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DETERMINANTS FOR THE TIMING OF ESCAPEMENT FROM THE SOCKEYE SALMON FISHERY OF THE COPPER RIVER, ALASKA:

A SIMULATION MODEL

by

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Approved by:

Phillip R. Mundy (Director)

ABSTRACT

DETERMINANTS FOR THE TIMING OF ESCAPEMENT FROM THE SOCKEYE SALMON FISHERY OF THE COPPER RIVER, ALASKA: A SIMULATION MODEL

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Old Dominion University, 1984
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A model to estimate determinants for migratory timing of catch and escapement in a terminal salmon fishery is presented. A method was developed to estimate average seasonal migration rates of salmon through a harvest area from catch and escapement data. The time series for the total population of Copper River sockeye salmon (Oncorhynchus nerka) was reconstructed in the reference frame of the commercial harvest area from catch and escapement data.

The catchability coefficients (q), derived from the reconstructed populations were found to vary within season and between seasons. The relation between q and effort was attributed to a highly competitive fishery.

The differences found between the descriptive statistics for the time densities of catch and catch per unit of effort (CPUE) are attributed to varying q. In a highly competitive terminal fishery the time density of catch was found to be a better representation of the time density of total abundance than that of CPUE. The comparison of

the time series of daily proportions of catch and CPUE was found to be a valuable diagnostic tool for determining whether q was variable over a season.

It was inferred from the reconstructed time series of total abundance that escapement from the commercial harvest area was underestimated by the sonar counter. The under estimation of escapement from the commercial harvest area may be attributed to two sources; (1) the delta stocks are higher than point estimates found by stock separation studies ; (2) the enumeration of escapement to the upper Copper River spawning areas are being underestimated by the sonar counter.

The simulation model was a useful tool for investigating the behavior of migratory time densities and for evaluating the success of alternative management strategies in terms of distributing an escapement goal proportionately over time.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

In a commercial fishery the harvest manager is usually given a specific harvest objective, or the complement, an escapement objective, as set by the political state. The manager directs the operation of fishing gear in order to achieve specific harvest objectives. The dynamic process by which harvest or escapement objectives are met is termed harvest control.

The commercial fishery for sockeye salmon (Oncorhynchus nerka) of the Copper River, Alaska, is a terminal fishery (Wright, 1981; Schnute and Sibert, 1984). A terminal fishery takes advantage of the migratory behavior of adult salmon by harvesting concentrations of fish before they reach the spawning grounds. In an attempt to insure that product quality is marketable, terminal areas are located in marine and estuarine waters adjacent to the mouths of rivers. It is standard harvest control procedure in Alaskan salmon net fisheries to spread an annual target level of catch proportionately across all time segments of the migration of a species to insure the survival of spawning salmon from each time segment (Mundy, 1982). The managers of such a fishery have a variable degree of control over whether or not escapement requirements for spawning are met. The variability is related to information resources and legal restrictions.

In the Copper River fishery the only means to control harvest operations is to restrict the amount of time the fishery is open. Within the course of a season, harvest control consists of a series of binary decisions to harvest or not to harvest. In the case of the Copper River, the harvest control decisions result in the escapement of sockeye salmon across all time segments of the migration. For the Copper River, escapement goals are spread proportionately across all time segments of the migration and scaled by a numerical escapement objective. Once the binary switch is set, the outcome cannot be changed, since escapement objectives are specified for each time interval. The basic information needed to deliver an escapement or harvest goal as a function of time is how the time distribution of openings (or closures) of a fishery will effect that distribution.

In order to make rational harvest decisions, the manager must be able to predict and monitor total abundance within the terminal fishing area through the duration of the migration. This monitoring has been traditionally accomplished by gauging the current seasons catch against the average performance of the fishery. The average performance of a fishery is constructed from averaging daily cumulative proportions of catch for all past years of record. The manager uses the average performance of the fishery to determine within which percentile of the total migration the fishery is operating. The year to year variation in the proportional performances of most Alaskan salmon fisheries imposes a high degree of uncertainty on harvest decisions.

The overall objective of the study was to quantify how the distribution of the openings (or closures) of the Copper River sockeye salmon fishery would effect the delivery of the annual escapement objective.

The first task of the investigation was to estimate the average seasonal rate of migration by analyzing commercial catch and sonar escapement data. Secondly, the number of salmon migrating was reconstructed, within the reference frame of the fishery, as a time series of bounded estimates of the daily total pooled abundance. Then develop a simulation model for the Copper River commercial sockeye salmon fishery. Using the catchability coefficients and the descriptive statistics of the migratory timing, which where estimated from the reconstructed migrations, the fishing of the migration was simulated.

One purpose for developing the simulation model was to determine whether the time density of catch or the time density of CPUE best represented the migratory timing. Then determine the cause for departure of a time density of catch or CPUE from the time density of total abundance.

Roberson et al. (1978) suggested that estimation of total seasonal Copper River sockeye salmon commercial catch combined with an escapement index figure could be used annually for modifications of the fishing periods to manipulate the catch and escapement. One application of the proposed simulation model was to quantify the effects of regulatory actions on the temporal distributions of catch and escapement. The problem was first investigated by simulating the fishery for the reconstructed migrations. Then evaluating the different schedules for opening the fishery in terms of meeting escapement objectives.

Since each stock, or geographic isolate, may have a characteristic migratory timing (Killick, 1955), the catch is distributed over time to avoid harvesting any one stock disproportionately. Thompson (1962) stresses the importance of designing fishing regulations to insure protection for a wide diversity of genotypes, including those represented by less productive stock units, in order to maintain the ability of the entire migration to adapt to changes in environmental conditions. In addition, MacLean and Evans (1981) argue that if population subdivision is an adaptive result of a set of coadaptive life history traits, then the stress which tends to modify that structure will alter the pattern of genetic variation and consequently, cause a decline in overall fitness. Therefore, the knowledge of the migratory timing of the target species is an essential piece of information for sound harvest control.

Migratory timing is abundance as a function of time in a fixed geographic reference frame (Mundy, 1979). Relatively large fluctuations of total seasonal abundance for salmon populations has required the use of the proportion of total abundance as a function of time, the migratory time density, for describing historical performance of the migration and its associated observations. The knowledge that the time density of a salmon migration is consistent from year to year, allows a historical average of time densities to be a useful predictive tool for total seasonal yield (Mundy, 1982; Schnute and Siebert, 1983).

An ideal data set that could insure biologically sound harvest control decisions for a terminal salmon fishery would include: the categories of preseason escapement goals as a function of time, escapement to date, commercial catch to date, historical averages of the cumulative time density to date, and the standard deviation of that figure. In reality biologically sound management decisions may be precluded by political pressures arising from social and economic conditions surrounding the fishery. In many cases, sound management is precluded by the absence of one or more of the preceeding data categories. Still it may be argued that economic and social factors should be included in an ideal harvest control data base.

Fortunately, in recent years the collection of data and the management policies of the Copper River sockeye salmon fishery closely approximate ideal harvest control conditions, wherein social and economic factors are excluded during the decision making process. The management takes a projected season harvest and allocates it into expected weekly harvest based on the historic pattern of catch in the commercial fishery. Monitoring of escapement trends is provided by the sonar counter on the main Copper River. Aerial escapement surveys of major spawning areas on the river delta account for escapement which is not covered by the sonar. The information is used to adjust weekly fishing times to meet weekly and seasonal escapement goals (Alaska Department of Fish and Game (ADF&G), 1982, and Roberson et al., 1978).

The commercial catch and escapement data collected by ADF&G for the Copper River sockeye salmon fishery provides the information to estimate how many fish are in the commercial fishing district each day. In addition, the daily exploitation rates can be estimated by including the daily fishing effort present. The error in estimation stems from the time differences between the commercial fishing area and the escapement enumeration locations (lag times) which are not exactly known. Determination of the rate of migration of the average fish while traversing the commercial fishing area and ascending the river is necessary to be able to reconstruct the time series of total sockeye abundance in the reference frame of the fishery (Mundy, 1979, and Brannian, 1982).

Schaefer (1968) has stated that one use of fisheries simulation is "... to arrive at the estimate of parameters in a model by varying them until an acceptable simulation of a series of data is achieved." It could be argued that this is a problem in statistical estimation theory. Paulik (1972) pointed out that simulation in applied ecology is an attempt to determine a set of parameters that will allow a dynamic model to generate an artificial sequence which mimics an observed historical time series involving a biological population. Simulation modeling of a commercial fishery offers a number of potential benefits, such as: (1) the organization of a complex system (2) evaluating the utility of the existing raw data base (3) predicting the impact of alternative management strategies and (4) an instructional tool for management training.

The process of modeling the fishery does provide an explanation and some organization to the system. First, by reconstructing the migration, the population can be organized into its time distribution of catch and escapement within the reference frame of the fishery. Secondly, simulations can indicate whether the variability of statistical attributes have been caused by fluctuating migration patterns of the fish, or by fluctuations in fishing effort. Estimating the sources of variability is an organizational exercise of overwhelming proportions without the aid of computer modeling.

Simulation lends insight on the value of existing raw data for evaluation of the basic distribution, timing, and abundance information used for harvest control operations. Lackey (1975) points out the modeler may become painfully aware of areas of missing data and subsequently make recommendations for data acquisition needed to improve management.

The Copper River salmon fishery is defined as a feedback control system, and modeled appropriately. A control system is an arrangement of physical components connected or related in such a manner as to command, direct, or regulate itself or another system (DiStefano et al., 1967).

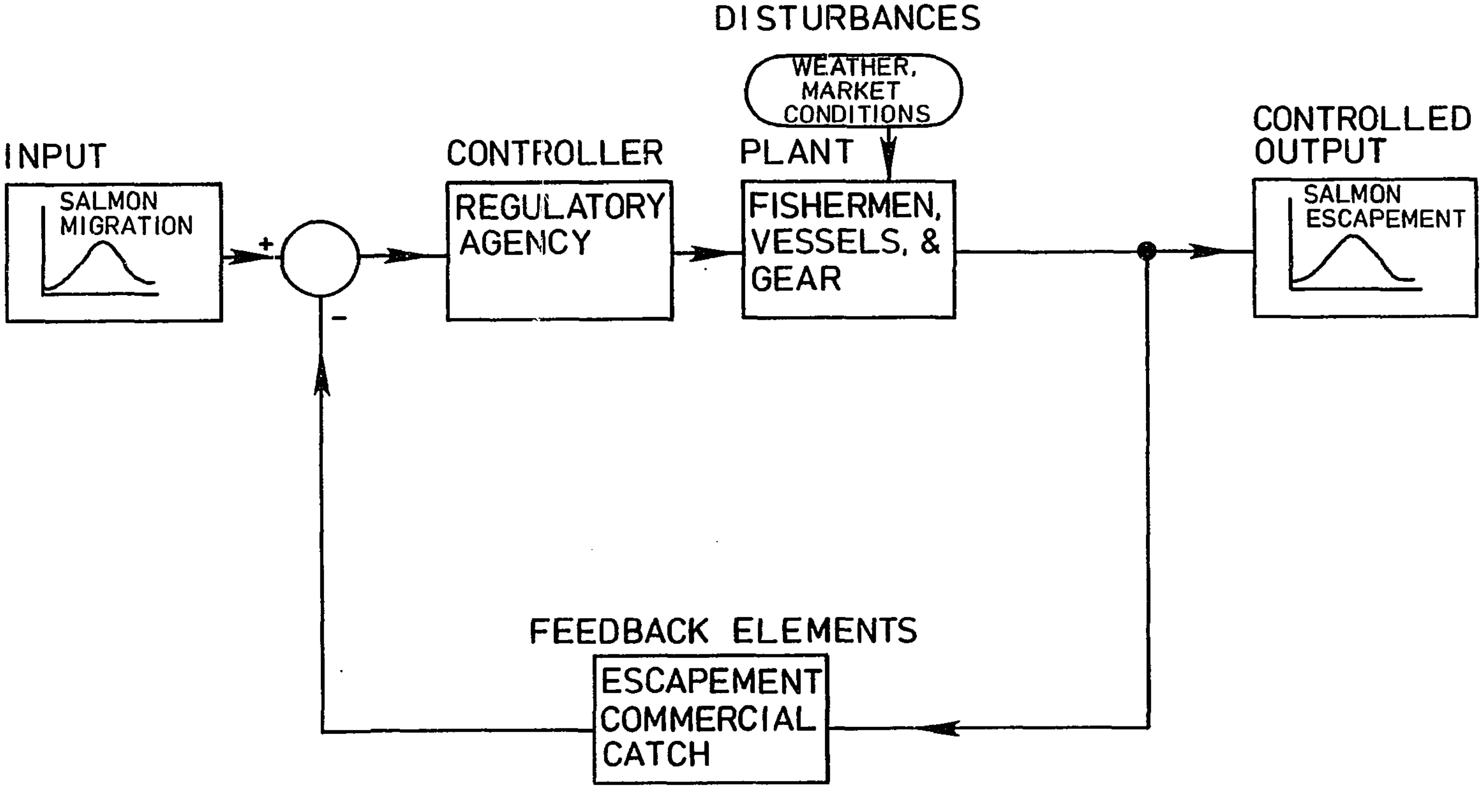
In the case of the Copper River fishery the input of the system is the migrating salmon and the output is the escapement of salmon. When the inputs and outputs are known for a control system, it is possible to identify or define the nature of the systems components.

A terminal fishery falls under the heading of a man-made control system, remembering that a fishery is a human activity (Royce, 1983). This type of fishery is classified as a closed-loop control system. A closed-loop control system, more commonly called a feedback control system, is one in which control action is dependent on output. Feedback is found to exist in a system when a closed sequence of cause-and-effect relations exists between system variables (DeStefano et al., 1967).

The major components of the Copper River fishery control system are the controller (regulatory agency) and the plant (fishermen, vessels, and gear) (Fig. 1). The feedback elements of the system are composed of the following: (1) current seasons commercial catch (2) average performance of commercial catch (3) current seasons sonar escapement and (4) average performance of the sonar escapement. The feedback elements establish a functional relation between the feedback signal and the controlled output, which is interpreted by the controller (Fig. 1). The controller sends the plant a signal in the form of harvest regulations. The plant may receive disturbances in the form of extreme weather conditions, market conditions, and labor disputes.

The model can be verified by mimicing historical distributions of catch and escapement. Once the model is verified, effectiveness of harvest control strategies of the management agencies can be examined. The method used to evaluate the effectiveness of a management strategy was to measure how close the distribution of input (migrating salmon)

Figure 1. Feedback control system diagram for the Copper River sockeye salmon fishery.


DISTURBANCES
WEATHER, MARKET CONDITIONS
INPUT
SALMON MIGRATION
+
−
CONTROLLER
REGULATORY AGENCY
PLANT
FISHERMEN, VESSELS, & GEAR
CONTROLLED OUTPUT
SALMON ESCAPEMENT
FEEDBACK ELEMENTS
ESCAPEMENT COMMERCIAL CATCH

matched the distribution of output (salmon escapement) of the control system. Historically, managers of commercial fisheries have been interested in predicting the impact of proposed fishing regulations or exploitation rates, where these entities are expressed in the form of a season, mesh size, or quota (Lackey, 1975). The model may be employed by management agencies to investigate the harvest control strategies which are the most effective for their particular objectives. Documented procedures for obtaining harvest objectives, under conditions of uncertainty, can be derived from simulation work shops attended by all parties involved in setting regulations.

Simulation gaming has been used extensively in business and by many aspects of the military, and there have been a few attempts in applying such games to teach the principles of resource management (Schaller and Barth, 1983; Mundy, 1983). Simulation models of this type would allow trainees to test their analytical skills as well as their decision making ability under real time conditions. The simulator would compress years of real time management experience into weeks or months according to trainees′ schedules. The progression of simulated training would familiarize students with the practical limitations on the analysis and interpretation of fisheries data, while permitting the actual conversion of these skills into management actions. The greatest asset of a management simulation program is exposing trainees to decision making under conditions of uncertainty.

CHAPTER 2

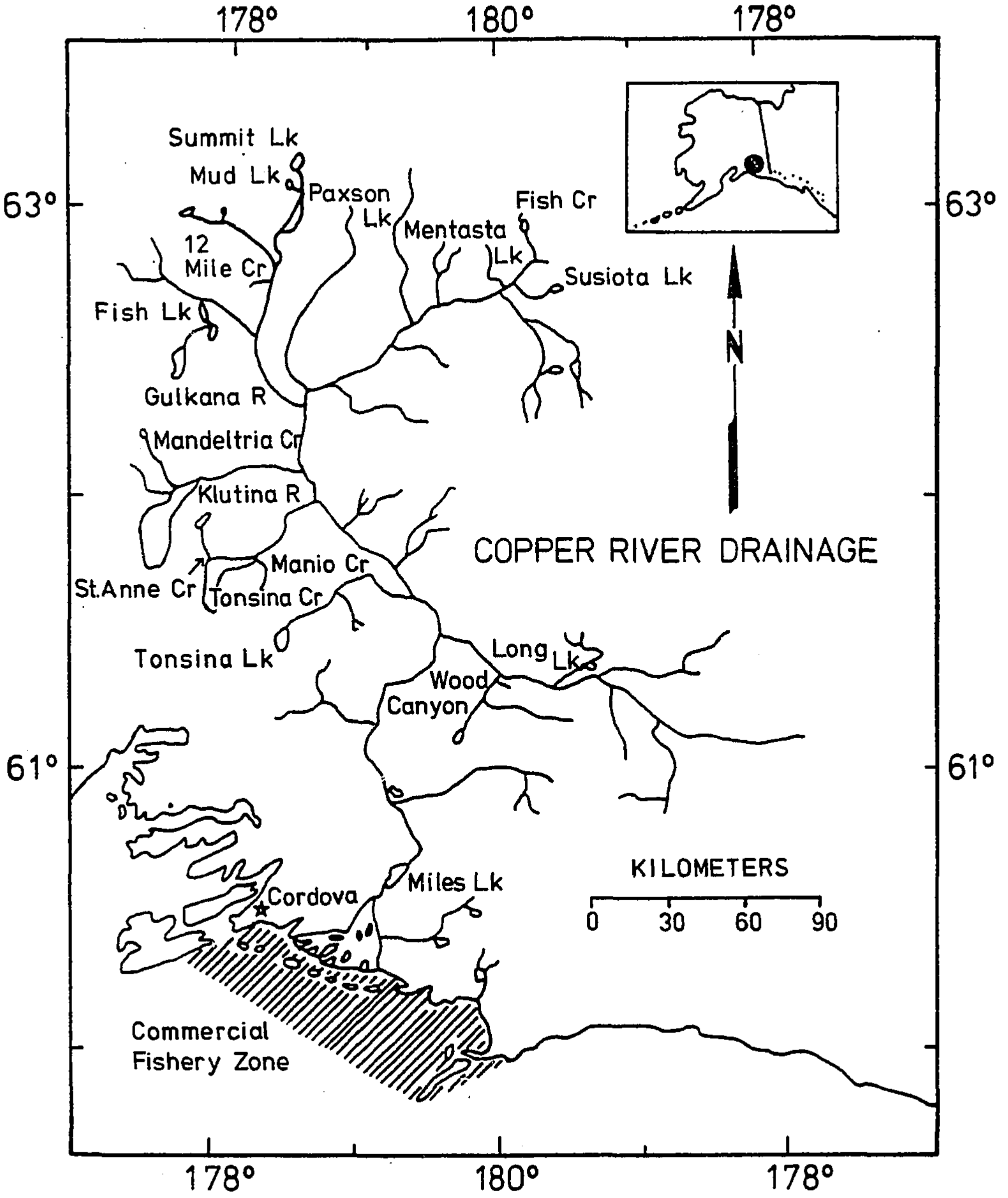
Study Area and Description of Fishery

Originating at the Copper Glacier on the north slope of Mt. Wrangell, the Copper River flows through the Chugach mountains, past a number of glaciers, until it merges with the flats of the delta (Fig. 2). The Copper River is more than 500 kilometers (km) long, has a total fall of approximately 1100 meters (m), and an average fall of about 2.9 m km^{-1} (Mendenhall, 1905).

The Copper River is the largest stream on the southern coast of Alaska frequented by salmon, but is only a moderate producer of salmon. The entire river system abounds in lakes which are fairly turbid due to large amounts of glacial action throughout the watershed. In the elaborate network of streams and lakes, favorable spawning grounds are comparatively limited and dispersed relative to other parts of Alaska (Rich and Ball, 1935).

The delta of the Copper River extends about 75 km along the Gulf of Alaska from Hinchinbrook Island to Point Martin in the east. The four major rivers that flow into the delta, from east to west, are Eyak, Glacier, Copper, and Martin. The most important contributor of the four rivers, in terms of volume, is the Copper. Together with the adjacent coastal waters these rivers form what is called the Copper River

Figure 2. The Copper River drainage.

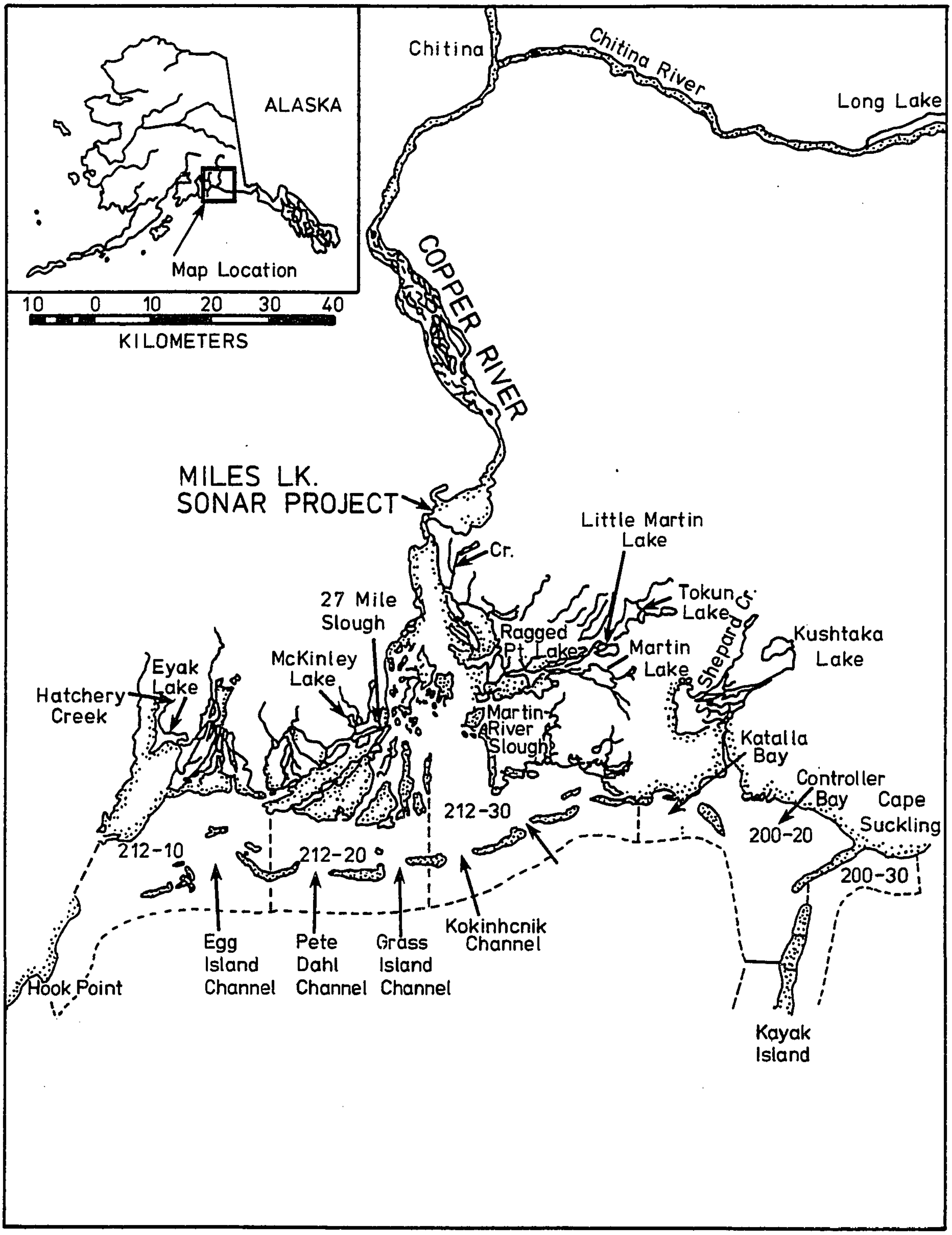

178°
180°
178°
63°
63°
61°
61°
Summit Lk
Mud Lk
Paxson Lk
12 Mile Cr
Fish Lk
Gulkana R
Mentasta Lk
Fish Cr
Susiota Lk
N
Mandeltria Cr
Klutina R
St.Anne Cr
Manio Cr
Tonsina Cr
Tonsina Lk
COPPER RIVER DRAINAGE
Long Lk
Wood Canyon
Cordova
Miles Lk
KILOMETERS
0
30
60
90
Commercial Fishery Zone
178°
180°
178°

commercial fishing district (Fig. 3).

The channels, or sloughs, and the mud flats between the sand bars and delta, have been the principal fishing grounds in the Copper River district since commercial exploitation of its salmon began. All five species of Pacific salmon are captured in the area, but only sockeye, coho, and chinook are of commercial importance. The gear is restricted to one drift gill net of 150 fathoms in length per boat. In 1982, 525 drift gill net permit holders participated at least some time during the season. Commercial fishing of sockeye salmon usually begins in mid May and is regulated by emergency management orders in terms of openings and closures during the season.

The commercial sockeye salmon fishery has been in existence since 1889. The exploitation of salmon began somewhat later in this area than in other important sockeye salmon streams, according to Thompson (1964), because of the relative inaccessibility of the Copper River area to vessels in use at the time. The 93 - year mean catch (1899 - 1982) for commercial sockeye salmon of the Copper River fishing district is 644,281 fish, with a standard deviation of 478,990.

Figure 3. Copper River and Bering River drainage showing the locations of the commercial fishing districts and the sonar escapement enumeration site.


ALASKA
Map Location
10 0 10 20 30 40
KILOMETERS
Chitina
Chitina River
Long Lake
COPPER RIVER
MILES LK. SONAR PROJECT
Cr.
Little Martin Lake
Tokun Lake
Shepard Cr.
Kushtaka Lake
27 Mile Slough
McKinley Lake
Ragged Pt. Lake
Martin Lake
Eyak Lake
Hatchery Creek
Martin River Slough
Katalla Bay
Controller Bay
Cape Suckling
212-30
200-20
212-10
212-20
200-30
Egg Island Channel
Pete Dahl Channel
Grass Island Channel
Kokinhcnik Channel
Hook Point
Kayak Island

CHAPTER 3

METHODS

3.1 Migratory timing for commercial catch and sonar escapement

Daily catch and effort data were drawn from the ADF&G commercial fisheries catch reporting system. The following time series of data categories were designated for analysis: daily catch, daily proportion of total catch, cumulative daily catch, cumulative daily proportion of total catch.

Daily escapement data for the upriver sockeye salmon stocks, collected at the Miles Lake sonar enumeration site, were drawn from the Prince William Sound Area Annual Management Reports (1978 - 1982). The following time series of data categories were designated for analysis; daily sonar escapement, daily proportion of total sonar escapement, cumulative daily sonar escapement, cumulative daily proportion of total sonar escapement.

The descriptive statistics for each annual migratory time density of the data categories previously described were computed. The mean (the central day of the migration) and the variance (the dispersion of the migration through time) were computed using the methods of Mundy (1982). The skewness (asymmetry of the migration) and kurtosis (peakedness of the migration), which are measures of departure of the observed frequency distributions from normality, were computed using the methods of Sokal and Rohlf (1981).

The average daily proportions and cumulative proportions were calculated for all years of catch and escapement. In the years 1979 and 1980 fishing was closed for a major portion of the season. A censored average of daily and cumulative proportions were calculated by eliminating the years 1979 and 1980.

3.2 Lag time estimation and total population reconstruction

A method for estimating the average travel time for a sockeye salmon between the commercial fishing area and the Miles Lake sonar site was accomplished by comparing the two time series of data in the following manner: (1) the time series of commercial catch was paired with each of the time series of escapement counts offset from 0 to 11 days back in time; (2) the lagging procedure was performed for the years 1978 to 1983; (3) the Pearson product moment correlation was calculated for the paired data sets of commercial catch at each of the 12 time lagged series of sonar escapement for 1978 to 1983; (4) correlation of paired offset data yielding the highest negative r value was considered to be the most reasonable estimate for the numbers of days offset between the two areas. The basic hypothesis for this procedure is that the larger the catch the larger the reduction in escapement. Therefore, the best estimate of lag time will yield the highest negative r value between the two time series of data. Once the best estimate for travel time was established, the escapement data was adjusted back into the commercial fishery and summed to estimate the time distribution of total population in the commercial fishery. The descriptive statistics for each estimated annual migratory time density of total population was computed.The first fifty days of the migration (day 1 = May 10) were used for all of the analysis which follow. This was to reduce complicating effects of delta stocks replacing upriver stocks in the catches late in the season. In addition the majority of catch for the commercial sockeye fishery is taken between late May and mid June (Merritt and Roberson, 1984).

The daily rates of exploitation, u_t, for each of the reconstructed time distributions of total population were calculated by:

$$u_t = \frac{C_t}{N_t} \qquad (1)$$

where

C_t = the total catch on day t

$N_t = C_t + E_{t-L}$ = the total population on day t

E_{t-L} = escapement lagged L days

L = the number of days escapement was lagged.

Incorporating Ricker's (1975) classification of idealized fish populations, it has been assumed that the Copper River is a Type 1 where natural mortality does not occur during the fishing season. The population is subject only to fishing mortality. The rate of exploitation is expressed in terms of instantaneous mortality rates:

$$u_t = 1 - e^{-F_t} \qquad (2)$$

where

$F_t = q_t f_t$ = the instantaneous fishing mortality rate

q_t = the catchability coefficient on day t

f_t = the effort on day t,

by substituting $q_t f_t$ for F_t Equation 2 becomes:

$$u_t = 1 - e^{-(q_t f_t)} \qquad (2a)$$

then solving for q_t (catchability) Equation 2a becomes:

$$q_t = \frac{\ln (1-u_t)}{-f_t} \qquad (2b)$$

The method for determination of lag time was compared with the method of Brannian (1982) (similar to the method of Mundy and Mathisen (1981)) for the commercial sockeye fishery of Togiak Bay, Alaska. The basic assumption of the method is that the catchability coefficient is constant in the theoretical model. One source of variance for catchability was believed to be an inadequate choice of lag time. A relation was developed and tested over a range of lag times where it was maintained that the best estimate of lag time for a given year was that which minimized the variance of q_t's. The catchability coefficient was calculated for a given day and year after Equations 1 and 2b as:

$$q_t = \frac{\ln(1-[C_t/(C_t+E_{t-L})])}{-f_t} \qquad (3)$$

where the lag time (L) is varied over a range, which is consistent with plausible swimming speeds for sockeye salmon, and the variance of q_t´s was calculated for each lag. The best estimate of lag time was that which showed the minimum coefficient of variation (CV) for q.

A simple linear regression model was constructed to estimate $\bar{u}$, the average seasonal rate of exploitation. The model is derived from Baranov´s catch equation:

$$C_t = F_t\bar{N}_t \qquad (4)$$

where

$\bar{N}_t$ = average abundance during day t.

The average abundance during day t can be expressed as:

$$\bar{N} = \int_{t=0}^{t=1} Ne^{-Z}dt$$

$$\bar{N} = \frac{N(1-e^{-Z})}{Z} \qquad (5)$$

where

Z = F+M = the total instantaneous mortality rate

M = the instantaneous natural mortality.

Assuming a Type 1 fishery $Z_t = F_t$,

$$A = 1-e^{-F_t} = u_t$$

where

A = the actual mortality rate

$\bar{u}$ = the arithmetic mean of the u_t over the m days

m = the number of days fished during the season

By substituting $N_t\bar{u}/F_t$ for $\bar{N}$ in Equation 4,

$$C_t = N_t\bar{u} \qquad (6)$$

which relates the catch on the time interval to the total population by the constant of proportionality, the average seasonal exploitation rate.

A regression model was constructed with the independent variable, X, being N (total population), and the dependent variable, Y, being C (catch). A "no-intercept" model seems appropriate in analyzing data where a zero independent value yields a zero dependent variable (Montgomery and Peck, 1982). In the case of a commercial fishery it is obvious that the independent variable N is zero when the dependent variable C is zero. The regression model is formally stated:

$$y = \beta_1 x+\varepsilon \qquad (7)$$

where

x = the total population, N

y = the catch, C

β_1 = the average rate of exploitation, $\bar{u}$

ε = the random error component, $N(0,1)$

The least squares estimate of the slope $\hat{\beta}_1$, which in this case is $\bar{u}$ is:

$$\bar{u} = \sum_{t=1}^{m} C_t N_t \Big/ \sum_{t=1}^{m} N_t^2 \qquad (9)$$

The estimate of σ^2 with n-1 degrees of freedom is:

$$\hat{\sigma}^2 = \{\sum_{t=1}^{m} C_t{}^2 - \bar{u}\sum_{t=1}^{m} C_t N_t\} \,/\, (n-1) \qquad (10)$$

where all quantities are previously defined.

The 100 $(1-\alpha)$ percent confidence interval for $\bar{u}$ is :

$$\bar{u} \pm t_{(\alpha/2,n-1)} \sqrt{\frac{\hat{\sigma}^2}{\sum_{t=1}^{n} N_t^2}} \qquad (11)$$

The unbiased estimate of $\bar{u}$ and the associated $100(1-\alpha)$ percent confidence interval were computed for all years of reconstructed migrations.

Traditional catch models have relied on the basic assumption that a unit of effort will capture a fixed proportion of the available population (Leslie and Davis, 1939; DeLury, 1951; Ricker, 1975). By definition, catch during time interval t is equal to catchability multiplied by effort and the mean population during the interval; that is:

$$C_t = qf_t\bar{N}_t \qquad (12)$$

which requires the catchability coefficient to be constant over time. There is evidence that, in Alaskan salmon net fisheries, catchability varies over a season (Brannian, 1982).

In the Copper River commercial sockeye fishery there are only drift gill nets participating, and it is assumed that each unit of gear is of the same efficiency. Gear efficiency is not considered to be a factor that significantly contributes to the variation of catchability.

Aggregation of gear in small areas, and large amounts of gear fishing at one time, can contribute to variation of catchability if competition or interference develops among units of gear. Fishing areas of consistent catchability become known by fishermen. In the case of the Copper River fishery these areas can become rapidly over-crowded. Increases in effort force fishermen to areas of lower or less consistent catchability. One source of variable catchability has been related to units of gear competing (Paulik and Greenough, 1966; Brannian, 1982).

Other sources of variability are from weather conditions which may reduce the efficiency of the gear. Investigators have demonstrated that catchability in gill nets varies with size of sockeye salmon (Todd and Larkin, 1971; Mundy, 1979). Brannian (1982) suggests day of migration may be a source of variation for catchability.

A linear model was developed in which daily catchability was regressed against previously mentioned sources of variability operating during the season. The model:

$$q_t = \beta_0 + \beta_1 X_1 + \beta_2 X_1 \qquad (13)$$

was tested for the independent variables, number of boats, and day of migration. These variables were selected for their ease of acquisition during the course of a season. The coefficients developed from the linear model for all years of data were used to predict total population from catch and effort data. The coefficients developed from individual years of data were used to supply the fishery simulation model with values of variable q. Linearized exponential, power law, and logarithmic regression models were also tested for the independent variable of effort since other fisheries have demonstrated this behavior (Brannian, 1982).

3.3 Fishery model derivation and simulations

A method that is accepted for calculating optimal fishing policies has been to specify a simple model of fishery dynamics, and then calculate by numerical methods the optimal policy to meet a specified objective (Clark, 1976; Beddington and May, 1977; Walters and Hilborn, 1978; Hilborn, 1979). The simulations follow this basic approach.

The entry of salmon into the fishing area was generated by the reconstructed migratory time density of total population or by a governing distribution function. Fish may have accumulated in the harvest area, when more than one time unit was necessary for passage. Fish are exposed to harvest operations during the time spent in the harvest area. The time of residence in the fishing area, which controls the accumulation of fish, is derived by calculating the amount of time necessary for the average individual fish to transit the harvest area. The estimate of residence time is:

$$t_r = \bar{d} \, / \, \bar{r} \qquad (14)$$

where

t_r = residence time

$\bar{d}$ = average length of the harvest area

$\bar{r}$ = average rate of migration calculated from the correlation analysis.

The migratory time densities and their associated descriptive statistics were calculated, within the reference frame of the harvest area, for all simulations of catch, CPUE, entry of salmon, and escapement.

The population is harvested by using Equation 4, a generalized catch equation. Catch equations are widely used in fisheries stock assessment. Such equations operate as accounting tools for predicting the loss of fish from a population to various mortality agents that operate smoothly and simultaneously over time (Argue et al., 1983). Generalized catch models are frequently used for large time intervals (weeks, months, years). When applying the catch equation to small time intervals the assumption of mortality operating smoothly over time is closely approximated.

The estimate of the average population, on a given time interval using Equation 5 does not take into account fish pooling in the commercial harvest area. The problem posed by fish pooling in the harvest area was adjusted by adding, the number of fish which were not caught in the previous time intervals and which had not migrated out of the harvest area, to N_t in Equation 5. This quantity is termed the residual population, N_t^R. Equation 5 was rewritten as:

$$\bar{N}_t = [(1-e^{-(q_t f_t+M)})/(q_t f_t+M)][N_t+N_t^R] \qquad (15)$$

where

N_t^R = residual total population

M = natural mortality = $.00001 \doteq 0$

For computational convention a very small value was used for M.

The residual total population is :

$$N_t^R = \sum_{j=1}^{L-1} N_{(t-j)} - N_{(t-j)}[1-e^{-(q_{(t-j)}f_{(t-j)}+M)}] \qquad (16)$$

where

L = residence time.

For ease of computation Equation 15 was converted to:

$$\bar{P}_t = [(1-e^{-(q_t f_t+M)})/(q_t f_t+M)][P_t+P_t^R] \qquad (17)$$

where

P_t = proportion of population on day t

The residual total population proportion on day t is:

$$P_t^R = \sum_{j=1}^{L-1} P_{(t-j)} - P_{(t-j)}[1-e^{-(q_{(t-j)}f_{(t-j)}+M)}] \qquad (18)$$

The proportion of the population on day t, P_t, was generated from a governing distribution. Two approaches were taken to supply a governing distribution: (1) the use of the proportions from the reconstructed total population of a given year; (2) the differenced cumulative proportions of a normal distribution function with a mean and variance equal to the migratory time density of the total reconstructed population of a given year. The formula for calculating harvesting a population was:

$$C_t = N_o \bar{P}_t q_t f_t \qquad (19)$$

where

N_o = the total population for the first 50 days of the season

Model Assumptions

1) Fish arrive in the harvest area according to a smooth distribution characterized by a single peak, possibly normal (Mundy, 1979; Clark, 1983). Fish migration is unidirectional, no backwash due to tidal

action.

2) This is a type 1 fishery, where instantaneous natural mortality does not take place during fishing (Ricker, 1975). A very small value for M is used as a computational convention, which is not to drive N to zero when fishing is absent.

3) During the period fish are present in the harvest area, their probabilities of capture are equal, regardless of when they entered the fishery.

4) Salmon fisheries belong to a general class of fisheries which may be designated as "gantlet fisheries" (Paulik and Greenough, 1966). In this type of fishery the gear passively intercept fish as they swim through the harvest area. The Copper River commercial sockeye fishery consists of many channels where gear passively intercepts migrating fish. The channels tend to get over crowded at the peak of the fishing season and physical interference of gear takes place (see discussion). The problem with modeling a gantlet fishery is that detailed information on spatial and temporal distribution of the species of interest in the harvest area is imperative. In addition, detailed records of catch and effort by exact locality from each boat along a gantlet are necessary. The lack of information about the location of individual boats, and the precise route of salmon migration, render the use of a gantlet fishery model for the Copper River impractical. Therefore, the model of a competitive fishery is adopted. The competitive fishery is a model where instant equal density is assumed available to all boats on a given interval (Ricker, 1975).

5) The estimation of catchability, q, was variable over the course of a season. The model has the proportionality constant, q, subscripted for

time inorder to accommodate competition between units of gear during periods of peak fishing.

6) It is assumed that all fish caught in the harvest area were destined to spawn in the upper Copper River.

Baseline for Comparision

The model was initially run with the empirical distributions of the reconstructed total populations for the years 1978 - 1983. Effort was calculated by multiplying the number of boats by the proportion of the day fished. The time series of catchability coefficients used for simulation, were those calculated from the reconstructed time series of total population for the corresponding year. The simulated time series of catch and escapement were compared to the time series of observed catch and lagged escapement.

The method used for comparing the observed and simulated data was a two fold procedure: (1) by inspection of the differences in the descriptive statistics of the time densities of observed and simulated catch and observed and simulated escapement; (2) by the computation of an index for percent error between the time series of observed and simulated data . Roff (1983) defined a statistic to provide an index of the percent error in a prediction. This index was used to estimate percent error for the base line simulations. The quantity is defined as:

$$MA\%E = 1/m \sum_{t=1}^{m} [O_t - P_t]/O_t \quad 100\% \qquad (20)$$

where

m = the number observations in a season

O_t = observed value

P_t = simulated value

The mean absolute percent error, MA%E, was used as an index for error between the observed and simulated data. The index calculated for the baseline simulations provided a value for error inherent in the model.

A number of simulations were performed to evaluate how various estimates of q would effect the time series of catch and escapement. Each one of the proposed simulations was evaluated by the previously mentioned method for comparision.

The years 1981 - 1983 were simulated as follows:

1) Using a seasonal average value for q, and all other inputs are the same as in the base line simulation;

2) Using a seasonal average for q weighted by number of boats on an interval, and all other inputs are the same as in the base line simulation;

3) Using the regression model for q that best fit each individual year, and all other inputs are the same as the base line simulation;

4) Using the regression model for q that best fit the years 1981 -

1983, and all other inputs are the same as the base line simulation;
5) Using a normal curve to generate the entry distribution, repeat simulations 1 -4;

The amount of effort that is present during a time interval is a function of a number of economic and logistic variables. Historically the number of boats participating early in the season were large. Many fishermen move to other fishing areas around the 30th to 40th coded day in the season. The number of boats also seems to be a function of how many hours the fishing period is open. There are also many economic factors such as price of fish and the general state of the economy.

A linear model was developed in which number of boats on an interval was regressed against the number of hours the interval was open to fishing, and coded day of the season. These variables were chosen for their ease of acquisition. In the simulations to follow, the regression model was used to predict the number of boats when choosing a schedule for open dates of fishing.

Simulations were performed with two strategies for opening fishing periods. The first schedule consisted of a small number of open periods which were extended for a long period of time (greater than 48 hours). The second strategy consisted of a large number of open periods open for a short period of time. The simulations were run using the empirical and a normal distribution to generate the entry of salmon into the harvest area.

The different strategies were evaluated by comparing the descriptive statistics calculated for simulated catch and escapement against the descriptive statistics calculated for the entry of salmon. Each time distribution of escapement simulated from the various strategies was graphically compared to a theoretical distribution of escapement. The theoretical distribution of escapement was the proportionate distribution for salmon entering the fishery scaled by an escapement objective of 350,000 sockeye salmon.

CHAPTER 4

RESULTS

4.1 Migratory timing for commercial catch and sonar escapement

Maturing sockeye salmon migrated from May 15 through August 30, based on commercial catches in gill nets from 1969 through 1982. On the average, 90% of all the commercial catch was taken during a period of 33 days (May 15 through July 17) in these years, with one half of the catch occurring prior to June 4 (Table 1.) Maturing salmon continued to migrate through the Copper River delta waters during August and September, but the migration was nearly over by the end of July. On the average, less than 1% of the commercial catches during 1969 - 1982 occurred after August 7.

On the average the central half of the population (25% - 75%), was available for harvest over a span of 25 days (May 25 - June 19). The curve for daily averages of cumulative proportion of catch for 1969 - 1982 showed a linear increase in catch of approximately 2.1% per day for the central half of the population (Fig. 4). The same curve also exhibited unusually large confidence limits beyond cumulative proportions of 0.7 (Fig. 4).

The censored average excluded years when the fishery was closed for

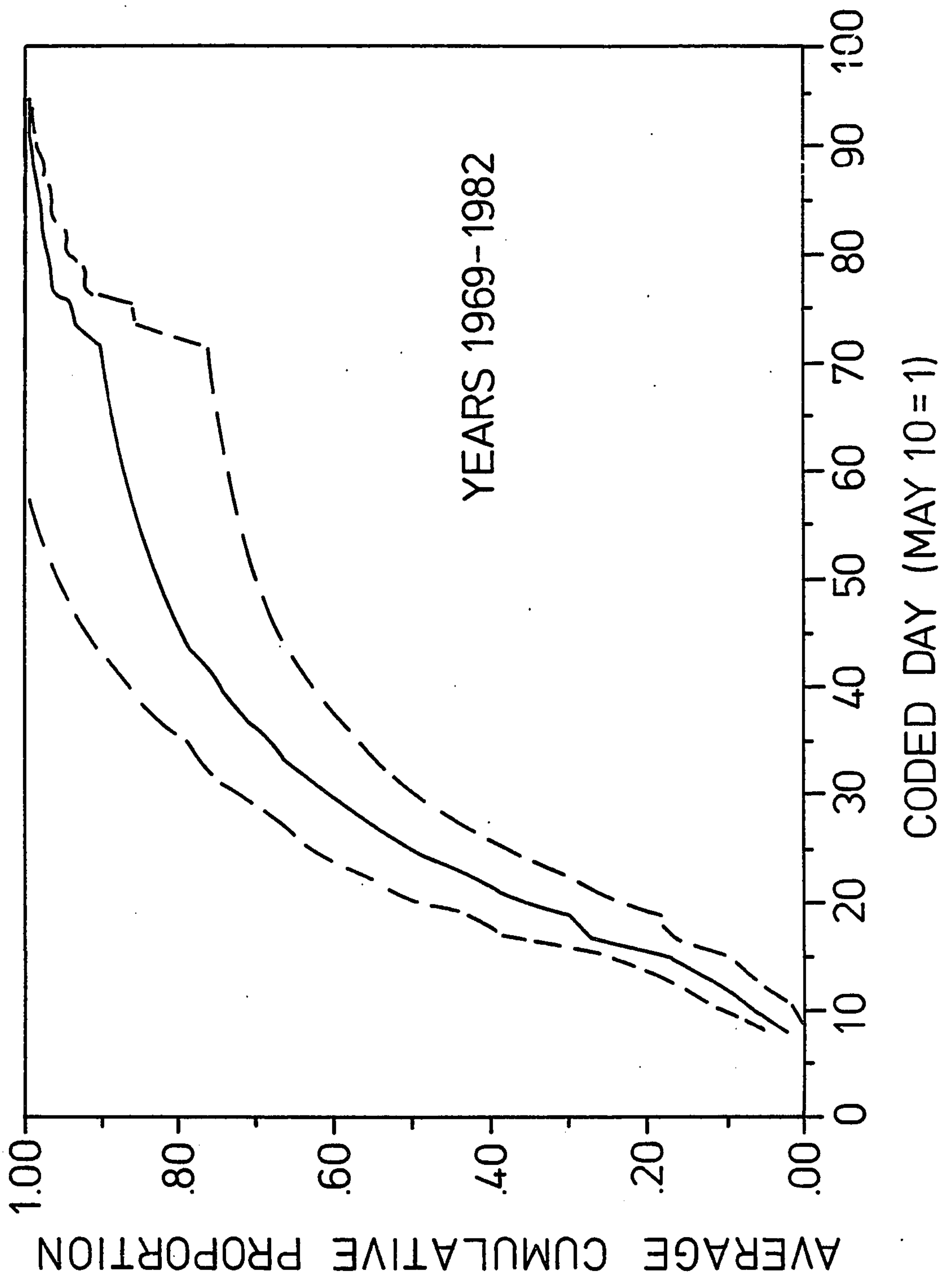
Table 1. Coefficients of variation and standard deviation (X100) of the average daily and cumulative proportions of sockeye catch by date, 1969 - 1982. The number of observations (N) also is shown.

Date	N	Daily Average	C.V.	Standard Deviation	N	Cum. Average	C.V.	Standard Deviation
515	2	.0264	98	2.59	2	.0264	98	2.59
516	5	.0144	90	1.31	5	.0250	132	3.30
517	6	.0065	128	.83	7	.0234	139	3.26
518	6	.0351	121	4.28	9	.0416	106	4.45
519	8	.0429	82	3.54	11	.0653	117	7.66
520	9	.0359	101	3.63	13	.0802	105	8.42
521	8	.0367	102	3.77	13	.1028	83	8.59
522	7	.0406	59	2.42	13	.1246	81	10.22
523	6	.0529	66	3.51	13	.1491	77	11.49
524	9	.0336	98	3.32	13	.1724	72	12.44
525	8	.0956	103	9.89	13	.2312	62	14.53
526	10	.0563	79	4.45	13	.2746	63	17.44
527	8	.0209	74	1.55	13	.2874	61	17.77
528	10	.0494	138	6.85	14	.3022	68	20.76
529	10	.0725	79	5.77	14	.3541	63	22.66
530	11	.0443	89	3.98	14	.3889	58	22.63
531	10	.0301	97	2.92	14	.4104	54	22.38
601	12	.0335	80	2.70	14	.4392	49	21.55
602	10	.0487	62	3.03	14	.4740	45	21.35
603	12	.0283	81	2.30	14	.4983	43	21.46
604	9	.0401	74	3.00	14	.5241	38	20.37
605	10	.0299	84	2.53	14	.5455	35	19.42
606	8	.0277	64	1.79	14	.5614	34	19.15
607	9	.0326	48	1.58	14	.5824	32	19.03
608	10	.0279	64	1.79	14	.6023	31	19.05
609	10	.0278	63	1.75	14	.6222	30	19.15
610	11	.0230	92	2.13	14	.6403	30	19.39
611	10	.0233	70	1.64	14	.6570	29	19.23
612	9	.0154	73	1.14	14	.6670	28	19.24
613	7	.0187	83	1.56	14	.6763	28	19.33
614	9	.0215	68	1.47	14	.6902	28	19.57
615	10	.0235	64	1.51	14	.7070	28	19.90
616	10	.0196	50	.99	14	.7210	27	20.13
617	10	.0155	96	1.49	14	.7321	27	20.29
618	8	.0188	50	.95	14	.7429	27	20.48
619	10	.0104	86	.90	14	.7504	27	20.58
620	9	.0196	93	1.83	14	.7630	27	20.80
621	9	.0185	66	1.24	14	.7749	27	21.12
622	12	.0120	64	.76	14	.7852	27	21.35
623	9	.0122	75	.91	14	.7931	27	21.46
624	10	.0099	91	.90	14	.8002	27	21.67
625	10	.0127	69	.88	14	.8093	26	21.80
626	7	.0117	66	.77	14	.8151	26	21.86
627	8	.0089	96	.85	14	.8202	26	21.94
628	8	.0075	49	.37	14	.8245	26	22.01
629	9	.0096	60	.58	14	.8308	26	22.13
630	10	.0081	84	.68	14	.8366	26	22.25
701	9	.0078	72	.57	14	.8416	26	22.41

Table 1. (continued)

Date	N	Daily Average	C.V.	Standard Deviation	N	Cum. Average	C.V.	Standard Deviation
702	9	.0088	51	.45	14	.8473	26	22.53
703	8	.0077	71	.55	14	.8517	26	22.61
704	6	.0062	89	.56	14	.8544	26	22.67
705	8	.0084	76	.64	14	.8593	26	22.77
706	9	.0074	59	.44	14	.8641	26	22.88
707	9	.0066	61	.40	14	.8683	26	23.00
708	10	.0053	67	.36	14	.8722	26	23.12
709	11	.0046	90	.42	14	.8758	26	23.22
710	9	.0054	86	.46	14	.8793	26	23.29
711	8	.0042	77	.32	14	.8817	26	23.35
712	8	.0040	61	.25	14	.8840	26	23.41
713	9	.0031	72	.22	14	.8860	26	23.46
714	10	.0040	74	.30	14	.8889	26	23.52
715	9	.0042	42	.17	14	.8916	26	23.60
716	10	.0039	92	.36	14	.8944	26	23.67
717	10	.0051	67	.34	14	.8981	26	23.76
718	8	.0036	52	.19	14	.9002	26	23.82
719	8	.0037	52	.19	14	.9024	26	23.87
720	9	.0044	65	.29	14	.9053	26	23.95
721	10	.0252	268	6.79	14	.9233	19	18.11
722	11	.0177	263	4.68	14	.9373	14	13.93
723	9	.0029	67	.20	14	.9392	14	13.99
724	10	.0036	51	.18	14	.9418	14	13.98
725	9	.0315	261	8.25	14	.9621	7	7.27
726	10	.0034	136	.47	14	.9646	7	6.87
727	10	.0018	63	.11	14	.9659	7	6.91
728	10	.0056	170	.96	14	.9699	6	6.11
729	11	.0062	264	1.64	14	.9748	4	4.69
730	8	.0018	89	.16	14	.9758	4	4.66
731	9	.0017	107	.19	14	.9769	4	4.69
801	9	.0077	238	1.84	14	.9819	3	3.29
802	8	.0010	51	.05	14	.9825	3	3.31
803	9	.0012	95	.11	14	.9833	3	3.33
804	10	.0013	101	.14	14	.9843	3	3.36
805	12	.0046	301	1.38	14	.9882	2	2.30
806	8	.0010	76	.08	14	.9888	2	2.29
807	9	.0062	191	1.20	14	.9928	1	1.38
808	7	.0029	219	.65	14	.9943	1	1.04
809	8	.0010	194	.19	14	.9949	0	.96
810	6	.0004	124	.05	14	.9951	0	.96
811	6	.0008	105	.09	14	.9955	0	.91
812	5	.0006	121	.08	14	.9957	0	.87

Figure 4. Average cumulative proportions of catch and the 95% confidence interval for years 1969 - 1982, Copper River district (212).


YEARS 1969-1982
AVERAGE CUMULATIVE PROPORTION
1.00
.80
.60
.40
.20
.00
CODED DAY (MAY 10=1)
0
10
20
30
40
50
60
70
80
90
100

a substantial portion of the season (1979 and 1980) from the average of all years of record (1969 - 1982). When observing the censored average of commercial catch, 90% of all catch was taken during a period of 25 days (May 18 through July 12), with one half of the catch occurring prior to June 5 (Table 2). Less than 1% of the commercial catches occurred after July 28, when observing the censored average.

In contrast to the uncensored average, the censored average revealed that the central half of the population was available for harvest over a span of 22 days (May 25 - June 16). The curve for the censored daily averages of cumulative proportion of catch showed a linear increase in catch of approximately 2.3% per day for the central half of the population (Fig. 5). The curve exhibited narrowing of the confidence limits about the censored average cumulative proportion greater than 0.7 (Fig. 5), unlike the average curve for all years of record.

The uncensored daily averages for proportion of catch indicated the actual daily proportion was highly variable. The extent of this variability is demonstrated by the behavior of the standard deviations of these observations as a function of time (Table 3). Daily variances of average cumulative proportion of catch were also large for the central 80% of the migration (Table 1).

The standard deviation of the daily proportions of catch from the censored average, revealed the actual daily proportions were not as variable as from the average of all years of record (Table 1, 2). The censored daily averages of proportion of catch gave the appearance of a

Table 2. Coefficients of variation and standard deviation (X100) of the average daily and cumulative proportions of sockeye catch by date, 1969 - 1978, 1981, and 1982. The number of observations (N) also is shown.

Date	N	Daily Average	C.V.	Standard Deviation	N	Cum. Average	C.V.	Standard Deviation
515	2	.0264	98	2.59	2	.0264	98	2.59
516	5	.0144	90	1.31	5	.0250	132	3.30
517	6	.0065	128	.83	7	.0234	139	3.26
518	5	.0422	103	4.36	8	.0469	95	4.46
519	7	.0484	71	3.46	9	.0793	98	7.80
520	9	.0359	101	3.63	11	.0943	89	8.42
521	8	.0367	102	3.77	11	.1210	66	8.10
522	7	.0406	59	2.42	11	.1468	65	9.55
523	6	.0529	66	3.51	11	.1757	59	10.48
524	8	.0332	105	3.52	11	.1999	57	11.53
525	7	.0606	60	3.65	11	.2385	56	13.52
526	9	.0491	83	4.10	11	.2787	56	15.73
527	7	.0234	64	1.51	11	.2936	55	16.17
528	9	.0297	123	3.67	12	.2914	57	16.76
529	9	.0607	78	4.78	12	.3370	46	15.62
530	9	.0500	82	4.14	12	.3745	40	15.10
531	10	.0301	97	2.92	12	.3996	37	14.88
601	11	.0363	72	2.64	12	.4330	31	13.63
602	10	.0487	62	3.03	12	.4736	28	13.37
603	11	.0304	75	2.29	12	.5015	27	13.68
604	9	.0401	74	3	12	.5316	21	11.45
605	9	.0313	84	2.63	12	.5551	17	9.90
606	8	.0277	64	1.79	12	.5736	15	9.03
607	9	.0326	48	1.58	12	.5981	13	8.35
608	10	.0279	64	1.79	12	.6214	12	7.91
609	10	.0278	63	1.75	12	.6446	11	7.56
610	11	.0230	92	2.13	12	.6657	11	7.62
611	9	.0254	62	1.60	12	.6848	9	6.72
612	9	.0154	73	1.14	12	.6964	8	6.24
613	7	.0187	83	1.56	12	.7074	8	6.01
614	9	.0215	68	1.47	12	.7236	8	6.07
615	10	.0235	64	1.51	12	.7432	8	6.21
616	10	.0196	50	.99	12	.7595	7	6.06
617	10	.0155	96	1.49	12	.7725	7	5.83
618	8	.0188	50	.95	12	.7851	7	5.73
619	10	.0104	86	.90	12	.7938	6	5.48
620	9	.0196	93	1.83	12	.8085	6	5.25
621	9	.0185	66	1.24	12	.8224	6	5.54
622	12	.0120	64	.76	12	.8344	6	5.52
623	9	.0122	75	.91	12	.8436	6	5.17
624	10	.0099	91	.90	12	.8518	6	5.37
625	10	.0127	69	.88	12	.8624	5	4.90
626	7	.0117	66	.77	12	.8693	5	4.46
627	8	.0089	96	.85	12	.8752	4	4.16
628	8	.0075	49	.37	12	.8803	4	3.96
629	9	.0096	60	.58	12	.8875	4	3.66
630	10	.0081	84	.68	12	.8943	3	3.46
701	9	.0078	72	.57	12	.9002	4	3.67

Table 2. (continued)

Date	N	Daily Average	C.V.	Standard Deviation	N	Cum. Average	C.V.	Standard Deviation
702	9	.0088	51	.45	12	.9068	3	3.50
703	8	.0077	71	.55	12	.9120	3	3.12
704	6	.0062	89	.56	12	.9151	3	3.08
705	8	.0084	76	.64	12	.9208	3	2.76
706	9	.0074	59	.44	12	.9264	2	2.63
707	9	.0066	61	.40	12	.9313	2	2.68
708	10	.0053	67	.36	12	.9358	2	2.80
709	11	.0046	90	.42	12	.9401	2	2.72
710	9	.0054	86	.46	12	.9441	2	2.50
711	8	.0042	77	.32	12	.9469	2	2.45
712	8	.0040	61	.25	12	.9496	2	2.32
713	9	.0031	72	.22	12	.9520	2	2.22
714	10	.0040	74	.30	12	.9554	2	1.96
715	9	.0042	42	.17	12	.9586	2	2.03
716	10	.0039	92	.36	12	.9618	2	1.95
717	10	.0051	67	.34	12	.9661	1	1.67
718	8	.0036	52	.19	12	.9686	1	1.61
719	8	.0037	52	.19	12	.9711	1	1.51
720	9	.0044	65	.29	12	.9744	1	1.34
721	9	.0026	46	.12	12	.9764	1	1.26
722	10	.0029	94	.28	12	.9789	1	1.31
723	9	.0029	67	.20	12	.9811	1	1.31
724	9	.0037	50	.19	12	.9840	1	1.14
725	8	.0024	102	.24	12	.9856	1	1.02
726	9	.0019	55	.10	12	.9870	0	.96
727	10	.0018	63	.11	12	.9885	0	.93
728	9	.0025	101	.25	12	.9904	0	.74
729	10	.0010	94	.09	12	.9913	0	.68
730	7	.0017	97	.17	12	.9923	0	.62
731	9	.0017	107	.19	12	.9936	0	.47
801	8	.0012	119	.14	12	.9944	0	.42
802	8	.0010	51	.05	12	.9951	0	.41
803	9	.0012	95	.11	12	.9960	0	.36
804	10	.0013	101	.14	12	.9972	0	.25
805	10	.0004	134	.06	12	.9975	0	.22
806	7	.0009	85	.08	12	.9981	0	.20
807	7	.0004	120	.04	12	.9984	0	.18
808	6	.0003	128	.04	12	.9985	0	.16
809	7	.0002	61	.01	12	.9987	0	.16
810	6	.0004	124	.05	12	.9989	0	.15
811	5	.0005	106	.05	12	.9991	0	.12
812	4	.0002	90	.02	12	.9992	0	.11

Figure 5. Average cumulative proportions of catch and the 95% confidence interval for years 1969 - 1978, 1981, and 1982, Copper River district (212).

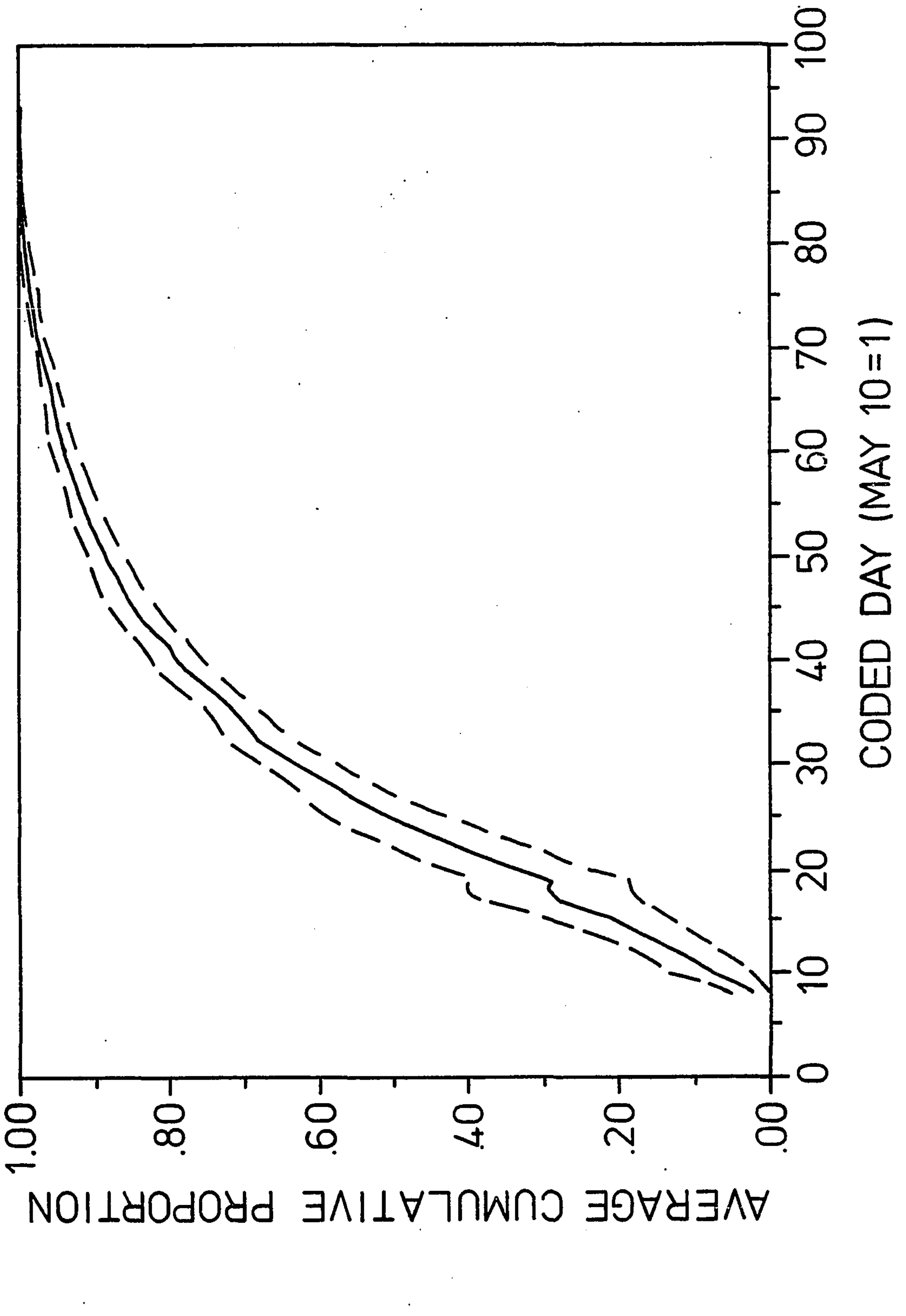

AVERAGE CUMULATIVE PROPORTION
.00
.20
.40
.60
.80
1.00
CODED DAY (MAY 10=1)
0
10
20
30
40
50
60
70
80
90
100

Table 3. The coded means, medians, and variances of sockeye salmon migration based on commercial catch from Copper River district (212).

		Coded Date				
Year	Mean Date	Mean	Median	Variance	Skewness	Kurtosis
1969	June 11	33	29	222.8	.4333	-.1577
1970	June 05	27-	23	250.3	.9579	.8340
1971	June 16	38+	30	266.5	1.0647	.4484
1972	June 12	34+	29	257.9	1.0528	.2707
1973	June 11	33+	29	213.2	1.0038	.5241
1974	June 09	31	28	230.9	.9194	1.0942
1975	June 06	28	25	187.1	.6851	.4887
1976	June 06	28	20	312.3	1.0603	.6777
1977	June 03	25-	20	236.6	1.2895	1.6808
1978	June 04	26-	20	397.2	1.4139	1.4584
1979a	June 01	23-	17	356.2	3.4070	10.2746
1980a	July 24	76+	76	167.1	-2.8298	11.1849
1981	June 05	27-	23	335.0	1.2628	1.6436
1982	June 05	27-	23	225.3	1.2214	2.0558
1983	June 14	36+	29	416.2	.4430	-.8357

$\bar{X}$ for coded mean date = 32.6; (SD = 12.8)
$\bar{X}b$ for coded mean date = 30.1; (SD = 4.6)

a - Years fishery was closed for a substantial portion of the season.
b - Censored averages exclude the years 1979 - 1980.
\- Observation less than lower bound of 95% C.I. on $\bar{X}b$
\+ Observation greater than upper bound of 95% C.I. on $\bar{X}b$

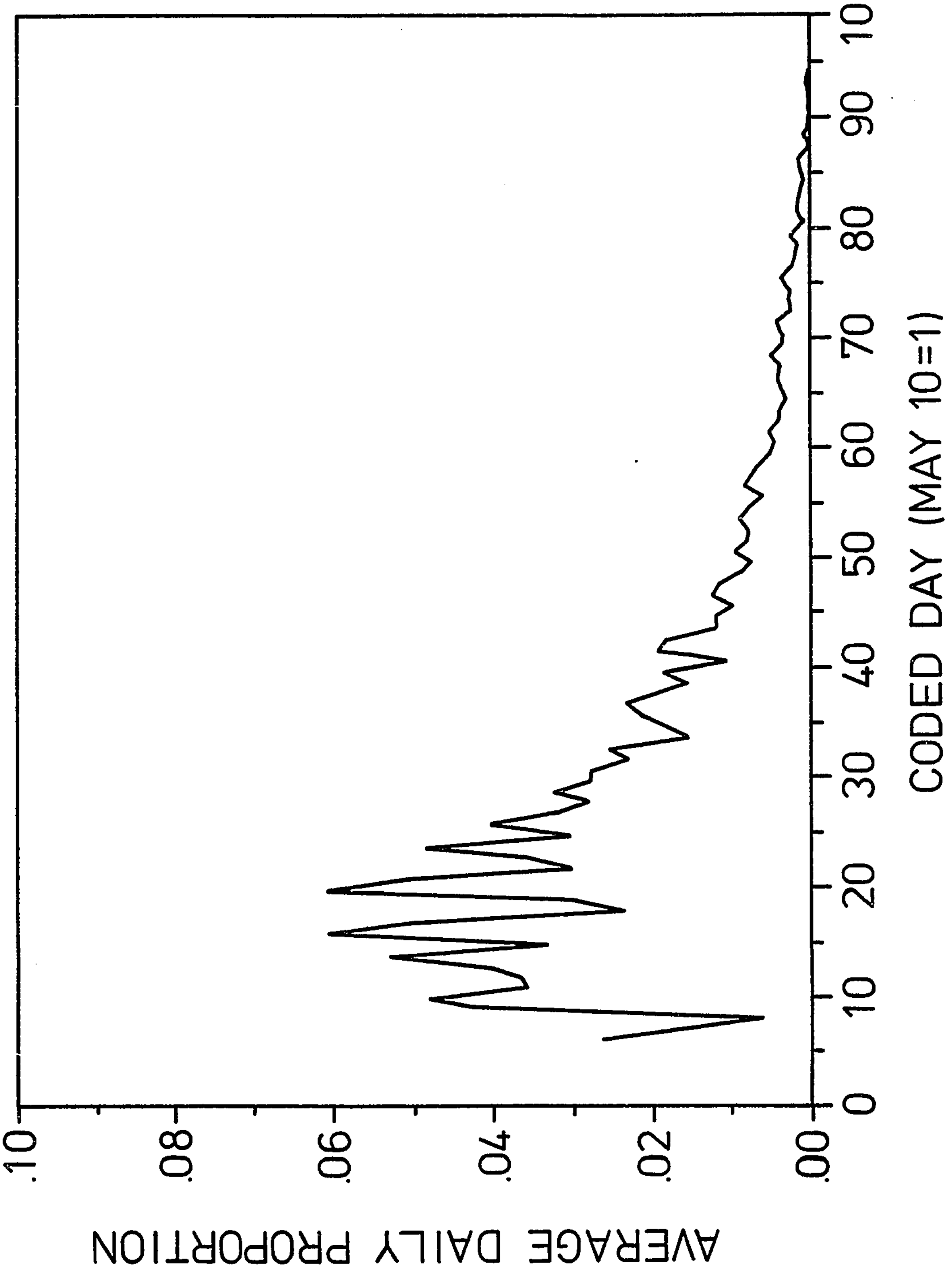
highly right skewed distribution (Fig. 6). Daily variances of the censored average cumulative proportions of catch fluctuated sharply, peaking when the cumulative proportion reached 0.3. The value of the coded standard deviations of the cumulative proportions were significantly smaller for the censored average as compared to the average over the course of the season (Table 1,2).

Using catch data, the mean dates of migration have varied between May 31 (1979) and July 24 (1980) during 1969 - 1983 (Table 3). These two extreme mean dates correspond to the years when the fishery was closed for a substantial portion of the season (1979 and 1980). The range limits of mean dates indicated by the censored years were June 6 (1977) - June 15 (1971), and the range limits of median dates were May 29 (1976,1977,1978) - June 6 (1971). The mean difference between the mean date of the migration and the median date was 5.1, with a standard deviation of 1.94 (1969 - 1978,1981,1982,1983).

The coefficients of variation (CV) for the daily proportions, from all years of record, were initially large, declining to a minimum about the grand mean date June 11. Beyond the mean date, the daily CV′s tended to increase to twice the initial value (Table 1). The time series of CV′s for the cumulative proportions decayed to the grand mean date, having a slope of -3.96. Decrease in the CV′s were comparatively small after the grand mean date.

The CV′s of daily proportions of the censored years were much smaller at the end of the time series than the average of all years

Figure 6. Average daily proportions of catch for years 1969 - 1978, 1981, and 1982, Copper River district (212).


.00
.02
.04
.06
.08
.10
AVERAGE DAILY PROPORTION
0
10
20
30
40
50
60
70
80
90
100
CODED DAY (MAY 10=1)

(Table 1, 2). The time series of the CV's for the cumulative proportions of the censored years decreased rapidly to the grand mean date (June 30), having a slope of -5.0. The CV (12) at the grand mean date for the censored average was less than one half the CV (29) at the grand mean date for the average of all years of record.

The Miles Lake sonar site began operation in 1978. Note, that with the possible exception of 1979 and 1980, the timing of escapement is a product of the fishery. On the average, 90% of the recorded salmon escaping commercial harvest occurred during a period of 62 days (May 17 - July 17) in the years 1978 - 1983. One half of the sonar escapement occurred prior to June 13 (Table 4). On the average, less than 1% of the sonar escapement occurred after July 31.

Observing the average, the central half of the population (25%-75%), passed the sonar site over a span of 30 days. The curve for daily averages of cumulative proportion of sonar escapement (1978 - 1983) shows a linear increase of approximately 1.6% per day for the central half of the population (Fig. 7). The same curve exhibits larger confidence intervals than those observed for the daily cumulative proportions from the censored average of catch (Figs. 5 and 7).

The averages of daily proportions for estimated escapement were highly variable over the duration of the migration. The standard deviation of these observations revealed that actual daily proportions were extremely variable during the early part of the season (Table 4). The distribution of daily average proportions for sonar escapement

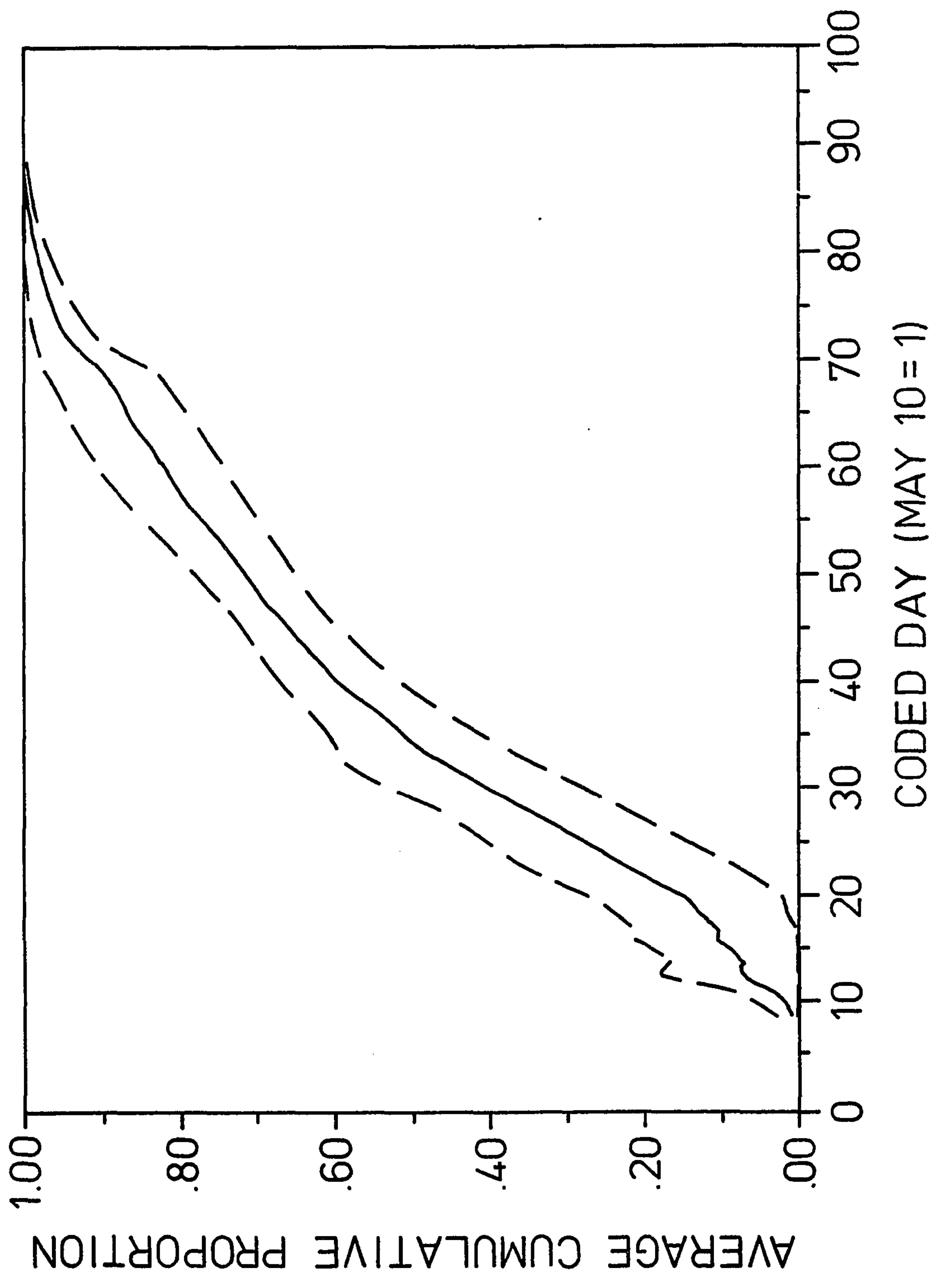
Table 4. Coefficients of variation and standard deviation (X100) of the average daily and cumulative proportions of sockeye escapement by date, 1978 -1983. The number of observations (N) also is shown.

Date	N	Daily Average	C.V.	Standard Deviation	N	Cum. Average	C.V.	Standard Deviation
517	2	.0050	98	.49	2	.0050	98	.49
518	4	.0053	137	.73	4	.0079	147	1.16
519	4	.0065	131	.85	4	.0144	140	2.02
520	4	.0125	84	1.06	4	.0270	98	2.65
521	4	.0311	131	4.09	4	.0582	91	5.31
522	4	.0163	94	1.54	4	.0746	90	6.76
523	5	.0101	56	.56	5	.0698	103	7.24
524	5	.0160	51	.83	5	.0860	91	7.90
525	5	.0181	58	1.06	5	.1041	84	8.82
526	6	.0161	69	1.12	6	.1030	95	9.84
527	6	.0156	62	.97	6	.1187	87	10.34
528	6	.0123	58	.72	6	.1311	82	10.85
529	6	.0122	79	.97	6	.1434	81	11.65
530	6	.0231	41	.96	6	.1666	73	12.18
531	6	.0284	30	.86	6	.1952	64	12.54
601	6	.0244	29	.71	6	.2197	56	12.47
602	6	.0253	39	.98	6	.2450	50	12.33
603	6	.0217	27	.60	6	.2668	45	12.25
604	6	.0229	33	.77	6	.2898	40	11.73
605	6	.0256	28	.73	6	.3155	35	11.23
606	6	.0245	15	.39	6	.3401	32	11.08
607	6	.0266	35	.93	6	.3668	30	11.31
608	6	.0275	44	1.22	6	.3945	29	11.72
609	6	.0244	28	.69	6	.4190	29	12.23
610	6	.0241	22	.53	6	.4432	27	12.13
611	6	.0219	46	1.01	6	.4651	24	11.30
612	6	.0188	62	1.18	6	.4841	21	10.39
613	6	.0174	47	.82	6	.5016	19	9.67
614	6	.0166	46	.77	6	.5183	17	9.12
615	6	.0199	39	.78	6	.5382	15	8.55
616	6	.0172	26	.45	6	.5555	14	8.30
617	6	.0178	35	.63	6	.5734	13	7.84
618	6	.0152	39	.59	6	.5887	12	7.40
619	6	.0129	56	.73	6	.6017	12	7.23
620	6	.0123	63	.77	6	.6141	11	6.96
621	6	.0122	51	.63	6	.6264	10	6.66
622	6	.0118	41	.48	6	.6383	10	6.39
623	6	.0132	51	.67	6	.6516	9	6.20
624	6	.0125	54	.68	6	.6642	9	5.98
625	6	.0127	38	.49	6	.6770	8	5.86
626	6	.0108	34	.37	6	.6878	8	5.99
627	6	.0104	50	.52	6	.6983	8	6.23
628	6	.0096	33	.32	6	.7079	8	6.22
629	6	.0104	35	.37	6	.7184	8	6.42
630	6	.0107	33	.35	6	.7292	9	6.64
701	6	.0105	29	.31	6	.7398	9	6.68
702	6	.0111	56	.62	6	.7510	9	6.83
703	6	.0117	55	.65	6	.7628	9	6.98

Table 4. (continued)

Date	N	Daily Average	C.V.	Standard Deviation	N	Cum. Average	C.V.	Standard Deviation
704	6	.0131	57	.75	6	.7760	9	7.24
705	6	.0115	40	.46	6	.7876	9	7.48
706	6	.0094	30	.28	6	.7971	9	7.67
707	6	.0084	31	.26	6	.8055	9	7.79
708	6	.0086	16	.13	6	.8142	9	7.79
709	6	.0087	28	.25	6	.8230	9	7.74
710	6	.0101	43	.44	6	.8332	9	7.70
711	6	.0106	53	.56	6	.8438	8	7.54
712	6	.0093	52	.49	6	.8532	8	7.37
713	6	.0069	52	.36	6	.8602	8	7.25
714	6	.0083	56	.47	6	.8686	8	7.13
715	6	.0084	47	.39	6	.8771	7	6.98
716	6	.0100	59	.59	6	.8871	7	6.89
717	6	.0082	60	.50	6	.8954	7	6.86
718	6	.0117	54	.63	6	.9073	7	6.40
719	6	.0147	83	1.23	6	.9221	5	5.31
720	6	.0137	88	1.21	6	.9359	4	4.29
721	6	.0113	80	.90	6	.9473	3	3.54
722	6	.0073	59	.43	6	.9546	3	3.14
723	6	.0058	62	.36	6	.9606	2	2.82
724	6	.0055	60	.33	6	.9662	2	2.55
725	6	.0043	66	.29	6	.9706	2	2.27
726	5	.0042	39	.16	6	.9741	2	2.08
727	5	.0035	60	.21	6	.9772	1	1.85
728	5	.0039	77	.30	6	.9805	1	1.59
729	5	.0034	87	.30	6	.9835	1	1.32
730	4	.0043	57	.24	6	.9864	1	1.07
731	4	.0036	59	.21	6	.9888	0	.88
801	4	.0039	34	.13	6	.9915	0	.69
802	4	.0033	32	.11	6	.9938	0	.52
803	4	.0027	41	.11	6	.9956	0	.38
804	4	.0028	52	.15	6	.9976	0	.30
805	3	.0018	45	.08	6	.9985	0	.20
806	3	.0018	59	.11	6	.9995	0	0
807	2	.0012	76	.09	6	.9999	0	0

Figure 7. Average cumulative proportions of escapement and the 95% confidence interval for years 1978 - 1983, Miles Lake sonar site.


AVERAGE CUMULATIVE PROPORTION
1.00
.80
.60
.40
.20
.00
CODED DAY (MAY 10 = 1)
0
10
20
30
40
50
60
70
80
90
100

appeared less symmetrical than average proportions for catch (Fig. 6 and 8). Daily variances of the cumulative proportions for estimated escapement fluctuated, peaking at the .22 cumulative proportion. The value of the coded standard deviations for the cumulative proportions were significantly smaller then those for the average and censored average of catch, over the course of the season (Table 1,2,4).

Using estimated escapement data, the mean dates of migration have varied between June 9 (1982) and June 23 (1980) during 1978 - 1983, and the range of median dates was June 4 (1982) - June 19 (1980) (Table 5). The mean difference between the mean date of the migration and the median date was 4.4, with a standard deviation of 1.52 for years 1978 - 1983.

The CV's for the daily proportions of sonar escapement were initially large, declining to a minimum about the grand mean date (June 17). Beyond the grand mean date, the daily CV's tended to increase (Table 4). The time series of CV's for the cumulative proportions decayed to the grand mean date, having a slope of -4.32. CV (13) of the cumulative proportion for sonar escapement at the grand mean date was approximately equal to the CV (12) at the grand mean for the censored average of catch.

Assuming the means of the migrations derived from catch are normally distributed, N(30.1, 21.5), it can be inferred that 95% of the migrations have means within the interval June 5 - June 11. It should be noted that the means of the migrations derived from CPUE were

Figure 8. Average daily proportions of escapement for years 1978 - 1983, Miles Lake sonar site.

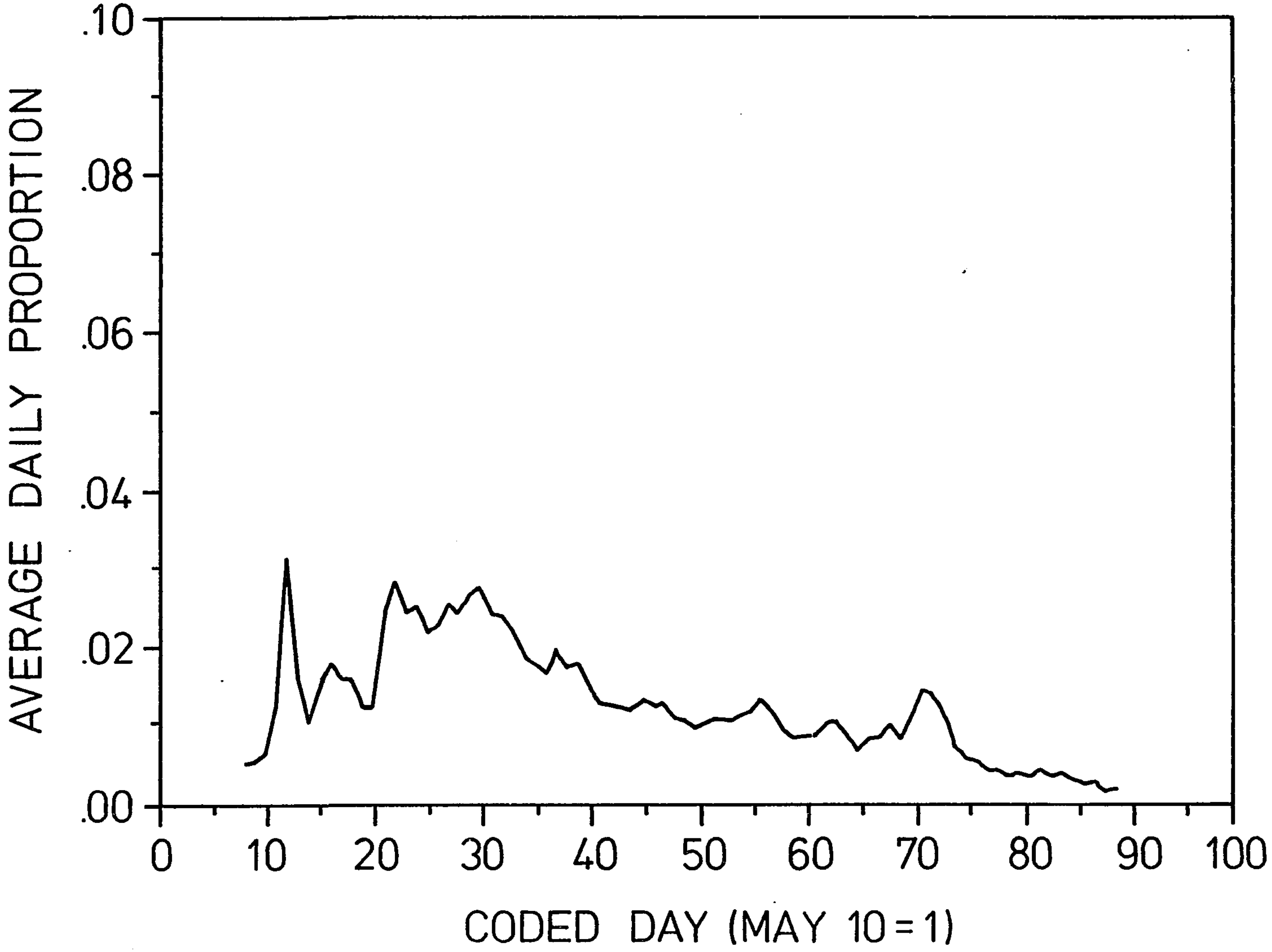

AVERAGE DAILY PROPORTION
.10
.08
.06
.04
.02
.00
0
10
20
30
40
50
60
70
80
90
100
CODED DAY (MAY 10 = 1)

Table 5. The coded dates for mean, median, and variance of sockeye salmon migration based on recorded escapement from the Miles Lake sonar site.

		Coded Date				
Year	Mean Date	Mean	Median	Variance	Skewness	Kurtosis
1978	June 18	40	38	164.1	-.0935	-0.8775
1979	June 20	42	37	379.9	.2277	-1.1734
1980	June 23	45+	41	315.2	.2731	-0.9020
1981	June 18	40	31	530.1	.3719	-1.2145
1982	June 09	31-	26	327.1	.6699	-0.6029
1983	June 19	41	35	373.8	.5035	-0.8222

$\bar{X}$ = 39.8; (SD = 4.7)

- Observation less than lower bound of 95% C.I. on $\bar{X}$

+ Observation greater than upper bound of 95% C.I. on $\bar{X}$

normally distributed, N(44.2,16.8) (Apppendix A). The grand mean calculated from CPUE differed by 14 days from the grand mean calculated from catch. The distribution of average daily proportions of CPUE differed considerably from the distribution of average daily proportions of catch (Appendix A). Also assuming the means of the migrations derived from sonar escapement are normally distributed, N(39.8, 21.6), it can be inferred that 95% of the migrations have means within the interval June 13 - June 22.

4.2 Lag time estimation and total population reconstruction

The correlation method for determining the average seasonal lag time between the commercial fishing area and the sonar site was successful for 4 out of the 6 years (1980 - 1983). The first year of operation for the sonar site (1978) began late in the season and was also in the experimental stage. Note that 1979 and 1980 were years when the fishery was closed for a major portion of the season. The correlation analysis for 1978 - 1979 yielded the highest negative r value for an unreasonable lag time of zero days (Table 6).

The correlation analysis for the years 1980 - 1982 produced the highest negative r value for a lag of 3 days (Table 6). Using the time series of the catch and escapement data for 1981, an example of the negative relation between the two categories was graphically demonstrated (Figs. 9a, 9b). A lag time of 4 days produced the highest negative r value (-.1166) for the year 1983. The average lag time for the years 1980 - 1983 was 3.25 days.

The average distance from the commercial fishing grounds to the sonar escapement enumeration site is approximately 61 km. The average rate of migration for 1980 - 1982 was 20.4 km day^{-1} and for the 1983 season it was 15.3 km day^{-1}. The mean of the average migration rates for the years 1980 -1983 calculated from the correlation method was 18.7 km day^{-1}.

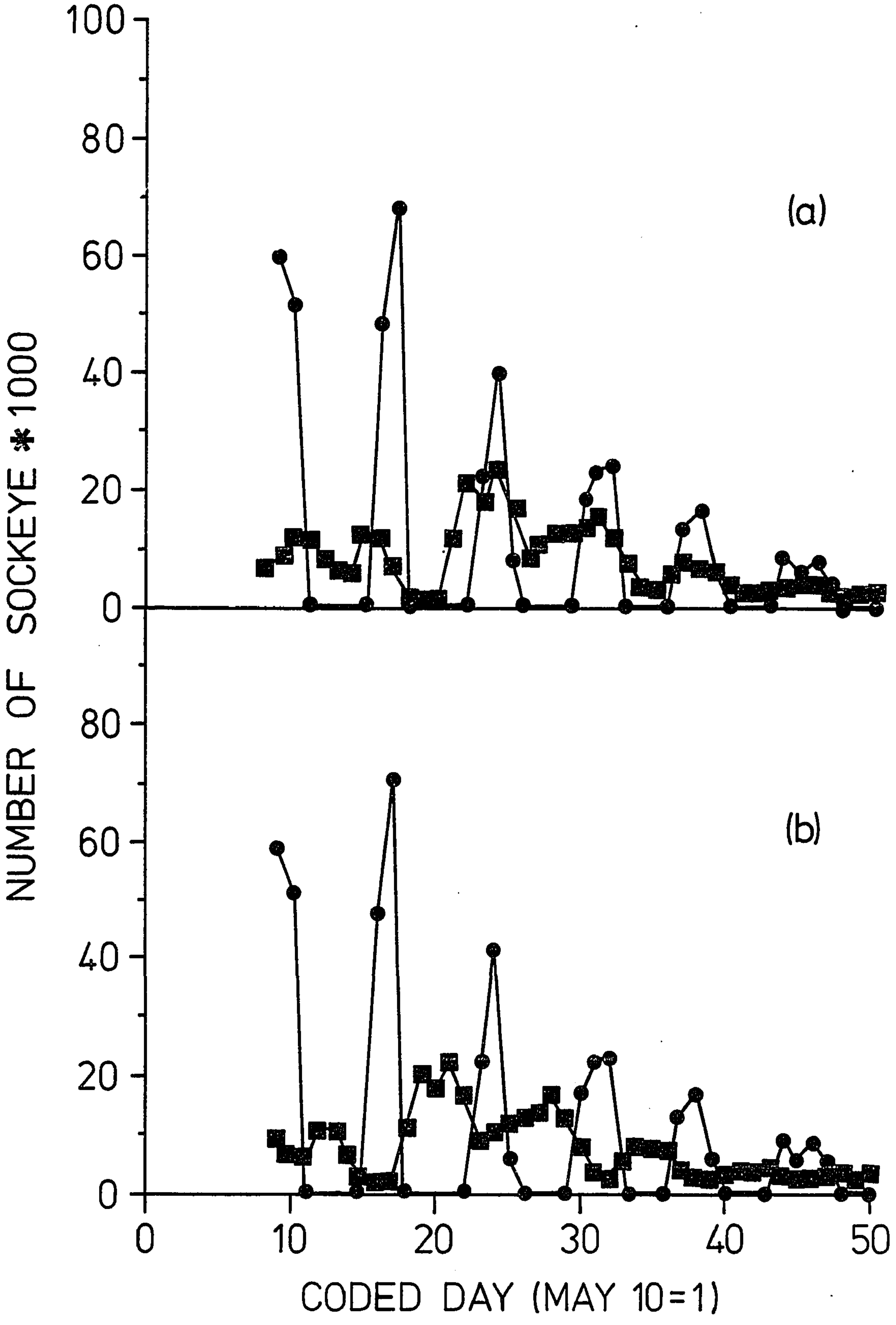
The lag times derived by minimizing the variance of catchability

Table 6. Pearson product moment correlations of the paired data sets for the commercial sockeye catch from the Copper River district (212) and the Miles Lake sonar escapement enumeration site, years 1978 - 1983. The number of days offset is equal to the number of days escapement is lagged back into the commercial fishing district.

			Pearson r Value			
Year	1978	1979	1980	1981	1982	1983
Day Offset						
0	-.22749	-.28123	.28102	.35477	.65773	.05441
1	.06661	.14343	.11565	.14751	.26349	.37866
2	.07578	.37288	-.07754	-.08441	-.00960	.23326
3	.14125	.03161	-.17549	-.20755	-.02301	-.03474
4	.15559	-.03563	-.08130	-.08324	.07074	-.11659
5	.06358	.22166	.07519	.29559	.28852	-.02728
6	.14257	.20797	.38942	.49838	.12093	.01457
7	.14827	-.03577	.36254	.51416	-.00893	.28195
8	.23364	.09868	.15455	.31602	.09192	.51480
9	.10376	.24641	.07509	-.00537	.16954	.26740
10	-.06725	.39068	.11124	-.15448	.09305	-.05031
11	-.01485	.58814	.01507	-.04228	.06233	-.08378
12	.33349	.51776	.18670	.25784	.12554	.08794
n_a	29	33	32	42	36	43

(a) n denotes number of data pairs

Figure 9. The top graph (a) is the time series of catch (o) compared to the time series of escapement (+) lagged zero days for the year 1981. The bottom graph (b) is the time series of catch (o) compared to the time series of escapement (+) lagged 3 days for the year 1981.


100
80
60
40
20
0
80
60
40
20
0
NUMBER OF SOCKEYE * 1000
(a)
(b)
0
10
20
30
40
50
CODED DAY (MAY 10=1)

were consistantly larger for all years. The minimization technique calculated a lag time 3 days greater than the correlation technique for 1983 (Table 6, 7). The lag times calculated by minimizing the variance of catchability were 1 day larger for 1981 and 2 days larger for 1982. Note that the coefficients of variation for 1982 differed by less than 1.1 % for the lag times from 3 to 5 days (Table 7). The coefficients of variation for 1983 reached a minimum at a 5 day lag then began to increase and then declined to a second minimum at a 7 day lag (Table 7).

The mean for the average rates of migration calculated from minimizing the variance of catchability was 12.4 km day^{-1} for 1978 - 1983. On the average, the correlation method for calculating lag time yielded a average migration rate which was 4.2 km day^{-1} faster.

After the lag times were estimated, the time series of data for sonar escapement was shifted back into the time series of catch to give the time series of estimated abundance (reconstructed total population) (Appendix B).

Using the estimated total population data, the mean dates of migration have varied between May 31 (1978, 1981) and June 6 (1980) during the years 1978 through 1983 (Table 8). The range limits of the mean dates calculated from catch for the first fifty coded days of the migration (May 10 = day 1) were May 26 (1979) to June 5 (1983). Assuming that the means of the migrations calculated from the estimates of total population were normally distributed, N (23.9, 4.57), it can be inferred that 95% of the migrations have means within the interval May

Table 7. The average seasonal catchability coefficient (q) the standard deviation, and coefficient of variation (CV) calculated from various lag times. The rates of migration calculated from the lag times that produced the lowest CV.

Year	Lag time (days)	n	$\bar{q}$	SD	CV	Lag time minimum CV	rate of migration km day^{-1}
1978	2	13	.01583	.01108	69.96		
	3	16	.01607	.01195	74.40		
	4	14	.01492	.00993	69.96	4	15.5
	5	14	.01415	.01019	72.01		
	6	14	.01637	.01396	85.30		
	7	14	.01616	.01490	92.24		
1979	2	6	.00561	.00305	54.46		
	3	6	.00582	.00248	42.75		
	4	6	.00613	.00156	25.48	4	15.5
	5	6	.00581	.00202	34.86		
	6	6	.00552	.00201	36.34		
	7	6	.00547	.00225	41.11		
1980	2	6	.00869	.01746	200.96		
	3	6	.00378	.00528	139.67	3	20.4
	4	6	.00231	.00337	146.40		
	5	6	.00234	.00403	171.74		
	6	6	.00163	.00287	176.47		
	7	6	.00271	.00192	151.05		
1981	2	17	.01758	.01879	106.89		
	3	17	.01801	.01720	95.47		
	4	17	.01717	.01524	88.74	4	15.5
	5	17	.01665	.02367	104.22		
	6	17	.01573	.01657	105.35		
	7	17	.01598	.01679	105.06		
1982	2	33	.03068	.03744	122.10		
	3	33	.02515	.02605	82.10		
	4	33	.02544	.02085	81.90		
	5	33	.02711	.02210	81.50	5	12.2
	6	33	.02729	.02277	83.40		
	7	33	.02705	.02303	85.10		
1983	2	17	.02844	.03156	110.90		
	3	17	.02858	.03035	106.20		
	4	17	.03169	.03354	105.80		
	5	17	.03106	.03209	103.30		
	6	18	.02993	.03238	107.90		
	7	18	.02770	.02827	102.10	7	8.7

Table 8. The coded means, and variances of adult sockeye salmon migration based on the reconstructed total population, commercial catch, and sonar escapement for the first 50 coded days from Copper River district (212).

		Coded Date			
Year	Mean date	Mean	Variance	Skewness	Kurtosis
		Reconstructed Total Population			
1978a	May 31	22.7	123.41	0.4619	-0.7330
1979a,b	June 01	23.1	50.23	0.8909	-0.2931
1980b	June 06	28.5	50.38	-0.2842	-0.5279
1981	May 31	22.5	120.01	0.5069	-0.5606
1982	June 01	23.5	116.11	0.5687	-0.7352
1983	June 05	27.1	126.82	0.4053	-0.7928
$\bar{X}$ for the coded mean date = 24.5; (SD = 2.56)					
Xb for the coded mean date = 23.9; (SD = 2.14)					
			Catch		
1978	May 29	20.1	115.55	0.6137	-0.6503
1979b	May 26	17.7	3.19	0.2732	-0.8776
1980b	June 01	23.9	38.55	-0.9233	0.3339
1981	May 30	21.9	120.58	0.6137	-0.6503
1982	June 01	23.9	106.14	0.5208	-0.4749
1983	June 04	26.7	144.94	0.4344	-0.8908
$\bar{X}$ for coded mean date = 22.3; (SD = 3.18)					
Xb for coded mean date = 23.2; (SD = 2.83)					
			Escapement		
1978	June	30.39	66.69	0.0774	-1.1606
1979	June 04	26.49	50.32	0.2372	-0.8776
1980	June 06	28.48	50.32	-0.2838	-0.5363
1981	June 01	23.32	118.38	0.3902	-0.3991
1982	May 31	27.51	106.13	0.3946	-0.7776
$\bar{X}$ for coded mean date = 26.39; (SD = 3.11)					
Xb for coded mean date = 25.85; (SD = 3.78)					

a - Years lag time calculated by minimizing variance of q.

b - Years fishery was closed for a substantial portion of the season.

29 - June 5. Also assuming the means of the migrations calculated from catch of the first fifty coded days of the migration are normally distributed, N (23.2, 8.0), it can be inferred that 95% of the migrations have means within the interval May 27 - June 5.

The average seasonal rates of exploitation for the commercial sockeye fishery, calculated from the regression model, ranged from 0.0198 (1980) to 0.862 (1978). The coefficients of determination for the regression analysis were all above 0.95 with the exception of 1980 which was 0.124 (Table 9). The mean value for the average seasonal rates of exploitation (1978 - 1983) was 0.7011, but the mean for the censored years (1978, 1981 - 1983) was 0.8587.

After reconstructing the time distribution of total population, for the years 1978 - 1983, it was observed that the value of catchability (q) was related to the effort (number of boats) (Fig. 9). The number of boats was adjusted by the proportion of the day the fishery was opened. The relation between the value of q and the effort was strengthened by adjusting the number of boats (Fig. 10, 11). No apparent relation was observed between q and the coded day of the season (Fig. 12).

The results of a forward stepwise regression analysis of the dependent variable q on the independent variables effort (standardized number of boats), coded day of the season, and catch, for the years 1981 - 1983, did not show a significant improvement over the single variable regression model of effort (Table 10). The addition of the independent variables, (coded day and catch), increased the coefficients of

Table 9. Average seasonal rates of exploitation derived by regression model which was forced through the origin. The independent variable is total population and the dependent variable is catch.

Year	Rates of exploitation	r^2	n	Upper 95% C.I.	Lower 95% C.I.
1978	.8260	.9971	14	.9297	.7942
1979	.7970	.9714	6	.9319	.6621
1980	.0198	.1240	6	.0527	.0000
1981	.8609	.9759	17	.9145	.8073
1982	.8611	.9533	33	.9217	.8005
1983	.8059	.9902	17	.8450	.7667
1981-83	.8505	.9624	67	.8839	.8170

$\bar{X}$ = mean of rates of exploitation for 1978-1983 = .7011; (SD=.3350)
$\bar{X}$ = mean of rates of exploitation for 1978, 1981-83 = .8587; (SD=.0052)

Figure 10. The relation of catchability coefficients (calculated from the reconstructed migrations 1981 - 1983) , to the daily effort measured in number of boats.

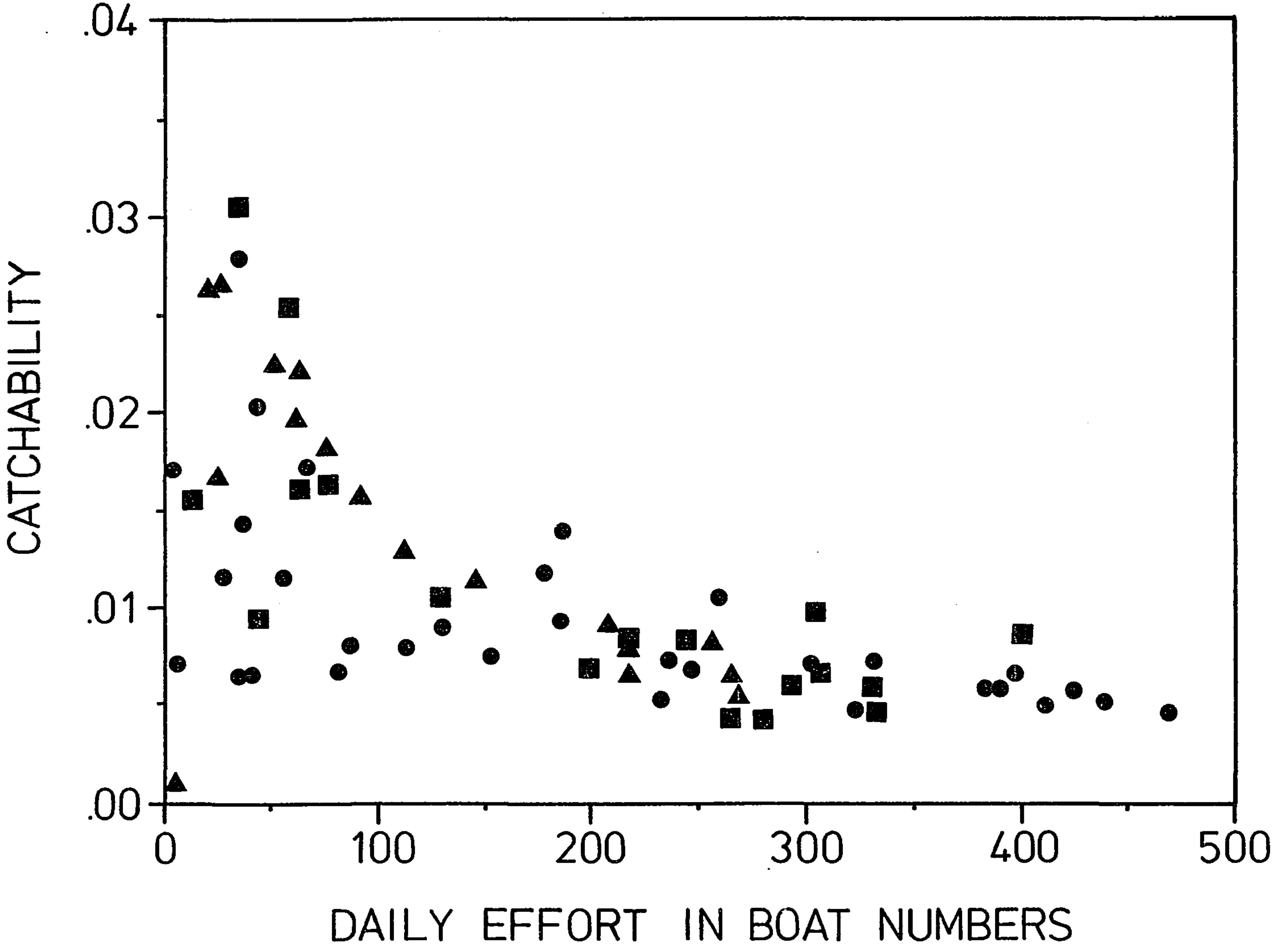

.04
.03
.02
.01
.00
CATCHABILITY
0
100
200
300
400
500
DAILY EFFORT IN BOAT NUMBERS

Figure 11. The relation of catchability coefficients (calculated from the reconstructed migrations 1981 - 1983), to the daily effort measured in number of boats standardized by the proportion of the day the fishery is open.

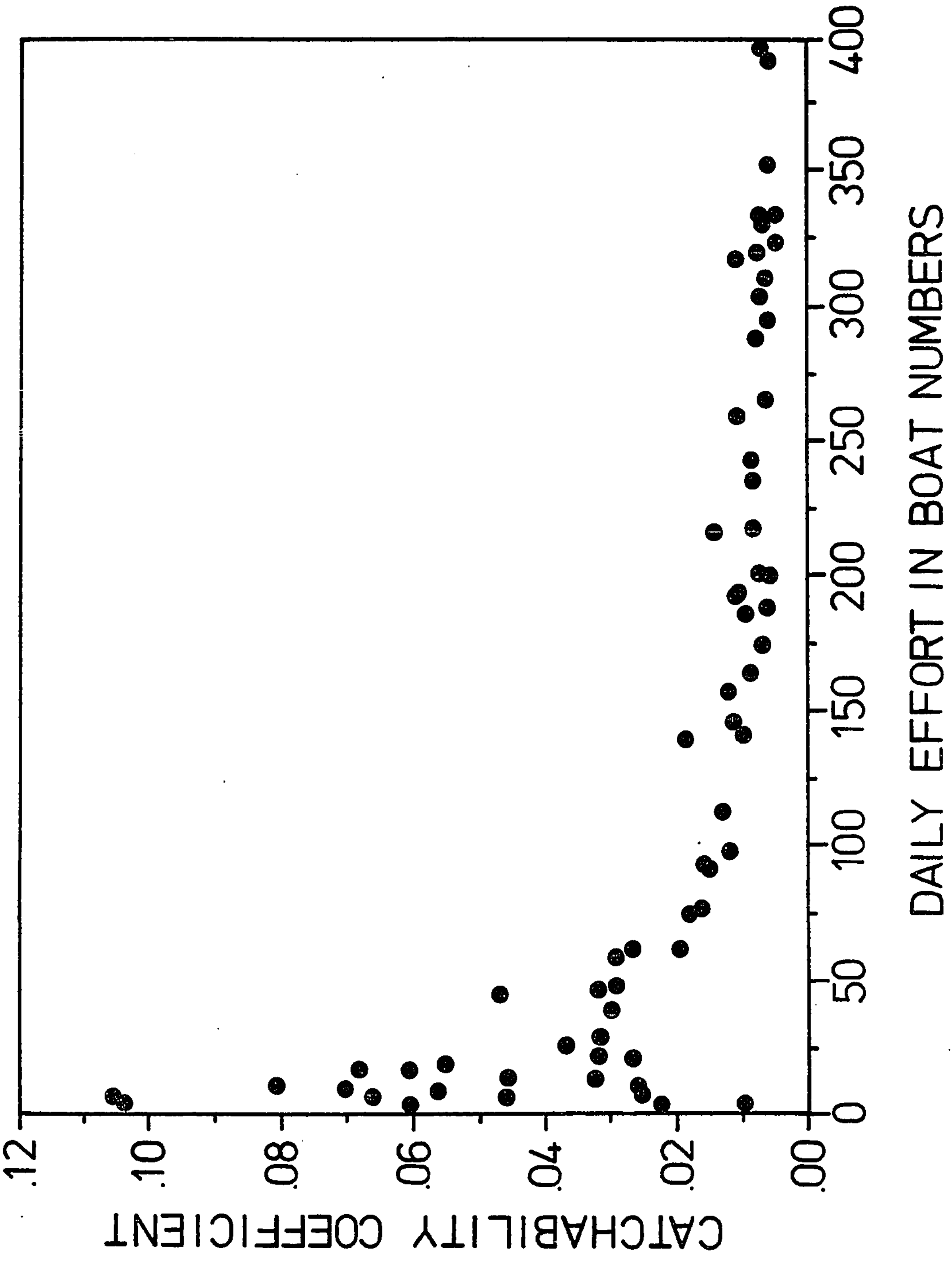

CATCHABILITY COEFFICIENT
.12
.10
.08
.06
.04
.02
.00
DAILY EFFORT IN BOAT NUMBERS
0
50
100
150
200
250
300
350
400

Figure 12. The relation of catchability coefficients (calculated from the reconstructed migrations 1981 - 1983), to the coded day of the season.

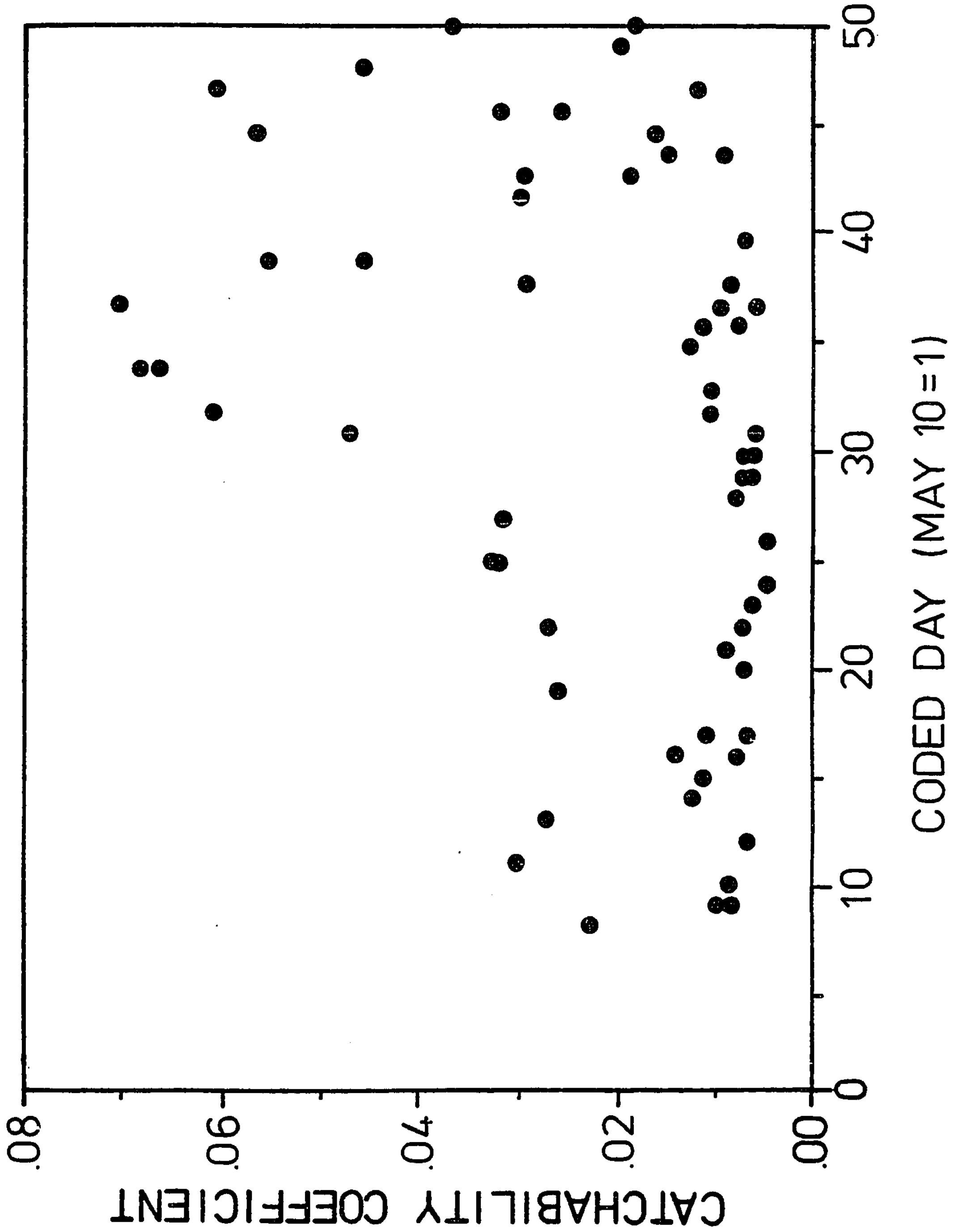

CATCHABILITY COEFFICIENT
.08
.06
.04
.02
.00
CODED DAY (MAY 10=1)
0
10
20
30
40
50

Table 10. Linear regression of catchability where effort was the adjusted number of boats.

Years	Effort	Coded Day	Catch
1981 - 1983			
r^2	.4793	.5017	.5243
CHANGE IN r^2	.4792	.0025	.0226

r^2 - the coefficients of determination
$p < .005$ for all tests

determination (r^2) by 0.022 each.

It was observed that the fit of the non-linear model was an improvement over the linear model (Fig. 13, 14). Of the non-linear models tested, for the years 1981 -1983, the power law model yielded the largest r^2 value of 0.7485 (Table 11).

The results of the regression analysis of q on effort for the individual years 1981 and 1983 again showed the power law model to provided the best fit (Table 11) (Fig. 15, 16). For 1982 the exponential model provided the best fit, with a coefficient of determination of 0.7629.

Figure 13. The linear regression of catchability on daily effort (measured by standardized number of boats), 1981 - 1983.

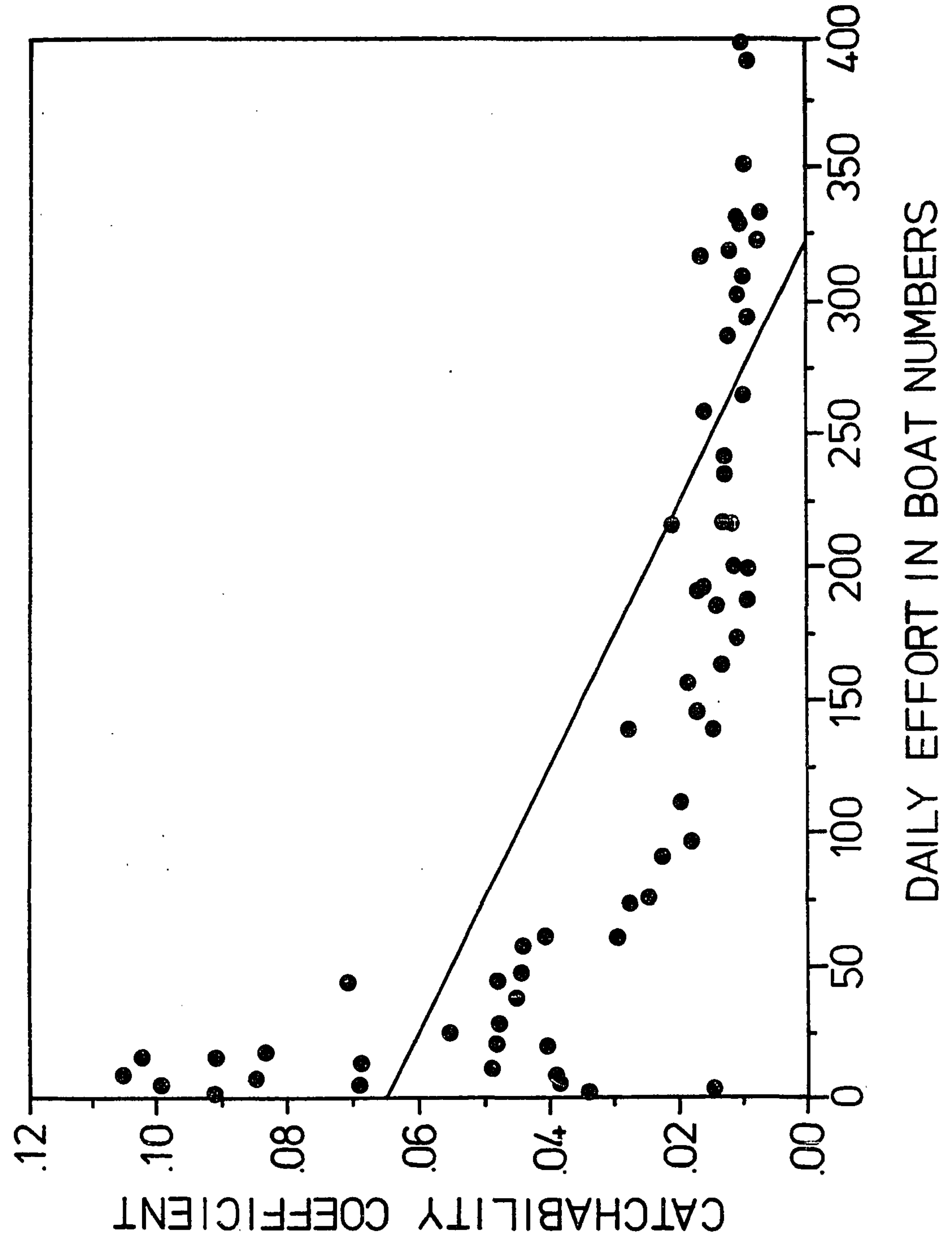

CATCHABILITY COEFFICIENT
.12
.10
.08
.06
.04
.02
.00
DAILY EFFORT IN BOAT NUMBERS
0
50
100
150
200
250
300
350
400

Figure 14. The regression of catchability on daily effort (measured by standardized number of boats) using the linearized power law model, 1981 - 1983.

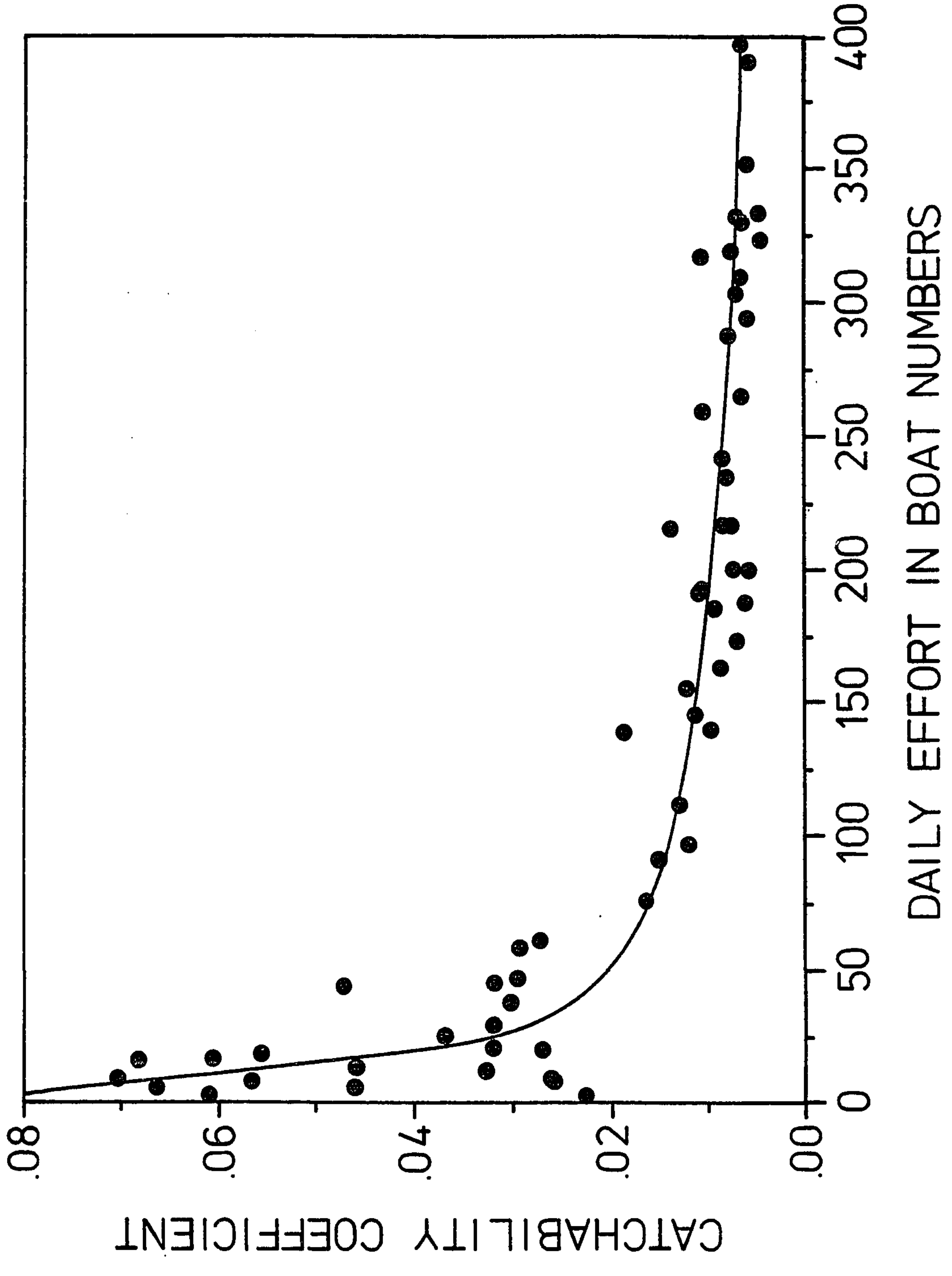

CATCHABILITY COEFFICIENT
.08
.06
.04
.02
.00
DAILY EFFORT IN BOAT NUMBERS
0
50
100
150
200
250
300
350
400

Table 11. Linear and curve-linear regression analysis of catchability on effort (standardized number of boats).

Year	A+(BX)	A*EXP(B*X)	A+B*LOG(X)	$A*X^B$
1981				
r^2	.6195	.7417	.8102	.8491
1982				
r^2	.5335	.7629	.5165	.6492
1983				
r^2	.5914	.8420	.9072	.9774
1981 - 1983				
r^2	.4791	.7378	.6188	.7485

Figure 15. The regression of catchability on daily effort (measured by the standardized number of boats) using the linearized power law model, 1981.

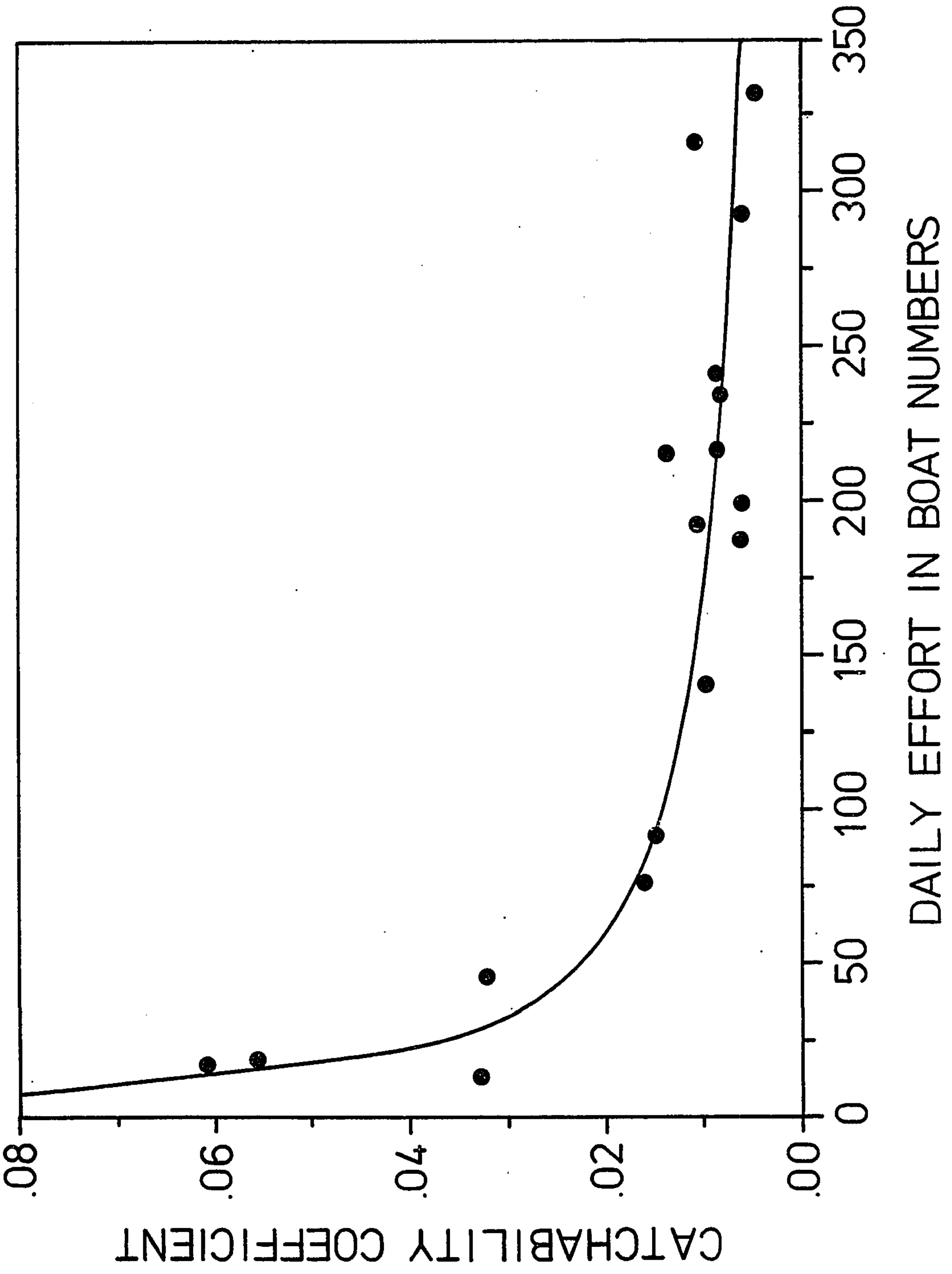
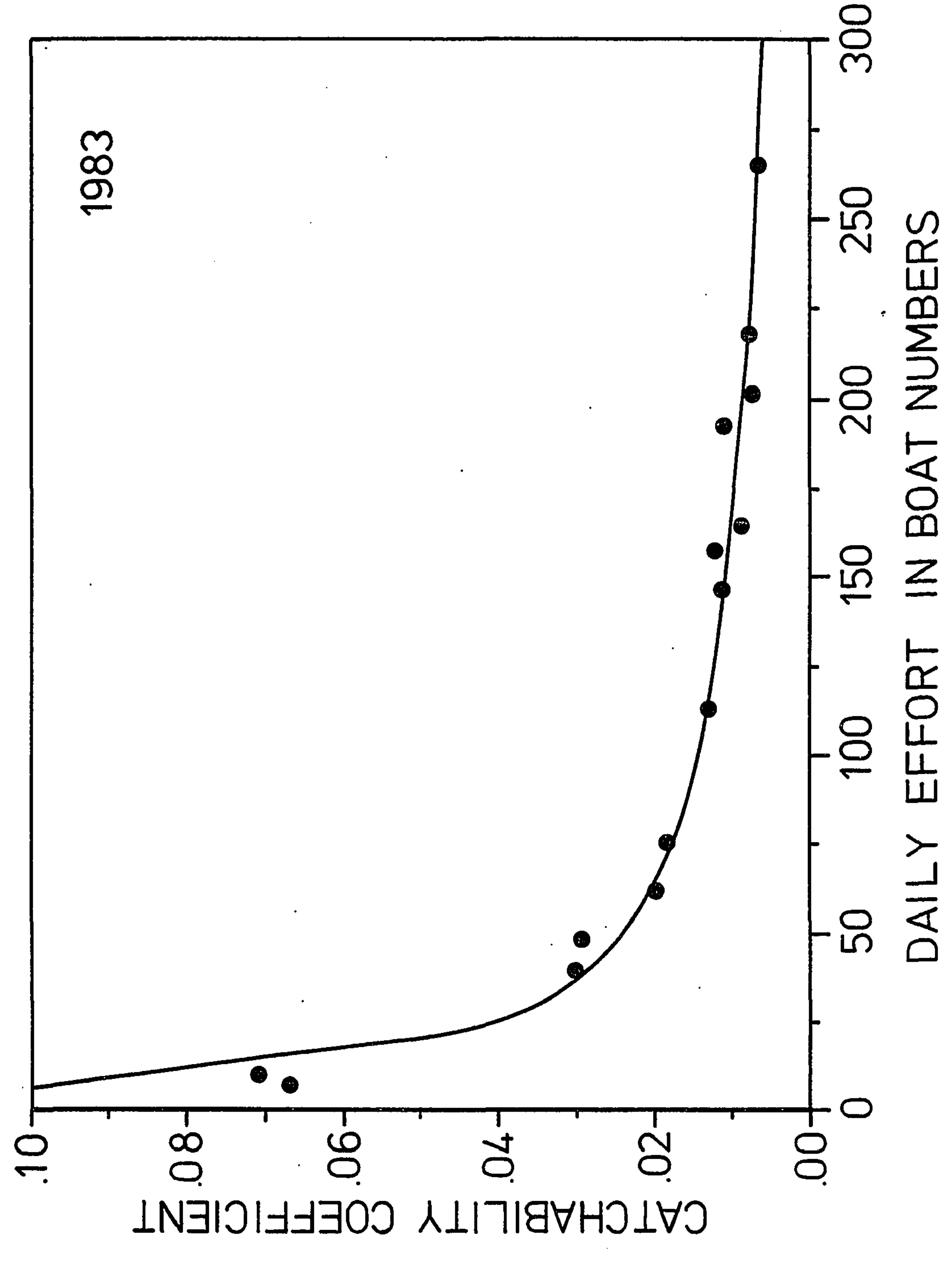

CATCHABILITY COEFFICIENT
.08
.06
.04
.02
.00
DAILY EFFORT IN BOAT NUMBERS
0
50
100
150
200
250
300
350

Figure 16. The regression of catchability on daily effort (measured by standardized number of boats) using the linearized power law model, 1983.


1983
CATCHABILITY COEFFICIENT
.10
.08
.06
.04
.02
.00
DAILY EFFORT IN BOAT NUMBERS
0
50
100
150
200
250
300

4.3 Simulation results

Baseline Model Results

The means calculated from the observed catch and the baseline simulated catch differed by 7 days and escapement means differed by 11 days for 1978 (Table 8, 12). The variances for the same categories differed by 36 and 64 days respectively. The baseline simulation for 1979 also revealed large differences between observed and simulated descriptive statistics (Table 8, 12). The were no differences observed between descriptive statistics calculated for the observed and simulated data for 1980.

The years 1978 and 1979 were not used in any further simulations because of poor results. The 1980 data was not considered to be representative of the migration because of extended closure of the fishing season.

The four descriptive statistics calculated from the observed and baseline simulated catch were identical for the years 1981 and 1982 (Table 8, 12). The MA%E between the observed and simulated catch was less than 1 percent for 1981 and 1982. The means of escapement differed by less than 0.2 days for 1981 and 1982. The variances of observed and baseline simulated escapement for 1981 and 1982 differed by a few days

Table 12. Coded descriptive statistics for baseline simulations years 1978 - 1983.

Category	Mean	Variance	Skewness	Kurtosis
		1978		
A	22.74	123.41	0.4621	-0.7329
C	27.19	79.14	1.0631	-0.6695
CPUE	30.94	101.51	0.0989	-1.7619
E	20.48	130.87	0.7930	-0.7679
		1979		
A	23.12	50.22	0.8910	-0.2929
C	17.91	3.16	0.0364	-0.5153
CPUE	18.00	3.99	0.1553	-1.3891
E	29.89	43.63	0.1593	-0.7354
		1980		
A	28.46	50.38	-0.2847	-0.5279
C	23.81	40.27	-0.9214	0.2197
CPUE	22.53	57.66	-0.5781	-0.9028
E	29.48	50.33	-0.2837	-0.5365
		1981		
A	22.51	120.01	0.5068	-0.5606
C	21.89	120.59	0.6132	-0.6511
CPUE	28.58	164.01	0.0039	-1.2804
E	24.03	113.89	0.3556	-0.4382
		1982		
A	23.51	116.10	0.5689	-0.7350
C	23.94	106.08	0.5207	-0.8840
CPUE	26.69	153.85	0.1847	-1.1487
E	23.03	135.03	0.7256	-0.4666
		1983		
A	26.59	133.07	0.3674	-0.7774
C	28.32	133.04	0.4213	-1.0382
CPUE	26.79	103.91	-0.8372	-0.2156
E	25.69	113.13	0.1907	-0.7231

A - Arrival of salmon into the harvest area
C - Commercial catch
CPUE - Commercial catch per boat hour
E - Escapement from commercial harvest area

(Table 8, 12). The MA%E for observed and baseline simulated escapement was less than 0.5 percent for 1981 and 1982 (Table 13).

The descriptive statistics calculated from the baseline simulation of catch for 1983 differed noticeably from the observed values (Table 8, 12). Descriptive statistics calculated from observed and simulated escapement also displayed distinct differences (Table 8, 12). The MA%E calculated between observed and simulated values of catch and escapement were in the 30 percent range (Table 13).

The simulations incorporating a regression model for q, of an individual year, produced an increase in MA%E for catch ranging from 0 to 20 percent over the baseline MA%E (Table 13). The increase in MA%E for escapement over the baseline values, for the previously mentioned regression models, ranged from 3 to 20%.

The simulations using the regression model for q, derived from 1981 - 1983 data, displayed an increase in MA%E for catch which ranged from 0 to 30 percent (Table 13). The increase in MA%E for escapement over the baseline simulations for the same regression model ranged from 3 to 25 percent (Table 13).

The effects of varying the catchability over time were examined by comparing the simulations which use an average value of q with those simulations employing the baseline and regression models. The means calculated for catch showed no differences between average and variable q simulations (Table 14). There was a reduction in the variances

Table 13. The MA%E for the time series of observed and simulated catch and observed and simulated escapement.

Category	Catch	Escapement
	Baseline	
1981	0.25	0.17
1982	0.99	0.50
1983	36.84	39.74
	q_a	
1981	10.87	18.82
1982	23.41	21.85
1983	36.17	43.34
	q_b	
1981	11.69	18.02
1982	38.84	26.90
1983	23.69	42.09
	q_c	
1981	23.52	28.52
1982	25.05	44.13
1983	38.40	54.17
	q_d	
1981	24.45	25.45
1982	37.41	57.86
1983	31.15	45.23

a - The q used in these simulations were calculated by the regression model that best fit each year.

b - The q used in these simulations were calculated by the regression model that best fit the years 1981 -1983.

c - q was an average value

d - q was an average weighted by number of boats on an interval

Table 14. Coded descriptive statistics for simulations using regression models for estimating q and simulations using average values of q.

Category	Mean	Variance	Skewness	Kurtosis
		q_a		
		1981		
A	22.51	120.01	0.5068	-0.5606
C	22.11	117.18	0.5422	-0.6800
CPUE	27.97	146.79	0.0951	-1.0816
E	23.78	118.32	0.4374	-0.4652
		1982		
A	23.51	116.10	0.5689	-0.7350
C	24.00	106.19	0.5235	-0.8472
CPUE	23.89	163.60	0.4393	-1.0384
E	22.88	132.78	0.7251	-0.5202
		1983		
A	26.59	133.07	0.3674	-0.7774
C	26.80	148.48	0.3523	-0.9032
CPUE	35.67	121.63	-0.8870	-0.0231
E	27.91	94.11	0.2987	-0.6591
		q_b		
		1981		
A	22.52	120.01	0.5068	-0.5606
C	21.89	114.42	0.5515	-0.6586
CPUE	27.43	149.49	0.1246	-1.1096
E	24.05	121.08	0.4229	-0.4971
		1982		
A	23.51	116.10	0.5689	-0.7350
C	23.69	105.16	0.5460	-0.8080
CPUE	22.46	175.72	0.5634	-1.0005
E	23.64	138.02	0.6251	-0.7127
		1983		
A	26.59	133.07	0.3674	-0.7774
C	26.20	145.48	0.4026	-0.8214
CPUE	34.69	136.49	-0.7271	-0.4684
E	28.53	99.41	0.2477	-0.7695

Table 14. continued.

Category	Mean	Variance	Skewness	Kurtosis
		q_c		
		1981		
A	22.51	120.01	0.5068	-0.5606
C	21.62	111.26	0.5510	-0.6697
CPUE	26.27	154.39	0.1897	-1.1748
E	24.61	125.22	0.3968	-0.4981
		1982		
A	23.51	116.10	0.5689	-0.7350
C	23.82	103.84	0.5390	-0.8450
CPUE	24.09	154.94	0.4306	-1.0095
E	22.82	149.28	0.7195	-0.6027
		1983		
A	26.59	133.07	0.3674	-0.7774
C	26.45	149.33	0.4065	-0.8557
CPUE	33.31	157.30	-0.5111	-0.9225
E	29.01	91.26	0.2173	-0.7414
		q_d		
		1981		
A	22.52	120.01	0.5068	-0.5606
C	21.16	103.82	0.5651	-0.6117
CPUE	24.98	147.69	0.3014	-1.0874
E	24.90	130.22	0.3710	-0.6368
		1982		
A	23.51	116.10	0.5689	-0.7530
C	23.56	97.89	0.5590	-0.8337
CPUE	24.27	139.65	0.4347	-0.9571
E	23.82	147.04	0.5641	-0.8520
		1983		
A	26.59	132.94	0.0367	-0.7774
C	25.43	135.69	0.5242	-0.5718
CPUE	31.32	171.26	-0.2253	-1.2205
E	29.97	108.54	0.1092	-0.9650

a - The q used in these simulations were calculated by the regression model that best fit each year.

b - The q used in these simulations were calculated by the regression model that best fit the years 1981 -1983.

c - q was an average value

d - q was an average weighted by number of boats on an interval

A - Arrival of salmon into the harvest area

C - Commercial catch

CPUE - Commercial catch per boat hour

E - Escapement from commercial harvest area

calculated from catch simulated using an average value of q for 1981 and 1982 (Table 14).

The means for escapement did not differ between average and variable q simulations. The variances calculated for simulated escapement, using an average value, of q displayed an increase over simulations using variable q (Table 14).

The MA%E for catch calculated by average q doubled over the values calculated using a variable q for 1981 and 1982 (Table 13). The MA%E for escapement calculated for average q increased 10 to 35 percent over escapement calculated by variable q (Table 13).

The means calculated for CPUE differed by 3 to 10 days from the means calculated for the arrival of sockeye (1981 - 1983) (Table 12). The means calculated for the CPUE from simulations using an average value of q only differed between the two categories by 1 to 3 days.

Normal Approximation for the Entry Distribution of Salmon

These simulations displayed an increase of 3 days for the mean calculated from catch over the observed values (Table 8, 15). The variances calculated from simulated catch displayed a decrease of 28 days from observed values. The means and variances calculated from escapement, for the same simulations , did not appreciably differ from observed data.

Table 15. Coded descriptive statistics from the baseline simulation using a normal approximation for the distribution of arriving salmon. The MA%E of observed and simulated data.

Category	MA%E	Mean	Variance	Skewness	Kurtosis
1981					
A		22.30	99.46	0.3136	-0.3612
C	47.87	24.79	91.62	0.1789	-0.6963
CPUE		28.87	89.56	0.1438	-0.5221
E	81.67	22.17	102.45	0.1070	-0.4677
1982					
A		23.23	98.57	0.2418	-0.3809
C	95.45	26.27	79.58	0.1072	-0.7397
CPUE		28.20	91.27	-0.2198	-0.4209
E	104.45	21.42	117.38	0.2383	-0.3339

A - Arrival of salmon into the harvest area
C - Commercial catch
CPUE - Commercial catch per boat hour
E - Escapement from commercial harvest area

The means calculated from catch for simulations using variable and average q did not appreciably differ from the simulations using empirical values of q (Tables 15 and 16). The variances calculated from catch for simulations using average values for q decreased from the simulations using empirical values of q.

The means calculated from escapement for simulations of average and variable q displayed no differences. The variances calculated from escapement for simulations using average values of q increased from simulations using empirical values of q (Table 15, 16).

The means for CPUE differed from the means of arrival of salmon by approximately 6 days. The means calculated for CPUE, simulated by using an average value of q, reduced the difference from the mean of arriving salmon (Table 16).

The regression analysis of the number of boats on the number of hours in a fishing period and the coded date of the migration had an r^2 value of 0.4526, and which was significant at the 0.005 level.

Empirical Distribution Used for Entry Distribution of Salmon

The management scenario M1, which opens one 48 hour period a week, only harvested 14 percent of the population for 1981. The simulation for 1982, M1 harvested 31 percent of the total population. The descriptive statistics calculated for simulated escapement approximated those of the arrival of salmon for 1981 and 1982 (Table 17). The

Table 16. Coded descriptive statistics from simulations using the normal approximation for the arriving distribution of salmon. An average value and a regression model are used to estimate q.

Category	Mean	Variance	Skewness	Kurtosis
		$q(a)$		
		1981		
A	22.30	99.47	0.3139	-0.3611
C	24.98	85.23	0.1220	-0.5564
CPUE	28.02	73.41	0.3800	-0.0460
E	22.06	104.04	0.1478	-0.4952
		1982		
A	23.23	98.57	0.2418	-0.3809
C	25.94	78.32	0.1632	-0.6322
CPUE	25.84	104.25	0.0173	-0.6205
E	21.74	110.25	0.1991	-0.4762
		$q(b)$		
		1981		
A	22.30	99.47	0.3139	-0.3611
C	24.53	81.29	0.0903	-0.6660
CPUE	26.93	90.24	0.1062	-0.4621
E	22.38	106.09	0.1467	-0.4842
		1982		
A	23.23	98.57	0.2418	-0.3809
C	25.47	74.63	0.1981	-0.7243
CPUE	25.95	95.71	0.0435	-0.4621
E	22.38	111.89	0.1459	-0.5153

A - Arrival of salmon into the harvest area
C - Commercial catch
CPUE - Commercial catch per boat hour
E - Escapement from commercial harvest area
$q_{(a)}$ - catchability calculated from the power law regression model
$q_{(b)}$ - average value of q weighted by the number of boats

Table 17. Coded descriptive statistics from simulations using two management scenarios. The arrival of salmon is generated from the migratory time density of the reconstructed total population.

Category	Mean	Variance	Skewness	Kurtosis
M1				
1981				
A	22.51	120.01	0.5068	-0.5606
C	20.43	86.51	0.2855	-0.4699
CPUE	21.70	90.70	0.2049	-0.5770
E	22.74	122.10	0.4907	-0.6605
1982				
A	23.51	116.10	0.5689	-0.7350
C	20.28	76.53	0.7007	-0.7113
CPUE	21.45	83.51	0.5200	-0.9757
E	24.72	121.88	0.4064	-0.9572
M2				
1981				
A	22.51	120.01	0.0568	-0.5606
C	23.79	131.24	0.2255	-0.8677
CPUE	29.55	154.30	-0.1665	-1.0409
E	21.55	108.70	0.7152	-0.1868
1982				
A	23.51	116.10	0.5689	-0.7350
C	25.83	99.13	0.1813	-0.6579
CPUE	30.86	126.04	-0.1129	-0.9405
E	21.74	118.29	0.8828	-0.4332

A - Arrival of salmon into the harvest area
C - Commercial catch
CPUE - Commercial catch per boat hour
E - Escapement from commercial harvest area
M1 - Management scenario with two 24 hour fishing periods per week
M2 - Management scenario with one 36 hour period and one 14 hour period per week

escapement appeared to be proportionately spread over the migration for 1981, but the simulated escapement was twice the desired escapement goal (Fig. 17).

The management scenario M2, which opens one 36 hour period and one 14 hour period a week, harvested 41 percent of the total population for 1981 and 1982. The descriptive statistics of escapement for 1981 and 1982 approximated the arrival distribution of salmon (Table 17). The escapement closely approximated the form of the theoretical escapement goal for 1981, but again over escapement was high (Fig. 18).

Normal Approximation for the Entry Distribution of Salmon

The M1 management scenario for these simulations harvested 25 percent of the population for 1981 and 1982. The distribution of escapement closely approximated the form of the theoretical escapement goal for 1981, but again simulated escapement was twice the goal for the M1 scenario (Fig. 19)

The M2 management scenario harvested 49 percent of the total population for 1981 and 1982. The descriptive statistics for escapement for 1981 and 1982 were almost identical to those for the arrival distribution of salmon (Table 18). The escapement closely approximated the form of the theoretical escapement goal, and the escapement was only 13 percent over the escapement goal (Fig. 20).

Figure 17. Theoretical escapement is a solid line, escapement simulated from a M1 management scenario is a dashed line (1981).

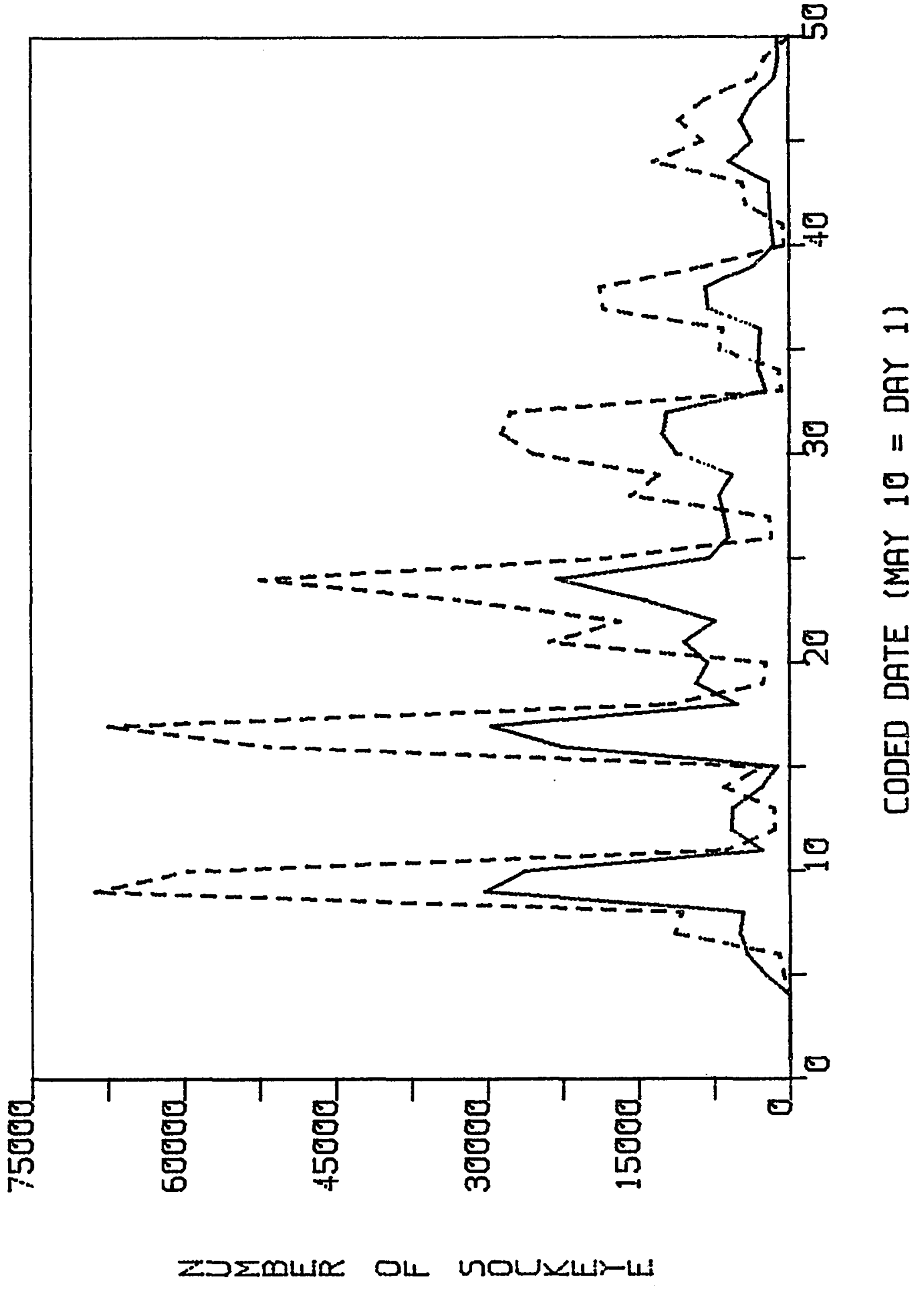

NUMBER OF SOCKEYE
75000
60000
45000
30000
15000
0
0
10
20
30
40
50
CODED DATE (MAY 10 = DAY 1)

Figure 18. Theoretical escapement is a solid line, escapement simulated from a M2 management scenario is a dashed line (1981).

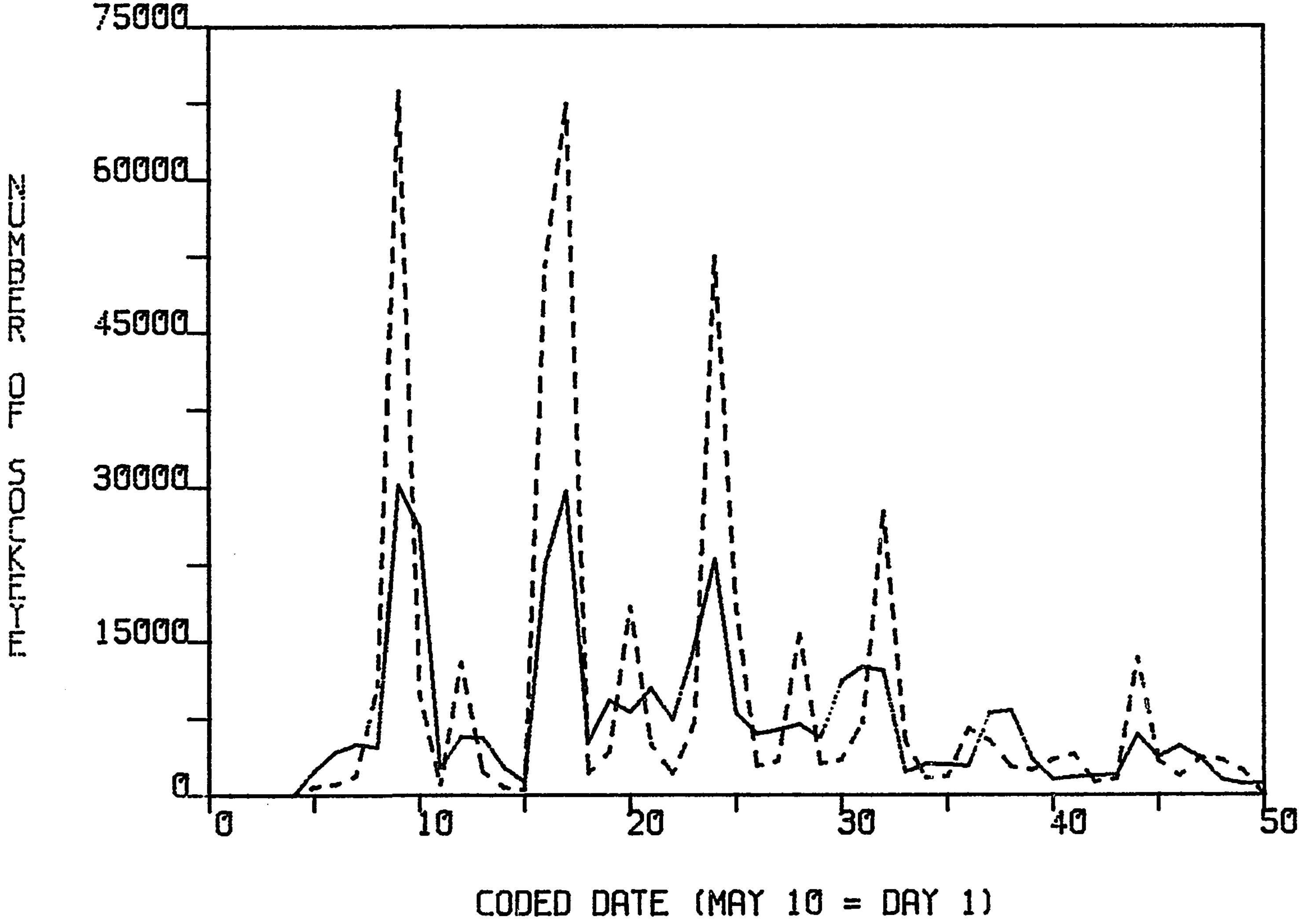

75000
60000
45000
30000
15000
0
NUMBER OF SOCKEYE
0
10
20
30
40
50
CODED DATE (MAY 10 = DAY 1)

Figure 19. Theoretical escapement is a solid line, escapement simulated from a M1 management scenario is a dashed line (1981).

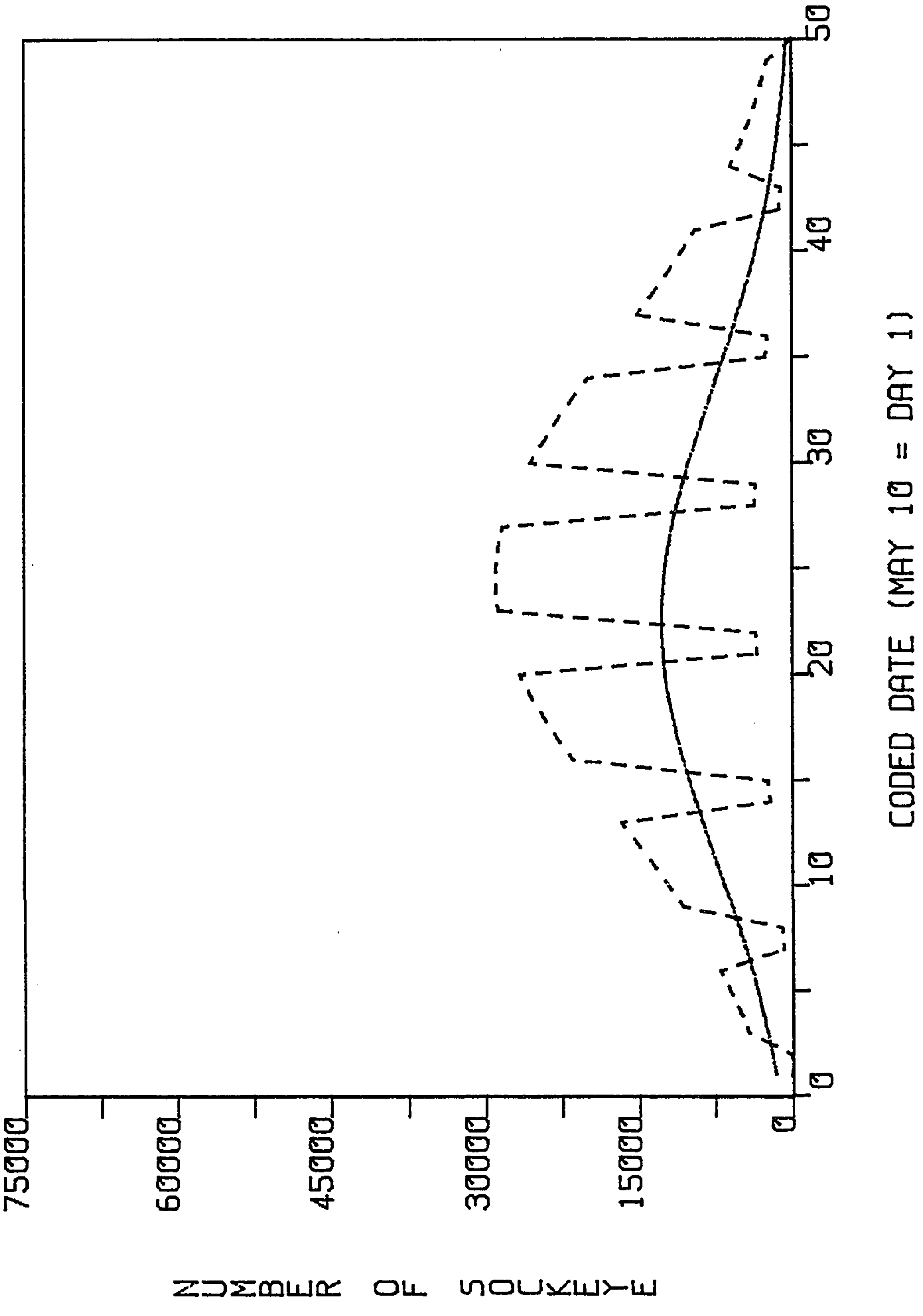
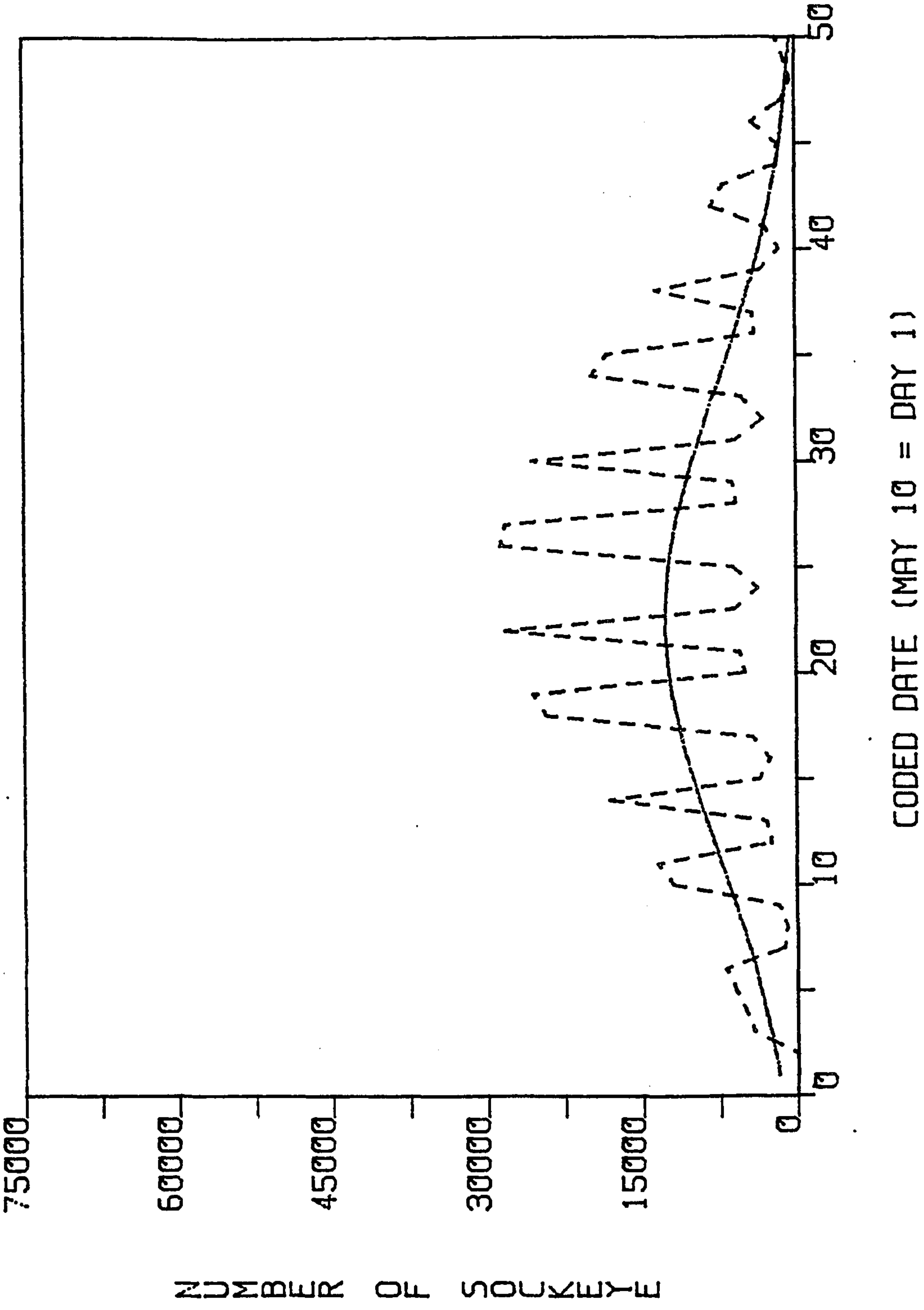

NUMBER OF SOCKEYE
75000
60000
45000
30000
15000
0
0
10
20
30
40
50
CODED DATE (MAY 10 = DAY 1)

Table 18. Coded descriptive statistics from simulations using two management scenarios. The arrival of salmon is generated by a normal approximation of the migratory time density of reconstructed total population.

Category	Mean	Variance	Skewness	Kurtosis
		M1		
		1981		
A	22.30	99.47	0.3139	-0.3611
C	22.50	89.32	0.0376	-0.7180
CPUE	23.81	90.33	-0.0620	-0.7293
E	23.01	104.04	0.1191	-0.4611
		1982		
A	23.23	98.57	0.2418	-0.3809
C	23.55	87.67	-0.0417	-0.6967
CPUE	24.85	87.71	-0.1396	-0.6873
E	23.77	103.40	0.0877	-0.4523
		M2		
		1981		
A	22.30	99.47	0.3139	-0.3611
C	22.93	91.39	0.2219	-0.4939
CPUE	26.89	109.62	0.0566	-0.6852
E	22.90	110.25	0.0428	-0.5079
		1982		
A	23.23	98.57	0.2418	-0.3809
C	23.75	89.11	0.1492	-0.5097
CPUE	27.50	102.99	-0.0086	-0.6352
E	23.74	112.36	0.0099	-0.5027

A - Arrival of salmon into the harvest area
C - Commercial catch
CPUE - Commercial catch per boat hour
E - Escapement from commercial harvest area
M1 - Management scenario with two 24 hour fishing periods per week
M2 - Management scenario with one 36 hour period and one 14 hour period per week

Figure 20. Theoretical escapement is a solid line, escapement simulated from a M2 management scenario is a dashed line (1981).


75000
60000
45000
30000
15000
0
NUMBER OF SOCKEYE
0
10
20
30
40
50
CODED DATE (MAY 10 = DAY 1)

CHAPTER 5

DISCUSSION

5.1 Migratory timing for commercial catch and escapement

The means of the migratory time densities of Copper River sockeye salmon commercial catch are conserved from year to year. Removing the years where fishing effort was greatly reduced (1979 and 1980) sharply reduced the variation of mean dates.

The coefficients of variation (CV′s) for cumulative proportional catch data clearly indicated a sharp reduction in variability upon removal of the years 1979 and 1980. The reduction in the variability of cumulative proportions appears to make the migratory timing information useful for harvest management operations. The values for the CV′s are much less than values calculated by Mundy (1983) for the lower Yukon chinook fishery. The coefficient of variation is 12 percent at the grand mean of the migration - June 08 (Table 1). Roberson et al., (1978) demonstrated a successful application of proportional data to predict total yield for the Copper River sockeye salmon fishery.

However, caution should be used in administering the cumulative proportions for harvest management purposes. Although the CV′s are relatively small about the mean date, the Copper River sockeye fishery displays a highly right skewed distribution (Fig. 6). The skewed distribution has also been reported for the migratory time densities of tagging data for upper Copper River sockeye stocks (Merritt and Roberson, 1983). Historically, a majority of catch occurred very early in the season. The CV′s are above 50 percent for the first 15 days of the season (Table 2). The CV′s do not fall below 25 percent until after 50 percent of the average migration has passed. Since the CV′s may be interpreted as the probability of error for predicting total yield from average performance, note that the CV does not fall below 50 percent until 50 percent of the historical catch is realized (Table 2). Therefore, a manager would be basing harvest decisions on the beginning 50 percent of the migration with poor predictive capability, and the latter 50 percent of the migration, which is historically spread over 70 days, with excellent predictive capability. Investigations into identifying sources of variability of migratory timing, such as atmospheric temperature and wind, river discharge and the extension of the Copper River plume into the gulf of Alaska, are obviously needed.

The means of migratory timing of Copper River sockeye sonar escapement appear to be conservative over years. It appears the means of escapement do not drastically differ from the means of escapement for the years when fishing was halted for an extended period of time (Table 8). The conservative behavior of the means of escapement may be attributed to the sound management policies for upper Copper River sockeye salmon. It appears that effort has been proportionately spread over the migration of upper Copper River stocks. The evidence is not as clear when comparing average daily proportionate data of catch and escapement for the first 20 coded days of the migration (Figs. 6 and 8). However, there has been recent evidence from stock separation studies of Copper River sockeye that, on the average, 40 percent of the catch, for the first 20 days of the migration, are bound for spawning areas of the Copper River delta and not the Copper River proper (Sharr et al., 1983). The high proportion of delta stocks found in catch may cause the discrepancies between proportionate data of catch and escapement. The delta stocks would not pass the sonar counter if not harvested. Therefore, by incorporating the delta stocks in the catch data exploitation rates are over estimated.

5.2 Lag time estimation and total population reconstruction

The correlation method used to estimate lag time agreed with the method which relied on the minimization of q only 1 out of 4 years. The differences for lag time estimation ranged from 1 to 3 days for the two methods. The method using the minimization of q is based on the hypothesis that q tends toward a constant seasonal value. It was demonstrated in Chapter 3 that q, derived from historical data, was highly variable over the course of a season. The worst agreement between the two methods occurred in a year (1983) with the highest amount of seasonal variability for q. Daily effort was found to explain 97 percent of the variability in q. The year the two methods agreed on a lag time was 1980 where fishing was only open to chinook salmon gear for a very limited time. The reason that the two methods agreed on a lag time for 1980 may be due to the fact that effort was relatively constant on each time interval which produced a constant seasonal value for q.

The migration rates calculated for sockeye salmon from the correlation analysis agreed with the range of migration rates (15.6 - 24.5 km day^{-1}) calculated from tagging studies for sockeye salmon of the Igushik River, Alaska (McBride and Clark, 1979; McBride, 1980). The migration rates calculated from tagging studies for upper Copper River sockeye ranged from 9.5 to 14 km day^{-1} (Merritt and Roberson, 1983). These rates were slower than those calculated by the correlation method, but migration rates were determined from tagged fish farther up the river in a much faster current than found in the commercial harvest area.

In Chapter 3 it was observed that means calculated from catch differed by less than a day from the means of the reconstructed total population for 1981 - 1983, and the variances of both distributions were also in close agreement. The mean dates calculated from escapement and the reconstructed total population differed by one day and less. The close agreement of descriptive statistics for the migratory time densities of the reconstructed total population and escapement are additional evidence that effort was proportionately spread across the migrations for 1981 - 1983.

The unusually high average exploitation rate of 85 percent can be partially attributed to the assumption, made in reconstructing the migrations, that all fish caught in the first 50 days were destined for the Copper River spawning grounds. Sharr et al.,(1984) presented convincing evidence that only approximately 61 percent of the commercial catch was bound for the upper Copper River spawning grounds during the first 50 coded days of the migration. The apportionment of catch was not extrapolated to the reconstructions of the population because the study of Sharr was only for 1982 data.

If one assumes a hypothetical situation where the rate of exploitation for the Copper River fishery is 100 percent a minimum value of escapement can be estimated. By intergrating the areas between the catch on the last day of a fishing period to the catch on the first day of the subsequent fishing period and summing the areas over a season a minimum escapement value for the Copper River and Delta can be obtained. Reducing the weekly catch for the time series of data for 1982 by the point estimates for the proportion of delta stocks found in the catch by Sharr et al., (1984) then a minimum upriver escapement can be estimated. If the hypothesized minimum value of escapement is higher than the sonar escapement (which appears to be highly probable from inspection of Fig. 9 and Appendix B), then three conclusions can be speculated. The first, point estimates for the proportion of delta stock catches are being under estimated. The second conclusion is that the sonar counter is under estimating escapement to the Copper River proper. The third possibility is that the under estimation of escapement is a combination of the two previous explanations.

Exploitation rates as high as 77 percent have been estimated for the Fraser river chinook salmon gill net fishery and 68 percent for the Georgia Strait chinook fishery (Argue et al., 1983). After reduction of catches to account for delta stocks, corrected estimates of exploitation rates agree with those of Argue et al., (1983).

In the generalized catch equation (Equation 12) it is assumed that each increase in a unit of effort causes a proportional increase in the instantaneous rate of fishing (F). Therefore, all units of effort must be adjusted to a standard unit of effort. In the Copper River fishery, since sockeye salmon are the target species of interest, only a small percentage of fishermen use a larger mesh size in the first fishing period or so to harvest chinook salmon (Randall et al., 1982). The assumptions made that the units of gear are relatively standard in terms of mesh size and overall net size are justified. The reconstructions of the migration were performed on one-day intervals. The "days" open to fishing in the Copper River did not always cover a 24 hour period. Therefore, the units of gear needed to be adjusted for the proportion of the day that fishing took place in order to have a standard unit of gear.

After all units of gear were adjusted by proportion of the day fished, it was apparent that a relation existed between catchability and number of boats. Daily adjusted effort on the average explained 74 percent of the variability associated with q. This validated the hypothesis stated in Chapter 3 that there was physical interference of units of effort during peak fishing periods. The condition of non-independent effort, where physical competition between units of gear takes place, has been described by Ricker (1975) and Seber (1982). The linearized power law regression model for catchability was also found to be the best fit for the sockeye salmon fishery of Togiak Bay, Alaska (Brannian, 1982).

Argue et al., (1983) presents data, from their model of a chinook salmon fishery, that suggests a non-linear relation between the number of boats on an interval and the value of q. An asymptotic relation for the number of boats as a function of time is presented for this fishery. This supports their statement that when the Georgia Straits fishery becomes saturated with boats and the fishing effort shifts to the west coast of Vancouver Island. The evidence suggests that physical interference of gear may be causing the reduction in the value of q with an increase in number of boats as the season progresses up to the coho salmon season.

The results of the baseline simulations demonstrated that the error associated with predicting escapement from the regression model for q was about 20 percent. The results of the simulations reveal that estimation of Copper river escapement can be made from commercial catch and number of boats on an interval.

The results of the first part of this study point toward a system of predictive models, which function during the season, to assist management personnel in making harvest control decisions for the Copper River sockeye salmon fishery. The system of models consists of the following major components: (1) a linearized power law regression model to predict the value of q; (2) a model to predict total yield during the season and; (3) a model to predict total sonar escapement during the season.

The number of boats is frequently counted by aerial survey during the season. Daily catch statistics are compiled by boat which refer to the actual sale of fish as recorded by the fish ticket. In season approximations of catch and effort can be calculated during the season from fish ticket data. The number of boats can be used in the regression model derived in Chapter 3 to estimate a value of q for the interval. Aerial surveys of effort yield good results weather permitting. Employing Equations 4 and 5, an estimate of total population for the interval can be made using the estimated value of q and the catch from fish ticket data. The catch can be subtracted from the total population estimate for estimation of Copper River sockeye escapement. The estimates of escapement can be compared to sonar escapement data at Miles Lake to calculate an inseason estimate of lag time (i.e. migration rate). The total population estimate can also be used to make an estimate for the rate of exploitation.

The function of the next model in the system is to estimate total escapement. A two parameter linear model, which is similar to the prediction model described by Barth (1984), can be developed to predict total seasonal sonar escapement. The proposed two parameter model is:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad (21)$$

where

Y = total seasonal sonar escapement

X_1 = cumulative sonar escapement to date

X_2 = cumulative catch to date

The next step in the series of models is a predictor for total yield. Barth (1983) evaluated intraseason yield models for the Copper River sockeye fishery and found a series of linear regression model, with the independent variable cumulative catch by date, to give the lowest error for total yield estimates. The method fits a linear regression model to each date of the migration and estimates total yield from cumulative catch to date.

The inseason estimates of total yield, total escapement, lag time between the harvest area and the sonar site, and the daily exploitation rates are sufficient information to evaluate how the current season compares to the average performance of the fishery. This information can be used by the harvest manager to evaluate if adjustments in the fishing schedule are needed to proportionately harvest the sockeye population through time.

5.3 Evaluation and utility of simulation model

The model reproduced the time series of catch and escapement with a MA%E less than one and it was able to accurately reproduce the descriptive statistics for the migratory time densities of catch and escapement for 1981 and 1982.

The model did not perform as well for data from 1983. One possible source for error may have been due to the estimate of the residence time in the harvest area. The simulation for 1983 had a residence time of two days. The model assumes a constant seasonal residence time (i.e. migration rate). A large variation in the intraseasonal migration rate could be the source for error in simulation of catch and escapement.

As presented in Chapter 4 the assumption of an average seasonal catchability coefficient does not force the means calculated from catch and escapement to depart from the means calculated from observed data. These results agree with the findings of Butt (1984), that the means of total abundance and catch compare well when a high proportion of the population is sampled, but when less than 12 percent of the population is sampled the error of estimated means tends to become very large. In other words, by using an average value of q, as long as a fair proportion of the population is sampled, the means of the two categories will be in close agreement. The high exploitation rates found for the Copper River fishery insure that the means calculated from catch are a very close approximations of the total population means. However, the lagged means of escapement may deviate from the means of the total population when exploitation rates are greater than 85 percent and if effort was not proportionately spread over the season.

The variances calculated from simulated catch, using an average value of q, decreased from variances calculated from observed data and simulations incorporating variable q. The assumption of an average value for q increased the variances for simulated escapement over those calculated from observed data and simulations using variable q.

These results suggest, that when agencies are planning the direction of harvest operations to deliver a harvest or escapement objective, caution should be taken when assuming an average value of q. In other words, depending on the level of effort it cannot always be assumed that each additional unit of effort will proportionally increase the catch over the course of the season. The assumption of an average q could result in a disproportionate harvest of the migration over time. Therefore, models that predict q as a function of effort or time (as described in Chapter 3) can be extremely helpful tools to management agencies for directing harvest operations with a goal of delivering a harvest or escapement objective distributed proportionately through time.

The evaluation of the time densities of simulated CPUE revealed that it was not as representative of the total population as was the time densities of catch. When simulations were run, using an average value of q, the means and variances of CPUE started to approach the values for the total population. The simulations revealed that caution should be taken when using the average migratory time density of CPUE to gauge the average performance of the fishery. The high variability found for q is believed to be the cause for departure of the descriptive statistics of CPUE from those of the total population. The descriptive statistics for catch closely approximate those of the total population, which is evidence for the population being proportionally harvested over the season. The fact that the descriptive statistics for CPUE differed from those for the total population is evidence that over a season the proportion of fish that one unit of effort captures is not constant.

A proposed procedure to identify if q is variable over a season is as follows: (1) compare the migratory timing of catch and CPUE; (2) then compare the migratory timing of standard effort to catch and CPUE and; (3) finally on the basis of the previous comparisons determine if catchability is constant or variable over a season. The criterion for deciding if q is relatively constant is the similarity of the descriptive statistics for the time densities of catch, CPUE, and effort. If it is found, by comparision of descriptive statistics, that the time densities of catch and effort are similar, but the time density of CPUE differs it may be assumed that q is variable over the season. The reasons for variability of q over a season were explained in Chapter 3.

It is found that traditionally, in a terminal salmon fishery, that effort is low at the tails of the migration. Therefore, at peak periods of fishing effort may saturate a harvest area causing physical competition between units of gear. This phenomenon will cause unusually high values for CPUE at the tails of the migration. The high values of CPUE at the tails is attributed to the higher values of q found during periods of low or no competition.

In the case of the Copper River sockeye salmon fishery participation is high at the beginning of the migration and tails off as the season progresses. The value of q is found to be higher towards the later part of the sockeye season. Therefore, high values of CPUE found later in the season cause the means of CPUE to occur much later than those found for catch and total abundance and also this also accounts for the variances of CPUE being much larger.

The assumptions that all fish caught in the commercial harvest area are destined to spawn in the upper Copper River is an over simplification of the system. It is the likely that the estimates for the rate of exploitation and the catchability coefficients were high due to the simplifying assumption. Similarly, over-simplification caused the reconstructed distributions for total population to have unusually high peaks on the days of catch (Appendix A). When the reconstructed distributions were used for the generating distribution of the model, it was found the population was under-exploited using an M1 scenario. The reason for under-exploitation was that with only one 24 hour fishing period a week, the days which had additional delta stocks had a higher probability of not being fished.

Although the assumptions complicated the interpretation of the results of the simulations, the estimated catchability coefficients from the regression model are still valid for prediction of escapement. The catch cannot be separated into upriver and delta stocks during the season with the present state of technology. Therefore, the regression model for q incorporates the upriver and delta stocks catch in its independent variable for catch. Unfortunately the estimation of escapement for the delta stocks remains problematic.

The regression model used to predict the number of boats, for simulation purposes, was only a fair model at best. The regression model could be improved by adding the variable of catch or CPUE on the previous interval, and the economic variables discussed in Chapter 3 (Argue et al., 1983).

At the present stage the model is a useful tool for fisheries research and for experienced management personnel who could use it to evaluate existing management practices and changes in management policies. The existing model runs for an entire season with a set management scenario. The effectiveness of the fishing schedule is then evaluated for the entire season. The model was also very effective in evaluating determinants for migratory time densities of different categories of data.

The model could be improved by the addition of real-time capabilities. The improvements could be accomplished as follows: (1) by stepping one interval at a time through a season; (2) the user is then informed of the catch, number of boats, and the escapement at the sonar counter for each interval; (3) the option is given to run information through the proposed system of intraseason prediction models; (4) the user is given an estimate for total seasonal catch and escapement and an estimate of the migration rate; (5) the user is then asked to submit a schedule of fishing for the remainder of the season and; (6) the process is then repeated for the subsequent intervals of the migration and the user has the option to update the fishing schedule each interval. The dynamic process incorporated into the model affords the user real-time management experience. The benefits of this type of simulation trainer for fisheries management was presented in Chapter 1.

CHAPTER 6

SUMMARY

1) The average seasonal migration rate estimated by the correlation method agreed with estimates for migration rates of sockeye salmon found by other investigators. The migration rates estimated by minimizing the variation of q were slow compared to other studies.

2) Catchability coefficients (q) derived from migrations reconstructed in the reference frame of the harvest area were found to vary within a season. Daily levels of effort, measured in boats per day, were found to explain 74 percent of the variation for q. Using the the linearized power law regression model, daily catch, and effort data daily escapement can be estimated during the season. Migration rates can be estimated during the season by correlating daily observed sonar escapement and daily predicted escapement.

3) It was inferred from the reconstructed time series of total abundance that the escapement from the commercial harvest area was underestimated by the sonar counter. The under estimation of escapement from the commercial harvest area may be attributed to two sources; (1) the delta stocks are higher than point estimates found by stock separation studies (Sharr et al., 1984); (2) the enumeration of escapement to the upper Copper River spawning areas are being

underestimated by the sonar counter at MIles Lake.

4) The differences between the descriptive statistics for the time densities of catch and CPUE can be attributable to varying q. A general statement can be made that in a competitive terminal fishery, of the two indices of abundance (catch and CPUE), the time density of catch will best represent the time density of total abundance. In fact the time density of catch and the time density of CPUE can be used as a diagnostic tool for detection of variable seasonal q, which is an indicator of a highly competitive fishery.

5) The model was found to be a useful tool for investigating the behavior of migratory time densities and evaluating the success of management strategies for delivering an escapement goal which is proportionately distributed over time.

6) The simulation model was lacking real-time capabilities. Proposed changes for the model will incorporate dynamic processes and a system of predictive models which afford the user real-time management experience.

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APPENDIX A

MIGRATORY TIMING OF CPUE DATA

Table 1A. Coefficients of variation and standard deviation (X100) of the average daily and cumulative proportions of sockeye catch per boat day (CPUE) by date, 1969 - 1978, 1981, 1982. The number of observations (n) also is shown.

Day No.	Date	Sample Size	Avg. Prop.	C.V.	S.D. x100	Sample Size	Avg. Cum. Prop.	C.V.	S.D. x100
6	515	3	.0155	40	0.62	3	.0155	40	0.62
7	516	5	.0132	39	0.51	5	.0225	49	1.12
8	517	6	.0164	46	0.77	7	.0301	49	1.50
9	518	5	.0301	39	1.18	8	.0452	45	2.06
10	519	7	.0245	40	0.99	9	.0586	46	2.75
11	520	9	.0203	50	1.03	11	.0645	58	3.80
12	521	8	.0234	46	1.09	11	.0815	51	4.16
13	522	7	.0238	36	0.87	11	.0969	52	5.08
14	523	6	.0242	41	1.01	11	.1100	52	5.79
15	524	8	.0253	46	1.17	11	.1286	41	5.29
16	525	7	.0284	30	0.86	11	.1467	39	5.80
17	526	9	.0208	50	1.04	11	.1639	40	6.58
18	527	7	.0152	26	0.40	11	.1736	40	7.03
19	528	9	.0193	55	1.07	12	.1736	47	8.23
20	529	9	.0255	57	1.45	12	.1928	41	7.98
21	530	9	.0228	67	1.54	12	.2098	37	7.95
22	531	10	.0223	79	1.77	12	.2285	31	7.20
23	601	11	.0225	81	1.83	12	.2491	25	6.25
24	602	10	.0259	58	1.51	12	.2708	21	5.83
25	603	11	.0207	41	0.84	12	.2897	21	6.22
26	604	9	.0202	40	0.82	12	.3050	19	6.03
27	605	9	.0205	48	1.00	12	.3202	18	5.87
28	606	8	.0178	37	0.66	12	.3321	17	5.86
29	607	9	.0165	39	0.65	12	.3445	16	5.82
30	608	10	.0150	53	0.80	12	.3570	15	5.51
31	609	10	.0160	45	0.73	12	.3706	14	5.35
32	610	11	.0151	52	0.80	12	.3843	14	5.70
33	611	9	.0147	46	0.68	12	.3952	15	6.00
34	612	9	.0132	35	0.46	12	.4054	15	6.26
35	613	7	.0130	33	0.44	12	.4130	15	6.47
36	614	9	.0139	32	0.45	12	.4234	15	6.76
37	615	10	.0151	36	0.55	12	.4360	15	6.88
38	616	10	.0166	37	0.62	12	.4500	14	6.70
39	617	10	.0144	48	0.69	12	.4620	15	6.95
40	618	8	.0213	71	1.52	12	.4761	15	7.25
41	619	10	.0196	73	1.43	12	.4925	15	7.52
42	620	9	.0190	58	1.12	12	.5068	15	7.68
43	621	9	.0165	52	0.87	12	.5192	15	7.98
44	622	12	.0164	45	0.75	12	.5357	15	8.13
45	623	9	.0146	36	0.53	12	.5467	14	7.90
46	624	10	.0149	70	1.05	12	.5593	14	7.92
47	625	10	.0188	48	0.92	12	.5750	13	7.91
48	626	7	.0155	18	0.29	12	.5841	13	7.81
49	627	8	.0128	47	0.60	12	.5925	13	7.88
50	628	8	.0148	36	0.54	12	.6025	12	7.80

Table 1A. continued

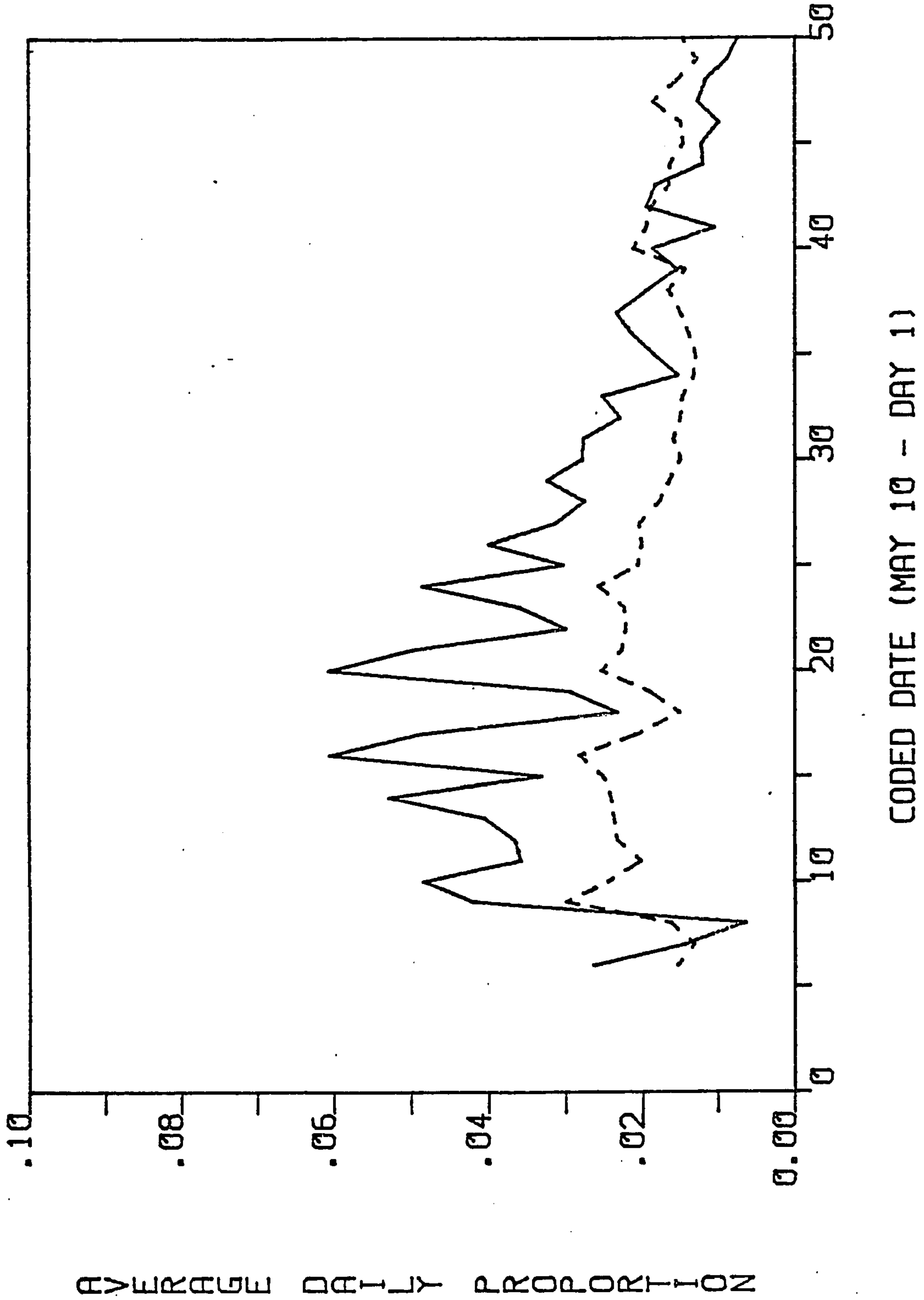
Day No.	Date	Sample Size	Avg. Prop.	C.V.	S.D. x100	Sample Size	Avg. Cum. Prop.	C.V.	S.D. x100
51	629	9	.0156	40	0.63	12	.6141	12	7.42
52	630	10	.0150	41	0.62	12	.6268	11	7.02
53	701	9	.0155	39	0.60	12	.6383	11	7.18
54	702	9	.0198	44	0.88	12	.6531	11	7.63
55	703	8	.0132	46	0.61	12	.6621	11	7.38
56	704	6	.0140	34	0.48	12	.6692	11	7.53
57	705	8	.0148	19	0.28	12	.6790	11	7.51
58	706	9	.0168	41	0.70	12	.6917	10	7.42
59	707	9	.0126	43	0.55	12	.7012	10	7.19
60	708	10	.0152	51	0.78	12	.7138	10	7.22
61	709	11	.0137	39	0.54	12	.7264	10	7.27
62	710	9	.0133	39	0.53	12	.7363	9	7.08
63	711	8	.0129	31	0.40	12	.7450	9	6.95
64	712	8	.0180	36	0.65	12	.7570	8	6.68
65	713	9	.0140	19	0.27	12	.7676	8	6.30
66	714	10	.0192	49	0.96	12	.7836	7	5.65
67	715	9	.0236	56	1.32	12	.8014	6	5.57
68	716	10	.0181	33	0.61	12	.8165	7	5.94
69	717	10	.0163	35	0.57	12	.8301	6	5.38
70	718	8	.0190	59	1.13	12	.8427	5	4.75
71	719	8	.0134	34	0.46	12	.8519	5	4.64
72	720	9	.0157	34	0.53	12	.8638	5	4.42
73	721	9	.0141	38	0.54	12	.8744	5	4.38
74	722	9	.0165	78	1.30	12	.8865	5	4.71
75	723	9	.0137	31	0.43	12	.8970	5	5.03
76	724	9	.0128	22	0.28	12	.9065	5	4.63
77	725	8	.0089	31	0.28	12	.9125	4	4.52
78	726	9	.0126	58	0.73	12	.9221	4	4.25
79	727	10	.0080	38	0.30	12	.9288	4	4.16
80	728	9	.0097	70	0.68	12	.9361	4	3.74
81	729	10	.0194	179	3.48	12	.9522	3	2.88
82	730	7	.0076	46	0.35	12	.9566	2	2.67
83	731	9	.0073	44	0.32	12	.9623	2	2.31
84	801	8	.0071	85	0.60	12	.9670	2	2.37
85	802	8	.0058	64	0.37	12	.9709	2	2.22
86	803	9	.0050	63	0.31	12	.9744	2	2.10
87	804	10	.0069	44	0.30	12	.9801	2	1.96
88	805	10	.0037	91	0.34	12	.9834	1	1.92
89	806	7	.0044	46	0.21	12	.9860	1	1.81
90	807	7	.0021	82	0.17	12	.9873	1	1.75

Table 2a. The coded means and variances of sockeye salmon migration based on commercial catch per boat day (CPUE) from Copper River district (212).

Year	Mean Date	Coded Date Mean	 Variance
1969	June 20	42.4	479.8
1970	June 17	39.3	530.5
1971	June 25	47.8	528.5
1972	June 24	46.9	526.0
1973	June 25	47.9	386.9
1974	June 19	41.3	407.5
1975	June 14	36.9	420.5
1976	June 25	47.9	670.9
1977	June 20	42.3	480.7
1978	June 21	43.6	675.3
1979	June 08	30.9	835.4
1980	July 22	74.6	202.7
1981	June 27	49.7	550.2
1982	June 18	40.0	544.4

X for the coded mean date (excluding 1979 and 1980) = 43.8; (SD = 4.12)

Figure 1A. Average daily proportions of catch (solid line) and CPUE (dashed line) for years 1969 - 1978, 1981, and 1982, Copper River district (212).


AVERAGE DAILY PROPORTION
.10
.08
.06
.04
.02
0.00
0
10
20
30
40
50
CODED DATE (MAY 10 - DAY 1)

APPENDIX B

TOTAL POPULATION RECONSTRUCTION

Table 1B. Catch, Escapement, and the reconstructed abundance using a lag time of 4 days, 1978. Coded day 1 is equal to May 10.

Date	Catch	Escapement	Total Pop.	Effort	Expl. Rate	q
6.	13096.	0.	13096.	240.	0.00000	0.00000
7.	9358.	0.	9358.	270.	0.00000	0.00000
8.	2724.	0.	2724.	97.	0.00000	0.00000
9.	1092.	0.	1092.	24.	0.00000	0.00000
10.	21998.	0.	21998.	318.	0.00000	0.00000
11.	15037.	0.	15037.	238.	0.00000	0.00000
12.	0.	0.	0.	0.	0.00000	0.00000
13.	15257.	0.	15257.	277.	0.00000	0.00000
14.	12992.	0.	12992.	358.	0.00000	0.00000
15.	734.	0.	734.	28.	0.00000	0.00000
16.	0.	0.	0.	0.	0.00000	0.00000
17.	11.	3241.	3252.	1.	0.00338	0.00339
18.	22.	2549.	2571.	1.	0.00856	0.00859
19.	851.	2616.	3467.	13.	0.24546	0.02166
20.	31921.	2811.	34732.	350.	0.91907	0.00718
21.	17156.	1837.	18993.	212.	0.90328	0.01102
22.	5761.	3256.	9017.	109.	0.63890	0.00935
23.	2136.	2970.	5106.	64.	0.41833	0.00847
24.	21051.	3318.	24369.	314.	0.86384	0.00635
25.	20486.	3808.	24294.	263.	0.84325	0.00705
26.	0.	3275.	3275.	0.	0.00000	0.00000
27.	0.	2252.	2252.	0.	0.00000	0.00000
28.	0.	3475.	3475.	0.	0.00000	0.00000
29.	0.	2490.	2490.	0.	0.00000	0.00000
30.	0.	2082.	2082.	0.	0.00000	0.00000
31.	0.	2419.	2419.	0.	0.00000	0.00000
32.	64.	2835.	2899.	1.	0.02208	0.02232
33.	0.	2913.	2913.	0.	0.00000	0.00000
34.	0.	2782.	2782.	0.	0.00000	0.00000
35.	0.	2779.	2779.	0.	0.00000	0.00000
36.	0.	2261.	2261.	0.	0.00000	0.00000
37.	0.	3035.	3035.	0.	0.00000	0.00000
38.	0.	3035.	3035.	0.	0.00000	0.00000
39.	0.	2515.	2515.	0.	0.00000	0.00000
40.	0.	2068.	2068.	0.	0.00000	0.00000
41.	234.	2841.	3075.	2.	0.07610	0.03957
42.	16042.	2616.	18658.	145.	0.85979	0.01355
43.	12333.	2130.	14463.	135.	0.85273	0.01419
44.	1803.	1771.	3574.	27.	0.50448	0.02601
45.	0.	2178.	2178.	0.	0.00000	0.00000

	Mean	Variance
Catch	20.05	115.55
Escapement	30.39	66.70
Total Population	22.74	123.41

Table 2B. Catch, Escapement, and the reconstructed abundance using a lag time of 4 days, 1979. Coded day 1 is equal to May 10.

Date	Catch	Escapement	Total Pop.	Effort	Expl. Rate	q
15.	2950.	2768.	5718.	92.	0.51591	0.00789
16.	27583.	3905.	31488.	371.	0.87598	0.00563
17.	9791.	7482.	17273.	138.	0.56684	0.00606
18.	0.	8655.	8655.	0.	0.00000	0.00000
19.	18297.	4078.	22375.	381.	0.81774	0.00447
20.	14503.	3465.	17968.	355.	0.80716	0.00464
21.	2596.	3536.	6132.	68.	0.42335	0.00810
22.	0.	2778.	2778.	0.	0.00000	0.00000
23.	0.	4352.	4352.	0.	0.00000	0.00000
24.	0.	6453.	6453.	0.	0.00000	0.00000
25.	0.	7031.	7031.	0.	0.00000	0.00000
26.	0.	11078.	11078.	0.	0.00000	0.00000
27.	0.	7985.	7985.	0.	0.00000	0.00000
28.	0.	5205.	5205.	0.	0.00000	0.00000
29.	0.	4426.	4426.	0.	0.00000	0.00000
30.	0.	2227.	2227.	0.	0.00000	0.00000
31.	0.	3903.	3903.	0.	0.00000	0.00000
32.	0.	2563.	2563.	0.	0.00000	0.00000
33.	0.	3351.	3351.	0.	0.00000	0.00000
34.	0.	3473.	3473.	0.	0.00000	0.00000
35.	0.	4640.	4640.	0.	0.00000	0.00000
36.	0.	3911.	3911.	0.	0.00000	0.00000
37.	0.	3413.	3413.	0.	0.00000	0.00000
38.	0.	1954.	1954.	0.	0.00000	0.00000
39.	0.	2223.	2223.	0.	0.00000	0.00000
40.	0.	2585.	2585.	0.	0.00000	0.00000
41.	0.	2865.	2865.	0.	0.00000	0.00000

	Mean	Variance
Catch	17.75	3.19
Escapement	26.49	50.32
Total Population	23.11	50.23

Table 3B. Catch, Escapement, and the reconstructed abundance using a lag time of 3 days, 1980. Coded day 1 is equal to May 10.

Date	Catch	Escapement	Total Pop.	Effort	Expl. Rate	q
6.	0.	218.	218.	0.	0.00000	0.00000
7.	0.	167.	167.	0.	0.00000	0.00000
8.	0.	221.	221.	0.	0.00000	0.00000
9.	0.	88.	88.	0.	0.00000	0.00000
10.	92.	391.	483.	16.	0.19048	0.01304
11.	0.	594.	594.	0.	0.00000	0.00000
12.	0.	494.	494.	0.	0.00000	0.00000
13.	0.	713.	713.	0.	0.00000	0.00000
14.	0.	1057.	1057.	0.	0.00000	0.00000
15.	0.	2115.	2115.	0.	0.00000	0.00000
16.	0.	1693.	1693.	0.	0.00000	0.00000
17.	0.	1080.	1080.	0.	0.00000	0.00000
18.	73.	1903.	1976.	35.	0.03694	0.00108
19.	0.	3620.	3620.	0.	0.00000	0.00000
20.	0.	5257.	5257.	0.	0.00000	0.00000
21.	89.	7061.	7150.	26.	0.01245	0.00049
22.	0.	7437.	7437.	0.	0.00000	0.00000
23.	0.	8996.	8996.	0.	0.00000	0.00000
24.	0.	9746.	9746.	0.	0.00000	0.00000
25.	102.	5407.	5509.	104.	0.01852	0.00018
26.	0.	2093.	2093.	0.	0.00000	0.00000
27.	330.	1349.	1679.	30.	0.19655	0.00734
28.	0.	3543.	3543.	0.	0.00000	0.00000
29.	0.	7301.	7301.	0.	0.00000	0.00000
30.	0.	12032.	12032.	0.	0.00000	0.00000
31.	0.	11584.	11584.	0.	0.00000	0.00000
32.	0.	7600.	7600.	0.	0.00000	0.00000
33.	81.	5661.	5742.	25.	0.01411	0.00058
34.	0.	7308.	7308.	0.	0.00000	0.00000
35.	0.	5655.	5655.	0.	0.00000	0.00000
36.	0.	7189.	7189.	0.	0.00000	0.00000
37.	0.	6741.	6741.	0.	0.00000	0.00000
38.	0.	2391.	2391.	0.	0.00000	0.00000
39.	0.	3597.	3597.	0.	0.00000	0.00000
40.	0.	4142.	4142.	0.	0.00000	0.00000
41.	0.	3954.	3954.	0.	0.00000	0.00000

	Mean	Variance
Catch	23.77	40.49
Escapement	28.48	50.32
Total Population	28.46	50.39

Table 4B. Catch, Escapement, and the reconstructed abundance using a lag time of 3 days, 1981. Coded day 1 is equal to May 10.

Date	Catch	Escapement	Total Pop.	Effort	Expl. Rate	q
5.	0.	5372.	5372.	0.	0.00000	0.00000
6.	0.	9665.	9665.	0.	0.00000	0.00000
7.	0.	11409.	11409.	0.	0.00000	0.00000
8.	0.	10733.	10733.	0.	0.00000	0.00000
9.	58954.	9729.	68683.	235.	0.85835	0.00832
10.	51841.	7558.	59399.	242.	0.87276	0.00853
11.	0.	6214.	6214.	0.	0.00000	0.00000
12.	0.	12985.	12985.	0.	0.00000	0.00000
13.	0.	12816.	12816.	0.	0.00000	0.00000
14.	0.	6383.	6383.	0.	0.00000	0.00000
15.	0.	2842.	2842.	0.	0.00000	0.00000
16.	48905.	2560.	51465.	216.	0.95026	0.01391
17.	65201.	2160.	67361.	317.	0.96793	0.01086
18.	0.	11822.	11822.	0.	0.00000	0.00000
19.	0.	21126.	21126.	0.	0.00000	0.00000
20.	0.	18415.	18415.	0.	0.00000	0.00000
21.	0.	23771.	23771.	0.	0.00000	0.00000
22.	0.	16716.	16716.	0.	0.00000	0.00000
23.	23114.	9755.	32869.	200.	0.70322	0.00609
24.	41966.	10478.	52444.	333.	0.80021	0.00484
25.	6164.	11975.	18139.	13.	0.33982	0.03270
26.	0.	13585.	13585.	0.	0.00000	0.00000
27.	0.	14412.	14412.	0.	0.00000	0.00000
28.	0.	15694.	15694.	0.	0.00000	0.00000
29.	0.	12856.	12856.	0.	0.00000	0.00000
30.	17497.	7877.	25374.	188.	0.68956	0.00622
31.	23706.	4844.	28550.	294.	0.83033	0.00603
32.	24082.	3556.	27638.	193.	0.87134	0.01064
33.	0.	5228.	5228.	0.	0.00000	0.00000
34.	0.	7071.	7071.	0.	0.00000	0.00000
35.	0.	6885.	6885.	0.	0.00000	0.00000
36.	0.	6467.	6467.	0.	0.00000	0.00000
37.	13795.	4565.	18360.	141.	0.75136	0.00985
38.	15759.	2985.	18744.	217.	0.84075	0.00847
39.	5200.	2891.	8091.	19.	0.64269	0.05563
40.	0.	3446.	3446.	0.	0.00000	0.00000
41.	0.	3997.	3997.	0.	0.00000	0.00000
42.	0.	4363.	4363.	0.	0.00000	0.00000
43.	0.	4651.	4651.	0.	0.00000	0.00000
44.	9989.	3398.	13387.	92.	0.74617	0.01497
45.	6076.	2412.	8488.	77.	0.71583	0.01634
46.	8380.	2507.	10887.	46.	0.76973	0.03206
47.	5342.	2949.	8291.	17.	0.64431	0.06081
48.	0.	3421.	3421.	0.	0.00000	0.00000
49.	0.	2378.	2378.	0.	0.00000	0.00000
50.	0.	2723.	2723.	0.	0.00000	0.00000

	Mean	Variance
Catch	21.89	120.58
Escapement	23.24	118.38
Total Population	22.51	120.01

Table 5B. Catch, Escapement, and the reconstructed abundance using a lag time of 3 days, 1982. Coded day 1 is equal to May 10.

Date	Catch	Escapement	Total Pop.	Effort	Expl. Rate	q
5.	0.	90.	90.	0.	0.00000	0.00000
6.	0.	493.	493.	0.	0.00000	0.00000
7.	0.	1023.	1023.	0.	0.00000	0.00000
8.	852.	12091.	12943.	3.	0.06583	0.02270
9.	2079.	47303.	49382.	5.	0.04210	0.00956
10.	0.	19671.	19671.	0.	0.00000	0.00000
11.	19369.	8781.	28150.	39.	0.68806	0.03026
12.	146715.	11389.	158104.	397.	0.92797	0.00663
13.	66483.	15385.	81868.	62.	0.81208	0.02718
14.	0.	17213.	17213.	0.	0.00000	0.00000
15.	0.	13383.	13383.	0.	0.00000	0.00000
16.	128399.	12355.	140754.	319.	0.91222	0.00763
17.	97992.	14806.	112798.	309.	0.86874	0.00657
18.	0.	15585.	15585.	0.	0.00000	0.00000
19.	3847.	12506.	16353.	10.	0.23525	0.02604
20.	72400.	8430.	80830.	330.	0.89571	0.00685
21.	0.	7017.	7017.	0.	0.00000	0.00000
22.	5602.	7599.	13201.	21.	0.42436	0.02694
23.	60669.	7879.	68548.	351.	0.88506	0.00616
24.	0.	8587.	8587.	0.	0.00000	0.00000
25.	10074.	9932.	20006.	22.	0.50355	0.03212
26.	47055.	12551.	59606.	323.	0.78943	0.00482
27.	18762.	12677.	31439.	29.	0.59677	0.03187
28.	0.	13595.	13595.	0.	0.00000	0.00000
29.	29390.	12030.	41420.	174.	0.70956	0.00711
30.	64985.	6544.	71529.	332.	0.90851	0.00720
31.	31447.	4369.	35816.	45.	0.87802	0.04728
32.	749.	3352.	4101.	3.	0.18264	0.06111
33.	48144.	3346.	51490.	259.	0.93502	0.01055
34.	9669.	4467.	14136.	17.	0.68400	0.06857
35.	0.	7031.	7031.	0.	0.00000	0.00000
36.	53700.	6329.	60029.	288.	0.89457	0.00781
37.	43229.	4903.	48132.	390.	0.89813	0.00586
38.	20614.	4416.	25030.	59.	0.82357	0.02940
39.	2535.	2732.	5267.	14.	0.48130	0.04590
40.	16819.	2174.	18993.	303.	0.88554	0.00715
41.	3074.	2130.	5204.	11.	0.59070	0.08121
42.	0.	2313.	2313.	0.	0.00000	0.00000
43.	27223.	2190.	29413.	140.	0.92554	0.01853
44.	20554.	4420.	24974.	186.	0.82302	0.00931
45.	4002.	5751.	9753.	9.	0.41034	0.05680
46.	1376.	5245.	6621.	9.	0.20782	0.02589
47.	11125.	4995.	16120.	98.	0.69014	0.01192
48.	2400.	6300.	8700.	7.	0.27586	0.04611
49.	0.	6171.	6171.	0.	0.00000	0.00000
50.	6579.	3990.	10569.	26.	0.62248	0.03704

	Mean	Variance
Catch	23.95	106.15
Escapement	22.29	141.26
Total Population	23.51	116.11

Table 6B. Catch, Escapement, and the reconstructed abundance using a lag time of 4 days, 1983. Coded day 1 is equal to May 10.

Date	Catch	Escapement	Total Pop.	Effort	Expl. Rate	q
7.	20632.	0.	20632.	128.	0.00000	0.00000
8.	25217.	0.	25217.	157.	0.00000	0.00000
9.	0.	0.	0.	0.	0.00000	0.00000
10.	0.	3310.	3310.	0.	0.00000	0.00000
11.	0.	8620.	8620.	0.	0.00000	0.00000
12.	0.	11587.	11587.	0.	0.00000	0.00000
13.	0.	10575.	10575.	0.	0.00000	0.00000
14.	50414.	8661.	59075.	157.	0.85339	0.01224
15.	61633.	8456.	70089.	192.	0.87935	0.01102
16.	0.	6380.	6380.	0.	0.00000	0.00000
17.	0.	8296.	8296.	0.	0.00000	0.00000
18.	0.	17123.	17123.	0.	0.00000	0.00000
19.	0.	18428.	18428.	0.	0.00000	0.00000
20.	0.	14414.	14414.	0.	0.00000	0.00000
21.	42027.	13137.	55164.	164.	0.76186	0,00878
22.	51366.	15357.	66723.	201.	0.76984	0.00731
23.	0.	19110.	19110.	0.	0.00000	0.00000
24.	0.	14069.	14069.	0.	0.00000	0.00000
25.	0.	19309.	19309.	0.	0.00000	0.00000
26.	0.	16094.	16094.	0.	0.00000	0.00000
27.	0.	11415.	11415.	0.	0.00000	0.00000
28.	37269.	8009.	45278.	217.	0.82312	0.00798
29.	45551.	9563.	55114.	265.	0.82649	0.00661
30.	0.	13292.	13292.	0.	0.00000	0.00000
31.	0.	13444.	13444.	0.	0.00000	0.00000
32.	0.	13831.	13831.	0.	0.00000	0.00000
33.	0.	15915.	15915.	0.	0.00000	0.00000
34.	4298.	7938.	12236.	7.	0.35126	0.06657
35.	18804.	5671.	24475.	113.	0.76829	0.01294
36.	24176.	5689.	29865.	146.	0.80951	0.01136
37.	6447.	6461.	12908.	10.	0.49946	0.07062
38.	0.	7382.	7382.	0.	0.00000	0.00000
39.	0.	8124.	8124.	0.	0.00000	0.00000
40.	0.	8005.	8005.	0.	0.00000	0.00000
41.	0.	7546.	7546.	0.	0.00000	0.00000
42.	13354.	6009.	19363.	39.	0.68967	0.03000
43.	16321.	5226.	21547.	48.	0.75746	0.02951
44.	0.	5638.	5638.	0.	0.00000	0.00000
45.	3496.	4738.	8234.	5.	0.42458	0.10427
46.	15538.	4697.	20235.	93.	0.76788	0.01570
47.	4273.	4304.	8577.	7.	0.49819	0.10608
48.	0.	6146.	6146.	0.	0.00000	0.00000
49.	14584.	6106.	20690.	62.	0.70488	0.01968
50.	17825.	6113.	23938.	75.	0.74463	0.01820

	Mean	Variance
Catch	25.79	154.73
Escapement	27.51	106.13
Total Population	26.59	133.08

AUTOBIOGRAPHICAL STATEMENT

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BORN:

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EDUCATION:

B.S., Biology, January 1975.
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PUBLICATIONS:

Schaller, H. A. 1980. A simulation predicting the effects of sewage treatment on phytoplankton in the lower Hudson Estuary. Master's Thesis. C.W. Post Center, Long Island University, Greenvale, New York.

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