	111.0	23.9	201.8	61.8	44.4
5	14.0	146.7	135.5	138.8	126.9	24.1	174.9	39.5	30.9
6	17.7	77.8	70.9	64.0	69.2	26.0	81.7	62.1	32.4
7	18.4	31.2	28.2	24.8	33.9	18.5	31.8	36.4	20.5
8	15.8	18.2	16.2	14.0	21.9	14.7	16.7	53.4	26.8
9	9.2	8.5	6.9	5.1	12.8	7.8	6.5	67.6	51.2
10	3.9	3.5	3.1	2.5	8.6	3.3	2.8	82.1	77.6
11	1.3	0.8	0.7	0.8	6.7	1.4	0.6	55.8	87.2
12	0.5	0.2	0.2	0.1	4.6	0.3	0.2	28.8	26.7
13	0.2	0.1	0.1	0.1	2.7	0.3	0.2	59.5	74.5
14	0.0	0.0	0.0	0.0	1.2	0.0	0.0	60.1	40.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Abundance:	1.49E+07	S.D. of Abundance:	1.06E+07
Grand Mean Date:	6.0	S.D. of Mean Dates:	0.9
MAPD for 5 Yr MA Estimates:	48.1	S.D. of 5 Yr MA MAPD:	29.6

Relative Error Summary Statistics:	Up to Mean Date MAPD	Up to Mean Date S.D.	At Mean Date MAPD	At Mean Date S.D.
Average Timing (ACP)	102.6	75.2	28.8	14.8
Ratio Estimator (RAT)	94.5	72.7	30.9	15.6
Censored Ratio (CR)	87.7	70.9	27.6	15.6
Regression Estimator (REG)	66.5	59.3	30.2	14.0
Linear Regression (LIN)	52.1	24.6	36.2	15.9
LIN Through Origin (ADJ LIN)	133.9	72.5	27.9	13.8
ACP c'(i+1,j) – (ACP PF)	92.5	60.7	61.3	73.0
LIN c'(i+1,j) – (LIN PF)	63.6	15.8	64.8	54.9

* Abundance data is grouped in 3 day intervals – Interval 1 begins June 15
** Calculated from all years of record, 1956–1975

Figure 3. Behavior of the predictive regression lines for the linear model (LIN) for the Bristol Bay fishery, calculated from sockeye abundance data for the years, 1956-1975 ($t=4$; $r^2=.40$, $t=6$; $r^2=.69$, $t=8$; $r^2=.90$, $t=10$; $r^2=1.0$)



CUMULATIVE ABUNDANCE
0
2E+06
4E+06
6E+06
8E+06
1E+07
t=4
t=6
t=8
t=10

Figure 4. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the regression estimator (○), and the five year moving average (—). Calculated from Bristol Bay sockeye abundance forecasts for the years, 1973-1983 (Table 7).

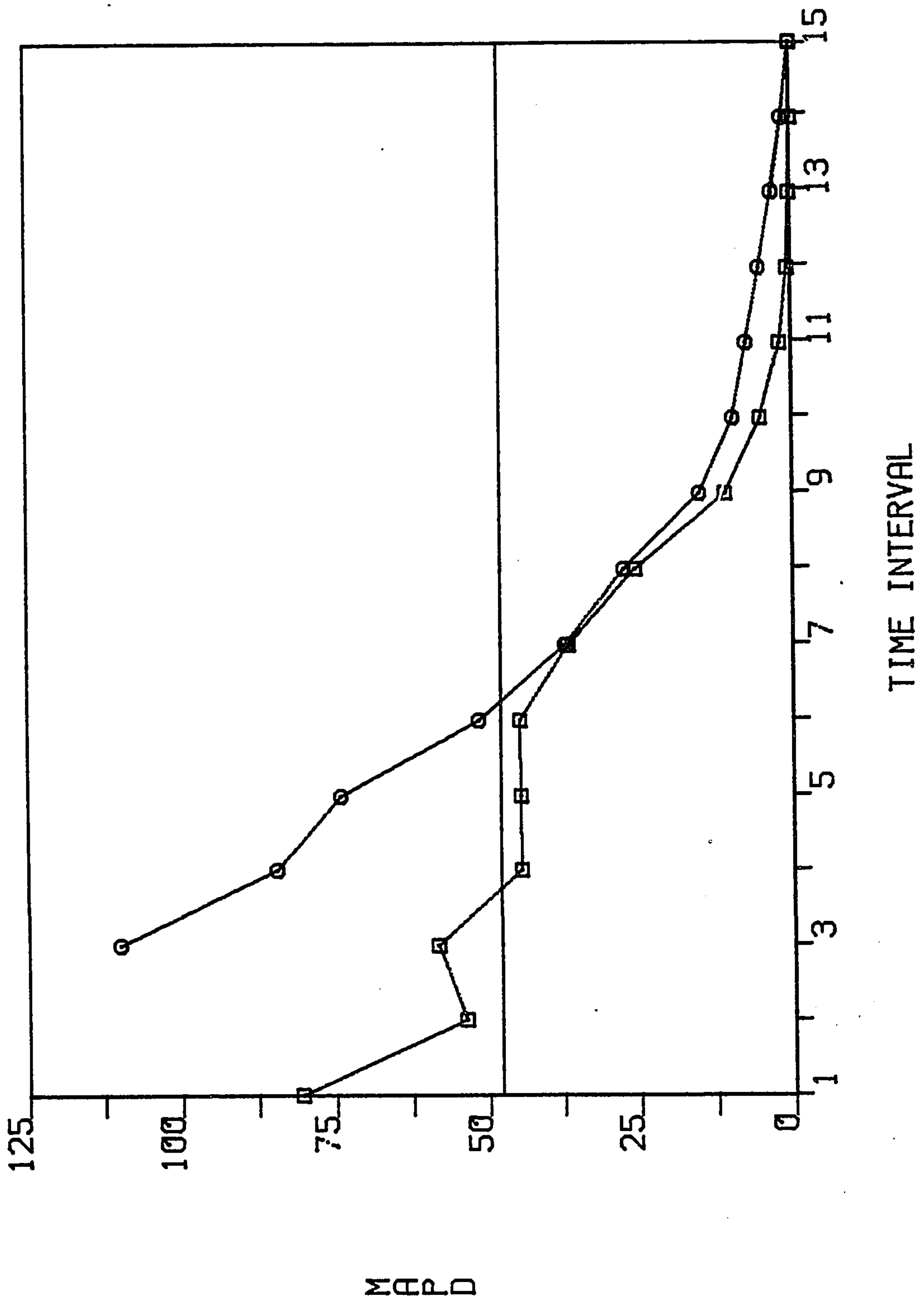

MAPD
TIME INTERVAL
125
100
75
50
25
0
1
3
5
7
9
11
13
15

Table 8. Summarization of the forecasting results for sockeye salmon catch data from Copper River, Alaska, 1976–1983, excluding 1979 and 1980.

Time Int*	$\bar{p}(i,j)$**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
				MEAN ABSOLUTE PERCENTAGE DEVIATION					
1	3.1	53.0	66.4	40.5	—	50.0	39.1	50.5	175.1
2	18.3	33.9	33.4	133.1	—	27.6	21.6	74.7	42.1
3	38.8	30.3	29.1	74.4	29.0	21.9	19.7	49.2	39.2
4	59.3	15.6	14.5	62.8	19.9	15.7	12.9	34.7	36.4
5	73.0	9.9	10.0	7.9	15.7	10.6	9.5	32.0	33.5
6	83.3	7.6	7.7	6.7	12.1	8.4	7.3	32.2	33.0
7	90.4	5.3	5.4	4.9	6.7	6.2	5.4	59.7	58.7
8	95.0	2.4	2.5	2.4	1.9	3.0	2.5	49.5	54.3
9	98.5	1.0	1.0	1.3	1.0	0.9	1.0	76.0	74.0
10	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**	STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION							
1	3.2	48.1	28.1	43.7	—	30.6	48.5	29.2	208.2
2	10.8	22.1	21.3	0.0	—	21.4	14.4	75.0	25.2
3	15.4	14.4	12.6	0.0	16.7	18.7	9.9	19.7	18.1
4	9.8	10.7	10.0	0.0	16.2	13.8	9.4	36.3	39.1
5	6.6	5.3	4.7	6.4	9.1	7.5	5.1	11.5	15.4
6	6.0	6.8	6.7	8.8	4.9	7.1	7.3	18.3	15.6
7	4.5	5.0	4.9	6.0	4.3	5.0	5.0	56.5	46.6
8	2.4	2.5	2.5	3.3	1.6	2.4	2.7	35.9	30.8
9	1.0	1.3	1.3	1.3	0.6	1.3	1.4	106.9	103.9
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Yield:	636,062	S.D. of Yields:	314,595
Grand Mean Date:	4.0	S.D. of Mean Dates:	0.6
MAPD for 5 Yr MA Estimates:	48.7	S.D. of 5 Yr MA MAPD:	48.3

Relative Error Summary Statistics:	Up to Mean Date		At Mean Date	
	MAPD	S.D.	MAPD	S.D.
Average Timing (ACP)	30.0	20.0	17.5	14.9
Ratio Estimator (RAT)	30.2	17.9	16.3	13.9
Censored Ratio (CR)	65.5	8.4	18.1	0.0
Regression Estimator (REG)	24.7	16.3	20.2	17.0
Linear Regression (LIN)	26.3	19.4	18.3	19.3
LIN Through Origin (ADJ LIN)	19.6	15.5	12.8	9.6
ACP c'(i+1,j) – (ACP PF)	52.6	23.9	29.7	16.6
LIN c'(i+1,j) – (LIN PF)	53.8	44.0	34.3	26.7

* Catch data grouped in 7 day intervals – Week one begins May 10
** Calculated from the years, 1969–1975, excluding 1979 and 1980

Figure 5. Behavior of the predictive regression lines for the linear model (LIN) for the Copper River sockeye fishery, calculated from catch data for the years, 1969-1983, excluding 1979 and 1980 ($t=1$; $r^2=.01$, $t=3$; $r^2=.70$, $t=4$; $r^2=.93$, $t=5$; $r^2=.96$, $t=7$; $r^2=.98$)

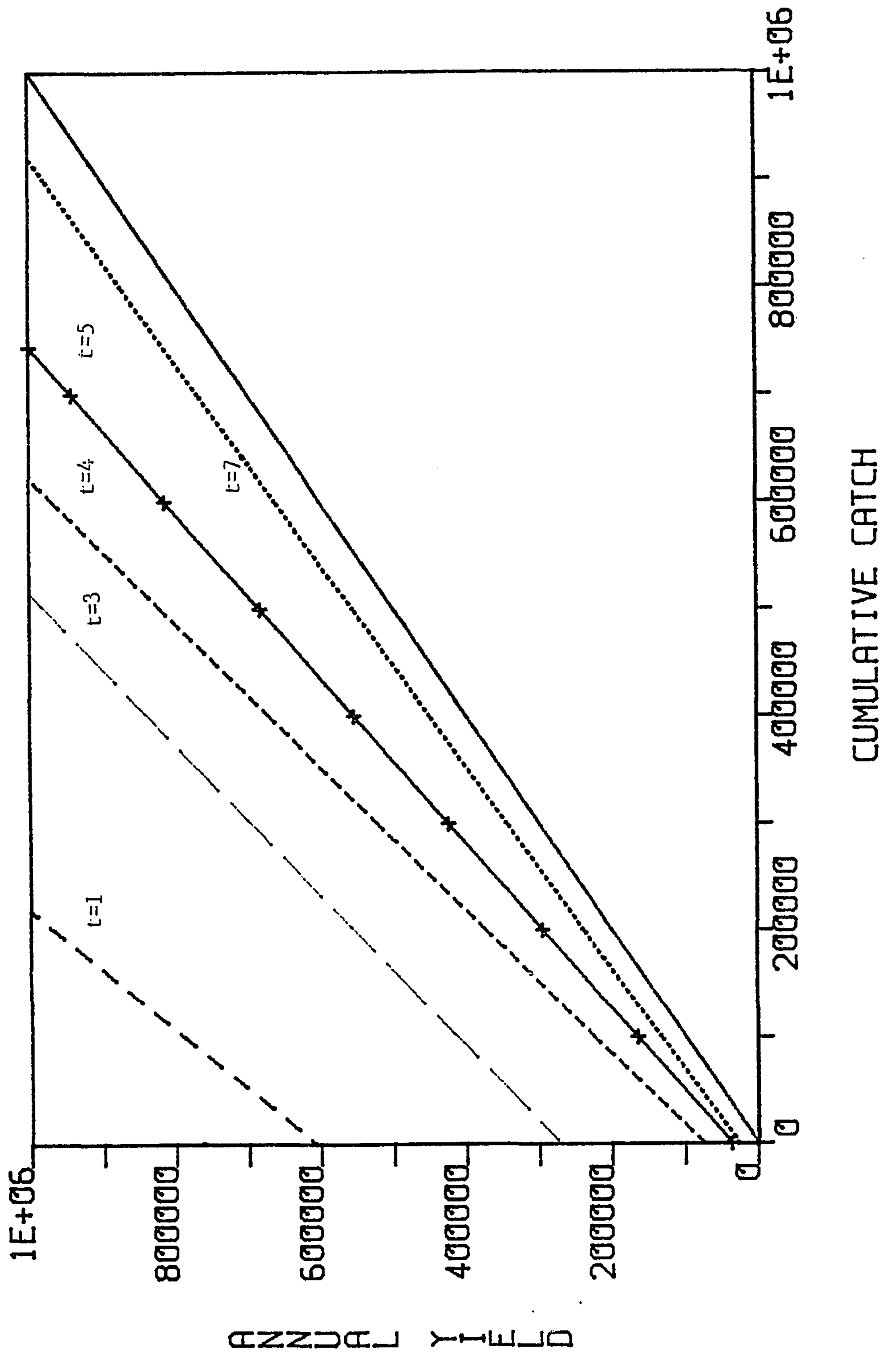

ANNUAL YIELD
1E+06
800000
600000
400000
200000
0
CUMULATIVE CATCH
0
200000
400000
600000
800000
1E+06
t=1
t=3
t=4
t=5
t=7

Figure 6. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the adjusted linear estimator (○), and the five year moving average (—). Calculated from Copper River sockeye catch forecasts for the years, 1976-1983 (Table 8).

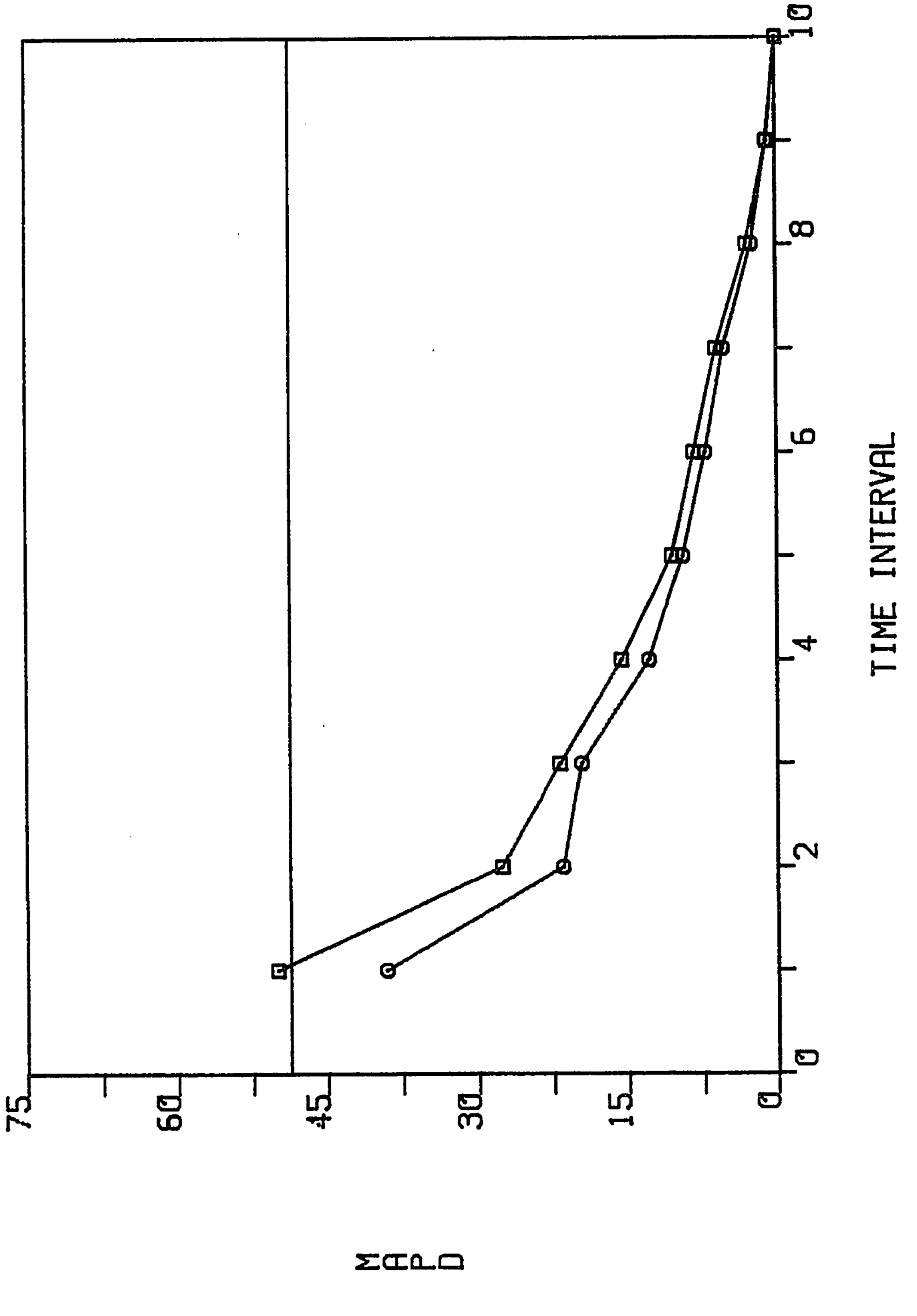

75
60
45
30
15
0
MAPD
0
2
4
6
8
10
TIME INTERVAL

Table 9. Summarization of the forecasting results for sockeye salmon catch data from Lynn Canal, Alaska, 1976-1981.

Time Int*	p̄(i,j)**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
					MEAN ABSOLUTE PERCENTAGE DEVIATION				
1	0.2	—	—	—	—	—	—	—	—
2	0.9	168.0	148.3	—	—	8.6	253.1	27.0	87.5
3	5.0	326.5	309.6	—	348.1	43.8	388.6	521.7	57.4
4	12.5	146.4	137.4	—	108.5	36.1	97.3	21.2	40.5
5	20.9	152.8	144.8	121.7	142.5	40.3	182.8	52.9	53.9
6	26.6	183.4	177.4	163.9	174.2	45.4	218.3	117.3	159.2
7	34.8	177.0	176.0	119.6	182.5	41.3	213.1	187.5	80.7
8	41.2	104.5	103.7	70.0	107.6	37.6	122.6	57.5	58.2
9	51.0	93.8	92.5	45.5	93.2	39.4	102.6	160.4	57.3
10	65.1	41.7	42.1	37.3	52.5	27.6	44.7	125.6	136.5
11	75.2	25.5	27.0	21.3	35.8	12.4	29.3	111.9	57.1
12	85.5	14.1	14.9	11.0	20.9	10.5	15.7	175.8	138.4
13	94.1	2.8	2.9	2.9	6.4	2.4	3.0	129.3	151.2
14	98.2	0.5	0.5	0.8	2.4	0.6	0.6	56.5	74.7
15	99.3	0.1	0.1	0.1	1.0	0.1	0.1	52.8	33.5
16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**			STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION					
1	0.1	—	—	—	—	—	—	—	—
2	0.8	0.0	0.0	—	—	0.0	0.0	0.0	0.0
3	4.0	166.8	152.1	—	333.6	19.5	146.6	146.5	22.0
4	8.7	166.4	161.9	—	123.6	37.7	51.2	39.2	37.6
5	12.2	129.7	123.3	107.8	127.9	31.8	156.8	38.6	37.2
6	15.0	172.4	165.3	166.0	170.1	33.0	206.7	142.5	227.9
7	17.8	222.6	217.7	140.3	239.8	23.4	263.6	286.3	52.2
8	17.9	86.1	85.3	91.7	92.9	24.4	108.6	37.6	23.4
9	19.1	73.3	71.9	64.0	73.9	21.5	87.6	113.3	39.6
10	14.4	32.7	33.5	27.7	39.8	21.7	37.6	132.4	128.8
11	12.6	26.3	26.3	21.0	33.3	9.3	27.4	114.2	46.1
12	9.7	9.2	9.6	8.8	11.6	5.6	10.1	115.4	130.4
13	7.9	2.3	2.5	2.6	2.7	2.1	2.7	131.5	187.3
14	2.2	0.2	0.2	0.3	2.0	0.3	0.3	33.8	52.3
15	0.9	0.1	0.1	0.1	1.0	0.2	0.1	36.4	22.5
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Yield:	118,642	S.D. of Yields:	48,971
Grand Mean Date:	9.5	S.D. of Mean Dates:	1.4
MAPD for 5 Yr MA Estimates:	30.1	S.D. of 5 Yr MA MAPD:	19.3

Relative Error Summary Statistics:	Up to Mean Date		At Mean Date	
	MAPD	S.D.	MAPD	S.D.
Average Timing (ACP)	140.3	91.1	46.9	24.5
Ratio Estimator (RAT)	136.2	87.4	48.0	25.5
Censored Ratio (CR)	98.0	89.5	41.8	24.7
Regression Estimator (REG)	135.9	86.1	59.5	33.7
Linear Regression (LIN)	38.8	24.7	30.6	19.5
LIN Through Origin (ADJ LIN)	158.4	101.4	48.0	30.8
ACP c'(i+1,j) - (ACP PF)	126.6	80.1	169.0	139.6
LIN c'(i+1,j) - (LIN PF)	84.9	51.4	125.4	137.5

* Catch data grouped in 7 day intervals - Week one begins May 28
** Calculated from the years, 1969-1981, excluding 1975

Figure 7. Behavior of the predictive regression lines for the linear model (LIN) for the Lynn Canal sockeye fishery, calculated from catch data for the years, 1969-1981, excluding 1975 ($t=1$; $r^2=.03$, $t=3$; $r^2=.01$, $t=5$; $r^2=.20$, $t=7$; $r^2=.40$, $t=9$; $r^2=.49$, $t=11$; $r^2=.92$)

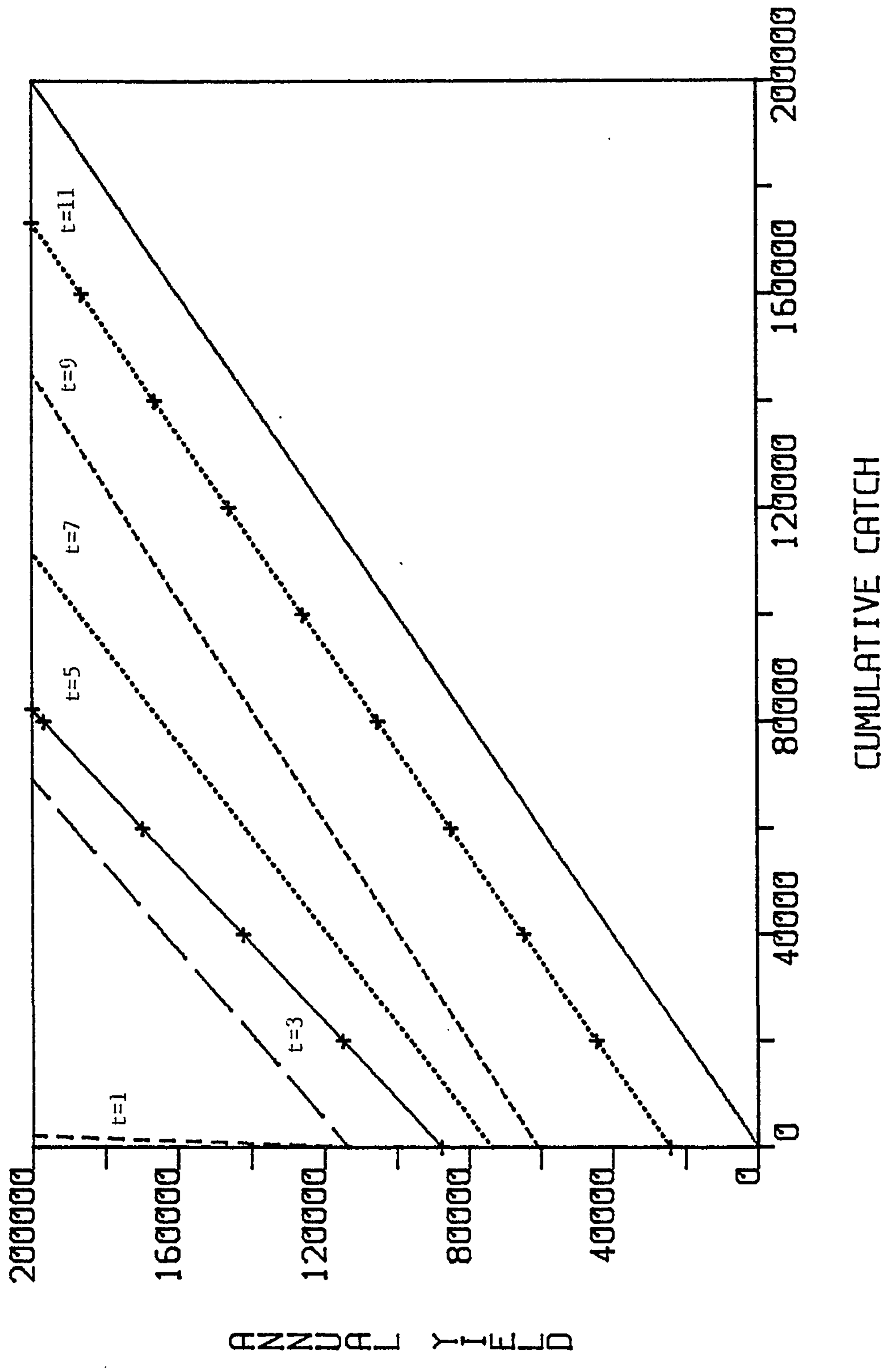

ANNUAL YIELD
CUMULATIVE CATCH
0
40000
80000
120000
160000
200000
t=1
t=3
t=5
t=7
t=9
t=11

Figure 8. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the censored ratio estimator (○), and the five year moving average (—). Calculated from Lynn Canal sockeye catch forecasts for the years, 1976-1981 (Table 9).

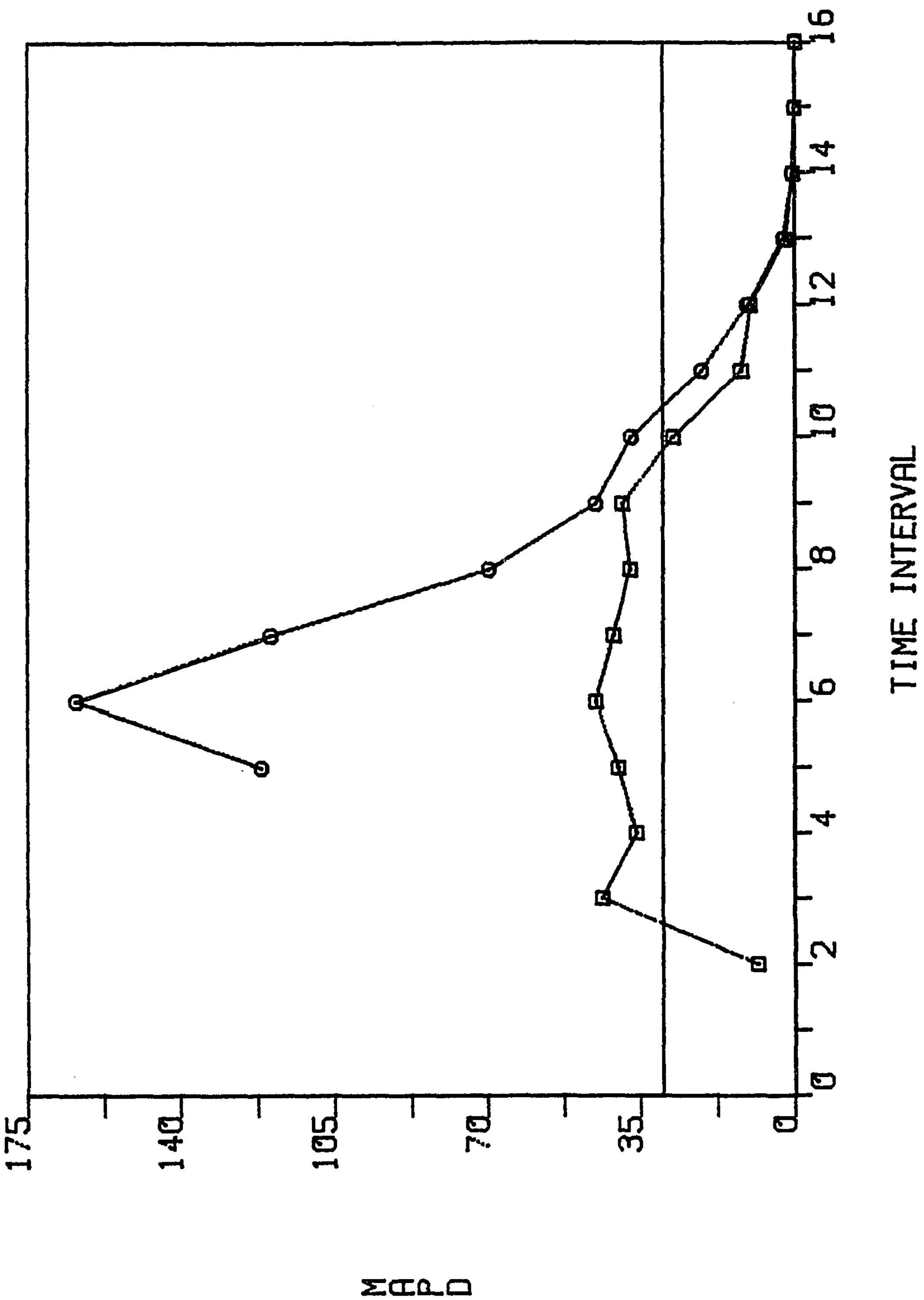

MAPD
175
140
105
70
35
0
TIME INTERVAL
0
2
4
6
8
10
12
14
16

Table 10. Summarization of the forecasting results for sockeye salmon CPUE data from Lynn Canal, Alaska, 1976–1981.

Time Int*	$\bar{p}(i,j)$**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
					MEAN ABSOLUTE PERCENTAGE DEVIATION				
1	1.5	—	—	—	—	—	—	—	—
2	5.2	107.0	93.8	—	—	36.0	246.6	71.6	68.4
3	11.8	408.8	389.2	—	307.5	32.0	495.7	27.7	38.8
4	16.8	208.3	193.0	—	147.4	32.6	251.7	31.0	56.1
5	24.8	143.5	133.3	105.9	120.4	30.8	162.5	147.8	115.4
6	31.0	137.7	130.2	110.0	121.3	25.2	149.4	129.7	101.5
7	40.4	135.7	132.0	46.9	134.9	32.1	142.5	79.7	227.1
8	48.4	39.8	38.9	32.2	39.4	22.7	42.3	26.2	25.7
9	58.3	38.2	37.1	16.7	36.7	24.0	39.6	91.9	56.7
10	71.0	18.7	18.5	12.9	27.5	17.0	19.1	70.0	69.8
11	81.4	10.6	10.7	6.1	20.8	10.1	11.5	68.9	63.0
12	90.6	5.0	5.2	6.7	14.5	5.3	5.4	90.9	120.4
13	96.2	1.1	1.1	1.9	6.1	1.0	1.1	71.9	158.5
14	99.0	0.3	0.3	0.2	2.5	0.3	0.3	58.4	69.7
15	99.6	0.1	0.1	0.1	1.0	0.1	0.1	88.1	96.6
16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**	STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION							
1	0.8	—	—	—	—	—	—	—	—
2	4.5	0.0	0.0	—	—	0.0	0.0	0.0	0.0
3	7.6	192.8	178.7	—	96.7	29.0	232.1	48.0	12.9
4	10.6	169.4	164.1	—	123.1	30.5	195.1	47.3	68.6
5	13.4	113.7	105.2	55.2	99.4	35.3	124.5	117.6	93.9
6	15.6	146.5	137.2	63.7	130.5	33.3	155.2	98.0	64.6
7	16.9	215.9	208.9	55.9	215.4	33.1	223.5	78.6	314.0
8	14.0	23.7	22.0	0.0	19.9	23.8	27.0	16.2	22.5
9	9.2	26.4	24.7	15.8	22.0	25.1	27.3	87.8	71.7
10	7.8	9.8	9.1	4.3	17.1	9.5	10.2	35.3	36.9
11	6.5	6.3	6.3	1.3	14.7	6.3	6.6	51.8	52.2
12	6.8	2.2	2.3	2.2	9.4	2.7	2.5	52.3	112.6
13	1.4	0.3	0.3	0.7	4.7	0.6	0.4	35.6	272.4
14	0.5	0.3	0.3	0.1	1.6	0.3	0.3	47.0	43.3
15	0.2	0.1	0.1	0.1	0.5	0.1	0.1	88.4	85.7
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Annual CPUE:	1152.7	S.D. of Annual CPUE:	294.4
Grand Mean Date:	9.2	S.D. of Mean Dates:	0.8
MAPD for 5 Yr MA Estimates:	24.5	S.D. of 5 Yr MA MAPD:	11.3

Relative Error Summary Statistics:	Up to Mean Date		At Mean Date	
	MAPD	S.D.	MAPD	S.D.
Average Timing (ACP)	128.3	83.8	31.3	25.1
Ratio Estimator (RAT)	121.3	78.3	30.8	24.0
Censored Ratio (CR)	66.4	42.3	13.6	16.5
Regression Estimator (REG)	107.4	71.2	34.0	20.6
Linear Regression (LIN)	27.6	27.0	26.4	23.5
LIN Through Origin (ADJ LIN)	149.4	92.9	31.6	25.9
ACP c'(i+1,j) – (ACP PF)	78.9	29.1	80.6	90.5
LIN c'(i+1,j) – (LIN PF)	90.2	37.5	71.4	69.3

* CPUE data is grouped in 7 day intervals – Week one begins May 28
** Calculated from years, 1969–1981, excluding 1975

Figure 9. Behavior of the predictive regression lines for the linear model (LIN) for the Lynn Canal fishery, calculated from CPUE data for the years, 1969-1981, excluding 1975 (t=3; r^2=.01, t=5; r^2=.03, t=7; r^2=.31, t=9; r^2=.45, t=11; r^2=.91)

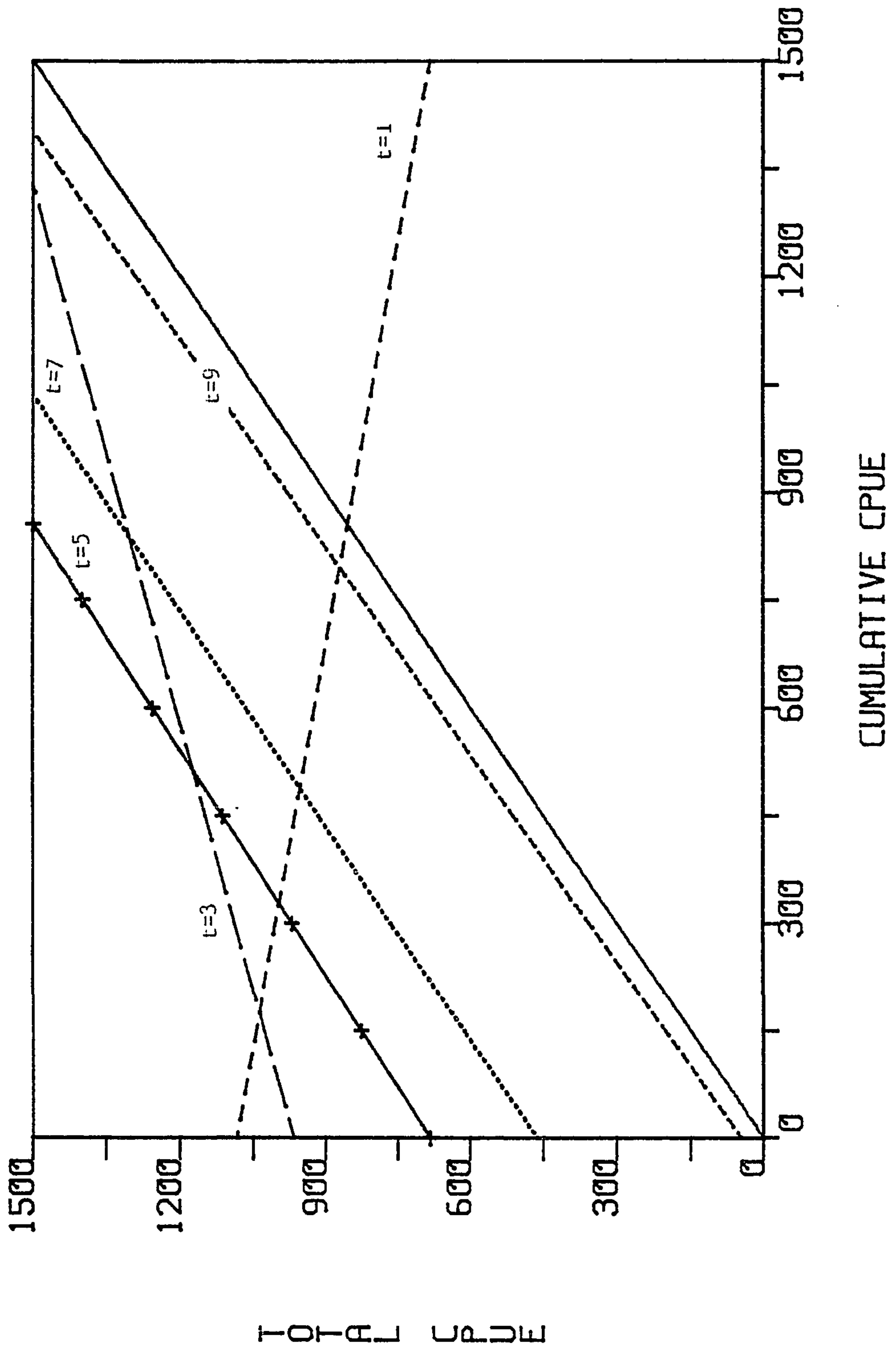

TOTAL CPUE
CUMULATIVE CPUE
0
300
600
900
1200
1500
t=1
t=3
t=5
t=7
t=9

Figure 10. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the censored ratio estimator (○), and the five year moving average (—). Calculated from Lynn Canal sockeye CPUE forecasts for the years, 1976-1981 (Table 10).

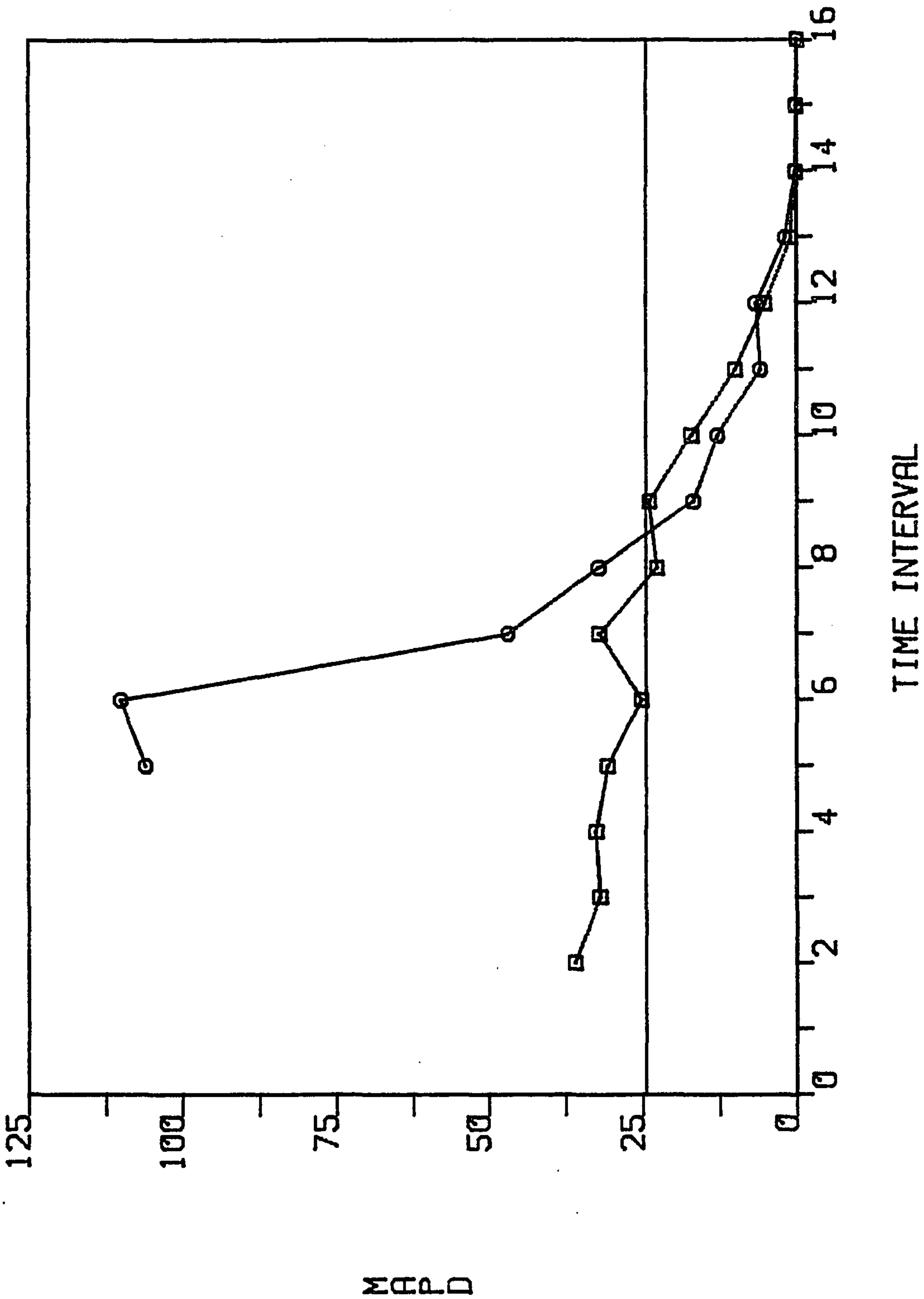

MAPD
125
100
75
50
25
0
0
2
4
6
8
10
12
14
16
TIME INTERVAL

Table 11. Summarization of the forecasting results for rock lobster CPUE data from Gisborne, New Zealand, 1970–1975.

Time Int*	$\bar{p}(i,j)$**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
				MEAN ABSOLUTE PERCENTAGE DEVIATION					
1	9.1	39.2	39.9	32.7	—	18.6	45.6	38.7	20.5
2	20.6	19.2	19.4	14.9	—	14.8	23.4	8.9	13.7
3	31.5	21.1	22.1	15.0	110.1	12.7	26.2	15.2	21.5
4	40.2	22.5	24.3	11.9	45.1	11.8	29.0	25.3	30.1
5	48.6	19.0	20.7	26.1	25.5	8.4	23.9	63.4	13.8
6	58.4	9.0	9.3	15.8	15.2	7.3	10.4	26.8	8.7
7	70.6	6.0	6.0	14.1	15.9	5.8	6.1	16.3	15.5
8	81.3	6.2	6.3	13.8	16.0	6.1	6.3	28.0	38.4
9	88.4	4.8	5.0	6.6	8.8	3.9	5.2	49.8	51.5
10	93.1	2.4	2.6	0.7	2.1	3.1	2.9	34.9	29.8
11	96.9	2.0	2.0	2.5	2.7	2.2	2.0	78.1	80.0
12	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**	STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION							
1	2.7	32.0	33.3	14.0	—	11.6	39.0	18.8	17.1
2	4.0	13.9	14.4	8.6	—	11.3	17.2	9.6	11.8
3	5.6	18.7	19.6	14.6	105.0	8.0	20.8	11.5	20.0
4	7.1	14.7	15.8	12.3	31.8	6.2	17.2	37.1	15.4
5	7.0	9.0	10.0	14.7	22.8	5.4	11.2	26.0	10.6
6	5.5	8.6	8.9	4.5	9.5	5.3	9.3	12.2	3.5
7	4.3	6.3	6.5	6.8	10.1	5.8	6.7	11.1	12.1
8	4.5	6.8	6.9	10.4	10.1	6.3	7.1	14.2	21.0
9	3.9	5.6	5.8	5.8	5.6	5.2	6.0	42.5	39.8
10	2.7	3.4	3.5	0.2	2.6	2.6	3.6	35.2	13.7
11	2.4	3.6	3.5	3.4	2.5	3.4	3.5	141.9	134.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Annual CPUE:	526.4	S.D. of Annual CPUE:	44.8
Grand Mean Date:	6.0	S.D. of Mean Dates:	0.6
MAPD for 5 Yr MA Estimates:	24.2	S.D. of 5 Yr MA MAPD:	12.1

Relative Error Summary Statistics:	Up to Mean Date		At Mean Date	
	MAPD	S.D.	MAPD	S.D.
Average Timing (ACP)	21.6	14.5	9.9	6.2
Ratio Estimator (RAT)	22.5	15.3	10.2	6.1
Censored Ratio (CR)	19.8	11.7	17.9	4.8
Regression Estimator (REG)	48.8	33.9	18.7	11.7
Linear Regression (LIN)	12.7	6.8	7.8	5.6
LIN Through Origin (ADJ LIN)	26.2	17.1	11.2	6.0
ACP c'(i+1,j) – (ACP PF)	29.2	14.3	31.6	27.7
LIN c'(i+1,j) – (LIN PF)	18.3	8.3	8.0	4.5

* CPUE data is grouped in monthly intervals – month one is June
** Calculated from all years of record, 1963–1975

Figure 11. Behavior of the predictive regression lines for the linear model (LIN) for the Gisborne rock lobster fishery, calculated from CPUE data for the years, 1963-1975 ($t=1$; $r^2=.69$, $t=3$; $r^2=.82$, $t=5$; $r^2=.89$, $t=7$; $r^2=.97$, $t=8$; $r^2=.98$)

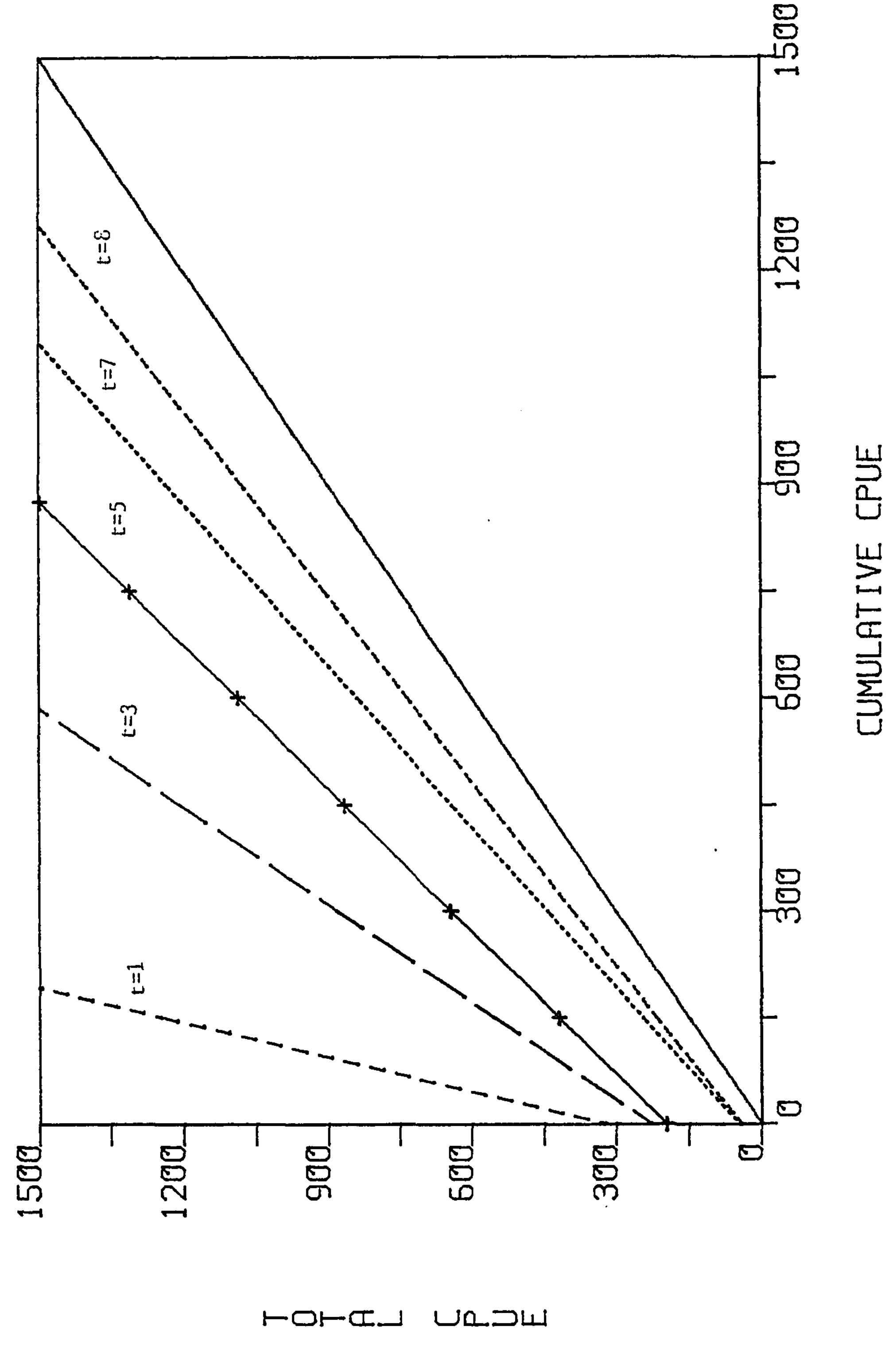
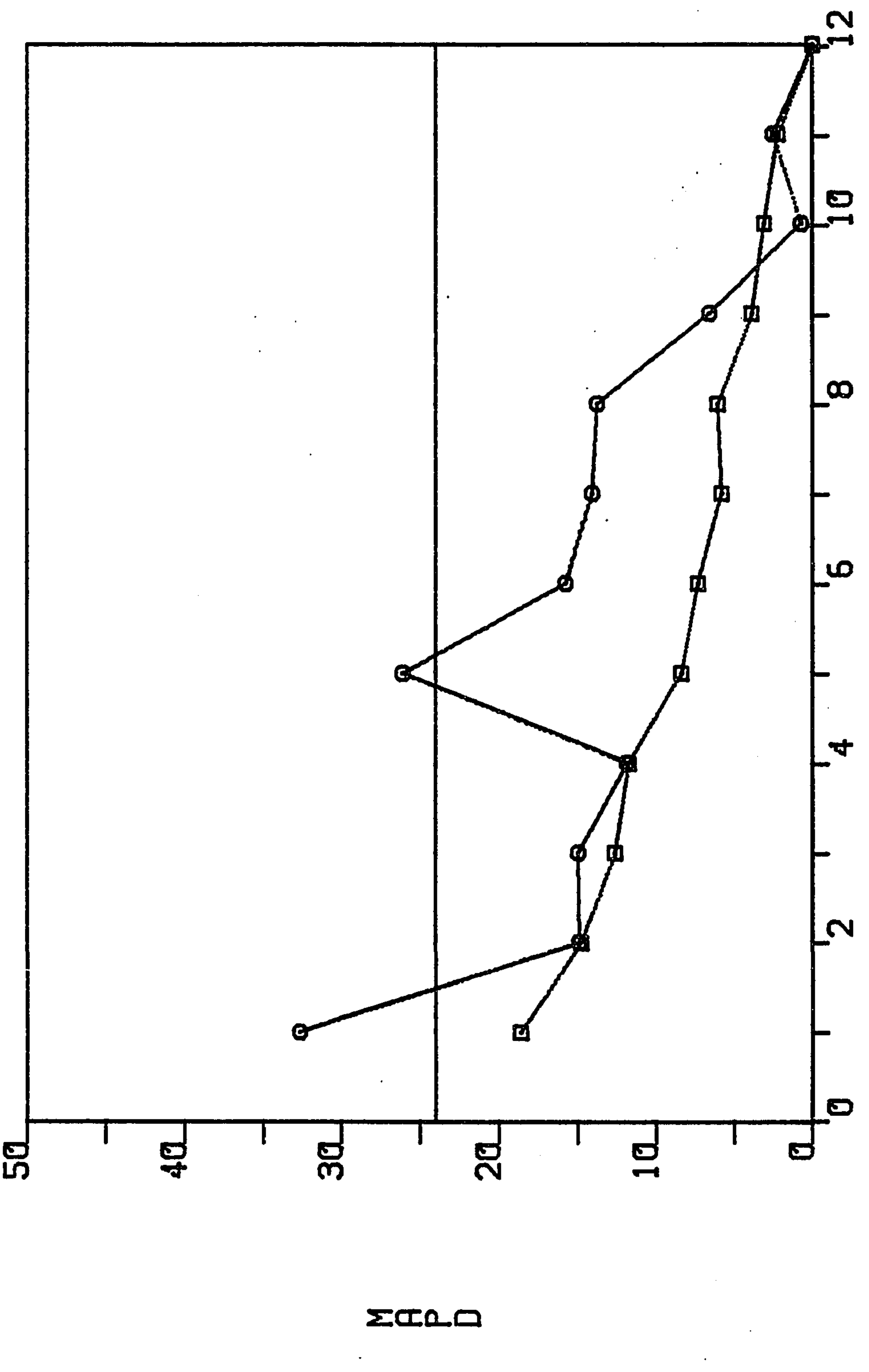

CUMULATIVE CPUE
TOTAL CPUE
0
300
600
900
1200
1500
t=1
t=3
t=5
t=7
t=8

Figure 12. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the censored ratio estimator (○), and the five year moving average (—). Calculated from Gisborne rock lobster CPUE forecasts for the years, 1971-1975 (Table 11).



TIME INTERVAL
MAPD
0
2
4
6
8
10
12
50
40
30
20
10
0

Table 12. Summarization of the forecasting results for blue crab catch data from Virginia, 1971-1980.

Time Int*	p̄(i,j)**	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
					MEAN ABSOLUTE PERCENTAGE DEVIATION				
1	5.7	61.6	63.1	31.5	—	13.7	83.4	38.1	29.6
2	10.1	46.7	48.2	20.6	—	12.9	59.7	36.4	32.2
3	13.1	49.4	50.4	24.3	67.6	12.2	57.6	48.3	39.7
4	18.4	46.3	47.3	21.2	57.9	13.9	51.3	49.9	34.2
5	26.3	28.8	30.5	31.9	29.8	12.3	33.9	40.6	21.9
6	37.0	16.3	16.6	16.3	14.0	10.9	18.0	32.6	17.4
7	49.5	9.6	9.1	9.2	7.6	9.6	9.6	23.4	18.3
8	62.7	5.9	5.5	4.2	4.9	8.2	4.8	17.6	18.0
9	74.4	4.1	3.9	3.8	3.8	6.0	3.5	16.0	22.0
10	85.3	2.8	2.8	2.8	3.1	4.1	2.8	38.7	40.7
11	90.3	2.1	2.1	2.2	2.0	2.1	2.1	21.7	20.5
12	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$s_{\bar{p}(i,j)}$**	STANDARD DEVIATION OF MEAN ABSOLUTE PERCENTAGE DEVIATION							
1	2.4	82.1	83.1	31.4	—	10.6	99.3	35.1	17.9
2	3.4	56.1	58.1	17.4	—	8.9	66.6	26.9	24.2
3	4.1	65.1	67.0	19.4	86.0	11.1	74.3	33.5	23.7
4	5.2	71.9	74.4	23.2	74.8	12.4	81.2	32.1	23.0
5	6.1	53.1	54.9	54.1	36.7	12.2	58.7	48.8	25.3
6	7.0	28.6	29.6	30.7	15.7	10.3	31.8	47.7	24.7
7	7.3	11.6	12.3	12.7	7.4	8.1	13.3	31.1	18.4
8	6.6	4.2	4.4	4.3	3.1	6.0	5.3	12.6	11.7
9	5.2	2.4	2.5	2.2	2.5	4.8	3.0	8.0	12.0
10	3.2	1.8	1.9	2.1	2.6	2.4	2.1	21.4	21.2
11	1.9	1.2	1.3	1.5	1.5	1.6	1.3	12.7	15.3
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Yield:	38.53E+06	S.D. of Yields:	6.52E+06
Grand Mean Date:	7.3	S.D. of Mean Dates:	0.5
MAPD for 5 Yr MA Estimates:	11.0	S.D. of 5 Yr MA MAPD:	11.7

Relative Error Summary Statistics:	Up to Mean Date MAPD	Up to Mean Date S.D.	At Mean Date MAPD	At Mean Date S.D.
Average Timing (ACP)	34.0	44.2	7.4	4.9
Ratio Estimator (RAT)	34.8	45.6	6.8	5.2
Censored Ratio (CR)	20.5	20.7	6.2	5.0
Regression Estimator (REG)	31.6	31.0	6.4	5.8
Linear Regression (LIN)	11.9	8.5	8.8	7.9
LIN Through Origin (ADJ LIN)	41.2	51.3	6.6	5.9
ACP c'(i+1,j) - (ACP PF)	37.3	22.1	20.2	14.1
LIN c'(i+1,j) - (LIN PF)	27.1	12.3	17.4	11.4

* Catch data grouped in monthly intervals - Month one is January
** Calculated from all years of record, 1960-1980

Figure 13. Behavior of the predictive regression lines for the linear model (LIN) for the Virginia blue crab fishery, calculated from catch data for the years, 1960-1980 ($t=1$; $r^2=.33$, $t=3$; $r^2=.57$, $t=5$; $r^2=.80$, $t=7$; $r^2=.82$, $t=9$; $r^2=.93$, $t=11$; $r^2=.97$)

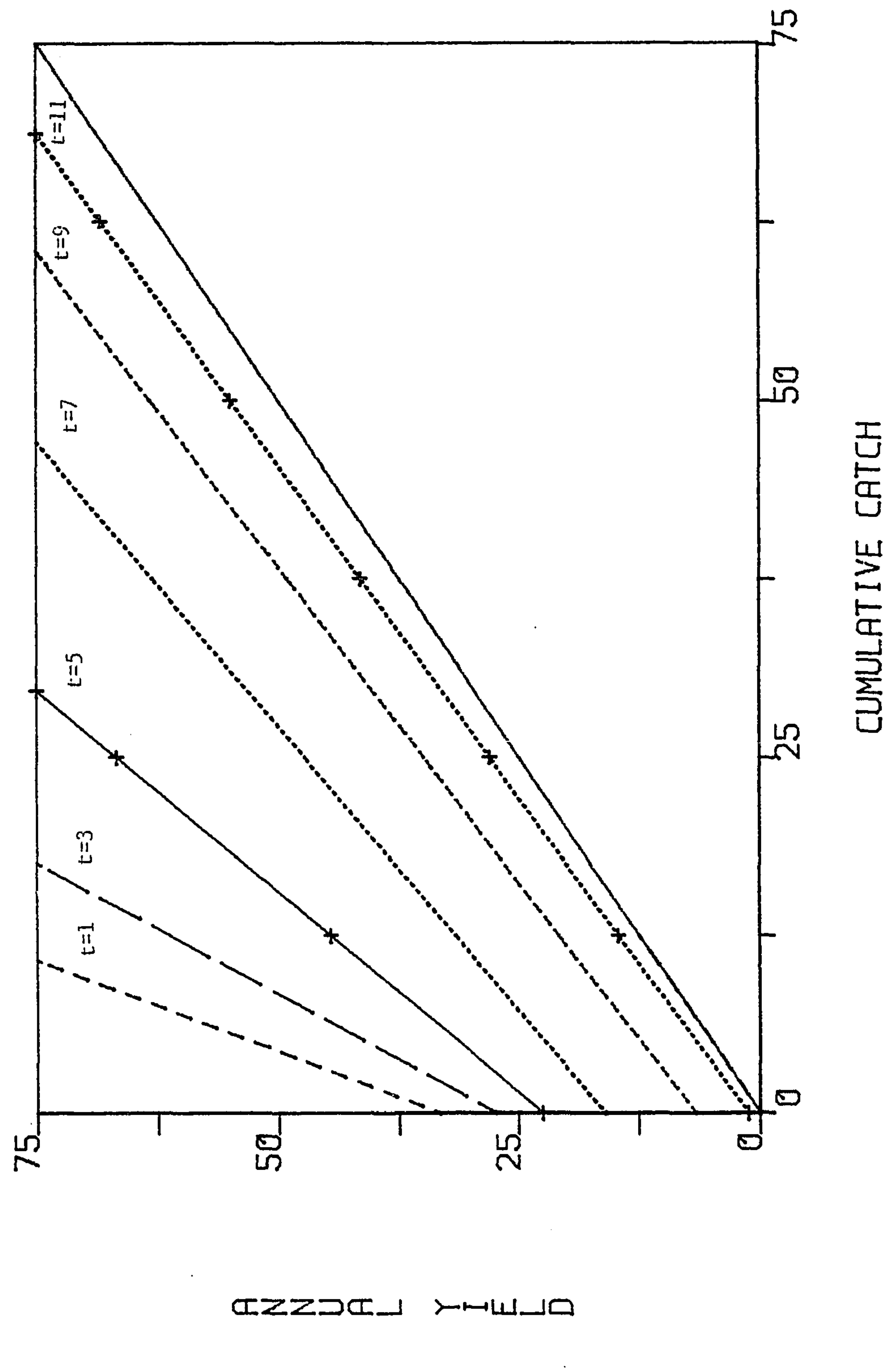
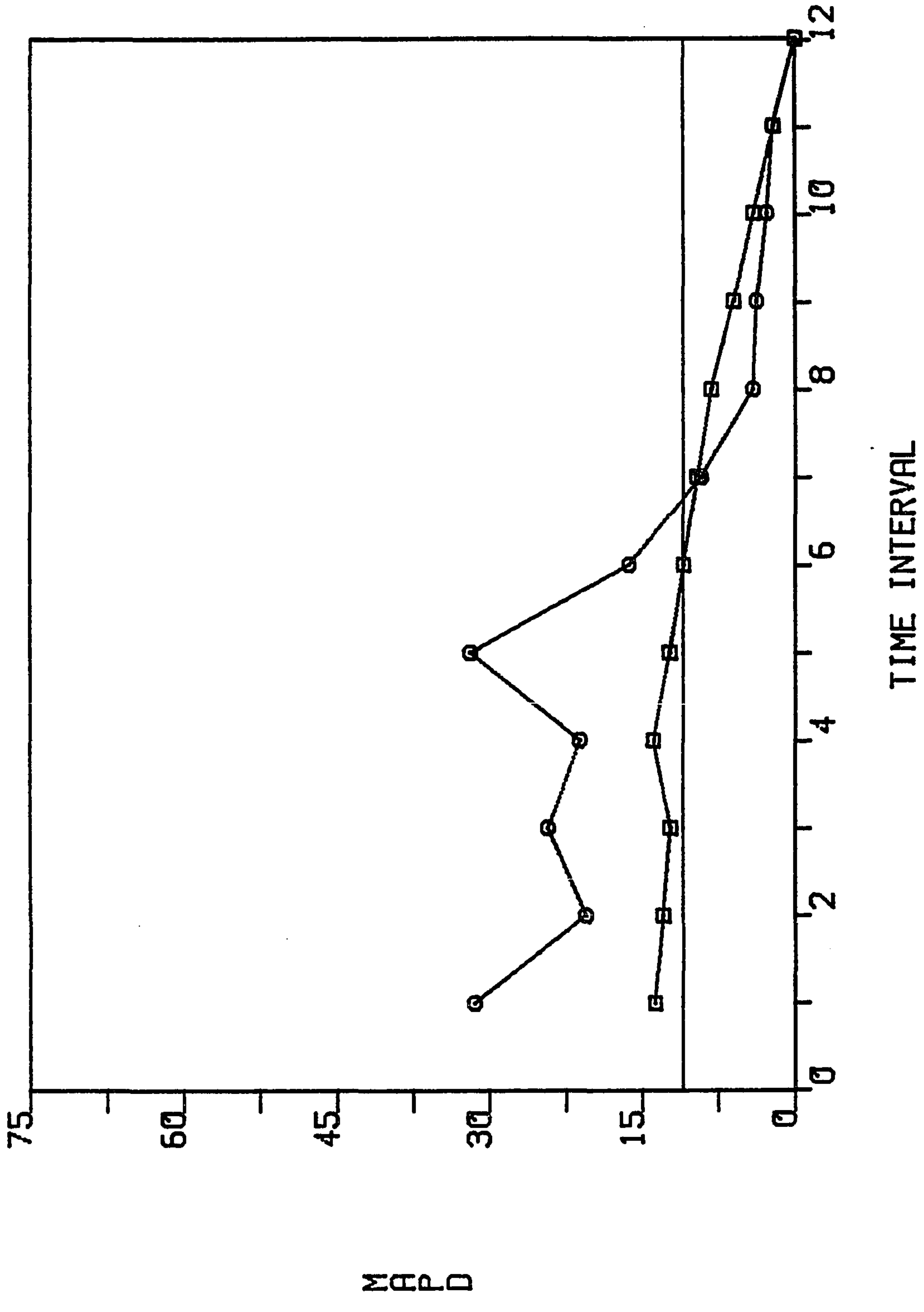

ANNUAL YIELD
CUMULATIVE CATCH
0
25
50
75
0
25
50
75
t=1
t=3
t=5
t=7
t=9
t=11

Figure 14. Comparison of the time series of estimation error (MAPD) for the linear regression estimator (□), the censored ratio estimator (o), and the five year moving average (—). Calculated from Virginia blue crab catch forecasts for the years, 1971-1980 (Table 12).


MAPD
75
60
45
30
15
0
0
2
4
6
8
10
12
TIME INTERVAL

forecasted, 1971-1975; the CV was only 8.5. All estimators were correspondingly accurate. The linear regression estimator performed very well. The MAPD up to the mean date was only 12.7 percent and the MAPD at the mean date was 7.8 percent. The time series of MAPD's for the linear model were also very low (see Fig. 12).

Monthly blue crab catches in Virginia were obtained for 1960-1980 from Hester (1983). Catch figures are in millions of pounds and are for hard crab landings only. Ten years of the fishery were backforecasted; 1971-1980, during this period annual crab catches were stable (CV=16.9).

The lowest MAPD for forecasts prior to and on the mean date was achieved by the linear regression estimator (MAPD = 11.9%). Which was also the lowest overall MAPD for any of the fisheries investigated. The five year MA estimate averaged only 11% for the ten years forecasted. The relatively accurate MA forecasts are another good indication of stable annual yields. In this particular situation the only advantage that the intraseason models have over the MA model would be the increases in accuracy as the season progresses. Note that the MAPD at the mean date was only 8.8% for the linear model. The remainder of the estimators had even lower MAPD's at the mean (see Table 12). The linear period forecasts averaged only 26 percent for the whole season.

The relative effectiveness of the estimators, as based on the MAPD summary statistics, is presented in Table 13. In comparison to the other methods the linear regression estimator performed very well during the early portion of a season (overall MAPD was 26%). The next best estimator was the censored ratio estimator (58.1%). The CR overall MAPD may be misleading in that forecasts were not made on every time interval.

The linear regression model was the only method which could be used to make an estimate on all intervals of the season. The average timing and ratio estimators occasionally had errors in excess of 1000 percent early in the season, however these values would be noticeably erroneous and were not considered as viable forecasts. On the average, average timing and ratio estimates were made on 98 percent of the time intervals prior to and including the mean date. In comparison, the regression and censored ratio estimators averaged 79 percent and 65 percent respectively. The regression estimator had the disadvantage of being uncalculable until the third interval in the season. For the censored ratio estimations, when none of the past years met the selection criteria, estimates were not made.

The period forecasts, as seen in each of the individual fisheries and in the overall MAPD's are inaccurate. The linear period forecasts (LIN PF - 58%) seemed to perform slightly better than the average timing period forecasts (ACP PF - 73%).

The annual forecasts on the mean date of the season were comparable in error by all methods. The lowest overall MAPD was achieved by the censored ratio estimate (19%).

The accuracy of the linear model estimates seems to be well correlated with the variability of the value being forecasted. A correlation of the MAPD up to the mean date for each of the fisheries with the corresponding CV's of annual performance was significantily different from zero ($r = 0.90$, $t = 4.65$, $P < 0.005$).

Table 13. Overall comparison of estimator performances as based on the average of MAPD summary statistics for all of the fisheries investigated.

	ACP	RAT	CR	REG	LIN	ADJ LIN	ACP PF	LIN PF
				MAPD up to mean date				
$\bar{x}$	74.4	72.2	58.1	69.1	26.5	86.8	73.3	58.2
s	49.2	46.0	30.4	40.3	14.8	60.0	35.2	27.3
				MAPD at mean date				
$\bar{x}$	22.6	22.8	19.9	28.2	20.0	21.9	---	---
s	13.9	14.5	11.6	16.6	11.2	14.7	---	---

CHAPTER 4

DISCUSSION

Effectiveness of estimators

The annual estimators will be discussed in the order suggested by the forecast results. Peer groups consisting of similar estimators will be defined and discussed. The average timing model (ACP), the ratio estimator (RAT), the adjusted linear estimator (ADJ LIN), and the censored ratio estimator (CR) could all be generally related as single parameter linear regression predictive models. The first three models are very similar in that the slope parameter is calculated from the same pairs of historical cumulative catch and annual yield data. The ACP estimator and RAT estimator performed almost identically, which was not unexpected since they were computationally similar. Curiously, the least squares estimate of the slope parameter used by the ADJ LIN model was often very much different from either of the estimates produced by the ACP and RAT models. The forecasts by the ADJ LIN model, like its parameter estimates, were also very different. Despite the difference in individual forecasts, their relative accuracy is not markedly different. Of all the the estimators evaluated, these three had the poorest performances during the early portion of a fishing season. Past the mean date of a season these estimators performed well. It may be for this reason that the intraseason annual forecasts which are based on average performance have been historically calculated at the midway point of the season (ie. Royce 1965).

The censored ratio estimator (CR), while also being a single parameter linear estimator of annual yield, was somewhat different from the others in its group. The data used to estimate the slope parameter are selected on the premise that data from years with similar patterns of catch provide a better basis for parameter estimates than do all of the years of data. As described in Chapter two, the selection was based on either standard deviations or correlation coefficients. Surprisingly, when compared to the other three single parameter models, the results for the CR estimator which used these selection procedures seemed often to provide some added overall accuracy. In fact, the CR estimator was the second best of the six estimators of annual totals. Unfortunately, a primary reason for lower average errors was the non-selection of historical information which prevented forecast calculation. Non-selection means that the period catches in past annual data sets were not sufficiently correlated (eg. $r < 0.8$) with the current series of period catches. In the situation where forecasts were not made the large errors which were typically recorded for the ACP, RAT, and ADJ LIN models were avoided. Although the failure to make a forecast explained the reduced average error in many cases, the CR estimator often produced better forecasts than the other methods in its group. A good example can be seen in the forecasting results for the Virginia blue crab fishery. The average error by the CR estimator was fourteen percent lower than the ACP and RAT average forecast errors and forecasts were made on 96% of the time intervals.

In order for the CR estimator to be effective the seasonal patterns must be conservative enough to allow comparison on the basis of the criteria suggested. It is also important to have a relatively large data base from which selection can occur. In the blue crab fishery, forecasts by the CR estimator were made on almost all intervals; whereas, the rock lobster CR forecasts were not made on every interval, perhaps because there were fewer years of historical data from which selection could occur. Although the CR estimator showed reduced forecasting error, there is not a fair comparison with the other estimators since forecasts were not made on every time interval. It is debatable whether the failure to forecast is an improvement over a highly inaccurate forecast, but the point is moot since the two parameter linear regression estimator was much better overall than all estimators in this peer group.

The regression estimator (REG) of sampling theory, in a peer group by itself, also did not perform favorably. However, the construction of this estimator is unique among the other annual estimators. The estimation formula contains interesting parameters which incorporate intraseason data in addition to the interseason data that the other estimators use. Recalling Equation 2.4,

$$\hat{C}(i,j)_{REG} = (N/i)\ [\ c(i,j) - b'(i)\ \bar{c}(i,j\text{-}1)\ ] + b'(i)\ \bar{C}(i,j\text{-}1)$$

The component, (N/i), represents the inverse of the percentage of the season which has occurred. As in all methods, c(i,j) is the cumulative catch of the current season. In the remainder of the methods c(i,j) is the independent variable of a linear model and is the only value which is produced within the season. In the regression estimator the slope parameter, b'(i), is also calculated within the season and must be updated on every interval of the season. As explained in Chapter two, this slope parameter is a partial measure of the relation between the pattern of current catches and the average pattern of catches. It is the inclusion of this component which incorporates an intraseason measure of the relation of current catches to the average pattern that makes the REG estimator unique. Unfortunately, the results obtained were not as promising as the construction of the estimator. In relation to the other annual estimators the REG estimator ranked third.

By far, the most reliable intraseason annual forecasts during the early season were produced by the linear regression model (LIN). The overall error of forecasts on or before the mean date of a fishing season was at least half the error of the other annual estimators (LIN-27%; next best was CR-58%; ACP-74%). In addition, forecasts by the LIN method were always within a realistic range at all times during a season, and were often within the historical maximum and minimum. Likewise, the ability to calculate statistically precise prediction intervals greatly enhances linear model forecasts. The prediction intervals also provided a good perspective on the range of values experienced historically. Finally, an important characteristic of the LIN model was its ability to produce viable forecasts for every time interval of the season.

Although not investigated, it is possible to make forecasts when cumulative catch remains at zero. When cumulative catch is zero the forecast equals the y-intercept of the regression line. By all other methods except the REG estimator forecasts on time intervals when cumulative catch was zero would also be zero. This behavior is a direct consequence of the underlying linear model for the ACP, RAT, ADJ LIN, and CR estimators which is forced through the origin. Since the LIN model can produce estimates when no catches have been recorded it may be useful for salmon fisheries in which closures early in the season are common.

Mechanically, the linear regression model is very similar to the simple autoregressive (SA) model suggested by Roff (1983) for pre-season forecasts. In fact, if a pre-season estimate of annual yield were to be made by the logic of the intraseason estimator, it could be considered a SA model of the form $C_{t+1} = A+BC_t$.

The concept of intraseason updates (forecasts) of annual estimates has not been widely addressed in the fisheries literature. Mendelssohn's (1980) use of an updated time series model in the investigation of a skipjack tuna fishery is a rare instance of an intraseason forecast. However, only one update was made and it was not noticeably better than the original forecast. Additionally, the update procedure involved the rather complicated refitting of the time series model. The methods described here have the advantages of becoming increasingly accurate as the season progresses and of being simple to calculate.

Wright (1981) acknowledged the existence of a group of intraseason update procedures which pertained directly to the management of Pacific salmon fisheries. Unfortunately, no specific examples were described. However, according to Mundy (personal communication) who participated in Puget Sound management and unpublished technical literature originating from management agencies in Washington and Oregon, it is likely that Wright (1981) was referring to models conceptually similar to the LIN model. A specific example of such literature is a Northwest Indian

Fisheries Commission (NWIFC) technical report on update methods for chum salmon abundance in different areas of Puget Sound, Washington (Anon. 1982). The described update models regressed total abundance on cumulative catch or in some cases cumulative catch divided by cumulative effort, the latter being a rudimentary method of calculating a cumulative CPUE. It would be more appropriate if the cumulative catch was divided by a weighted sum of effort. Weights would be determined by the time in the season that the effort was expended. Cumulative CPUE calculated in this manner would be a more useful index of abundance. Mundy and Schaller (1983) also reported improved forecasts when annual yield estimates on the Yukon River were based on CPUE data rather than catch data. However, the relation between cumulative CPUE and annual yield is not apparent, other than the fact that catch is approximately proportional to abundance of which CPUE is an indicator. Schaller (1984) showed for the Copper River, Alaska sockeye fishery that CPUE data would provide a very poor basis for yield forecasting because of variable catchability. These type of conflicting results are typical and the correct approach must be determined for each specific fishery. Wright (1981) mentioned that virtually any combination of catch and effort data is used in intraseason forecasting. Specific combinations of data are probably used either because there is improved fit to a regression line or simply because there is a perceived reduction in forecast error.

The intraseason forecasts described by the NWIFC report point out the fact that the linear regression technique using cumulative catch data can be used to forecast annual performance indicators other than annual yield. For example, cumulative catch can be an indicator of annual abundance and possibly annual escapement. It is usually only in those select few salmon fisheries where total enumeration of the stocks permits investigation of these premises.

A possible improvement for the linear regression technique would be the expansion to a multiple regression model which includes environmental or economic variables. The variables included should have some effect on the annual yield or abundance, following the same rationales typically advanced for pre-season forecast models. In the case of salmon fisheries, a relevant variable may be the mean air temperature at the time of egg deposition. A cold harsh winter may be detrimental to egg and fry survival which alters abundance and ultimately yield. In the case of the Chesapeake Bay blue crab fishery Hester (1983) reports that wind may play a vital role in juvenile survival. The inclusion of the wind data, lagged by the number of years until recruitment may improve the predictive capability of the linear regression models for that fishery. The incorporation of exogenous variables seems to be a very promising lead in intraseason forecasting research.

Ultimately the most useful information for harvest control will be accurate assessments of period catches. The typical queries concerning the target species are where, when and how many. Where the fish are located is established by the source of the data base. The questions, when and how many, are addressed in part by an annual forecast, but eventually specific period forecasts must be developed.

By the average timing method (ACP PF) the individual period forecasts are a percentage of the ACP annual forecast. As was discussed previously the ACP annual forecasts were less than satisfactory early in the season. Therefore it would be expected that the early season ACP period forecasts be inaccurate. In general, however, all period forecasts during a season were inaccurate and high errors early in the season were not noticeable. Likewise, late in the season when annual forecasts were accurate, corresponding low period forecast error was not evident. For all of the fisheries investigated the average error for ACP period forecasts was 80%. The error experienced in the four salmon fisheries was approximately 100%, while the two crustacean fisheries averaged only 34%.

The results for linear period forecasts (LIN PF) were also fairly inaccurate but were slightly better than the ACP forecasts. The overall error was 81%. Again there were large differences in average error between the crustacean fisheries and the salmon fisheries; the average errors were 28% and 66% respectively.

The large discrepancy in error is due to the nature of both types of fisheries. The duration of salmon fisheries is much less than a year, as a result the variability experienced on any one interval is large. Typically the salmon data were grouped in three to seven day intervals, therefore the data is likely to be highly susceptible to variability caused by weather, effort, and fish behavior. If the same data was grouped in monthly intervals the interannual variability would be much lower. Unfortunately a salmon migration is seldomly longer than three months. Breaking a season into so few intervals would defeat the purpose of intraseason forecasting.

In crustacean fisheries, fishing occured during the whole year and the data were grouped in monthly intervals. The seasonal patterns as a result were conservative and intraseason forecasting was very successful.

The difficulty of forecasting any value for a small interval of time is one which is likely to remain until highly specialized models are developed. The situation could be compared to weather forecasting; a science in which vast amounts of data are required to make weather predictions three to five days ahead. The sophistication required for similar forecasting of period catches in fisheries may never be realized. In business, such realities are taken for granted. Business data is rarely forecasted for time intervals shorter than a month. The most common interval used in analysis is the quarter. In fisheries a compromise between forecast accuracy and forecast sophistication needs to be developed.

Developement of an Intraseason Forecasting System

The following discussion will be devoted to a recapitualization of the steps involved in the development of a simple intraseason forecasting system for a commercial fishery. Although several categories of fisheries data have been investigated, the primary application of these procedures will probably be to commercial catch data.

The system begins with the collection of the basic fisheries data. It may be necessary to standardize data in cases where recording methods have changed, although the evaluation of forecast error prior to standardization attempts is strongly recommended. If the errors are acceptable, the cost of standardization is not justifiable. Once the data has been properly structured, the annual data sets should be inspected for extended closures of the fishing season. Such years convey little information about the seasonal behavior of the fishery and may be excluded. Based on results presented by Butt (1984), years in which less than 15% of the total fishable time intervals are actually fished, and in years in which n many consecutive time intervals which contain more than 50% of the expected proportion of catch, $\bar{p}(i,j-1)$, are dubious records of the seasonal performance of a fishery.

After this point it is neccessary to characterize the seasonality of the data. Average performance information fullfills this crucial requirement. By calculating the time series of average proportion of catch, the seasonal patterns of a fishery become readily apparent. More importantly, a review of the coefficients of variation for both cumulative and period percentage performances provides a good measure of the consistency of a fishery's seasonal pattern. In many cases, the CV's of average cumulative proportion of catch are fairly high early in the time series; a high value is greater than fifty percent. At some point in the series the CV's should gradually drop below twenty percent. The earlier in the time series that the dropoff occurs then the more useful the seasonal pattern. If the CV's for period percentage performance are low, eg. less than 20%, then period forecasts expressed as a function of annual forecasts may be successful.

If the series of CV's remain very high and irregular past the mid-way point of the season it may be neccessary to redefine the data base. Some of the possible options are as follows: 1) redefine the fishing season; 2) look at data from smaller geographical areas; 3) stratify the data by endogenous criteria such as age, size or stock composition.

When refinement of the data base is not possible then data stratification by exogenous criteria, as suggested by Mundy (1982), may be warranted. However, as shown in the forecast results, the linear regression model did not improve appreciably when stratified data was used (Tables 5 and 6). For this reason it may be neccessary to compare the MSE's of the linear models using stratified and unstratified data to judge whether or not stratification is warranted.

Once the data base has been established and characterized, the forecast methods can be assessed. As should be apparent by the forecast results for the six annual estimators, the series of predictive models should first be posed as two parameter linear regression models.

After the regression lines are calculated, it is informative to inspect the behavior of the lines. If the series of lines have small intercepts and gradually decreasing slopes then the linear regression model should provide accurate forecast results (see Fig. 11). On the other hand, erratic changes between regression lines indicate potential difficulties (see Fig. 9). To reinforce the impressions gained from regression line plots, the coefficient of determination for each line should be checked. Values not significantly different from zero indicate a poor relationship betweem cumulative catch and annual yield.

The final analytical test of the predictive models is provided by an evaluation of the backforecasts for a portion of the data base. The statistic used for forecast evaluation in this study was mean absolute percentage deviation (MAPD). Although MAPD is easy to interpret, there are some problems concerning its use. The most important of which is the interpretation of MAPD when only a few years are backforecasted. In general, the reliability of this average error statistic increases as the number of years of forecasts which are evaluated increases. Probably a more satisfactory measure of relative accuracy of forecasts will be the MSE. The confidence in a forecast will be reflected by the width of the prediction interval which is a function of MSE and sampling variability.

Once the backforecasts have been evaluated it must be determined whether or not the precision of the forecasts is acceptable. To accomplish this it may be useful to compare the overall MAPD of forecasts on or before the mean date to the CV of annual yield. As was seen for the linear model the MAPD is usually higher if the values being forecasted are highly variable; which is an understandable relation (see Table 14). If prediction intervals exceed the historical range of values no information has been conveyed.

If the relative precision of the forecasts is not accepted, it may be possible to find covariants of annual yield which can then be incorporated in multiple regression predictive models. As was suggested earlier in this chapter lagged environmental data may be useful for such applications.

The ultimate test of the forecasting procedures is an actual application during the course of a season (Mundy and Schaller 1983). Comparisons of the forecasts to those of the harvest control manager's should be reviewed to detect ways of improving the models. At the end of the season the forecast errors should be calculated; if acceptable, the parameter estimates for the prediction models should be updated.

If a system of adequate predictive models can not be formulated by these methods then at least some quantitative understanding of the seasonality of the fishery has been obtained. The person responsible for the analysis will also have an increased understanding of the fishery by which responsible judgements can be made.

Table 14. Comparison of average error in forecasts on or before the mean date and the variability of annual performance for the seven data categories. Both CV's and MAPD's are calculated from forecast years only.

	CV	MAPD
Yukon River chinook catch	23	15
Bristol Bay sockeye abundance	71	52
Copper River sockeye catch	49	26
Lynn Canal sockeye catch	41	39
Lynn Canal sockeye CPUE	26	28
Gisborne rock lobster CPUE	9	13
Virginia blue crab catch	17	12

CHAPTER 5

CONCLUSION

It is now apparent that the large error and variability which occurred in forecasts by the ACP estimator can be improved by use of a linear regression model (eg. LIN estimator). The LIN estimator and the ACP estimator, are developed from linear regression models which use cumulative performance as an indicator of annual performance. Although the two methods react similarily to changes in cumulative performance the effects on LIN forecasts are dampened by the inclusion of an intercept parameter in the underlying model. As a result the forecasts are less variable and more accurate early in a fishing season.

The relative precision of forecasts by the LIN model was linked to the variability in the seasonal pattern for a particular fishery. It was useful to calculate the average proportions of performance and their corresponding coefficients of variation to determine the characteristics of the seasonal pattern and its suitability for intraseason forecasting. In addition, the standard techniques associated with the LIN model were a great improvement over the methods previously used to characterize the behavior of intraseason forecasting techniques by the ACP estimator. In particular, the coefficient of determination, prediction intervals and residual plots were valuable for assessing the historical performance information.

The period forecasts that were evaluated displayed large errors and a great deal of variability. However, as with the LIN annual estimator the LIN period forecast model may be improved by the incorporation of exogenous variables.

The overall forecast results for the salmon fisheries were adequate, but in several cases the analysis should have been performed on more specific management units of a fishery. The results for the crustacean fisheries were very good because the two fisheries exhibited conservative seasonal patterns. The low variability in the patterns was partially due to the long fishing seasons and the smoothing effect that is achieved by grouping data for large time intervals such as months. Undoubtedly, however, the stable patterns of effort and of availability of the target species contributed to the conservative nature of the seasonal patterns of the crustacean fishery.

In general the procedures followed provide a rapid means for inspecting a fishery and for learning its characteristics. Specifically the methods provide a convenient structure for documenting the behavior of the historical data for a fishery.

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APPENDIX A

RELATION OF THE YIELD ESTIMATORS TO COCHRAN'S RATIO AND REGRESSION ESTIMATORS

The ratio and regression estimators are used to estimate several basic parameters of finite populations. The population attributes of interest are the population mean, $\bar{Y}$, and the population total, Y. The collection of N catch observations, made on evenly spaced time intervals during a fishing season, is the population considered in the yield forecasting problem. The sum of the catch observations (Y_i) is the population total or the annual yield. The population mean represents the average catch for all time periods in a season. Note that $N\bar{Y}$ equals Y.

The primary concern of sampling theory is to derive estimates of population mean and the population total without measuring the whole population. The same is true in the fisheries forecasting problem; it is desireable to know the annual yield before the season is over.

The most basic means of achieving such estimates would be to calculate sample statistics from a random sample. The sample observations are denoted by lower case characters, ie. y_i. The sample mean, $\bar{y}$, would be an estimate of the population mean and $N\bar{y}$ would be an estimate of the population total.

However, it is only possible to take a true random sample of period catches when the season has ended. By the end of the season the annual yield is known and it is no longer necessary to estimate the population total. The inability to randomly sample catch observations during a season is an unfortunate departure from sampling theory.

Regardless of the improper sampling, the basic methods for calculating population estimates can still be followed. The use of $\bar{y}$ to estimate $\bar{Y}$ and Y may be useful for fisheries in which the time distribution of period catches is approximately uniform. However few fisheries have such seasonal distributions. Consider a fishery in which monthly catches are approximately bell shaped. A running average of period catches will tend to under-estimate the population mean prior to the midpoint of the season; and then over-estimate the mean until the end of the season.

To avoid this problem it is useful to incorporate additional information about the seasonal pattern of catches into the estimator. The seasonal behavior of a fishery is often well described by average performance, which is designated the time series of average period catches. Two methods suggested by Cochran (1977) which will incorporate this additional information are the ratio and regression estimators.

The ratio estimator compares n sample values y_i to corresponding auxillary variates x_i. Or in this case, the series of currently available period catches to the series of average period catches. The population ratio is estimated from these two series. From Cochran's Equation 6.1,

$$\hat{R} = [\ \bar{y} / \bar{x}\ ] = [\ y / x\ ]$$

$$\hat{Y}_{RAT} = \hat{R}\ X = [\ y / x\ ]\ X$$

where,

$\hat{R}$ = population ratio estimate, ie. the ratio Y/X
$\hat{Y}$ = population total estimate, ie. annual yield etimate
$\bar{y}$ = average of current catches to date

$\bar{x}$ = average of corresponding average period catches

y = c(i,j) = current cumulative catch to date

x = $\bar{c}$(i,j-1) = average cumulative catch to date

X = $\bar{C}$(j-1) = known population total of x_i, ie. the average annual catch

Therefore, the estimate of current year annual catch equals the average annual yield for the fishery multiplied by the ratio of the current cumulative catch to the average cumulative catch.

As mentioned in Chapter two, the ratio estimator performs well when the relation of Y_i and X_i is linear and goes through the origin. It is not neccessarily true that a regression of current period catches and average period catches passes through the origin. Therefore, the regression estimator developed by Cochran (1977) has been tested as a yield estimator. From Cochran equation 7.1,

$$\hat{\bar{Y}}_{REG} = \bar{y} + b\ (\ \bar{X} - \bar{x}\ )$$

where,

$\hat{\bar{Y}}$ = population mean estimate, ie. estimate of average period catch for season

$\bar{X}$ = the population mean of X_i or the average of average period catch for all N periods of a season.

b = slope of regression of y_i and x_i.

Since the rest of the yield estimators have been posed in terms of cumulative catches, Equation 7.1 has been modified in the following manner:

$$N\ \hat{\bar{Y}}_{REG} = N\ [\ \bar{y} + b\bar{X} - b\ \bar{x}\ ]$$

$$\hat{Y}_{REG} = N\ \bar{y} + bX - N\ b\ \bar{x}$$

$$\hat{Y}_{REG} = N/n\ [\ y - b\ x\ ]\ + b\ X$$

Which is equivalent to Equation 2.4,

$$\hat{Y}(i,j)_{REG} = N/i\ [\ c(i,j) - b'(i)\ \bar{c}(i,j-1)\ ] + b'(i)\ \bar{C}(j-1)$$

APPENDIX B

FISHERY DATA BASES

Table B1. Abundance of sockeye salmon from Bristol Bay, Alaska. Abundance data are grouped in three day intervals; first interval begins on June 15.

Year Time Interval	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
										c'(i,j)										
1	46	0	825	1596	5972	6891	1881	17754	16277	2748	2793	27970	5918	1503	32123	4	0	922	3038	2782
2	3011	13714	10541	10494	49844	230718	57571	84537	18391	115850	22011	450846	28304	3242	60706	64	20697	22673	20889	7500
3	7258	70876	90252	84630	250750	698298	71200	51907	71582	1448890	122546	746292	435098	130553	924719	17859	23495	50369	345697	32826
4	161928	388767	171712	359506	535138	1275560	1412970	215273	513506	2317050	375942	1934000	1160910	1303830	3136760	177549	175809	84133	1410170	1427360
5	410414	830536	354511	851615	2080010	2487010	630275	684298	346454	5184630	1486900	2835150	1854180	3675320	7944180	335591	741153	229849	2474430	2447550
6	858872	893826	1233300	2668790	4657850	4174340	3628600	1140100	1848950	10011700	5203890	1271950	2038870	4119270	7481810	1124910	1606200	406108	2865750	4180910
7	2063780	2185320	1591670	1723570	8224000	3773180	2188060	1720270	1945410	9520510	4310370	1300850	1031740	4592310	8994970	2540770	1227190	646465	1759100	4439370
8	3380290	2862910	860741	1900770	7408290	2569580	1060350	1525060	3420730	8302730	3524600	650753	710800	2272710	5097390	2704380	956302	365287	923351	4606560
9	6427570	1892710	481753	2469820	6432880	1685720	687628	517241	1353330	5831070	915762	232050	312006	1368040	3146880	3290540	263932	125626	441081	3599880
10	5150520	512772	141150	1197820	3792210	394494	526593	226653	329711	5110240	776274	344378	132273	743628	1182290	2547360	70902	49296	315293	1622360
11	2029170	377159	121141	640368	1749430	165957	244908	136492	299092	2843130	217649	81539	46057	284559	506814	1638580	40015	34266	60813	731668
12	571236	269355	43116	147558	337062	148908	146956	104166	178494	1702110	77675	125016	31810	161429	257281	634090	50508	71040	39526	172927
13	174999	87248	67682	116375	286711	69656	24706	54560	60803	272355	56137	52817	11455	18327	76771	78726	22438	9525	10148	50717
14	66713	22876	37921	67535	95589	11451	15594	11462	25785	28723	4411	6092	9356	6968	25132	109488	1762	2793	4874	15743
15	1864	0	1131	1648	2798	2034	3295	0	5094	1670	88	1594	1484	0	436	1450	541	782	0	0
										c(i,j)										
1	46	0	825	1596	5972	6891	1881	17754	16277	2748	2793	27970	5918	1503	32123	4	0	922	3038	2782
2	3057	13714	11366	12090	55816	237609	59452	102291	34668	118598	24804	478816	34222	4745	92829	68	20697	23595	23927	10282
3	10315	84590	101618	96720	306566	935907	130652	154198	106250	1567490	147350	1225110	469320	135298	1017550	17927	44192	73964	369624	43108
4	172243	473357	273330	456226	841704	2211470	1543620	369471	619756	3884540	523292	3159110	1630230	1439130	4154310	195476	220001	158097	1779790	1470470
5	582657	1303890	627841	1307840	2921710	4698480	2173900	1053770	966210	9069170	2010190	5994260	3484410	5114450	12098500	531067	961154	387946	4254220	3918020
6	1441530	2197720	1861140	3976630	7579560	8872820	5802500	2193870	2815160	19080900	7214080	7266210	5523280	9233720	19580300	1655980	2567350	794054	7119970	8098930
7	3505310	4383040	3452810	5700200	15803600	12646000	7990560	3914140	4760570	28601400	11524500	8567060	6555020	13826000	28575300	4196750	3794540	1440520	8879070	12538300
8	6885600	7245950	4313550	7600970	23211900	15215600	9050910	5439200	8181300	36904100	15049100	9217810	7265820	16098700	33672700	6901130	4750850	1805810	9802430	17144900
9	13313200	9138660	4795310	10070800	29644700	16901300	9738540	5956440	9534630	42735200	15964800	9449860	7577830	17466800	36819500	10191700	5014780	1931430	10243500	20744700
10	18463700	9651430	4936460	11268600	33436900	17295800	10265100	6183090	9864340	47845400	16741100	9794240	7710100	18210400	38001800	12739000	5085680	1980730	10558800	22367100
11	20492900	10028600	5057600	11909000	35186400	17461800	10510000	6319590	10163400	50688600	16958700	9875780	7756160	18495000	38508600	14377600	5125700	2014990	10619600	23098800
12	21064100	10297900	5100710	12056500	35523400	17610700	10657000	6423750	10341900	52390700	17036400	10000800	7787970	18656400	38765900	15011700	5176200	2086030	10659100	23271700
13	21239100	10385200	5168390	12172900	35810200	17680300	10681700	6478310	10402700	52663000	17092600	10053600	7799420	18674700	38842700	15090400	5198640	2095560	10669300	23322400
14	21305800	10408100	5206320	12240400	35905700	17691800	10697300	6489770	10428500	52691700	17097000	10059700	7808780	18681700	38867800	15199900	5200400	2098350	10674200	23338200
15	21307700	10408100	5207450	12242100	35908500	17693800	10700600	6489770	10433600	52693400	17097100	10061300	7810260	18681700	38868300	15201400	5200940	2099130	10674200	23338200

Table B2. Catches of sockeye salmon from Copper River, Alaska. Catch data are grouped in weekly intervals; first interval begins on May 10.

Year / Time Interval	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1981	1982	1983
							c'(i,j)						
1	2252	30088	0	0	0	0	6213	585	0	22454	0	0	20632
2	72013	235207	121	20	0	83476	63697	157917	168101	69100	110795	235498	75631
3	112613	231606	120	205135	94660	83639	71878	282643	147259	50695	113626	302638	103660
4	146971	212966	274000	189967	64324	126122	47323	80723	104794	49434	71244	142162	88635
5	87749	105458	87193	88485	69691	119666	66845	95934	65967	64	65155	184384	68653
6	100194	122524	62961	57631	30138	98006	36199	75229	43558	16276	34740	139971	37569
7	77722	72758	53371	45662	27040	30940	18068	47360	34230	14136	24302	66680	54212
8	48548	37542	42550	45766	14416	16838	11949	41277	15493	0	16024	34461	51760
9	26679	25843	31436	34704	16382	15048	5567	38194	12236	4018	10092	31872	37796
10	6656	6234	12808	11183	2779	9623	2086	10733	8709	3982	6868	625	25584
							c(i,j)						
1	2252	30088	0	0	0	0	6213	585	0	22454	0	0	20632
2	74265	265295	121	20	0	83476	69910	158502	168101	91554	110795	235498	96263
3	186878	496901	241	205155	94660	167115	141788	441145	315360	142249	224421	538136	199923
4	333849	709867	274241	395122	158984	293237	189111	521868	420154	191683	295665	680298	288558
5	421598	815325	361434	483607	228675	412903	255956	617802	486121	191747	360820	864682	357211
6	521792	937849	424395	541238	258813	510909	292155	693031	529679	208023	395560	1004650	394780
7	599514	1010610	477766	586900	285853	541849	310223	740391	563909	222159	419862	1071330	448992
8	648062	1048150	520316	632666	300269	558687	322172	781668	579402	222159	435886	1105790	500752
9	674741	1073990	551752	667370	316651	573735	327739	819862	591638	226177	445978	1137670	538548
10	681397	1080230	564560	678553	319430	583358	329825	830595	600347	230159	452846	1138290	564132

Table B3. Catches of sockeye salmon from Lynn Canal, Alaska. Catch data are grouped in weekly intervals; first interval begins on May 28.

Year / Time Interval	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
							c'(i,j)						
1	345	41	31	86	0	658	10	0	0	0	0	0	0
2	1087	391	77	2151	706	1056	111	467	0	0	0	0	0
3	9583	5309	2704	2322	6131	2996	2479	634	0	0	0	554	1478
4	9714	8040	4026	11531	11614	5743	3836	8116	29718	7057	4096	1895	4870
5	11819	6513	8863	13014	17423	9150	1784	8044	27751	3827	6227	0	5527
6	11156	4185	5856	5478	15264	8837	1727	7994	15301	0	2410	0	4330
7	13388	6817	5520	4998	28314	8703	2338	4338	18997	2348	17019	0	11763
8	13038	8764	3754	4193	19705	0	0	8387	8768	4628	6105	3780	12637
9	15402	14916	8633	9416	23229	20524	0	3957	11568	5039	19744	2437	13954
10	15389	6564	7746	6173	26249	47456	0	32800	14520	23037	26740	9511	7873
11	13868	8694	5556	5005	23147	12950	0	12431	11198	19619	53165	4149	1834
12	6141	6102	10370	7471	10136	25060	0	13012	9118	22560	21808	12067	2894
13	3893	2074	4950	6972	5488	3803	0	20356	6348	12218	21399	10328	18921
14	1806	359	4319	180	827	1821	4060	1226	1549	3413	7227	4118	3341
15	632	146	1252	699	828	895	986	561	294	1341	1774	402	1113
16	283	25	818	162	218	83	0	105	77	282	899	165	291
							c'(i,j)						
1	345	41	31	86	0	658	10	0	0	0	0	0	0
2	1432	432	108	2237	706	1714	121	467	0	0	0	0	0
3	11015	5741	2812	4559	6837	4710	2600	1101	0	0	0	554	1478
4	20729	13781	6838	16090	18451	10453	6436	9217	29718	7057	4096	2449	6348
5	32548	20294	15701	29104	35874	19603	8220	17261	57469	10884	10323	2449	11875
6	43704	24479	21557	34582	51138	28440	9947	25255	72770	10884	12733	2449	16205
7	57092	31296	27077	39580	79452	37143	12285	29593	91767	13232	29752	2449	27968
8	70130	40060	30831	43773	99157	37143	12285	37980	100535	17860	35857	6229	40605
9	85532	54976	39464	53189	122386	57667	12285	41937	112103	22899	55601	8666	54559
10	100921	61540	47210	59362	148635	105123	12285	74737	126623	45936	82341	18177	62432
11	114789	70234	52766	64367	171782	118073	12285	87168	137821	65555	135506	22326	64266
12	120930	76336	63136	71838	181918	143133	12285	100180	146939	88115	157314	34393	67160
13	124823	78410	68086	78810	187406	146936	12285	120536	153287	100333	178713	44721	86081
14	126629	78769	72405	78990	188233	148757	16345	121762	154836	103746	185940	48839	89422
15	127261	78915	73657	79689	189061	149652	17331	122323	155130	105087	187714	49241	90535
16	127544	78940	74475	79851	189279	149735	17331	122428	155207	105369	188613	49406	90826

Table B4. CPUE (catch per boat day) of sockeye salmon from Lynn Canal, Alaska. CPUE data are grouped in weekly intervals; first interval begins on May 28.

Year / Time Interval	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
							c'(i,j)						
1	15.7	4.6	3.9	24.6	0.0	24.4	1.7	0.0	0.0	0.0	0.0	0.0	0.0
2	38.8	16.3	9.6	119.5	26.6	20.7	10.1	35.9	0.0	0.0	0.0	0.0	0.0
3	129.5	45.8	73.1	86.0	168.0	57.6	26.0	29.5	0.0	0.0	0.0	17.3	23.1
4	83.0	61.4	42.8	103.0	122.3	52.7	30.0	65.2	163.3	57.6	48.5	36.1	51.0
5	90.2	50.9	70.1	89.8	113.9	69.9	31.3	46.5	180.8	70.9	90.3	0.0	63.2
6	65.6	44.1	41.5	48.9	79.7	58.3	27.9	63.4	136.0	0.0	141.8	0.0	66.1
7	74.4	51.3	46.8	40.6	172.1	139.3	28.9	49.0	135.7	87.0	233.1	0.0	181.0
8	63.6	63.1	29.3	38.5	149.3	0.0	0.0	113.3	115.4	68.6	68.6	236.3	120.4
9	73.0	99.4	89.0	101.3	169.6	126.3	0.0	66.0	134.5	63.0	188.9	84.0	145.4
10	91.1	46.9	118.3	48.6	195.9	249.8	0.0	315.4	130.2	174.5	222.8	146.3	78.7
11	93.1	59.1	53.4	42.8	158.0	199.2	0.0	173.9	94.9	142.7	322.2	116.9	53.9
12	38.6	36.8	122.0	59.1	117.2	119.9	0.0	236.6	55.6	120.6	141.6	145.4	67.3
13	20.7	14.2	66.0	52.8	25.5	24.8	0.0	128.8	46.5	77.1	132.5	73.0	114.7
14	8.0	1.8	27.3	11.3	5.0	7.5	45.6	4.1	6.2	20.1	30.4	16.8	16.6
15	2.3	0.5	6.5	3.3	3.6	3.0	7.4	1.9	1.0	4.1	5.5	2.4	7.1
16	1.1	0.1	3.9	0.8	2.5	1.0	0.0	0.8	0.2	0.8	2.9	1.6	4.9
							c(i,j)						
1	15.7	4.6	3.9	24.6	0.0	24.4	1.7	0.0	0.0	0.0	0.0	0.0	0.0
2	54.5	20.8	13.5	144.1	26.6	45.1	11.8	35.9	0.0	0.0	0.0	0.0	0.0
3	184.0	66.6	86.6	230.1	194.6	102.7	37.7	65.4	0.0	0.0	0.0	17.3	23.1
4	267.0	128.0	129.4	333.0	316.9	155.4	67.7	130.6	163.3	57.6	48.5	53.4	74.1
5	357.3	178.9	199.5	422.8	430.7	225.2	99.0	177.1	344.1	128.5	138.7	53.4	137.3
6	422.9	222.9	241.0	471.7	510.5	283.6	126.8	240.5	480.1	128.5	280.5	53.4	203.4
7	497.3	274.2	287.8	512.3	682.6	422.8	155.7	289.6	615.8	215.4	513.6	53.4	384.3
8	560.9	337.2	317.1	550.8	831.9	422.8	155.7	402.9	731.2	284.0	582.2	289.7	504.7
9	633.9	436.7	406.1	652.0	1001.4	549.1	155.7	468.9	865.7	347.0	771.2	373.7	650.0
10	724.9	483.6	524.4	700.7	1197.3	798.9	155.7	784.2	995.9	521.5	994.0	520.0	728.8
11	818.0	542.7	577.8	743.4	1355.3	998.1	155.7	958.1	1090.8	664.2	1316.2	636.9	782.7
12	856.6	579.5	699.8	802.5	1472.5	1118.0	155.7	1194.7	1146.4	784.8	1457.8	782.3	850.0
13	877.3	593.7	765.8	855.3	1498.0	1142.8	155.7	1323.5	1192.9	861.9	1590.3	855.3	964.7
14	885.3	595.4	793.1	866.6	1503.0	1150.3	201.3	1327.6	1199.1	882.0	1620.7	872.1	981.3
15	887.6	595.9	799.7	869.9	1506.6	1153.3	208.8	1329.5	1200.1	886.1	1626.2	874.5	988.4
16	888.7	596.1	803.5	870.7	1509.1	1154.4	208.8	1330.3	1200.3	886.8	1629.1	876.1	993.3

Table B5. CPUE (Kg per fleet day) of rock lobster from Gisborne, New Zealand (Saila et al 1980). Data are grouped in monthly intervals; first interval is June.

Year / Time Interval	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
						c'(i,j)							
1	104.3	139.3	123.4	111.6	100.2	47.2	58.5	46.7	57.2	31.3	52.2	27.2	38.1
2	98.9	195.5	108.9	108.4	100.7	94.3	107.5	66.2	52.2	60.8	42.2	52.6	61.7
3	171.9	180.1	117.0	86.6	86.2	83.5	102.5	59.9	51.7	47.6	54.0	31.3	53.5
4	116.6	157.4	103.9	66.7	102.1	60.3	80.7	43.1	29.0	42.6	38.1	35.4	40.4
5	132.5	94.8	70.8	58.1	87.1	67.6	79.8	40.4	37.2	30.4	46.3	57.2	38.1
6	109.3	61.2	69.9	64.0	78.9	68.5	69.9	67.6	48.5	56.7	72.1	74.8	61.7
7	204.6	88.5	99.8	87.1	96.6	89.4	88.0	76.2	63.1	73.5	65.3	76.2	74.4
8	183.3	98.9	87.1	81.2	120.7	101.6	69.9	61.7	62.6	63.5	43.5	40.4	54.0
9	128.8	70.8	70.8	60.8	77.6	54.4	51.7	24.0	23.6	32.2	40.4	44.5	49.4
10	61.7	42.2	36.3	32.7	47.6	22.2	28.1	18.6	24.9	28.6	26.3	30.8	54.0
11	28.6	25.9	24.5	40.4	31.8	32.2	23.1	16.3	19.5	19.1	27.2	34.0	20.0
12	29.9	28.1	15.9	47.2	29.0	13.6	12.7	14.5	11.8	15.0	4.1	14.1	64.9
						c(i,j)							
1	104.3	139.3	123.4	111.6	100.2	47.2	58.5	46.7	57.2	31.3	52.2	27.2	38.1
2	203.2	334.8	232.3	220.0	200.9	141.5	166.0	112.9	109.4	92.1	94.4	79.8	99.8
3	375.1	514.9	349.3	306.6	287.1	225.0	268.5	172.8	161.1	139.7	148.4	111.1	153.3
4	491.7	672.3	453.2	373.3	389.2	285.3	349.2	215.9	190.1	182.3	186.5	146.5	193.7
5	624.2	767.1	524.0	431.4	476.3	352.9	429.0	256.3	227.3	212.7	232.8	203.7	231.8
6	733.5	828.3	593.9	495.4	555.2	421.4	498.9	323.9	275.8	269.4	304.9	278.5	293.5
7	938.1	916.8	693.7	582.5	651.8	510.8	586.9	400.1	338.9	342.9	370.2	354.7	367.9
8	1121.4	1015.7	780.8	663.7	772.5	612.4	656.8	461.8	401.5	406.4	413.7	395.1	421.9
9	1250.2	1086.5	851.6	724.5	850.1	666.8	708.5	485.8	425.1	438.6	454.1	439.6	471.3
10	1311.9	1128.7	887.9	757.2	897.7	689.0	736.6	504.4	450.0	467.2	480.4	470.4	525.3
11	1340.5	1154.6	912.4	797.6	929.5	721.2	759.7	520.7	469.5	486.3	507.6	504.4	545.3
12	1370.4	1182.7	928.3	844.8	958.5	734.8	772.4	535.2	481.3	501.3	511.7	518.5	610.2

Table B6. Landings of blue crab (hard) from Virginia (Hester 1983). Landings are in millions of pounds. Data are grouped in monthly intervals; first interval is January.

Year Time Interval	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
											c'(i,j)										
1	0.840	2.627	3.007	6.150	4.233	2.444	3.738	4.209	3.116	2.164	1.737	1.444	2.694	2.579	2.533	1.414	1.970	0.649	1.994	1.014	1.963
2	0.875	2.896	2.757	2.405	4.258	1.555	3.464	2.167	2.130	1.107	2.307	2.376	2.239	2.033	1.178	0.724	0.953	0.815	1.364	0.969	2.038
3	0.664	2.478	2.360	0.864	1.237	0.960	2.044	2.493	1.312	0.683	2.136	1.369	2.166	1.157	1.020	0.514	1.508	0.187	0.755	1.058	1.319
4	1.082	2.951	4.628	1.360	2.020	2.884	4.785	4.044	1.536	0.909	1.545	2.400	3.662	2.190	3.502	2.175	1.372	0.459	0.816	1.630	3.018
5	2.245	2.898	5.169	2.260	5.257	5.218	5.571	5.513	3.105	1.076	4.076	5.281	4.202	2.230	4.485	3.856	1.095	1.615	2.264	3.653	2.650
6	2.508	5.127	6.368	2.340	4.382	6.338	6.388	7.146	4.523	2.369	4.235	4.859	5.107	3.629	4.978	5.771	3.170	3.543	3.928	5.693	3.976
7	4.338	6.118	5.531	4.531	6.742	6.735	6.963	7.921	5.890	2.258	4.542	5.530	4.800	4.573	5.044	5.285	3.975	6.060	5.217	6.011	4.709
8	5.128	5.236	6.522	6.859	5.543	4.323	7.724	7.212	6.394	3.901	5.981	5.705	6.825	5.259	4.815	4.008	2.941	6.861	5.890	5.718	5.335
9	6.277	4.437	4.524	6.140	5.043	5.693	7.480	5.219	6.274	4.893	4.311	4.965	4.740	4.636	4.265	4.164	2.739	5.453	4.900	3.496	4.230
10	3.716	4.498	5.330	6.760	5.383	5.826	6.233	4.083	5.171	6.808	5.018	4.560	4.419	3.935	3.805	3.160	2.673	4.595	3.887	4.019	3.273
11	2.067	1.823	0.978	1.461	2.727	3.197	3.316	1.146	1.930	3.689	2.759	3.262	3.363	1.225	1.643	1.861	0.341	2.855	2.530	2.413	1.000
12	4.448	4.464	4.626	4.969	4.746	5.387	6.028	3.650	3.358	3.878	3.769	6.056	4.338	3.301	3.580	1.885	3.023	4.085	2.510	4.161	4.186
											c(i,j)										
1	0.840	2.627	3.007	6.150	4.233	2.444	3.738	4.209	3.116	2.164	1.737	1.444	2.694	2.579	2.533	1.414	1.970	0.649	1.994	1.014	1.963
2	1.715	5.523	5.764	8.555	8.491	3.999	7.202	6.376	5.246	3.271	4.044	3.820	4.933	4.612	3.711	2.138	2.923	1.464	3.358	1.983	4.001
3	2.379	8.001	8.124	9.419	9.728	4.959	9.246	8.869	6.558	3.954	6.180	5.189	7.099	5.769	4.731	2.652	4.431	1.651	4.113	3.041	5.320
4	3.461	10.952	12.752	10.779	11.748	7.843	14.031	12.913	8.094	4.863	7.725	7.589	10.761	7.959	8.233	4.827	5.803	2.110	4.929	4.671	8.338
5	5.706	13.850	17.921	13.039	17.005	13.061	19.602	18.426	11.199	5.939	11.801	12.870	14.963	10.189	12.718	8.683	6.898	3.725	7.193	8.324	10.988
6	8.214	18.977	24.289	15.379	21.387	19.399	25.990	25.572	15.722	8.308	16.036	17.729	20.070	13.818	17.696	14.454	10.068	7.268	11.121	14.017	14.964
7	12.552	25.095	29.820	19.910	28.129	26.134	32.953	33.493	21.612	10.566	20.578	23.259	24.870	18.391	22.740	19.739	14.043	13.328	16.338	20.028	19.673
8	17.680	30.331	36.342	26.769	33.672	30.457	40.677	40.705	28.006	14.467	26.559	28.964	31.695	23.650	27.555	23.747	16.984	20.189	22.228	25.746	25.008
9	23.957	34.768	40.866	32.909	38.715	36.150	48.157	45.924	34.280	19.360	30.870	33.929	36.435	28.286	31.820	27.911	19.723	25.642	27.128	29.242	29.238
10	27.673	39.266	46.196	39.669	44.098	41.976	54.390	50.007	39.451	26.168	35.888	38.489	40.854	32.221	35.625	31.071	22.396	30.237	31.015	33.261	32.511
11	29.740	41.089	47.174	41.130	46.825	45.173	57.706	51.153	41.381	29.857	38.647	41.751	44.217	33.446	37.268	32.932	22.737	33.092	33.545	35.674	33.511
12	34.188	45.553	51.800	46.099	51.571	50.560	63.734	54.803	44.739	33.735	42.416	47.807	48.555	36.747	40.848	34.817	25.760	37.177	36.055	39.835	37.697

VITA

Erik John Barth was born on March 28, 1959 in Portsmouth, Virginia. He attended Virginia Polytechnic Institute and State University in Blacksburg, Virginia and graduated in June, 1980 with a Bachlelor of Science in Forestry and Fisheries Science. He was granted a bypass of Master of Science at Old Dominion University in 1981. He is a member of Phi Kappa Phi.