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NUSHAGAK BAY SALMON FISHERY MODEL

by

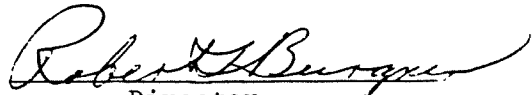
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FINAL REPORT

for the period October 1, 1979 to March 31, 1980
Alaska Department of Fish and Game
Contract No. 80-267

Approved

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Director

PREFACE

On April 1, 1979, a six-month contract was initiated with Alaska Department of Fish and Game entitled: Nushagak Bay Salmon Fishery Model. This contract served as the first step in a three-year project designed to produce a realistic model of the Nushagak salmon fishery which resource managers can use to evaluate harvest strategies. The results of the first contract were reported in a University of Washington circular, FRI-UW-7926.

A second contract with Alaska Department of Fish and Game was executed for the period October 1, 1979 through March 30, 1980. Because of the extensive work commitment of the first contract, the first three months of the new contract were devoted to preparing the first contract report. During the final three months, the following work pertaining to the contract was undertaken:

1. About 25 percent of the time was spent studying past computer output from work with the Bristol Bay data base and becoming familiar with the data base.
2. Work on all of the objectives specified in the contract was initiated, which meets the intent of the contract since the objectives were broad and comprehensive. Progress on the model simulation procedure was confined to consideration of a few techniques. Since the progress for this objective was minimal, it will not be addressed specifically in this report.

Objectives of this contract:

1. To initiate a search of available data concerning abundance, distribution, and timing of salmon stocks other than sockeye returning to Nushagak Bay.

Accomplishments:

- A. Examined and condensed catch data for king, chum, and pink salmon.
 - B. Reviewed escapement, fishing effort, age, and sex data for king, chum, and pink salmon.
2. To refine the intraseason abundance estimation procedure for Nushagak Bay sockeye salmon.

Accomplishments:

- A. Calculated migratory time density functions¹ based on the normal probability density functions for the Nushagak District and Wood, Igushik, and Nuyakuk Rivers.
- B. Calculated probability of occurrence of the mean of the migratory time density on a particular day for the migration to the Nushagak District, the Wood, Igushik, and Nuyakuk Rivers.
- C. Defined the variance of the mean of the migratory time densities for sockeye returning to the Nushagak District, Wood River, Igushik River, and Nuyakuk Rivers.
- D. Discussed techniques for improving the timeliness of the intraseason abundance estimates based on catch and

¹Migratory time density theory relies on the inherent tendency for a particular animal species to move past a fixed location at a fixed time. Mundy (1979) defined migratory time densities as follows: "The probability of occurrence of any time unit during the migration is specified by the proportion of the population which occurs during the time unit as measured from a fixed location."

escapement data.

E. Calculated daily and annual exploitation rates.

3. To initiate and/or refine the abundance estimation procedures for Nushagak Bay king, chum, and pink salmon.

Accomplishments:

Developed preliminary abundance estimation procedures for king, chum, and pink salmon.

4. To develop a model simulation procedure to determine accuracy of the abundance estimation procedure outlined in objectives 2 and 3.

Accomplishments:

Briefly reviewed simulation procedures.

5. To develop a flow chart that outlines a decision-making model for a multi-species salmon fishery.

Accomplishments:

- A. Prepared a flow-chart defining policy and harvest-control decisions.
- B. Discussed policy and harvest-control decisions.

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BACKGROUND

Among the world's salmon fisheries, those of Alaska and specifically of Bristol Bay are among the largest and best-researched in the world. The Bristol Bay fishery is composed of five fishing districts. The Nushagak Bay fishery has the widest diversity of species harvested and is the largest salmon fishery of Bristol Bay, except for cyclical extremes of abundance of sockeye salmon migrating to the Kvichak River. As with many fisheries, the Nushagak Bay salmon fishery has declined drastically since the turn of the century. Because of the decline in the 1940's a rigorous research program was developed by the Fisheries Research Institute, College of Fisheries, University of Washington, with financial support from the salmon industry in Bristol Bay. Therefore there is a data base of extraordinarily high quality and detail to provide a rational basis for salmon management.

Management of salmon in Nushagak Bay, Alaska, means harvest control of five species of salmon: king, sockeye, 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. sockeye 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 gillnets currently fished may prevent such considerations from having practical application.

The overall objective for work associated with the Nushagak Bay Salmon Model is to define and quantify the elements of harvest control decisions and to automate the decision-making process. The output from the automatic process should be a recommendation to open or close the fishery with the risks of such a decision clearly defined.

The key element for harvest-control decisions for sockeye salmon is an accurate knowledge of the abundance of fish returning to a specific fishing district and ideally to the individual river systems. Until 1979, the only estimate of abundance available was long-range forecasts. From 1955 through 1977, the accuracy of the forecasted returns ranged from approximately .5 to 2 times the observed return. During 1979, development of an intraseason abundance estimation procedure for Nushagak Bay sockeye salmon was initiated to reduce the variance of the total abundance estimate and provide estimates of daily abundance. This estimation process must be refined and abundance estimates for species other than sockeye developed. Given accurate estimates of abundance, the other elements of the decision-making process can be readily defined.

OBJECTIVE 1: REVIEW OF AVAILABLE
SALMON DATA FOR NUSHAGAK BAY

Introduction

An excellent data base has been developed by the Fisheries Research Institute of the University of Washington and the Alaska Department of Fish and Game for Bristol Bay salmon. Although the emphasis has been placed on sockeye salmon, data for other species is available. Much of the sockeye salmon data have been computerized (Knudsen, Poe, and Mathisen 1972, and Mundy and Mathisen 1977). Rogers (1974) developed a list of 23 publications and over 250 notes, circulars, reports, or theses that have been prepared for Nushagak Bay. Nelson (1979) listed 73 Bristol Bay Data Reports. In addition to data compiled in publications, xerox copies of unpublished data deposited in the Dillingham office of Alaska Department of Fish and Game were made.

Results

The emphasis of this objective was to review data for species other than sockeye salmon. As an initial step, catch statistics for king, sockeye, chum, and pink salmon were examined. Data for coho salmon were not studied extensively because of the limited nature of the fishery. The smallest catch of 2,851 coho salmon occurred during 1965 while the largest catch of 48,867 occurred in 1968.

Catch statistics for king, sockeye, chum, and pink salmon were compiled for Nushagak Bay from the late 1890's by Alaska Department of Fish and Game (ADF&G). ADF&G has also prepared weekly catch statistics for king (since 1958), sockeye (since 1960), chum (since 1960), and pink (since 1958). All

these data will eventually be incorporated into individual data files.

Generally speaking, king salmon enter Nushagak Bay first, followed by sockeye salmon, which overlap considerably with chum salmon (Tables 1-3). Finally, pink salmon return to Nushagak Bay; however, the pink salmon run is only of large magnitude during even numbered years (Table 4).

The mode of the king salmon catch varied from June 15 to June 29 (Table 1). The earliest catches of king salmon were reported on May 25. The harvest lasted from 9 to 13 weeks. Annual catches ranged from 21,454 in 1975 to 87,547 in 1970. The majority of catches exceeded 45,000 fish.

The mode of the sockeye salmon catch varied from June 30 to July 10 (Table 2). The earliest catches of sockeye salmon were reported on May 31. The harvest generally lasted from 8 to 12 weeks. Catches ranged from 272,093 in 1973 to 1,517,988 in 1960. The majority of catches exceeded 500,000 fish.

The mode of the chum salmon catch varied from June 22 to July 20 (Table 3). The earliest catches of chum salmon were reported on June 1. The harvest generally lasted from 8 to 13 weeks. Catches ranged from 129,344 in 1966 to 801,064 in 1976. The majority of catches exceeded 200,000 fish.

The mode of the pink salmon catch varied from July 21 to August 4 (Table 4). The earliest catches of pink salmon were reported on June 10. The harvest generally lasted from 3 to 10 weeks. Catches ranged from 67,953 in 1972 to 2,337,066 in 1966. The majority of catches exceeded 400,000 fish.

Table 1. Historic catch distribution of king salmon for Nushagak Bay, Alaska.¹

Year	Range		No. weeks	Annual catch
	Mode (End of week)	Dates		
1960	6/22	6/01 - 8/17	11	81,416
1961	6/15	5/29 - 8/19	11	60,953
1962	6/22	6/02 - 8/11	10	61,283
1963	6/22	6/08 - 8/17	10	45,979
1964	6/22	6/08 - 8/08	9	108,606
1965	6/22	5/31 - 7/31	9	85,910
1966	6/22	6/06 - 8/06	9	58,184
1967	6/22	5/29 - 8/12	11	96,240
1968	6/15	5/27 - 8/19	12	78,201
1969	6/22	5/26 - 8/23	13	80,803
1970	6/22	5/25 - 8/11	11	87,547
1971	6/29	5/31 - 8/07	10	82,769
1972	6/29	6/01 - 8/19	13	46,045
1973	6/22	6/02 - 8/18	11	30,470
1974	6/15	6/01 - 8/10	10	32,053
1975	6/22	6/01 - 8/10	10	21,454
1976	6/22	5/31 - 8/28	13	60,682

¹Condensed from Alaska Department of Fish and Game, Bristol Bay Data Management Reports.

Table 2. Historic catch distribution of sockeye salmon for Nushagak Bay, Alaska.¹

Year	Mode (End of week)	Range		Annual catch
		Dates	No. weeks	
1960	7/05	6/01 - 8/17	11	1,517,988
1961	7/05	6/01 - 8/26	12	511,453
1962	7/05	6/04 - 8/11	10	1,432,079
1963	7/10	6/22 - 8/31	10	818,071
1964	7/05	6/20 - 8/15	8	1,380,314
1965	7/10	5/31 - 7/31	9	793,323
1966	7/10	6/06 - 8/27	12	1,170,271
1967	6/30	5/29 - 8/12	11	657,711
1968	6/30	6/03 - 8/17	10	749,281
1969	7/05	6/09 - 8/23	10	773,207
1970	7/05	6/08 - 8/11	9	1,188,524
1971	7/10	6/14 - 8/14	9	1,256,799
1972	7/10	6/01 - 8/12	12	381,347
1973	7/05	6/02 - 8/25	12	272,093
1974	7/05	6/01 - 8/10	10	510,571
1975	7/10	6/14 - 8/16	9	645,902
1976	7/05	6/07 - 8/28	12	1,265,424

¹Condensed from Alaska Department of Fish and Game, Bristol Bay Data Management Reports.

Table 3. Historic catch distribution of chum salmon for Nushagak Bay, Alaska.¹

Year	Mode (End of week)	Range		Annual catch
		Dates	No. weeks	
1960	7/06	6/06 - 8/17	10	642,099
1961	6/22	6/01 - 9/01	13	267,176
1962	7/13	6/04 - 8/18	10	280,886
1963	7/13	6/22 - 8/31	10	225,896
1964	7/06	6/20 - 8/15	8	442,773
1965	6/29	6/07 - 7/31	8	177,434
1966	7/13	6/13 - 8/06	8	129,344
1967	7/20	6/12 - 8/12	9	338,286
1968	7/06	6/08 - 8/17	11	178,786
1969	7/13	6/09 - 8/30	12	214,235
1970	7/06	6/08 - 8/11	9	435,033
1971	7/13	6/14 - 8/14	9	360,015
1972	7/13	6/01 - 8/19	11	310,126
1973	7/20	6/04 - 8/25	12	336,331
1974	7/13	7/13 - 8/17	11	157,941
1975	7/20	6/20 - 8/23	9	152,891
1976	6/29	6/17 - 8/28	10	801,064

¹Condensed from Alaska Department of Fish and Game, Bristol Bay Data Management Reports.

Table 4. Historic catch distribution of pink salmon for Nushagak Bay, Alaska.¹

Year	Mode (End of week)	Range		Annual catch
		Dates	No. weeks	
1960	7/28	7/03 - 8/17	6	289,781
1962	7/21	7/11 - 8/18	5	880,424
1964	7/28	7/10 - 8/15	5	1,497,817
1966	7/21	7/21 - 8/27	5	2,337,066
1968	7/21	7/10 - 8/17	5	1,705,150
1970	8/04	6/22 - 8/11	3	417,834
1972	7/21	6/19 - 8/19	9	67,953
1974	7/21	6/10 - 8/17	10	413,613
1976	7/21	6/22 - 8/28	9	739,590

¹Condensed from Alaska Department of Fish and Game, Bristol Bay Data Management Reports.

OBJECTIVE 2: INTRASEASON ABUNDANCE ESTIMATION
FOR SOCKEYE SALMON IN NUSHAGAK BAY

Introduction

Mundy and Mathisen (1978) developed a method based on migratory timing to estimate the daily abundance of sockeye salmon moving past a fixed locality. They estimated the necessary parameters by minimizing the squared difference between expected and observed data points. Such a process is questionable for abundance estimates based on catch and escapement data. Walters and Buckingham (1975) criticized the use of catch plus escapement to calculate total seasonal abundance for Skeena River sockeye and found it to be lacking since acceptable accuracy was not attained until 60 percent of the run had occurred. However, Hornberger, Mundy and Mathisen (1979) provided evidence that intraseason abundance estimation based on catch plus escapement data can be employed to estimate total abundance early enough to aid managers in deciding whether or not to allow fishing.

Methods

With refinements of the estimation process it is possible that daily estimates of total abundance based on catch and escapement data can be substantially improved. The potential for improving the timeliness of the estimates depends upon two adjustments to the estimation process.

First, the primary input into the abundance estimates is the cumulative observed run size. This information lags two to three days behind the fishery because of swimming time from the fishery past a counting tower or an indexing location. That is, the estimated time required for sockeye salmon to swim

past the Wood River counting tower, the Igushik River inside test-fishing project, or the Nushagak River sonar project is two to three days. To overcome this time delay it is possible to estimate the run size on any given day if exploitation rates are known, as follows:

$$\hat{N} = \frac{C}{u} \quad (1)$$

where N represents abundance
 C represents catch
 u represents exploitation rate

$$u_1 = \frac{C_K}{N_K} \quad (2)$$

where C_K represents total catch during year K
 N_K represents total abundance during year K
 or

$$u_2 = \frac{C_i}{N_i} \quad (3)$$

where $N_i = C_i + \sum E_{ij}$
 N_i represents abundance on day i
 C_i represents catch on day i
 E_{ij} represents escapement on day i in river j

$$i = d_j - t_j$$

(assume a constant time for fish to migrate from the fishing district past a counting location)

t_j = the time needed for the fish to swim from the fishing district past the counting tower of the respective river j
 $t_j = 0$ when the fish were within the fishing district
 d_j = the day the fish swam past the counting tower

The accuracy of these estimates of daily abundance depends on the variance of the exploitation rates. Not only do exploitation rates vary from year to year (Table 5), they vary within a year (Appendix B). Since u_2 is a function of effort (f), the accuracy of \hat{N}_1 can be improved by predicting u_2 based on f .

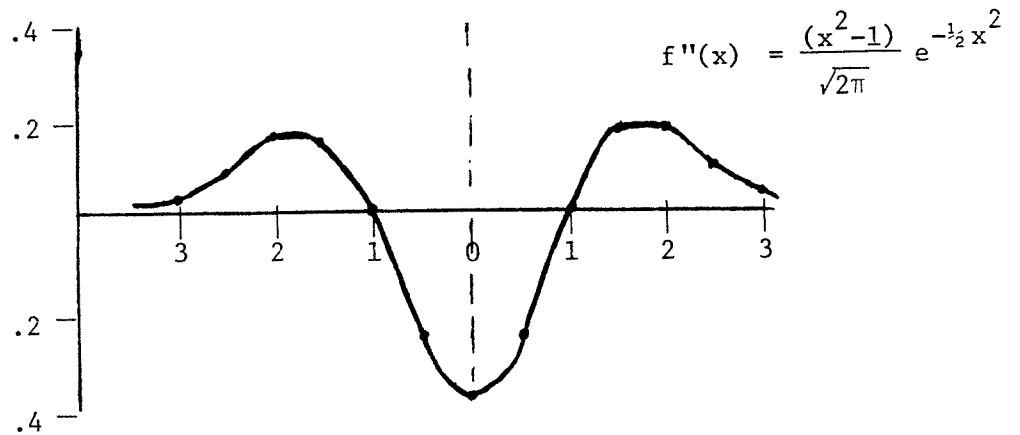
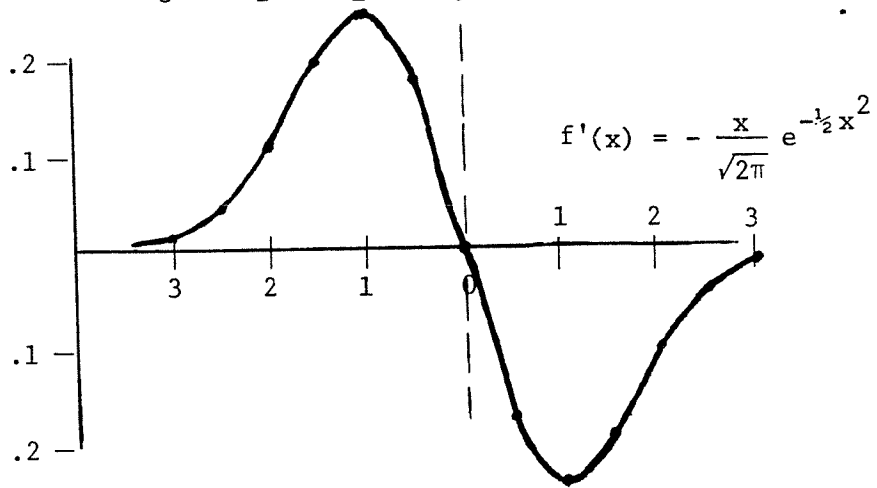
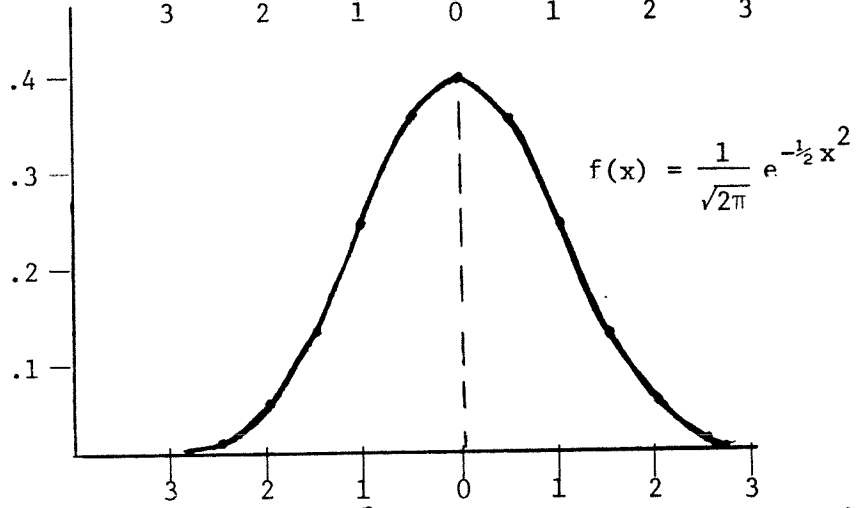
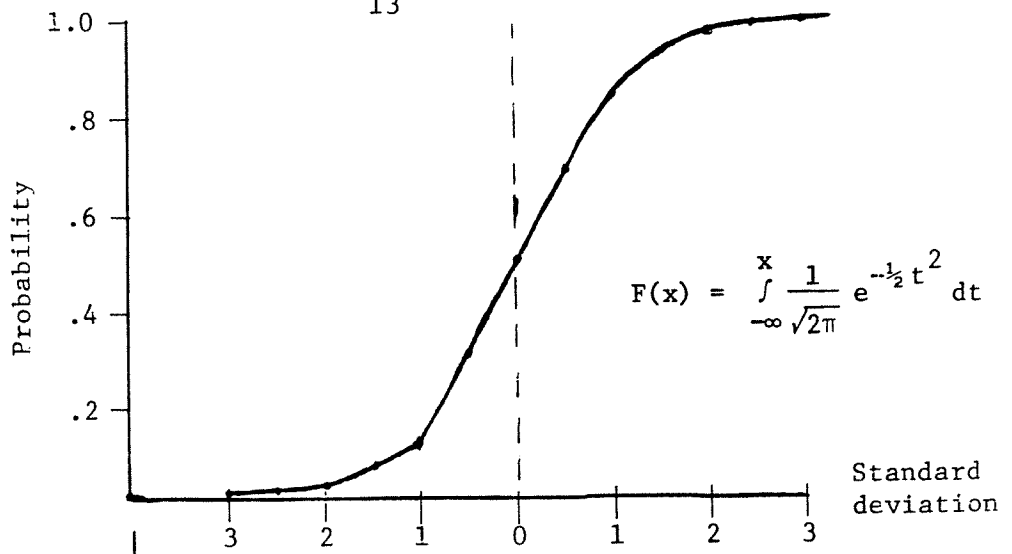
In addition to facilitating the estimation process by estimating daily abundance employing catch data and information concerning exploitation rates, the ambiguity of the procedure for minimizing the squared difference between expected and observed data points must be alleviated. To overcome this ambiguity critical points of the migration must be defined. Mundy (1979) was primarily concerned with identifying the mean of the run as the critical point for providing accurate estimates of abundance. This approach is not acceptable for abundance estimates based on catch and escapement data, since by the time the mean of the migration has occurred, over 50 percent of the fish will have escaped the fishery. Theoretically, the critical point that appears useful for this technique is to define $\max f''(x)$ where $F(x)$ is the cumulative normal probability function (Figure 1). Although the maximum value occurs at approximately the 5 percent point on the normal curve, defining this point from observed data is difficult because of errors associated with catch data, deviations of the observed data from the theoretical, and errors produced by inaccuracies of the procedure for lagging escapement to the catch to calculate daily abundance. However, the

Table 5. Exploitation rates for Nushagak Bay sockeye salmon.

Year	$u_1 = \frac{C_K}{N_K}$
1959	.372
1960	.478
1961	.375
1962	.612
1963	.461
1964	.519
1965	.428
1966	.426
1967	.445
1968	.444
1969	.391
1970	.338
1971	.494
1972	.423
1973	.349
1974	.187
1975	.221
1976	.471
1977	.391
1978	.489
1979	.527

$\bar{x} = .421$
 $s = .097$

Figure 1. The normal probability function and related functions.



intraseason identification of this critical point coupled with the minimization procedure should allow accurate timely estimates of abundance to be calculated.

Thus far the discussion has been centered on calculating total abundance for the entire Nushagak Bay district from migratory time densities. Migratory time density functions can also be estimated for each of the river systems and abundance estimates prepared. In order to calculate migratory time density statistics for each river system a procedure to allocate catch must be defined. The technique employed was based on apportionment of all catch according to the daily escapement to each river system (Hornberger, Mundy, and Mathisen 1979). This procedure assumes that the catch from river system j on day i , C_{ij} , is proportional to daily escapement, E_{ij} . The proportionality factor is the ratio of the escapement to river j on day i , E_{ij} , to the total daily escapement to all rivers, E_i .

Symbolically

$$C_{ij} = C_i \cdot \frac{E_{ij}}{E_i} \quad (6)$$

Once the catch was apportioned to the respective river systems, the escapement for that day (E_{ij}) was added to the catch C_{ij} to establish the daily abundance as follows:

$$N_{ij} = (C_{ij} + E_{ij}) \quad (7)$$

where N_{ij} = abundance associated with river j on day i

C_{ij} = catch associated with river j on day i

$i = d_j - t_j$

The E_{ij} were based on counts from counting towers on each of the rivers. The basis for determining time (t) between the fishing district and counting towers for each river was tagging studies conducted by ADF&G and represents a mean migratory time in days (McBride 1978, 1979; Mills 1979; Pahlke 1979).

$$n(x; \bar{x}, s^2) = \frac{1}{s\sqrt{2\pi}} e^{-\frac{1}{2} \frac{(x-\bar{x})^2}{s^2}} \quad (8)$$

where n represents normal distribution

x represents day of the migration

\bar{x} represents the mean day of the migration

s^2 represents the variance in days of the migration

Results and Discussion

The means and variances of the migratory time density statistics are very similar across the years observed (Table 6). The mean of the means and the variance of the means for the migratory time densities of the return to the entire district and individual river systems are qualitatively very similar (Table 7). The Nuyakuk migration appears to be the earliest followed by the Igushik and then the Wood River return (Table 7). There is considerable variability in the mean date of the migration (Table 8). The variance of the mean is highest for the Nuyakuk. The large variance in migratory timing could reflect stocks depleted by overharvest or be related to the smaller abundance or the longer migration from the fishery to the tower. The migratory time densities for Igushik are the next most variable, while the Wood River appears to be the most stable. It is interesting to note that the

Table 6. Migratory time density statistics for Nushagak Bay.

Year	Migratory time densities							
	Nushagak District		Wood ² River		Igushik ² River		Nuyakuk ² River	
	\bar{x}^1	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	18.68
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 \bar{x} represents the mean day of the migration with day 1 = June 15, 2 = June 16, etc.

²Daily catch was allocated to each of the river systems based on daily proportions of escapement.

Table 7. Means of migratory time density statistics for Nushagak Bay.

Year	Nushagak District	Wood River	Igushik River	Nuyakuk River
\bar{x}	21.30	22.15	20.72	20.23
$s_{\bar{x}}$	2.26	2.67	3.05	3.62
$s_{\bar{x}}^2$	5.09	7.12	9.32	13.07

Table 8. Probability of occurrence of the mean of the migratory time density on a particular day.

Date	Day	Nushagak District		Wood River		Igushik River		Nuyakuk River	
		No.	Prop.	No.	Prop.	No.	Prop.	No.	Prop.
6/29	14					1	.048	1	.048
6/30	15							2	.095
7/01	16							2	.095
7/02	17			1	.048	2	.095		
7/03	18	3	.143					1	.048
7/04	19	2	.095	2	.095	5	.238	1	.048
7/05	20	1	.048	2	.095	2	.095	3	.143
7/06	21	4	.190	2	.095	3	.143	3	.143
7/07	22	7	.333	7	.333	2	.095	4	.190
7/08	23	2	.095	2	.095	2	.095	1	.048
7/09	24	1	.048	2	.095	2	.095	1	.048
7/10	25			1	.048	1	.048	1	.048
7/11	26								
7/12	27	1	.048	1	.048			1	.048
7/13	28					1	.048		
7/14	29			1	.048				

migratory time densities for fish returning to Nushagak Bay are less variable than the migratory time densities for fish returning to an individual river system. The stability of the migratory time densities for the Wood River could reflect the fact that the Wood River system produces the most sockeye salmon in Nushagak Bay.

The day of occurrence of the mean of the migratory time densities for Nushagak Bay has become more variable since 1966 (Figure 2). This is especially reflected by changes in the mean of the migratory time density for sockeye salmon returning to the Wood River system (Figure 3). The means for the Igushik and Nuyakuk Rivers also reflect this increase in variability (Figures 4 and 5).

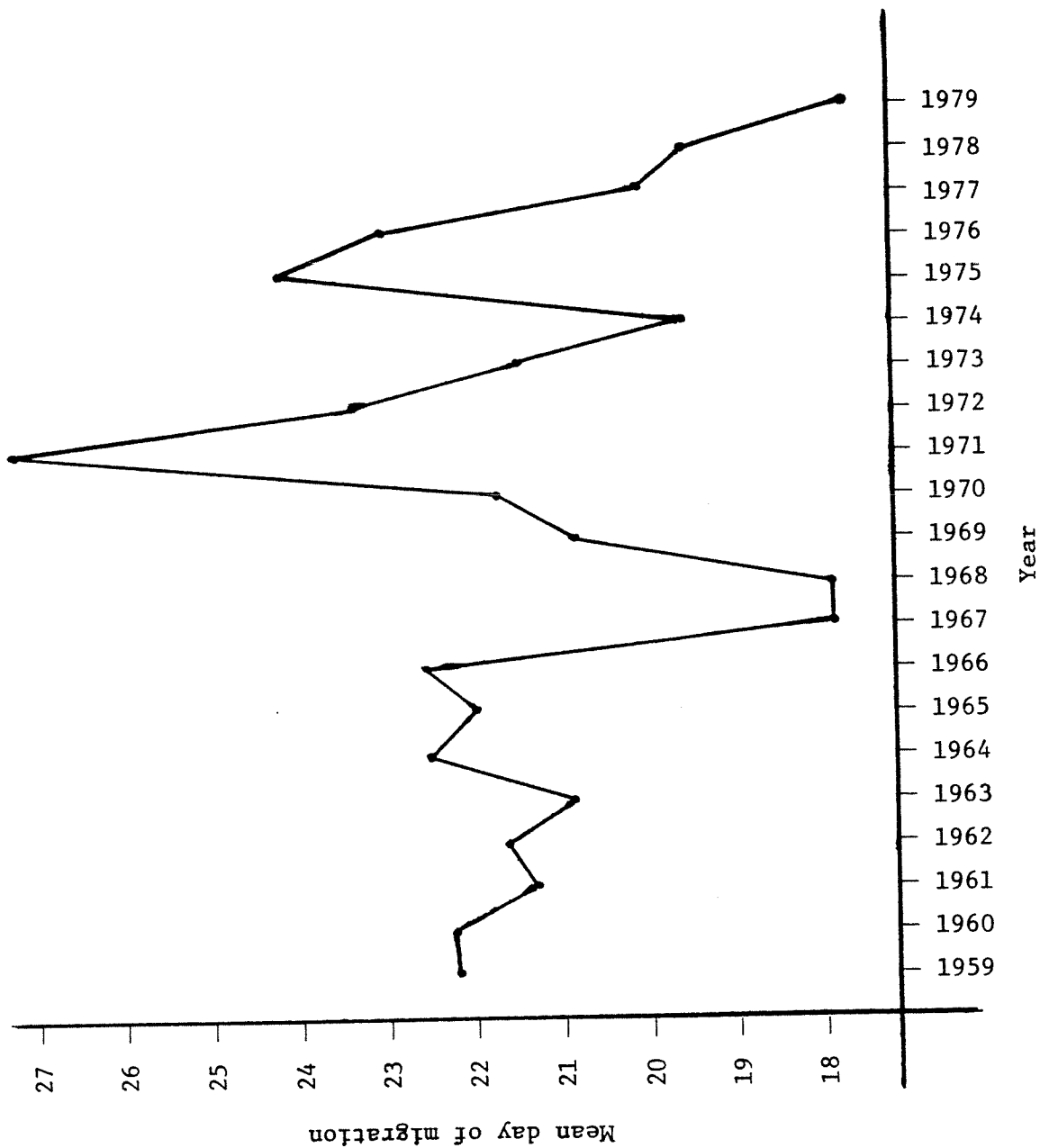


Figure 2. Mean day of migration for sockeye salmon returning to the Nushagak District.

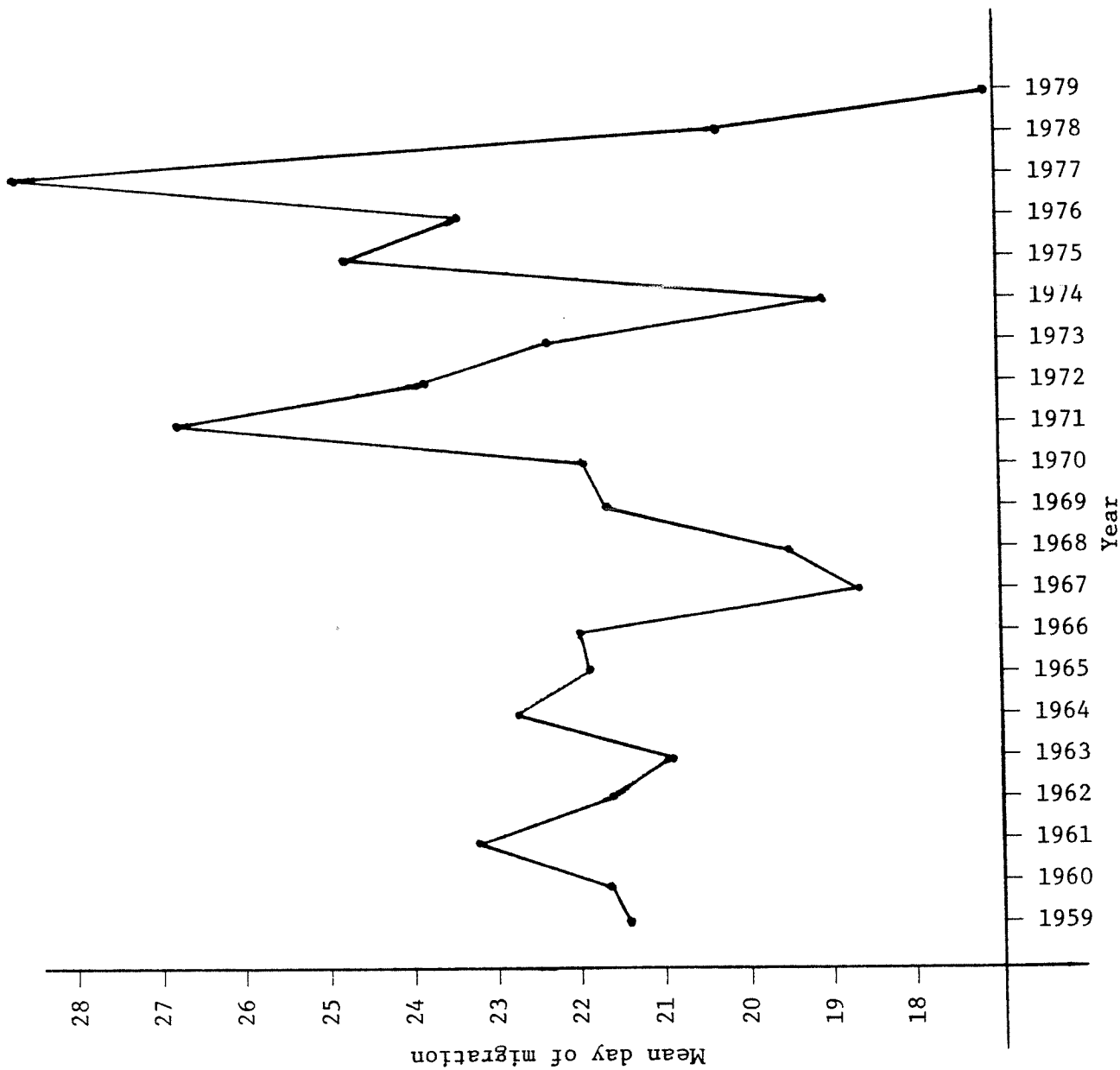


Figure 3. Mean day of migration for sockeye salmon returning to Wood River.

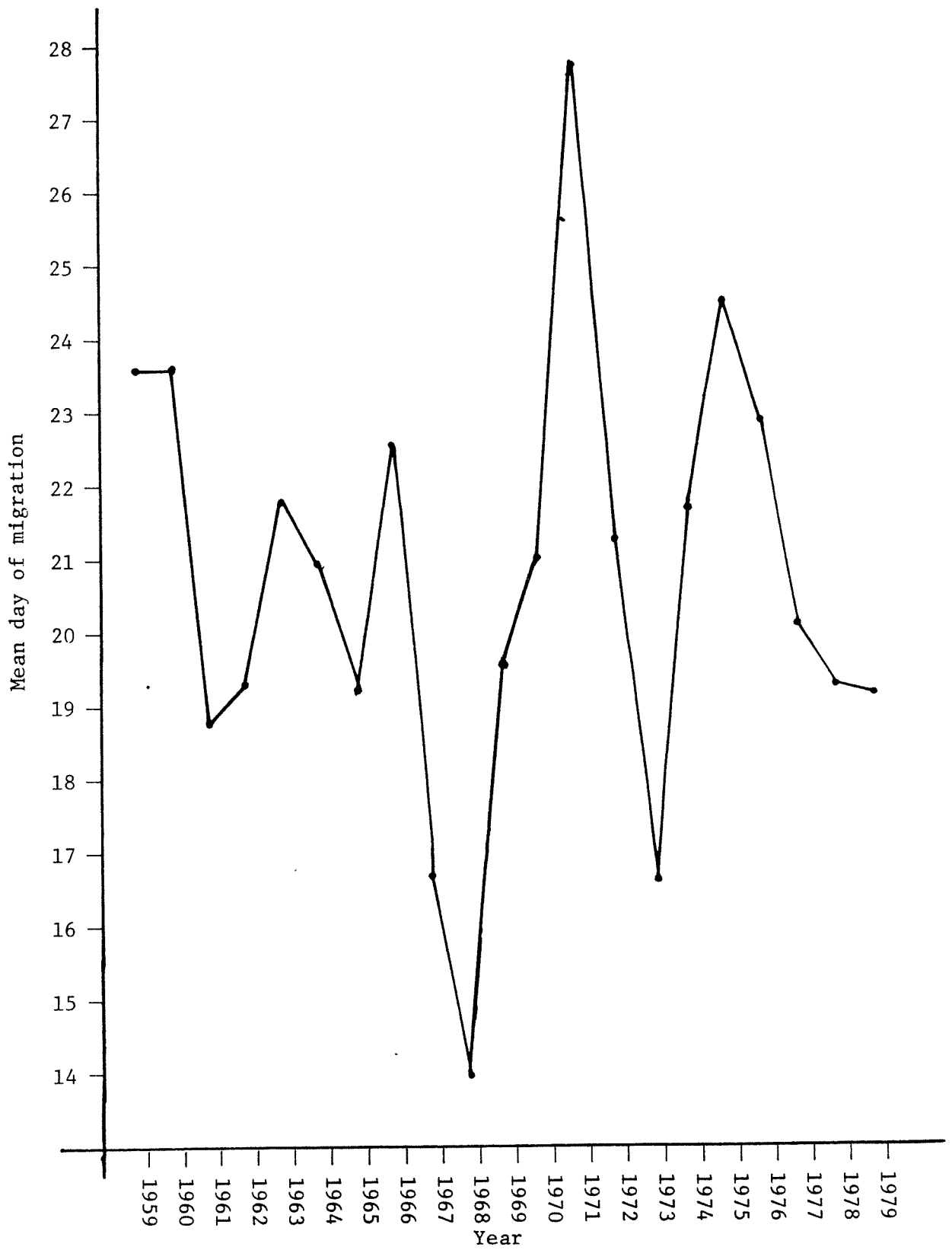


Figure 4. Mean day of migration for sockeye salmon returning to Igushik River.

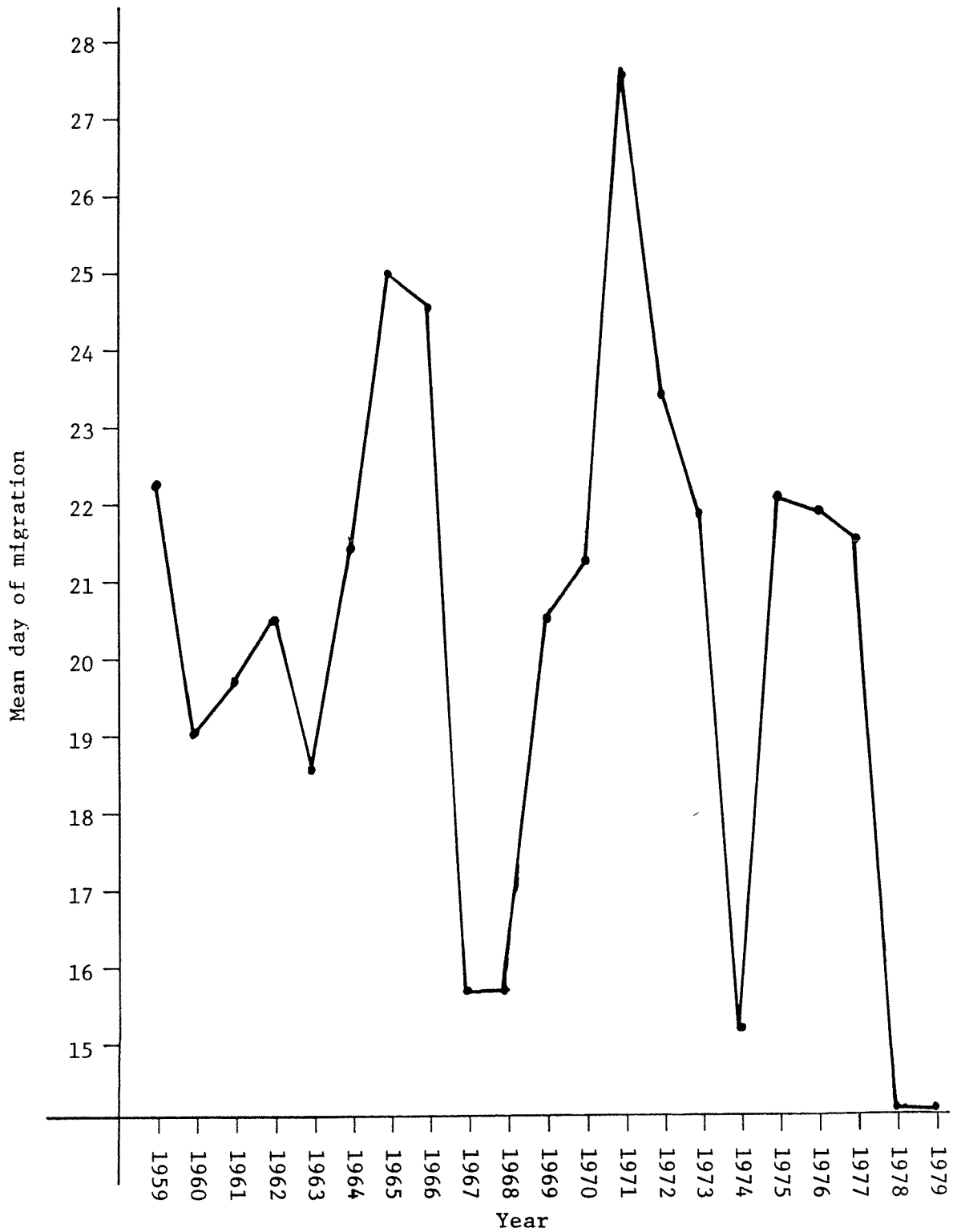


Figure 5. Mean day of migration for sockeye salmon returning to Nushagak Bay.

ABUNDANCE ESTIMATION FOR KING, CHUM, AND PINK SALMON

Introduction

An estimate of the daily abundance of salmon returning to Nushagak Bay requires knowledge of the migratory timing or exploitation rate of the species in order for total abundance estimation to be practical. The data for sockeye salmon are especially strong because an accurate estimate of daily escapement is available from the counting towers on all major river systems. Such counts, coupled with catch information, can serve as the basis for an accurate estimate of total abundance (Mundy 1979). Unfortunately such data are not consistently available for the other species, the majority of which migrate to and spawn in the Nuyakuk or Nushagak-Mulchatna River system.

King Salmon

King salmon are the first salmon to enter Nushagak Bay. Accurate catch and effort statistics are available. From these data, percentage catch by day can be calculated and catch estimates generated by procedures similar to those of Mundy (1979) and Hornberger, Mundy, and Mathisen (1979). Employing catch information weakens the abundance estimation process because migratory time densities are only truly attributes of the population and not of the catch. In a situation of constant effort the curves based on catch are the same as those based on measures of the population. In cases where effort is not constant, CPUE data can be employed to calculate curves characteristic of the population. In addition, estimates of abundance can be calculated directly from CPUE data as follows:

$$C = F \bar{N} = q f \bar{N}$$

$$\frac{C}{f} = q \bar{N} \text{ where } q \text{ is a function of mesh size and fish size.}$$

Unfortunately, catchability (q) varies with gear. As a result, CPUE data from the fishery must be standardized. Calculating the catchability coefficient q to relate gill net CPUE data to total abundance is weak because of poor estimates of escapement. Only total escapement estimates can be conducted because the mid-stream migratory habits of king salmon, coupled with poor visibility in the Nushagak River, make daily enumeration difficult. As a result, tower counts from the Nushagak are questionable. Spawning escapements generated from aerial surveys are weak because not all the streams are flown consistently, and weather conditions and water color affect the ability to count the fish.

Chum Salmon

Chum salmon are taken concurrently with sockeye salmon in the Nushagak district. Although chum size is much more uniform than king salmon size, the problems of abundance estimation are the same. The techniques to be considered are the same except Port Moller gill net indices could be employed to estimate total return to Nushagak Bay. Instituting such a program should be relatively simple since ADF&G has already compiled data comparing seasonal catches and adjusted indices from the Port Moller offshore test fishing program for chum salmon from 1968-1978. The limitations of data are the same except that some fish do swim past the Nuyakuk tower.

Pink Salmon

Of the species other than sockeye salmon, migratory time density functions can best be applied to pink salmon because the majority of Nuyakuk River pink salmon swim past the Nuyakuk River counting tower to the upper portion of

the Nuyakuk and Tikchik Rivers. The problems of abundance estimation are the same for pink salmon as for other species.

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.

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 elements of the decision-making process involve policy decisions as well as goals specific for intraseason management (Figure 6). The intraseason goals may be established in terms of fixed escapement goals by species for each river system or a specified harvest level. The constraints on these goals, biological, sociological, political and economic, must be fixed in advance of

P O L I C Y

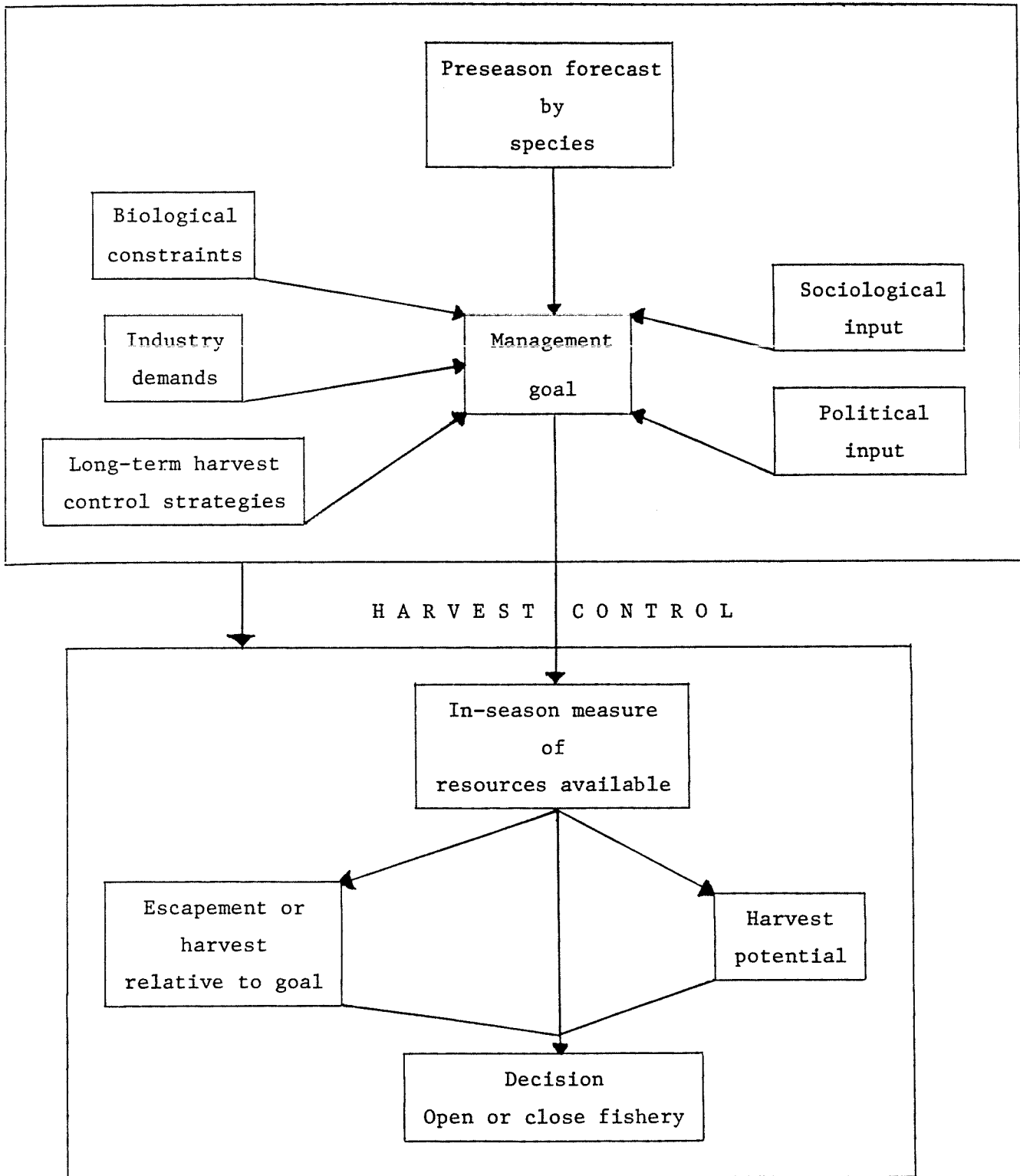


Figure 6. Flow chart for policy and harvest control decisions for salmon fisheries managers.

the actual salmon migration. Essential biological constraints serve as bounds that guarantee the survival of the population and perpetuate an economically viable industry. Peterman (1975) outlined a conceptual model employed by a manager when considering policy decisions and also described a procedure to aid managers in formulating policy. The emphasis for the decision-making model to be developed under contract with the Alaska Department of Fish and Game, however, will be intraseason harvest control. The work of Walters and Buckingham (1975) is perhaps the most directly related to this aspect of the proposed work. They attempted to quantify the conceptual model that the resource manager for the Skeena River employed to open and close the fishery. The questions that they asked were, "Can the control system meet overall target exploitation rates for most input situations, and does it result in a smooth sequence of exploitation rates across each season?" While they concluded that there appeared to be as much variability between the model as actual management practice in achieving a given exploitation rate relative to a given population size, they did state, "In terms of within-season stability of exploitation rates, the proposed control system does appear to be better than the intuitive system now used." Unlike Walters and Buckingham (1975), who questioned the importance of accurate pre-season forecasts of abundance to develop their model, the proposed model will rely on an accurate intra-season estimate of run size as an essential ingredient in the decision-making model.

The division between overall policy and intraseason harvest control is critical to providing effective management of the resource. Decisions of policy are complex and a variety of inputs must be examined and weighed to develop responsible long-term strategies. Such complex issues involve input from numerous sources and as such are time-consuming to prepare. Intraseason

decisions, however, must be aimed at delivering a predetermined goal and be relatively inflexible to last-minute changes because of the short duration of the run and complexity of information produced during the migration. It is possible that specific harvest goals can be adjusted for a given species if the observed abundance does not correspond to the expected or if unusual market conditions develop for a particular species; however, maximum adjustment levels should be defined prior to the beginning of the migration to guarantee the conservation of the species.

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

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.

As stated previously, the emphasis for the proposed work will be to develop the harvest-control decision-making model.

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APPENDIX

DAILY EXPLOITATION RATES

$$(u_2 = \frac{C_i}{N_i})$$

FOR NUSHAGAK BAY SOCKEYE SALMON

FROM 1959-1970

DAY	1959	1960	1961	1962	1963	1964	1965
1	.000	.999	.999	.987	.980	.999	.999
2	.000	.999	.999	.966	.000	.999	.999
3	.000	.922	.997	.000	.999	.999	.999
4	.000	.724	.000	.999	.997	.987	.999
5	.000	.000	.976	.999	.999	.827	.984
6	.000	.994	.983	.967	.996	.622	.000
7	.000	.993	.989	.982	.964	.000	.996
8	.545	.985	.965	.980	.746	.943	.995
9	.426	.947	.838	.885	.000	.841	.998
10	.000	.719	.338	.000	.000	.000	.935
11	.180	.438	.000	.958	.000	.878	.833
12	.029	.000	.697	.894	.150	.809	.635
13	.000	.785	.525	.000	.092	.000	.000
14	.000	.699	.000	.000	.000	.000	.000
15	.162	.000	.496	.000	.018	.896	.974
16	.080	.930	.298	.000	.000	.940	.000
17	.000	.806	.000	.000	.011	.000	.000
18	.547	.000	.000	.651	.055	.891	.969
19	.440	.519	.668	.468	.073	.794	.224
20	.382	.580	.549	.000	.319	.000	.000
21	.000	.302	.197	.780	.830	.000	.000
22	.660	.000	.231	.889	.823	.000	.000
23	.573	.000	.263	.603	.000	.000	.327
24	.776	.000	.216	.670	.729	.000	.470
25	.828	.434	.251	.850	.000	.000	.271
26	.555	.636	.132	.867	.825	.755	.545
27	.000	.636	.137	.935	.787	.291	.640
28	.000	.679	.210	.962	.000	.637	.745
29	.508	.632	.422	.917	.622	.653	.651
30	.763	.631	.671	.807	.689	.800	.687
31	.573	.655	.714	.935	.718	.795	.727
32	.481	.725	.219	.942	.736	.881	.713
33	.598	.754	.609	.961	.632	.886	.803
34	.553	.256	.740	.946	.692	.913	.921
35	.000	.296	.935	.960	.492	.946	.902
36	.515	.362	.873	.973	.541	.916	.681
37	.672	.449	.811	.820	.000	.913	.683
38	.487	.450	.740	.000	.652	.926	.751
39	.618	.254	.000	.676	.835	.947	.889
40	.744	.000	.437	.780	.865	.958	.801
41	.697	.093	.671	.822	.926	.929	.000
42	.000	.234	.556	.562	.939	.000	.471
43	.000	.215	.701	.398	.916	.953	.488
44	.000	.288	.645	.566	.000	.977	.473
45	.000	.331	.715	.000	.880	.979	.373
46	.000	.159	.000	.853	.986	.959	.996
47	.000	.000	.993	.999	.986	.933	.990

DAY	1966	1967	1968	1969	1970	1971	1972
1	.996	.997	.000	.000	.999	.000	.000
2	.996	.997	.000	.500	.992	.667	.000
3	.996	.519	.337	.500	.871	.750	.000
4	.789	.000	.996	.000	.861	.750	.000
5	.000	.845	.000	.980	.653	.500	.000
6	.980	.802	.000	.124	.608	.000	.000
7	.962	.660	.399	.000	.667	.998	.000
8	.972	.370	.128	.000	.859	.999	.999
9	.977	.000	.000	.000	.697	.938	.957
10	.000	.842	.000	.000	.833	.000	.455
11	.970	.807	.781	.093	.911	.963	.000
12	.887	.000	.501	.038	.901	.991	.923
13	.000	.000	.000	.023	.768	.976	.977
14	.000	.000	.652	.006	.964	.000	.998
15	.575	.844	.000	.002	.842	.824	.987
16	.579	.000	.858	.000	.709	.913	.000
17	.000	.000	.000	.059	.533	.000	.000
18	.514	.000	.316	.000	.140	.819	.998
19	.368	.000	.140	.503	.106	.625	.000
20	.000	.594	.054	.676	.136	.000	.000
21	.122	.409	.392	.096	.347	.915	.000
22	.355	.000	.368	.308	.224	.549	.000
23	.515	.000	.194	.284	.440	.352	.000
24	.764	.126	.233	.401	.520	.774	.214
25	.673	.271	.634	.664	.335	.466	.338
26	.303	.287	.690	.730	.351	.000	.724
27	.420	.274	.693	.753	.430	.563	.000
28	.675	.409	.723	.584	.309	.563	.000
29	.784	.789	.562	.736	.465	.000	.000
30	.844	.819	.000	.798	.675	.000	.000
31	.841	.815	.277	.830	.741	.248	.000
32	.874	.869	.534	.460	.821	.777	.000
33	.000	.926	.797	.492	.797	.732	.525
34	.687	.911	.615	.593	.895	.865	.727
35	.880	.705	.589	.448	.679	.333	.830
36	.903	.743	.713	.000	.740	.000	.881
37	.946	.749	.974	.483	.790	.000	.943
38	.990	.641	.999	.637	.877	.000	.917
39	.859	.000	.999	.772	.882	.000	.000
40	.000	.907	.999	.893	.961	.000	.696
41	.966	.986	.999	.966	.941	.366	.734
42	.998	.999	.999	.997	.779	.526	.903
43	.000	.999	.999	.000	.860	.505	.941
44	.948	.999	.999	.977	.998	.810	.998
45	.976	.998	.987	.996	.998	.999	.993
46	.916	.000	.987	.986	.998	.999	.000
47	.000	.987	.997	.986	.998	.997	.988

DAY	1973	1974	1975	1976	1977	1978	1979
1	.998	.000	.000	.000	.997	.994	.000
2	.996	.000	.000	.000	.997	.994	.000
3	.000	.839	.000	.992	.997	.000	.000
4	.000	.000	.000	.962	.997	.000	.000
5	.167	.000	.000	.000	.000	.000	.864
6	.292	.000	.000	.000	.000	.856	.625
7	.000	.000	.000	.000	.000	.000	.524
8	.980	.000	.000	.942	.829	.000	.000
9	.980	.000	.000	.000	.313	.573	.343
10	.000	.000	.000	.000	.373	.119	.000
11	.000	.000	.000	.963	.366	.000	.418
12	.000	.000	.000	.000	.000	.000	.121
13	.814	.000	.000	.000	.520	.000	.757
14	.000	.000	.000	.972	.000	.741	.744
15	.267	.000	.000	.000	.000	.000	.355
16	.000	.000	.000	.000	.455	.000	.032
17	.000	.000	.000	.000	.752	.000	.577
18	.000	.000	.000	.820	.000	.405	.493
19	.893	.000	.000	.507	.000	.425	.697
20	.000	.225	.013	.000	.000	.513	.548
21	.000	.486	.000	.000	.000	.641	.487
22	.000	.573	.000	.552	.000	.588	.710
23	.000	.358	.123	.549	.000	.659	.763
24	.000	.523	.092	.000	.000	.725	.733
25	.000	.582	.487	.000	.000	.560	.909
26	.000	.674	.225	.000	.823	.632	.892
27	.000	.768	.363	.244	.000	.689	.898
28	.000	.762	.598	.728	.000	.815	.893
29	.000	.739	.449	.721	.817	.867	.871
30	.000	.754	.472	.786	.885	.910	.808
31	.000	.221	.566	.567	.887	.859	.889
32	.861	.384	.642	.791	.693	.774	.857
33	.933	.523	.776	.663	.000	.762	.769
34	.946	.603	.851	.417	.601	.768	.625
35	.965	.490	.847	.441	.529	.772	.545
36	.984	.669	.000	.547	.745	.843	.000
37	.947	.000	.597	.802	.664	.854	.000
38	.000	.225	.749	.820	.638	.977	.000
39	.998	.264	.894	.902	.762	.000	.000
40	.999	.000	.999	.878	.000	.999	.000
41	.999	.000	.999	.000	.210	.999	.000
42	.999	.000	.000	.000	.245	.000	.000
43	.999	.000	.000	.000	.619	.999	.000
44	.997	.000	.997	.999	.998	.999	.000
45	.000	.999	.997	.999	.998	.999	.000
46	.990	.000	.997	.000	.998	.998	.000
47	.990	.000	.997	.000	.000	.998	.000