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NUSHAGAK BAY KING SALMON

ESCAPEMENT MODEL

by

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FINAL REPORT
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for Roy E. Nakatani
Director

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FOREWORD

On October 27, 1980 a contract was approved by the Alaska Department of Fish and Game for analysis of Nushagak king salmon data by the Fisheries Research Institute of the University of Washington. The main objective was to estimate the size of the escapement from the catches made in the subsistence fishery in the Nushagak River. However, it soon became evident that variations in year class strength and net selectivity influenced age composition and sex ratios and thereby strongly affected the potential egg deposition. Thus a brief review of the entire life history was desirable in order to establish a proper perspective.

A study of king salmon in Nushagak Bay and the accumulation of vital statistics was begun by Mr. M. L. Nelson, Senior Area Management Biologist for Bristol Bay soon after statehood. Over the years as data collection became more routine in nature Mr. Nelson supervised this work as well as primary data analysis. The entire data base for this study was provided by the Alaska Department of Fish and Game. Some of the results are published in the Annual Reports of the Management Division. Other data were supplied directly from the Dillingham office of the Department. Acknowledgment of other published data is given through the indicated citations.

ABSTRACT

The general life history of king salmon in the Nushagak is discussed for the purpose of establishing a few important facts. The pertinent points are:

1. Age composition data of the commercial catches indicate that the total returns as 4, 5, 6 and 7-year-old fish from a brood year on the average equals the total run in that brood year. With an exploitation rate of 0.5, which is indicated from catch and aerial survey data, the recruit-to-spawner ratio is then on the average 2.0.

2. Egg production is a function of fish size and escapement should be measured in total biomass of females escaping. Larger meshed nets used in the king fishery select for older age groups which represent most of the egg production.

3. The subsistence catches can be considered as an indicator of the escapement of kings. This fishery indicates that all segments of the king run are escaping. A scaling factor was developed to calculate absolute escapement from subsistence catches based on catch per unit of effort data and aerial estimates. The discrepancy between these two sets of data is large.

The scaling factor could be improved by

1. Improvement of statistics of subsistence fishery sampling especially on gear used and effort.
2. Collection of age and sex ratio data from subsistence fishery and escapement.
3. Real progress depends on an accurate baseline estimate of the escapement for one year, as accuracy of the scaling largely depends on the accuracy of the aerial estimates.

THE NUSHAGAK KING SALMON RUNS AND FISHERY

I. The Nushagak Fishery

The Bristol Bay fishery for king salmon (*Oncorhynchus tshawytscha*) has averaged 100 thousand fish annually in this century (Meacham 1980). The Nushagak district accounted for virtually all of the catch until the 1950's and since then for about 70 percent of the total Bristol Bay king catch (Table 1).

June is the peak month of the king fishery, with 75-95 percent of the king catch made by June 30th (Table 1). Both drift and set gillnets are used, but driftnets account for more than 95 percent of the total catches.

In the early 1970's the king catches fell to 20-45 thousand fish annually, but since 1976 the trend has been upward. Effort has been variable over the years (Table 1) and comparison of absolute catches and catch per boat day (Fig. 1) shows that the recent increase in catches is due to some increased effort, but probably also to an increase in run size.

II. Life History of Nushagak King Salmon

Spawning Streams and Fecundity

King salmon spawn in North America from California to Alaska and spawning is concentrated in the larger river systems (Major et al. 1978). Figure 2 shows the spawning distribution in the Nushagak River, where spawning occurs in the trunk stream and in larger tributaries. Kings are the first salmon species to appear in the river, and peak spawning is in early August (Nelson 1972).

Table 1. King salmon fishery in Bristol Bay and Nushagak district, 1961-1980.[1]

Year	Total Bristol Bay catch	Nushagak District Catch	% caught by driftnet	% caught by 6.30	Effort[4] No. boat days 6.1-6.30	Kings per boat day
1961	88,656	60,953				
1962	84,047	61,283	97.74	91.8		
1963	62,269	45,979	95.20	91.1		
1964	139,536	108,606	95.63	85.2		
1965	112,967	85,910	95.35	97.7		
1966	77,472	58,184	96.25	94.4	1,778	32.43
1967	117,193	96,240	97.46	96.2	3,022	30.64
1968	103,723	78,201	99.00	92.8	4,698	15.95
1969	124,908	80,803	98.27	72.7	1,629	47.72
1970	140,511	87,547	97.26	83.7	1,438	56.68
1971	123,015	82,769	98.37	79.2	2,148	36.91
1972	69,546	46,045	98.86	85.8	2,351	18.80
1973	44,044	30,470	97.61	93.1	1,630	18.23
1974	45,664	32,053	98.98	82.0	965	32.97
1975	29,992	21,454	97.70	63.2	766	27.60
1976	95,968	60,573	94.94	77.3	1,647	36.19
1977[2]	130,526	84,944	99.04	94.9	2,613	32.08
1978[2]	191,539	135,226[3]				
1979[2]	202,000	142,612[3]				
1980	96,700	68,270[3]				

1 Catch data from Meacham 1980.

2 Preliminary data.

3 Estimated — assuming Nushagak catch is 70.6 percent of total Bristol Bay catch.

4 Effort is number of driftnet boat days.

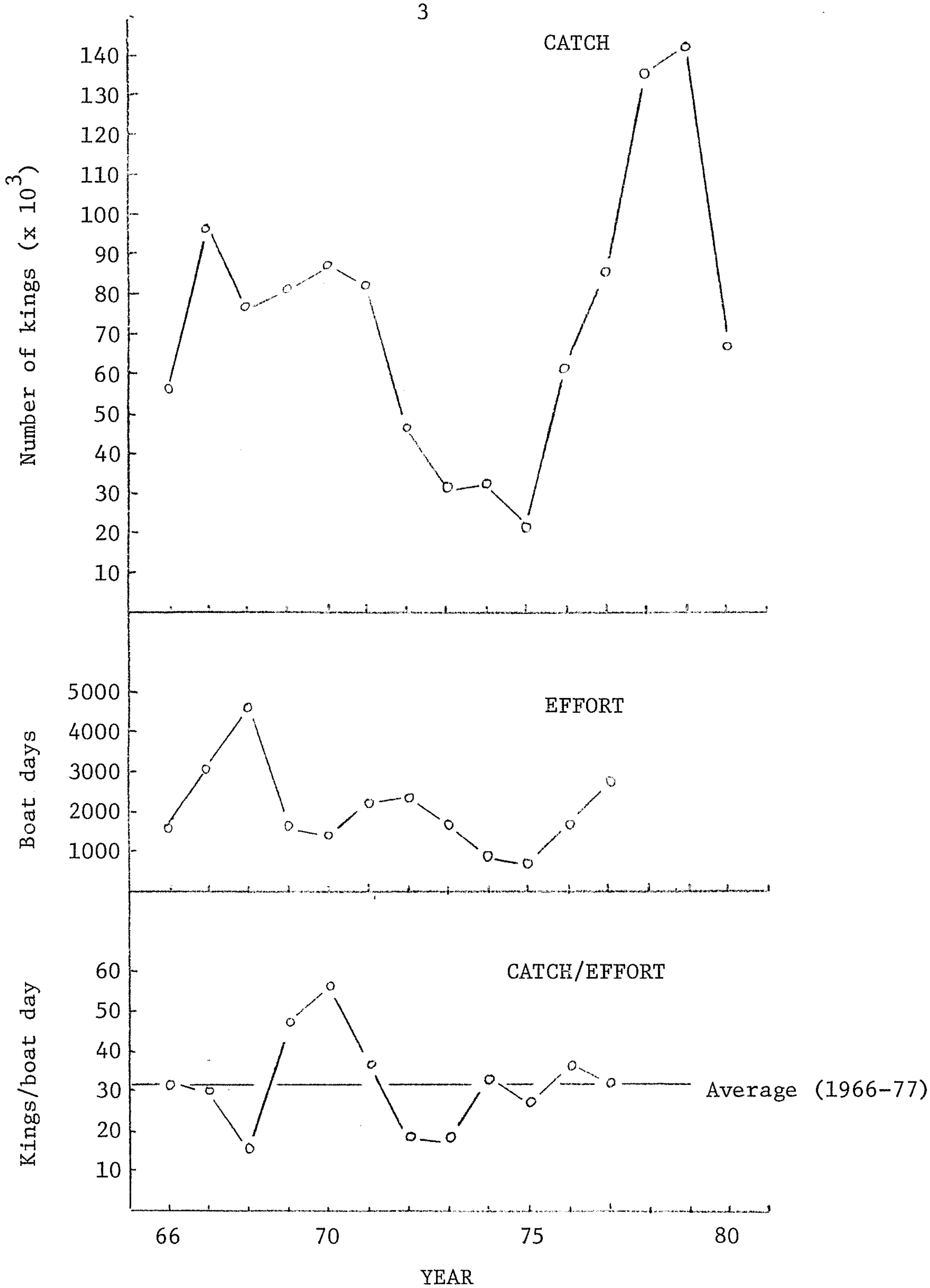

Figure 1. Catch, effort and catch/effort in Nushagak Bay 1966-1980.

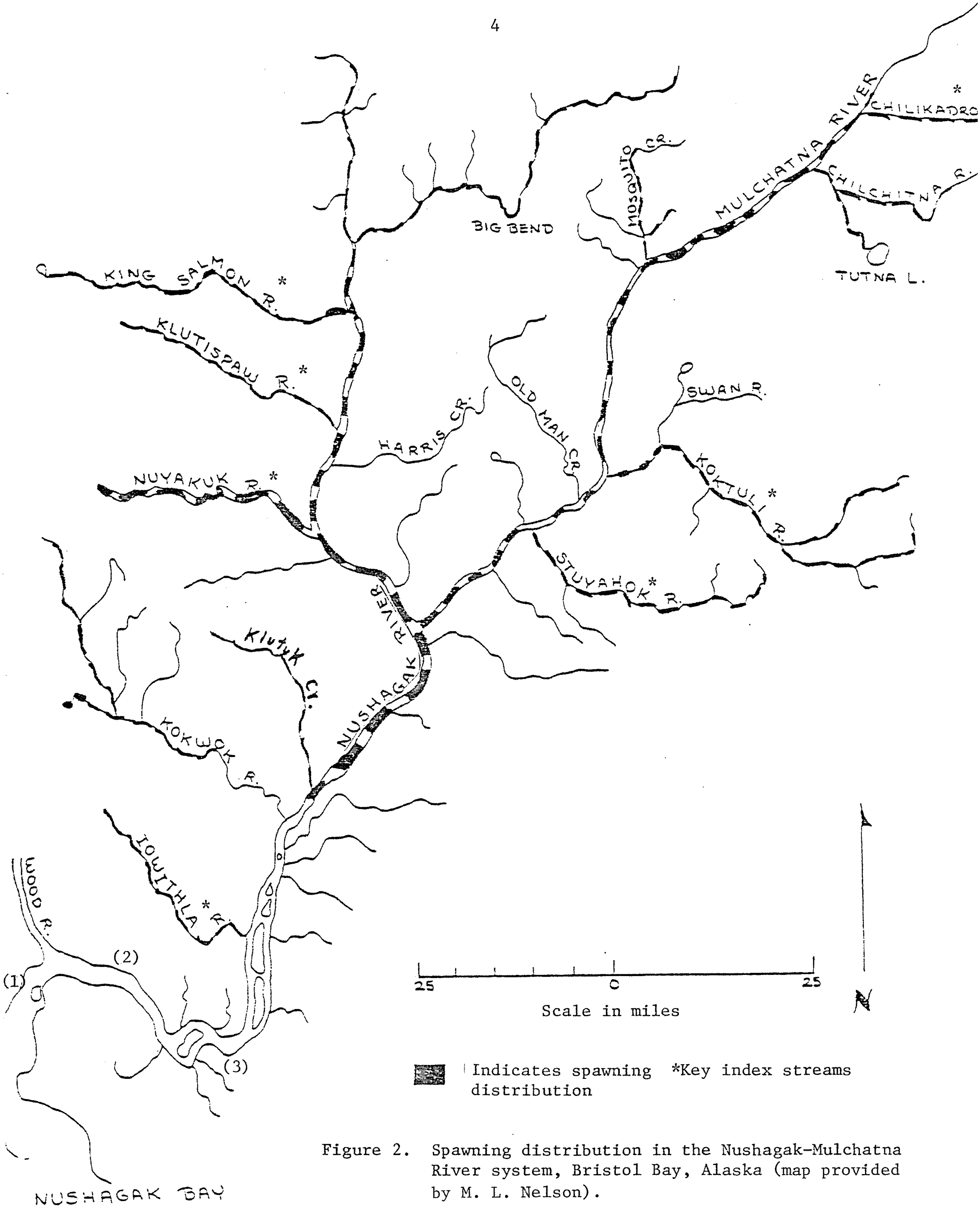

Figure 2. Spawning distribution in the Nushagak-Mulchatna River system, Bristol Bay, Alaska (map provided by M. L. Nelson).

King salmon have the highest fecundity of the Pacific salmon species and the largest eggs (Major et al. 1978). Nelson et al. (1969) measured fecundity of kings in 1966 and 1968 in the Nushagak. The data are plotted in Figure 3, as well as the fecundity by age. The average number of eggs for a 5-year-old female was ca. 8,400 eggs, 6-year-old ca. 10,300 eggs and a 7-year-old ca. 12,000 eggs. No 4-year-old females were sampled, but using a regression derived for the fecundity-length relationship (Fig. 3) and an average length for 4-year-old females of about 660 mm, then the average fecundity is calculated to be about 6,400 eggs/female (Table 2).

Freshwater Stages

Major et al. (1978) state that kings appear to have two life history patterns:

1. "Ocean-type", which originates on spawning grounds near to the ocean and migrate seaward as fry or age 0, and
2. "Stream-type", originating further upstream, which tend to remain in fresh water a year or longer. Only the second pattern is found in the northern part of the range.

According to age composition data reported by Meacham (1980) the Nushagak kings migrate seawards in their second year of life corresponding to their being of the "stream-type".

Ocean Life Stages

Little is known about the early ocean life of kings but in their second

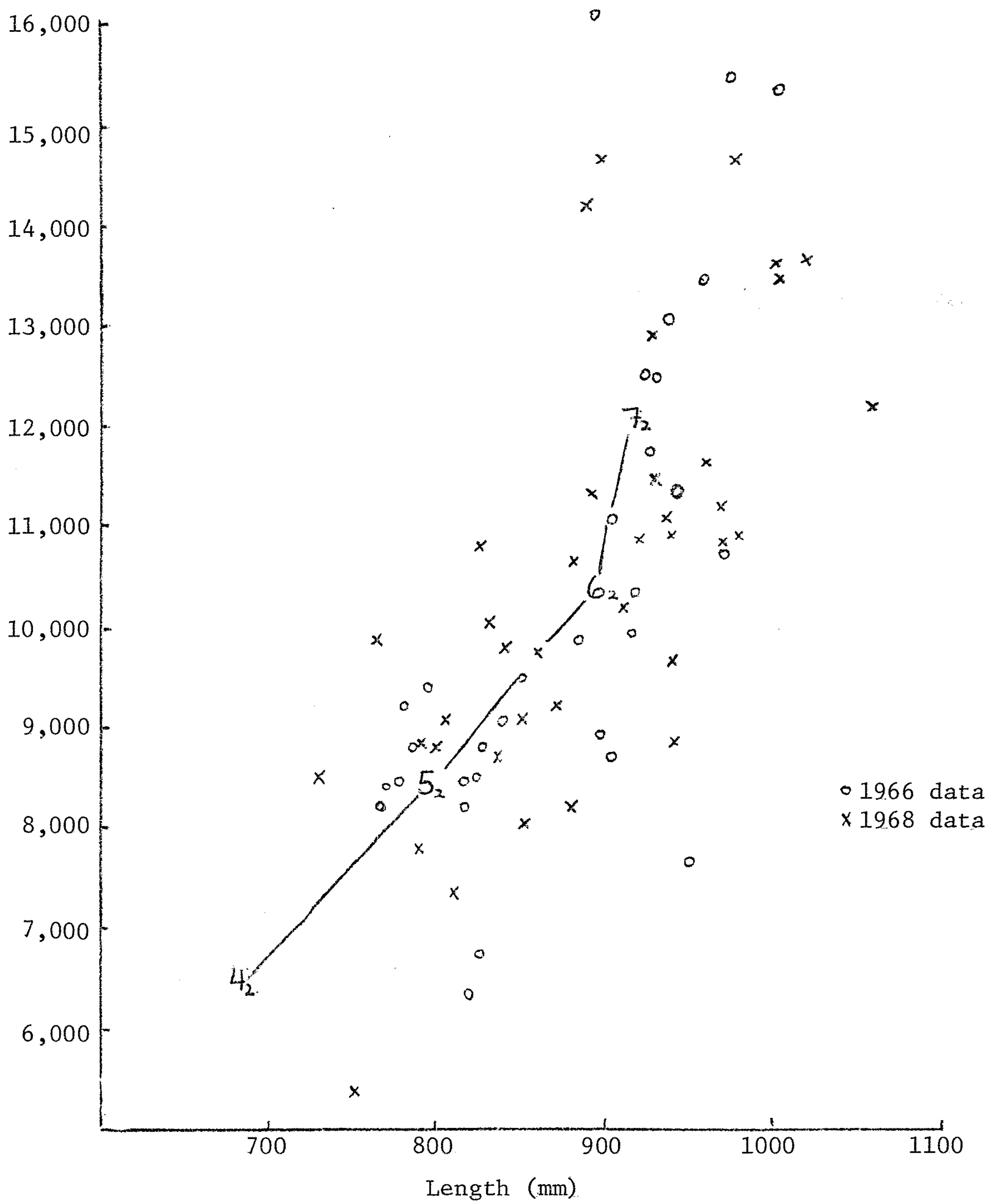

Figure 3. Fecundity and length of chinook salmon with mean fecundity for each age plotted. Data plotted from Nelson and Biwer (1968).

Table 2. Fecundity of king salmon in the Nushagak district.[1]

	Fecundity (eggs/female)			
Age	Average	Range	Mean weight (lbs)	Eggs per lb
4_2[2]	6,400		12.4	516
5_2	8,400	5,300 – 9,300	18.2	461
6_2	10,300	6,300 – 15,500	26.8	384
7_2	12,000	7,600 – 51,300	33.3	360

[1] Data from Nelson et al. (1968).

[2] Calculated from regression of fecundity on length (Figure 3).

year of ocean life they appear in the catches of the high seas fishing fleet in the North Pacific and Bering Sea. Tagging studies (Major et al. 1978) indicate that western Alaskan stocks are distributed in the Bering Sea as far west as 165°E and in the North Pacific from 170°E to 175°W. In the same tagging study ocean age in the catches was compared by month, and the number of ocean age .2 fish increased as the season progressed both for immature and mature fish, indicating that a higher percentage of older fish (i.e. ocean age .3 and .4) mature and leave for home streams than ocean age .2 fish and that the mature ocean age .2 fish arrive in coastal areas later in the season than the older fish.

Size and Growth

The average weight of the king in the Nushagak catch is 9.4 kilos (20.7 lbs). The average size for females is 11.41 kilos (25.1 lbs) and for males 7.95 kilos (17.5 lbs). Younger females are considerably larger than males (Fig. 4).

Sex Ratios

Male kings mature earlier and make up nearly all of the 2 sea year fish returning (Major et al. 1978). This corresponds to results obtained by Meacham (1980) on the kings in commercial catches of western Alaska. Four and 5-year-olds were predominantly male, while the older age classes were largely females (Table 3).

Age Composition

Ages of maturing kings vary from 2 to 8 years. From California to Cook Inlet, Alaska, 3 to 5-year-olds predominate while more 5 and 6-year-olds

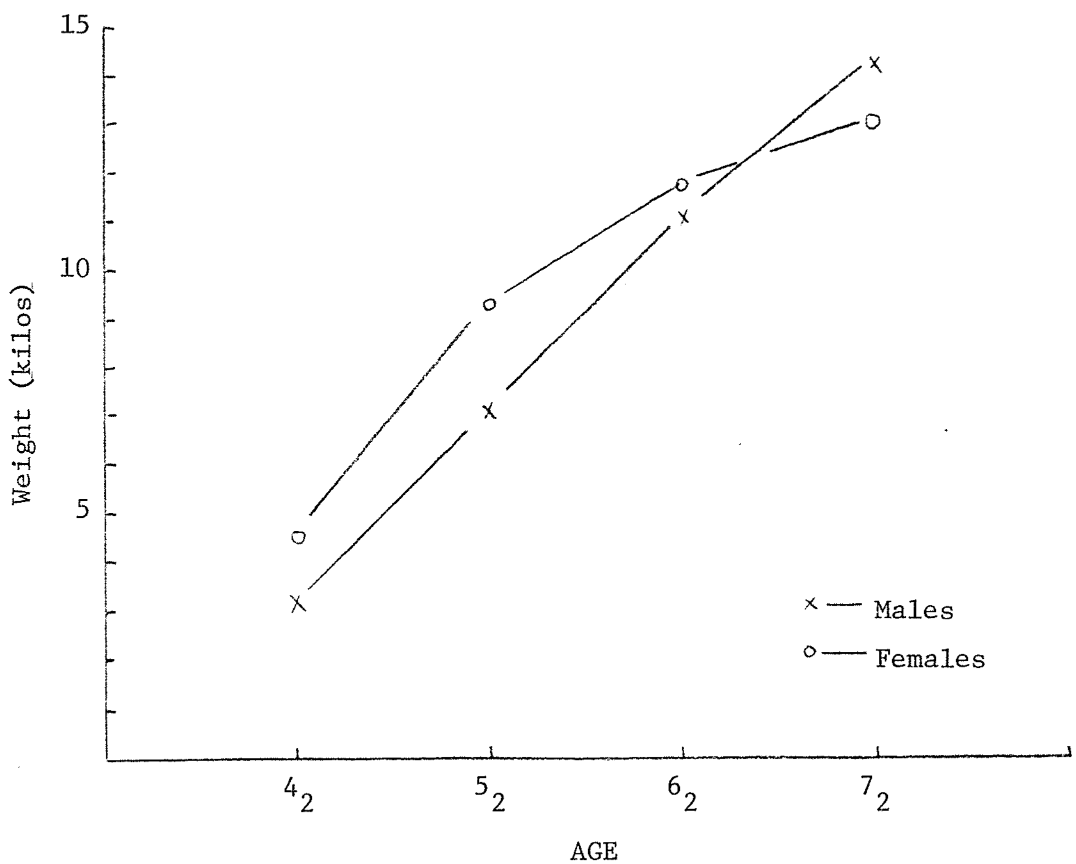

Figure 4. Growth of chinook salmon. Mean weight by age in commercial catch of Nushagak district (from Meacham 1980).

Table 3. Percent males in age classes in catch in Nushagak district.[1]

Year	4_2		5_2		6_2		7_2	
1964	100	(106)	84.2	(38)	29.8	(57)	71.4	(7)
1965	100	(30)	80.9	(89)	39.8	(103)	50.0	(18)
1966	100	(109)	90.1	(243)	38.9	(344)	23.1	(13)
1967	98.7	(76)	87.4	(215)	40.6	(429)	50.0	(44)
1968	100	(36)	85.3	(157)	41.9	(236)	23.7	(38)
1969	94.8	(58)	61.2	(85)	31.4	(175)	28.6	(21)
1970	100	(6)	63.1	(157)	30.2	(63)	62.5	(8)
1971	100	(9)	87.2	(47)	26.1	(188)	0	(4)
1972	95	(40)	66.7	(51)	35.7	(140)	21.4	(14)
1973	—	(0)	66.7	(18)	37.5	(64)	25.0	(16)
1974	0	(1)	71.4	(7)	57.6	(33)	12.5	(16)
1975	—	(0)	42.2	(64)	26.9	(26)	44.4	(9)
1976	85.7	(21)	52.2	(46)	33.3	(90)	33.3	(3)
1977	0	(2)	57.1	(63)	41.5	(106)	25.0	(4)
Mean	97.4		73.3		36.5		33.6	

[1] Calculated from sample data in Meacham (1980). Sample sizes given in parentheses.

occur from Bristol Bay northwards (Major et al. 1978).

Age composition data from the commercial fishery in Bristol Bay (Meacham 1980) was recalculated to show actual numbers in each age class. The return by age to each year class (Table 4) shows that 5 and 6-year-olds are most numerous with about 6 percent returning as 7-year-olds while 1-20 percent return as 4-year-olds.

Year Class Strength and Reproductive Success

Assuming catch per boat day is representative of the actual run size, return from each year class was calculated in catch per boat day units (Table 5) to get an idea of year class strength.

Reproductive success (RS) was also calculated from catch-effort data (Table 5). If one assumes that catch per boat-day is representative of the total population then the ratio of the sum of catch per boat day for each returning age installment from a given brood year to the total catch per boat day in the considered brood year is proportional to the ratio of the returns from a brood year to the average total population entering the fishery in that brood year.

$$RS = \frac{\sum_{i=1}^{4} (c/f)_{is}}{(c/f)_s} \simeq \frac{R_s}{\bar{N}_s} \qquad (1)$$

where: $(c/f)_{is}$ = catch per boat day from brood year s of age i

$(c/f)_s$ = catch per boat day of year s

R = return from brood year s

N = average population entering fishery in year s

Table 4. Distribution of commercial catch by age class and return to fishery of each year class in Bristol Bay king fishery (calculated from total catch and age composition data from Meacham 1980).

Year i		Total catch	Catch by age class				Return from year class i				Total return
			4_2	5_2	6_2	7_2	4_2	5_2	6_2	7_2	
1962	No.	62,932	4,342	9,377	42,857	4,594	8,960	25,888	38,788	4,606	78,242
	%		6.9	14.9	68.1	7.3	11.4	33.1	49.6	5.9	
1963	No.	45,979	21,012	5,977	13,978	5,012	21,173	25,024	41,856	2,189	100,242
	%		45.7	13.0	30.4	10.9	21.1	25.0	41.7	2.2	
1964	No.	108,600	50,517	19,548	29,322	3,584	4,223	21,170	19,698	579	45,670
	%		50.2	18.0	27.0	3.3	9.3	46.3	43.1	1.3	
1965	No.	85,900	10,566	31,353	36,250	6,700	10,100	53,053	57,028	2,118	122,299
			12.3	36.5	42.2	7.8	8.3	43.4	46.6	1.7	
1966	No.	58,184	8,960	19,724	27,928	1,047	6,566	17,878	23,391	2,620	50,455
	%		15.4	33.9	48.0	1.8	13.0	35.4	46.4	5.2	
1967	No.	96,240	21,173	25,888	40,806	4,716	3,807	10,222	19.074	7,020	40,123
	%		22.0	26.9	42.4	4.9	9.5	25.5	47.5	17.5	
1968	No.	78,201	4,223	25,024	38,788	6,882	8,472	7,526	20,033	1,845	37,876
	%		5.4	32.0	49.6	8.8	22.4	19.9	52.9	4.9	
1969	No.	80,803	10,100	21,170	41,856	4,606	487	4,327	6,436	727	11,977
	%		12.5	26.2	51.8	5.7	4.1	36.1	53.7	6.1	
1970	No.	87,547	6,566	53,053	19,698	2,189	449	12,336	31,437	2,293	46,515
	%		7.5	60.6	22.5	2.5	1.0	26.5	67.6	4.9	
1971	No.	82,769	3,807	17,878	57,028	579	536	21,806	50,457		(72,799)
	%		4.6	21.6	68.9	0.7					
1972	No.	46,045	8,472	10,222	23,391	2,118	5,633	29,306			
	%		18.4	22.2	50.8	4.6					
1973	No.	30,470	487	7,526	19,074	2,620	1,784				
	%		1.6	24.7	62.6	8.6					
1974	No.	32,053	449	4,327	20,033	7,020					
	%		1.4	13.5	62.5	21.9					
1975	No.	21,454	536	12,336	6,436	1,845					
	%		2.5	57.5	30.0	8.6					
1976	No.	60,573	5,633	21,806	31,437	727					
	%		9.3	36.0	51.9	1.2					
1977	No.	84,944	1,784	29,306	50,457	2,293					
	%		2.1	34.5	59.4	2.7					

Table 5. Return to fishery of each year class in catch per unit of effort (c/f) — kings per boat day.

Brood Year s	$(c/f)_s$ [1]	4_2	Return to fishery 5_2	6_2	7_2	Total	R/S [2]
1962	19.71	5.04	8.57	8.26	2.83	24.7	1.25
%		20.4	34.7	23.8	11.5		
1963	75.10	7.01	5.33	25.69	1.52	39.55	.53
%		17.72	13.48	64.95	3.84		
1964	27.54	.90	13.0	13.70	.27	27.87	1.01
%		3.23	46.64	49.16	.93		
1965	27.21	6.20	36.89	26.55	.90	70.54	2.59
%		8.79	52.30	37.64	1.28		
1966	32.43	4.57	8.32	9.95	1.61	24.45	.75
%		18.69	34.03	40.69	6.58		
1967	30.64	1.77	4.35	11.70	7.27	25.09	.82
%		7.05	17.34	46.63	.29		
1968	15.95	3.60	4.62	20.76	2.41	31.39	1.97
%		11.47	14.72	66.14	7.68		
1969	47.72	.30	4.48	8.40	.44	13.62	.28
%		2.20	32.89	61.67	3.23		
1970	56.68	.46	16.10	19.09	.88	36.53	.64
%		1.26	44.07	52.26	2.41		
1971	36.91	.70	13.24	19.31			
%							
1972	18.80	3.42	11.21				
%							
1973	18.23	.68					

[1] c/f = total catch of kings / boat days by July 1.

[2] $R/S = \frac{\Sigma(c/f)_{is}}{(c/f)_s}$ where i = age class, s = brood year

The RS values fluctuate around a mean value of about 1.00 (Fig. 5). Exploitation in the commercial fishery is about .5 (Table 6), and so the number of spawners is .5 the total population. Therefore the recruit-to-spawner ratio is on the average 2.00, and each year's run is basically maintaining itself at present exploitation rates.

Year Class Contributions to Fishery

Year class strength was on the average 33 kings per boat day, each year contributing returns to the fishery over 4 years with the 5 and 6-year-olds being the most important age groups.

1965 was an unusually successful brood year with an RS value of 2.6 and it was also the largest year class with 70.5 kings per boat day (Table 5). The 1965 year class contributed especially to the 1970 and 1971 catches, both years of high catches (Table 1). On the other hand, 1969 was a failure, with only 0.28 fish returning per spawner and only 13.6 kings/boat day returning to the fisheries, mainly in 1974 and 1975, years of low catches. This was also true for the 1969 sockeye spawning in this brood year.

These fluctuations in year class strength can have various causes, e.g.

1) real year class differences in number of smolts migrating to sea;

2) selectivity in fishery; and

3) changes in maturity schedule.

1) Real differences in year classes

Assuming estuarine and ocean mortality operates equally on all age classes and maturity schedules are constant, then the percent returns to the fishery of each year class by age would be constant over the years. Figure 6 shows the trends in each age, which fluctuate, suggesting there are mortality and

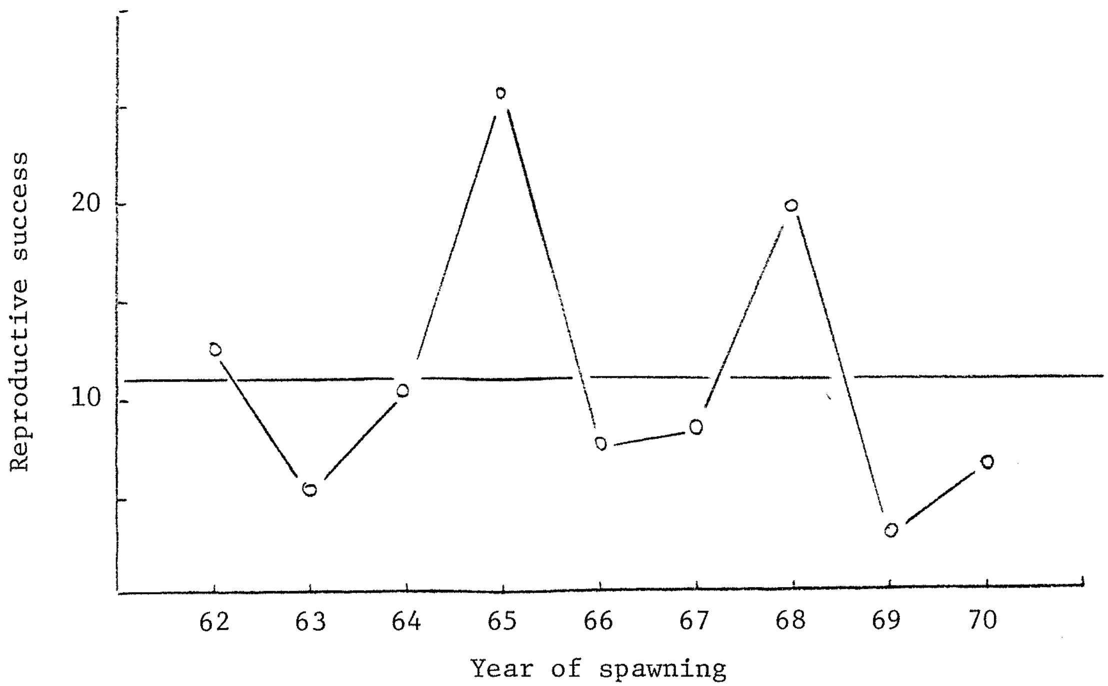

Figure 5. Reproductive success estimated from catch per unit of effort (C/f) data.

Table 6. Catch in commercial fishery, subsistence catch, estimated escapement, and total run in the Nushagak district, 1961-1977.

Year	Commercial catch	Subsistence catch	Total estimated escapement	Total run[1]	$\frac{E}{C+E}$
1966	58,184	3,700	40,000	101,844	.40
1967	96,240	3,700	65,000	164,940	.40
1968	78,201	6,600	70,000	154,801	.45
1969	80,803	7,100	35,000	122,903	.28
1970	87,547	6,900	50,000	144,447	.35
1971	82,769	4,400			
1972	46,045	4,000	25,000	75,045	.33
1973	30,470	6,600	35,000	72,070	.49
1974	32,053	7,600	75,000	114,653	.66
1975	21,454	7,100	70,000	98,554	.71
1976	60,573	6,900	100,000	167,473	.60
1977	84,944	5,200	65,000	155,144	.42
1978	135,226[2]	5,400[3]	130,000	270,626	.48
1979	142,612[2]	5,400[3]	95,000	243,012	.39
1980	68,270[2]	5,400[3]	145,000[4]	218,670	.66

[1] Total run = commercial catch + subsistence catch + escapement.

[2] Estimated catch (see Table 1).

[3] Average of years 1966-1977.

[4] Preliminary data.

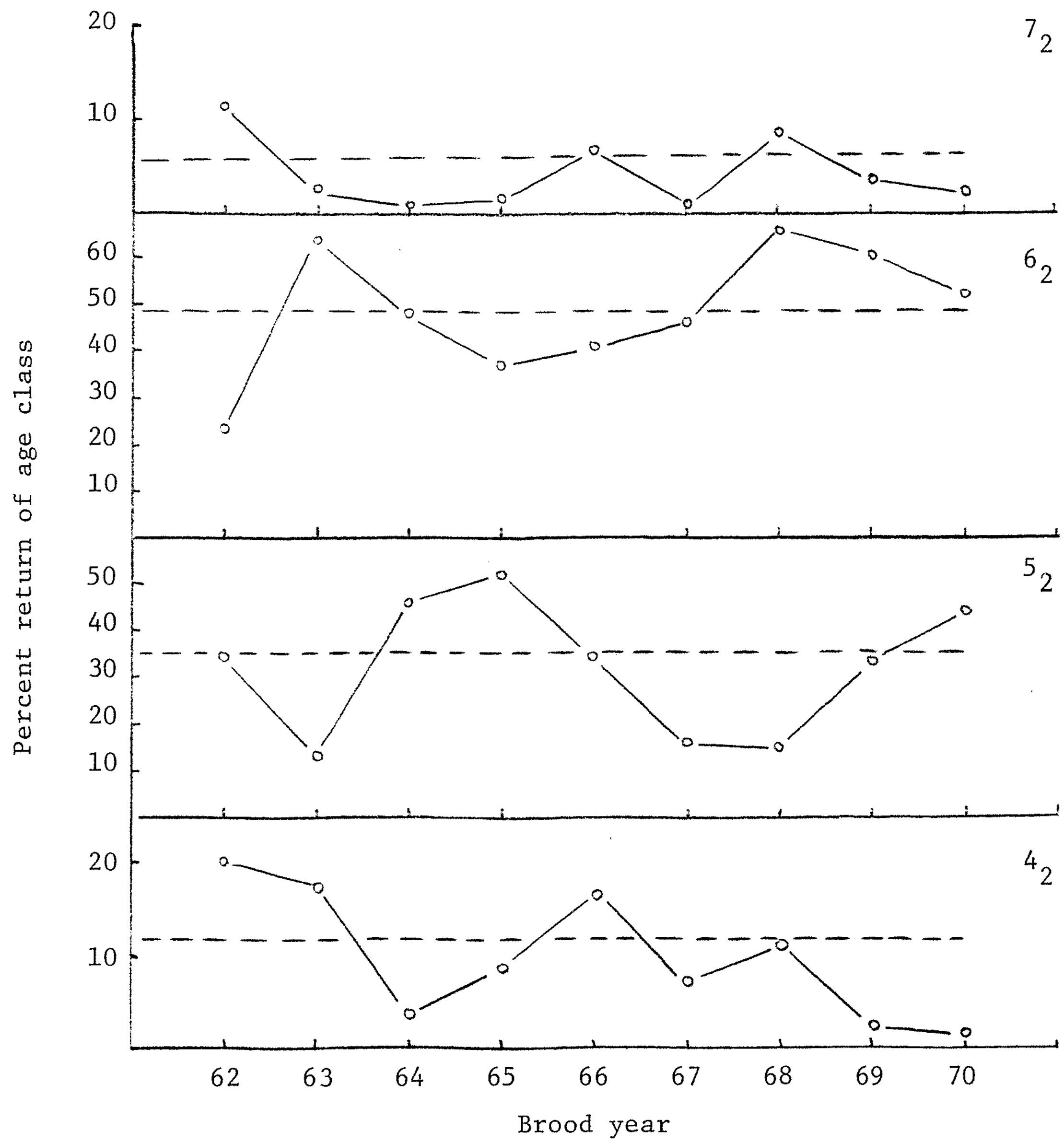

Figure 6. Annual trends in percent return of age classes for separate brood years.

other factors operating during the ocean phase which influence the age classes differently.

2) Selectivity in fishery

The salmon fisheries, both in Bristol Bay and on the high seas are gillnet fisheries and are, as such, selective. Major et al. (1978) states that "gillnet selectivity is a greater source of error in studies of king salmon than for any other species of salmon". Gillnet selectivity will be discussed more fully later in this report, but two factors are of major importance for kings according to Major et al. (1978).

a. Vertical distribution. Gillnets fish only in the upper 6 m. Kings appear to inhabit greater depths than any other species of salmon and a wide range of depths, from the surface to 110 m on the high seas. They are caught in trawls, even in summer, when other salmon species stay in surface waters. Differences in temperature or sea conditions would probably be important factors, determining at what depth the kings are found.

b. Selectivity due to mesh size. Two-ocean age king salmon (4_2) are taken with relatively high efficiency in the high seas fishery which uses 111 and 118 mm (4 1/4" and 4 3/4") mesh sizes at the right places and at the right times. Older fish are probably underrepresented (Major et al. 1978). The kings at either end of the size range are most likely to have variable vulnerability with time of year, i.e. depending on whether they have grown into (1-ocean age) or out of (3-ocean and older) the selectivity range. It should be noted that the results quoted above from INPFC reports and from age composition data in the Bristol Bay fishery are all subject to bias because of possible gillnet selectivity.

3) Changes in maturity schedules

Major et al. (1978) found that there was a general increase in the proportions of 2-ocean fish over the period 1966-1970, especially in the immature fish. Although they felt this was not an artifact of the sampling method, it could not be determined whether this was due to an increase in 2-year fish or a decrease in older fish.

In the Nushagak there seems to have been a decrease in the percentage of 4-year-olds, which are 2-ocean age fish, returning to the fishery.

III. Management

The goal of management is basically to assure an escapement which meets certain specific criteria, or more basically a specified potential egg deposition. The number of females in the run, their age, size and fecundity need therefore to be considered. The numerical size of the escapement of kings into the Nushagak district is not well known because of the variability inherent in aerial surveys. No data are available on age composition or sex ratios in the escapement and the values from the commercial fishery must therefore be used temporarily. Since the run size is not diminishing at present rates of exploitation, assuming the catches are proportional to population size, then these rates should be retained for the present. In order to improve management methods and secure the necessary escapement some in-season indicator of daily or weekly escapement is needed. Hornberger and Mathisen (1980) used a seasonal estimate of the rate of exploitation to compute daily abundance from which an estimate of daily escapement could be obtained. This assumes that the exploitation rate is constant during the season and from year to year.

Another in-season indicator of escapement rates is the catch per unit of effort in the resident river fishery. At present there are no explicit methods to relate the resident river net catches to the number of kings that ascend the river. In a 1980 preliminary study (Hornberger and Mathisen 1980) data from subsistence catches in the Dillingham area were pooled and compared to escapements as estimated from the aerial surveys. The purpose of the present project was to investigate this possibility further by looking at separate sections of the subsistence fishery and develop a scaling factor for each section relating subsistence catches to total escapement by using the historical data available on

1. escapements estimated by aerial survey
2. resident net catches, and
3. the expended efforts.

ESTIMATION OF ESCAPEMENT FROM SUBSISTENCE FISHERY

I. Total Escapement

King salmon have been surveyed annually since 1968 (Nelson 1972). The surveys are flown at the peak of the king salmon spawning period. Key index streams, starred on the map in Figure 1, are flown every year. All live fish are estimated in these streams. Nelson (1972) estimates that 25-35 percent of the fish were accounted for in the index streams. According to the same author, weather and water conditions often adversely affected the success of the survey. The index streams were chosen because of their visibility and importance to king spawning. The inability to estimate spawning numbers in the turbid trunk rivers is a major problem as these may be important spawning areas. Bevan (1961) did a study on the variability in aerial counts of salmon, comparing counts by different observers in the same and different streams and counts by the same observer at different times. He found variance to be proportionate to the escapement size and that only differences of plus or minus 50 percent can be detected by an observer. His recommendations were that the aerial counts be used only as indices, not as actual counts. However, because of lack of any other data the aerial estimates are used here for escapement estimates.

II. Catches and Expended Effort in Subsistence Fishery

Catches in the resident nets in the Nushagak area have totalled from 3-8 thousand kings for the years 1963-1977, compared to estimated escapements of 25-100 thousand (Table 6). For this study catch data were used from three locations, Kanakanak Beach, Lewis Point and Portage Creek (Fig. 1), chosen because of their proximity to the commercial fishery. Data were used only from those permit holders who recorded daily catches consistently throughout the season. The catch data were summarized as average daily catch per unit of effort (C/f), where the unit of effort was 100 fathom hours.

All of these locations are on the lower reaches of the trunk stream and subject to some tidal influence. The tidal influence will be strongest in the lowest area, where the fish may move past faster with the tides. Some may drift back on the low tide, and further up where tides are not as strong may spread out more or slow down. As the fish move up the river, assuming few drift back, they are subject to a series of nets in the resident fishery, which then is a gauntlet fishery, and the daily catch per unit of effort can be set proportional to the daily escapement because of the low numbers involved relative to the total escapement.

$$C_i = q \, f_i \, E_i \qquad (2)$$

where C_i = catch in numbers during day i

f_i = effort in 100 fathom hours during day i

E_i = the escapement of kings during day i

q = the catchability coefficient

III. Estimation of Scaling Factor

For the purposes of this section q was assumed to be

1) the same for all ages

2) the same for both sexes

3) constant throughout the season

as no data were available on age or sex of the catch. Therefore catch per unit of effort $(C/f)_i$ can be summed over the season and related to total escapement by

$$\sum_{i=1}^{n} (C/f)_i = q \times \sum_{i=1}^{n} E_i \qquad (3)$$

where n is the last day of the season.

Catchability was estimated by

$$q = \frac{\sum_{i=1}^{n} (C/f)_i}{\sum_{i=1}^{n} E_i} \qquad (4)$$

The scaling factor (I) relates catch per unit of effort to total escapement and is the reciprocal of q:

$$I = \frac{1}{q} = \frac{\sum_{i=1}^{n} E_i}{\sum_{i=1}^{n} (C/f)_i} \qquad (5)$$

Thus the scaling factor is the number of fish in the escapement per fish caught per unit of effort in the resident fishery and the estimated escapement, E_e, is

$$E_e = I \cdot C/f \qquad (6)$$

This model assumes that the resident fishery is representative of the escapement or that the pattern in the resident fishery reflects the pattern of escapement up the river. Figure 7 shows the daily catch per unit of effort in the resident fishery which seems to validate this assumption.

Assuming also that the catchability is constant through the season, the seasonal scaling factor I can then be used to calculate a daily or weekly escapement using information on catch and effort in the resident fishery. The scaling factor was derived for all years for which data were available (Table 7). There was considerable variation between years at each location.

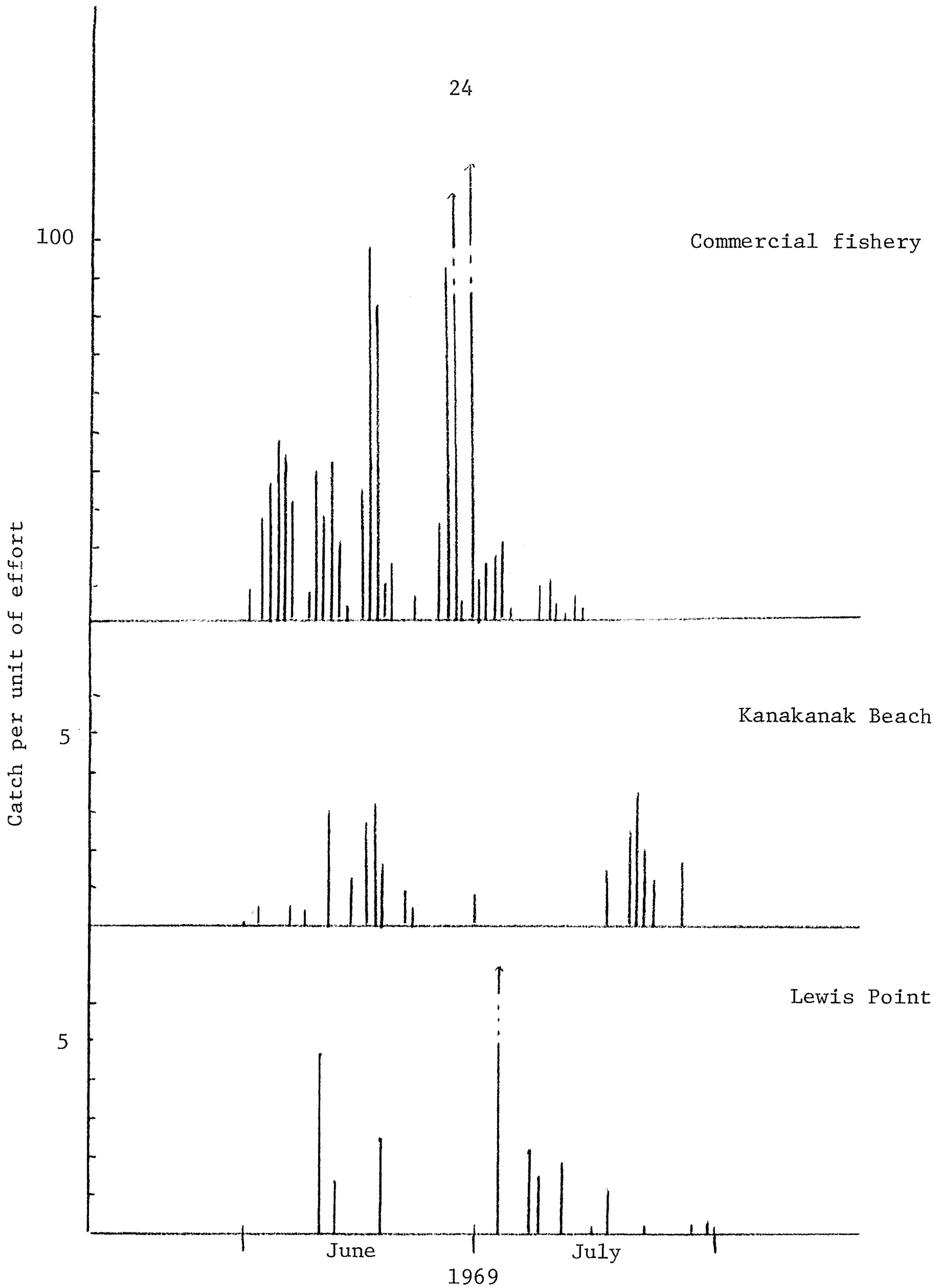

Figure 7a. Catch per unit of effort in resident (kings/100 fathom hours) and commercial (kings/drift boat day) fisheries in the Nushagak district (1969-1977).

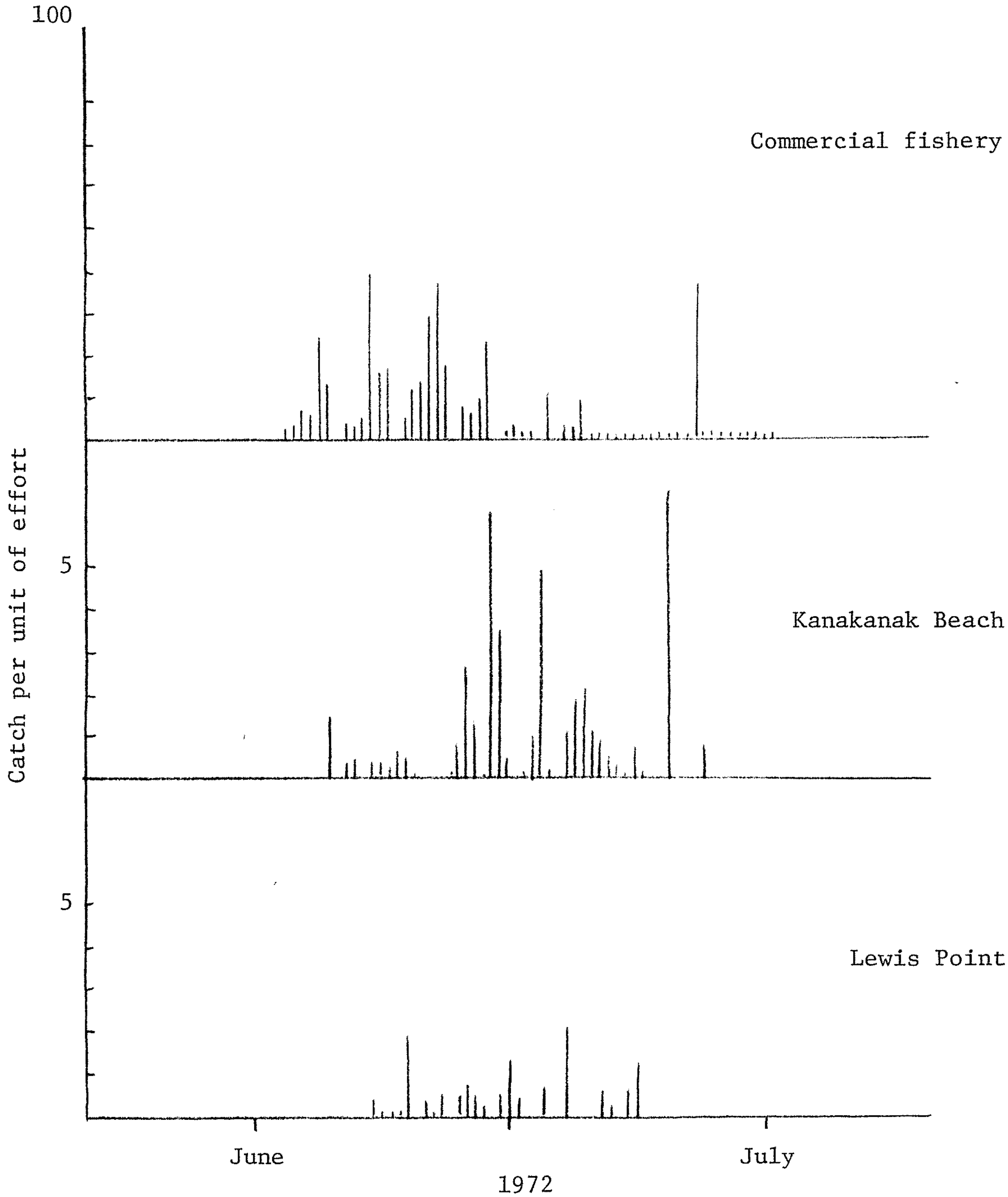

Figure 7b. Catch per unit of effort in resident (kings/100 fathom hours) and commercial (kings/drift boat day) fisheries in the Nushagak district (1969-1977).

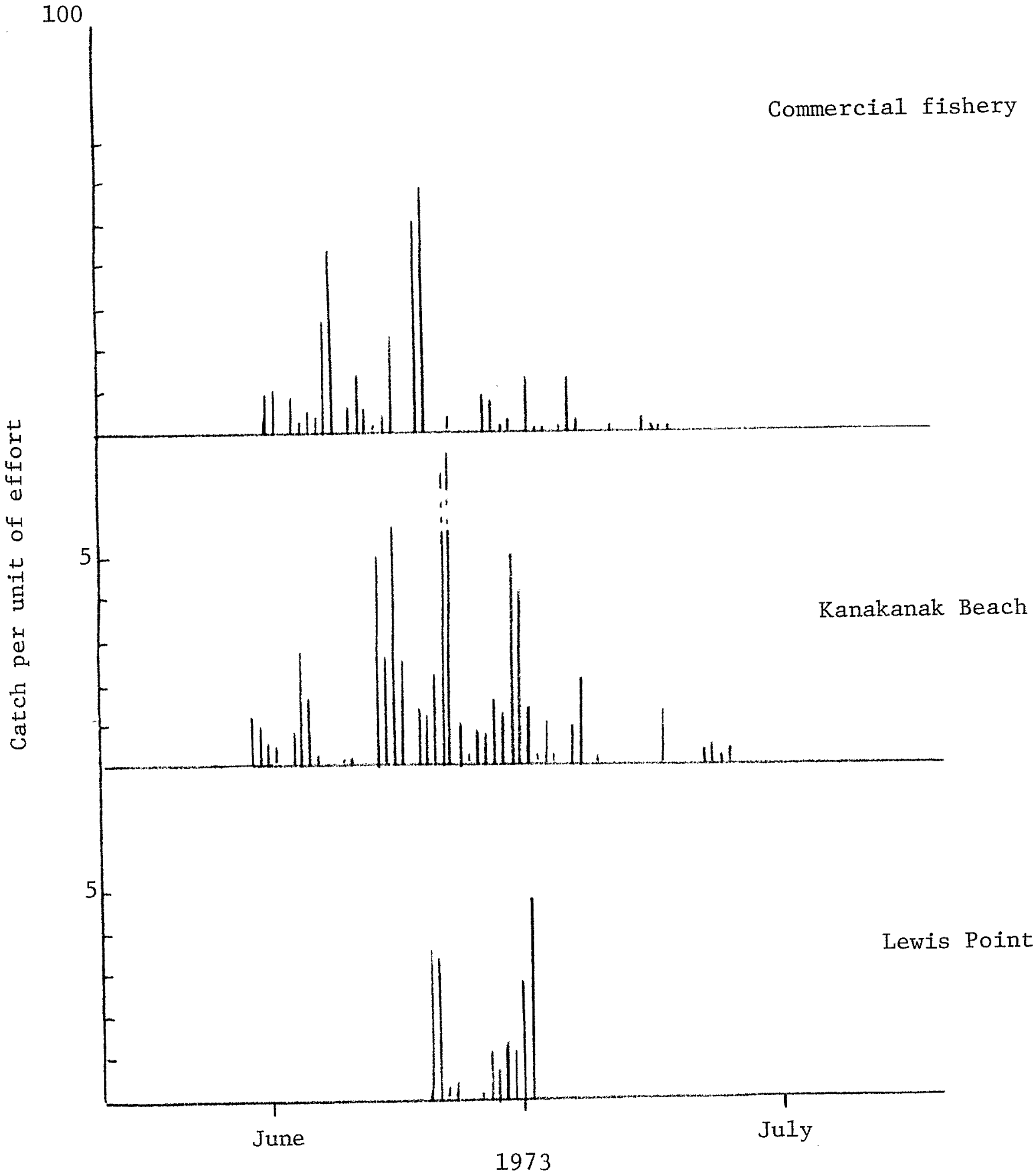

Figure 7c. Catch per unit of effort in resident (kings/100 fathom hours) and commercial (kings/drift boat day) fisheries in the Nushagak district (1969-1977).

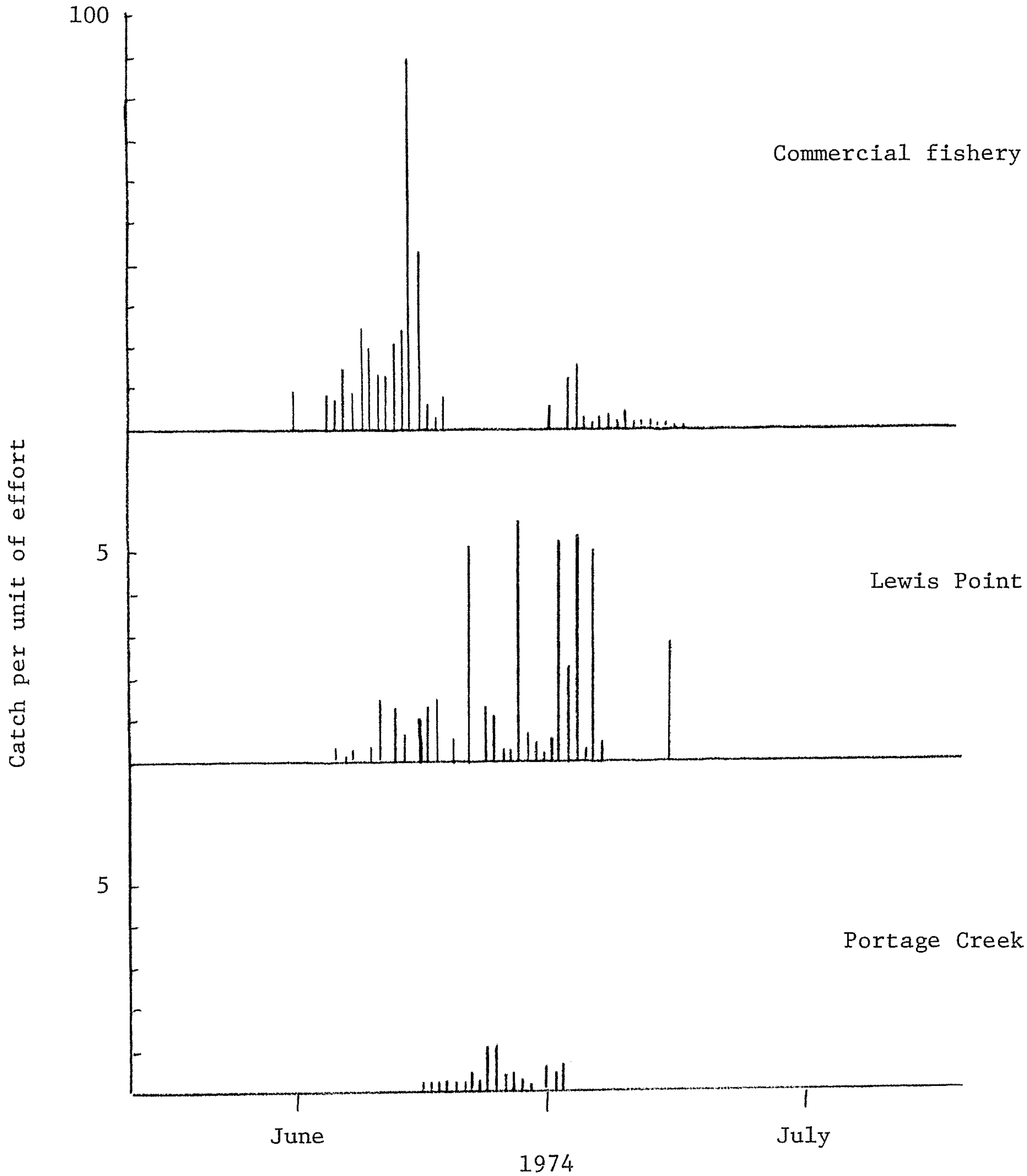

Figure 7d. Catch per unit of effort in resident (kings/100 fathom hours) and commercial (kings/drift boat day) fisheries in the Nushagak district (1969-1977).

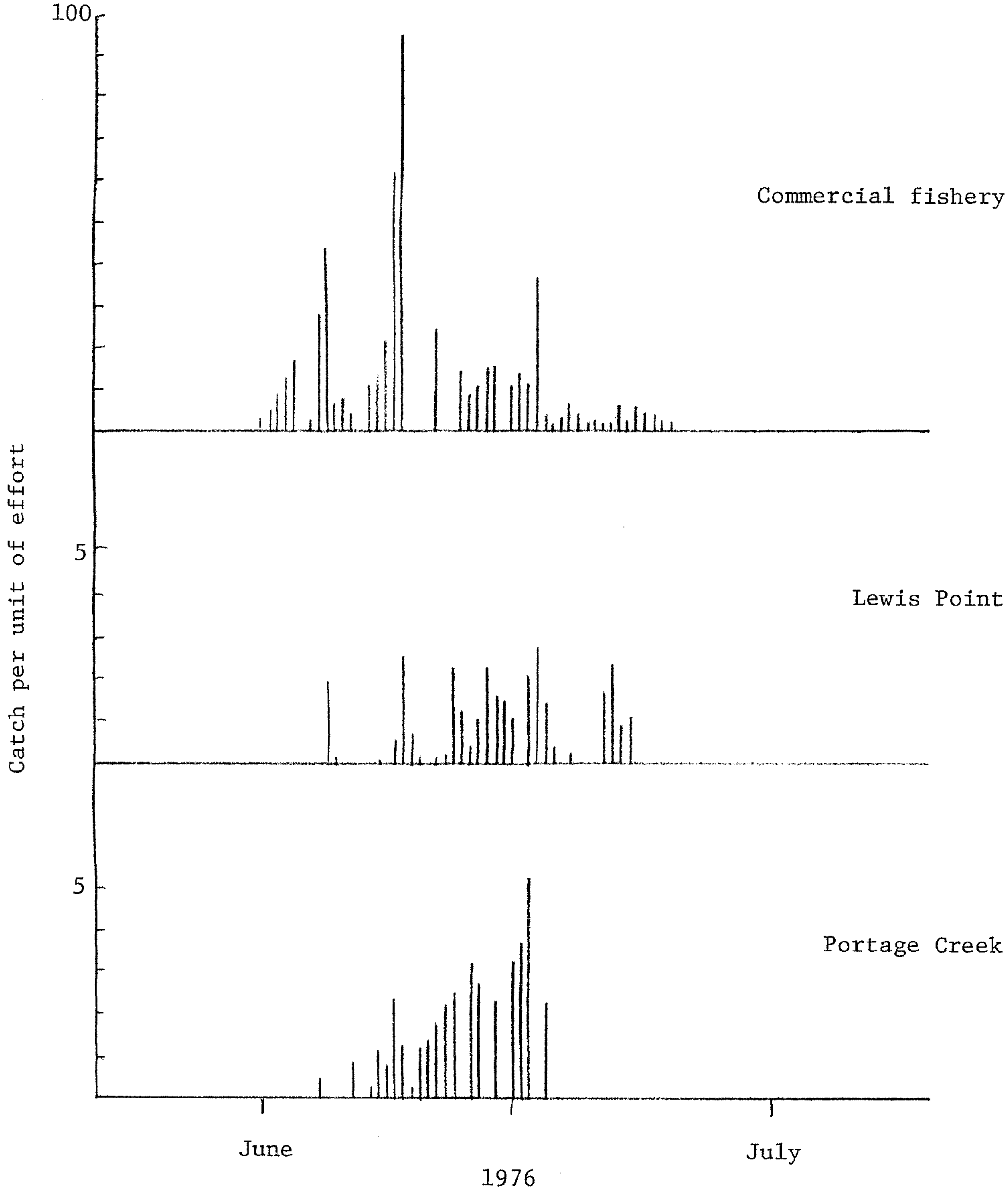

Figure 7e. Catch per unit of effort in resident (kings/100 fathom hours) and commercial (kings/drift boat day) fisheries in the Nushagak district (1969-1977).

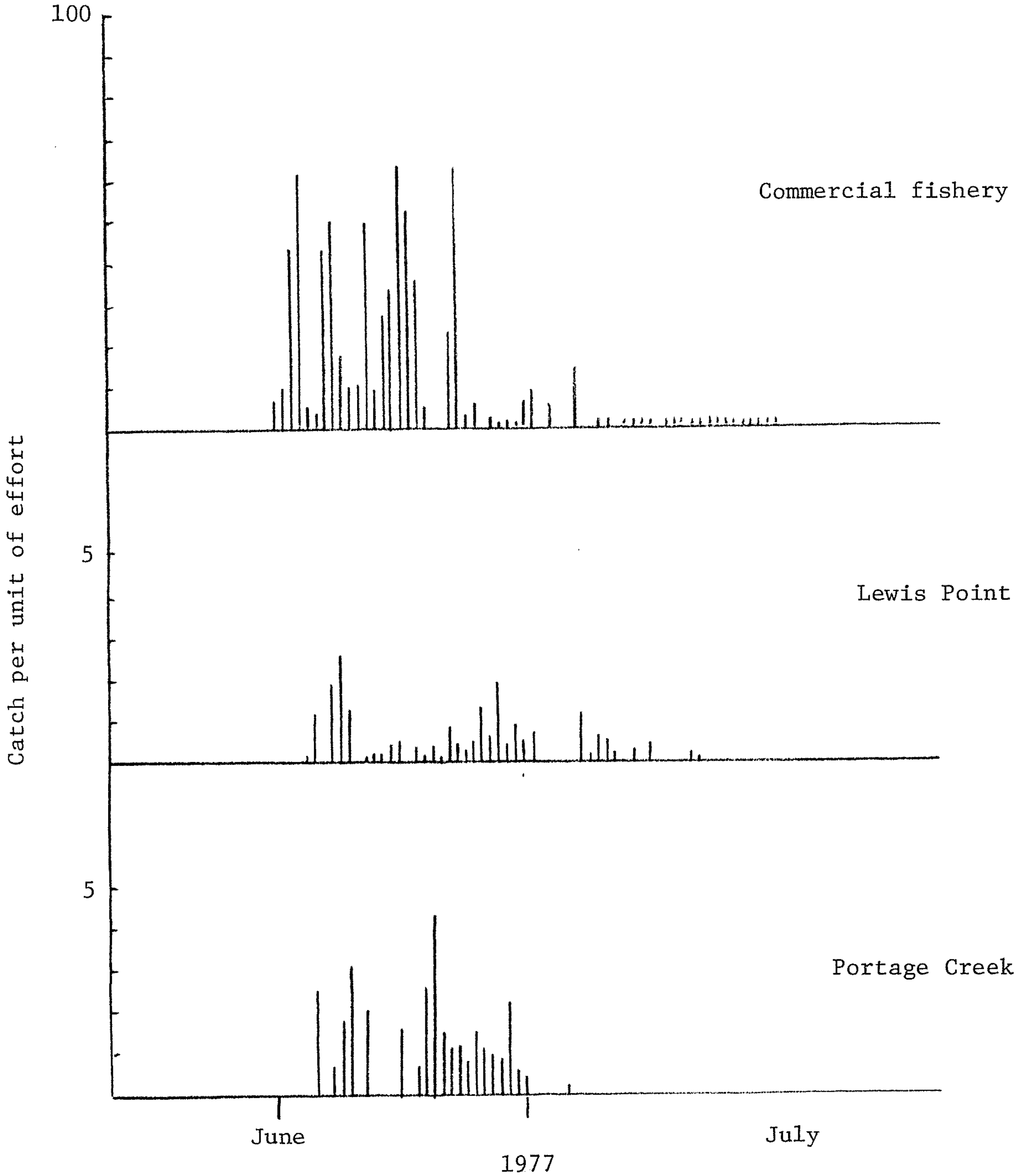

Figure 7f. Catch per unit of effort in resident (kings/100 fathom hours) and commercial (kings/drift boat day) fisheries in the Nushagak district (1969-1977).

Table 7. Historical data for king salmon escapement estimation and estimated scaling factor I for 3 stations in Nushagak River.

Year	Escapement E_0	Kanakanak Σ CPUE	Kanakanak I	Lewis Point Σ CPUE	Lewis Point I	Portage Creek Σ CPUE	Portage Creek I
1966	40,000	35.64	1122.18				
1967	65,000	73.80	880.76				
1968	70,000	30.77	2274.65	12.05	5809		
1969	35,000	24.57	1424.69	49.39	708.6		
1970	50,000	24.50	2041.09	19.91	2511		
1972	25,000	22.20	1126.32	14.90	1774		
1973	35,000	26.27	1332.52	20.06	1745		
1974	70,000			47.13	1485.2	8.50	8235
1975	70,000					22.1	3169.6
1976	100,000			32.17	3108	38.76	2580.0
1977	65,000			22.93	2834	31.68	2052
1978	130,000			27.32	4788.2	17.27	7527.5
1979	95,000			53.94	1761	13.19	7202

	Kanakanak	Lewis Point	Portage Creek
1) Mean I $\bar{I} = \frac{\Sigma I}{n}$	1457.46	2652.	5127.5
95% confidence limits	± 1231	± 3307	± 7803
2) Minimization	1126.32	1485.2	3169.6
$\frac{\Sigma(E_o - E_e)^2}{E_e}$	35308	196445	124357
3) Regression E = I x (C/f)	1187.6	1931.0	3271.0
95% confidence limits	± 482.6	± 779.3	± 2294.0

Three methods of estimating an overall scaling factor for each location were considered (Table 7)

1. A mean of the calculated yearly values
2. The sum of differences squared was calculated for the ith I-value by

$$\frac{\sum_{n=1}^{m} (E_o - E_e)^2}{E_e} \qquad (7)$$

where E_o = observed escapement

E_e = calculated escapement using scaling factor I

i = year i

n = year of (C/f) data used to calculate E_e

The I_i value which gave the smallest value for equation (7) is then considered the "best" I.

3. Escapement was regressed on catch per unit of effort (Fig. 8) according to equation (6).

The values derived by methods (2) and (3) were similar and the regression method was chosen as the better one since confidence limits could be considered.

IV. Variability in Scaling Factor

Calculated escapements (E_e) were compared to estimated escapements (E_o) from the aerial surveys (Table 8). The differences between calculated and observed values are consistently large, except for a few years. Further,

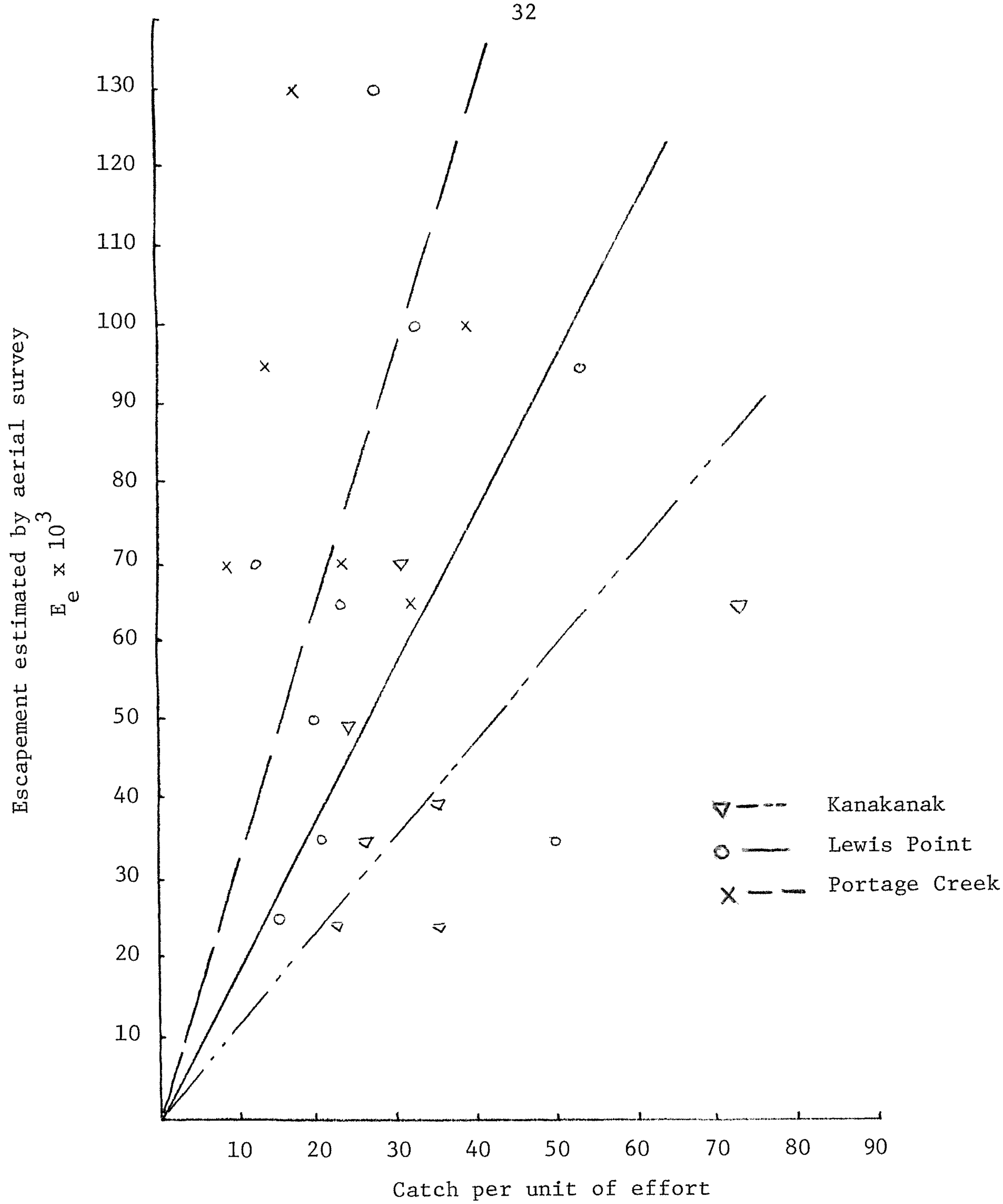

Figure 8. Escapement and catch per unit of effort (kings per 100 fathom hours) at 3 stations in the Nushagak River.

Table 8. Expected escapement (E_e) and observed escapement (E_o).

Year	Aerial survey escapement	Kanakanak I = 1187.6		Lewis Point I = 1931.00		Portage Creek I = 3271	
		Expected	$E_e - E_o$	Expected	$E_e - E_o$	Expected	$E_e - E_o$
1966	40,000	42,326	+ 2,326				
1967	65,000	87,645	+22,645				
1968	70,000	36,542	-33,457	23,268	-46,731		
1969	35,000	29,179	- 5,821	95,372	25,372		
1970	50,000	29,096	-20,904	38,446	-11,554		
1972	25,000	26,365	1,365	28,772	3,772		
1973	35,000	31,198	- 3,802	38,736	3,736		
1974	70,000			91,008	21,008	27,803	-42,196
1975	70,000					72,289	2,289
1976	100,000			62,120	-37,880	126,784	26,784
1977	65,000			44,278	-20,722	103,625	38,625
1978	130,000			52,755	-77,245	56,490	-73,510
1979	95,000			104,158	9,158	43,144	-51,855
1980	∿145,000			88,096	-87,951		

if the calculated scaling factor of 1931 is applied to the catch and effort data from Lewis Point for 1980 (45.6 kings per 100 fathom hours), the estimated escapement for 1980 is 88,000 fish compared to 145,000 estimated by aerial survey (Table 8). This difference may stem from many sources. The assumptions made at the start of the study, i.e. that the catchability, q is constant throughout the season and between years and equal for all ages and for both sexes may not hold. Two possible causes for violation of these assumptions are:

1) <u>Changes in gear composition</u>

King salmon are being caught by a number of net sizes in the Nushagak district. The standard mesh size for kings in the subsistence fishery is 8 3/4". In the commercial fishery there is a minimum of 6 3/4" before June 16 (ADFG 1980). Kings are also caught in sockeye gear, 5 1/4", both in the commercial and subsistence fishery. If the gear used in the subsistence fishery changes from year to year, i.e. if the proportion of one mesh to the other changes, so must the catchability coefficient q.

2) <u>Changes in age composition</u>

As discussed in the Introduction gillnet selectivity is an important factor in a king fishery due to the wide range of sizes of the fish in the four age classes (4, 5, 6 and 7-year-olds). Selectivity of a gillnet is basically a function of the mesh size and the girth of the fish. It has been related to length using various conversion equations as length is a more easily obtained parameter. McCombie and Berst (1969) found that the efficiency of gillnets was greatest when the maximum girth of the fish was about 1.25 times as great as the perimeter of the mesh ($G/p = 1.25$) and negligible at G/p values less than 0.8, when the fish could easily swim through the mesh opening, and at G/p values over 1.6, when the mesh could not reach above the operculum of the fish. Fish are caught by wedging and tangling and in general gillnet selectivity curves are broader and more skewed to the right when many fish are tangled, i.e. large fish tend more to tangle than fish smaller than the modal length (Hamley 1975). The relative importance of wedging and tangling is determined by the body form of the fish and the hanging coefficient of the net (Ishida 1969). A net loosely hung will catch more fish by tangling.

Selection curves for salmon (Ishida 1969) decline more rapidly below the modal length (Fig. 9). Assuming the modal length occurs at G/p = 1.25 and the upper bound at G/p = 2.00, selectivity as a function of length for king salmon was postulated following the shape of the curves in Figure 9. Since no data on length-girth relationships for king salmon were available a relationship derived for sockeye in the Nushagak in 1946-48 was used (Burgner 1947). Lengths for the critical G/p values were calculated (Table 9) and curves plotted (Fig. 10).

Average lengths of each age class, male and female, are indicated by arrows in Figure 10. The position of the mean lengths relative to the modal lengths of the selectivity curves suggests that 8 3/4" mesh nets select mainly for 5 and 6-year-olds and take few 4-year-olds, while 6 3/4" nets take mainly 4-year-olds.

Yearly or in-season variation in age composition will result in changes in catchability. In the subsistence net fishery the larger meshed nets are selecting for older fish, which are predominantly females (Table 3), and

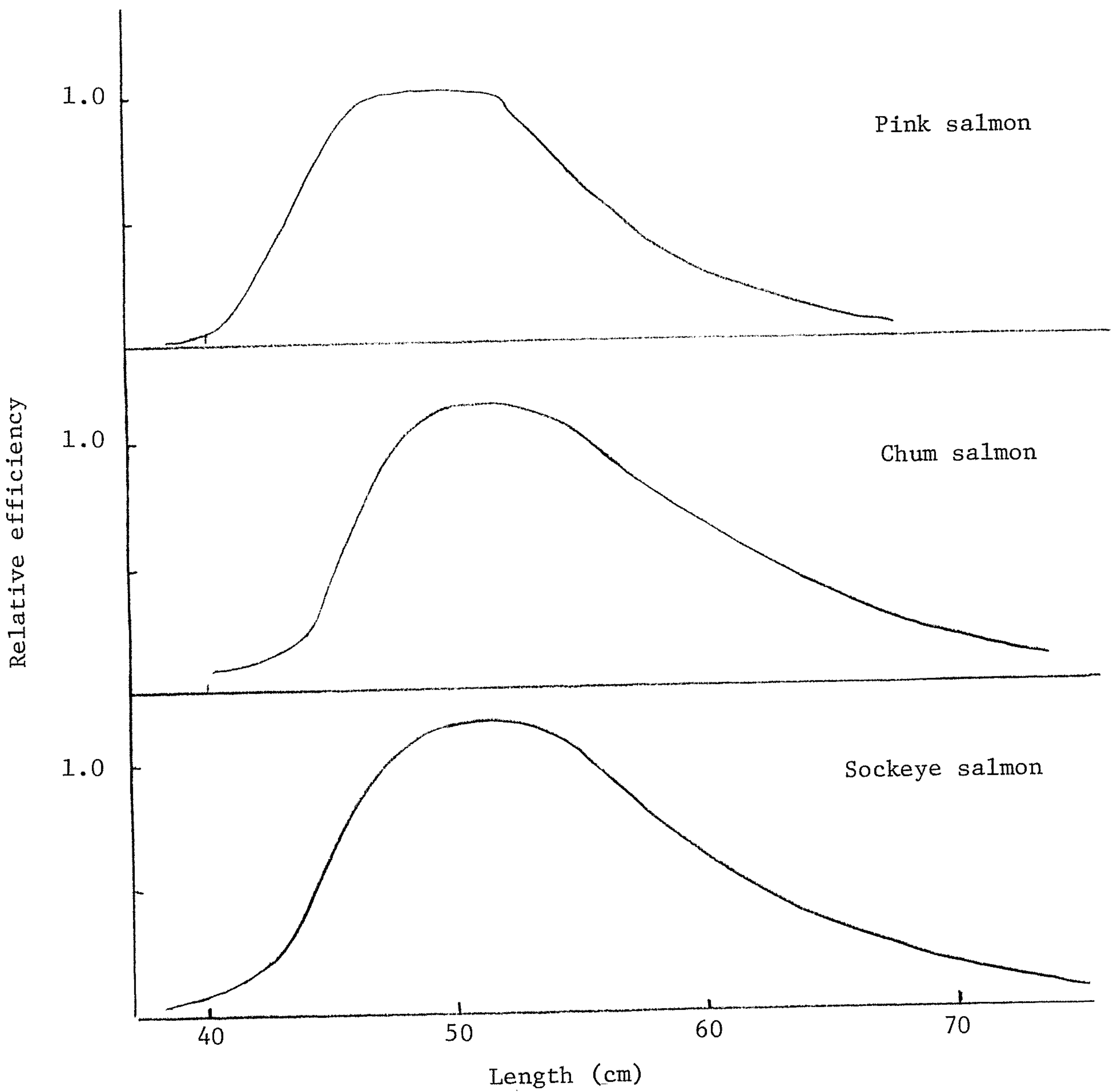

Figure 9. Selectivity curves for Pacific salmon (from Ishida 1969) of 4 1/2" mesh.

Table 9 (a). Girth-length relationship derived for sockeye salmon in Nushagak 1946-48.[1]

$$G = a + bL$$

Sex	a	b	r	n
F	-105.0	.829	.77	2117
M	- 98.9	.794	.71	2322

Table 9 (b). Lengths derived for critical values of girth to mesh perimeter ratio (G/p).

Mesh (inches)	Perimeter (mm)	Sex	Lengths (mm) G/p=1	G/p=1.25	G/p=1.6	G/p=2.0
6 3/4	343	F	557	665	816	989
"	∿	M	539	643	787	953
8 3/4	448	F	689	830	1030	1256
∿	∿	M	666	801	990	1206

[1] F.R.I. 1951. Mesh experiments 1946-1948. F.R.I. Bristol Bay Research unpublished data.

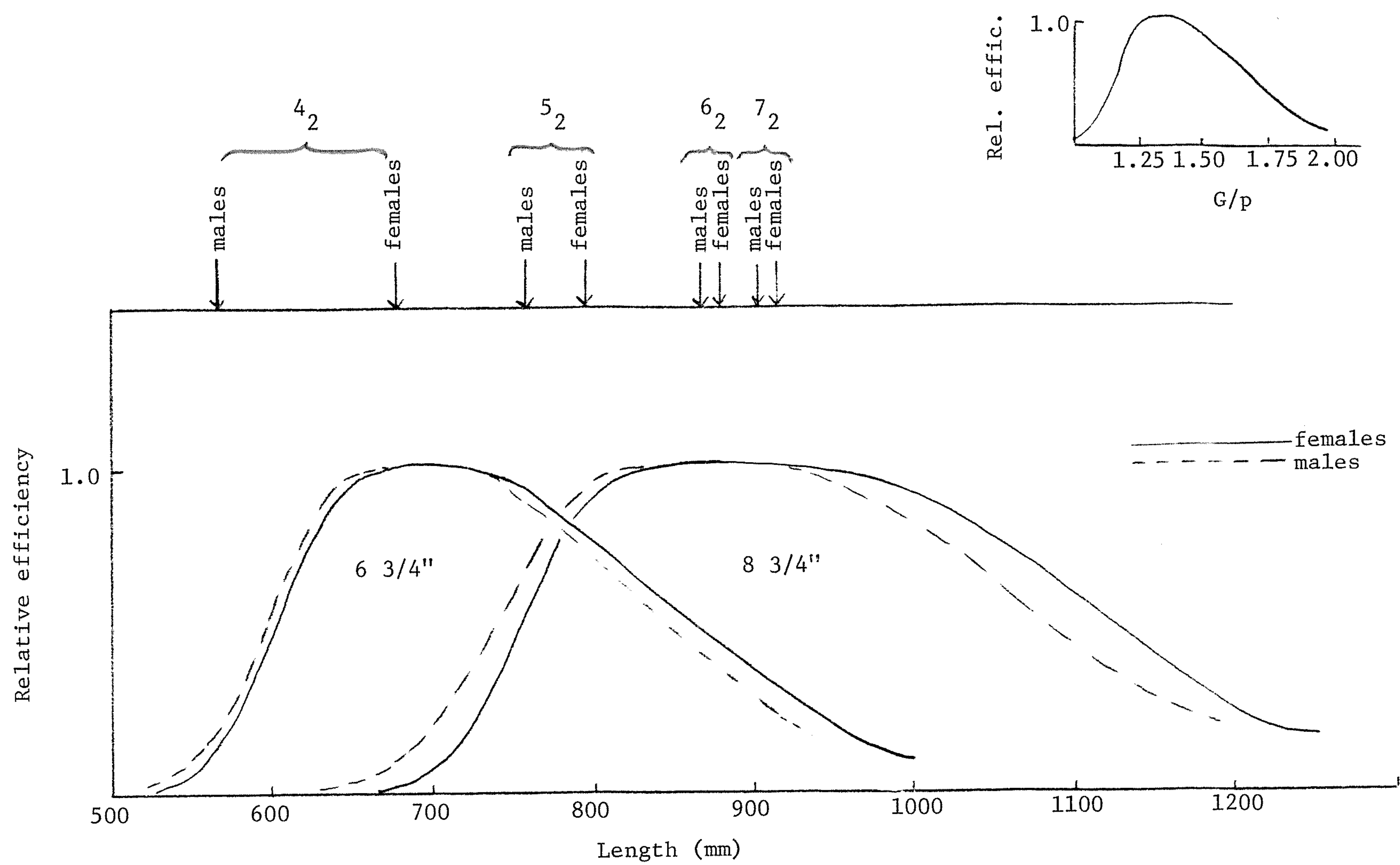

Figure 10. Selectivity by length and mean lengths by age class for king salmon. Calculated on the basis of the shape of selectivity curves in Figure 9 setting modal length equal to G/p = 1.25 and that upper bound of vulnerability equals G/p = 2.0 from right-hand insert.

allowing the 4-year-olds, mainly male, to escape. Assuming the mesh used is over 8" for kings and the catch represents 5, 6 and 7-year-olds, then true catchability is

$$q = \frac{C_5 + C_6 + C_7}{E_5 + E_6 + E_7}$$

where C_5 = catch of 5-year-olds

E_5 = escapement of 5-year-olds

Four-year-olds are not represented in the catch, but presumably counted in the aerial surveys. The catchability therefore is biased as aerial surveys were used in its estimate. The error will depend on the variable proportion of 4-year-olds in the run, e.g. in years with a high proportion of 4-year-olds the catchability would be underestimated.

DISCUSSION AND CONCLUSIONS

Management of king salmon, like that of sockeye, is complicated by the multi-age nature of the returning populations and the differences in sex ratios between age classes. Presently the data base for king salmon management in the Nushagak district consists of catch and effort data from the commercial fishery, age, weight and length data from the same and the numerical aerial estimate of the escapement.

Certain points can be made in reference to present management:

1. The resident fishery is a good relative indicator of escapement, i.e. that all segments are escaping. This can be measured by

a) absolute resident catches, and

b) catch per unit of effort.

By comparing the commercial catches to catches in the river in-season the manager can judge whether an adequate proportion of the run is escaping. This is important because

a) separate spawning populations may arrive at different times of the season, and

b) the age classes arrive at different times as discussed in the Introduction.

2. The scaling factor derived in this study is an index of the escapement past the sampling points, and cannot be used as an accurate estimation of escapement.

There are two important factors involved:

a) variability in catchability due to changes in mesh sizes used and differing composition of run, and

b) the aerial estimate of escapement is by its nature a relative estimate and not a precise measure.

RECOMMENDATIONS

The catches in the resident subsistence fishery or the catch per unit of standardized effort reflect the daily escapement in relative terms. Such a daily or seasonal index can be converted into absolute units by applying a proper scaling factor.

However, escapement calculated in terms of number of fish is not the most useful measure of the escapement which properly should be calculated in terms of potential egg deposition. This necessitates determination of sex ratios within each age group. Some recommendations follow to achieve these many objectives.

1. Assign one field biologist to study and document the resident subsistence fishery for kings in the Nushagak River for the purpose of clarifying net selectivity, observing sex ratios in the catches and variability between the nets at one location or between locations. More specifically the separate steps would be as follows.
2. Explore the possibility of introducing a simple log book system in the resident subsistence king fishery to selected permit holders for recording fishing time and daily catches by size groups or at least isolate catches of 4-year-olds. Otherwise this will require the assignment of a biologist since it is essential to build a reliable data file.
3. Since fecundity is a linear function of the weight of females, net selectivity, if any, for the 5-year or older females must be studied, and two possible methods are available:
    a. Conduct a variable mesh experiment in the resident fishery with, for example, 5 3/8", 6 1/4" and 8 1/2" mesh nets as the commonly used mesh sizes to reveal if size selection is a serious factor.
    b. Regularly measure lengths in the resident subsistence fishery during the season and compare an overall seasonal length frequency distribution to that established from measurements in the commercial fishery. This is another way of establishing the ongoing size selection in the fishery and its extent.

4. An in-season estimate of the absolute size of the escapement is necessary for efficient management. However, the scaling factors developed in this paper are based on aerial escapement estimates. If this is underestimated by 50 percent the scaling factor is overestimated by the same amount and vice-versa. A random error, even if it is of a considerable magnitude, would be less serious than a systematic bias in addition to a random error. A baseline study with one or two years of extensive ground surveys, possibly including limited tagging studies on selected spawning beds, to provide a ground truth for aerial estimates is clearly needed. In addition, this calibration would render a more realistic estimate of the average rate of exploitation and the catchability coefficient from which the managers could use catch per unit of effort in the fishery to estimate the escapement.

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