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NUSHAGAK BAY SALMON FISHERY MODEL

by

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FINAL REPORT

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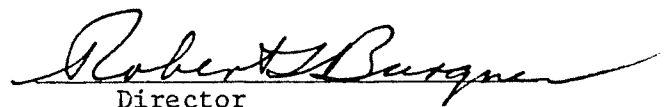

Director

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	iv
LIST OF TABLES	v
ACKNOWLEDGEMENTS	x
PREFACE	1
ABUNDANCE ESTIMATION BASED ON MIGRATORY TIME DENSITY FUNCTIONS	4
Introduction	4
Methods	5
Results	18
Discussion	18
ABUNDANCE ESTIMATION FOR CHINOOK SALMON	25
Introduction	25
Methods	26
Abundance Estimation	26
Escapement Estimation	27
Results	39
Abundance Estimation	39
Escapement Estimation	39
Discussion	41
Abundance Estimation	41
Escapement Estimation	41
ABUNDANCE ESTIMATION FOR SOCKEYE SALMON	43
Introduction	43
Methods	43
Results	45
Discussion	47
ABUNDANCE ESTIMATION FOR CHUM SALMON	69
Introduction	69
Methods	70

	<u>Page</u>
Results	75
Discussion	75
ABUNDANCE ESTIMATE FOR PINK SALMON	79
Introduction	79
Methods	79
Results	83
Discussion	83
CONSIDERATIONS FOR A DECISION-MAKING MODEL FOR A MULTISPECIES SALMON FISHERY	90
Conceptual Framework	90
Discussion	90
Policy	92
Harvest Control	93
LITERATURE CITED	97

LIST OF FIGURES

<u>Number</u>		<u>Page</u>
1	Nushagak Bay, major river systems, and location of salmon counting towers	8
2	The normal probability function and related functions	14
3	Observed and expected daily proportions of total abundance for the 1979 migration of sockeye salmon to Nushagak Bay	17
4	Predicted and observed data for the polynomial regression of E/CPUE and weight for chinook salmon from Nushagak Bay . .	36
5	Residual analysis of the polynomial regression of E/CPUE and weight for chinook salmon from Nushagak Bay	37
6	Mean distribution of daily proportions of sockeye salmon entering Nushagak Bay. Day 1 was defined as the maximum of the rate of change of the daily rate of change of the daily number of fish entering the district	46
7	Mean distribution of daily proportions of pink salmon entering Nushagak Bay. Day 1 was defined as the maximum of the rate of change of the daily rate of change of the daily number of fish entering the district	87
8	Flow chart for policy and harvest control decisions for salmon fisheries managers	91

LIST OF TABLES

<u>Number</u>		<u>Page</u>
1	Calculation of \bar{t} and s^2 data from 1960 Nushagak pink salmon data	11
2	Observed cumulative proportion of abundance by day for sockeye salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	19
3	Expected proportion of abundance based on a normal curve with $\bar{x} = 21.30$ and $s^2 = 36.68$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nushagak Bay sockeye salmon abundance data	20
4	Observed cumulative proportion of total abundance by date of sockeye salmon for Nushagak Bay from 1959-1979	21
5	Abundance estimation process for pink salmon from Nushagak Bay for 1980	22
6	Migratory time density statistics for Nushagak Bay chinook salmon. These calculations are based on adjusted catch data	28
7	Expected proportion of catch by day based on a normal curve with $\bar{x} = 21.17$ and $s^2 = 88.81$, which represents the mean of the mean days of the migration and the mean of the variance for 1960-1976 (excluding 1963 and 1964) for Nushagak Bay chinook salmon based on adjusted catch data	29
8	Observed proportions of cumulative abundance on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay chinook salmon based on adjusted catch data	30
9	Observed proportion of catch by day for chinook salmon for Nushagak Bay from 1960-1976 (excluding 1963 and 1964). Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	31

<u>Number</u>		<u>Page</u>
10	Observed proportion of catch by date of chinook salmon for Nushagak Bay from 1960-1976 (excluding 1963 and 1964) . . .	32
11	Abundance estimates for chinook salmon for Nushagak Bay from 1966-1979	33
12	Subsistence catch statistics from set nets from Dillingham and vicinity from 1966-1973	35
13	Error of expected and observed escapement of Nushagak River chinook salmon from 1966-1973	38
14	Abundance estimates for chinook salmon for Nushagak Bay, 1980	40
15	Migratory time density statistics for Nushagak Bay sockeye salmon. These calculations are based on total abundance . . .	44
16	Expected proportion of abundance based on a normal curve with $\bar{x} = 21.30$ and $s^2 = 36.68$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nushagak Bay sockeye salmon abundance data	48
17	Expected proportion of abundance based on a normal curve with $\bar{x} = 22.15$ and $s^2 = 24.80$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Wood River sockeye salmon abundance data	49
18	Expected proportion of abundance based on a normal curve with $\bar{x} = 20.72$ and $s^2 = 33.65$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Igushik River sockeye salmon abundance data	50
19	Expected proportion of abundance based on a normal curve with $\bar{x} = 20.23$ and $s^2 = 22.97$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nuyakuk River sockeye salmon abundance data	51
20	Observed proportions of abundance on days of expected maxima of the second and third derivatives of the cumulative	

<u>Number</u>		<u>Page</u>
	normal probability density function for Nushagak Bay sockeye salmon	52
21	Observed proportions of abundance on days of expected maxima of the second and third derivatives of the cumu- lative normal probability density function for Wood River sockeye salmon	53
22	Observed proportions of abundance on days of expected maxima of the second and third derivatives of the cumu- lative normal probability density function for Igushik River sockeye salmon	54
23	Observed proportions of abundance on days of expected maxima of the second and third derivatives of the cumu- lative normal probability density function for Nuyakuk River sockeye salmon	55
24	Observed proportion of abundance by day for sockeye salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second deriva- tive of the normal curve for each year	56
25	Observed proportion of abundance by day for sockeye salmon from Wood River during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	57
26	Observed proportion of abundance by day for sockeye salmon from Igushik River during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	58
27	Observed proportion of abundance by day for sockeye salmon from Nuyakuk River during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	59
28	Observed proportion of total abundance by date of sockeye salmon for Nushagak Bay from 1959-1979	60
29	Observed proportion of total abundance by date of sockeye salmon for Wood River from 1959-1979	61

<u>Number</u>		<u>Page</u>
30	Observed proportion of total abundance by date of sockeye salmon for Igushik River from 1959-1979	62
31	Observed proportion of total abundance by date of sockeye salmon for Nuyakuk River from 1959-1979	63
32	Cumulative proportions calculated from observed data. Day 1 was defined as the maximum rate of change of the daily rate of change of the number of fish entering the district	64
33	Abundance estimate for Nushagak Bay sockeye salmon for 1980.	65
34	Abundance estimate for Wood River sockeye salmon	66
35	Abundance estimate for Igushik River sockeye salmon	67
36	Abundance estimate for Nuyakuk River sockeye salmon	68
37	Migratory time density statistics for Nushagak Bay chum salmon. These calculations are based on adjusted catch data	71
38	Expected proportion of catch based on a normal curve with $\bar{x} = 22.98$ and $s^2 = 68.28$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nushagak Bay chum salmon abundance data	72
39	Observed proportions of catch on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay chum salmon	73
40	Observed proportions of catch by day for chum salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	74
41	Observed proportion of catch by date of chum salmon for Nushagak Bay from 1960-1976 (excluding 1963 and 1964)	76
42	Abundance estimates for Nushagak Bay chum salmon for 1980	77
43	Migratory time density statistics for Nushagak Bay pink salmon. These calculations are based on total abundance	80

<u>Number</u>		<u>Page</u>
44	Expected proportion of abundance based on a normal curve with $\bar{x} = 24.54$ and $s^2 = 39.46$, which represents the mean of the mean days of the migration and the mean of the variance for 1960-1978 Nushagak Bay pink salmon abundance data	81
45	Observed proportion of abundance on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay pink salmon	82
46	Observed proportion of abundance by day for pink salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year	84
47	Observed proportion of abundance by date of pink salmon for Nushagak Bay from 1960-1978 (even years only)	85
48	Mean cumulative proportion of pink salmon entering Nushagak Bay calculated from observed data. Day 1 was defined as the maximum rate of change of the daily rate of change of the number of fish entering the district	86
49	Abundance estimates for Nushagak Bay pink salmon for 1980	88

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PREFACE

The original long-term objective of research associated with the Nushagak Bay salmon model was to develop a realistic and verifiable decision-making model of the Nushagak salmon fishery which resource managers could use to evaluate harvest strategies to achieve their biological, social and economic objectives. To attain this goal, subobjectives by year were established. The following specific objectives were developed for this contract:

1. To estimate total and daily abundance of sockeye salmon returning to Nushagak Bay during 1980.
2. To evaluate the performance of estimation procedures for sockeye salmon.
3. To refine abundance estimation procedures for sockeye salmon.
4. To develop and initiate in-season abundance estimates for chinook, chum, and pink salmon.
5. To develop a preliminary multi-species decision-making model.

This report emphasizes the progress from April 1, 1980 through March 31, 1981; however, previous progress is incorporated for completeness. Although the long-term goal for research in Nushagak Bay should be the development of a realistic and verifiable decision-making model of the Nushagak salmon fishery which resource managers could use to evaluate harvest strategies to achieve their biological, social and economic objectives, time constraints and limitations of data prevent this goal from being achieved in three years. In response to these limitations the Nushagak Bay salmon model has been redefined. To assess the progress of this and previous contracts, this definition must be clarified.

To provide a common reference frame, I will separate management into two

parts: 1) policy and 2) harvest control. The separation of these two levels of decision-making is essential for effective fishery management.

Ideally, policy decisions are concerned with the establishment of fixed escapement goals by species for each river system or a specified harvest level. Management is probably most effective in the long term when it is based on fixed escapement goals that are biologically sound; however, decisions of policy are complex and require sociological, political and economic input as well. Because this input must be examined and weighed to develop responsible short-term and long-term strategic policy these decisions require considerable time to prepare.

Harvest control decisions are those decisions aimed at delivering a predetermined escapement or harvest goal. Such decisions must be relatively inflexible to change because of the short duration of the migration and complexity of the information produced during the migration. Maximum adjustment levels should be defined prior to the beginning of the migration as part of the policy level decisions.

The intended purpose of current research on the Nushagak Bay Salmon Model is to provide for harvest control of Nushagak Bay salmon, which means developing a quantitative procedure for obtaining predetermined harvest or escapement goals.

The critical components of harvest control are

- 1) accurate knowledge of abundance of fish returning to a specific fishing district and ideally to individual river systems
- 2) accurate knowledge of the rate of removal of fish by the fishery.

The emphasis of the contractual work for the Nushagak Bay salmon model

has been intraseason abundance estimation for Nushagak Bay. Substantial progress has been achieved in the intraseason abundance estimation procedure for Nushagak Bay salmon. During the development of this procedure, several assumptions concerning the migratory pattern of salmon were made. If decisions are to be based on quantitative criteria, the impact of those assumptions must be assessed. If a reliable quantitative model is to be developed, the rate of removal of fish by the fleet must be defined. The work directed at this need has been limited to assembling catch and effort data from 1960 through 1977 for the five species of salmon migrating to Nushagak Bay.

ABUNDANCE ESTIMATION BASED ON MIGRATORY TIME DENSITY FUNCTIONS

Introduction

The primary biological goal of salmon management is to provide a predetermined escapement.¹ This task is extremely difficult in a fishing district such as Nushagak, where the manager must not only deal with mixed stocks from a given species but also multiple species. The key element in this decision-making process is an accurate abundance estimate of returning fish.

Abundance estimation techniques are diverse. The techniques reported by Walters and Buckingham (1975) and more recently by Mundy (1979) and Mundy and Mathisen (1978 and 1979) served as the foundation for the abundance estimation procedures applied to the Nushagak Bay sockeye salmon migration of 1979. The following four estimates of sockeye salmon total abundance (in millions) were prepared: 29 June (5.5), 30 June (3.6), 5 July (4.4), and 9 July (5.5). The best available data indicate that the actual sockeye salmon total abundance was approximately 6.15 million fish. All estimates were below the actual abundance. The first estimate of 5.5 million was 10 percent low, the second estimate of 3.6 million was 40 percent low, and the estimate of 4.4 million was 30 percent low. The accomplishments in 1979 demonstrated that review, refinement and expansion of this process to other species was necessary in order to provide managers with intraseason forecasts of abundance to aid management decisions.

¹ Escapement throughout the report is defined as the fish that have moved past the inside line of the fishing district and proceeded toward their spawning ground.

Methods

The abundance estimate relies on migratory time density functions described by Mundy (1979) and Mundy and Mathisen (1978 and 1979).

Several assumptions are fundamental to the application of migratory time density distributions to intraseason abundance estimation.

- 1) The migratory species must move past a fixed point in a continuous fashion.
- 2) The analytical form of the time density function must be constant — or relatively constant.

The following summary represents a step-by-step breakdown of the abundance estimation process. There are four key elements:

- 1) data required
- 2) calculation of cumulative abundance
- 3) calculation of proportions
- 4) abundance estimation

1. Data required:

The essential ingredient in developing migratory time density statistics is a long-term, reliable data base. The data needed are measures of total abundance. These could include

- 1) catch,
- 2) catch per unit of effort, or
- 3) actual observed abundance.

The utility of catch and CPUE data depends on the following relationship:

$$C = q f \bar{N} \quad (1)$$

where

- C represents catch
- q represents catchability
- f represents fishing effort
- \bar{N} represents mean abundance

As can be noted from this equation, catch accurately reflects population size as long as q and f are constant; CPUE reflects population size as long as q remains constant. Obviously, observations of abundance provide the most reliable data.

2. Calculation of accumulative abundance

Accumulative abundance is easily calculated by summing catch plus escapement. Only sockeye and the majority of pink salmon swim past counting towers where they can be enumerated. Chum, king, and coho salmon escapements are estimated from aerial surveys after the fish have migrated to the spawning grounds.

There are three fundamental weaknesses of this process:

1. There are errors in the counts reported by the crews at the counting towers.
2. Passage rate through the district is important since a passage rate of one day is assumed. To improve knowledge of abundance on any given day, the passage rate through the district should be measured and catch adjusted to quantitatively define the number of fish that entered the fishing district during a specified 24-hour period.

3. Travel time from the fishing district to the counting tower must be estimated so that the escapement can be lagged to the fishery and summed with the catch (Fig. 1). According to Mundy (1979), the rate of migration is variable, thus introducing error. For this report, travel time from the counting tower to the middle of the fishing district was fixed as follows:

<u>River</u>	<u>Days</u>	<u>Species</u>
Wood River	2	Sockeye
Igushik River	5	Sockeye
Nuyakuk River	10	Sockeye, Pink

Given the appropriate lagging factor, catch was added to escapement to calculate total abundance within the district. In addition to district abundance, an attempt was made to estimate daily abundance for each of the three major river systems of Nushagak Bay. This was accomplished by allocating catch according to the following equation:

$$C_{ij} = C_i \cdot \frac{E_{kj}}{E_k} \quad (2)$$

where

- C_{ij} \equiv catch associated with river j on day i
- E_{kj} \equiv escapement associated with river j on day k
- i \equiv the day fish were caught
- j \equiv either Wood, Igushik, or Nuyakuk River
- k \equiv the lagged escapement $k = d_j - t_j$
- t_j \equiv the time needed for the fish to swim from the fishing district past the counting tower on river j

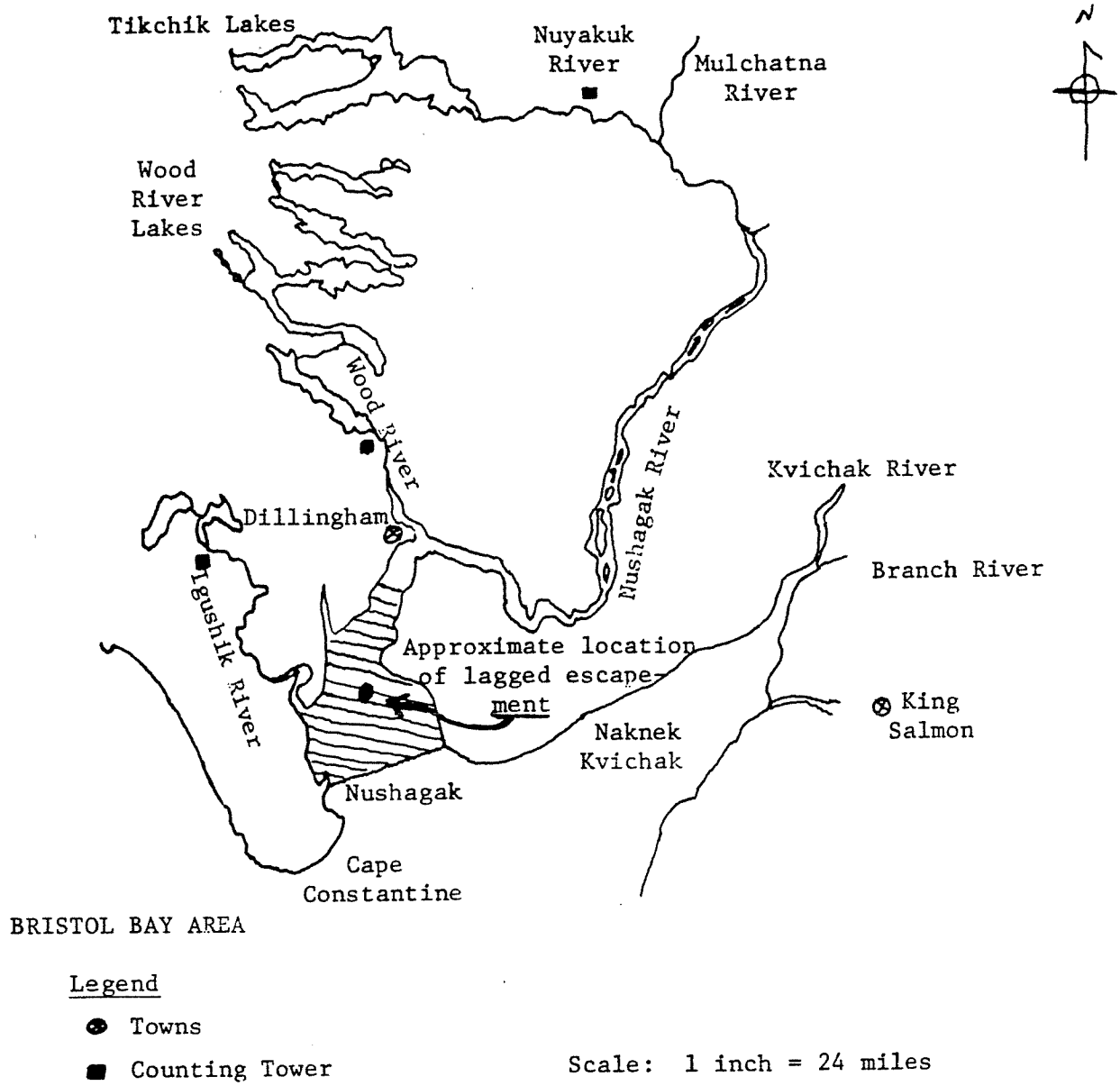


Fig. 1. Nushagak Bay, major river systems, and location of salmon counting towers. (Adapted from ADF&G Technical Report No. 19, Figure 1, page 3.)

$d_j \equiv$ the day the fish swam past the counting tower on river j

The assumptions regarding this type of allocation are gross. The three most obvious assumptions are

1. that the migratory time density function (entry pattern) for all river systems is the same
2. that the riverine passage rates are constant
3. that fish from each river have equivalent catchabilities and are equally vulnerable to capture.

3. Calculation of proportions

Three procedures have been employed to calculate proportions. Two involve empirical probability distributions and the other involves the normal. The empirical probability distributions were calculated as follows:

$$f(t_i) = \frac{n_i}{n} \quad (3)$$

where $f(t_i) \equiv$ the probability of a given day occurring
 $n_i \equiv$ represents the abundance, catch, or CPUE for a given day
 $n \equiv$ represents total abundance, catch, or CPUE

Calculating expected probabilities based on the normal distribution involves three steps (Mundy 1979).

The steps involve calculating

$$\bar{t}, s_t^2, N(\bar{t}, s_t^2),$$

$$\bar{\bar{t}}, \bar{s}_t^2, N(\bar{\bar{t}}, \bar{s}_t^2)$$

The first sequence of calculations provides for the calculation of yearly normal distributions and the second for the average distribution for all years of data.

$$\bar{t} = \sum_{i=1}^{\ell} t_i f(t_i) \quad (4)$$

where t_i represents time in days of the migration (e.g. 1, 2, 3, 4, ..., ℓ); day 1 (in this case) should be standardized to a specified calendar date (for example, day 1 = June 15 for sockeye salmon)

$f(t_i)$ represents the probability of a given day occurring defined as $\frac{n_i}{n}$ where n_i represents the number on a day and n represents total number.

$$s^2 = \sum_{i=1}^{\ell} (t_i - \bar{t})^2 f(t_i) \quad (5)$$

An example of calculating (\bar{t}) and (s^2) is provided in Table 1. After the mean (\bar{t}) and variance (s^2) have been calculated the normal distribution can be calculated by the following equation:

$$N(t; \bar{t}, s) = \frac{1}{s\sqrt{2\pi}} \left(e^{-\frac{(t_i - \bar{t})^2}{2s^2}} \right) \quad (6)$$

Given several years of data a mean normal curve can be calculated. The mean for several years of data can be defined

$$\bar{t} = \frac{\sum_{i=1}^d \bar{t}}{d} \quad (7)$$

where d represents sample size, i.e. number of years of data.

$$\hat{s}^2 = \frac{\sum_{i=1}^d s^2}{d} \quad (8)$$

Equations (7) and (8) imply that \bar{t} and s^2 are normally distributed random variables of equivalent sample size. The assumption that \bar{t} is a normally distributed random variable is reasonable because according to the central limit theorem — as sample size increases, the means of samples drawn from a population of any distribution will approach the normal distribution. The assumption that s^2 is a normally distributed random variable may not be rigorous; however, the deviations from normality probably are not sufficient to detract from the utility of s^2 for calculating a mean normal curve for all years of observations.

After the normal probabilities have been calculated for each year, the first empirical distribution can be calculated. Before the distribution can be calculated, however, the first and second derivative of the normal curve must be calculated according to the following equations:

$$\frac{(\bar{x} - x)}{s^3 \sqrt{2\pi}} e^{-\frac{(x-\bar{x})^2}{2s^2}} \quad (9)$$

where x represents time in days

\bar{x} represents the mean of the migratory time density function

s represents the standard deviation of the migratory time density function

$$\frac{(\bar{x} - x)^2}{s^5 \sqrt{2\pi}} e^{-\frac{(x-\bar{x})^2}{2s^2}} \quad (10)$$

The first (9) and second (10) derivative can also be approximated as follows:

$$\frac{y_{i+1} - y_i}{x_{i+1} - x_i} = \frac{\Delta y}{\Delta x} \quad (11)$$

$$\frac{\Delta y_{i+1} - \Delta y_i}{\Delta x_{i+1} - \Delta x_i} \quad (12)$$

Defining critical points during initial stages of the migration is essential if catch plus escapement data are employed for intraseason abundance estimation. The initiation of the migration was defined as the maximum of the second derivative of the normal curve (Fig. 2). There are, however, discrepancies between the expected value of the second derivative of the normal curve and the observed proportion associated with the expected day of the maximum of the second derivative

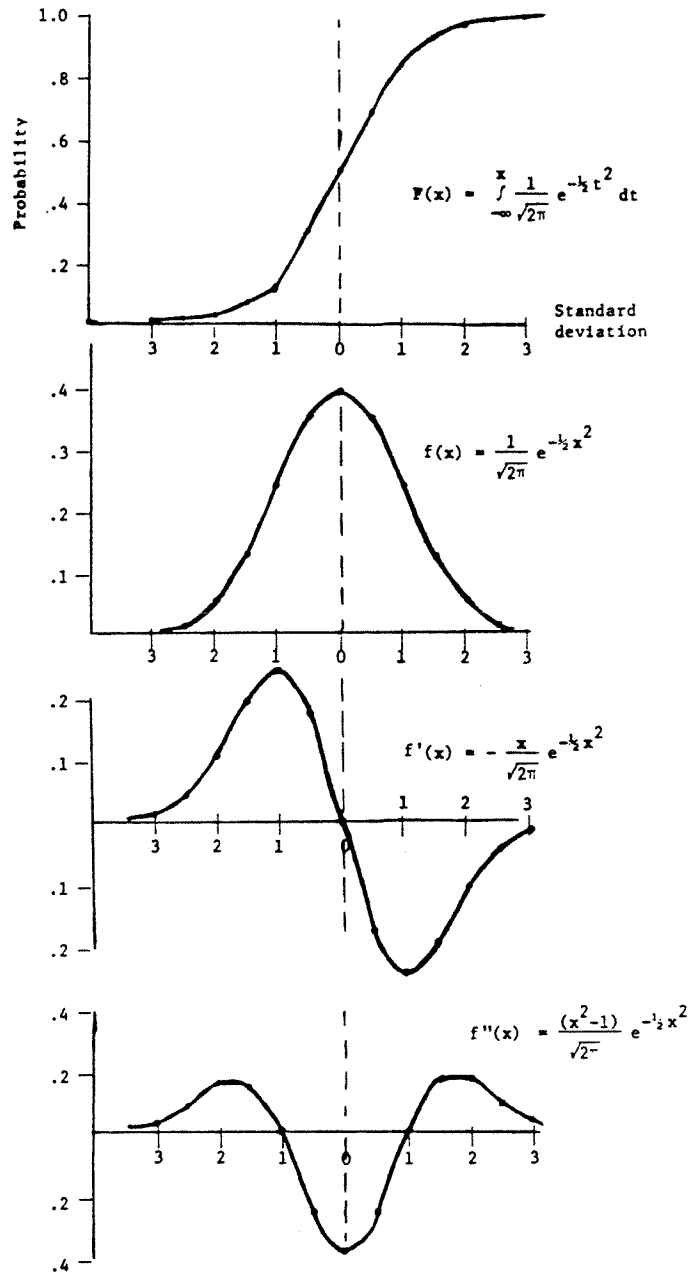


Fig. 2. The normal probability function and related functions.

of the normal curve. These differences are caused by errors associated with catch data, deviations of the observed data from the normal, and errors produced by inaccuracies of the procedure for lagging escapement to the catch to calculate daily abundance.

The first and second derivatives of the normal curve were approximated by equations (11) and (12), rather than rigorously evaluated by equations (9) and (10). A key factor contributing to the decision to approximate the first and second derivatives of the normal curve was the fact that approximation by differences is the only feasible technique for calculating derivatives intraseasonally.

The day the maximum of the second derivative of the normal curve occurs was labeled day 1 for all years. The empirical distribution for each year is then calculated according to equation (3). The mean distribution is calculated as follows:

$$\sum_{k=1}^j \left(\frac{n_{ki}}{n_k} \right) k \quad (13)$$

where

n_{ki} \equiv the abundance, catch, or CPUE for a given day in a given year

i \equiv a given day

n \equiv total abundance, catch, or CPUE

k \equiv a given year

j \equiv the number of years of data

An empirical distribution can also be calculated by labeling day 1 as the maximum rate of change of the observed rate of change of fish entering the district. The empirical distribution is calculated according to equation 3 and the mean distribution according to equation 13.

The final empirical distribution was calculated by labeling a specific calendar day as day 1 (for example, for sockeye salmon June 15 was day 1) and then calculating the proportions according to equation (3) and (13).

The utility of the distributions for abundance estimation depends on how well the expected distribution reflects the observed. Subjective evaluation yields the following ranking:

1. empirical distribution for which day 1 was defined as the maximum rate of change of the observed daily rate of change of fish entering the district
2. empirical distribution for which day 1 was defined as the maximum of the second derivative of the fitted normal curve
3. distribution based on normal curve
4. empirical distribution for which day 1 was defined as a specific calendar day.

The empirical distribution with day 1 defined as the maximum of the second derivative of the normal curve was ranked first because of the apparent lack of fit of the normal curve to the observed data (Fig. 3); and the apparent reduction in range of the probabilities compared with the empirical distribution for which day 1 was defined as a specific

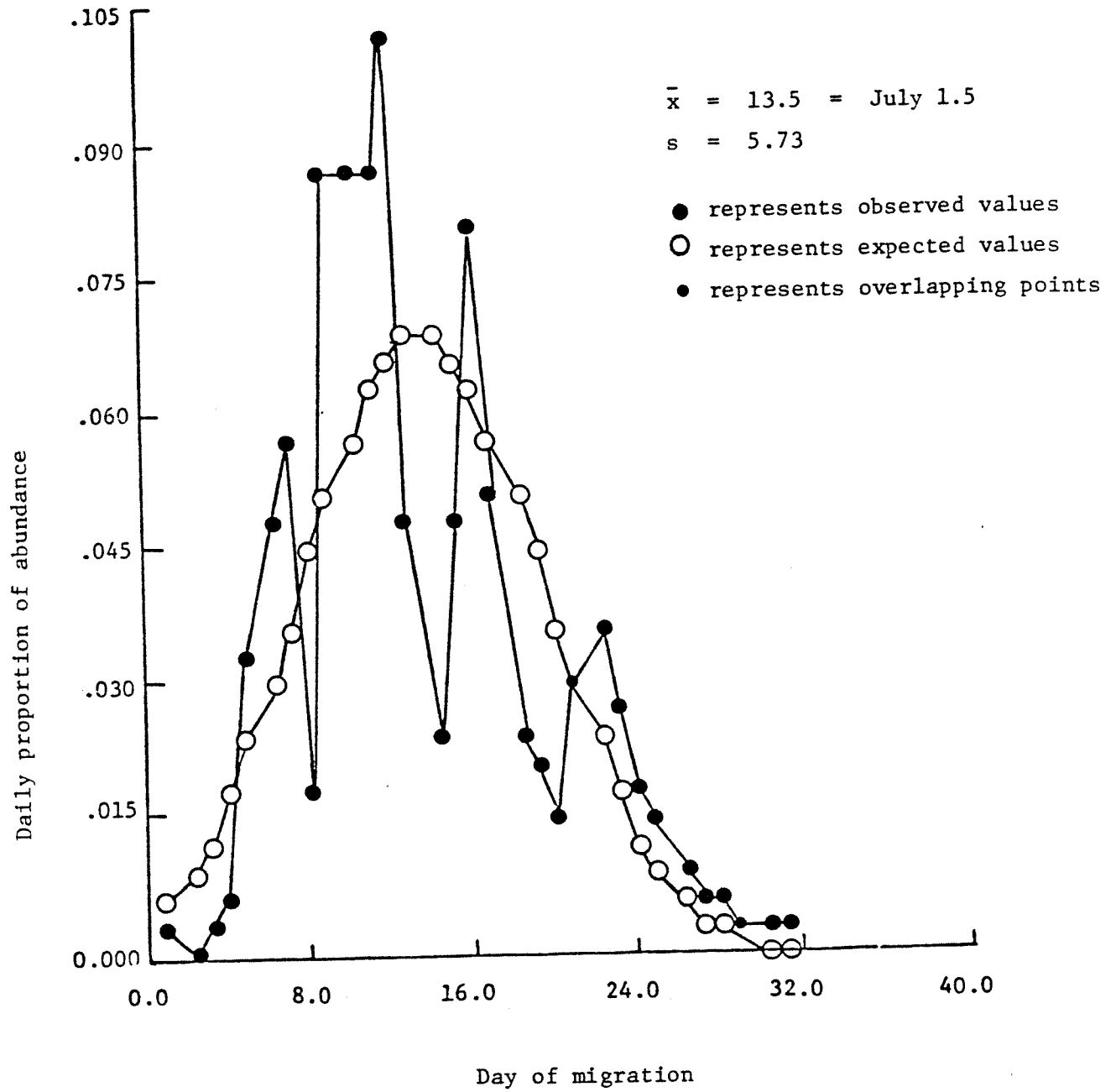


Fig. 3. Observed and expected daily proportions of total abundance for the 1979 migration of sockeye salmon to Nushagak Bay.

calendar day. The differences in the probabilities based on these four distributions can be seen in Tables 2, 3, 4 and 32.

4. The abundance estimate was calculated according to the following equation presented by Walters and Buckingham (1975):

$$\begin{aligned} \text{total abundance estimate} &= \frac{(\text{catch and lagged escapement to date})}{\text{cumulative proportion to date}} \\ &= \frac{\text{cumulative abundance}}{\text{cumulative proportion to date}} \quad (14) \end{aligned}$$

Table 5 demonstrates the abundance estimation procedure as presently applied and was based on preliminary data from the 1980 pink salmon migration for Nushagak Bay.

Results

These procedures for intraseason abundance estimation served as the basis for abundance estimation during the 1980 salmon migration to Nushagak Bay. Developing the statistics to perform these procedures and evaluating the performance of these procedures is the basis for the remainder of this report.

Discussion

The abundance estimation process described represents a unique application of migratory time density functions to intraseason abundance estimation. This process represents advances over the procedure employed in 1979 and represents progress toward describing the Nushagak Bay fishery in quantitative terms. The most important difference between the process described here and the

Table 2. Observed cumulative proportion of abundance¹ by day for sockeye salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.042	.016	.013	.071	21
2	.074	.042	.025	.218	21
3	.108	.044	.034	.219	21
4	.158	.058	.075	.309	21
5	.221	.074	.120	.387	21
6	.304	.109	.145	.510	21
7	.418	.170	.161	.610	21
8	.501	.143	.268	.744	21
9	.589	.130	.377	.817	21
10	.660	.122	.500	.904	21
11	.713	.113	.551	.931	21
12	.764	.101	.594	.948	21
13	.808	.092	.632	.959	21
14	.842	.083	.678	.966	21
15	.873	.072	.718	.973	21
16	.897	.062	.792	.976	21
17	.918	.051	.828	.982	21
18	.935	.044	.857	.993	21
19	.947	.036	.884	.994	21
20	.959	.031	.902	.995	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 3. Expected proportion of abundance based on a normal curve with $\bar{x} = 21.30$ and $s^2 = 36.68$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nushagak Bay sockeye salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.000	.000
2	.000	.000
3	.001	.001
4	.001	.002
5	.002	.004
6	.003	.007
7	.004	.011
8	.006	.017
9	.008	.025
10	.012	.037
11	.016	.053
12	.020	.073
13	.026	.099
14	.032	.131
15	.038	.169
16	.045	.214
17	.051	.265
18	.057	.322
19	.061	.383
20	.064	.447
21	.066	.513
22	.065	.578
23	.063	.641
24	.060	.701
25	.055	.756
26	.049	.805
27	.042	.847
28	.036	.883
29	.029	.912
30	.023	.935
31	.018	.953
32	.014	.967
33	.010	.977
34	.007	.984
35	.005	.989
36	.003	.992
37	.002	.994
38	.001	.995
39	.001	.996
40	.001	.997

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 4. Observed cumulative proportion of total abundance¹ by date of sockeye salmon for Nushagak Bay from 1959-1979.

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 15	.000	.000	.000	.001	21
16	.000	.000	.000	.001	21
17	.001	.001	.000	.006	21
18	.002	.004	.000	.017	21
19	.003	.006	.000	.027	21
20	.006	.009	.000	.037	21
21	.009	.012	.000	.048	21
22	.013	.014	.000	.053	21
23	.019	.019	.000	.055	21
24	.028	.029	.000	.097	21
25	.041	.043	.000	.153	21
26	.053	.055	.001	.170	21
27	.074	.070	.002	.258	21
28	.099	.092	.004	.344	21
29	.039	.128	.006	.434	21
30	.183	.161	.012	.532	21
July 1	.227	.184	.018	.582	21
2	.307	.187	.047	.650	21
3	.405	.185	.055	.720	21
4	.482	.191	.058	.789	21
5	.549	.190	.126	.838	21
6	.611	.189	.157	.869	21
7	.672	.169	.205	.887	21
8	.737	.136	.293	.897	21
9	.787	.118	.359	.906	21
10	.836	.108	.427	.925	21
11	.868	.094	.511	.944	21
12	.894	.073	.629	.963	21
13	.914	.062	.688	.971	21
14	.933	.051	.744	.977	21
15	.947	.043	.787	.988	21
16	.961	.033	.842	.991	21
17	.972	.021	.901	.994	21
18	.979	.014	.936	.996	21
19	.985	.008	.970	.998	21
20	.989	.005	.980	.998	21
21	.992	.004	.985	.998	21
22	.994	.003	.990	.999	21
23	.996	.002	.991	.999	21
24	.997	.002	.993	.999	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 5. Abundance estimation process for pink salmon from Nushagak Bay for 1980.

Date	Daily catch (thousands)	Cumulative catch (thousands)	Daily escapement (thousands)	Cumulative escapement (thousands)	Daily abundance (thousands)	Cumulative abundance (thousands)	Adjusted cumulative abundance (thousands)
7/16	4	4	$7\frac{1}{2}$	7	11	11	
7/17	6	10	$10\frac{1}{2}$	17	16	27	
7/18	15	25	$8\frac{1}{2}$	25	23	50	
7/19	22	47	$4\frac{1}{2}$	29	26	76	
7/20	27	74	$4\frac{1}{2}$	33	31	107	
7/21	62	136	$13\frac{1}{2}$	46	75	182	
7/22	101	237	$30\frac{1}{2}$	76	131	313	
7/23	150	387	$6\frac{2}{2}$	82	156	469	
7/24	206	593	$8\frac{2}{2}$	90	214	683	
7/25	190	783	$10\frac{2}{2}$	100	200	883	
7/26	170	953	$41\frac{2}{2}$	141	$211\frac{4}{2}$	1,094	
7/27	0	953	$35\frac{2}{2}$	176	$35\frac{4}{5}$	1,129	1,244
7/28	0	953	$50\frac{2}{2}$	226	$50\frac{5}{2}$	1,179	1,394
7/29	300	1,253	$30\frac{3}{2}$	256	330	1,509	1,724

1/ Escapement estimates based on Nuyakuk River tower counts lagged 8 days to the fishery.

2/ Estimates based on sonar counts at Portage Creek.

3/ Estimate based on aerial survey data.

4-5/ These estimates are considered minimum and the daily abundance was adjusted to 150,000 fish to correspond more closely with the abundance trends developed to that time.

The abundance estimate is based on defining the initiation of the migration as 21 July based on the maximum rate of change of the second derivative of the normal curve approximately by differences in daily observations of abundance as follows:

Date	Daily abundance	Approx. 1st derivative	Approx. 2nd derivative
7/17	15,606		
7/18	23,088	7,482	
7/19	26,284	3,196	-4,286
7/20	30,978	4,694	1,498
7/21	74,978	44,000	39,306*
7/22	131,000	56,022	12,022
7/23	156,000	25,000	-31,022
7/24	214,000	58,000*	33,000
7/25	200,000	-14,000	-72,000
7/26	211,000	11,000	25,000

Table 5. Abundance estimation process for pink salmon from Nushagak Bay for 1980 (continued).

Date	Cumulative abundance	Expected cumulative proportion	Point abundance estimate (millions)	Mean abundance estimate (millions)
7/21	182,934	.068	2.7	
7/22	313,934	.092	3.4	3.1
7/23	469,934	.123	3.8	3.3
7/24	683,934	.159	4.3	3.6
7/25	883,934	.202	4.4	3.7
7/26	1,094,934	.251	4.4	3.8*

* This estimate would serve as the abundance estimate. Assuming a total abundance of 3.8 million fish, the daily entry can be approximated as follows:

Date	Cumulative proportion	Expected cumulative abundance	Expected daily abundance
7/21	.068	258,000	
7/22	.092	350,000	92,000
7/23	.123	467,000	117,000
7/24	.159	604,000	137,000
7/25	.202	768,000	164,000
7/26	.251	954,000	186,000
7/27	.305	1,159,000	205,000
7/28	.364	1,383,000	224,000
7/29	.426	1,619,000	236,000
7/30	.489	1,858,000	239,000
7/31	.552	2,098,000	240,000
8/01	.613	2,329,000	231,000
8/02	.671	2,550,000	221,000
8/03	.724	2,751,000	201,000
8/04	.772	2,934,000	183,000
8/05	.815	3,097,000	163,000
8/06	.862	3,276,000	179,000
8/07	.883	3,355,000	79,000
8/08	.909	3,454,000	99,000
8/09	.930	3,534,000	80,000
8/10	.947	3,594,000	65,000

process employed in 1979 was the identification of the third derivative of the cumulative normal curve as the critical point to initiate the abundance estimation process rather than attempting to identify the mean day of the migration. In addition, the abundance estimation process described provides an alternative source of proportions based on mean observed proportions rather than expected proportions based strictly on the normal distribution.

Although the process described represents an advance in the available technology and is functional, refinements remain. First, distributions other than the normal need to be tested to minimize the deviations between the observed and expected proportions. Secondly, a procedure for quantitatively describing the migratory time density function intraseasonally rather than relying on a mean observed function based on all years of data is needed. Accurately defining the migratory time density intraseasonally would increase the reliability of the estimation process by reducing deviations between the expected and observed proportions.

ABUNDANCE ESTIMATION FOR CHINOOK SALMON

Introduction

Chinook salmon are the first salmon to enter Nushagak Bay. The majority of fish migrate to the Nushagak River system with the main river Nushagak and its tributaries serving as the primary spawning grounds for the species. Accurate catch and effort statistics are well documented since 1960. Unlike sockeye salmon, however, daily escapements have not been measured. Only total escapement estimates have been made because the mid-stream migratory habits of chinook salmon, coupled with poor visibility in the Nushagak River, make daily enumeration difficult. As a result, tower counts from the Nushagak are questionable. Escapements estimated from aerial surveys are inaccurate because not all the streams are flown consistently, and weather conditions and water color affect the ability to count the fish. Lack of daily escapement data increases the difficulty of intraseason abundance estimation which is the first essential step to quantifying management decisions. Currently, management decisions are based on qualitative evaluation of the magnitude of the run and comparison of observed catches relative to historic means.

Because of the lack of daily escapement data, catch data served as the primary input into the abundance estimation process which was developed during this contract and employed for the first time during the 1980 salmon migration. In addition to abundance estimates based on catch data, a preliminary feasibility study to estimate escapement intraseasonally was conducted to eventually base the abundance estimation process on migratory time density statistics calculated from catch plus escapement data rather than catch.

MethodsAbundance Estimation

The abundance estimation process for chinook salmon was based on catch data from 1960 through 1976, omitting 1963 and 1964 because of an inadequate breakdown of the catch prior to 20 June for both years. The calculated curves were adjusted for days of no fishing; however, no adjustments of catch were made for days of partial openings, and differences in effort were not taken into account. The estimation process was modified to first calculate total catch as follows:

$$\text{total catch} = \frac{\text{cumulative catch}}{\text{expected cumulative proportion of catch}} \quad (15)$$

Total abundance was then estimated from the relationship

$$N = \frac{C}{u} \quad (16)$$

where: N represents total abundance

C represents total catch

u represents exploitation rate

Since catch and total abundance had been estimated, preliminary spawning escapement was estimated as follows:

$$N - C = E \quad (17)$$

where: N represents abundance

C represents catch

E represents spawning escapement

Later in the season, escapement estimates based on the techniques described in the escapement estimation section were employed.

The two techniques described previously were employed to calculate the proportions required for the abundance estimation process. First, \bar{x} and s^2 were calculated (Table 6); then the expected daily and cumulative proportions based on the mean curve for all years of observations were calculated (Table 7). Given the normal distribution for each year, the expected maxima of the first and second derivatives of the cumulative normal probability density function were defined (Table 8). The day of the maximum of the second derivative was identified as day 1 for all years. The observed proportion of catch was then noted and the mean observed catch for all years was calculated (Table 9). These proportions were employed in the abundance estimation process.

The proportions calculated thus far were not associated with a specific calendar date. As Mundy (1979) demonstrated, migratory time densities for sockeye are consistent from year to year. Consequently the proportion of the migration accounted for between specified dates can be defined. To associate calendar date with expected proportion, the observed proportions by date were averaged (Table 10).

Finally, to calculate total abundance, the mean exploitation rate (\hat{u}) was calculated from 1966 through 1979 (Table 11). Two exploitation rates were calculated; one procedure was based strictly on the reported catch and the second method provided adjustments for periods of closures.

Escapement Estimation

Catch data from chinook salmon subsistence nets for Dillingham and vicinity from 1966-1973 were examined to evaluate their usefulness for

Table 6. Migratory time density statistics for Nushagak Bay chinook salmon. These calculations are based on adjusted catch¹ data.

Migratory time densities			
Year	\bar{x}^2	s^2	s
1960	20.49	88.37	9.40
1961	15.52	55.15	7.43
1962	19.85	77.16	8.78
1965	19.12	64.56	8.03
1966	21.70	41.98	6.48
1967	22.43	58.78	7.67
1968	18.97	76.45	8.74
1969	19.22	146.90	12.12
1970	19.97	94.50	9.72
1971	28.66	75.47	8.69
1972	26.35	102.75	10.14
1973	19.65	119.39	10.93
1974	16.77	114.87	10.72
1975	24.93	140.32	11.85
1976	23.98	75.50	8.69

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

² \bar{x} represents the mean day of the migration with day 1 = June 1, 2 = June 2, etc.

Table 7. Expected proportion of catch by day based on a normal curve with $\bar{x} = 21.17$ and $s^2 = 88.81$, which represents the mean of the mean days of the migration and the mean of the variance for 1960-1976 (excluding 1963 and 1964) for Nushagak Bay chinook salmon based on adjusted catch¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.004	.004
2	.005	.009
3	.007	.016
4	.008	.024
5	.010	.034
6	.012	.046
7	.014	.060
8	.016	.076
9	.018	.094
10	.021	.115
11	.024	.139
12	.026	.165
13	.029	.194
14	.032	.226
15	.034	.260
16	.037	.297
17	.038	.335
18	.040	.375
19	.041	.416
20	.042	.458
21	.042	.050
22	.042	.542
23	.042	.584
24	.039	.664
26	.037	.701
27	.035	.736
28	.033	.769
29	.030	.799
30	.027	.826
31	.025	.851
32	.022	.873
33	.019	.892
34	.017	.909
35	.014	.923
36	.012	.935
37	.010	.945
38	.009	.954
39	.007	.961
40	.005	.966

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 8. Observed proportions of cumulative abundance on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay chinook salmon based on adjusted catch¹ data.

Year	Expected day of maximum		Observed		Expected day of maximum		Observed	
	2nd derivative	3rd derivative	Daily proportion	Cumulative proportion	3rd derivative	Daily proportion	Daily proportion	Cumulative proportion
1960	12	5	.036	.159	5	.002	.011	
1961	9	4	.038	.214	4	.020	.024	
1962	12	6	.029	.230	6	.022	.079	
1965	12	6	.018	.175	6	.014	.065	
1966	16	11	.055	.256	11	.001	.008	
1967	15	10	.024	.186	10	.010	.073	
1968	11	5	.037	.194	5	.010	.067	
1969	8	3	.026	.202	3	.027	.069	
1970	11	4	.038	.223	4	.008	.033	
1971	20	15	.017	.172	15	.022	.066	
1972	17	10	.027	.203	10	.003	.030	
1973	9	3	.024	.202	3	.024	.060	
1974	7	3	.016	.102	3	.016	.039	
1975	14	5	.013	.110	5	.004	.018	
1976	16	10	.046	.156	10	.007	.038	

$\bar{x} = .186$ $\bar{x} = .045$
 $\sigma = .042$ $\sigma = .024$

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 9. Observed proportion of catch¹ by day for chinook salmon for Nushagak Bay from 1960-1976 (excluding 1963 and 1964). Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.045	.024	.008	.079	15
2	.064	.026	.022	.101	15
3	.085	.030	.026	.123	15
4	.108	.036	.034	.149	15
5	.134	.042	.047	.201	15
6	.161	.049	.060	.256	15
7	.191	.055	.072	.310	15
8	.228	.062	.085	.365	15
9	.268	.073	.098	.408	15
10	.309	.085	.110	.440	15
11	.353	.094	.157	.523	15
12	.399	.103	.237	.611	15
13	.452	.110	.281	.699	15
14	.510	.112	.293	.745	15
15	.569	.106	.357	.751	15
16	.620	.105	.422	.824	15
17	.662	.096	.540	.879	15
18	.699	.095	.567	.934	15
19	.732	.087	.589	.940	15
20	.761	.085	.610	.945	15
21	.784	.086	.632	.952	15
22	.806	.086	.653	.961	15
23	.822	.090	.675	.969	15
24	.840	.090	.696	.975	15
25	.857	.085	.718	.979	15
26	.875	.083	.739	.983	15
27	.886	.083	.740	.985	15
28	.895	.082	.740	.987	15
29	.900	.083	.740	.987	15
30	.909	.078	.741	.987	15
31	.920	.071	.742	.987	15
32	.931	.067	.744	.989	15

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 10. Observed proportion of catch¹ by date of chinook salmon for Nushagak Bay from 1960-1976 (excluding 1963 and 1964).

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 1	.006	.006	.000	.021	15
2	.014	.015	.000	.042	15
3	.022	.022	.000	.068	15
4	.032	.030	.000	.095	15
5	.044	.038	.000	.122	15
6	.057	.046	.001	.149	15
7	.072	.055	.003	.176	15
8	.088	.065	.004	.202	15
9	.107	.076	.005	.226	15
10	.130	.092	.006	.258	15
11	.155	.109	.008	.346	15
12	.184	.125	.010	.434	15
13	.219	.139	.021	.522	15
14	.256	.153	.044	.611	15
15	.297	.168	.066	.699	15
16	.341	.175	.088	.745	15
17	.393	.177	.110	.751	15
18	.442	.176	.132	.756	15
19	.488	.174	.154	.762	15
20	.527	.174	.172	.776	15
21	.560	.175	.184	.806	15
22	.593	.170	.196	.837	15
23	.624	.164	.208	.867	15
24	.660	.155	.253	.898	15
25	.697	.141	.331	.919	15
26	.730	.132	.408	.940	15
27	.760	.121	.486	.947	15
28	.791	.108	.561	.953	15
29	.818	.094	.634	.959	15
30	.844	.086	.706	.965	15
July 1	.865	.085	.739	.970	15
2	.877	.085	.740	.976	15
3	.889	.083	.740	.981	15
4	.899	.080	.741	.986	15
5	.909	.079	.742	.987	15
6	.915	.078	.744	.988	15
7	.921	.078	.746	.989	15
8	.930	.067	.793	.991	15
9	.942	.051	.852	.991	15
10	.950	.043	.864	.991	15

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of the hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 11. Abundance statistics for chinook salmon for Nushagak Bay from 1966-1979.

Year	Catch	Escapement	Total abundance	Exploitation rate (\hat{u})	Adjusted catch ¹	Adjusted exploitation rate (\hat{u}')
1966	58,184	40,000	98,184	.593	78,859	.803
1967	96,240	65,000	161,240	.597	159,652	.990
1968	78,201	70,000	148,201	.528	114,858	.775
1969	80,803	35,000	115,803	.700	99,828	.862
1970	87,547	50,000	137,547	.636	91,653	.666
1971	82,769	—	—	—	—	—
1972	46,045	25,000	71,045	.648	65,330	.920
1973	30,470	35,000	65,470	.465	53,423	.816
1974	32,053	70,000	102,053	.314	40,587	.398
1975	21,454	70,000	91,454	.235	31,170	.341
1976	60,682	100,000	160,682	.378	129,526	.806
1977	86,261	65,000	151,261	.570	—	—
1978	105,718	130,000	235,718	.448	—	—
1979	142,800	95,000	237,800	.601	—	—

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

intraseason escapement estimation as follows:

1. CPUE for each year was calculated by dividing the total catch by total number of permits issued (Table 12).

$$\text{CPUE (fish/permit)} = \frac{\text{total annual catch}}{\text{total annual number of permits}} \quad (18)$$

2. To relate CPUE to escapement, total escapement (E) was divided by cumulative CPUE (Table 12)

$$E/\text{CPUE} = \frac{\text{total annual escapement}}{\text{cumulative CPUE}} \quad (19)$$

3. To compensate for differential catchability, a polynomial regression model was constructed to relate E/CPUE to the average weight of chinook salmon caught (Figures 4 and 5).
4. The total escapement for each year was calculated by multiplying CPUE times the E/CPUE predicted by the regression equation for that year.

$$\text{Escapement (E)} = \text{CPUE} \times (E/\text{CPUE}) \quad (20)$$

5. The total expected escapement (e) was then compared with the total observed escapement (o) by calculation of percent error (Table 13).

$$\frac{e - o}{o} \times 100 \quad (21)$$

Table 12. Subsistence catch statistics¹ from set nets from Dillingham and vicinity² from 1966-1973.³

Year	Total subsistence catch	Total effort (number of permits)	CPUE		Total escapement ⁴	E/CPUE ⁵	Mean weight (lbs.)
			Cumulative subsistence catch	Total effort			
1966	1,091	21	52	40,000	769	18.3	
1967	826	20	41	65,000	1,585	21.0	
1968	1,618	34	48	70,000	1,458	21.6	
1969	745	24	31	35,000	1,129	19.2	
1970	810	16	51	50,000	980	18.3	
1972	1,104	68	16	25,000	1,563	19.8	
1973	2,294	81	28	35,000	1,250	22.6	

¹ Data from Alaska Department of Fish and Game.

² Dillingham and vicinity defined as Dillingham, Kanakanak, Olsonville, Clark's Point, Nushagak Slough, Ekuk, Igushik Beach and Lewis Point fish camps.

³ 1971 was omitted because there was no estimate of escapement.

⁴ These data are from Nelson (1979).

⁵ E/CPUE represents total observed escapement divided by CPUE.

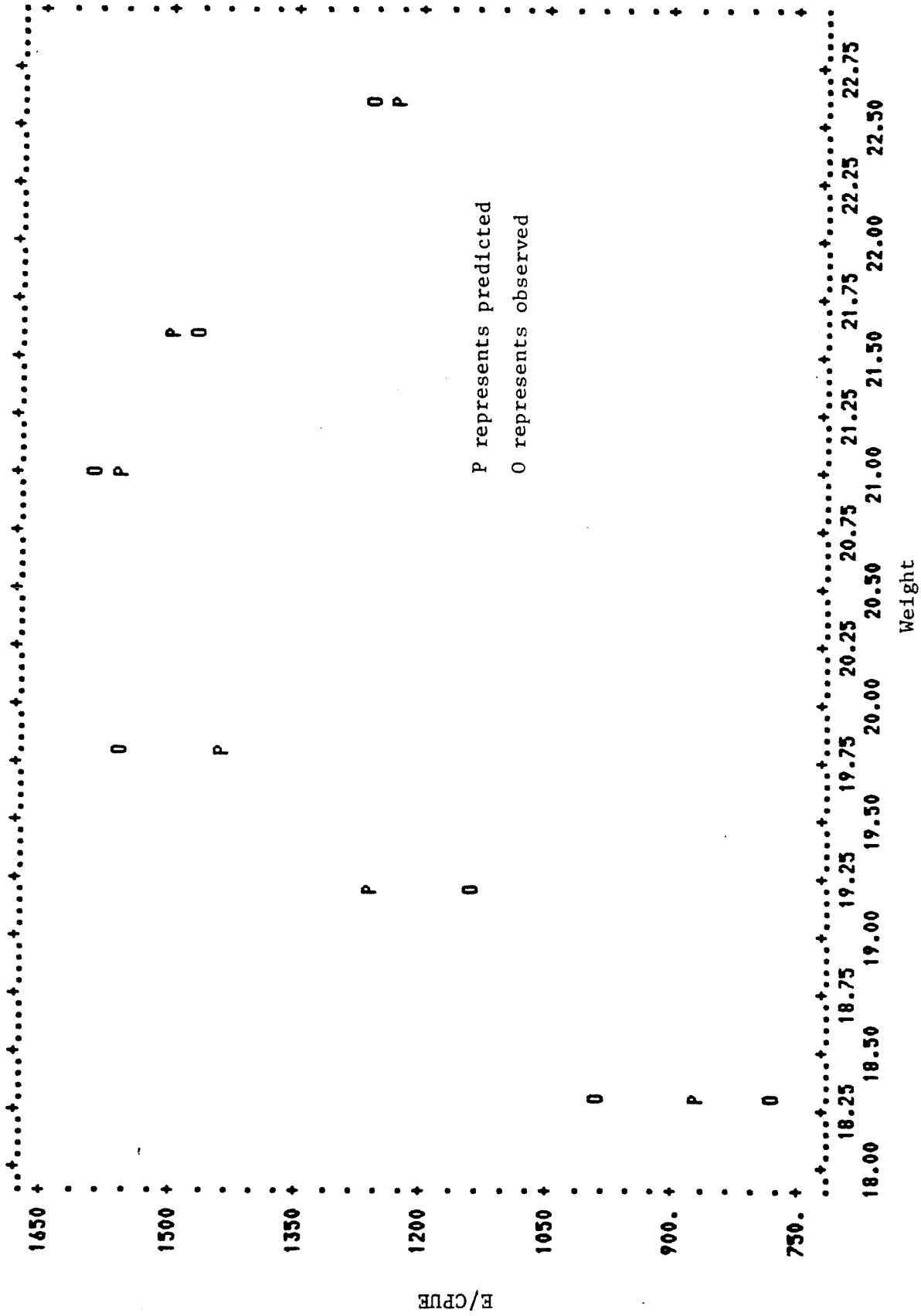


Fig. 4. Predicted and observed data for the polynomial regression of E/CPUE and weight for chinook salmon from Nushagak Bay.

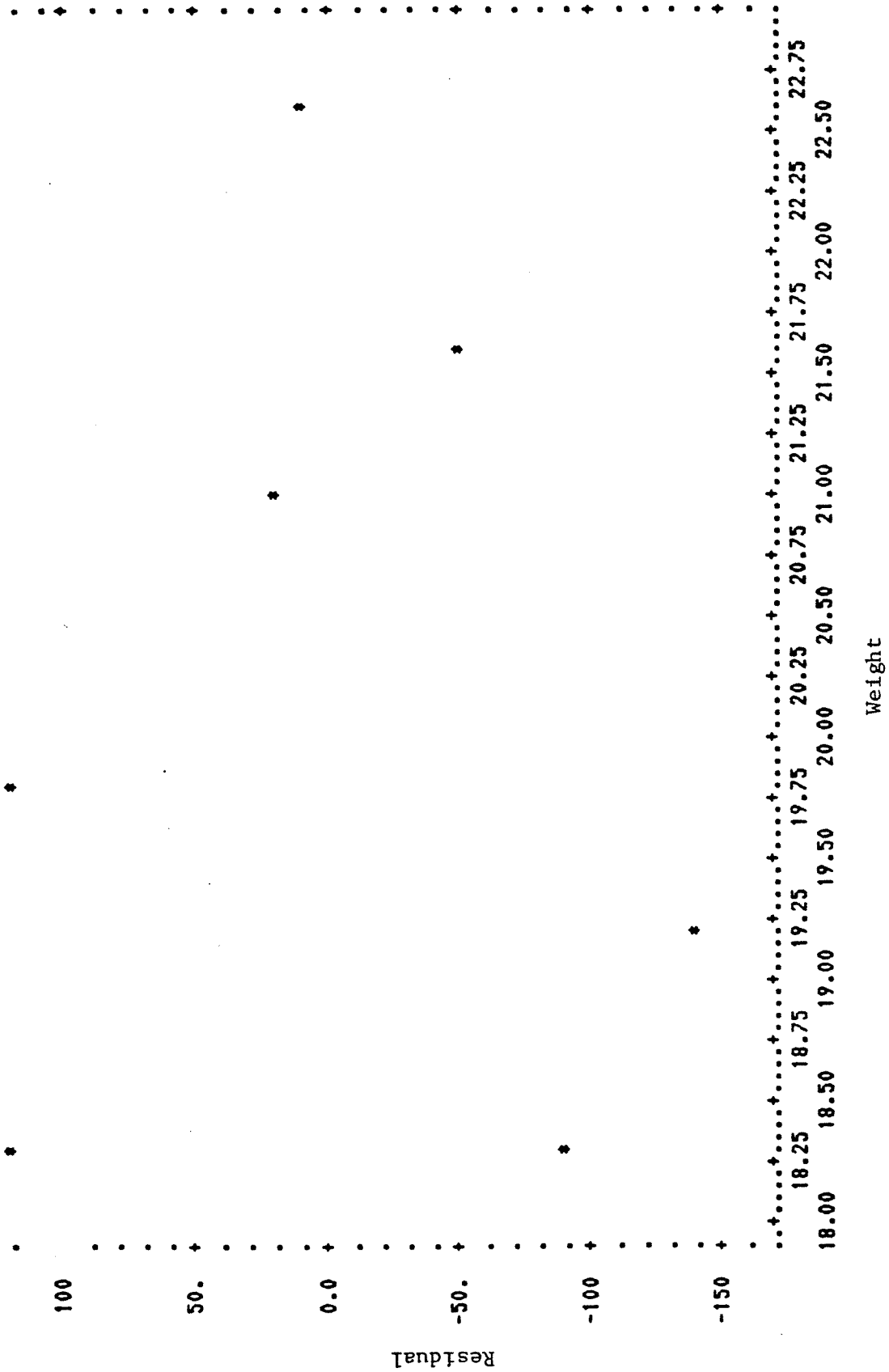


Fig. 5. Residual analysis of the polynomial regression of E/CPUE and weight for chinook salmon from Nushagak Bay.

Table 13. Error of expected and observed escapement of Nushagak River chinook salmon from 1966-1973.

Year	Total escapement observed (o)	Total escapement expected (e)	Error e-o	% Error $\frac{e-o}{o}$
1966	40,000	53,978	13,978	+ 35
1967	65,000	56,168	-8,832	- 16
1968	70,000	68,098	-1,902	- 03
1969	35,000	35,573	573	+ 02
1970	50,000	52,599	2,599	+ 05
1972	25,000	19,758	-5,242	- 27
1973	35,000	43,898	8,898	+ 20

Results

Abundance Estimation

During the chinook salmon migration 5 estimates of abundance were calculated (Table 14). In addition, on June 12 a "worst possible case" scenario was constructed from the historical data base. Since 1960 (omitting 1963 and 1964 data), 30 percent of the total catch was accounted for in only 1 of 15 years by 10 June. With a cumulative catch of 33,000 fish through 10 June a minimum of 110,000 fish should be caught assuming continuous fishing (with a minimum of 12 hrs of fishing per day). A minimum total run of 150,000 fish was estimated assuming an average exploitation rate of .74 with the previous assumptions concerning fishing. This "worst possible case" scenario was evident when decisions regarding openings and closures were made.

Preliminary catch data suggest that the final catch was about 64,000. According to preliminary aerial surveys, chinook salmon escapement was approximately 130-150,000 fish. As such, even though the abundance estimates ranged from 162,000 to 270,000, no individual estimate probably had a proportion of error greater than .50. The wide divergence in the estimates reflects the lack of rigor of the abundance estimation process for chinook salmon and involved assumptions.

Escapement Estimation

The following points summarize the results.

1. The E/CPUE ranged from 769 fish/CPUE in 1966 (average weight = 18.3 lbs.) to 1,585 fish/CPUE in 1967 (average weight = 21.8 lbs.) (Table 12).

Table 14. Abundance estimates for chinook salmon for Nushagak Bay, 1980.

Date of estimate	Estimated abundance	Estimated catch	Estimated escapement	Date of 50% point
June 12	240,000	178,000 ¹	62,000	June 19
June 15	270,000	202,000 ¹	68,000	June 19
June 24	162,000	83,600 ²	78,400	June 19
June 30	162,000	69,600 ²	92,400	June 19
July 5	162,000	65,787 ²	96,213	June 19

Preliminary observed abundance

Catch = 64,000

Escapement \approx 130,000

Approximate total abundance \approx 200,000

¹ Assumed mean exploitation rate of .74 given at least 12 hours of continuous fishing.

² Assumed mean exploitation rate of .516 which represented the mean annual exploitation rate for chinook salmon.

2. The polynomial relationship of E/CPUE as the dependent variable and mean chinook salmon weight as the independent variable was

$$\hat{y} = 4523.8x - 108.4x^2 - 45615.1.$$

3. The percent error of observed and expected escapement varied from +35 percent to -27 percent (Table 13).

Discussion

Abundance Estimation

Provided a reliable measure of daily escapement of chinook salmon is possible, the intraseason abundance estimation process can be substantially improved. The abundance estimation procedure can be based on catch plus escapement data which are a much more reliable measure of total abundance than catch.

During this contract, the chinook salmon data base was improved by entering daily catch and effort data provided by the Alaska Department of Fish and Game onto computer tape. From these data, daily CPUE can be calculated. The CPUE data can subsequently be employed to calculate the cumulative proportions of fish present in the district on any day according to equations (3) and (13).

Escapement Estimation

The purpose of this study was to evaluate the feasibility of estimating intraseason chinook salmon escapement from subsistence net catches. The results clearly demonstrate that subsistence net data can be successfully employed

for intraseason escapement estimation, but the following points need to be considered:

1. The data examined represent combined catches from subsistence nets from Dillingham and vicinity. Historic subsistence net data should be grouped by specific subsistence net fishery such as Lewis Point, Kanak-kanak or Scandinavian Beach to determine whether E/CPUE can be reduced.
2. The data should be examined first to evaluate the consistency of the information. Locations with consistent, long-term records are preferred.
3. Several locations should be selected to supply in-season data for escapement estimation so that independent escapement estimates can be calculated. Such a system would provide necessary checks of the estimates to ensure their reliability. Preference should be given to sites: (1) that have the least variable E/CPUE values; (2) that are closest to the fishing district; and (3) where there is continuous fishing.
4. Since gillnets are selective, a significant source of bias in the mean weight may be caused by the transition from chinook gear to sockeye gear. It may be advantageous to develop two models based on the different gear types.
5. Development of a method to accurately assess in-season escapement will allow tremendous improvement in the ability to forecast total abundance. The present model is based solely on catch. In-season escapement estimates will allow a model based on the total abundance which should be more accurate.

ABUNDANCE ESTIMATION FOR SOCKEYE SALMON

Introduction

Sockeye salmon are generally the most abundant and economically valuable species to enter Nushagak Bay, and the migration of sockeye salmon usually begins after the chinook salmon migration has peaked. Accurate catch, effort and spawning escapement statistics are available since 1959; however, abundance estimates based on migratory time density statistics were first applied to Nushagak Bay sockeye salmon in 1979.

Methods

The abundance estimation process for sockeye salmon was based on catch plus escapement data from 1959 through 1979. To calculate daily abundance of sockeye salmon returning to Nushagak Bay, the catch was added to the escapement. Estimates of escapement were lagged back two days to the fishery from the Wood River tower, two days from the Igushik inside gillnet test fishing project or 5 days from the Igushik River tower, and 2 days from the Portage Creek sonar site or 10 days from the Nuyakuk River tower. Daily abundances of fish returning to each of the major river systems were calculated from the catch allocated according to the procedures described earlier. The abundance estimation process followed the steps previously described.

The four techniques described previously were employed to calculate the proportions required for the abundance estimation process. First, \bar{x} and s^2 were calculated for the migration to Nushagak District, Wood River, Igushik River and Nuyakuk River (Table 15). Then the expected daily and cumulative

Table 15. Migratory time density statistics for Nushagak Bay sockeye salmon. These calculations are based on total abundance.¹

Year	Migratory time densities							
	Nushagak District		Wood ³ River		Igushik ³ River		Nuyakuk ³ River	
	\bar{x}^2	s^2	\bar{x}	s^2	\bar{x}	s^2	\bar{x}	s^2
1959	22.05	38.30	21.48	34.21	23.60	45.74	22.18	47.55
1960	22.16	42.15	21.71	35.89	23.67	56.12	18.90	4.00
1961	21.15	39.79	23.33	22.70	18.81	52.08	19.64	25.48
1962	21.54	25.35	21.63	25.83	19.30	20.48	20.46	12.85
1963	20.75	29.47	20.95	32.33	21.93	25.07	18.48	11.61
1964	22.36	31.95	22.80	28.39	21.01	33.37	21.32	49.87
1965	21.87	32.24	21.95	23.45	19.21	40.45	24.90	29.64
1966	22.45	20.51	22.10	20.07	22.58	17.42	24.46	22.24
1967	17.77	32.60	18.67	25.49	16.70	41.27	15.62	11.00
1968	17.80	33.62	19.59	30.02	13.96	30.95	15.61	11.27
1969	20.73	19.05	21.74	17.66	19.56	19.08	20.47	12.26
1970	21.63	17.06	22.01	13.09	21.02	23.37	21.15	20.97
1971	27.20	24.56	26.94	19.23	27.83	48.57	27.49	28.68
1972	23.27	17.00	23.93	10.22	21.32	25.50	23.29	37.46
1973	21.35	35.46	22.42	38.08	16.63	22.98	21.79	23.02
1974	19.41	24.17	19.13	19.72	21.73	28.55	15.11	27.06
1975	24.09	14.84	24.94	12.96	24.61	21.49	22.00	10.18
1976	22.90	26.89	23.54	23.19	22.98	40.57	21.89	22.97
1977	19.92	37.34	28.89	28.59	20.16	40.96	21.46	46.01
1978	19.46	33.68	20.42	29.70	19.33	33.87	14.99	28.14
1979	17.52	34.22	17.06	29.92	19.27	38.81	13.72	10.24

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

² \bar{x} represents the mean day of the migration with day 1 = June 15, 2 = June 16, etc.

³ Daily catch was allocated to each of the river systems based on daily proportions of escapement.

proportions based on the mean curve for all years of observation were calculated for the migration to the Nushagak District (Table 16), the Wood River (Table 17), the Igushik River (Table 18), and Nuyakuk River (Table 19). Given the normal distribution for each year, the expected maxima of the first and second derivatives of the normal probability density function were defined for the migration to the Nushagak District (Table 20), Wood River (Table 21), Igushik River (Table 22), and Nuyakuk River (Table 23). The day of the second derivative was identified as day 1 for all years. The observed proportion of abundance was then noted and the mean observed abundance for all years was calculated for the migration to Nushagak Bay (Table 24), Wood River (Table 25), Igushik River (Table 26), and Nuyakuk River (Table 27). These proportions were employed in the abundance estimation process.

The proportions calculated thus far were not associated with a specific calendar date. To associate calendar date with expected proportions, the observed proportions by date were averaged for the migration to Nushagak Bay (Table 28), Wood River (Table 29), Igushik River (Table 30), and Nuyakuk River (Table 31).

Since the first progress report, proportions were calculated entirely from observed data. Day 1 was defined as the maximum of the rate of change of the daily rate of change of the daily number of fish entering the district (Table 32). This distribution appears to be bimodal (Fig. 6).

Results

During the 1980 sockeye salmon migration, four estimates of abundance were calculated for Nushagak District, Wood River, Igushik River, and Nuyakuk River

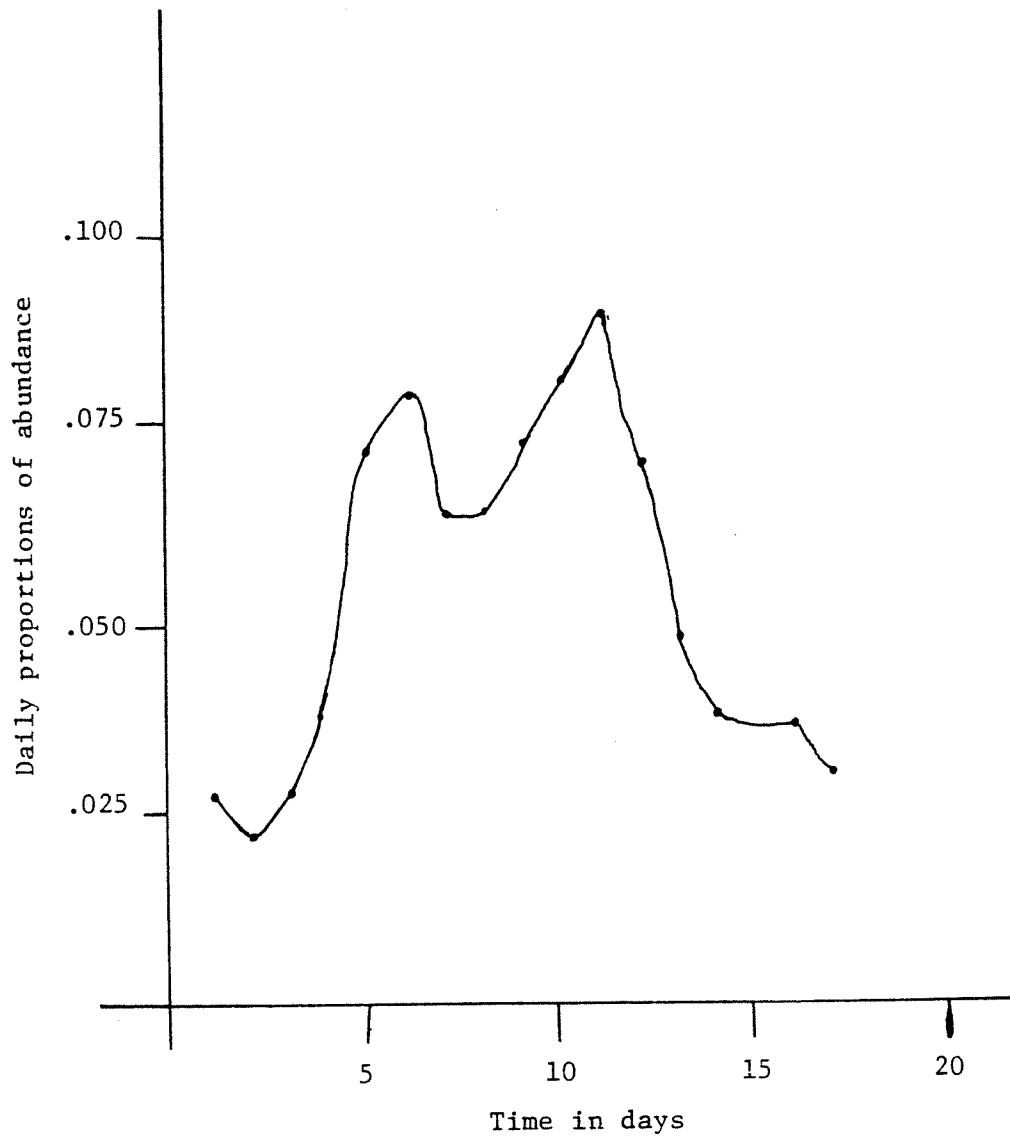


Fig. 6. Mean distribution of daily proportions of sockeye salmon entering Nushagak Bay. Day 1 was defined as the maximum of the rate of change of the daily rate of change of the daily number of fish entering the district.

(Tables 33, 34, 35, 36). The proportion of error ($\frac{e-0}{0}$) for the estimates follow: Nushagak District (-.54, -.55, -.27, .09), Wood River (-.37, -.17, +.03, +.22), Igushik River (-.53, -.45, -.18, -.02), Nuyakuk River (-.84, -.68, -.65, -.35). The first estimates were made with .086, .151, .108, .016 of the migration completed to the respective locations.

Discussion

The abundance estimation procedure employed during the 1980 sockeye salmon migration did not perform as well as during 1979. The estimates were useful, however, because the management strategy based on the first estimate of 5.7 million fish, which corresponded closely to ADF&G's pre-season forecast of 6.2 million fish, differed little from that required by a migration of 12.4 million fish. The management strategies were analogous because of the large differential between the required escapement of 1.27 million fish and the observed abundance. Then, too, the migration of 12.4 million fish was the largest migration of sockeye salmon to Nushagak Bay since the turn of the century.

The greatest source of error in the abundance estimation process was the underestimation of the return to the Nuyakuk River system. The error can be associated with two factors. First, the initial forecast to the Nuyakuk River system was premature; i.e., insufficient escapement data were available from the Nuyakuk River to justify a forecast. Secondly, the historic migratory time density functions for sockeye returning to the Nuyakuk River are highly variable.

Table 16. Expected proportion of abundance based on a normal curve with $\bar{x} = 21.30$ and $s^2 = 36.68$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nushagak Bay sockeye salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.000	.000
2	.000	.000
3	.001	.001
4	.001	.002
5	.002	.004
6	.003	.007
7	.004	.011
8	.006	.017
9	.008	.025
10	.012	.037
11	.016	.053
12	.020	.073
13	.026	.099
14	.032	.131
15	.038	.169
16	.045	.214
17	.051	.265
18	.057	.322
19	.061	.383
20	.064	.447
21	.066	.513
22	.065	.578
23	.063	.641
24	.060	.701
25	.055	.756
26	.049	.805
27	.042	.847
28	.036	.883
29	.029	.912
30	.023	.935
31	.018	.953
32	.014	.967
33	.010	.977
34	.007	.984
35	.005	.989
36	.003	.992
37	.002	.994
38	.001	.995
39	.001	.996
40	.001	.997

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 17. Expected proportion of abundance based on a normal curve with $\bar{x} = 22.15$ and $s^2 = 24.80$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Wood River sockeye salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.000	.000
2	.000	.000
3	.000	.000
4	.000	.000
5	.000	.000
6	.000	.000
7	.001	.001
8	.001	.002
9	.002	.004
10	.004	.008
11	.007	.015
12	.010	.025
13	.015	.040
14	.021	.061
15	.029	.090
16	.037	.127
17	.047	.174
18	.057	.231
19	.066	.297
20	.073	.370
21	.078	.448
22	.080	.528
23	.079	.607
24	.075	.682
25	.068	.750
26	.059	.809
27	.050	.859
28	.040	.899
29	.031	.930
30	.023	.953
31	.017	.970
32	.011	.981
33	.007	.988
34	.005	.993
35	.003	.996
36	.002	.998
37	.001	.999
38	.001	1.000
39	.000	1.000
40	.000	1.000

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 18. Expected proportion of abundance based on a normal curve with $\bar{x} = 20.72$ and $s^2 = 33.65$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Igushik River sockeye salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.000	.000
2	.000	.000
3	.001	.001
4	.001	.002
5	.002	.004
6	.003	.007
7	.004	.011
8	.006	.017
9	.009	.026
10	.012	.038
11	.017	.055
12	.022	.077
13	.028	.105
14	.035	.140
15	.042	.182
16	.049	.231
17	.056	.287
18	.062	.349
19	.066	.415
20	.068	.483
21	.069	.552
22	.067	.619
23	.064	.683
24	.059	.742
25	.052	.794
26	.045	.839
27	.038	.877
28	.031	.908
29	.025	.933
30	.019	.952
31	.014	.966
32	.010	.976
33	.007	.983
34	.005	.988
35	.003	.991
36	.002	.993
37	.001	.994
38	.001	.995
39	.000	.995
40	.000	.995

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 5 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 19. Expected proportion of abundance based on a normal curve with $\bar{x} = 20.23$ and $s^2 = 22.97$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nuyakuk River sockeye salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.000	.000
2	.000	.000
3	.000	.000
4	.000	.000
5	.001	.001
6	.001	.002
7	.002	.004
8	.003	.007
9	.005	.012
10	.009	.021
11	.013	.034
12	.019	.053
13	.027	.080
14	.036	.116
15	.046	.162
16	.056	.218
17	.066	.284
18	.075	.359
19	.081	.440
20	.083	.523
21	.082	.605
22	.078	.683
23	.070	.753
24	.061	.814
25	.051	.865
26	.040	.905
27	.031	.936
28	.022	.958
29	.016	.974
30	.010	.984
31	.007	.991
32	.004	.995
33	.002	.997
34	.001	.998
35	.001	.999
36	.000	.999
37	.000	.999
38	.000	.999
39	.000	.999
40	.000	.999

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 10 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 20. Observed proportions of abundance¹ on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay sockeye salmon.

Year	Expected day of maximum		Observed		Expected day of maximum		Observed	
	2nd derivative	Cumulative proportion	Daily proportion	Cumulative proportion	3rd derivative	Daily proportion	Cumulative proportion	
1959	16	.150	.038	.150	12	.026	.039	
1960	16	.165	.067	.165	12	.002	.071	
1961	15	.181	.037	.181	11	.010	.055	
1962	17	.075	.041	.075	14	.002	.030	
1963	16	.120	.029	.120	12	.006	.064	
1964	17	.120	.003	.120	14	.007	.051	
1965	17	.138	.001	.138	13	.004	.064	
1966	18	.144	.110	.144	16	.010	.023	
1967	13	.129	.012	.129	9	.006	.039	
1968	12	.209	.083	.209	9	.023	.048	
1969	17	.186	.081	.186	14	.009	.040	
1970	18	.154	.070	.154	15	.015	.047	
1971	23	.205	.048	.205	20	.003	.058	
1972	20	.224	.005	.224	17	.002	.048	
1973	16	.216	.018	.216	12	.005	.013	
1974	15	.166	.075	.166	12	.009	.028	
1975	21	.203	.034	.203	18	.029	.047	
1976	18	.222	.156	.222	15	.001	.040	
1977	14	.140	.044	.140	10	.007	.018	
1978	14	.223	.111	.223	10	.014	.049	
1979	12	.171	.017	.171	8	.007	.016	
		$\bar{x} = .168$				$\bar{x} = .042$		
		$\sigma = .041$				$\sigma = .016$		

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 21. Observed proportions of abundance¹ on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Wood River sockeye salmon.

Year	Expected day of maximum		Observed		Expected day of maximum		Observed	
	2nd derivative	3rd derivative	Daily proportion	Cumulative proportion	3rd derivative	Daily proportion	Daily proportion	Cumulative proportion
1959	16	12	.038	.153	12	.033	.042	
1960	16	12	.015	.130	12	.002	.099	
1961	19	16	.106	.226	16	.019	.060	
1962	17	14	.040	.069	14	.001	.027	
1963	16	12	.003	.090	12	.005	.074	
1964	18	15	.025	.101	15	.009	.071	
1965	17	13	.000	.062	13	.000	.042	
1966	18	16	.111	.155	16	.013	.029	
1967	13	9	.005	.040	9	.002	.005	
1968	15	11	.025	.178	11	.011	.033	
1969	18	15	.088	.226	15	.001	.001	
1970	19	17	.077	.191	17	.003	.029	
1971	23	20	.057	.170	20	.001	.026	
1972	20	17	.000	.078	17	.000	.046	
1973	17	13	.020	.225	13	.038	.061	
1974	15	12	.080	.142	12	.001	.005	
1975	22	20	.124	.171	20	.000	.027	
1976	19	16	.184	.290	16	.000	.014	
1977	14	11	.077	.214	11	.007	.025	
1978	14	10	.091	.142	10	.001	.011	
1979	12	9	.007	.224	9	.029	.035	

$\bar{x} = .156$
 $\sigma = .066$

$\bar{x} = .036$
 $\sigma = .025$

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 22. Observed proportions of abundance¹ on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Igushik River sockeye salmon.

Year	Expected		Observed		Expected		Observed	
	day of maximum	2nd derivative	Daily proportion	Cumulative proportion	day of maximum	3rd derivative	Daily proportion	Cumulative proportion
1959	17		.047	.184	13		.014	.046
1960	17		.065	.298	12		.003	.048
1961	12		.074	.192	7		.017	.046
1962	15		.007	.185	12		.060	.160
1963	17		.009	.079	14		.005	.053
1964	16		.124	.281	12		.011	.012
1965	13		.016	.165	9		.013	.031
1966	19		.143	.340	16		.000	.006
1967	11		.066	.214	7		.025	.157
1968	9		.060	.141	5		.002	.003
1969	16		.054	.191	13		.010	.072
1970	17		.027	.176	14		.026	.091
1971	21		.086	.303	17		.013	.105
1972	17		.006	.044	14		.000	.000
1973	12		.000	.000	9		.000	.000
1974	17		.092	.255	13		.012	.029
1975	20		.114	.209	18		.017	.026
1976	17		.011	.169	13		.001	.035
1977	14		.018	.213	10		.025	.075
1978	14		.087	.236	10		.010	.084
1979	14		.188	.324	9		.017	.037

\bar{x}	=	.200
σ	=	.087
\bar{x}	=	.048
σ	=	.040

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 10 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 23. Observed proportions of abundance¹ on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nuyakuk River sockeye salmon.

Year	Expected day of maximum		Observed		Expected day of maximum		Observed	
	2nd derivative	3rd derivative	Daily proportion	Cumulative proportion	3rd derivative	Daily proportion	Cumulative proportion	
1959	16	11	.077	.212	11	.008	.008	
1960	17	14	.147	.247	14	.007	.009	
1961	15	12	.175	.284	12	.000	.000	
1962	17	15	.069	.137	15	.018	.050	
1963	16	14	.195	.335	14	.004	.041	
1964	15	10	.013	.014	10	.000	.000	
1965	20	16	.081	.190	16	.000	.005	
1966	20	17	.007	.016	17	.001	.003	
1967	13	11	.024	.145	11	.027	.113	
1968	13	11	.021	.200	11	.081	.129	
1969	17	15	.101	.154	15	.009	.010	
1970	17	14	.073	.148	14	.005	.005	
1971	24	21	.071	.287	21	.082	.094	
1972	18	14	.258	.342	14	.083	.083	
1973	17	14	.006	.027	14	.003	.006	
1974	10	7	.077	.086	7	.001	.001	
1975	19	17	.194	.297	17	.003	.008	
1976	18	15	.254	.340	15	.002	.014	
1977	15	11	.001	.001	11	.000	.000	
1978	10	7	.081	.188	7	.008	.053	
1979	11	9	.026	.188	9	.089	.130	

\bar{x}	=	.183	\bar{x}	=	.036
σ	=	.110	σ	=	.046

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 10 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 24. Observed proportion of abundance¹ by day for sockeye salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.042	.016	.013	.071	21
2	.074	.042	.025	.218	21
3	.108	.044	.034	.219	21
4	.158	.058	.075	.309	21
5	.221	.074	.120	.387	21
6	.304	.109	.145	.510	21
7	.418	.170	.161	.610	21
8	.501	.143	.268	.744	21
9	.589	.130	.377	.817	21
10	.660	.122	.500	.904	21
11	.713	.113	.551	.931	21
12	.764	.101	.594	.948	21
13	.808	.092	.632	.959	21
14	.842	.083	.678	.966	21
15	.873	.072	.718	.973	21
16	.897	.062	.792	.976	21
17	.918	.511	.828	.982	21
18	.935	.044	.857	.993	21
19	.947	.036	.884	.994	21
20	.959	.031	.902	.995	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 25. Observed proportion of abundance¹ by day for sockeye salmon from Wood River during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.036	.025	.001	.099	21
2	.060	.036	.007	.121	21
3	.109	.058	.015	.218	21
4	.171	.099	.034	.375	21
5	.248	.137	.040	.474	21
6	.330	.185	.053	.693	21
7	.410	.200	.079	.787	21
8	.481	.206	.084	.846	21
9	.572	.178	.218	.877	21
10	.664	.124	.416	.897	21
11	.742	.101	.587	.938	21
12	.800	.085	.635	.954	21
13	.849	.078	.666	.965	21
14	.877	.069	.690	.972	21
15	.903	.056	.768	.979	21
16	.922	.047	.843	.988	21
17	.939	.040	.873	.990	21
18	.952	.034	.891	.993	21
19	.962	.030	.896	.995	21
20	.971	.025	.908	.998	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 26. Observed proportion of abundance¹ by day for sockeye salmon from Igushik River during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.049	.041	.000	.160	21
2	.077	.051	.000	.171	21
3	.112	.059	.000	.209	21
4	.153	.080	.000	.289	21
5	.258	.126	.114	.599	21
6	.314	.125	.165	.601	21
7	.392	.114	.247	.614	21
8	.469	.130	.289	.720	21
9	.528	.132	.329	.770	21
10	.587	.136	.345	.806	21
11	.648	.141	.409	.847	21
12	.694	.142	.455	.890	21
13	.738	.136	.457	.941	21
14	.779	.130	.501	.968	21
15	.816	.120	.559	.980	21
16	.846	.111	.603	.982	21
17	.885	.085	.715	.987	21
18	.910	.075	.756	1.000	21
19	.932	.058	.796	1.000	21
20	.950	.048	.831	1.000	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 5 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 27. Observed proportion of abundance¹ by day for sockeye salmon from Nuyakuk River during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.036	.046	.000	.130	21
2	.060	.060	.000	.179	21
3	.111	.096	.000	.335	21
4	.200	.148	.000	.503	21
5	.315	.193	.000	.666	21
6	.453	.212	.014	.771	21
7	.554	.194	.153	.879	21
8	.647	.196	.167	.934	21
9	.721	.163	.425	.955	21
10	.777	.143	.521	.973	21
11	.814	.132	.557	.985	21
12	.850	.114	.618	.994	21
13	.882	.097	.645	.997	21
14	.903	.902	.667	.998	21
15	.917	.086	.696	.999	21
16	.931	.073	.739	1.000	21
17	.938	.067	.758	1.000	21
18	.942	.064	.775	1.000	21
19	.949	.058	.810	1.000	21
20	.959	.044	.866	1.000	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 10 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 28. Observed proportion of total abundance¹ by date of sockeye salmon for Nushagak Bay from 1959-1979.

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 15	.000	.000	.000	.001	21
16	.000	.000	.000	.001	21
17	.001	.001	.000	.006	21
18	.002	.004	.000	.017	21
19	.003	.006	.000	.027	21
20	.006	.009	.000	.037	21
21	.009	.012	.000	.048	21
22	.013	.014	.000	.053	21
23	.019	.019	.000	.055	21
24	.028	.029	.000	.097	21
25	.041	.043	.000	.153	21
26	.053	.055	.001	.170	21
27	.074	.070	.002	.258	21
28	.099	.092	.004	.344	21
29	.039	.128	.006	.434	21
30	.183	.161	.012	.532	21
July 1	.227	.184	.018	.582	21
2	.307	.187	.047	.650	21
3	.405	.185	.055	.720	21
4	.482	.191	.058	.789	21
5	.549	.190	.126	.838	21
6	.611	.189	.157	.869	21
7	.672	.169	.205	.887	21
8	.737	.136	.293	.897	21
9	.787	.118	.359	.906	21
10	.836	.108	.427	.925	21
11	.868	.094	.511	.944	21
12	.894	.073	.629	.963	21
13	.914	.062	.688	.971	21
14	.933	.051	.744	.977	21
15	.947	.043	.787	.988	21
16	.961	.033	.842	.991	21
17	.972	.021	.901	.994	21
18	.979	.014	.936	.996	21
19	.985	.008	.970	.998	21
20	.989	.005	.980	.998	21
21	.992	.004	.985	.998	21
22	.994	.003	.990	.999	21
23	.996	.002	.991	.999	21
24	.997	.002	.993	.999	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days for Wood River, 5 days for Igushik River, and 10 days for Nuyakuk River.

Table 29. Observed proportion of total abundance¹ by date of sockeye salmon for Wood River from 1959-1979.

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 15	.000	.000	.000	.001	21
16	.001	.001	.000	.003	21
17	.001	.002	.000	.009	21
18	.002	.005	.000	.023	21
19	.003	.008	.000	.037	21
20	.005	.010	.000	.044	21
21	.007	.014	.000	.058	21
22	.010	.017	.000	.065	21
23	.015	.020	.000	.067	21
24	.022	.032	.000	.121	21
25	.031	.049	.000	.217	21
26	.041	.052	.000	.224	21
27	.055	.059	.000	.242	21
28	.072	.069	.000	.254	21
29	.110	.111	.001	.397	21
30	.148	.154	.014	.588	21
July 1	.185	.180	.014	.620	21
2	.258	.203	.025	.626	21
3	.356	.212	.026	.648	21
4	.435	.227	.026	.777	21
5	.509	.234	.079	.856	21
6	.578	.235	.084	.878	21
7	.649	.207	.170	.889	21
8	.725	.156	.287	.903	21
9	.782	.128	.374	.914	21
10	.836	.107	.457	.934	21
11	.875	.088	.540	.954	21
12	.903	.063	.675	.964	21
13	.924	.050	.755	.979	21
14	.941	.038	.821	.987	21
15	.956	.033	.859	.990	21
16	.969	.023	.911	.993	21
17	.977	.017	.929	.994	21
18	.984	.011	.951	.996	21
19	.988	.008	.966	.998	21
20	.991	.006	.978	.999	21
21	.994	.004	.987	.999	21
22	.995	.004	.989	1.000	21
23	.996	.003	.991	1.000	21
24	.997	.003	.991	1.000	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 2 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 30. Observed proportion of total abundance¹ by date of sockeye salmon for Igushik River from 1959-1979.

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 15	.000	.000	.000	.000	21
16	.000	.000	.000	.000	21
17	.000	.000	.000	.003	21
18	.001	.002	.000	.009	21
19	.003	.004	.000	.013	21
20	.009	.013	.000	.041	21
21	.014	.020	.000	.057	21
22	.022	.027	.000	.081	21
23	.031	.038	.000	.141	21
24	.043	.054	.000	.194	21
25	.071	.093	.000	.393	21
26	.090	.119	.000	.512	21
27	.132	.154	.000	.556	21
28	.169	.178	.000	.681	21
29	.221	.205	.000	.714	21
30	.265	.218	.003	.835	21
July 1	.297	.224	.006	.851	21
2	.387	.207	.026	.875	21
3	.461	.202	.095	.894	21
4	.525	.193	.209	.904	21
5	.589	.172	.289	.924	21
6	.643	.166	.308	.924	21
7	.690	.157	.312	.931	21
8	.733	.154	.318	.941	21
9	.771	.149	.329	.949	21
10	.814	.146	.345	.960	21
11	.841	.136	.409	.970	21
12	.864	.127	.455	.979	21
13	.887	.122	.457	.983	21
14	.912	.109	.501	.995	21
15	.932	.097	.559	.999	21
16	.950	.087	.603	1.000	21
17	.969	.050	.775	1.000	21
18	.975	.049	.775	1.000	21
19	.988	.021	.933	1.000	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 5 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 31. Observed proportion of total abundance¹ by date of sockeye salmon for Nuyakuk River from 1959-1979.

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 15	.000	.000	.000	.000	21
16	.000	.000	.000	.000	21
17	.000	.000	.000	.000	21
18	.000	.000	.000	.000	21
19	.000	.000	.000	.004	21
20	.002	.010	.000	.045	21
21	.003	.012	.000	.053	21
22	.006	.015	.000	.057	21
23	.014	.036	.000	.130	21
24	.027	.056	.000	.188	21
25	.044	.083	.000	.251	21
26	.059	.111	.000	.340	21
27	.087	.162	.000	.541	21
28	.130	.222	.000	.727	21
29	.186	.269	.000	.760	21
30	.262	.305	.001	.793	21
July 1	.305	.309	.001	.872	21
2	.425	.301	.006	.926	21
3	.525	.276	.009	.963	21
4	.590	.279	.012	.971	21
5	.660	.257	.094	.976	21
6	.722	.229	.157	.985	21
7	.768	.200	.217	.995	21
8	.808	.175	.287	1.000	21
9	.842	.158	.339	1.000	21
10	.875	.136	.403	1.000	21
11	.894	.115	.511	1.000	21
12	.911	.092	.643	1.000	21
13	.924	.083	.686	1.000	21
14	.937	.072	.719	1.000	21
15	.946	.062	.764	1.000	21
16	.954	.050	.840	1.000	21
17	.961	.040	.891	1.000	21
18	.970	.032	.913	1.000	21
19	.977	.026	.925	1.000	21

¹ Observed abundance was based on daily catch plus escapement where escapement was lagged to the fishery 10 days. Daily catch was allocated to the river based on daily proportions of escapement to all rivers.

Table 32. Cumulative proportions calculated from observed data. Day 1 was defined as the maximum rate of change of the daily rate of change of the number of fish entering the district.

Day	\bar{x}	Max.	Min.
	0.0061	.02703	.0000
	0.0102	.0373	.0002
	0.0160	.0480	.0003
	0.0212	.0532	.0009
	0.0267	.0592	.0027
1	0.0524	.0957	.0111
2	0.0751	.1660	.0242
3	0.1036	.2841	.0285
4	0.1402	.3092	.0301
5	0.2125	.5491	.0317
6	0.2918	.6327	.0336
7	0.3564	.7010	.0746
8	0.4213	.7516	.1378
9	0.4934	.8174	.1609
10	0.5740	.8630	.2555
11	0.6637	.8907	.3466
12	0.7296	.9108	.4793
13	0.7781	.9299	.5838
14	0.8154	.9459	.6787
15	0.8523	.9600	.7361
16	0.8826	.9717	.7719
17	0.9077	.9823	.8008
18	0.9260	.9929	.8280
19	0.9414	.9937	.8571
20	0.9542	.9953	.8863
21	0.9650	.9966	.9143
22	0.9740	.9976	.9307
23	0.9810	.9986	.9473
24	0.9848	.9952	.9621
25	0.9892	.9952	.9751

Table 33. Abundance estimate for Nushagak Bay sockeye salmon for 1980.

Date of abundance estimate	Abundance estimate (millions)	Date of 50 percent point
July 1	5.7	July 5
July 5	5.6	July 4
July 10	9.0	July 4
July 14	11.3	July 5

Preliminary observed abundance for sockeye salmon for Nushagak District follows:

Abundance = 12.4 million
 Catch = 4.4 million
 Escapement = 8.0 million

Table 34. Abundance estimates for Wood River sockeye salmon.

Date of abundance estimate	Abundance estimate (millions)	Date of 50 percent point
July 1	2.76	July 5
July 5	3.67	July 4
July 10	4.53	July 4
July 14	5.38	July 5

Preliminary observed abundance for sockeye salmon for Wood River follows:

Abundance = 4.4 million

Catch = 1.4 million (catch allocation based on equation ())

Escapement = 3.0 million

Table 35. Abundance estimates for Igushik River sockeye salmon.

Date of abundance estimate	Abundance estimate (millions)	Date of 50 percent point
July 1	1.42	July 6
July 5	1.64	July 5
July 10	2.47	July 5
July 14	2.93	July 6

Preliminary observed abundance for sockeye salmon for Igushik River follows:

Abundance = 3.0 million

Catch = 1.0 million (catch allocation based on equation ())

Escapement = 2.0 million

Table 36. Abundance estimate for Nuyakuk River sockeye salmon.

Date of abundance estimate	Abundance estimate (millions)	Date of 50 percent point
July 1	.82	July 5
July 5	1.60	July 3
July 10	1.75	July 3
July 14	3.27	July 5

Preliminary observed abundance for sockeye salmon for Nuyakuk River follows:

Abundance = 5.0 million

Catch = 2.0 million (catch allocation based on equation ())

Escapement = 3.0 million

ABUNDANCE ESTIMATION FOR CHUM SALMON

Introduction

Chum salmon are harvested concurrently with sockeye salmon in Nushagak Bay, and the majority of fish migrate to the Nushagak River system. Accurate catch and effort statistics are well documented since 1960. Unlike sockeye salmon, however, daily escapements have not been measured, and total escapement has been estimated from aerial survey data. With the advent of the sonar project at Portage Creek, there is potential not only to improve the accuracy of the total escapement estimates but to provide accurate estimates of daily escapement. As previously mentioned, lack of daily escapement data increases the difficulty of intraseason abundance estimation. Because of the lack of daily escapement data, catch data served as the primary input into the abundance estimation process which was developed during this contract and employed for the first time during the 1980 salmon migration.

Because the chum salmon migration overlaps the sockeye salmon migration and sockeye salmon are substantially more valuable than chum salmon, management decisions regarding chum salmon are only secondarily important. Few decisions are based solely on chum salmon abundance. There are situations, however, where knowledge of chum salmon abundance would be important. For instance, if the sockeye salmon abundance is marginal and chum salmon abundance is large, a decision to open the fishery may be made to allow harvest of the chum salmon even though sockeye salmon escapement is inadequate.

During this contract, the chum salmon data base was improved by entering daily catch and effort data provided by the Alaska Department of Fish and

Game onto computer tape. From these data, daily CPUE can be calculated. The CPUE data can subsequently be employed to calculate cumulative proportions of fish present in the district on any day according to equations (3) and (13).

Methods

The abundance estimation process for chum salmon was based on catch data from 1960 through 1976 omitting 1963 and 1964. The calculated curves were adjusted for days of no fishing; however, no adjustments of catch were made for days of partial openings and differences of effort were not taken into account. Effort was not included because effort had not been incorporated in the original data base. The abundance estimates were calculated based on equation (14). Even though the expected cumulative proportions were based on catch, these proportions were assumed to accurately reflect the migratory time densities of the population and served as the divisor for the abundance estimates. The numerator was comprised of catch plus escapement monitored at the sonar site and lagged two days to the fishery.

The two techniques described previously were employed in calculating the proportions required for the abundance estimation process. First, \bar{x} and s^2 were calculated (Table 37); then the expected daily and cumulative proportions based on the mean curve for all years of observations were calculated (Table 38). Given the normal distribution for each year, the expected maxima of the second and third derivatives of the cumulative normal probability density function were defined (Table 39). The day of the third derivative was identified as day 1 for all years. The observed proportion of catch was then noted and the mean observed catch for all years was calculated (Table 40).

Table 37. Migratory time density statistics for Nushagak Bay chum salmon. These calculations are based on adjusted catch¹ data.

Migratory time densities		
Year	\bar{x}^2	s^2
1960	24.36	93.36
1961	17.79	105.21
1962	19.68	72.29
1965	17.07	49.63
1966	22.46	126.88
1967	19.88	56.90
1968	20.09	74.13
1969	29.52	53.44
1970	20.71	61.51
1971	26.56	48.99
1972	26.33	52.38
1973	26.08	56.90
1974	21.23	70.46
1975	33.21	38.56
1976	19.71	63.57

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

² \bar{x} represents the mean day of the migration with day 1 = June 14, 2 = June 15, etc.

Table 38. Expected proportion of catch based on a normal curve with $\bar{x} = 22.98$ and $s^2 = 68.28$, which represents the mean of the mean days of the migration and the mean of the variance for 1959-1979 Nushagak Bay chum salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.001	.001
2	.002	.003
3	.003	.006
4	.003	.009
5	.005	.014
6	.006	.020
7	.007	.027
8	.009	.036
9	.012	.048
10	.014	.062
11	.017	.079
12	.020	.099
13	.023	.122
14	.027	.149
15	.030	.179
16	.034	.213
17	.037	.250
18	.040	.290
19	.043	.333
20	.045	.378
21	.047	.425
22	.048	.473
23	.048	.521
24	.048	.569
25	.047	.616
26	.045	.661
27	.043	.704
28	.040	.744
29	.037	.781
30	.034	.815
31	.030	.845
32	.027	.872
33	.023	.895
34	.020	.915
35	.017	.932
36	.014	.946
37	.011	.957
38	.009	.966
39	.007	.973
40	.006	.979

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing, the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 39. Observed proportions of catch¹ on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay chum salmon.

Year	Expected		Observed		Expected		Observed	
	2nd derivative	day of maximum	Daily proportion	Cumulative proportion	3rd derivative	day of maximum	Daily proportion	Cumulative proportion
1960	15		.010	.134	9		.012	.066
1961	8		.040	.154	3		.003	.010
1962	12		.066	.206	6		.015	.040
1965	11		.045	.210	6		.001	.009
1966	12		.069	.233	4		.000	.001
1967	13		.066	.178	8		.006	.020
1968	12		.052	.166	6		.008	.009
1969	23		.005	.214	18		.003	.010
1970	13		.000	.101	8		.000	.006
1971	20		.031	.229	15		.024	.046
1972	20		.044	.268	15		.018	.028
1973	19		.029	.186	14		.030	.082
1974	13		.028	.221	8		.028	.083
1975	27		.030	.252	23		.000	.002
1976	12		.063	.161	7		.005	.011
			$\bar{x} = .194$				$\bar{x} = .028$	
			$\sigma = .046$				$\sigma = .029$	

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing, the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 40. Observed proportion of catch¹ by day for chum salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard derivative	Minimum proportion	Maximum proportion	Sample size
1	.028	.029	.001	.083	15
2	.044	.035	.001	.111	15
3	.076	.039	.025	.138	15
4	.116	.055	.051	.222	15
5	.147	.057	.084	.252	15
6	.179	.058	.101	.282	15
7	.223	.057	.120	.313	15
8	.271	.061	.164	.369	15
9	.331	.065	.229	.425	15
10	.384	.074	.249	.481	15
11	.444	.081	.332	.579	15
12	.512	.090	.354	.649	15
13	.562	.102	.412	.718	15
14	.599	.101	.410	.738	15
15	.646	.107	.434	.759	15
16	.675	.090	.470	.786	15
17	.712	.085	.505	.820	15
18	.745	.086	.535	.855	15
19	.771	.088	.560	.889	15
20	.795	.089	.584	.923	15
21	.808	.078	.609	.958	15
22	.835	.085	.633	.976	15
23	.857	.080	.658	.978	15
24	.879	.078	.675	.981	15
25	.898	.077	.793	.966	15
26	.914	.076	.710	.985	15
27	.924	.073	.727	.989	15
28	.933	.069	.745	.991	15
29	.941	.066	.763	.992	15
30	.948	.062	.780	.995	15

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

These proportions were employed in the abundance estimation process.

The proportions calculated thus far were not associated with a specific calendar date. To associate calendar date with expected proportions, the observed proportions by date were averaged (Table 41).

Results

During the chum salmon migration, three estimates of abundance were calculated (Table 42). The proportion of error ($\frac{e-o}{o}$) for each estimate follows: -.057, +.655, +.377. The first estimate, which was calculated with .227 of the migration completed, was an underestimate and the subsequent two were overestimates. The proportion of error for the second estimate was perhaps exaggerated because the true abundance may have been higher than 1.184 million fish if the spawning escapement was underestimated.

Discussion

These abundance estimates represent the first attempt at predicting chum salmon abundance. Substantial progress has been made toward providing reliable estimates; however, refinements remain to be made. Not only are refinements in the estimation process needed, the accuracy of the catch and spawning escapement data provided during the migration must be verified.

Table 41. Observed proportion of catch¹ by date of chum salmon for Nushagak Bay from 1960-1976 (excluding 1963 and 1964).

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
June 14	.001	.001	.000	.005	15
15	.001	.003	.000	.009	15
16	.002	.004	.000	.014	15
17	.003	.006	.000	.018	15
18	.007	.011	.000	.035	15
19	.015	.021	.000	.075	15
20	.027	.032	.000	.114	15
21	.040	.046	.000	.154	15
22	.054	.058	.000	.194	15
23	.073	.070	.000	.233	15
24	.096	.084	.000	.273	15
25	.127	.104	.000	.324	15
26	.160	.128	.001	.387	15
27	.201	.156	.001	.497	15
28	.237	.177	.001	.543	15
29	.283	.200	.001	.586	15
30	.323	.225	.001	.649	15
July 1	.383	.243	.001	.718	15
2	.420	.243	.001	.738	15
3	.452	.238	.001	.759	15
4	.486	.233	.001	.795	15
5	.521	.235	.002	.797	15
6	.564	.240	.002	.825	15
7	.575	.242	.002	.849	15
8	.607	.231	.097	.878	15
9	.645	.197	.222	.887	15
10	.676	.179	.252	.896	15
11	.707	.164	.282	.907	15
12	.736	.154	.313	.918	15
13	.770	.142	.369	.929	15
14	.803	.131	.425	.939	15
15	.830	.118	.481	.950	15
16	.854	.109	.537	.964	15
17	.875	.099	.594	.972	15
18	.892	.088	.650	.982	15

¹ Catch was adjusted from catch by fishing period reported by the Alaska Department of Fish and Game in their annual Bristol Bay management reports to catch by date. Whenever a catch period was longer than 24 hrs, catch was assigned to a calendar date on the basis of hours fished on that date. For days closed to fishing, the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table 42. Abundance estimates for Nushagak Bay chum salmon for 1980.

Date of abundance estimate	Abundance estimate ¹ (millions)	Catch estimate ² (millions)	Spawning escapement estimate ³ (millions)	Date of 50 percent point
July 5	1.117	.412	.412	July 11
July 10	1.960	1.148	.812	July 11
July 14	1.630	.940	.690	July 11
Preliminary observed abundance ⁴				
	~ 1.600	.782	~ .800	

¹ The abundance estimate was based on catch plus escapement lagged two days to the fishery. The expected proportions were calculated from catch data. These proportions were assumed to accurately reflect the migratory time density functions of the population.

² Catch was calculated by multiplying the mean annual exploitation rate for chum salmon (63.1 percent) times the estimated abundance.

³ The spawning escapement estimates were based on equation (17) -

$$N = C + E \text{ or } E = N - C.$$

⁴ These are strictly preliminary observations with abundance calculated by adding cumulative catch and cumulative spawning escapement. Cumulative catch was calculated by multiplying the daily catch times the percent chums reported by processors for that day and summing over all days fished. The cumulative spawning escapement was based on counts from the Portage Creek sonar site. Preliminary evidence suggests that this is a minimum number. The actual escapement may have been three times greater.

As mentioned previously, the chum salmon migration extensively overlaps the sockeye salmon migration. Sockeye are more valuable and typically substantially more abundant. Because of these relationships, the need for abundance estimates may be questioned. Abundance estimates, however, may provide the foundation for sockeye-chum salmon management decisions. Knowledge of abundance is especially critical if the abundance of either or both species is depressed. If the fishery intensifies, knowledge of abundance will be even more critical to assure conservation of these species.

ABUNDANCE ESTIMATE FOR PINK SALMON

Introduction

Pink salmon occur in abundance in Nushagak Bay only during even years. They enter the fishing district after the sockeye salmon, but their timing overlaps that of coho salmon. Accurate catch, effort and escapement statistics are available since 1960. Of the species other than sockeye salmon, migratory time density functions can best be applied to pink salmon because the majority of pink salmon migrate to the Nuyakuk River and swim past the counting tower to the upper portion of the Nuyakuk and Tikchik Rivers.

Methods

The abundance estimation process for pink salmon was based on catch plus escapement data from 1960 through 1978. Escapement was lagged back 10 days from Nuyakuk tower to the fishery and added to the catch. No adjustments were made for fish that spawned below Nuyakuk tower. The equations and procedures for the abundance estimation process were the same as those described in the section on abundance estimation techniques.

The four techniques described previously were employed in calculating the proportions required for the abundance estimation process. First, \bar{x} and s^2 were calculated (Table 43); then the expected daily and cumulative proportions based on the mean curve for all years of observation were calculated (Table 44). Given the normal distribution for each year, the expected maxima of the first and second derivatives of the cumulative normal probability density function were defined (Table 45). The day of the maximum of the

Table 43. Migratory time density statistics for Nushagak Bay pink salmon. These calculations are based on total abundance.¹

Migratory time densities		
Year	\bar{x}^2	s^2
1960	26.67	32.42
1962	19.91	26.81
1964	23.53	26.88
1966	26.02	47.99
1968	24.11	55.37
1970	25.80	38.05
1972	22.75	37.55
1974	22.24	46.27
1976	25.88	49.58
1978	28.44	33.67

¹ Observed abundance was based on daily catch plus escapement past the Nuyakuk counting tower. The escapement was lagged to the fishery 10 days.

² \bar{x} represents the mean day of the migration with day 1 = July 1, 2 = July 2, etc.

Table 44. Expected proportion of abundance based on a normal curve with $\bar{x} = 24.54$ and $s^2 = 39.46$, which represents the mean of the mean days of the migration and the mean of the variance for 1960-1978 Nushagak Bay pink salmon abundance¹ data.

Day	Expected daily proportion	Expected cumulative proportion
1	.000	.000
2	.000	.000
3	.000	.000
4	.000	.000
5	.001	.001
6	.001	.002
7	.001	.003
8	.002	.005
9	.003	.008
10	.004	.012
11	.006	.018
12	.009	.027
13	.012	.039
14	.016	.055
15	.020	.075
16	.025	.100
17	.031	.131
18	.037	.168
19	.043	.211
20	.049	.260
21	.054	.314
22	.059	.373
23	.062	.435
24	.063	.498
25	.063	.561
26	.062	.623
27	.059	.682
28	.055	.737
29	.049	.786
30	.044	.830
31	.037	.867
32	.031	.898
33	.026	.924
34	.020	.944
35	.016	.960
36	.012	.972
37	.009	.981
38	.006	.987
39	.004	.991
40	.003	.994

¹ Observed abundance was based on daily catch plus escapement past the Nuyakuk counting tower. The escapement was lagged to the fishery 10 days.

Table 45. Observed proportion of abundance on days of expected maxima of the second and third derivatives of the cumulative normal probability density function for Nushagak Bay pink salmon.

Year	Expected day of maximum		Observed		Expected day of maximum		Observed	
	2nd derivative	3rd derivative	Daily proportion	Cumulative proportion	3rd derivative	Daily proportion	Daily proportion	Cumulative proportion
1960	21	18	.063	.176	18	.007	.045	
1962	15	12	.033	.199	12	.035	.103	
1964	19	16	.036	.133	16	.012	.040	
1966	20	15	.076	.229	15	.012	.023	
1968	17	12	.058	.206	12	.009	.027	
1970	20	16	.026	.194	16	.023	.049	
1972	17	13	.015	.153	13	.008	.061	
1974	16	11	.065	.195	11	.005	.025	
1976	19	15	.139	.195	15	.016	.032	
1978	23	19	.066	.170	19	.008	.028	

\bar{x} = .185	\bar{x} = .069
s = .028	σ = .078

1 Observed abundance was based on daily catch plus escapement past the Nuyakuk counting tower. The escapement was lagged to the fishery 10 days.

second derivative was identified as day 1 for all years. The observed proportion of abundance was then noted and the mean observed abundance for all years was calculated (Table 46). These proportions were employed in the abundance estimation process.

The proportions calculated thus far were not associated with a specific calendar date. To associate calendar date with expected proportions, the observed proportions by date were averaged (Table 47).

During this contract period, an additional procedure to calculate the mean entry patterns was employed. After the proportions of fish entering the fishing district by day were calculated for each year, mean proportions for all years were calculated according to equation (3) (Table 48). Day 1 was defined as the maximum rate of change of the daily rate of change of the number of fish entering the district. This distribution appears to be bimodal (Fig. 7).

Results

During the pink salmon migration, two estimates of abundance were calculated (Table 49). The proportion of error ($\frac{e-o}{o}$) for each estimate follows: -.167, -.188. The first estimate was calculated with .184 of the migration completed. Both estimates were underestimates.

Discussion

These abundance estimates represent the first attempt at predicting pink salmon abundance intraseasonally and were considered for management decisions. Substantial progress has been made toward providing reliable estimates;

Table 46. Observed proportion of abundance¹ by day for pink salmon from Nushagak Bay during 1959-1979. Day 1 was defined as the date of the maximum of the second derivative of the normal curve for each year.

Day	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
1	.068	.009	.056	.087	10
2	.092	.015	.075	.122	10
3	.123	.022	.097	.148	10
4	.159	.031	.123	.218	10
5	.202	.041	.152	.279	10
6	.251	.053	.186	.347	10
7	.305	.065	.224	.421	10
8	.364	.076	.290	.497	10
9	.426	.087	.313	.574	10
10	.489	.096	.362	.648	10
11	.552	.102	.413	.717	10
12	.613	.105	.466	.778	10
13	.671	.105	.520	.831	10
14	.724	.102	.573	.875	10
15	.772	.097	.625	.911	10
16	.815	.089	.675	.929	10
17	.862	.088	.722	.958	10
18	.883	.070	.765	.973	10
19	.909	.060	.804	.983	10
20	.930	.051	.839	.990	10

¹ Observed abundance was based on daily catch plus escapement past the Nuyakuk counting tower. The escapement was lagged to the fishery 10 days.

Table 47. Observed proportion of abundance¹ by date of pink salmon for Nushagak Bay from 1960-1978 (even years only).

Date	Mean proportion	Standard deviation	Minimum proportion	Maximum proportion	Sample size
July 1	.000	.000	.000	.001	10
2	.000	.001	.000	.002	10
3	.000	.001	.000	.002	10
4	.000	.001	.000	.003	10
5	.000	.002	.000	.005	10
6	.002	.003	.000	.008	10
7	.004	.005	.000	.015	10
8	.006	.007	.000	.023	10
9	.009	.009	.000	.031	10
10	.013	.012	.000	.038	10
11	.020	.021	.000	.068	10
12	.028	.031	.000	.103	10
13	.034	.035	.000	.117	10
14	.046	.050	.001	.166	10
15	.068	.063	.005	.199	10
16	.093	.078	.010	.230	10
17	.121	.098	.014	.274	10
18	.154	.120	.020	.341	10
19	.218	.139	.028	.433	10
20	.288	.156	.038	.555	10
21	.366	.175	.055	.650	10
22	.425	.180	.104	.729	10
23	.482	.179	.170	.807	10
24	.535	.177	.251	.852	10
25	.591	.167	.330	.893	10
26	.653	.147	.411	.920	10
27	.710	.129	.517	.942	10
28	.755	.113	.608	.954	10
29	.784	.101	.655	.960	10
30	.810	.092	.677	.965	10
31	.835	.083	.702	.970	10
August 1	.863	.074	.736	.977	10
2	.889	.063	.773	.986	10
3	.917	.047	.850	.991	10
4	.935	.041	.871	.993	10
5	.948	.038	.887	.996	10
6	.959	.034	.902	1.000	10
7	.969	.029	.917	1.000	10
8	.977	.024	.933	1.000	10
9	.983	.019	.951	1.000	10

¹ Observed abundance was based on daily catch plus escapement past the Nuyakuk counting tower. The escapement was lagged to the fishery 10 days.

Table 48. Mean cumulative proportion of pink salmon entering Nushagak Bay calculated from observed data. Day 1 was defined as the maximum rate of change of the daily rate of change of the number of fish entering the district.

Day	Mean x	Max.	Min.
	.0083	.0136	.0000
	.0117	.0382	.0007
	.0167	.0458	.0058
	.0223	.0534	.0072
	.0280	.0612	.0087
1	.0459	.0203	.0899
2	.0729	.0248	.1145
3	.1026	.2063	.0294
4	.1404	.2803	.0339
5	.2036	.3359	.0384
6	.2750	.4079	.0452
7	.3404	.5225	.0632
8	.4012	.6114	.1129
9	.4638	.7055	.1761
10	.5183	.7484	.2415
11	.5782	.7793	.3160
12	.6424	.8107	.3747
13	.6955	.8283	.4312
14	.7408	.8489	.5192
15	.7790	.8781	.5734
16	.8126	.8995	.6321
17	.8365	.9231	.6749
18	.8616	.9425	.7156
19	.8851	.9575	.7652
20	.9111	.9704	.8307
21	.9296	.9695	.8826
22	.9452	.9847	.9074
23	.9582	.9924	.9257
24	.9710	1.0000	.9436
25	.9801	1.0000	.9544

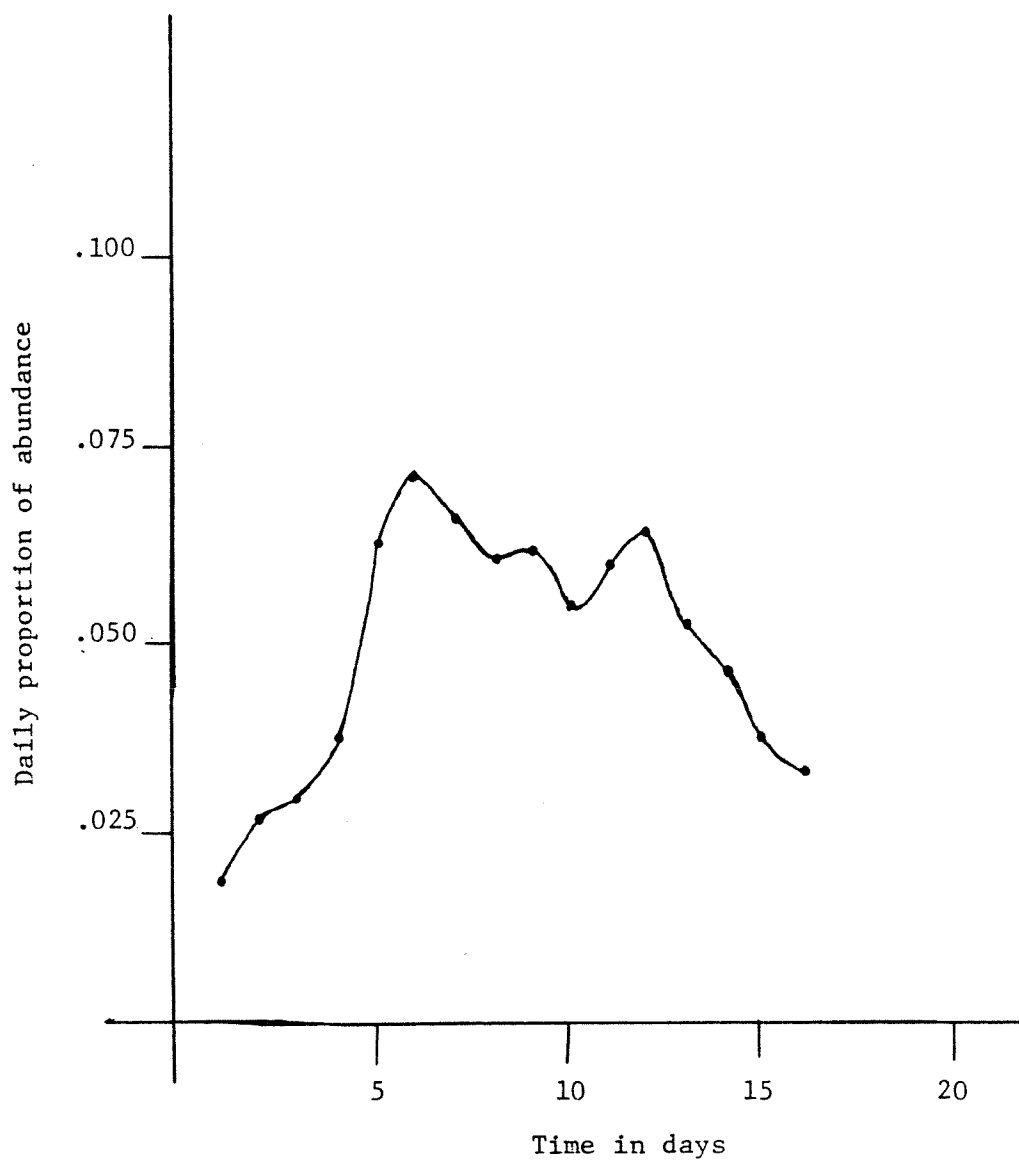


Fig. 7. Mean distribution of daily proportions of pink salmon entering Nushagak Bay. Day 1 was defined as the maximum of the rate of change of the daily rate of change of the daily number of fish entering the district.

Table 49. Abundance estimates for Nushagak Bay pink salmon for 1980.

Date of abundance estimate	Abundance estimate (millions)	Date of 50 percent point
July 26	4.0	July 30
July 31	3.9	July 30

Preliminary observed abundance for pink salmon follows:

Abundance = 4.8 million

Catch = 2.3 million

Escapement = 2.5 million

however, reliable refinements remain to be made. Calibration of the counts from the Portage Creek sonar site to obtain accurate estimates of spawning escapement is the greatest need.

CONSIDERATIONS FOR A DECISION-MAKING MODEL
FOR A MULTISPECIES SALMON FISHERY

Conceptual Framework

The following pages outline the ingredients for a harvest decision-making model of a multi-species salmon fishery. Although some aspects of the model are designed specifically for Nushagak Bay, Alaska, the concepts can be extrapolated to other salmon fisheries. The separation of management into policy and harvest control decisions as stated in the preface and as outlined in Figure 8 is essential for effective management.

Discussion

Management of salmon in Nushagak Bay, Alaska, means harvest control of five species of salmon: king, red, chum, coho and pink, as well as several stocks for each species. While management has functioned well, the primary concern has been harvest control for an entire population or, in certain cases, i.e. red salmon, management has been concerned with the composite stocks returning to the most productive system, i.e. the Wood River system. Current knowledge does not allow management of individual stocks and, even with advances in knowledge, practical management limitations may preclude effective management of individual stocks. That is, overlapping times of entry of different stocks and the vulnerability of all stocks to harvest by the gill nets currently fished may prevent such considerations from having practical application.

The following synopsis defines primary considerations for each of the decision-making elements:

P O L I C Y

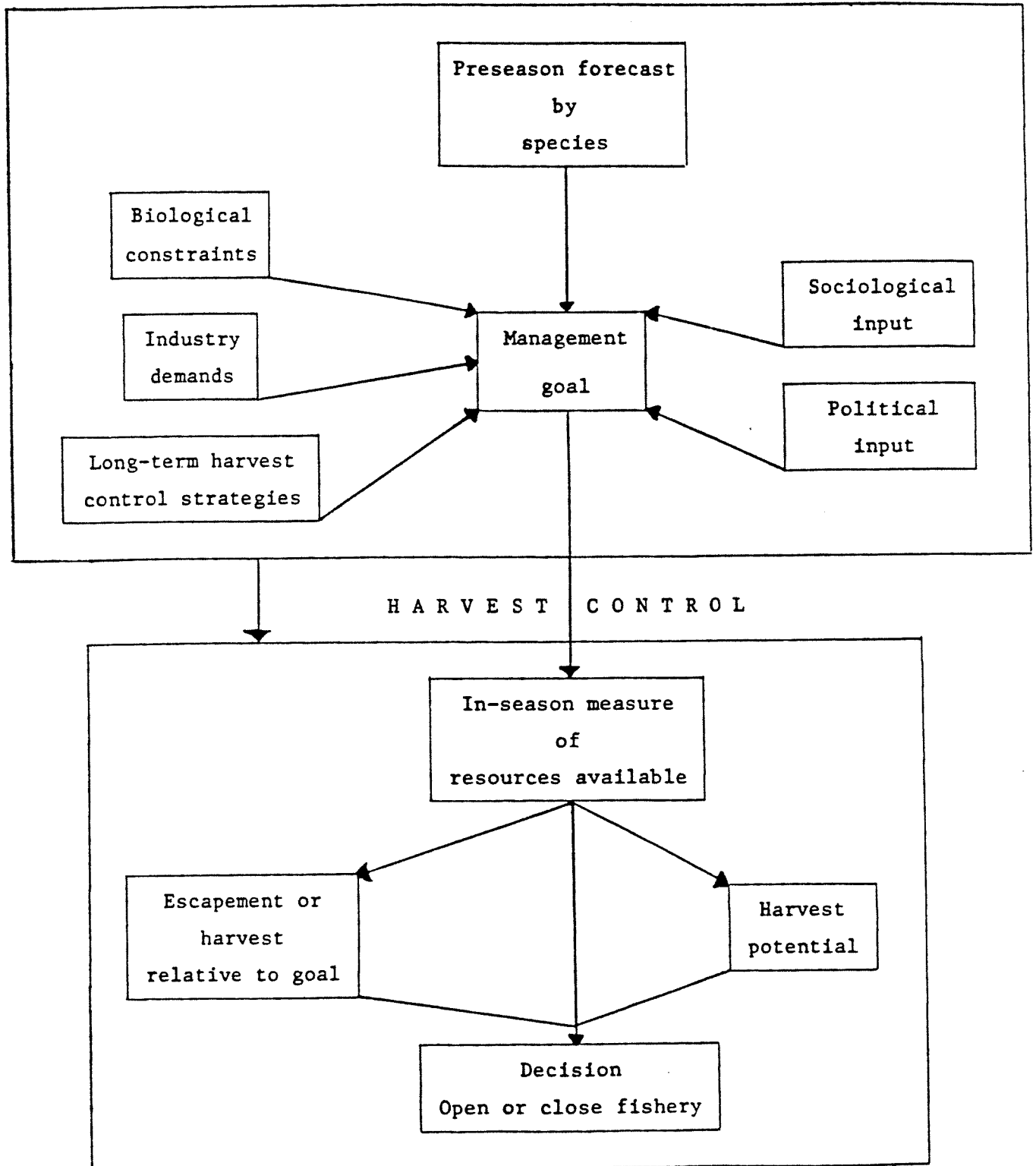


Fig. 8. Flow chart for policy and harvest control decisions for salmon fisheries managers.

Policy

Preseason forecast by species critical to

1. Processors preparing facilities, evaluating markets and purchasing supplies;
2. Fishermen considering capital investments;
3. Managers adjusting harvest or escapement goals.

Sociological input:

1. Native fishing rights;
2. Commercial and sport needs;
3. Financial status of the fishing community;
4. Labor-management relations.

Political input:

1. Status of international fishing community;
2. Foreign processing capacity;
3. State of Alaska economy;
4. State of American economy.

Biological constraints:

1. Minimum level of escapement to ensure conservation of the species;
2. Carrying capacity and general production limitations especially influenced by the previous year's level of escapement.

Industry demands (socio-economic):

1. Status of the market by species;
2. Price structure by species;
3. Processing capacity.

Long-term policy:

1. Manage to achieve a specified escapement;
2. Manage to achieve a specified harvest;
3. Manage to rebuild a specific stock or species.

Harvest Control

Abundance estimation

1. Estimates based on migratory timing with input from
 - a. Port Moller,
 - b. catch and escapement data from within season,
 - c. gill net sampling program along the seaward boundary of the fishing district,
 - d. escapement estimates from Igushik and Nuyakuk sampling programs;
2. Estimates of daily abundance based on exploitation rates and effort.

Goal status

Difference between abundance estimate and desired escapement or harvest goal and percentage of migration remaining.

Harvest potential

1. Fleet size and distribution;
2. Processing capacity;
3. Exploitation rate.

Decision — (open or close fishery)

1. Tide stage;
2. Length of opening.

Given the preceding information, the foundation of a quantitative basis for decisions can be laid. A very simple approach to regulating fishing time is to calculate harvestable surplus according to equation (22) and subsequently regulating the fishery to distribute the harvest uniformly throughout the migration.

$$(N - E) = H \quad (22)$$

where $N \equiv$ total abundance
 $E \equiv$ desired escapement
 $H \equiv$ harvestable surplus

Given accurate estimates of total and daily abundance and knowledge of exploitation rates and effort, the decisions for fishery regulation become simple. Unfortunately these quantities are variable and therefore decisions are made with uncertainty of the outcome. Given current knowledge, perhaps an appropriate approach for quantitative management decisions, at least during early stages of the migration, is to develop worst-possible-case scenarios for the expected total abundance and base decisions on the anticipated abundance. Minimum levels of abundance could be calculated either by using only catch or maximum observed proportions in equation (14). This approach would lead to conservative management and possibly result in overescapement. Overescapement is negative if future abundance is less than the abundance possible from smaller escapements. In an economic sense, overescapement is especially negative when

$$R/S (M_F) < M_C \quad (23)$$

where

$R/S \equiv$ return per spawner

$M_F \equiv$ future market value of the fish

$M_C \equiv$ current market value of the fish

or if the current economic situation requires maximum harvest to maintain the industry.

Harvest controls, as thus far defined, depend completely upon data associated with the fishery; that is, the number of fish or the rate of removal of fish by the fishery. Political, social and economic inputs may be required for some intraseason decisions; however, scenarios reviewing worst-possible-case events should be developed prior to the fishing season as part of the policy level decisions. The conditions for which such input should override biological management should be clearly stated.

Given a clear policy, the following model of the fishery data could serve as the first very simple attempt at providing a quantitative foundation for harvest control decisions.

1. Calculate total and daily abundance employing mean historic proportions of abundance and observed abundance (if available) (Equation 14).
2. Develop worst-possible-case scenarios by employing catch data rather than abundance and maximum observed historic proportions rather than the mean.
3. Determine the harvestable surplus (Equation 22).
4. Given knowledge of exploitation rate and effort determine the number

of fish that could be harvested by continuous fishing. Use both mean exploitation rates and maximum exploitation rates to develop a worst-possible-case scenario.

5. Determine a harvest strategy that would spread the harvest uniformly throughout the migration and meet potential conflicts such as imposition of other fisheries, i.e. the sockeye fishery during the final stages of the chinook salmon migration.
6. Update and adjust both the abundance estimates and harvestable surplus information intraseasonally as more information is available.
7. Decide whether or not to open the fishery based on estimated total abundance, status of the migration, status of required escapement, exploitation rates and effort.

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