

FRI-UW-8121
December 1981

FISHERIES RESEARCH INSTITUTE
School of Fisheries
University of Washington
Seattle, Washington 98195

NUSHAGAK BAY SALMON FISHERY MODEL

by

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FINAL REPORT
for the period
May 1, 1981 - October 31, 1981
Alaska Department of Fish and Game
Contract No. 81-831

Submitted February 26, 1982

Approved



Director

PREFACE

The research performed during the contractual obligations was designed to provide quantitative input for management decisions. The overall objective of this contract report as for previous contract reports (Hornberger, M.L., P. R. Mundy and O. A. Mathisen 1979; Hornberger, M.L. and O. A. Mathisen 1980; and Hornberger, M.L. and O. A. Mathisen 1981) was to develop a management model for the salmon fisheries in Nushagak Bay, Alaska. The specific objectives of this contract were:

1. to refine the abundance estimation procedure for each species of salmon returning to Nushagak Bay, to evaluate the reliability of the procedure for management and to estimate exploitation rates for each species of salmon;
2. to apply abundance estimation procedures and the harvest control scenarios for chinook, sockeye and chum salmon during the 1981 salmon migration;
3. to develop harvest control scenarios for possible levels of abundance for each species and maximum and average exploitation rates.

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ACKNOWLEDGEMENTS

The ideas presented represent the cumulative results of two and one half years of work. Certainly the concepts presented are not solely original, but they represent an integration of ideas present in the literature and incorporate input from numerous individuals associated with the Fisheries Research Institute (FRI) and the Alaska Department of Fish and Game (ADF&G). P. R. Mundy formalized the concept of migratory time density distributions, which had been alluded to or applied in one way or another in the past three decades. The experience of D. E. Rogers provided invaluable insight into Nushagak Bay salmon management problems. J. H. Clark and D. McBride of ADF&G have also been intimately involved with the project and have supplied invaluable assistance. Thanks also go to the Nushagak management biologists Mike Nelson, Jeff Skrade, and Wes Bucher for sharing their vast knowledge of the Nushagak system.

ABUNDANCE ESTIMATION FOR NUSHAGAK BAY SALMON

Introduction

The emphasis of our work has been the development of abundance estimation procedures for salmon migrating to Nushagak Bay. The initial premise was that abundance estimation, coupled with knowledge of entry pattern, would serve as the foundation for a harvest control procedure. The abundance estimation procedure depends on the concept of migratory timing as described by Mundy and Mathisen (1979). The following assumptions are fundamental to the estimation procedure:

- 1) The migratory species must move past a fixed point or a defined area systematically.
- 2) The form of the entry pattern must be constant or approximately constant from year to year.

Materials and Methods

Although the concepts for abundance estimation are similar to those presented by Mundy and Mathisen (1979), some further developments were described by Hornberger and Mathisen (1981). The abundance estimates were calculated according to the following equations based on Walters and Buckingham (1975):

- A. First, daily proportions of abundance were calculated from the historical data base:

$$p_{ik}(x) = \frac{n_{ik}}{N_k} \quad (1)$$

where $p_{ik}(x) \equiv$ observed proportion of abundance, catch or catch
per unit of effort (CPUE) on day i in year k

$n_{ik} \equiv$ observed abundance, catch, or CPUE on day i in year k

$N_k \equiv$ observed total abundance, catch, or CPUE in year k

and

B. Second, mean proportions of abundance for each day were calculated from the historical data base:

$$\overline{p(x_i)} = \frac{\sum_{k=1}^m p_{ik}(x)}{m} \quad (2)$$

where $\overline{p(x_i)} \equiv$ mean daily proportion on day i

$m \equiv$ total number of years of data

and

C. Third, a point estimate of total abundance can be calculated either from the historical data base or intraseasonally:

$$\hat{N}_{ik} = \frac{\sum_{i=1}^i n_{ik}}{\sum_{i=1}^i \overline{p(x_i)}} \quad \text{or} \quad \frac{\sum_{i=1}^i n_{ik}}{P(x_i)} \quad (3)$$

where $\hat{N}_{ik} \equiv$ total estimated abundance for year k on day i

$$P(x_i) \equiv \sum_{i=1}^i \overline{p(x_i)}$$

$l \equiv$ total number of days of observations in year k or i_{\max}

when $P(x_l) = 1$

The abundance estimation procedure depends on knowledge of daily abundance and a historical entry pattern. Historical entry patterns have been calculated and reported in previous contract reports (Hornberger and Mathisen 1981). These tables have been finalized (Appendix A, Tables A1-A10). Data for chinook, sockeye and pink salmon were stratified by abundance in an attempt to reduce variance. The finalized tables reflect improvements in daily catch data by substituting daily catch data reported as part of the Alaska Department of Fish and Game IBM data base for estimates of daily catch calculated from catch reported by fishing periods. The source of data by species and year is documented in Table 1. Since swimming speeds from the district to the point of enumeration are known to vary annually, the lagging factors were estimated visually for sockeye and pink salmon each year by matching increases in escapement following fishing district closures or decreases in escapement following fishing district openings (Table 2). No adjustments were made for intra-annual variability in rate of migration in the different river systems. Adjustments were made for an assumed two-day retention time within the fishing district by dividing the catch of the first day following a closed fishing period by two and assigning half of the catch to the previous day. For closures greater than a day, this same adjustment was employed and all fish that entered two days prior to the closure were assumed to have escaped. When the fishery was operating, no adjustments for retention time were made because of the potentially high daily exploitation rates (Hornberger and Mathisen 1980) and mobility of the fleet. Finally, by employing empirical data to calculate entry pattern, a closer approximation to the entry pattern was achieved.

Table 1. Sources of Nushagak Bay salmon data by species and year.

Species	Chinook		Sockeye		Chum		Pink		Coho	
	Catch	Escape-	Catch	Escape-	Catch	Escape-	Catch	Escape-	Catch	Escape-
Year										
1959	ND ¹	ND	BBD ⁵	BBD	ND	ND	ND	ND	ND	ND
1960	IBM ²	ND	IBM	BBD	IBM	ND	IBM	BBR	IBM	ND
1961	IBM	ND	IBM	BBD	IBM	ND	ND	ND	IBM	ND
1962	IBM	ND	BBD	BBD	ND	ND	IBM	BBR	ND	ND
1963	IBM	ND	BBD	BBD	ND	ND	ND	ND	IBM	ND
1964	IBM	ND	BBD	BBD	ND	ND	ND	BBR	IBM	ND
1965	IBM	ND	BBD	BBD	ND	ND	ND	ND	IBM	ND
1966	IBM	ND ⁴	BBD	BBD	IBM	ND	IBM	BBR	IBM	ND
1967	IBM	BBR	BBD	BBD	ND	BBR	ND	ND	IBM	ND
1968	IBM	BBR	BBD	BBD	ND	BBR	BBR	BBR	IBM	ND
1969	IBM	BBR	BBD	BBD	ND	BBR	BBR	BBR	IBM	ND
1970	IBM	BBR	BBD	BBD	IBM	BBR	ND	ND	IBM	ND
1971	IBM	BBR	BBD	BBD	ND	BBR	BBR	BBR	ND	ND
1972	IBM	BBR	BBD	BBD	IBM	BBR	BBR	BBR	IBM	ND
1973	IBM	BBR	BBD	BBD	ND	BBR	BBR	BBR	ND	ND
1974	IBM	BBR	BBD	BBD	IBM	BBR	BBR	BBR	IBM	ND
1975	IBM	BBR	BBD	BBD	IBM	BBR	BBR	BBR	IBM	ND
1976	IBM	BBR	BBD	BBD	IBM	BBR	BBR	BBR	IBM	ND
1977	IBM	BBR	BBD	BBD	IBM	BBR	BBR	BBR	IBM	ND
1978	PD ³	PD	PD	PD	PD	PD	PD	BBR	ND	ND
1979	PD	PD	PD	PD	PD	PD	ND	ND	ND	ND

¹ ND = no data.

² IBM = data from Alaska Department of Fish and Game IBM reports.

³ PD = preliminary data obtained from Alaska Department of Fish and Game.

⁴ BBR = data from Bristol Bay Management Reports and Bristol Bay Data Reports.

⁵ BBD = Bristol Bay Data Base (Mundy 1977).

Table 2. Number of days passage from fishing district to enumeration site for sockeye and pink salmon, estimated by visual inspection of escapement curves.

Year	Sockeye salmon			Pink salmon
	Wood River	Igushik River	Nuyakuk River	Nuyakuk River
1959	2	8	13	
1960	2	7	10	12
1961	2	7	13	
1962	6	9	14	8
1963	3	7	9	
1964	4	7	14	11
1965	2	5	10	
1966	3	8	12	9
1967	4	6	12	
1968	2	5	10	9
1969	2	5	12	
1970	2	5	10	10
1971	2	6	10	
1972	3	9	13	10
1973	2	5	11	
1974	2	5	10	8
1975	2	5	10	
1976	2	7	11	10
1977	2	6	12	
1978	4	7	12	11
1979	2	5	10	
Mean value	2.6	6.4	11.3	9.8

For sockeye and pink salmon daily abundance was calculated as follows:

$$n_i = C_i + \sum_{j=1}^3 E_{i-d_j} \quad (4)$$

where n_i \equiv abundance on day i

C_i \equiv catch on day i

E_i \equiv escapement on day i

d_j \equiv the time needed for the fish to swim from the fishing district past the counting tower of river j

Daily catch data were employed for calculating the entry pattern for chinook, chum and coho salmon, since daily escapement records are not available. During closures or period of marginal effort (less than 30 boats) when daily catches would not be comparable to days with normal fishing effort, daily entry was estimated by averaging catches prior to and following days of fishing at this effort level. Rate of exploitation has been considered constant for effort above 30 boats on open fishing days. Similar adjustments were made for chum and coho salmon.

Two entry patterns were calculated for each species. One was calculated by averaging proportions (Equation 2) across calendar dates. These tables represent an accurate expression of the past industry practice and were calculated from catch records as a convenient means of anticipating the arrival of the salmon and development of the run. The other tables were calculated by defining day 1 as a local maximum in the daily rate of change of the daily entry of fish into the bay. The premise is that a general mathematical function describes the daily entry of fish into the district. Each derivative or rate of change in turn has a continuous underlying

distribution. Mathematically maxima are defined by setting the second derivative of a probability density function equal to zero. When the mathematical function is unknown, maxima can be approximated by the subtraction procedure described by Hornberger and Mathisen (1981).

After day 1 was defined (Table 3) and the average curve calculated, abundance estimates were calculated for each species for each year of reliable data. In some years the observed curve deviates substantially from the average curve and some other intraseason inputs are needed to identify day 1 appropriately. Since several days typically separate day 1 and false local maxima, additional criteria should be sought. The following inputs can be considered, such as the initiation of the run or day 1 as observed:

- 1) past Port Moller,
- 2) into Nushagak Bay measured by the gillnet test fishing boat sampling along the outside boundary of the fishing district, or more indirectly from
- 3) passage past Shumagin Islands,
- 4) passage past False Pass.

The data selected to calculate the entry patterns met the following criteria:

- 1) the fishery operated during the entire migration of the species; i.e., there were no strikes;
- 2) the IBM data were consistent with the data reported in the management reports;
- 3) records of daily catch as opposed to period catches were available or had been approximated by Mundy (1977).

Table 3. Day 1 defined for Nushagak Bay salmon migrations.

Year	Chinook salmon	Sockeye salmon	Chum salmon	Coho salmon	Pink salmon
1959	ND ¹	6/26	ND	ND	ND
1960	6/5	6/24	6/16	ND	7/17
1961	ND	6/25	ND	ND	ND
1962	6/7	6/27	ND	ND	7/12
1963	ND	ND	ND	ND	ND
1964	6/5	6/28	ND	ND	7/16
1965	6/2	6/25	ND	ND	ND
1966	6/5	6/29	6/22	7/23	7/16
1967	6/5	6/23	ND	7/20	ND
1968	6/6	6/23	ND	7/18	7/12
1969	6/3	6/28	6/21	7/22	ND
1970	ND	ND	ND	ND	7/16
1971	ND	7/02	6/26	7/21	ND
1972	6/9	6/28	6/27	7/20	7/14
1973	6/8	6/26	6/25	7/19	ND
1974	6/7	6/27	6/19	7/18	7/12
1975	6/8	7/02	7/09	7/23	ND
1976	6/8	6/29	6/19	7/22	7/16
1977	6/3	6/25	6/19	7/21	ND
1978	ND	6/22	ND	ND	7/19
1979	ND	6/23	ND	ND	ND

¹ ND ≡ No data.

Results and Discussion

The abundance estimation was revised and applied to four of the five species migrating to Nushagak Bay. The results demonstrate that the abundance estimation procedure can be successfully applied intraseasonally.

Attempts to stratify the data by total abundance produced non-conclusive results (Figures 1-3). The standard deviations for the greatest abundance categories were less than for other categories in the case of chinook and sockeye salmon but not in the case of pink salmon. The benefits of stratifying the data by abundance are not substantial from this analysis. Furthermore, intraseason abundance estimation tables based on stratified data have utility only after an abundance has been calculated employing the mean proportions.

In addition to abundance estimation, entry patterns were described for all species of salmon. Future work should be directed at relating entry pattern to environmental conditions. Such efforts might reduce variance of the entry patterns.

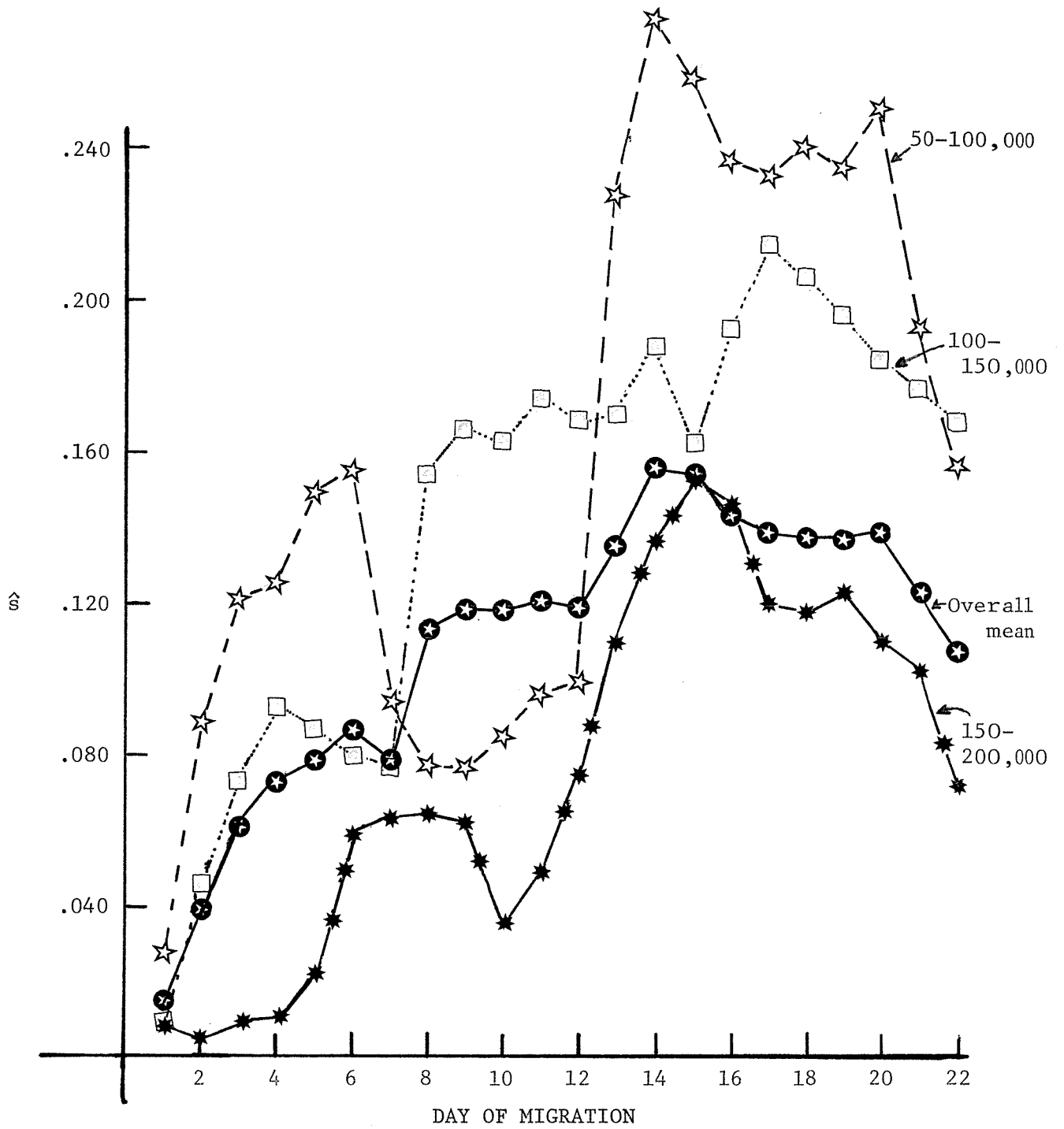


Fig. 1. Standard deviation of cumulative proportions of abundance by day of chinook salmon migration for overall mean and stratified data. Day 1 was defined as a local maximum rate of change of the daily rate of change of abundance.

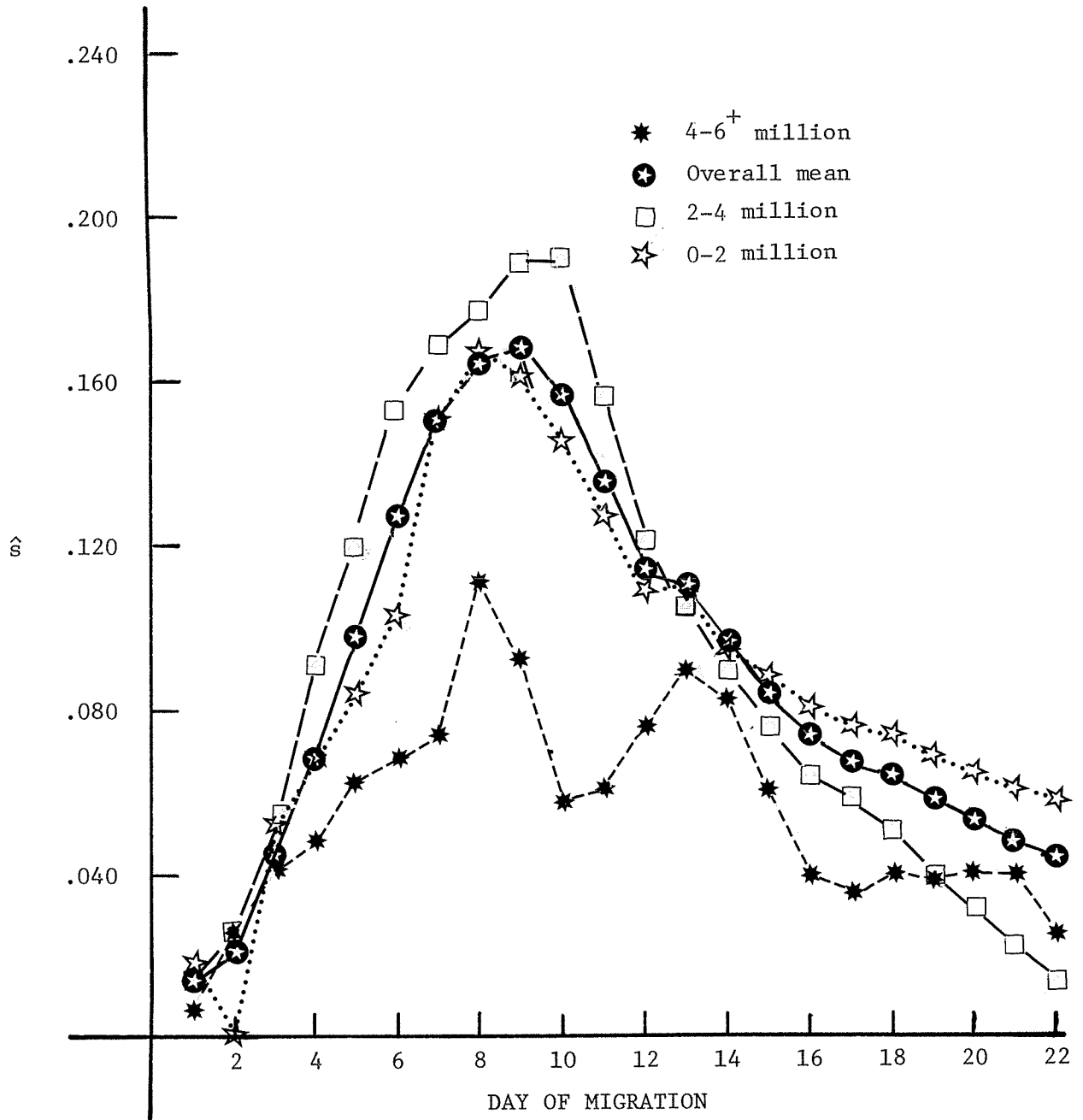


Fig. 2. Standard deviation of cumulative proportions of abundance by day of sockeye salmon migration for overall mean and stratified data. Day 1 was defined as a local maximum rate of change of the daily rate of change of abundance.

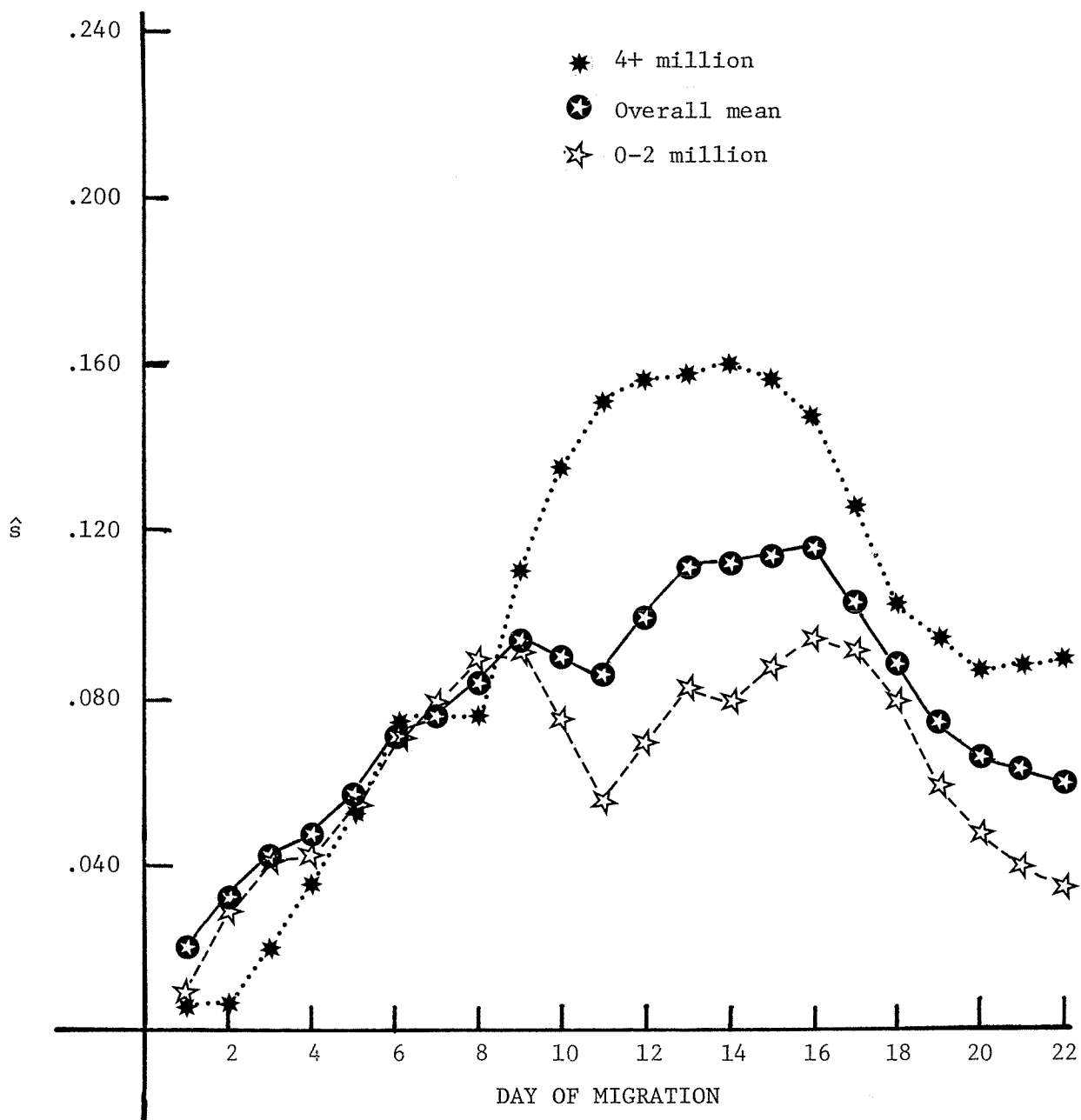


Fig. 3. Standard deviation of cumulative proportions of abundance by day of the pink salmon migration for overall mean and stratified data. Day 1 was defined as a local maximum rate of change of the daily rate of change of abundance.

CHINOOK SALMON MIGRATION — NUSHAGAK BAY, 1981

Introduction

Chinook salmon are the first salmon to return to Nushagak Bay in spring. In 1981, chinook salmon began to appear in Nushagak Bay during the last week of May. Because of the escapements of 70,000 fish in 1975 and 100,000 fish in 1976 and favorable environmental conditions, a substantial chinook salmon return was anticipated for 1981.

The purpose of the contractual work was to provide intraseason abundance estimates during the 1981 chinook salmon migration. A procedure to estimate chinook salmon total escapement was developed in conjunction with the abundance estimation procedure.

Materials and Methods

The abundance estimates were prepared according to the procedures discussed previously in this report and by Hornberger and Mathisen (1981), namely:

$$\hat{C}_i = \frac{\sum c_i}{P(x_i)} \quad (5)$$

based on catch rather than abundance data (Table 4). The estimate of expected catch is an underestimate of the expected total run since the escapement is not included. However, it may serve in the field as a lower bound of the total run estimate. For each fishing day i of the season it is then possible to derive two estimates of the total catch \hat{C}_i . The first estimate is based on a Julian day entry pattern. A second one is based on an entry pattern

Table 4. Preliminary chinook salmon catch data for the 1981 Nushagak Bay salmon migration.

Date	Daily catch	Cumulative catch	Date	Daily catch	Cumulative catch
Prior to 6/01		4,324	6/22	8,250	99,497
6/01	2,719	7,043	6/23	17,750	117,247
6/02	5,469	12,512	6/24	10,000	127,247
6/03	5,341	17,853	6/25	11,000	138,247
6/04	1,825	19,678	6/26	10,000	148,247
6/05	2,135	21,813	6/27	1,000	149,247
6/06	C ¹		6/28	14,000	163,247
6/07	C		6/29	1,000	164,247
6/08	7,726	29,539	6/30	4,000	168,247
6/09	17,309	46,848	7/01	0	168,247
6/10	15,094	61,942	7/02	7,000	175,247
6/11	3,900	65,842	7/03	C	
6/12	C		7/04	2,000	177,247
6/13	C		7/05	5,000	182,247
6/14	C		7/06	2,000	184,247
6/15	C		7/07	1,000	185,247
6/16	9,175	75,017	7/08	2,000	187,247
6/17	7,764	82,781	7/09	0	187,247
6/18	C		7/10	0	187,247
6/19	3,880	86,661	7/11	1,000	188,247
6/20	4,586	91,247	7/12	1,000	189,247
6/21	C		7/13	1,000	190,247

¹ C represents closed fishing periods.

where day 1 is defined as indicated in Table 5.

The accuracy of the intraseason abundance estimates depends on identifying day 1 correctly. During the 1981 chinook salmon migration day 1 may have been incorrectly identified as 1 June instead of 2 June because the catch reported prior to 1 June was reported as cumulative catch. In order to apply the procedure for defining day 1, daily catch records are required. Secondly, 1 June, which was on a Monday, followed the traditional weekend closure. Therefore, knowledge of the number of fish that had entered the fishing district during the weekend was lacking. To compensate for lack of daily catch records from the fishery, daily catch information was gathered from selected processors beginning 27 May. Day 1 was then defined (Table 5). No adjustments were made in the catch reported on 1 June to compensate for the weekend closure. Given the post-season status of the chinook salmon abundance, this lack of adjustment was inappropriate. When the data were adjusted, day 1 was redefined as 2 June (Table 6).

Results and Discussion

The cumulative catch during the 1981 chinook salmon migration was 195,000 fish and the cumulative escapement estimated from aerial surveys was 150,000. The total run was thus estimated to be 345,000 fish.

Abundance was estimated intraseasonally and post-seasonally (Table 7). The abundance estimates calculated intraseasonally were based on equation (5) and represent estimates of total catch to be made, since intraseason daily escapement data are not available. This can be converted to a total run estimate if the rate of exploitation μ is known. Since

Table 5. King salmon catches in Nushagak Bay, 1981, used to define day 1 (catch data from one cannery only).

Date	Catch	Approx. 1st DER.	Approx. 2nd DER.
5/27	7		
5/28	52	45	
5/29	321	269	224
6/01	900	579	310*
6/02	1,300	400	-179
6/03	550	-750	—
6/04	175	-375	—

* marks day 1.

Catches made from midnight to 9 a.m. on Saturday, May 30, were not known during the season and therefore not entered in this table.

Table 6. King salmon catches in Nushagak Bay, 1981, used to redefine day 1 post-seasonally (catch data from one cannery only).

Date	Catch	Approx. 1st DER.	Approx. 2nd DER.
5/27	7		
5/28	52	45	
5/29	321	269	224
5/30	150	-171	440
5/31	300	+150	+321
6/01	450	+150	0
6/02	1300	850	625*
6/03	550	-750	-1600
6/04	175	-375	-1125

* marks day 1.

Catch on 6/01 was 900 fish, half of which were assumed to be fish entering on 5/31 and 5/30 and divided in the ratio 2:1. The trace catch delivered on 5/30 has not been considered. This is not very accurate, but is of no consequence in this case.

Table 7. Chinook salmon catch estimates for 1981.

Date	Proportion of expected catch	Method I ¹		Method II ²	
		\hat{C}	$\hat{C}-C$	\hat{C}	$\hat{C}-C$
June 6	.058	208,000	+13,000	623,000	+428,000
June 9	.125	192,000	-3,000	488,000	+293,000
June 13	.176	200,000	+5,000	352,000	+157,000

¹ Method I — The abundance estimates (\hat{C}) were calculated according to equation 5. The $P(x_i)$ were calculated after day 1 had been defined as a local maximum of the rate of change of daily abundance. These estimates were calculated intraseasonally with day 1 defined as June 1.

² Method II — \hat{C} were calculated as the estimates derived from equation 5. The $P(x_i)$ were calculated from data classified by calendar date. No adjustments in catch were calculated for closures. These estimates were calculated post-seasonally.

C = total seasonal catch.

\hat{C} = total estimated catch for the season estimated from daily catches to date.

$$\mu = \frac{C}{N} = \frac{C}{C + E} \quad ,$$

then

$$E = \frac{1}{\mu} C - C \quad .$$

Hence

$$\hat{N}_i = \frac{\Sigma C_i + \Sigma E_i}{P(x_i)} = \frac{1}{P(x_i)} \frac{1}{\mu} \Sigma C_i \quad (6)$$

μ can be estimated from the percentage time fishing was permitted, either for the entire season or part of it. The regression line of proportion of fishing time that the district was open during the first 20 days of the migration and exploitation rate is illustrated in Fig. 4 based on data in Table 8. Since king salmon gear was used almost exclusively, by applying this correction factor to the catch estimates, abundance estimates were calculated. The deviations between the estimates and observed catch and escapement are displayed in Figure 5. The deviations reflect the errors of $P(x_i)$ and $\hat{\mu}$. The exploitation rate was overestimated because of the large number of 4-year-old fish in 1981 and the substantial migration after the first 20 days.

The discussion has thus far dealt with the abundance estimates that were prepared. The emphasis of the remaining review of the 1981 chinook salmon migration will concern the harvest control tables that were prepared.

The harvest control tables are the first attempt to provide managers with quantitative input for decisions. The advice provided managers was

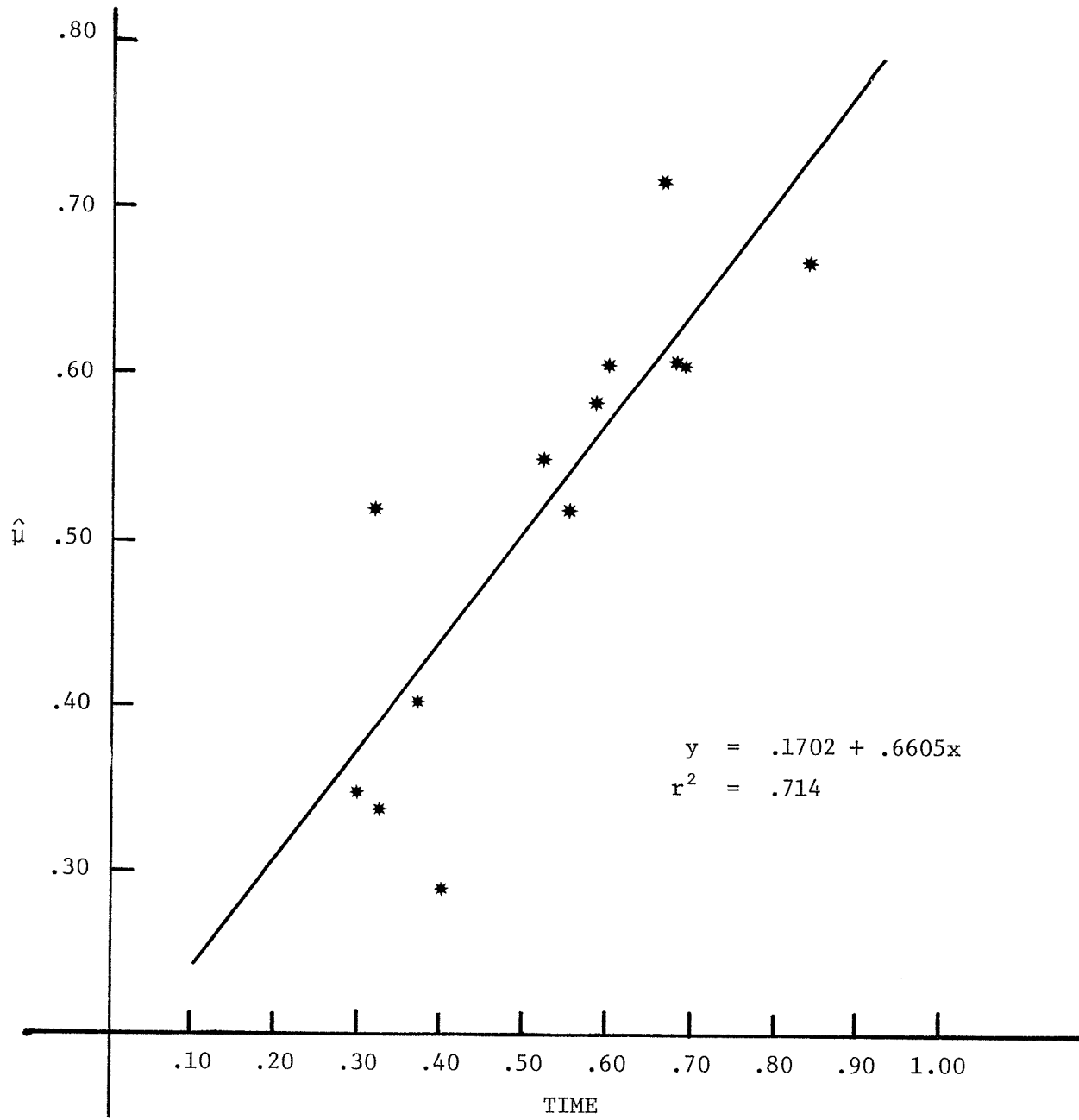


Fig. 4. Relationship between exploitation rate and proportion of time that the chinook salmon fishery was open to fishing during the first 20 days of the migration.

Table 8. Exploitation rate and effort for Nushagak Bay chinook salmon.

Year	Catch ¹	Escapement	Total abundance	Exploitation rate \hat{u}	Proportion of fishing time		Cumulative No. of boat-days
					First 20 days of migration	First 20 days of migration	
1966	61,884	40,000	101,844	.608	.681	1744	
1967	99,940	65,000	164,940	.606	.694	2523	
1968	84,801	70,000	154,801	.548	.523	3212	
1969	87,903	35,000	122,903	.715	.667	1486	
1970	94,447	50,000	144,447	.654	ND	ND	
1971	82,769	ND	ND	ND	ND	ND	
1972	50,045	25,000	75,045	.667	.844	2368	
1973	37,170	35,000	72,070	.516	.552	1285	
1974	39,653	75,000	114,653	.346	.300	1564	
1975	28,554	70,000	98,554	.290	.400	728	
1976	67,473	100,000	167,473	.403	.373	1447	
1977	90,144	65,000	155,144	.581	.585	2175	
1978	140,626	130,000	270,626	.520	.319	ND	
1979	148,012	95,000	243,012	.609	.600	ND	
1980	73,670	141,000	214,670	.343	.326	ND	

¹ Catch represents the combined commercial and subsistence catch reported by Alexandersdottir and Mathisen (1981).

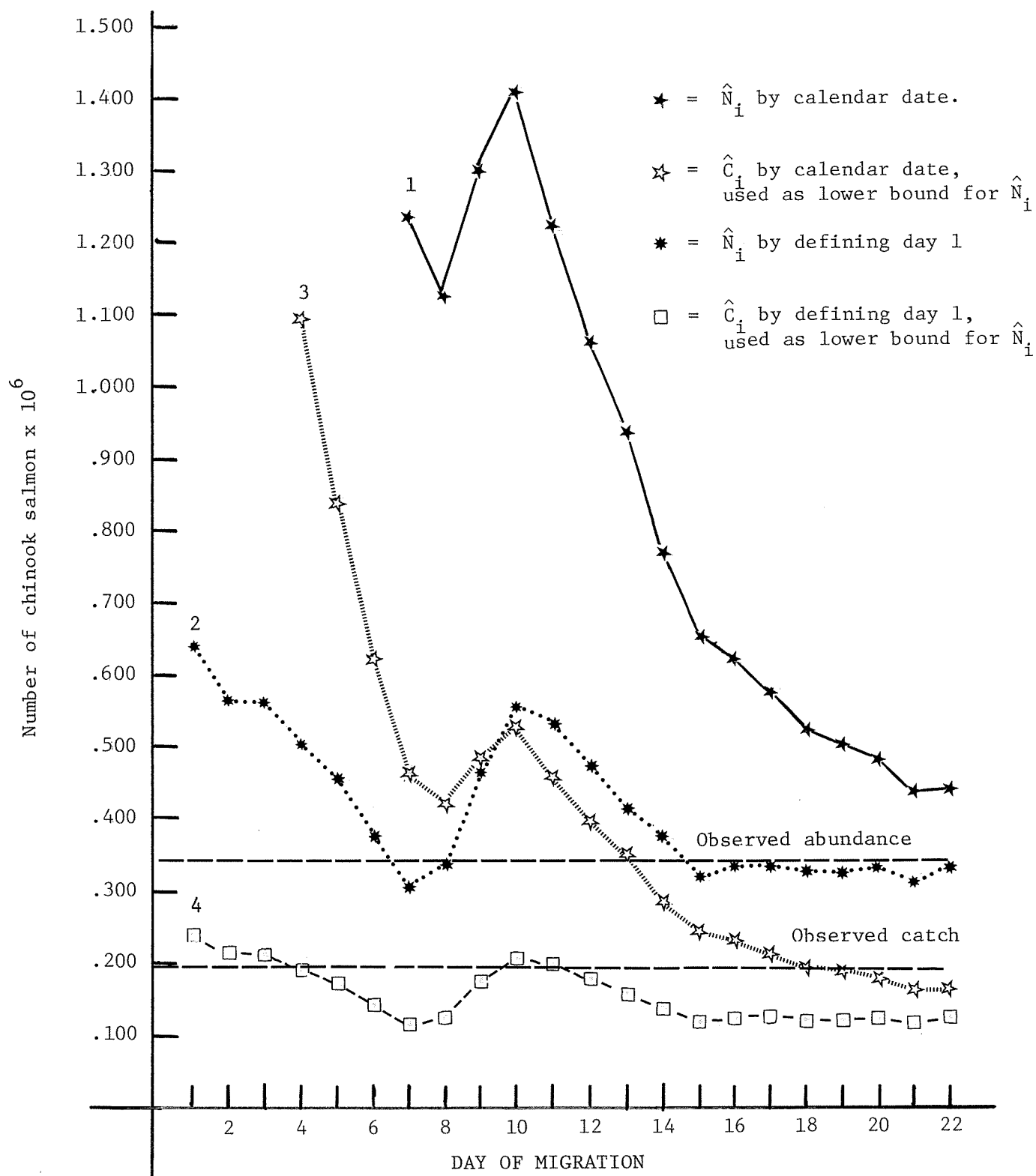


Fig. 5. Estimates of total seasonal catch and total run of chinook. The entry pattern represented the mean curve calculated from data classified by calendar date (1), or the mean curve calculated after day 1 had been defined as a local maximum of the rate of change of daily abundance (2). Catch data were not adjusted for fisheries district closures. Abundance was estimated according to equation 6 (1 and 2) and equation 5 (3 and 4).

The harvest control tables are the first attempt to provide managers with quantitative input for decisions. The advice provided managers was based on an estimated total catch of about 200,000 fish. The goal for the model was to provide a procedure to allow a minimum escapement of 50,000 fish during the first 20 days of the migration, which for 1981 corresponded to 20 June. The recommendation to managers was to limit the harvest to 100,000 fish during the first 20 days. The harvest control table provided suggestions for distributing the catch across the migration (Table 9). Certainly the harvest control tables are static and intraseason adjustments are required; however, they do serve as a convenient reference base for decisions. The greatest adjustments necessary intraseasonally are adjustments based on weather. Since the kings are more susceptible to catch on windy days, the openings and closures therefore cannot be rigorously fixed to calendar dates but must shift with the weather conditions. The harvest control tables should be employed to provide information on relative magnitude of fish to expect and provide a quantitative basis for opening or closing the fishery.

Table 9. Chinook salmon expected cumulative proportions and expected daily and cumulative abundance for a catch of 210,000 fish. Day 1 was defined as the maximum of the observed daily rate of change of catch. Data from 1960-1977, excluding 1961, 1963, 1970, and 1971.

Regulation	Day	Date	Expected cumulative proportions	Expected cumulative abundance	Observed cumulative abundance	Expected daily abundance	Observed daily abundance
Open	1	6/01*	.0294	6,174	7,043		2,719
Open	2	6/02*	.0587	12,327	12,512	6,153	5,469
Open	3	6/03*	.0843	17,703	17,853	5,376	5,341
Open	4	6/04*	.1034	21,714	19,678	4,011	1,825
Open	5	6/05*	.1270	26,670	21,813	4,956	2,135
Closed after 9:00 a.m.	6	6/06	.1544	32,424	26,744	5,754	
Closed	7	6/07	.1893	39,653	31,675	7,329	
Open after 9:00 a.m.	8	6/08	.2317	48,657	39,401	8,904	7,726
Open	9	6/09*	.2676	56,196	56,710	7,539	17,309
Open	10	6/10*	.2959	62,139	71,804	5,943	15,094
Closed	11	6/11*	.3274	68,754	75,704	6,615	3,900
9:00 a.m. Closed	12	6/12*	.3672	77,112		8,358	
Closed	13	6/13*	.4197	88,137		11,025	
Closed	14	6/14	.4788	100,548		12,411	
Closed	15	6/15	.5470	114,870		14,322	
Open	16	6/16*	.6015	126,315		11,445	
11:00 a.m. Closed	17	6/17*	.6501	136,521		10,206	
11:00 a.m. Closed	18	6/18*	.6801	142,821		6,300	
Open	19	6/19*	.7094	148,974		6,153	
1:00 p.m. Closed	20	6/20	.7319	153,699		4,725	
1:00 p.m. Closed							

* days open to fishing.

SOCKEYE SALMON MIGRATION — NUSHAGAK BAY, 1981

Introduction

The sockeye salmon migration, which is numerically the largest single species return to Nushagak Bay, began during the last week of June in 1981. The 1981 migration of sockeye to Nushagak Bay was extraordinarily large. This return represents a continuation of the increased abundance of sockeye salmon which began in 1978 when approximately 6.7 million sockeye salmon returned to Nushagak Bay.

Materials and Methods

During the sockeye salmon migration, five abundance estimates were prepared according to procedures described previously in this report and by Hornberger and Mathisen (1981). The intraseason abundance estimates relied on mean entry patterns which were calculated after day 1 was defined as a local maximum of the rate of change in daily abundance. Post-season estimates were calculated employing mean entry patterns determined from data classified by calendar date.

Results and Discussion

The recent annual extremes in abundance have presented difficult circumstances for abundance estimation. The primary difficulty has been in believing a large forecast such as 10 million fish during preliminary stages of the migration. This disbelief was created by the substantial departure of an abundance of 10 million fish from the pre-season forecast and departure from a

magnitude expected given the historic magnitude of abundance. These factors, added to an aberrant initial entry into the district, contributed substantially to the misidentification of 22 June (Table 10) as day 1 of the sockeye salmon migration with, in turn, caused the first estimate to considerably underestimate the observed final abundance (Table 11). Day 1 was subsequently re-identified as 25 June, and the remaining four estimates reflect the accuracy of the estimation process after day 1 had been properly identified. The failure of the first estimate also demonstrated that the intraseason abundance estimation process cannot be entirely isolated from other input such as data from the sampling program near Port Moller.

Although the estimation process is sound, as the second estimate demonstrates, the procedure for defining day 1 requires further clarification. Because of the substantial difference in the estimates resulting from the misidentification of day 1 and that obtained by properly identifying day 1, additional criteria for correctly identifying the initiation of the migration are needed.

The deviations of \hat{N}_1 from the true value are depicted in Figure 6 assuming day 1 was 25 June. In addition to the estimates based on defining day 1, estimates based on calendar date were calculated (Table 12). The deviations of \hat{N}_1 are depicted in Figure 6).

Although the first estimate failed, certain aspects of the abundance estimation process should be noted:

1. The second abundance estimate, which was calculated when less than .30 (according to preliminary data) of the fish had been caught or been counted past points where escapement was enumerated, was

Table 10. Sockeye salmon migration to Nushagak Bay. Final estimate of day 1.

Date	Daily abundance (thousands)	Approximate first derivative	Approximate second derivative
6/16	6.0		
6/17	5.4	-.6	
6/18	11.8	6.4	7.0
6/19	19.9	8.1	1.7
6/20	24.9	5.0	-3.1
6/21	23.6	-.7	-5.7
6/22	101.0	77.4	81.1*
6/23	64.7	-37.3	-114.7
6/24	68.2	3.5	40.8
6/25	200.0	132.0	129.5
6/26			

* Day 1.

Table 11. Sockeye salmon abundance estimates for Nushagak Bay, 1981.

Date prepared	Cumulative proportion of run (catch and escapement)	Method I ¹		Method II ²	
		\bar{N}	$\bar{N}-N$	\bar{N}	$\bar{N}-N$
June 26	.031	3.5	-7.06	10.6	+0.04
July 4 (9:30 a.m.)	.276	8.0	-2.56	9.1	-1.46
July 7	.581	7.7	-2.86	9.6	-.96
July 10	.781	10.0	-.56	9.9	-.66
July 14	.933	10.5	-.06		

¹ Method I — The abundance estimates (\bar{N}) were the means of daily estimates calculated according to equation (3). The $P(x_i)$ were calculated after day 1 had been defined as a local maximum of the rate of change in daily abundance. These estimates were calculated intraseasonally with day 1 defined as 22 June for the first estimate and 25 June for subsequent estimates.

² Method II — \bar{N} 's were calculated as the mean of estimates calculated according to equation (3). The $P(x_i)$ were calculated from data classified by calendar date. These estimates were calculated post-seasonally.

True Abundance $N = 10.56 \cdot 10^6$.

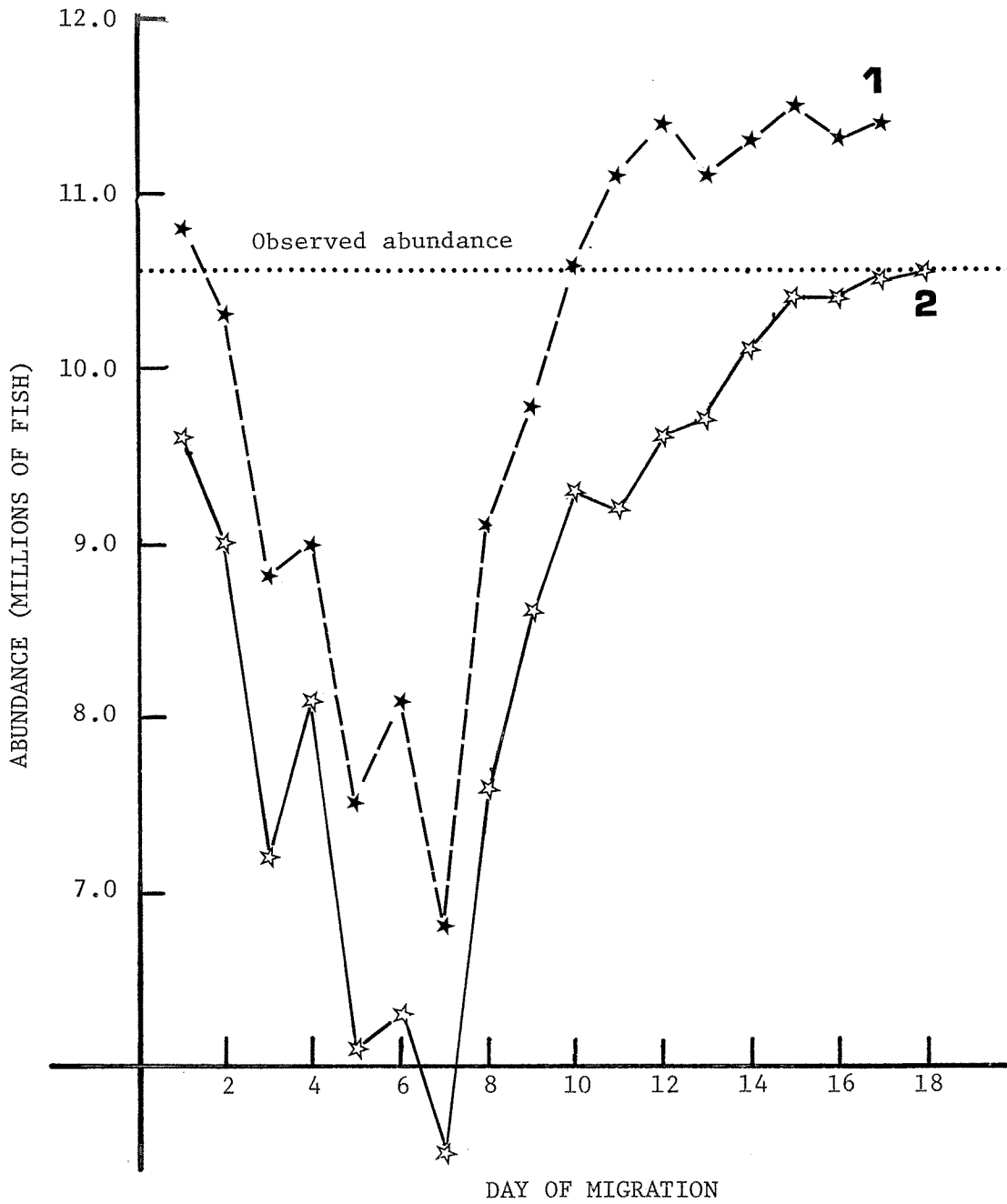


Fig. 6. Daily sockeye salmon abundance estimates from the observed abundance through the fishing season. The entry pattern represented the mean curve calculated from the data classified by calendar date (2) and after day 1 had been defined as a local maximum rate of change of the rate of change of daily abundance (1). Day 1 was defined as June 25.

Table 12. Sockeye salmon abundance estimates. The entry pattern represented the mean curve calculated from data classified by calendar date.

Date	Cumulative abundance	Expected proportion	\hat{N}
6/25	498.1	.046	10.8
6/26	671.4	.065	10.3
6/27	744.9	.085	8.8
6/28	1133.8	.126	9.0
6/29	1301.8	.174	7.5
6/30	1837.5	.228	8.1
7/01	1968.3	.289	6.8
7/02	3189.6	.352	9.1
7/03	4245.2	.431	9.8
7/04	5317.7	.500	10.6
7/05	6126.0	.553	11.1
7/06	6989.0	.614	11.4
7/07	7514.0	.679	11.1
7/08	8204.0	.725	11.3
7/09	8852.0	.767	11.5
7/10	9146.0	.808	11.3
7/11	9554.0	.840	11.4

31 percent below the preliminary final abundance.

2. Estimates in 1981 were underestimates because the build-up in fish abundance was slower than in an average year, and the averaging process worked better in this year.

In addition to the abundance estimates, harvest control tables were prepared during the sockeye salmon migration as follows:

$$\hat{N}_i = \hat{N}_k P(x_i) \quad (8)$$

$$\hat{n}_i = \hat{N}_{i+1} - \hat{N}_i \quad (9)$$

where

\hat{N}_k \equiv estimated total abundance in year k

\hat{N}_i \equiv estimated cumulative run by day i, $\hat{N}_i = \sum_i n_i$

\hat{n}_i \equiv estimated abundance on day i in year k

Although the initial estimate of 3.5 million fish was an unacceptable abundance estimate, the harvest control strategy based on a run of this size closely approximated the management strategy actually employed during 1981 (Table 13). The similarity in management strategies reflects the substantial difference between the estimated abundance and the fish required for escapement. The differences between the harvest control tables and actual management reflect the static nature of the harvest control tables. These tables, however, can provide a quantitative reference for managers. The differences between the strategy proposed and that practiced represent adjustments necessary to compensate for weather patterns, exploitation rates, and migratory rates which are unique to each year. The noteworthy

Table 13. Sockeye salmon expected cumulative proportions, expected daily and cumulative abundance and potential daily harvest for a migration of 3,500,000 fish and a maximum exploitation rate of .9.¹ Day 1 was defined as the maximum rate of change of the observed daily rate of change of abundance. Data from 1959-1979.

Day	Date	Expected cumulative proportion	Expected cumulative abundance	Expected daily abundance	Potential daily harvest	Actual opening ³
1	June 22	.0524	183,400	183,400	165,060* ²	3P-12M
2	23	.0751	262,850	79,450	71,505*	Open
3	24	.1036	362,600	99,750	89,775	Open
4	25	.1402	490,700	128,100	115,290*	Open
5	26	.2125	743,750	253,050	227,745*	Open to 9P
6	27	.2918	1,021,300	277,550	249,795	Open from 9P
7	28	.3564	1,247,400	226,100	203,490*	9P closed
8	29	.4213	1,474,550	227,150	204,435*	Closed
9	30	.4934	1,726,900	252,350	227,115*	Open 10A-10P
10	July 1	.5740	2,009,000	282,100	253,890	Closed
11	2	.6637	2,322,950	313,950	282,555	Open 12N-12M
12	3	.7296	2,553,600	230,650	207,585*	Closed
13	4	.7781	2,723,350	169,750	152,775*	Open from 9P
14	5	.8154	2,853,900	130,550	117,495*	Open
15	6	.8523	2,983,050	129,150	116,235*	"
16	7	.8826	3,089,100	106,050	95,445*	"
17	8	.9077	3,176,950	87,850	79,065*	"
18	9	.9260	3,241,000	64,050	56,645*	"
19	10	.9414	3,294,900	53,900	48,510*	"
20	11	.9542	3,339,700	44,800	40,320*	"
21	12	.9650	3,377,500	37,800	34,020*	"
22	13	.9740	3,409,000	31,500	28,350*	"
23	14	.9810	3,433,500	24,500	22,050*	"
24	15	.9848	3,446,800	13,300	11,970*	"
25	16	.9892	3,462,200	15,400	13,860*	"

Igushik open

¹Observed 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"*" denotes days when fishing should be allowed. If no "*" is present, no openings should be allowed.

³The Igushik section was open to continuous fishing except for the closure from 12 M 2 July to 3P 4 July.

The exploitation rate of .9 in Table 13 represents the expected exploitation rate for the fleet. Given an abundance of 3.5 million fish, only 350,000 fish would therefore escape the fishery. The days of closure were selected to spread the harvest across the stocks giving priority to early season closures to allow for the conservation of sockeye returning to the Nushagak-Mulchatna River system.

differences during 1981 were the continuous fishing in the Igushik section and the 2 July opening, which followed a period of strong winds.

CHUM SALMON MIGRATION — NUSHAGAK BAY, 1981

The chum salmon migration overlaps with the sockeye salmon migration. Since sockeye typically are the most numerous and economically more desirable species, management decisions are based on sockeye salmon. Because of the favorable environmental conditions and large escapements during 1977, a substantial chum salmon return was anticipated for 1981.

Materials and Methods

During the chum salmon migration, three abundance estimates were prepared according to procedures described previously in this report and by Hornberger and Mathisen (1981). The intraseason abundance estimates relied on mean entry patterns which were calculated after day 1 was defined as a local maximum of the daily rate of change in abundance. Escapement was estimated by estimating the number of fish that swam past a side-scanning sonar unit in the Nushagak River near Portage Creek, Alaska. The counts were apportioned between chinook, sockeye, and chum salmon by calculating the frequency of fishes captured in gill nets and beach seines. These counts were lagged two days to the fishery. Post-season estimates were calculated employing entry patterns which were calculated from data classified by calendar date.

Results and Discussion

During the chum salmon migration, three estimates of abundance were prepared (Table 14), and they agreed well among themselves.

Table 14. Chum salmon abundance estimates¹ during 1981.

Date prepared	Proportion of migration	Method I ²		Method II ³	
		$\overline{\hat{N}}$	$\overline{\hat{N}-N}$	$\overline{\hat{N}}$	$\overline{\hat{N}-N}$
June 25	.06	1.2	+ .129	3.5	2.429
June 27	.19	1.2	+ .129	3.4	2.329
July 9	.52	1.5	+ .429	2.4	1.329

¹ Assumes an actual total abundance $N = 1.071$ million fish.

² Method I — The abundance estimates ($\overline{\hat{N}}$) were calculated as the mean of estimates calculated according to equation (3). The $P(x_i)$ were calculated after day 1 had been defined as a local maximum of the rate of change of daily abundance. These estimates were calculated intraseasonally with day 1 defined as 20 June for the first 2 estimates and 21 June for the third.

³ Method II — $\overline{\hat{N}}$'s were calculated as the mean of estimates calculated according to equation (3). The $P(x_i)$'s were calculated from data classified by calendar date. These estimates were calculated post-seasonally.

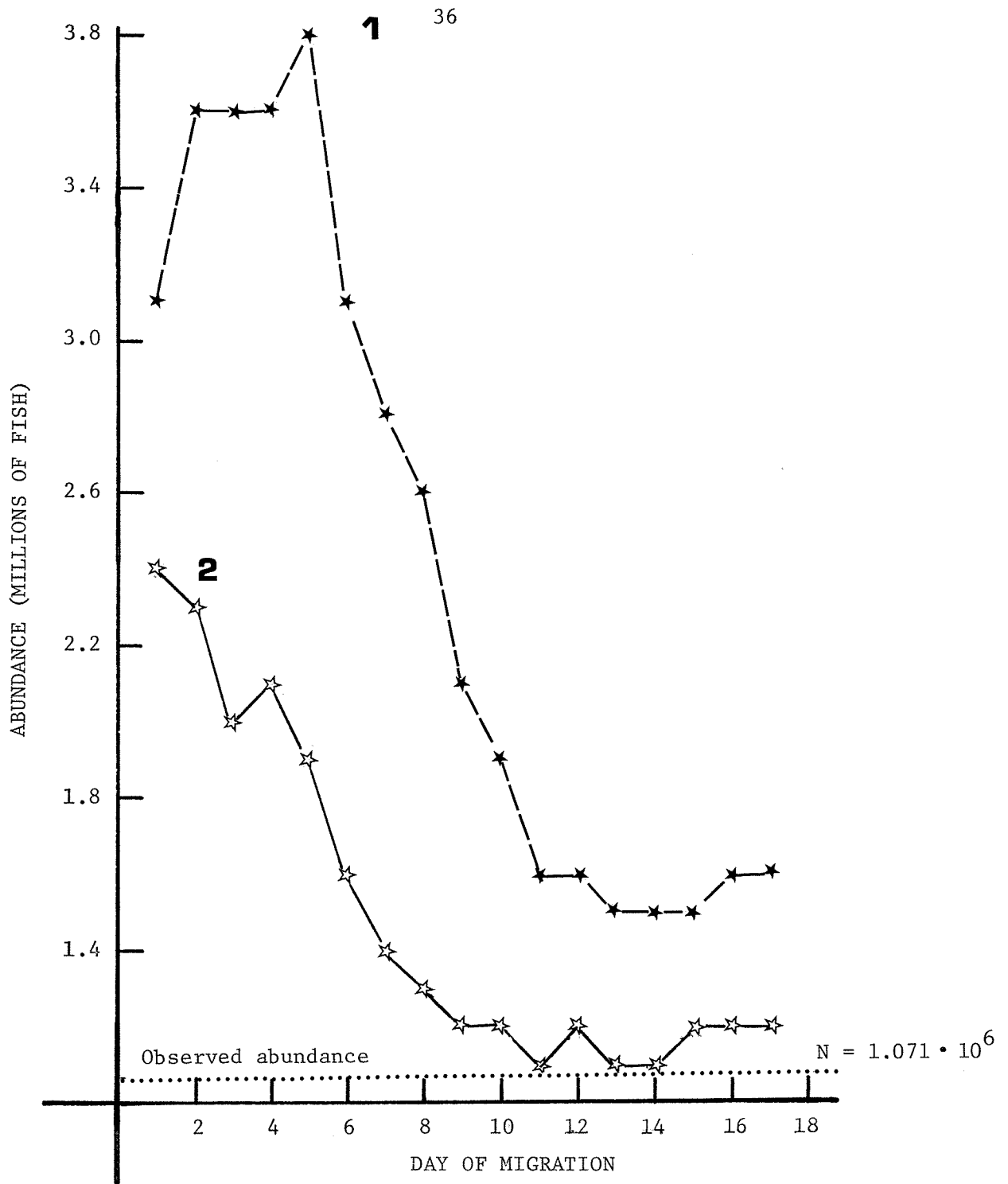


Fig. 7. Deviation of the daily chum salmon abundance estimates from the observed abundance. The entry pattern represented the mean curve calculated from the data classified by calendar date (1) and after day 1 had been defined as a local maximum of the rate of change of daily abundance (2). Day 1 was defined as June 21.

The deviations of \hat{N}_i from true value are depicted in Figure 7 assuming day 1 was 21 June. In addition to the estimates based on defining day 1, estimates based on calendar date were calculated (Table 15). The deviations of \hat{N}_i are depicted in Fig. 7. Because of the overlap between the sockeye and chum salmon migration, the emphasis on sockeye management, and the lack of escapement goals for chum salmon, specific harvest control scenarios were not prepared for chum salmon. Tables relating the expected daily and cumulative abundance of sockeye and chum salmon were prepared.

Table 15. Chum salmon abundance estimates. The entry pattern represented the mean curve calculated from data classified by calendar date.

Date	Cumulative abundance	Expected proportion	\hat{N}
6/21	56,159	.018	3.1
6/22	96,347	.027	3.6
6/23	129,655	.036	3.6
6/24	164,865	.046	3.6
6/25	213,630	.056	3.8
6/26	249,897	.080	3.1
6/27	268,170	.096	2.8
6/28	291,296	.114	2.6
6/29	295,257	.142	2.1
6/30	326,028	.173	1.9
7/01	333,608	.206	1.6
7/02	382,636	.233	1.6
7/03	387,580	.267	1.5
7/04	454,915	.311	1.5
7/05	533,574	.350	1.5
7/06	604,460	.386	1.6
7/07	672,044	.419	1.6

Table 16. Post-season comparison of expected daily and cumulative abundance for Nushagak Bay sockeye¹ and chum² salmon, 1981.

Date	Daily expected sockeye abundance	Daily expected chum abundance	Cumulative expected sockeye abundance	Cumulative expected chum abundance
6/21				35
6/22		28		63
6/23		35		98
6/24		21		119
6/25		47	550	166
6/26	239	70	789	236
6/27	299	52	1,088	288
6/28	384	45	1,472	333
6/29	759	36	2,231	369
6/30	833	34	3,064	403
7/01	678	44	3,742	447
7/02	682	35	4,424	482
7/03	757	51	5,181	533
7/04	846	79	6,027	632
7/05	935	69	6,962	681
7/06	699	59	7,661	740
7/07	509	72	8,170	812
7/08	392	55	8,562	867
7/09	387	81	8,949	948
7/10	318	98	9,267	1,046
7/11	264	73	9,531	1,119
7/12	192	51	9,723	1,170
7/13	162	54	9,885	1,224
7/14	134	9	10,019	1,233
7/15	103	21	10,122	1,254
7/16	105	56	10,227	1,310
7/17	73	21	10,300	1,331
7/18	43	25	10,343	1,356

¹Preliminary final sockeye salmon abundance of 10.5 million fish.

²Preliminary final chum salmon abundance of 1.3 million fish.

HARVEST CONTROL MODEL

Introduction

Management of salmon in Nushagak Bay, Alaska, includes harvest control of five species of salmon: chinook, sockeye, chum, coho, and pink, as well as several separate stocks within each species. Current knowledge does not allow management of individual stocks and, except for the Igushik District, 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.

To simplify the management process, two categories of management have been defined: 1) policy, and 2) harvest control (Hornberger and Mathisen 1981). Policy is concerned with the establishment of escapement goals by species for each river system. Decisions of policy are complex and require biological, sociological, political, and economic input. Harvest control, on the other hand, should be a mechanical process aimed at delivering a pre-determined escapement or harvest goal. Constraints and maximum adjustment levels should be defined prior to the beginning of the migration as part of the policy.

Materials and Methods

To develop a harvest control model, entry patterns were calculated for each species of salmon returning to Nushagak Bay (Appendix A, Tables A1-A10). Daily and cumulative proportions of abundance were plotted against time to

determine the interrelationship of the migration of the various species (Fig. 8). To provide a common abscissa for comparing entry patterns based on data averaged by calendar date and those averaged after day 1 of the migration had been defined, day 1 was assigned an average calendar date (Fig. 9):

<u>Species</u>	<u>Day 1</u>
Chinook	8 June
Sockeye	26 June
Chum	26 June
Pink	16 July
Coho	23 July

Finally the cumulative proportion of the migration completed for each species relative to the other species was defined (Figs. 10-11). Harvest control tables can be calculated as follows:

$$\hat{N}_i = P(x_i) \hat{N}_k \quad (10)$$

$$\hat{n}_i = P(x_i) \hat{N}_k \quad (11)$$

where \hat{N}_k = Total run in year k

\hat{N}_i = Cumulative run to day i

\hat{n}_i = Abundance on day i

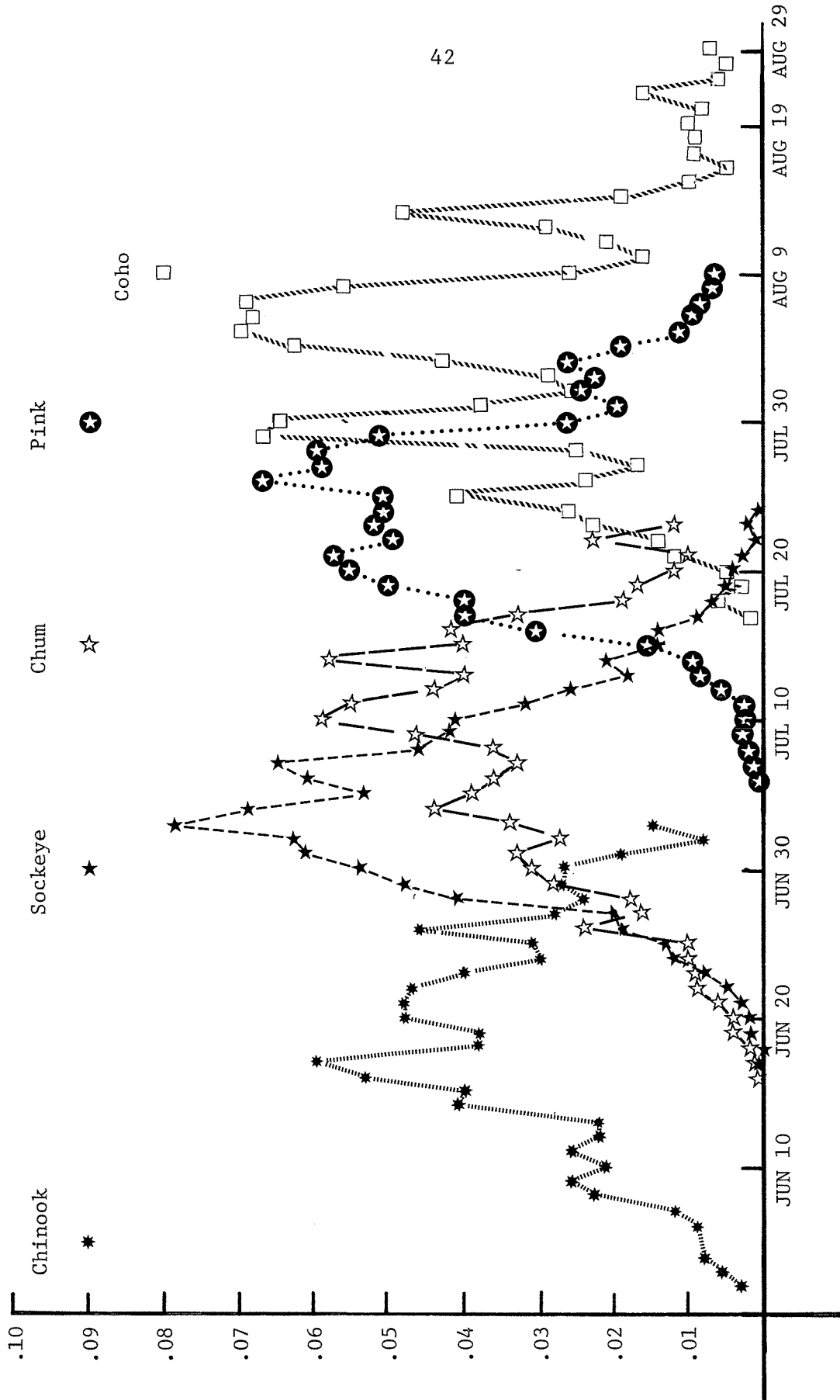


Fig. 8. Daily entry patterns for Nushagak Bay salmon. The means were calculated after data were classified by calendar date.

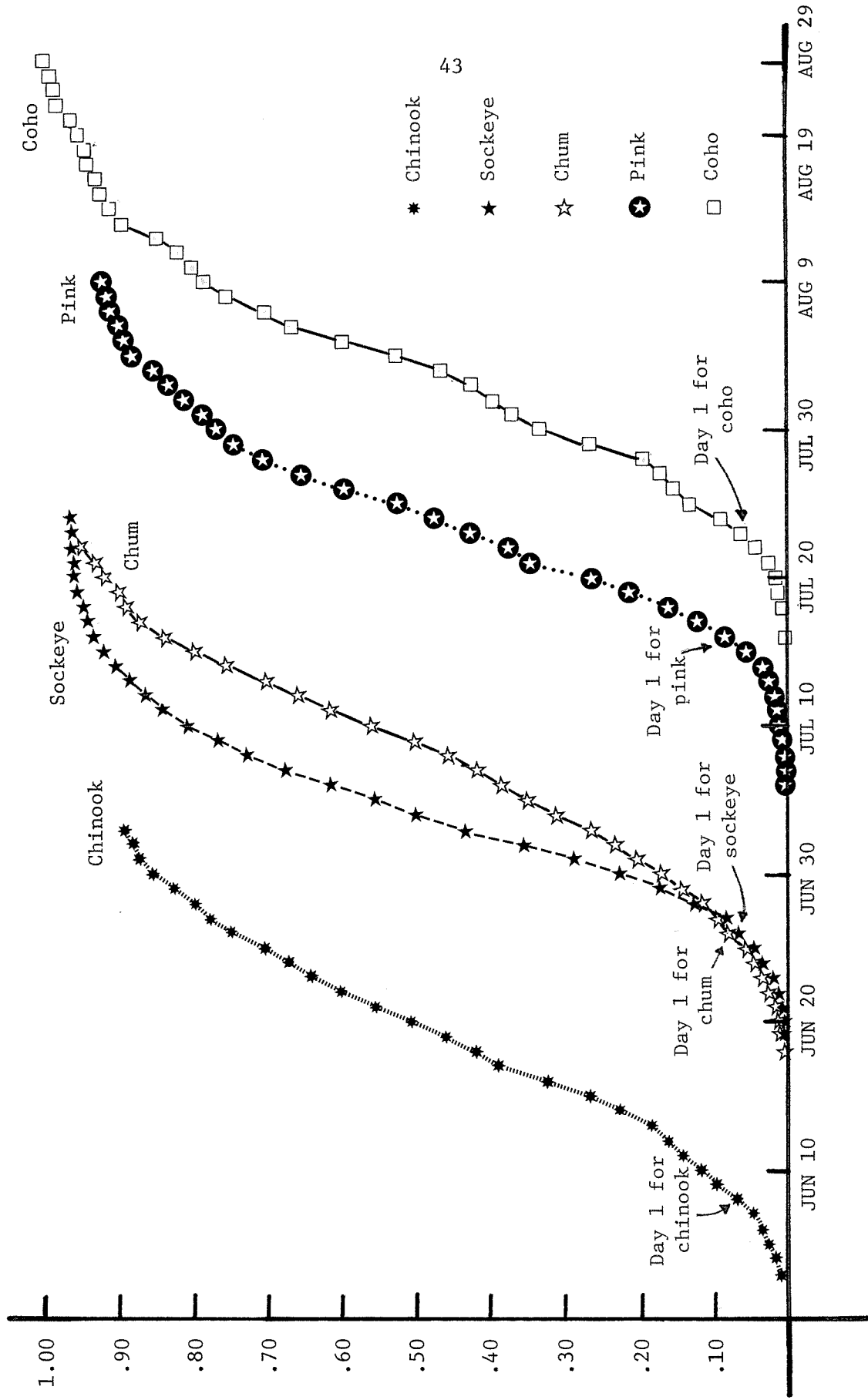


Fig. 9. Cumulative entry patterns for Nushagak Bay salmon. The means were calculated after the data had been classified by calendar date.

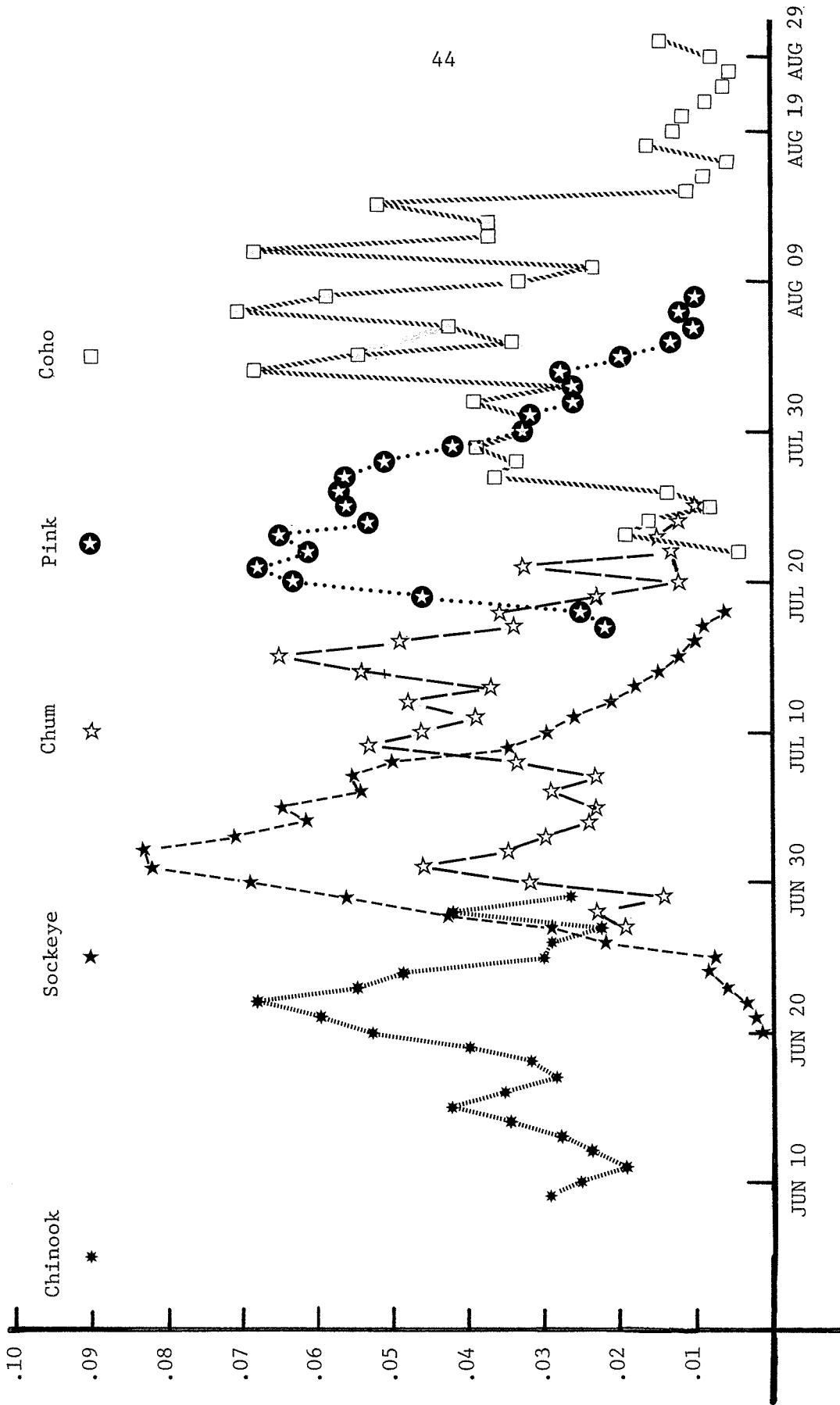


Fig. 10. Daily entry patterns for Nushagak Bay salmon. The means were calculated after day 1 had been defined as a local maximum rate of change of the daily rate of change of abundance.

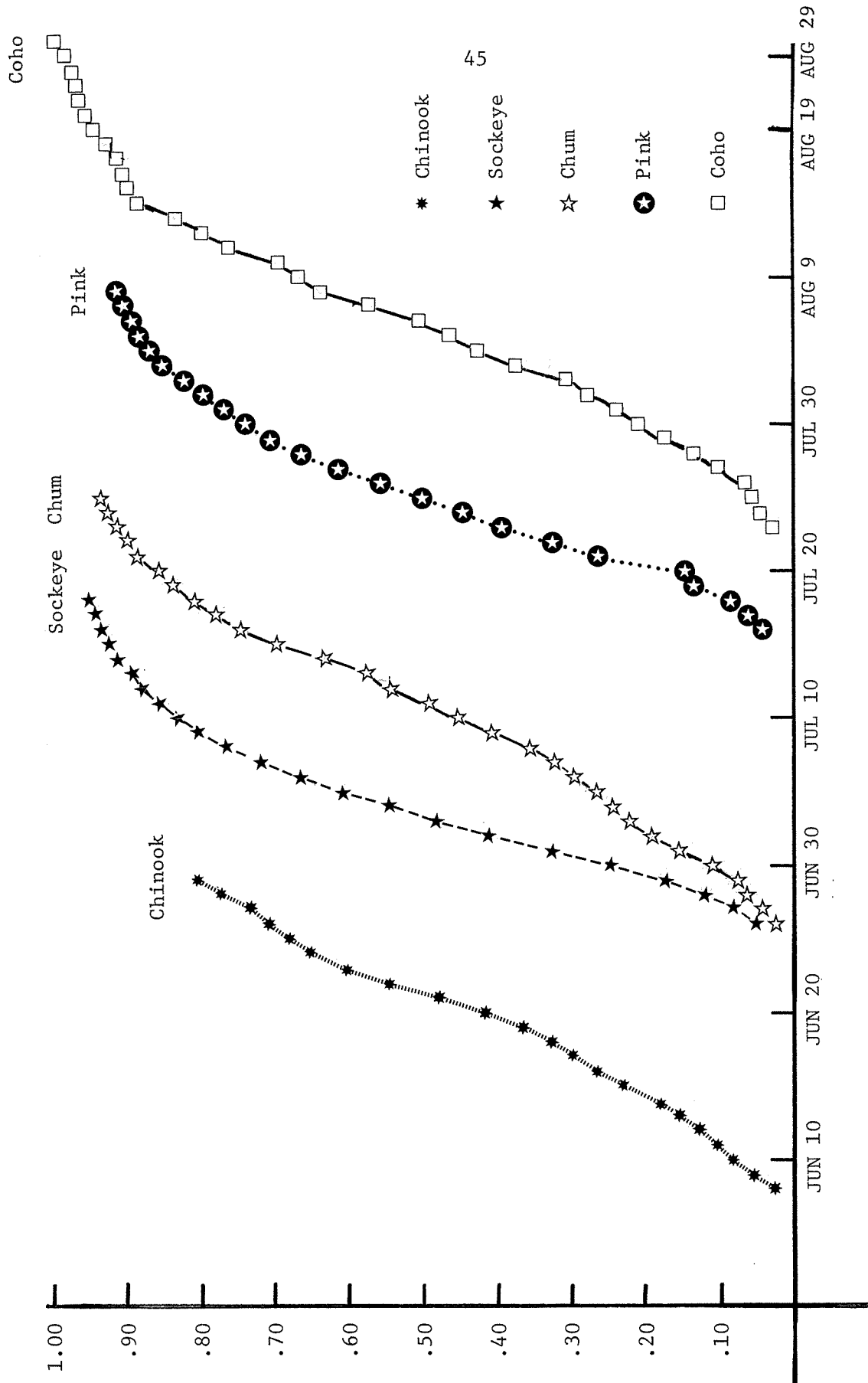


Fig. 11. Cumulative entry patterns for Nushagak Bay salmon. The means were calculated after day 1 had been defined as a local maximum rate of change of the daily rate of change of abundance.

If the defined entry patterns reflect the entry during the migration, then the probability of overescapement or of reaching an escapement goal in one tide can be established for all abundance levels for any migration.

Multispecies Salmon Management

To consider multispecies management for Nushagak Bay the relationship between the times of entry of the various species must be documented and discussed. For practical application, decisions are based on single species management. As Figures 9 and 11 demonstrate, there are periods when each species could be given priority and managed. For the purpose of multispecies management, the transition between priority species has been assumed to be at a cumulative abundance of $\approx .75$ of the priority species migration. Given the relative timing of entry, schedules for management can be prepared based both on calendar date and by defining day 1 (Table 17). These relative entry patterns allow pre-season management scenarios to be developed to facilitate intraseason harvest control.

Harvest Control Tables

The fundamental flaw of harvest control tables is that they are static and do not provide adjustments for intraseason environmental circumstances. This is a fault of the stage of development rather than a flaw of the procedure.

Given an accurate abundance estimate and predetermined entry pattern, decisions to open or close the fishery can be discussed in relatively simple terms (Figure 12 and Table 18).

Table 17. Preliminary management scheme for Nushagak Bay salmon.

Calendar date	Species	Days of single species management	Proportion of migration completed during management
1. <u>Even year</u>			
1 June - 26 June	Chinook	26	0 - .75
27 June - 8 July	Sockeye	12	.083 - .614
9 July - 16 July	Chum	8	.501 - .840
17 July - 29 July	Pink	13	.123 - .744
30 July - 24 August	Coho	26	.331 - 1.000
<u>Odd year</u>			
1 June - 26 June	Chinook	26	0 - .75
27 June - 8 July	Sockeye	12	.083 - .614
9 July - 23 July	Chum	15	.501 - .966
24 July - 24 August	Coho	31	.092 - 1.000
2. <u>Day of migration</u>			
<u>Even year</u>			
1 - 20	Chinook	20	.029 - .732
2 - 13	Sockeye	12	.080 - .768
14 - 21	Chum	8	.408 - .746
2 - 15	Pink	14	.063 - .739
9 - 34	Coho	26	.444 - .996
<u>Odd year</u>			
1 - 20	Chinook	20	.029 - .732
2 - 13	Sockeye	12	.080 - .768
14 - 28	Chum	15	.408 - .913
2 - 34	Coho	33	.044 - .996

1. Entry patterns calculated by averaging cumulative proportions of fish that entered the district on a specific calendar date.
2. Entry patterns calculated by averaging cumulative proportions of fish that entered the district after day 1 had been identified for each species separately.

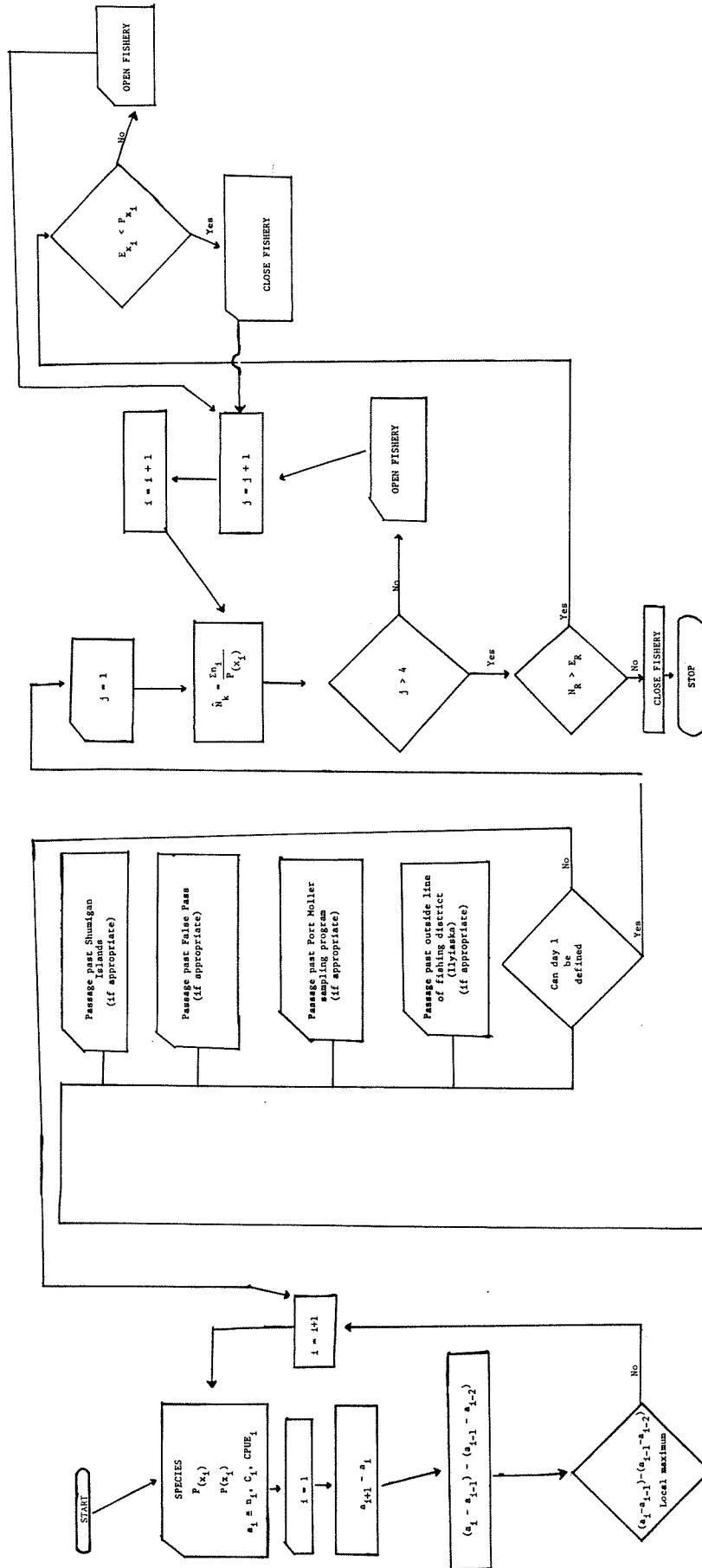


Fig. 12. Flow chart of criteria to regulate Nushagak Bay salmon fishery.

Table 18. Symbols and constraints for flow chart of Nushagak Bay harvest control.

1. $P(x_i)$ \equiv cumulative proportion of abundance on day i .
2. $p(x_i)$ \equiv proportion of abundance on day i .
3. i \equiv initial day (some arbitrary calendar date) that abundance is first tabulated or that boats begin to fish
4. l \equiv days of migration assuming that the initiation of the migration has been correctly identified.
5. k \equiv year.
6. a_i \equiv observed magnitude of the migration on day i ; measured as abundance on day i (n_i) or catch per unit of effort on day i ($CPUE_i$) or approximated by catch on day i (C_i).
7. \hat{N}_R \equiv estimated number of fish remaining in migration.
 \hat{N}_R \equiv $\hat{N}_k - \sum n_i$ where
 N_k \equiv estimated total abundance for year k
 $\sum n_i$ \equiv observed total abundance by day i
8. E_R \equiv number of fish needed to reach the escapement goal.
 E_R \equiv $E_G - \sum_j \sum_i E_{ij}$
 E_G \equiv predetermined escapement goal by species
 $\sum_j \sum_i E_{ij}$ \equiv observed total escapement by day i for all rivers j

9. E_{x_i} \equiv expected cumulative proportion of escapement desired.
10. This procedure
- a) assumes day 1 can be accurately defined;
 - b) provides for single species management;
 - c) assumes that escapement goals have been established for each species and that these goals are appropriate;
 - d) assumes that once day 1 is defined that the entry of the remaining fish will follow the predetermined pattern.

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APPENDIX A
MIGRATORY TIME DENSITY DISTRIBUTIONS
FOR NUSHAGAK BAY CHINOOK, SOCKEYE,
CHUM, PINK AND COHO SALMON

Table A1. Chinook salmon cumulative catch proportions based on adjusted catch data.¹ Day 1 was defined as a local maximum rate of change of daily rate of change of observed daily catch. Data from 1960-1977 (excluding 1961, 1963, 1970 and 1971).

Day	\bar{x}	\hat{s}	Max.	Min.
1	.0294	.0149	.0615	.0117
2	.0587	.0393	.1539	.0143
3	.0843	.0609	.2052	.0209
4	.1034	.0734	.2612	.0317
5	.1270	.0784	.2706	.0334
6	.1544	.0852	.3287	.0366
7	.1893	.0785	.3545	.0720
8	.2317	.1134	.5030	.0879
9	.2651	.1200	.5815	.1097
10	.2959	.1184	.6254	.1967
11	.3274	.1204	.6693	.2052
12	.3672	.1183	.6785	.2279
13	.4197	.1347	.6913	.2373
14	.4788	.1561	.7040	.2519
15	.5470	.1514	.7806	.3003
16	.6015	.1435	.8644	.3378
17	.6501	.1391	.9483	.4643
18	.6801	.1376	.9571	.4834
19	.7094	.1387	.9626	.5083
20	.7319	.1390	.9648	.5140
21	.7741	.1229	.9755	.5993
22	.8008	.1065	.9811	.6241
23				
24				
25				

¹Catch was adjusted from catch reported by the Alaska Department of Fish and Game in their annual IBM reports. For days closed to fishing or when effort was less than 30 boats, the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table A2. Chinook salmon catch proportions based on adjusted catch data.¹
 Data averaged by calendar date for 1960-1977 (excluding 1961,
 1963, 1970 and 1971).

Date	\bar{x}	\hat{s}	Minimum	Maximum
June 1	.001	.003	.000	.010
2	.004	.006	.000	.018
3	.010	.014	.000	.047
4	.018	.025	.000	.068
5	.026	.035	.000	.118
6	.034	.044	.001	.164
7	.047	.053	.001	.197
8	.070	.066	.001	.218
9	.096	.071	.004	.225
10	.117	.085	.005	.266
11	.143	.096	.006	.295
12	.165	.110	.006	.338
13	.187	.114	.017	.360
14	.228	.138	.021	.503
15	.268	.134	.087	.582
16	.321	.134	.110	.625
17	.380	.154	.168	.669
18	.419	.159	.174	.679
19	.457	.169	.178	.691
20	.505	.174	.183	.721
21	.553	.180	.187	.795
22	.600	.190	.214	.797
23	.640	.188	.227	.906
24	.670	.185	.236	.907
25	.701	.182	.242	.916
26	.747	.146	.444	.921
27	.775	.134	.512	.923
28	.799	.133	.514	.923
29	.826	.126	.560	.948
30	.853	.100	.663	.957
July 1	.872	.086	.691	.965
2	.880	.081	.717	.967
3	.895	.080	.728	.969

¹Catch was adjusted from catch reported by the Alaska Department of Fish and Game in their annual IBM reports. For days closed to fishing or when effort was less than 30 boats, the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table A3. Sockeye salmon observed cumulative proportion of abundance¹ by day for Nushagak Bay from 1959 to 1979 (excluding 1963 and 1970). Day 1 was defined as a local maximum rate of change of the observed daily rate of change of abundance.

Day	\bar{x}	\hat{s}	Minimum	Maximum
-6	.002	.002	.000	.006
-5	.003	.003	.000	.009
-4	.005	.004	.000	.013
-3	.008	.006	.001	.023
-2	.014	.009	.006	.037
-1	.022	.013	.006	.054
0	.029	.014	.007	.060
1	.051	.014	.031	.082
2	.0795	.0215	.056	.109
3	.122	.045	.062	.234
4	.178	.068	.081	.278
5	.247	.098	.096	.404
6	.329	.127	.128	.538
7	.412	.151	.156	.628
8	.483	.165	.181	.688
9	.544	.168	.238	.770
10	.609	.157	.274	.840
11	.663	.136	.374	.862
12	.718	.114	.503	.876
13	.768	.110	.586	.933
14	.803	.097	.646	.949
15	.833	.084	.696	.957
16	.859	.074	.721	.961
17	.880	.067	.731	.968
18	.898	.064	.747	.971
19	.913	.058	.773	.974
20	.925	.053	.787	.971
21	.935	.048	.801	.977
22	.944	.044	.804	.981
23	.950	.041	.814	.988

¹Abundance was calculated according to equation (4). The lagging factors for each year are presented in Table 12.

Table A4. Sockeye salmon observed cumulative proportion of abundance¹ by calendar day for Nushagak Bay from 1959-1979 (excluding 1963 and 1970).

Date	\bar{x}	\hat{s}	Minimum	Maximum
June 15	.000	.000	.000	.001
16	.000	.001	.000	.002
17	.001	.001	.000	.003
18	.001	.001	.000	.004
19	.003	.003	.000	.011
20	.005	.006	.000	.019
21	.008	.009	.000	.030
22	.013	.014	.000	.042
23	.021	.021	.000	.058
24	.033	.034	.000	.109
25	.046	.048	.000	.154
26	.065	.063	.001	.204
27	.085	.082	.002	.259
28	.126	.111	.004	.345
29	.174	.145	.006	.493
30	.228	.178	.012	.610
July 1	.289	.188	.017	.676
2	.352	.190	.045	.707
3	.431	.191	.056	.758
4	.500	.197	.069	.808
5	.553	.201	.084	.850
6	.614	.189	.138	.859
7	.679	.159	.192	.866
8	.725	.144	.262	.871
9	.767	.127	.351	.890
10	.808	.116	.421	.913
11	.840	.103	.498	.941
12	.866	.085	.613	.959
13	.884	.076	.678	.973
14	.905	.066	.735	.981
15	.919	.061	.764	.988
16	.933	.050	.801	.994
17	.942	.046	.804	.998
18	.949	.041	.814	1.000
19	.954	.038	.830	1.000
20	.958	.037	.835	1.000
21	.961	.037	.837	1.000
22	.962	.037	.840	1.000
23	.964	.037	.841	1.000
24	.965	.037	.842	1.000

¹Abundance was calculated according to equation (4). The lagging factors for each year are presented in Table 12.

Table A5. Chum salmon cumulative catch proportions based on adjusted catch data.¹ Day 1 was defined as a local maximum rate of change of daily rate of change of observed daily catch. Data from 1960, 1966, 1969, 1971-1977.

Day	\bar{x}	\hat{s}	Minimum	Maximum
1	.023	.026	.002	.093
2	.042	.057	.004	.198
3	.065	.085	.005	.301
4	.079	.090	.006	.324
5	.111	.094	.009	.338
6	.157	.145	.010	.516
7	.192	.174	.011	.616
8	.222	.189	.015	.663
9	.246	.196	.021	.701
10	.269	.198	.029	.720
11	.298	.197	.036	.733
12	.321	.203	.045	.753
13	.355	.201	.107	.781
14	.408	.203	.155	.853
15	.454	.208	.201	.908
16	.493	.207	.247	.943
17	.541	.199	.293	.959
18	.578	.199	.339	.970
19	.632	.188	.385	.980
20	.697	.178	.431	.991
21	.746	.172	.477	.996
22	.780	.162	.522	.998
23	.816	.150	.557	1.000
24	.839	.140	.593	1.000
25	.852	.134	.618	1.000
26	.885	.134	.690	1.000
27	.898	.100	.722	1.000
28	.913	.090	.761	1.000
29	.925	.081	.790	1.000
30	.935	.074	.809	1.000

¹Catch was adjusted from catch reported by the Alaska Department of Fish and Game in their annual IBM reports. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table A6. Chum salmon cumulative proportions based on adjusted catch data.¹
 Data averaged by calendar date for 1960, 1966, 1969, 1971-1977.

Date	\bar{x}	\hat{s}	Minimum	Maximum
June 14	.000	.000	.000	.001
15	.000	.001	.000	.002
16	.001	.003	.000	.008
17	.002	.005	.000	.017
18	.004	.009	.000	.028
19	.008	.013	.000	.038
20	.012	.018	.000	.046
21	.018	.024	.000	.065
22	.027	.032	.000	.086
23	.036	.039	.000	.107
24	.046	.047	.000	.128
25	.056	.056	.000	.149
26	.080	.075	.001	.195
27	.096	.091	.001	.271
28	.114	.112	.001	.347
29	.142	.135	.001	.424
30	.173	.139	.001	.447
July 1	.206	.140	.001	.466
2	.233	.140	.001	.480
3	.267	.149	.001	.532
4	.311	.157	.001	.571
5	.350	.169	.001	.595
6	.386	.181	.001	.645
7	.419	.195	.002	.666
8	.455	.215	.002	.748
9	.501	.200	.093	.795
10	.560	.176	.198	.825
11	.615	.163	.301	.860
12	.659	.161	.324	.876
13	.700	.157	.338	.890
14	.758	.112	.515	.900
15	.798	.084	.616	.908
16	.840	.082	.662	.940
17	.873	.079	.701	.954
18	.892	.078	.720	.965
19	.909	.073	.733	.974
20	.921	.069	.753	.984
21	.931	.063	.781	.987
22	.954	.040	.853	.990
23	.966	.025	.908	.992

¹Catch was adjusted from catch reported by the Alaska Department of Fish and Game in their annual IBM reports. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of probable catch.

Table A7. Pink salmon cumulative proportions of abundance.¹ Day 1 was defined as a local maximum rate of change of daily rate of change of observed daily abundance. Data from 1960-1978.

Day	\bar{x}	\hat{s}	Minimum	Maximum
1	.041	.020	.0166	.0789
2	.063	.032	.0244	.1216
3	.088	.042	.0319	.1675
4	.134	.047	.0543	.1788
5	.197	.057	.0961	.3244
6	.265	.071	.1501	.4195
7	.326	.075	.2150	.4742
8	.391	.083	.2733	.5634
9	.444	.094	.2964	.6295
10	.500	.091	.3389	.6559
11	.557	.085	.3844	.6853
12	.613	.099	.4121	.7333
13	.664	.111	.4365	.8016
14	.706	.112	.4681	.8496
15	.739	.114	.5145	.8370
16	.771	.116	.5548	.8976
17	.797	.103	.6205	.9077
18	.823	.088	.6748	.9139
19	.851	.074	.7160	.9311
20	.871	.066	.7479	.9420
21	.884	.063	.7628	.9491
22	.894	.060	.7777	.9539
23	.906	.058	.7889	.9635
24	.916	.056	.8016	.9720

¹Abundance was calculated according to equation (4). The lagging factors for each year are presented in Table 12.

Table A8. Pink salmon observed cumulative proportion of abundance.¹ Data averaged by calendar day from 1960 to 1978.

Date	\bar{x}	\hat{s}	Minimum	Maximum	
July	1	.0001	.0003	.000	.001
	2	.0003	.0007	.000	.002
	3	.0003	.0007	.000	.002
	4	.0004	.0011	.000	.003
	5	.0007	.0015	.000	.005
	6	.0019	.0025	.000	.007
	7	.0035	.0045	.000	.014
	8	.0056	.0065	.000	.021
	9	.0086	.0084	.000	.028
	10	.0113	.0107	.000	.036
	11	.0138	.0127	.000	.043
	12	.0196	.0159	.000	.051
	13	.0279	.0241	.000	.069
	14	.0374	.0346	.001	.103
	15	.0526	.0468	.005	.130
	16	.0834	.0693	.010	.197
	17	.1231	.0989	.014	.294
	18	.1628	.1222	.020	.359
	19	.2126	.1337	.028	.413
	20	.2679	.1471	.038	.483
	21	.3250	.1587	.055	.542
	22	.3743	.1554	.104	.590
	23	.4263	.1570	.170	.659
	24	.4766	.1611	.251	.720
	25	.5274	.1532	.330	.767
	26	.5944	.1356	.411	.821
	27	.6530	.1336	.516	.870
	28	.7025	.1227	.541	.889
	29	.7437	.1043	.590	.897
	30	.7700	.1015	.597	.917
	31	.7896	.0998	.607	.925
August	1	.8140	.0918	.629	.929
	2	.8365	.0811	.675	.930
	3	.8628	.0668	.759	.934
	4	.8820	.0616	.799	.952
	5	.8932	.0597	.804	.968
	6	.9030	.0578	.813	.983
	7	.9116	.0554	.820	.989
	8	.9185	.0530	.827	.991
	9	.9253	.0513	.836	.992

¹Abundance was calculated according to equation (4). The lagging factors for each year are presented in Table 12.

Table A9. Coho salmon cumulative catch proportions based on adjusted catch data.¹ Day 1 was defined as a local maximum rate of change of daily rate of change of observed daily abundance. Data from 1966-1969 and 1971-1977.

Day	\bar{x}	\hat{s}	Minimum	Maximum
-1	.0053	.0060	.0015	.0075
0	.0095	.0062	.0037	.0089
1	.0283	.0164	.0100	.0595
2	.0443	.0212	.0132	.0772
3	.0524	.0228	.0192	.0876
4	.0659	.0337	.0192	.1313
5	.1024	.0683	.0283	.2781
6	.1360	.0887	.0530	.3360
7	.1750	.0834	.0897	.3736
8	.2076	.0794	.0979	.3780
9	.2393	.0810	.1061	.3954
10	.2790	.1024	.1143	.4654
11	.3068	.1131	.1243	.5073
12	.3751	.0983	.1710	.5487
13	.4294	.1057	.1947	.5893
14	.4637	.0838	.3310	.6394
15	.5064	.1042	.3431	.6543
16	.5772	.1385	.3621	.8064
17	.6359	.1579	.4197	.8044
18	.6691	.1564	.4685	.9746
19	.6925	.1516	.4744	.9862
20	.7611	.1343	.5703	.9907
21	.7983	.1256	.6172	.9908
22	.8359	.0952	.6938	1.0000
23	.8878	.0661	.8106	1.0000
24	.8988	.0638	.8178	1.0000
25	.9074	.0643	.8178	1.0000
26	.9125	.0650	.8182	1.0000
27	.9291	.0598	.8199	1.0000
28	.9420	.0592	.8202	1.0000
29	.9538	.0582	.8204	1.0000
30	.9621	.0537	.8253	1.0000
31	.9685	.0513	.8260	1.0000
32	.9738	.0498	.8280	1.0000
33	.9816	.0403	.8627	1.0000
34	.9960	.0076	.9765	1.0000

¹ Catch was adjusted from catch reported by the Alaska Department of Fish and Game in their annual IBM reports. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.

Table A10. Coho salmon cumulative catch proportions based on adjusted catch data.¹ Data averaged by calendar date from 1966-1969 and 1971-1977.

Date	\bar{x}	\hat{s}	Minimum	Maximum	
July	16	.001	.002	.000	.008
	17	.003	.004	.000	.011
	18	.009	.013	.000	.033
	19	.012	.017	.000	.047
	20	.017	.018	.001	.058
	21	.029	.026	.002	.072
	22	.046	.042	.003	.152
	23	.066	.051	.019	.201
	24	.092	.055	.028	.222
	25	.133	.084	.043	.278
	26	.157	.095	.048	.336
	27	.174	.107	.050	.374
	28	.199	.105	.053	.378
	29	.266	.103	.119	.398
	30	.331	.117	.123	.411
	31	.369	.118	.128	.545
August	1	.394	.127	.138	.551
	2	.423	.125	.154	.589
	3	.466	.134	.171	.639
	4	.529	.153	.195	.749
	5	.599	.163	.331	.806
	6	.667	.186	.343	.956
	7	.702	.184	.362	.975
	8	.758	.161	.420	.986
	9	.784	.158	.477	.991
	10	.800	.145	.535	.991
	11	.821	.141	.592	1.000
	12	.850	.120	.650	1.000
	13	.898	.080	.746	1.000
	14	.917	.066	.820	1.000
15	.927	.064	.820	1.000	
16	.932	.066	.820	1.000	
17	.941	.063	.825	1.000	
18	.948	.061	.826	1.000	
19	.958	.061	.828	1.000	
20	.966	.052	.863	1.000	
21	.982	.029	.899	1.000	
22	.988	.020	.933	1.000	
23	.993	.011	.966	1.000	
24	1.000	.000	1.000	1.000	

¹ Catch was adjusted from catch reported by the Alaska Department of Fish and Game in their annual IBM reports. For days closed to fishing the catch prior to and following the closure was averaged to provide an estimate of the probable catch.