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EVALUATION OF NUSHAGAK SOCKEYE ESCAPEMENTS

by

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EVALUATION OF NUSHAGAK SOCKEYE ESCAPEMENTS

INTRODUCTION

The sockeye salmon runs to the Nushagak District of Bristol Bay increased in 1978 and have remained above the recent (since 1949) average through 1982. With the large runs there were large escapements in 1978-80 to the Wood River lake system and 1978-81 to the Igushik lake system that were greater than most of the escapements over the previous 30 years. The 1980 escapements to the Nushagak lake systems were the largest enumerated escapements on record and the density (in terms of lake surface area) of spawners in the Igushik Lakes was the highest ever recorded in Bristol Bay (27,000 per km^2).

There are few observations on the relative production from large escapements in Bristol Bay or on the effects of large escapements on the lake ecosystems which provide the rearing areas for juvenile sockeye salmon. The impact of large escapements and returns on the management of sockeye salmon runs can be profound because they may significantly alter the spawner-return relationships that form the basis for escapement goals and forecasts of future runs. Extreme conditions, e.g., very low or very high abundance, growth, temperature, etc., also provide the most important information on the factors and mechanisms that regulate the abundance of sockeye salmon runs.

The objectives of this two-year research program were:

A. Monitor populations in the Wood River lakes to estimate 1) escapements and returns to individual lakes, 2) relative abundance and growth of juveniles, and 3) biological and physical parameters associated with the growth and production of juveniles.

B. Evaluate the impact of the record large escapements in the Igushik system by estimating 1) growth and relative abundance of juvenile salmon and competitor species, 2) densities of phytoplankton (chlorophyll _a_) and secondary producers (zooplankton), 3) age composition of juvenile sockeye to determine holdover rate, and 4) optimum escapement based on freshwater data.

C. Estimate the optimum escapement for the Wood River lake system from spawner-return relationships for individual lakes and type of spawning ground.

Much of the data from our monitoring of conditions in the Wood River lake system were presented in the preliminary report (October 1982). The Wood River data that are pertinent to the evaluation of the observations collected in the Igushik Lakes in 1981 and 1982 are included in this report along with the rather limited historical data from the Igushik

Lakes. The main emphasis of this report is on the estimates of escapement goals for the Wood River lake system. Finally, spawner-return data for Nushagak pink salmon are examined to determine whether variability can be reduced by annual temperature data. Most of the spawner-return data presented in this report were presented at the Bristol Bay Interagency meeting in Anchorage (February 1983).

METHODS

The sampling in the Igushik lakes in 1981 and 1982 was very similar to the sampling conducted in 1965-66 and 1974 and followed procedures employed in the Wood River lake system since the early 1960s. Chlorophyll, zooplankton, and beach seine sampling were conducted once in late-July and once in early-August 1981 and 1982. Both Igushik lakes were sampled in 1981 but only Lake Amanka was sampled in 1982 because funding was reduced.

Aerial surveys of spawning sockeye salmon in the Igushik Lakes were conducted annually from the early 1950s through 1966, but then only in 1974 and 1980. Lake Ualik had about 60% of the aerially estimated escapement in 1980, but since no surveys were conducted in most recent years, it was not possible to examine separate spawner-return relationships for each of the Igushik Lakes. Aerial surveys have been conducted in the Wood River lake system annually since the late 1940s.[1]

The escapments to the individual Wood River lakes and types of spawning grounds were estimated by apportioning the enumerated lake system escapement (aerial surveys 1946-51 and towers 1952-82) according to the aerial estimates for rivers and beaches and ground survey estimates for most creeks. The age compositions of the escapements were estimated from spawning ground sampling for otoliths (usually 100 males and 100 females per spawning ground). The sex ratio observed from the escapement to the lake system was used to combine the age compositions by sex. The runs to the lakes and spawning grounds were then estimated (by age) from the ratios of run to escapement (by age) for the lake system. Historical (pre-1945) escapements and returns for the Nushagak District were estimated from catch statistics by Mathisen (1971).

RESULTS

Along with the increased abundance of salmon in the Nushagak District (and in most of Western and Central Alaska) since 1978, there was a

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[1]Nelson (1979) presents a description of the methods used in recent years and Gilbert (1968) describes the methods used in earlier years.

change in the weather. Both winter and summer temperatures were generally above average and precipitation was below average until the summer of 1982 which was very cool and wet (Figs. 1 and 2). For most of the sockeye salmon returning in 1978-1980, the change in weather occurred while the fish were at sea. The winters were still quite cold for the 1973-1975 brood years (Fig. 3).

Coincidental with the change in weather, there was also a reduction in the high seas catches of salmon as a result of a renegotiated INPFC treaty with Japan that greatly reduced the area of the fishery in 1978. The Nushagak sockeye salmon runs declined in the late 1940's-early 1950's with large parent escapements and a cooling of the weather in Western Alaska, but in the absence of a high seas fishery (Fig. 4). The stocks appeared to be building in the mid-1950s, but the high seas fishery probably kept the inshore runs at a relatively low level, particularly those stocks with predominantly 3-ocean fish (Igushik, Nuyakuk and the Wood River river spawners).

The runs reached a low point in 1972-73, following the very cold years of 1971-72. The Nushagak fishery was greatly restricted in 1974 and 1975 (particularly in the early part of the run) and escapements were increased primarily in the Wood River and Nuyakuk systems (Fig. 5). The Wood River and Igushik systems have had large runs each year since 1978 and the Nuyakuk each year since 1980. However, within the Wood River system, the runs have not been consistently large to all of the lakes (Fig. 6). Of the large lakes, only Lake Aleknagik and the north arm of Lake Nerka, which contain most of the 3-ocean fish, have had consistently large runs and escapements since 1978. Little Togiak Lake has also had large runs each year since 1978 but this small lake was fertilized during 1974-78. The data from Lakes Aleknagik and Little Togiak in 1981 and 1982 were most comparable to the data collected from the Igushik lakes in those years.

Limnological Data

Limnological sampling in the Nushagak lake systems during the 1960s indicated that the Igushik lakes were the most productive (chlorophyll *a* and secchi depth) of the Nushagak lakes (Burgner et al. 1969). However, the sampling in 1981 and 1982 indicated that the Igushik lakes were similar to the Wood River lakes in productivity (Table 1). During the early 1960s, sockeye salmon escapement densities were relatively low in the Wood River lakes but were high in the Igushik Lakes. There has been an increase in the average summer concentration of chlorophyll *a* in Lake Aleknagik in recent years (Table 2). This increase has occurred with a general increase in sockeye escapements to the lake. Therefore, the primary productivity of the Nushagak lakes may be tied to the abundance of sockeye salmon carcasses which are an important source of nutrients (primarily phosphorus).

The addition of phosphate fertilizer to Little Togiak resulted in an increase in phytoplankton standing crop and a subsequent increase in the standing stock of zooplankton late in the summer (Rogers et al. 1982). The summer abundance of zooplankton in the large Wood River lakes from 1967 through 1978 was inversely correlated with the abundance of fry or parent spawners, although there was considerable variation among the lakes (Fig. 7). The increase in escapements in 1978 and presumably in fry abundance in 1979 did not result in a substantial reduction in zooplankton abundance as would be expected from an increase in predation by the fry. This suggests that zooplankton production was increased from an increase in phytoplankton production that may ultimately have been caused by an increase in nutrients from the larger escapements.

Although zooplankton sampling was rather limited in the Igushik Lakes, the abundances of herbivors in Lake Amanka in 1981 and 1982 (following large sockeye escapements) was higher than the abundances in the earlier years and cladoceans were also more abundant in 1981 in Lake Ualik than in the earlier years (Table 3). So the same phenomenon that was suggested for the Wood River lakes may also have occurred in the Igushik lakes. However, the abundances of the herbivorous zooplankters changes significantly during the summer in the Wood River lakes (Table 4) and we don't know what the summer pattern was in the Igushik lakes because sampling was conducted on only a few selected dates.

Juvenile Fish Abundance and Growth

Beach seine sampling has been conducted annually during the early summer in Lake Aleknagik since 1962 to 1) estimate the relative abundances of sockeye salmon juveniles and associated small fish and 2) the growth rates of sockeye salmon fry, age I threespine stickleback and Arctic char fry. Sampling was also conducted in Little Togiak Lake from 1973 through 1982. Catches of sockeye salmon fry usually declined in late-July as the fish moved offshore (Fig. 8). Notable exceptions occurred in 1972 and 1977 when water temperatures were exceptionally cold (1972) or the lake level was exceptionally high (1977). When water temperatures were very warm, the fry tended to move offshore earlier (e.g., 1974, 1979, 1981). Threespine stickleback also move offshore (primarily the age I fish) with the sockeye fry, whereas the other species remain in the littoral during the summer.

The annual beach seine catches of sockeye salmon fry in Lake Aleknagik from 1962 through 1973 were correlated with the adult returns; however, the adult returns from the 1973-77 brood years were all much greater than expected from the catches in 1974-78. This suggests that the large runs in recent years were caused more by favorable marine survival than by conditions in freshwater.

The beach seine sampling in the Igushik lakes was not as extensive as in Lake Aleknagik and most of it was in late-July or August (Table 5). Nevertheless, some limited inferences can be made. Sockeye fry were more abundant in Lake Amanka than in Lake Ualik, although sockeye spawners were usually more abundant in Lake Ualik; however, the fry in Lake Ualik may move offshore to a greater extent than those in Lake Amanka. The Lake Amanka catches of fry and threespine stickleback were generally higher than catches in Lake Aleknagik for comparable dates and there appeared to be a significant holdover of fry from the 1980 brood because the average catch of yearling sockeye in Lake Amanka in 1982 was relatively high. Beach seine catches of yearlings in Lake Aleknagik during late-July and early-August 1982 were also high (1982 mean = 9; 1962-81 mean = 2, annual range = 0-11).

The Igushik Lakes have historically produced a higher proportion of age 2. adult sockeye in the returns (22%) than the other Nushagak lake systems (Wood 13%, Nuyakuk 9%) and this was probably caused by the higher spawner densities and presumably higher densities and poorer growth of fry in the Igushik lakes. The sockeye salmon in the Nushagak District probably have a genetically controlled tendency to smoltify after one year in the lake; however, if growth is reduced from either cold temperatures or high densities, a variable proportion of the juveniles may be too small for smoltification (i.e., less than 60 mm) after one summer's growth.

The annual growth of sockeye salmon fry was estimated from the periodic beach seine sampling and tow-net sampling in late-August to early-September. The statistics for 1982 from Lake Aleknagik and Little Togiak Lake are given in Tables 6 and 7. The annual length trajectories for Lake Aleknagik are shown in Figure 10 which illustrates the variety of growth patterns which have occurred over the past 21 years. In 1974 and 1981 there were warm spring temperatures and early ice breakups. The fry were large during the early summer in both years; however, in 1974 there was a low density of fry and a high growth rate in August, whereas in 1981, there was a high density of fry and a low growth rate in August. Water temperatures were cold in 1982, nearly as cold as those in 1971 and 1972, and growth was poor in the early summer.

The same factors (temperature and fish density) that affect the growth of sockeye salmon fry in Lake Aleknagik appear to affect the growth of fry in Lake Amanka. The length statistics from the beach seine sampling in the Igushik Lakes are given in Table 8 and the mean lengths of sockeye salmon fry and age I threespine sticklebacks on selected dates are plotted with the Lake Aleknagik length trajectories in Figure 11. The data for 1966 were similar to 1982 and were omitted for clarity. The mean lengths of sockeye salmon fry were similar for the two lakes in each year. The mean lengths in 1981 and 1982 were not as small as expected from the abundance of parent spawners. The growth of the fry in 1981 was enhanced by the early spring and warm temperatures, whereas the growth in 1982 was probably enhanced by the high primary productivity which was indicated by the high chlorophyll concentrations in 1982 (Tables 1 and 2).

The threespine stickleback is the main competitor with sockeye salmon fry and the annual mean lengths of the age I stickleback and sockeye fry were correlated in the Wood River lakes (Tables 9 and 10). Annual fluctuations in the abundance of sockeye salmon affects the growth of the stickleback but stickleback abundance may also affect their growth. They were more abundant in Lake Amanka than in Lake Aleknagik and their lengths were consistently shorter (Fig. 11).

The abundance of sockeye salmon may affect the abundance of threespine stickleback from the effect on their growth. The abundance of threespine stickleback in Lake Aleknagik apparently declined in the early 1970s as a result of the very cold springs in 1971 and 1972 (Fig. 9). The populations built up in the mid-1970s but have been relatively low since 1978 as the sockeye escapements to Lake Aleknagik increased. Tow net catches of threespine stickleback were very low in 1971-73 and in 1980-82.

The annual mean lengths of sockeye salmon fry on September 1 were inversely correlated with the parent spawner density in the Wood River lakes, but in recent years the fry have been larger than expected from the density of parent spawners (Table 11). Either the number of fry produced per spawner declined or growth conditions improved.

Sockeye Escapements and Returns

Management of the Nushagak sockeye salmon since the 1960s has been aimed at regulating the fishery to obtain escapement goals for the three main lake systems. The escapement goals were estimated from spawner (escapement) - return relationships which were calculated by regressing the logarithm of the return per spawner on the number of spawners (a linear fit of the Ricker curve). The optimum escapment (escapement goal) was that escapement which on the average produced the largest difference between the predicted return and the replacement line (number of return - number of spawners). Spawner-return relationships need periodical evaluation as new data points are accumulated and particularly when these data points are outside the historical data base, as has occurred in the past few years. In addition, computer programs are now available to fit least-squares curves to the data.

Spawner-return relationships are most applicable to individual spawning populations or lakes and become less applicable the greater the number of populations and lakes combined. Unfortunately, the accuracy of the data declines with small units (spawning populations or lakes) because of the potential error in prorating the catch and estimating escapements within a lake system.

If only the escapements since 1952 are considered (the most reliable data), then the returns from the recent brood years (1973-77) to the Nushagak District greatly altered the escapement-return curve (Fig. 12). However, between 1952 and 1977, there was only one escapement greater than 3 million (1959) and the escapements in 1978-80 were all greater than 3 million. Thus, the relationship for the Nushagak District will likely change significantly, provided that the historical data (1924-46) are applicable to the present.

Escapement-return relationships for the major lake systems in the Nushagak District are shown in Figures 13 and 14. The recent large returns greatly altered the relationship for the Nuyakuk system and an optimum escapement is not apparent. However, considering the rather limited spawning area in the Tikchik lakes, it is likely that the optimum is somewhere below 1 million spawners. The recent large returns to the Igushik system did not significantly alter the shape of the escapement-return relationship. The curve was just elevated from higher returns at intermediate escapements.

The Wood River system has historically produced the largest portion of the Nushagak sockeye salmon runs, and in recent years, there were some significant changes within the lake system that are not apparent from the statistics for the lake system as a whole (Figs. 6 and 15). There was a recent increase in the runs to the large interconnecting rivers (Agulowak and Agulukpak) with five consecutive large runs (1978-82). Only two of the past five runs to the beaches and creeks in the system have been relatively large and these were not as large as some historical runs.

The spawner-return curves for the beaches and creeks were not significantly altered by the recent returns, as was the case for the river spawners (Fig. 16). Little Togiak Lake which contains primarily beach spawners was an exception (Fig. 17); however, the lake was fertilized during 1974-78 and it apparently had a positive effect on the survival of the juveniles.

The spawner-return curves for beach spawners and lakes with predominant beach spawners (e.g., Beverley and Kulik) tend to be flat, i.e., without a sharp reduction in returns at large escapements. The curves for creek spawners do show a sharp reduction in returns from large escapements and the rivers will probably show sharp declines from the large escapements since 1978 (Figs. 18-24). Large numbers of spawners on most of the beaches in the lake system typically result in the utilization of marginal spawning areas, e.g., too shallow and subject to freezing. The fish simply spread out more at high densities. However, in small creeks and in the interconnecting rivers, there is little room to spread out, so superimposition and high densities of eggs result from high densities of spawners, and there is a decline in production rather than a leveling of production at high densities.

Optimum escapements for the Wood River system were calculated by lake, type of spawning area, for the system as a whole, and for different data sets (Table 12). The present escapement goal of 700-800,000 is probably too low to achieve a maximum future production (catch) or to sustain the runs at their recent high level of about 4 million. An escapement goal of 1.2-1.3 million is indicated for maximum sustainable catches in the future, provided that recent environmental conditions (including minimum high seas fishing) continue and that the annual runs will be distributed among the spawning grounds approximately in proportion to their capacities. Escapement goals for the large rivers may change in the next few years because the historical data contains few returns from large escapements.

Higher escapement goals are compatible with the observed higher productivity in the lakes from the recent large escapements. However, until the returns from the 1978-80 brood years are complete, escapements greater than 2 million should be avoided because the decline in the Wood River runs in the early 1950s followed from consecutive large escapements in 1946-48.

Future research needs in the Wood River lake system include 1) continued monitoring of the juvenile sockeye salmon and threespine stickleback populations and the easily measured environmental conditions, 2) continued monitoring of the spawning grounds to estimate the annual escapements and returns within the lake system, and 3) a critical examination of the assumption that the runs bound for the various spawning grounds and lakes are uniformly distributed throughout the run and thus subjected to equal rates of exploitation.

The question of the timing of individual populations within the lake system is pertinent to the validity of the statistics on the populations in the individual lakes and future management strategy. Changes in the age composition of the daily Wood River escapements in 1982 and the difference in the abundances and age compositions on the spawning grounds suggested that the individual populations were not uniformly distributed (Fig. 25). Fish bound for Lake Aleknagik and the north arm of Lake Nerka apparently came mostly from the early half of the escapement, whereas the fishery took a higher proportion of the fish in the middle and late part of the run.

The daily escapements to Little Togiak Lake were enumerated for nine years and they annually lagged behind the Wood River escapements from 3 to 6 days (Fig. 26). Since the time required for sockeye adults to swim from Wood River to Little Togiak River is about 2-3 days, the Little Togiak escapements were lagged back 3 days (4 days for 1982) and compared to the Wood River escapements (Fig. 27). Although the Little Togiak sockeye obviously came from all parts of the Wood River escapement, there was a tendency for the Little Togiak fish to be more represented in the late portion of the run - except in 1961 when the escapement was very small.

A tagging experiment was conducted in 1961 but the results were inconclusive because a very high proportion of the escapement went to the rivers and relatively few fish to the lake beaches. We again conducted a tagging experiment in 1982, but the results were also inconclusive because exceptionally high and turbid water prevented recoveries from the upper lakes' beaches. Another experiment is planned for 1983.

Nushagak Pink Salmon

Pink salmon are ideally suited to examine environmental effects on the relative production because they have a short 2-year life cycle. Early in the Nushagak fishery, there were both even and odd-year runs, but only the stronger even-year run has persisted in significant numbers. Based on the commercial catches, the runs were quite small (probably less than 2 million) from 1922 through 1956. In 1958, an exceptional run occurred, and since then, annual estimates of the escapements have been made by ADF&G. The aerial surveys were not always complete; so to make the annual estimates comparable, I included estimates of missing data (Table 13). Pink salmon spawning is concentrated in the Nuyakuk and Tikchik Rivers.

Bristol Bay air temperatures (an average of the Dillingham and King Salmon weather stations) were correlated with the return per spawner and the best correlation was obtained by regressing R/S on the annual (June-May) air temperature prior to their return in late July for escapements less than 1 million (Fig. 28). For higher escapements, there was a correlation between winter temperatures (during incubation) and the deviations from the spawner-return curve.

The returns were adjusted by the temperature regressions and a free-hand curve was drawn to compare with the least-squares curve fitted to the original data (Fig. 29, Table 14). The adjusted curve which indicates the returns to be expected from long-term average temperatures is quite narrow and suggests that returns are very sensitive to the abundance of spawners. Both curves indicate that the optimum escapements is very close to the escapement that on the average has produced the largest returns, i.e., about one million.

The Nushagak pink salmon stock is difficult to manage for maximum sustainable catch because the stock is so sensitive to over or under escapement. However, if escapements can be kept between .5 and 1.5 million, the stock has the potential for average even-year catches of about 7 million.

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Table 1. Comparative limnological measurements made in the Igushik Lakes and the Wood River Lakes in late July to early August, 1981 and 1982

Lake	Date	Density of chlorophyll a 0-20 m (mg/m^2)	Conductivity (micromhos/cm)	Secchi depth (m)	Inshore surface temperature
1981					
Amanka	7/28	--	34.0	7.8	15.7
	8/11	19.9	35.5	8.5	--
Ualik	7/27	--	34.3	9.7	14.0
	8/9	--	--	9.5	--
Aleknagik	8/2	25.3	36.2	9.4	14.2
Little Togiak	7/29	30.2	50.0	8.4	14.0
	8/14	23.0	--	8.8	--
1982					
Amanka	7/23	39.7	36.0	6.3	11.8
	8/16	33.4	36.0	6.3	15.2
Aleknagik	8/3	36.4	36.2	6.8	10.4
Little Togiak	7/20	55.0	48.2	4.9	9.5
	8/13	40.6	49.0	5.8	12.9

Table 2. Average concentration of chlorophyll a (mg/m^2, 0-20 m) for two stations in Lake Aleknagik by dates and days after ice breakup (d), 1963-1982.

Year	June 21-25		July 10-16		Aug. 1-6		Sept. 1-5		Sept.	
	d	mg/m^2	3	mg/m^2	d	mg/m^2	d	mg/m^2	d	mg/m^2
1963	--	--	39	20	70	12	95	14		--
1964	--	--	29	40	51	26	86	20		--
1965	21	22	44	33	67	20	99	22		--
1966	19	20	38	15	66	9	91	21		--
1967	29	10	47	10	72	6	99	12		--
1968	29	20	45	21	68	18	96	23		--
1969	21	18	42	31	65	14	95	16		--
1970	30	28	51	22	75	16	104	18		--
1971	7	15	27	40	51	26	85	14		--
1972	15	21	35	33	56	21	88	17		--
1973	22	34	41	34	64	24	95	26	116	--
1974	32	41	52	24	76	10	105	26		--
1975	18	21	37	31	58	22	86	22		--
1976	15	24	40	29	60	19	90	22		--
1977	22	32	44	43	64	26	94	32		--
1978	34	25	54	17	76	26	103	20	122	--
1979	36	29	57	23	79	24	109	37		--
1980	36	26	60	37	79	36	111	36		--
1981	32	40	48	26	73	25	101	22		--
1982	20	45	39	40	59	36	90	24		--

Table 3. Geometric means from zooplankton hauls in the Igushik lakes.

				Thousands per m^2							Volume
Lake	Year	Date	n	Cyclops	Calanoid	Daphnia	Eubosmina	Holopedium	Total	Rotifer	ml/m^2
Amanka	65	7/8-10	7	73	36	8	14	12	155	--	89
	66	7/2	2	73	30	4	8	13	143	--	152
	74	8/27	3	3	6	29	37	+	77	+	11
	81	7/28	3	63	22	30	156	5	290	15	99
		8/10	2	27	16	38	100	4	203	6	36
	82	7/23	3	110	24	11	14	1	182	126	71
		8/6	3	64	19	27	37	3	156	31	93
Ualik	65	7/9	5	151	37	21	25	19	261	--	148
	66	7/20	3	270	45	5	42	24	398	--	219
	74	9/8	3	28	97	47	50	5	239	+	74
	81	7/27	3	38	18	48	82	12	210	16	88
		8/9	3	17	29	74	87	16	228	3	92

Table 4. Geometric means from zooplankton hauls in 1982 by lake and date (n = 6).

		Thousands per m²							
		Copepods		Cladocera					Volume
Lake	Date	Cyclops	Calanoid	Daphnia	Eubosmina	Holopedium	Total	Rotifers	ml/m²
Little Togiak	6/20	54	10	1	14	0	82	2	29
	7/3	62	6	1	16	0.1	88	2	26
	7/11	55	5	1	13	0	77	3	15
	7/20	85	6	1	13	0.1	111	3	28
	8/13	131	26	14	96	0	279	64	50
	8/30	80	29	32	98	0.1	249	37	44
Aleknagik	6/25	112	9	1	7	2.2	136	17	20
	7/14	184	14	1	7	1.2	214	48	77
	8/3	169	19	1	19	7.6	230	235	109
	9/3	78	30	10	93	5.5	247	42	83
Lake Nerka									
North	8/31	99	22	19	155	0.2	308	2	75
Central	8/28	110	32	17	54	1.6	234	27	110
South	9/1	104	14	21	85	7.7	252	13	122
Beverley	8/23	131	70	62	115	0.9	386	7	96
Kulik	8/21	153	90	21	48	12.2	339	17	145
Lake system weighted mean 8/21-9/3		109	41	27	100	3.9	298	17	99
1967-1981 system mean		95	46	29	78	4.0	264	9	89
Annual range LL		53	24	7	46	1.0	186	3	44
UL		166	64	70	111	9.0	376	15	126

Table 5. Geometric means of beach seine catches in the Igushik lakes.

Lake	Year	Date	Hauls (n)	Sockeye Salmon Age 0	Sockeye Salmon Age I+	Sticklebacks Threespine	Sticklebacks Ninespine	Sculpin	Char (Age 0)
Amanka	65	6/28-30	12	284	1.3	937	9	8	4.0
		7/25-27	6	34	0.6	559	26	4	3.0
	66	7/28	4	408	14.0	605	8	6	1.0
	74	8/12	10	8	0.2	467	31	29	0.2
		8/30	10	5	0.2	142	25	20	0.0
	81	7/27	10	54	0.1	187	8	8	0.1
		8/10	8	38	0.1	118	12	2	0.0
	82	7/23	10	135	6.0	285	5	3	2.0
		8/6	10	218	8.0	536	23	5	1.0
Ualik	65	6/29	11	92	0.3	165	2	22	12.0
	74	8/15	10	1	0.1	21	2	33	1.0
		8/27	9	1	0.1	164	14	43	1.0
	81	7/26	10	2	0.1	169	3	2	18.0

Table 6. Geometric means of beach seine catches and mean lengths (live equivalent, mm) by sampling area in Lake Aleknagik, 1982.

Date	Area A		Area B		Area C		Weighted mean	
	$\bar{C}$	$\bar{L}$	$\bar{C}$	$\bar{L}$	$\bar{C}$	$\bar{L}$	$\bar{C}$	$\bar{L}$
				Sockeye salmon (age 0)				
6/24	3	30.4	100	30.7	195	29.6	38	30.0
7/1	9	32.1	82	30.3	11	31.3	20	30.6
7/7	6	32.1	46	31.8	126	32.1	32	32.0
7/13	156	34.6	155	33.4	67	34.9	118	34.2
7/24	24	37.3	8	34.6	34	35.5	19	36.0
8/1	23	43.0	18	38.1	26	38.5	22	39.9
9/2*	34	53.4	42	49.1	317	53.1	77	52.7
				Threespine Stickleback (age I)				
6/24	5	31.4	17	30.0	37	37.1	15	30.2
7/1	3	34.1	42	30.4	7	32.1	10	30.8
7/7	10	33.5	25	31.0	35	33.2	21	32.5
7/13	61	34.9	112	32.9	134	33.3	97	33.5
7/24	26	35.6	3	34.0	4	33.7	7	35.2
8/1	13	35.9	6	33.9	4	36.8	7	35.5
9/2*	4	43.7	4	42.2	16	43.5	6	43.3
				Arctic Char (age 0)				
6/24	3	30.0	2	29.9	1	28.9	2	29.7
7/1	1	30.1	1	30.0	+	31.9	1	30.3
7/7	4	30.5	1	30.6	1	29.6	2	30.3
7/13	2	31.5	+	30.6	+	29.9	1	31.1
7/24	5	36.8	1	30.9	1	32.8	2	35.7
8/1	1	35.1	2	30.2	1	34.5	1	32.7

*Townet sampling

Table 7. Geometric means of beach seine catches and mean lengths (live equivalent, mm) by sampling area in Little Togiak Lake, 1982

Date	Area A		Area B		Area C		Weighted mean	
	$\bar{C}$	$\bar{L}$	$\bar{C}$	$\bar{L}$	$\bar{C}$	$\bar{L}$	$\bar{C}$	$\bar{L}$
			Sockeye salmon (age 0)					
6/22	1	28.0	18	29.8	1	29.4	3	29.6
6/30	+	28.9	96	31.3	10	30.5	10	31.2
7/8	16	29.6	8	29.9	9	31.3	11	30.1
7/17	26	30.3	52	30.8	174	31.3	61	31.1
8/30*	88	46.1	52	47.8	94	50.2	75	48.1
8/31	0	--	1	38.7	15	43.0	2	42.8
			Threespine Stickleback (age I)					
6/22	1	24.9	1	28.4	0	--	1	27.0
6/30	0	--	5	29.6	3	27.6	2	28.8
7/8	3	28.2	4	27.4	2	28.0	3	27.9
7/17	6	26.6	11	27.5	43	29.0	14	28.5
8/30*	7	38.4	10	38.6	11	38.1	9	38.4
8.31	0	--	2	36.3	32	37.5	4	37.4
			Arctic Char (age 0)					
6/22	+	28.9	1	29.1	2	29.2	1	29.1
6/30	5	30.0	4	29.9	8	29.7	6	29.8
7/8	5	30.1	11	30.3	17	29.6	10	29.9
7/17	9	30.1	81	30.8	27	30.5	27	30.7
8/31	1	32.3	10	38.6	10	39.2	5	38.6

*Townet sampling

Table 8. Mean lengths (live equivalent, mm) from beach seine sampling in the Igushik Lakes.

Lake	Year	Mean Date	Sockeye Salmon Age 0		Sockeye Salmon Age I		Threespine stickle. (I)		Char (age 0)	
			n	$\bar{L}$	n	$\bar{L}$	n	$\bar{L}$	n	$\bar{L}$
Amanka	65	6/29	1031	32.6	91	66.4	1037	26.1	19	33.7
		7/26	215	42.2	18	91.8	492	30.2	150	28.9
	66	7/28	211	32.1	190	62.8	437	26.1	1	28.0
	74	8/12	--	53.0	--	--	--	43.2	--	47.4
		8/30	--	56.2	--	--	--	44.3	--	--
	81	7/28	370	43.0	2	82.8	207	37.8	1	30.0
		8/10	164	44.1	1	62.5	72	39.8	18	38.7
	82	7/23	569	37.1	105	57.2	880	31.2	18	30.8
		8/6	513	39.6	68	65.5	1007	33.4	3	33.3
Ualik	66	6/29	450	29.3	23	86.1	86	26.1	281	29.3
	74	8/15	--	43.4	--		--	37.9	--	42.4
		8/27	--	48.8	--		--	46.3	--	40.9
	81	7/26	12	40.4	1	65.0	79	36.6	146	35.1

Table 9. Mean lengths (mm) on selected dates and growth rates in mm/day for sockeye salmon fry, threespine stickleback, and Arctic char fry from Lake Aleknagik, 1962-1982.

	Sockeye salmon (age 0)						Threespine stickleback (age I)						Arctic char (age 0)		
	Mean length			Growth rates			Mean lengths			Growth rates			Mean length		Growth rate
Year	6/20	7/20	9/1	6/20-7/20	7/20-9/1	6/20-9/1	6/20	7/20	9/1	6/20-7/20	7/20-9/1	6/20-9/1	6/20	7/20	6/20-7/20
1962	30.6	38.1	54.1	.25	.37	.32	29.1	33.9	43.6	.16	.23	.20	--	--	--
1963	--	44.9	62.1	--	.40	(.43)	--	36.9	46.7	--	.23	(.22)	--	35.3	(.18)
1964	30.3	36.4	60.4	.20	.56	.41	31.4	34.0	43.0	.09	.21	.16	28.3	32.7	.15
1965	29.0	35.5	53.6	.22	.42	.34	28.1	31.8	39.5	.12	.18	.16	28.6	32.9	.14
1966	29.8	33.0	47.5	.11	.34	.24	27.0	30.6	39.4	.12	.20	.17	28.9	31.8	.10
1967	29.5	35.1	43.4	.19	.19	.19	28.2	31.5	41.3	.11	.23	.18	27.6	32.3	.16
1968	30.8	43.9	57.9	.44	.33	.37	30.2	35.4	43.4	.17	.19	.18	30.0	34.7	.16
1969	30.6	39.2	61.4	.29	.52	.42	32.0	35.3	44.0	.11	.20	.16	27.9	33.6	.19
1970	29.8	40.4	59.0	.35	.43	.40	31.4	36.6	42.6	.17	.14	.15	28.4	34.6	.21
1971	29.5	33.5	54.6	.13	.49	.34	28.8	33.1	42.9	.14	.23	.19	28.5	31.5	.10
1972	28.5	34.3	54.8	.19	.48	.36	27.8	32.8	44.4	.17	.27	.23	26.6	33.2	.22
1973	28.0	36.6	66.7	.29	.70	.53	29.0	35.4	49.5	.21	.33	.28	28.3	33.2	.16
1974	35.9	42.2	62.8	.21	.48	.37	32.8	39.7	50.1	.23	.24	.24	28.9	37.0	.27
1975	28.5	34.1	55.3	.19	.49	.37	31.1	34.7	42.3	.12	.18	.15	29.0	32.8	.13
1976	28.6	35.1	49.8	.22	.34	.29	26.3	31.8	39.6	.18	.18	.18	27.8	32.3	.15
1977	29.5	34.1	48.0	.15	.32	.25	28.2	32.5	40.8	.14	.19	.17	28.5	31.0	.08
1978	32.4	39.7	62.5	.24	.53	.41	30.5	35.5	47.5	.17	.28	.23	30.4	33.5	.10
1979	31.4	39.4	51.5	.27	.28	.28	33.0	37.7	42.3	.16	.11	.13	28.6	32.0	.11
1980	30.7	38.0	56.4	.24	.43	.35	30.3	34.0	44.9	.12	.25	.20	29.3	33.5	.14
1981	32.0	41.4	51.3	.31	.23	.26	34.5	39.0	45.5	.15	.15	.15	29.9	37.0	.24
1982	29.2	35.5	52.2	.21	.39	.32	29.0	34.5	43.1	.18	.20	.19	29.3	32.0	.09

Table 10. Mean lengths (mm) on selected dates and growth rates in mm/day for sockeye salmon fry, threespine stickleback, and Arctic char fry from Little Togiak Lake, 1973-1982.

	Sockeye salmon (age 0)						Threespine stickleback (age I)						Arctic char (age 0)				
	Mean length			Growth rates			Mean lengths			Growth rates			Mean length			Growth rate	
Year	6/20	7/20	9/1	6/20-7/20	7/20-9/1	6/20-9/1	6/20	7/20	9/1	6/20-7/20	7/20-9/1	6/20 9/1	6/20	7/20	8/10	6/20-7-20	7/20-8/10
1973	28.5	35.0	56.3	.22	.50	.38	27.0*	31.0*	42.0*	.13	.26	.21	28.0	31.5	37.0	.18	.52
1974	30.5	33.0	53.9	.08	.49	.32	30.5	35.0	48.5	.15	.31	.25	29.5	35.0	46.0*	.18	.52
1975	28.5	31.5	44.6	.08	.32	.22	29.5	34.0	41.0	.15	.16	.16	29.0	31.5	35.0*	.08	.17
1976	29.0	31.5	49.0	.08	.41	.27	26.5	33.5	41.0	.23	.17	.20	29.0	30.5	34.5*	.05	.19
1977	25.5	33.0	45.4	.25	.29	.27	25.0	28.5	38.5	.12	.23	.18	28.5	31.0	34.5*	.08	.17
1978	29.5	34.5	54.9	.16	.47	.35	27.5	30.0	41.1	.08	.26	.19	29.4	33.7	39.5*	.14	.28
1979	29.8	38.5	58.5	.29	.46	.39	28.6	32.7	41.6	.14	.21	.18	28.5	31.6	35.0*	.10	.16
1980	29.7	32.7	48.4	.10	.36	.26	28.0	30.0	40.6	.07	.25	.17	28.5	31.4	34.5*	.10	.15
1981	30.5	36.5	54.0	.20	.41	.32	27.6	31.6	42.2	.13	.25	.20	30.2	33.5	38.7*	.11	.25
1982	29.2	34.2	49.2	.17	.35	.27	27.0	29.6	38.7	.09	.21	.16	28.8	31.0	34.4	.07	.16

*Small sample sizes

Table 11. Parent spawner densities (1,000s per km^2 of lake surface area) and the mean lengths (mm) and calculated mean weight (gm) of sockeye salmon fry on September 1 of the following year.[1]

Brood	Aleknagik			South Nerka			Central Nerka			North Nerka			Little Togiak			Beverley			Kulik		
Year	S	$\bar{L}$	$\bar{W}$	S	$\bar{L}$	$\bar{W}$	S	$\bar{L}$	$\bar{W}$	S	$\bar{L}$	$\bar{W}$	S	$\bar{L}$	$\bar{W}$	S	$\bar{L}$	$\bar{W}$	S	$\bar{L}$	$\bar{W}$
1957	1.1	62.1	2.15	1.2	61.8	2.12	1.1	60.1	1.95	.6	61.5	2.09	.9	60.3	1.97	.1	61.5	2.09	.1	61.8	2.12
1958	.8	62.7	2.22	2.6	65.7	2.55	1.1	61.3	2.06	2.2	61.3	2.07	2.7	63.1	2.26	3.9	56.2	1.60	2.2	61.1	2.05
1959	2.5	55.5	1.54	8.9	58.4	1.79	6.5	55.3	1.52	4.6	51.3	1.22	6.7	55.4	1.53	4.6	46.8	.92	6.3	53.4	1.37
1960	1.0	58.4	1.79	3.6	58.6	1.81	2.7	55.9	1.57	2.5	54.2	1.44	2.8	55.2	1.51	2.3	55.9	1.57	2.3	54.8	1.48
1961	1.8	54.1	1.43	.8	63.6	2.32	1.0	59.0	1.85	1.7	59.9	1.85	1.8	57.4	1.70	.4	61.8	2.12	.4	61.2	2.06
1962	.6	62.1	2.15	1.5	62.0	2.14	1.4	60.3	1.97	1.5	61.7	2.11	1.7	60.7	2.01	4.6	55.4	1.53	1.8	55.3	1.52
1963	.4	60.4	1.98	.9	57.4	1.70	1.3	55.4	1.53	1.3	63.6	2.31	3.5	54.0	1.42	3.1	49.4	1.08	3.2	51.1	1.20
1964	1.9	53.6	1.39	1.7	56.9	1.66	3.1	53.6	1.39	1.9	53.8	1.40	2.5	51.1	1.20	3.6	50.6	1.17	3.0	49.0	1.06
1965	2.7	47.6	.97	.9	57.4	1.70	1.5	53.6	1.39	2.1	54.2	1.44	4.4	46.4	.90	.7	56.5	1.62	.6	55.6	1.55
1966	3.5	43.4	.74	2.4	63.6	2.32	2.7	58.0	1.76	2.8	59.0	1.85	3.7	53.0	1.34	3.1	55.3	1.52	1.6	62.6	2.21
1967	1.1	57.9	1.75	.7	68.5	2.89	1.2	64.1	2.37	1.3	65.0	2.47	1.7	56.3	1.61	1.3	64.1	2.37	1.4	71.1	3.23
1968	2.1	61.5	2.09	.7	65.2	2.49	2.0	60.9	2.03	1.7	59.4	1.89	3.3	50.6	1.17	1.2	58.5	1.80	.7	63.0	2.25
1969	1.9	59.0	1.85	.8	59.0	1.85	1.1	64.7	2.44	3.1	62.7	2.22	3.3	54.2	1.44	.3	58.7	1.82	.4	63.6	2.32
1970	3.6	54.6	1.46	2.2	54.0	1.42	2.6	51.6	1.24	2.7	57.8	1.74	9.2	47.3	.95	2.6	52.9	1.33	1.2	53.6	1.39
1971	2.2	54.8	1.48	1.1	57.2	1.68	1.4	55.4	1.53	2.1	54.8	1.48	3.9	48.8	1.05	2.7	56.3	1.61	1.5	53.2	1.36
1972	1.2	67.1	2.72	.6	60.8	2.02	1.6	60.7	2.01	1.3	60.9	2.03	2.3	56.2	1.60	.6	66.4	2.63	.7	59.0	1.85
1973	2.0	62.8	2.23	.3	68.7	2.92	.6	63.6	2.32	1.0	64.4	2.40	2.3	53.9	1.41	.1	--	--	.2	--	--
1974	2.9	55.3	1.52	3.7	58.2	1.77	2.7	54.0	1.42	2.8	53.4	1.37	8.0	44.7	.80	4.6	53.5	1.38	7.5	45.8	.86
1975	5.5	49.8	1.11	2.0	52.3	1.29	1.3	49.0	1.06	3.4	45.4	.84	5.0	49.0	1.06	1.4	--	--	3.0	47.4	1.80
1976	3.8	48.0	1.00	1.0	55.0	1.50	1.3	54.6	1.46	2.0	51.3	1.22	3.0	45.4	.84	.9	56.7	1.64	1.7	58.5	1.80
1977	1.8	62.7	2.22	1.1	55.7	1.56	1.3	60.9	2.03	2.0	63.3	2.28	4.3	54.9	1.49	.4	--	--	.8	--	--
1978	7.4	51.5	1.23	2.4	64.4	2.40	3.5	53.6	1.39	5.3	58.0	1.76	7.5	58.5	1.80	4.6	--	--	8.3	59.7	1.91
1979	4.3	56.3	1.61	3.9	52.1	1.27	2.8	48.9	1.05	3.3	47.1	.94	7.3	48.4	1.02	4.0	46.0	.88	4.9	53.2	1.36
1980	14.8	51.3	1.22	3.5	59.4	1.89	4.4	55.0	1.50	6.5	54.7	1.47	13.5	54.0	1.42	4.2	--	--	5.5	57.9	1.75
1981	5.5	52.2	1.28	1.4	54.1	1.43	3.3	55.7	1.56	4.0	54.6	1.46	10.0	49.0	1.07	.7	59.0	1.85	.9	59.4	1.89
1982	4.1			.5			.8			4.6			6.0			.8			1.4		

[1] Mean weight calculated from mean length by: $\bar{w} = \bar{L}^3$ (.000009).

Table 12. Estimates of optimum escapements (thousands of sockeye salmon for the Wood River lake system.

Spawning stock	Date Set (brood years) 1949-1968	1950-1974	1950-1970	1946-1977
Aleknagik	112		245	
South Nerka	92		125	
Central Nerka	90		100	
North Nerka	130		200	
Beverley	189		390	
Kulik	74		155	
Little Togiak	13		26	
TOTAL	700		1,241	
Large Rivers		170	470	560
Creeks		230	230	210
Beaches		675	630	430
TOTAL		1,075	1,330	1,200
Lake system	800	1,400	1,300	900

Table 13. Pink salmon runs to the Nushagak District (number of fish in thousands).

Year	Catch	Escapement: Nuyakuk (tower)	Other Nushagak[1]	Total Nushagak	Wood River	Igushik River	Snake River	Total District	run
1950	30	--	--	--	--	--	--	--	--
1952	7	--	--	--	--	--	--	--	--
1954	99	--	--	--	--	--	--	--	--
1956	91	--	--	--	--	--	--	--	--
1958	1,114	--	--	3,200[2]	(130)[2]	(28)	(5)	3,463	4,577
1960	290	146	(31)	177	(7)	(1)	(+)	185	475
1962	880	494	6	500	25	12	6	543	1,432
1964	1,498	743	165	908	2	1	+	911	2,409
1966	2,337	1,442	(303)	1,745	(72)	(14)	(3)	1,834	4,171
1968	1,705	2,161	(454)	2,615	(108)	(22)	(4)	2,749	4,454
1970	418	153	(32)	185	(8)	(2)	(+)	195	613
1972	68	59	(12)	71	(3)	(1)	(+)	75	143
1974	414	456	76	532	45	8	1	586	1,000
1976	741	701	135	836	20	5	+	861	1,602
1978	4,369	7,190	1,972	9,162	205	16	3	9,386	13,755
1980	2,311	2,537	213	2,750	31	4	1	2,786	5,097
1982	1,286	1,538	73	1,611	37	8	1	1,657	2,943

[1]Aerial estimates of spawners in Nuyakuk (below tower), Nushagak and Mulchatna Rivers.

[2]Aerial estimates of Nushagak ranged from 2.5 to 4.0 million and the mean is used.

[3]Numbers in parenthesis are estimates based on the mean percent of the Nuyakuk escapement: 21% for other Nushagak, 5% Wood River, 1% Igushik, .2% Snake.

Table 14. Nushagak pink salmon escapements and returns (millions).

Brood year*(y)	Escapement	Observed Return	R/E	Predicted Return[1]	Obs. R-Pred. R.	Temperatures[2]		
						Eggs	Fry	At Sea
1956	< .25	4.58	> 18.0	--	--	-1.2	2.6	1.4
1958	3.46	.48	.1	1.7	-1.2	.5	- .5	- .1
1960	.19	1.43	7.5	2.4	-1.0	.2	1.0	- .9
1962	.54	2.41	4.5	4.4	-2.0	- .5	- .5	-1.3
1964	.91	4.17	4.6	5.4	-1.2	1.3	-1.4	-1.4
1966	1.83	4.45	2.4	4.5	0	.1	1.8	.5
1968	2.75	.61	.2	2.8	-2.2	-1.0	1.4	.6
1970	.20	.14	.7	2.4	-2.3	-4.0	-3.0	-2.1
1972	.08	1.00	12.5	1.3	- .3	-1.0	.9	- .3
1974	.59	1.60	2.7	4.8	-3.2	-3.5	-2.2	-1.7
1976	.86	13.76	16.0	5.4	8.4	4.7	-1.8	-1.0
1978	9.39	5.10	.5	.0	5.1	3.8	3.1	.9
1980	2.79	2.94	1.1	2.6	.3	3.3	3.0	- .5
1982	1.66	--	--	4.8	--			

[1]From a least-squares fit of a return-escapement relationship (Ricker): $R = E e^{-BE}$.

[2]Deviations (c) from long-term air temperatures in Bristol Bay: November (y) - March (y+1) for eggs, April-May (y+1) for fry,a nd June (y+1) - May (y+2) for immature fish at sea.

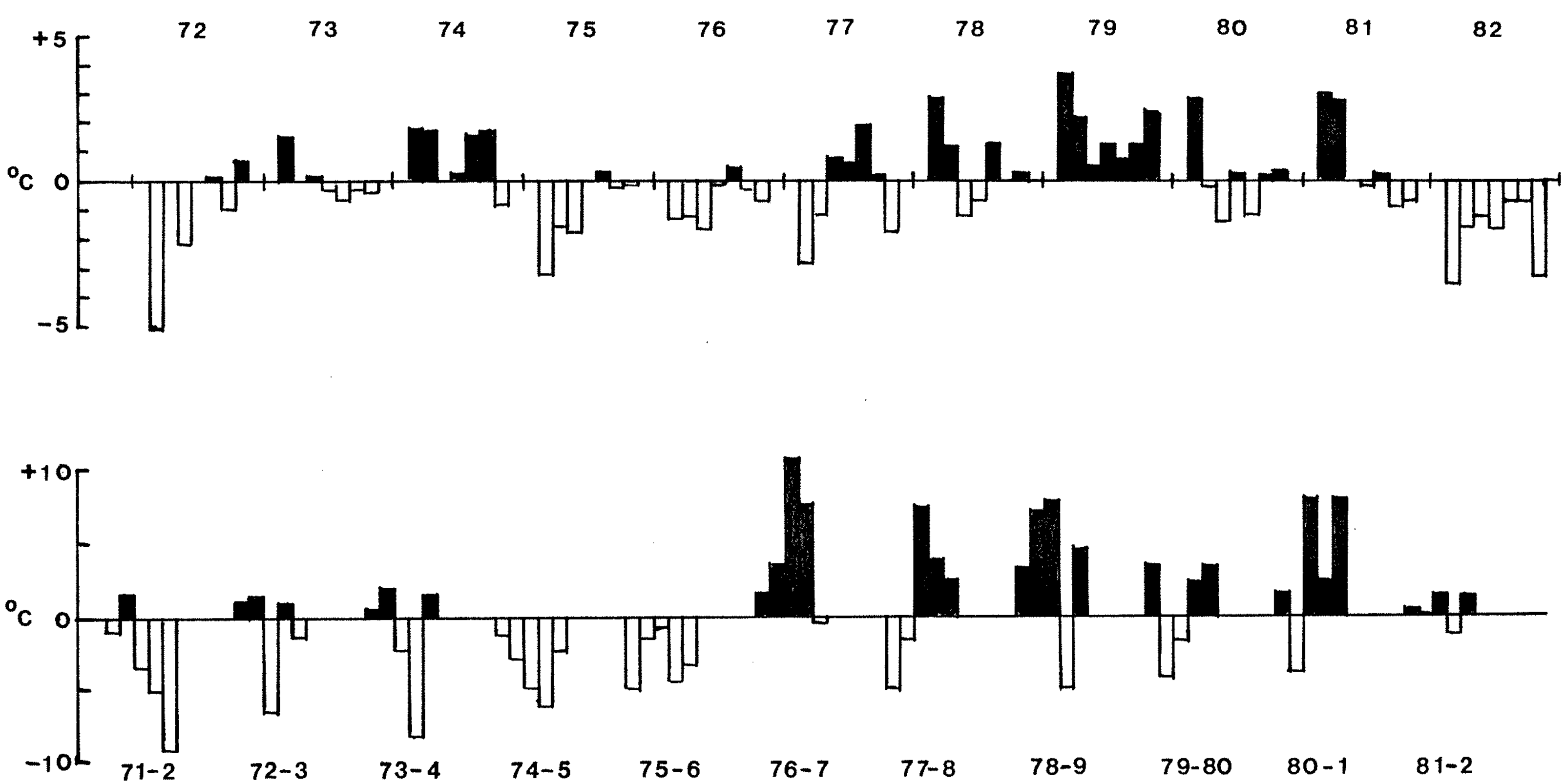

Fig. 1. Deviations from long-term means of monthly average air temperatures at Dillingham-King Salmon for summer months, April-October (top) and winter months, November-March (bottom); Nov. 1971 through October 1982.

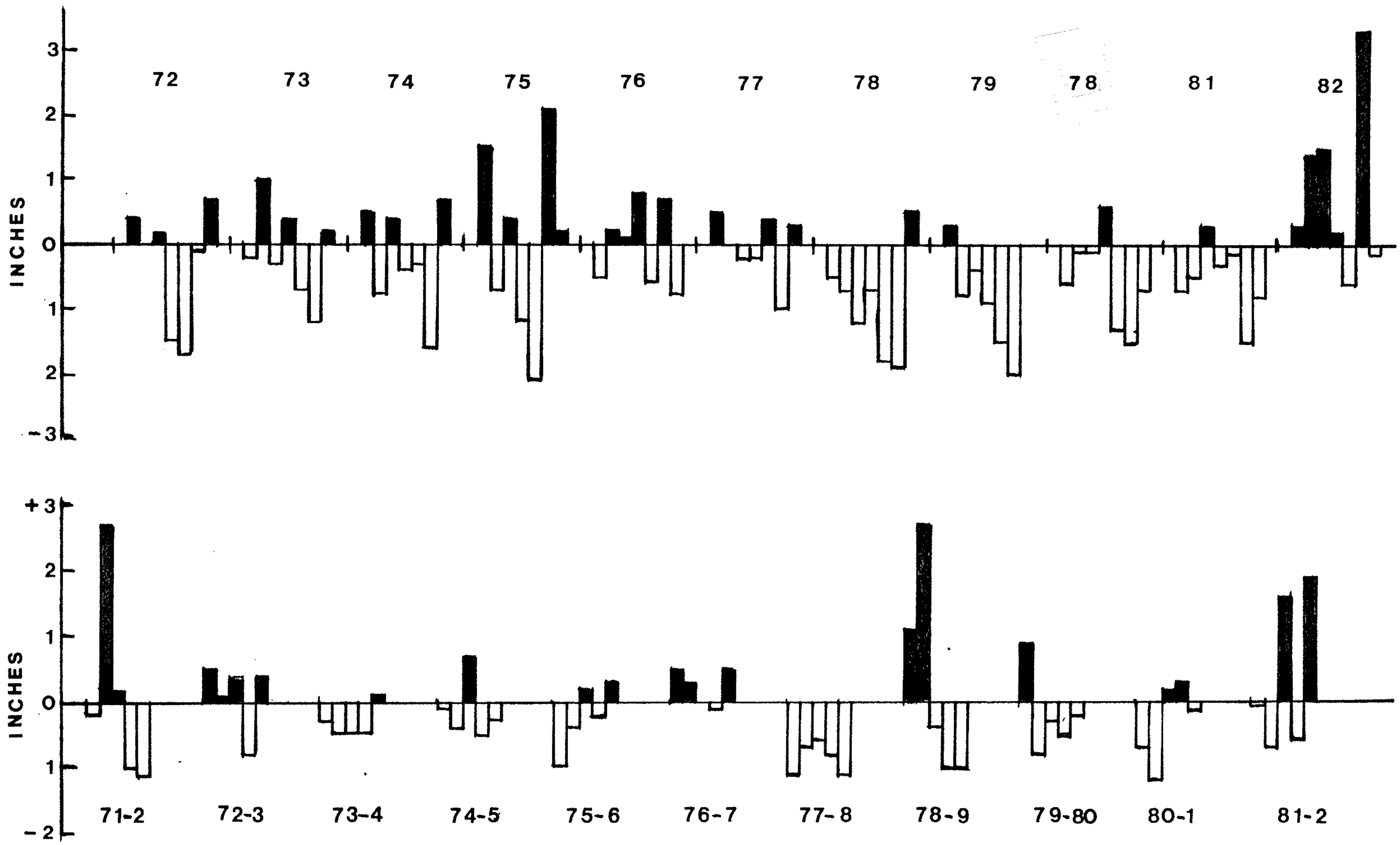

Fig. 2. Deviations from long-term means of monthly total precipitation at Dillingham-King Salmon for summer months, April-October (top) and winter months, November-March (bottom); Nov. 1971 through Oct. 1982.

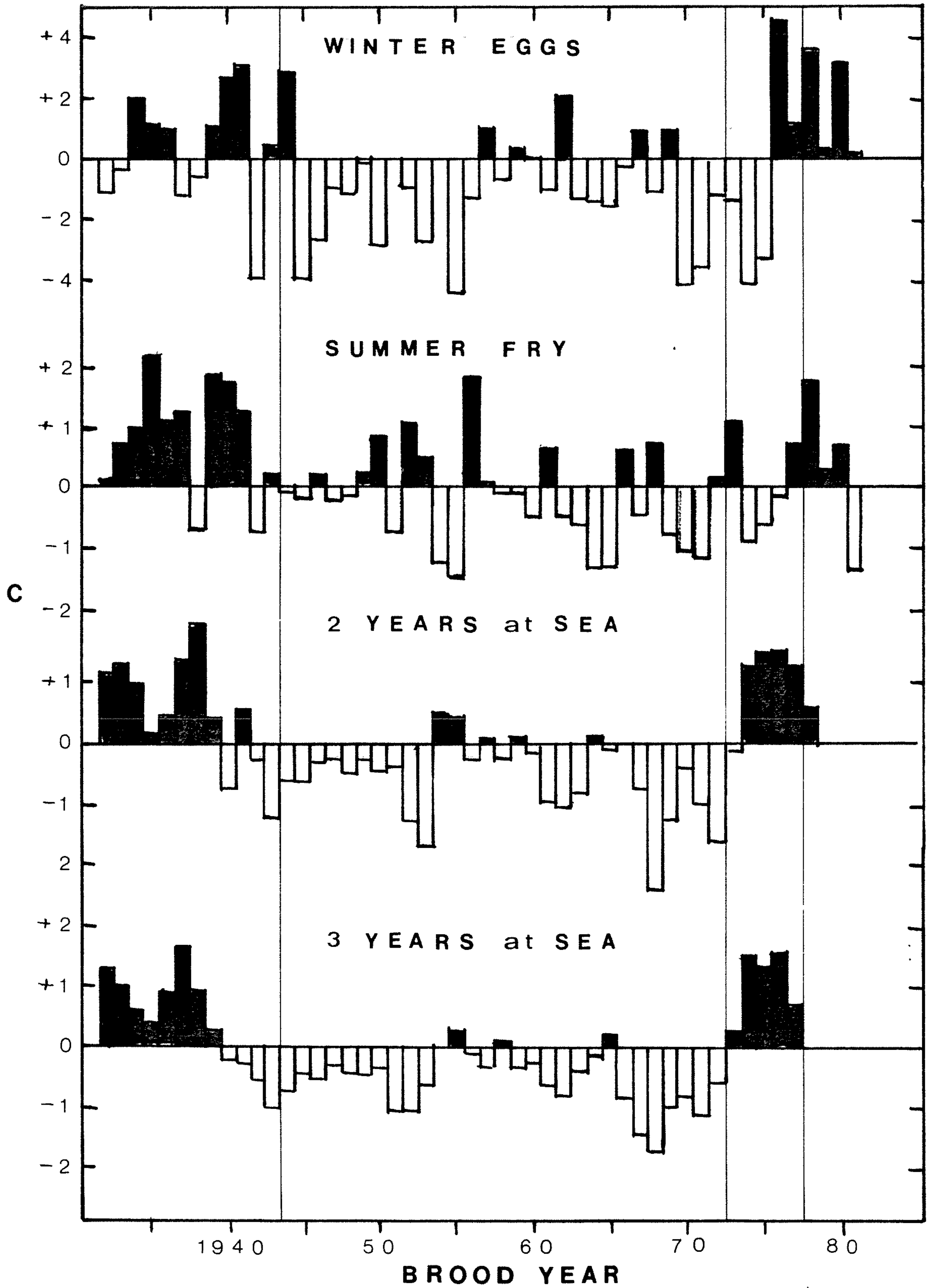

Fig. 3. Deviations from long-term air temperatures in Bristol Bay according to life history stages for sockeye salmon that migrated to sea as age I smolts.

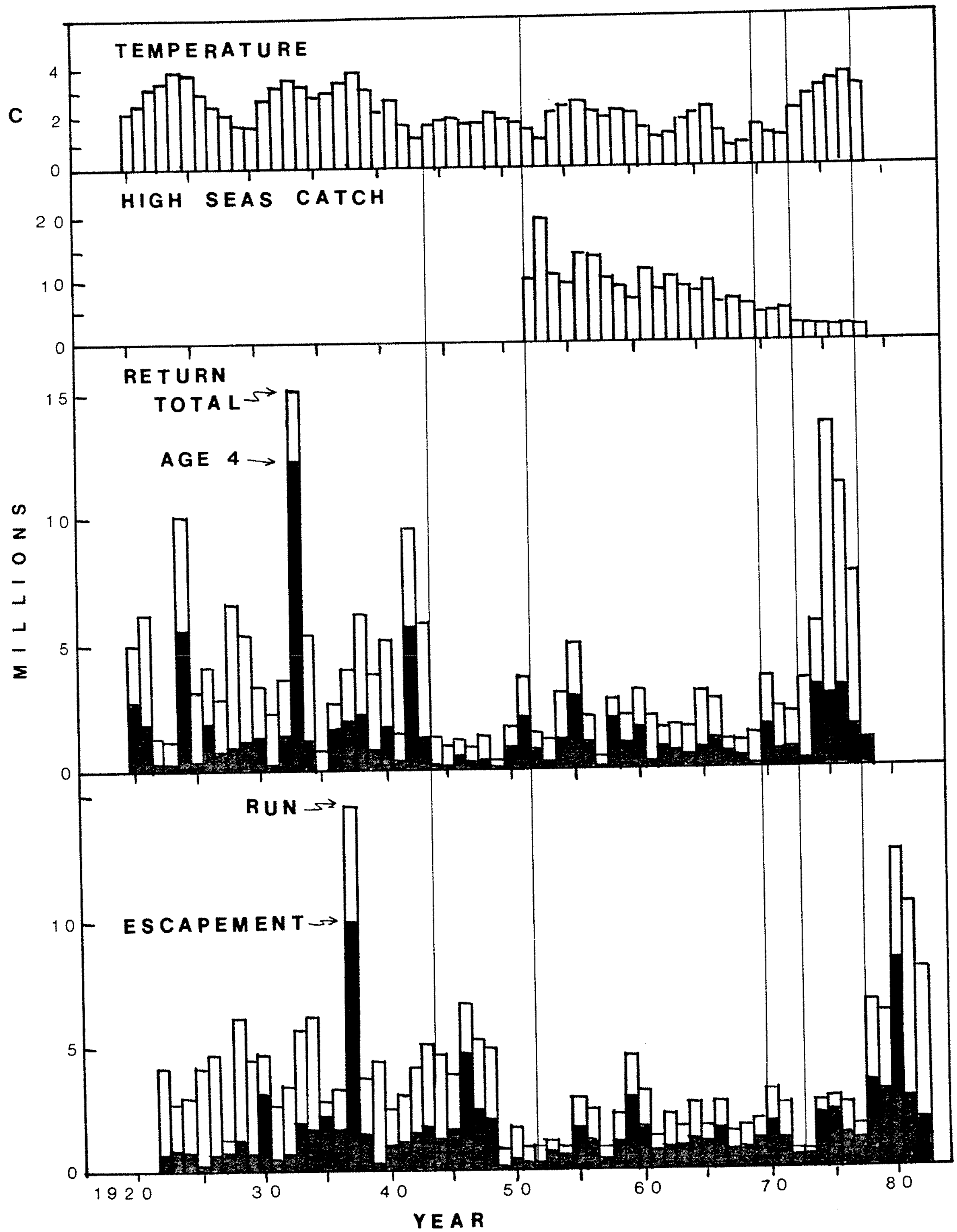

Fig. 4. Estimates of annual escapements, runs and adult returns of sockeye salmon to the Nushagak District and the trends in Bristol Bay air temperature and high seas catch of sockeye salmon by Japan while the returning fish were at sea.

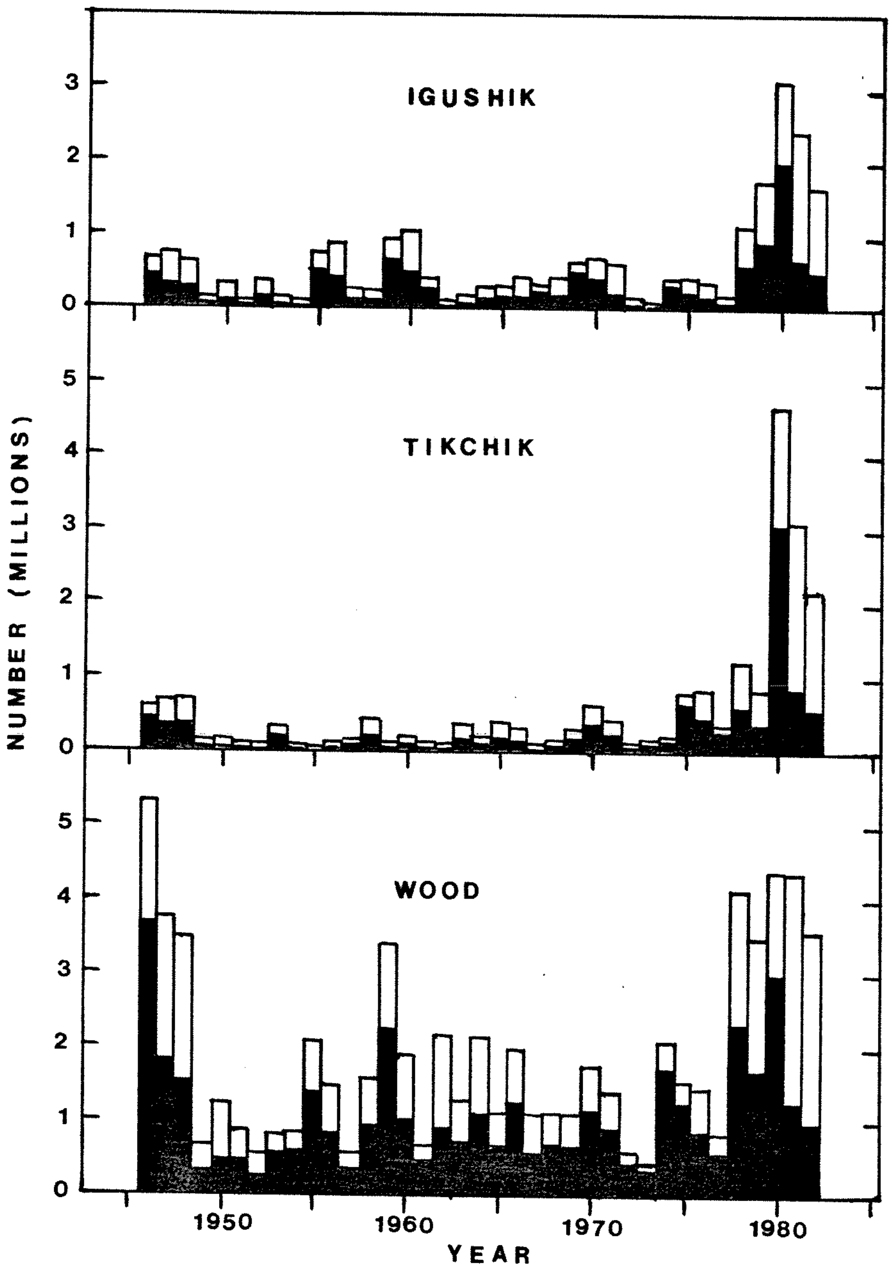

Fig. 5. Annual escapements (shaded) and runs of sockeye salmon to the Igushik, Tikchik (Nuyakuk) and Wood River lake systems, 1946-82.

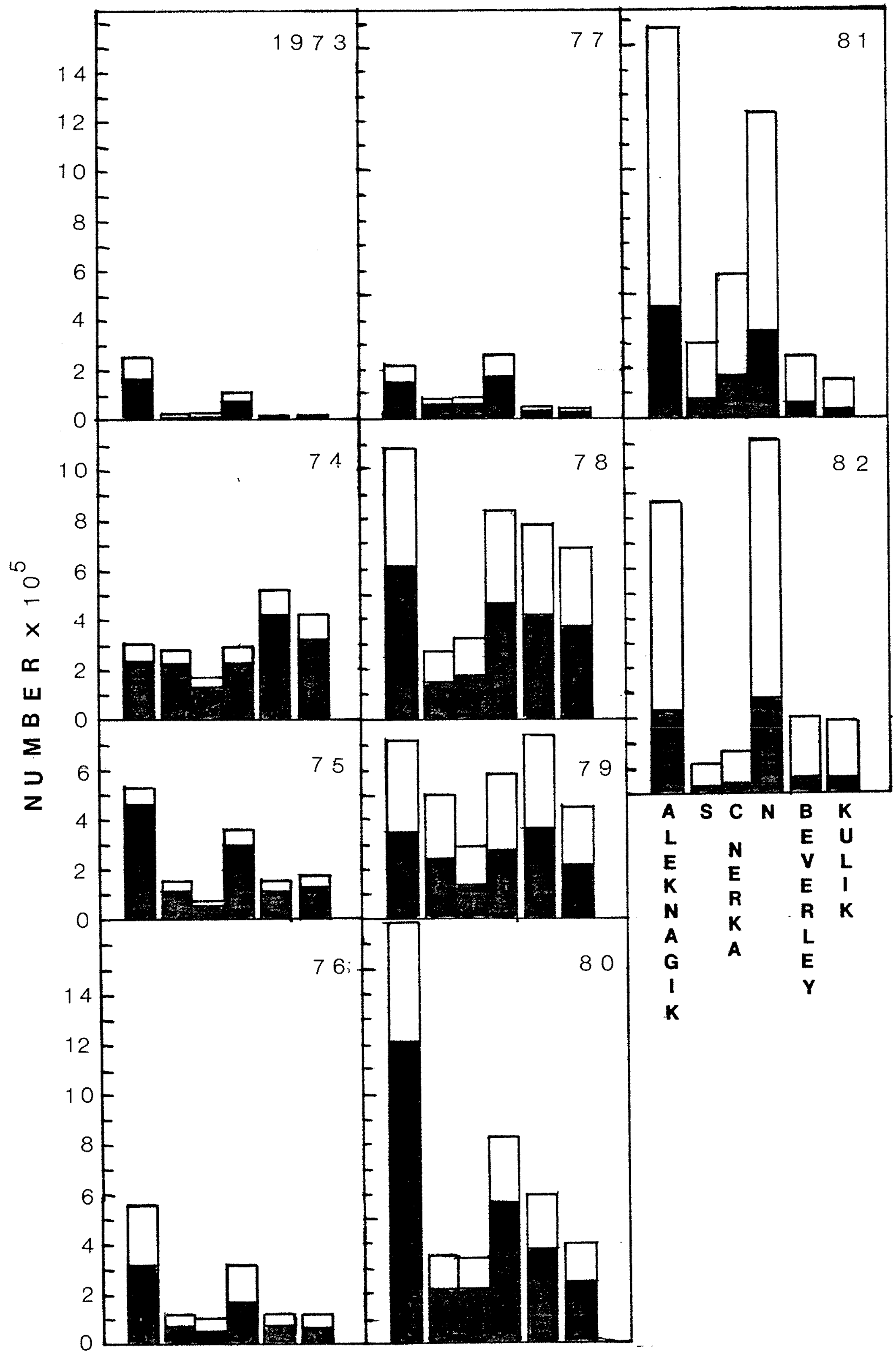

Fig. 6. Annual escapements (shaded) and runs to the large Wood River lakes and basins (Lake Nerka), 1973-82.

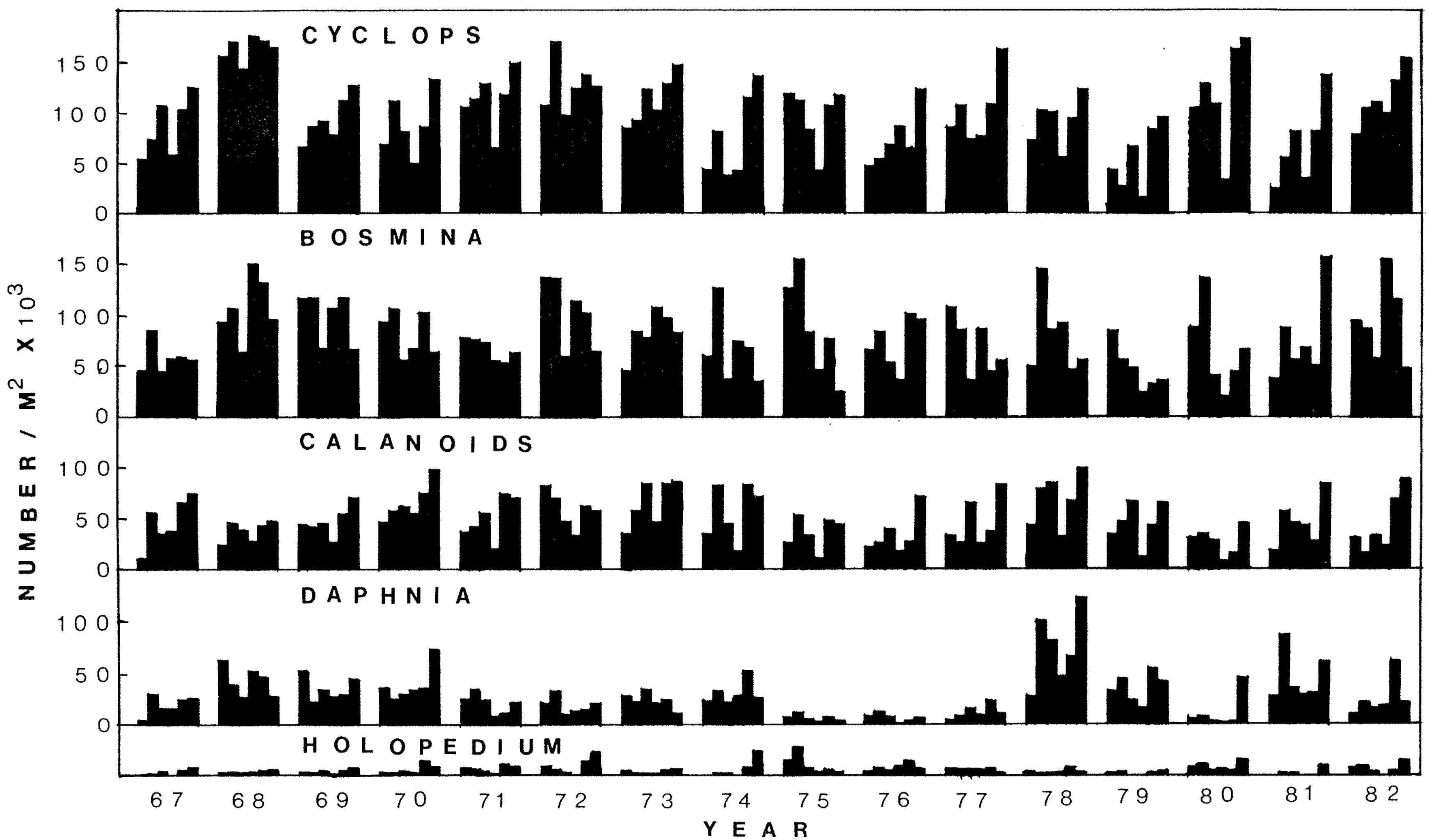

Fig. 7. Annual abundances of zooplankters in the Wood River lake system during August 20 - September 5, 1967-82. Lakes in order from left to right: Aleknagik, South Nerka, Central Nerka, North Nerka, Beverley and Kulik.

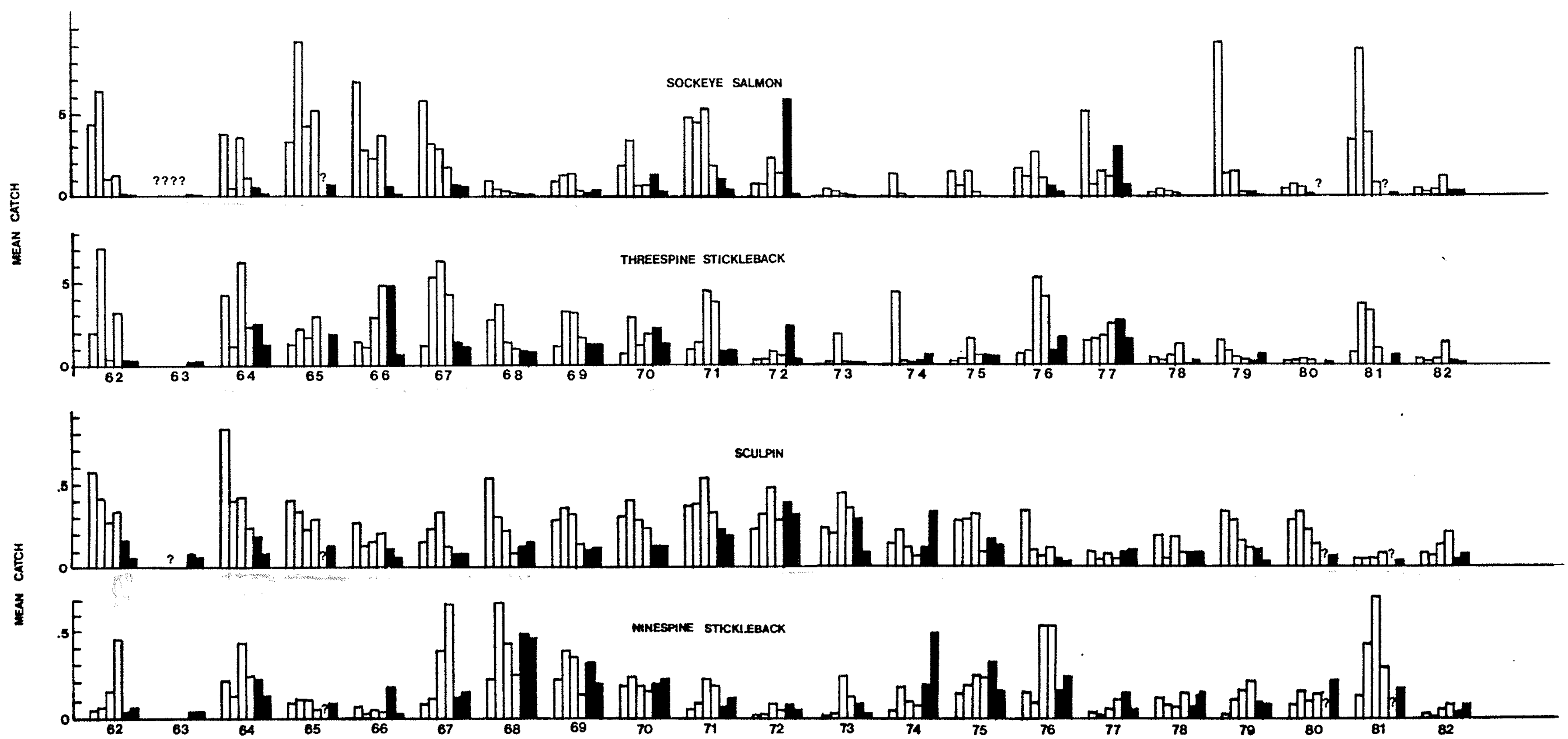

Fig. 8. Geometric means of beach seine catches (in hundreds) at ten stations in Lake Aleknagik from weekly sampling during June 22 - July 16 (open bars) and during July 22 - August 4 (solid bars), 1962-82.

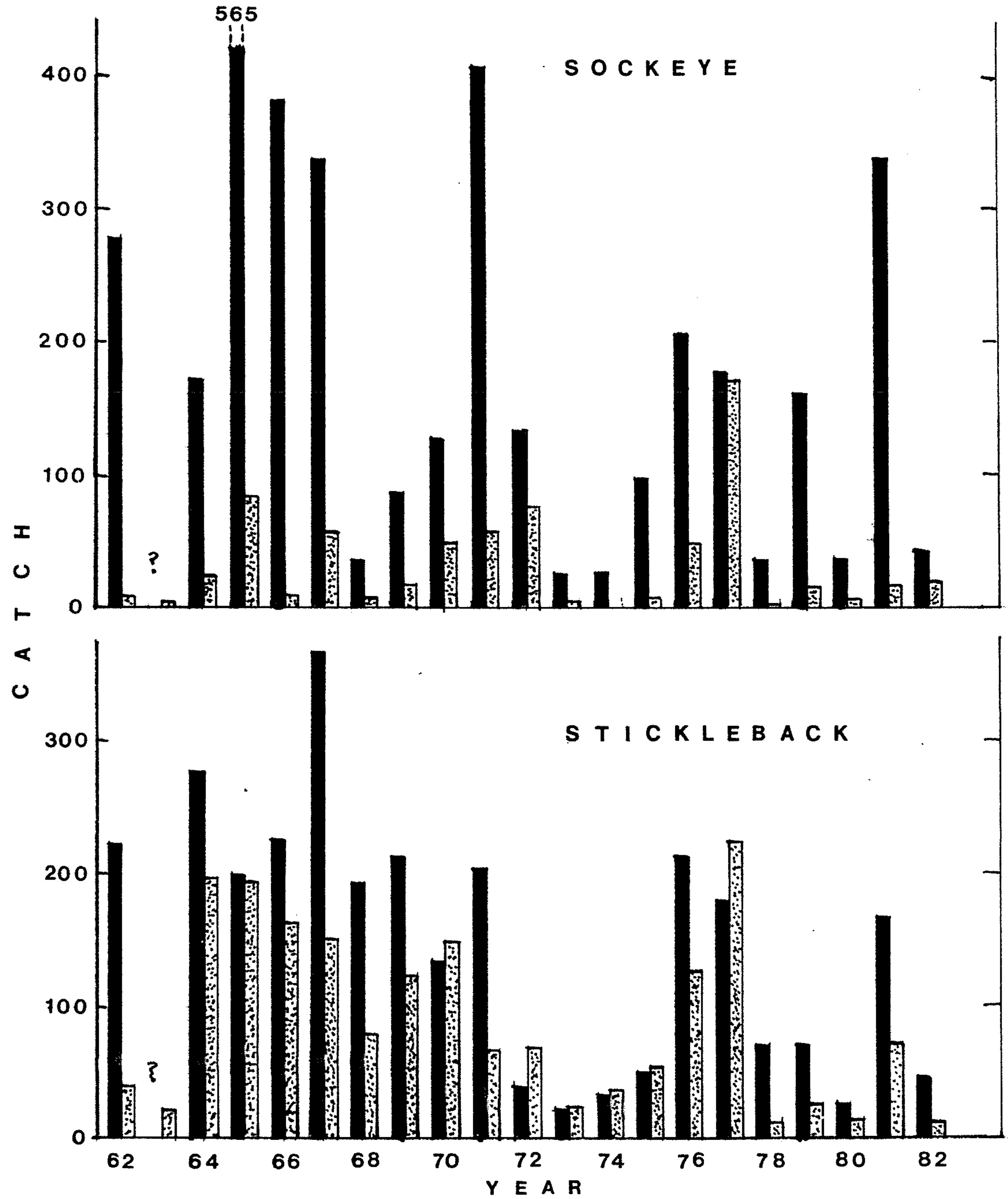

Fig. 9. Annual averages of weekly mean beach seine catches of sockeye salmon fry and threespine stickleback in Lake Aleknagik during June 22 - July 16 (solid bars) and July 22 - August 4 (shaded bars), 1962-82.

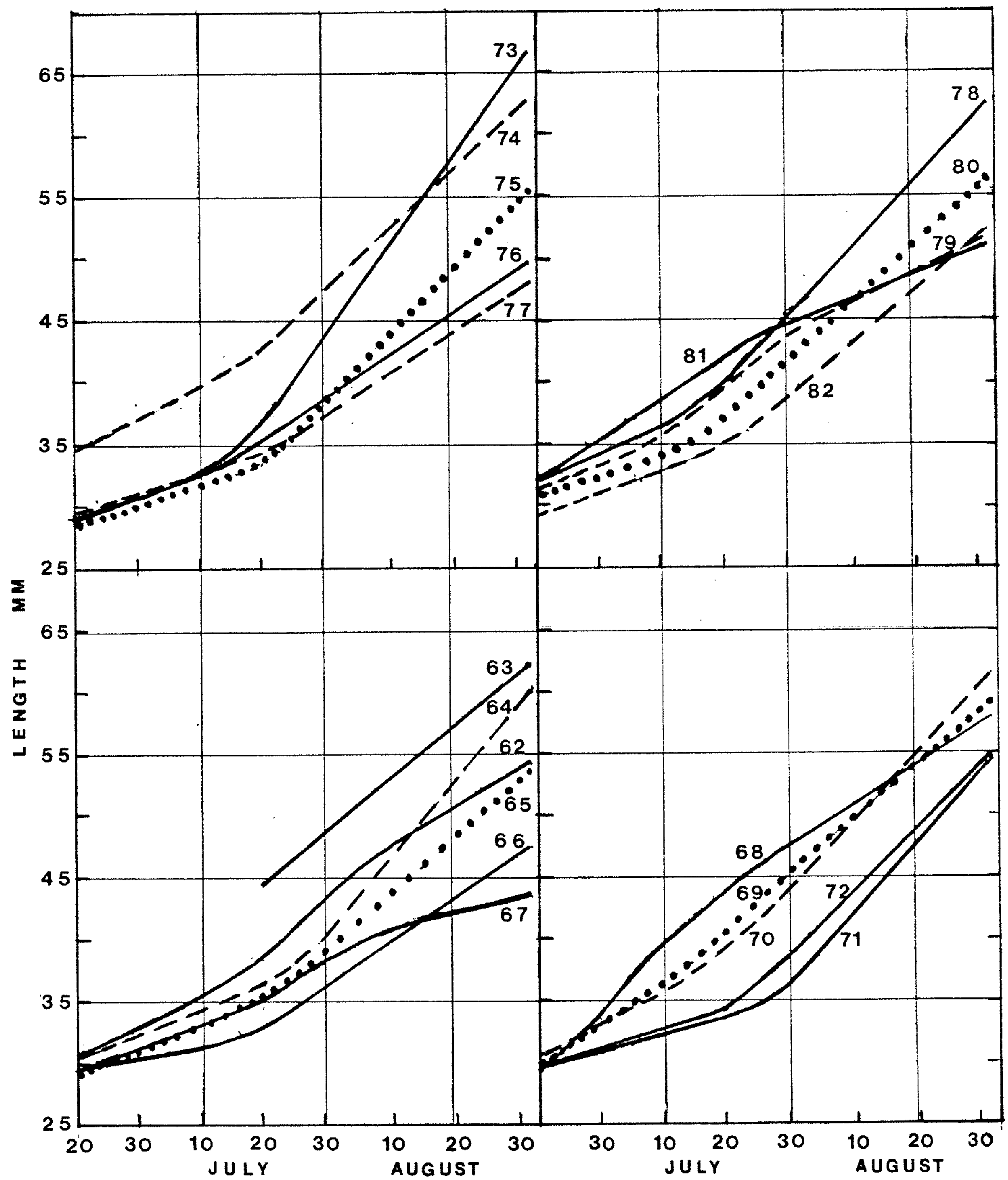

Fig. 10. Length trajectories for sockeye salmon fry in Lake Aleknagik from sampling between June 20 and September 1, 1962-82.

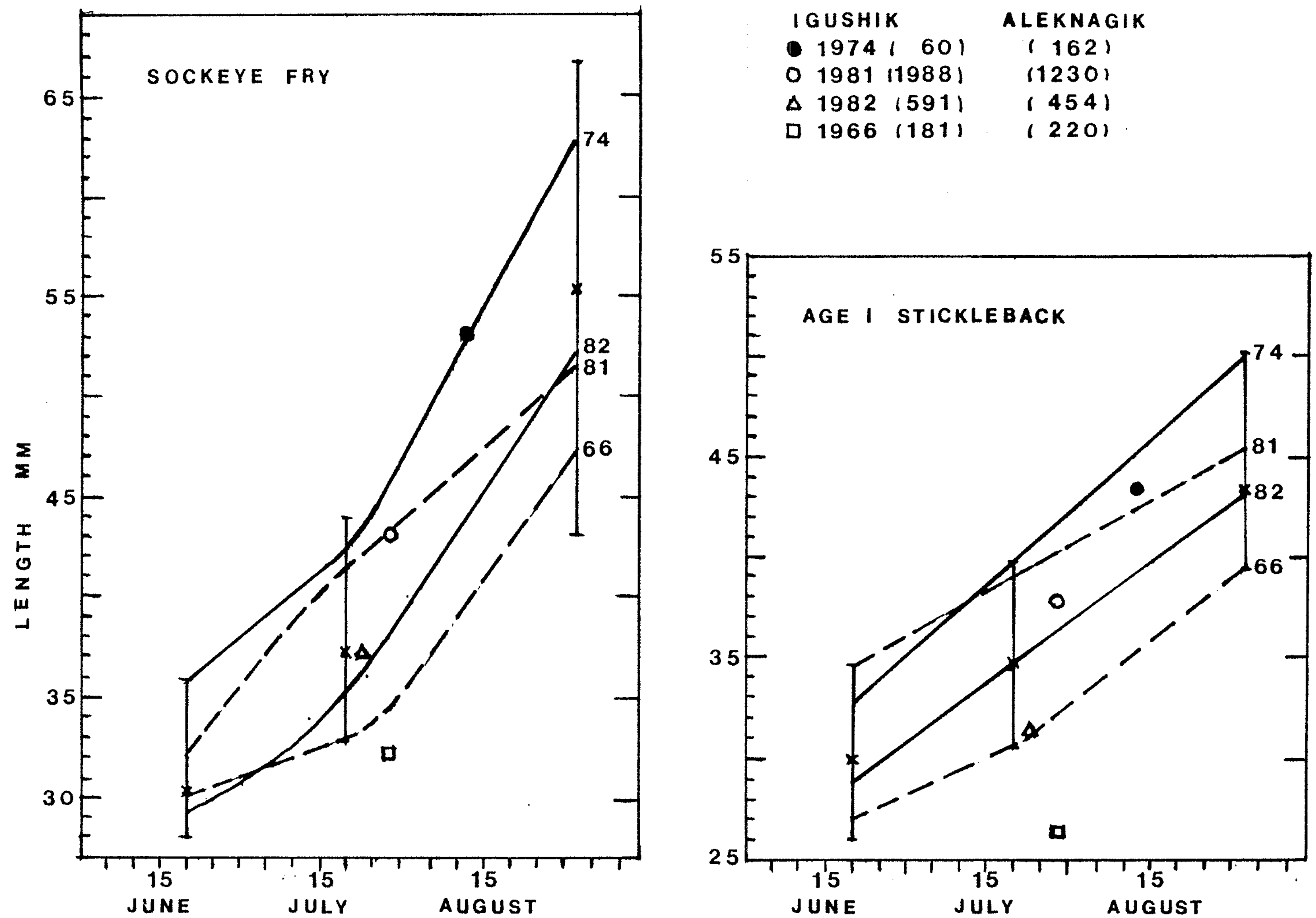

Fig. 11. Comparisons of the mean lengths of sockeye salmon fry and age I threespine stickleback between samples collected on selected dates from Lake Amanka (Igushik) and the length trajectories from Lake Aleknagik. Vertical lines indicate the range and mean (x) for the Aleknagik data since 1962. Parent sockeye salmon escapements are given in parentheses (1,000s).

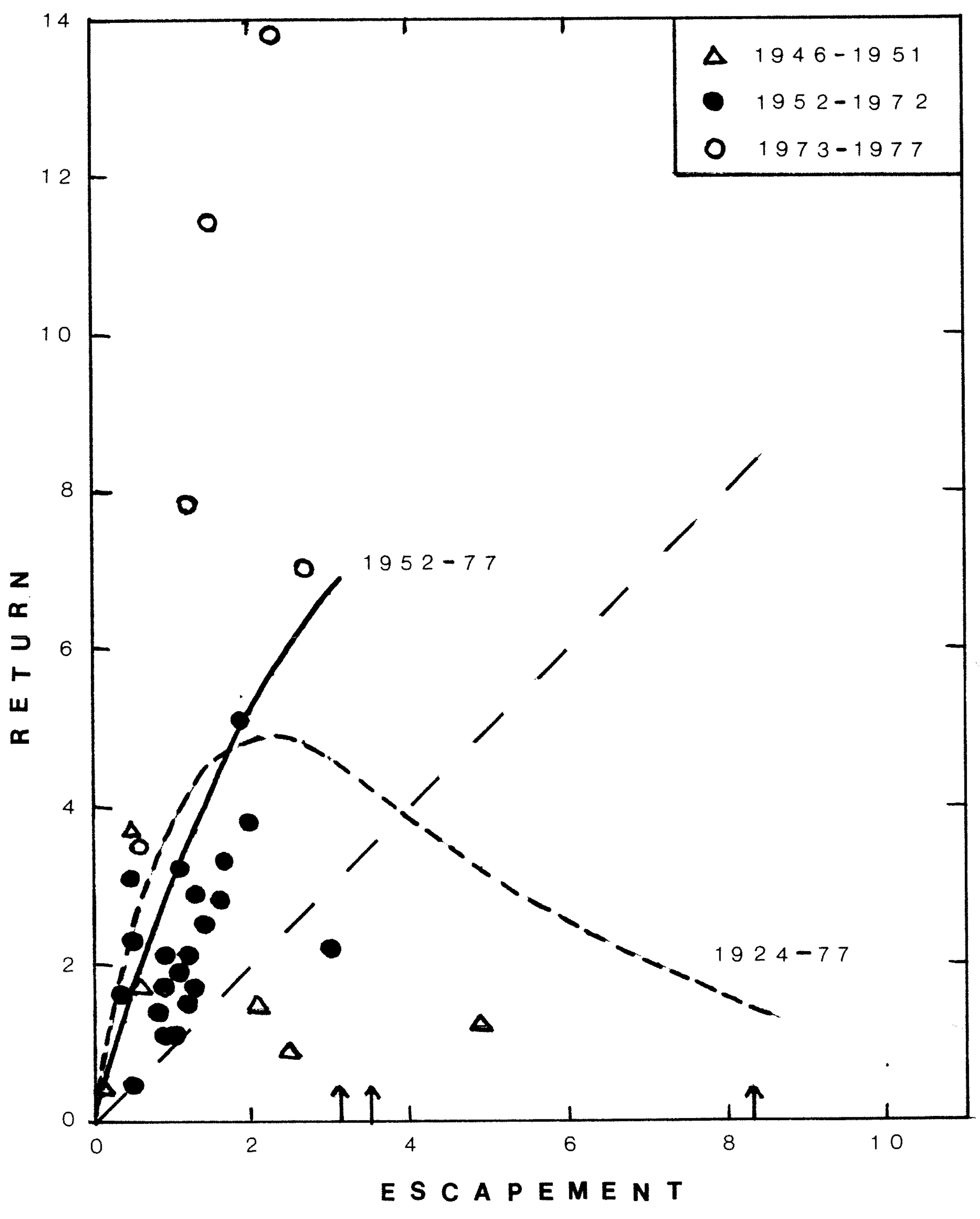

Fig. 12. Escapements and returns of sockeye salmon to the Nushagak District. Least-squares curves fitted to 1952-77 and 1924-77 brood years. Arrows indicate the 1978-80 escapements.

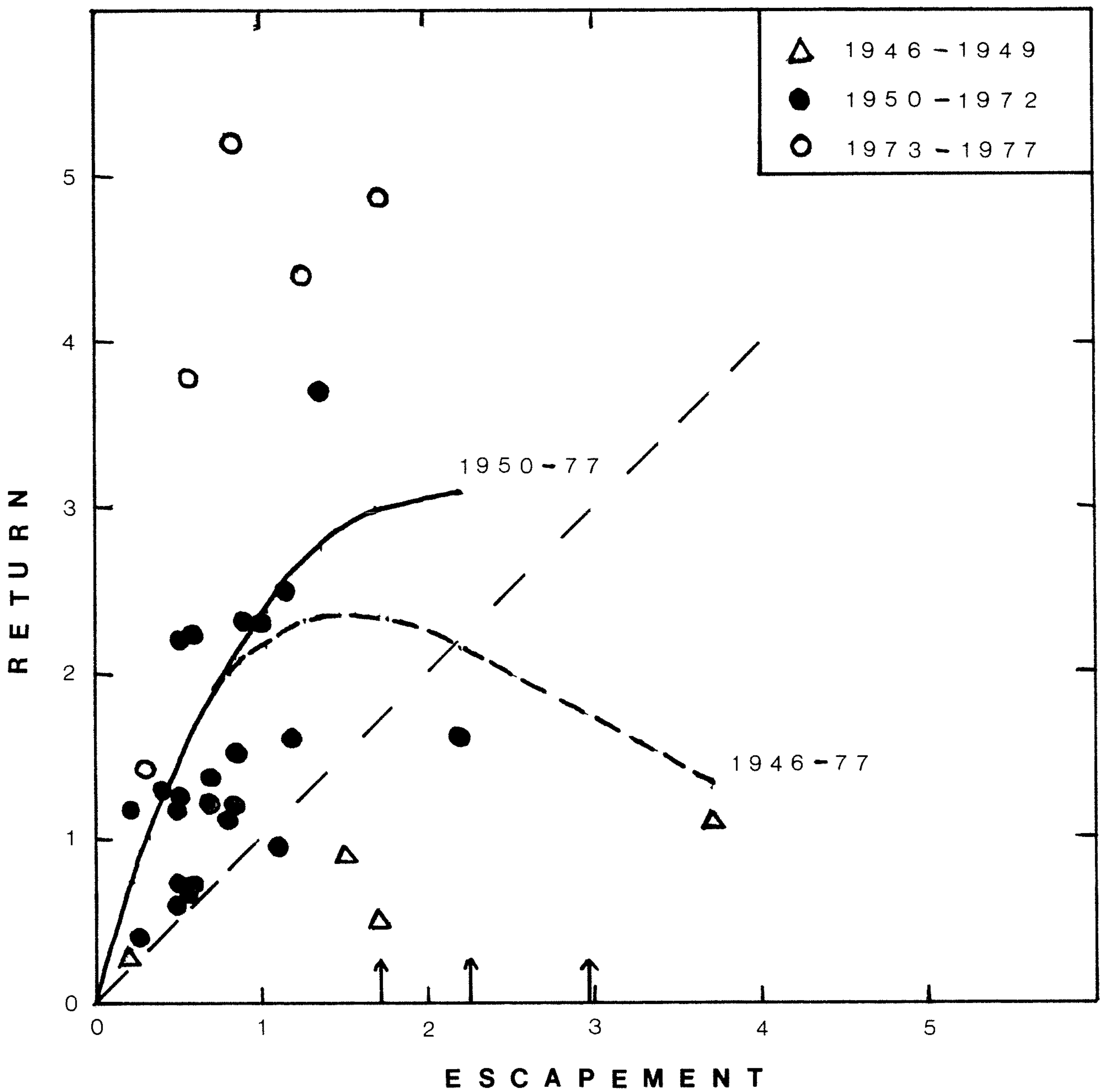

Fig. 13. Escapements and returns of sockeye salmon to the Wood River lake system with least-squares curves fitted to the 1946-77 and 1950-77 brood years. Arrows indicate escapements in 1978-80.

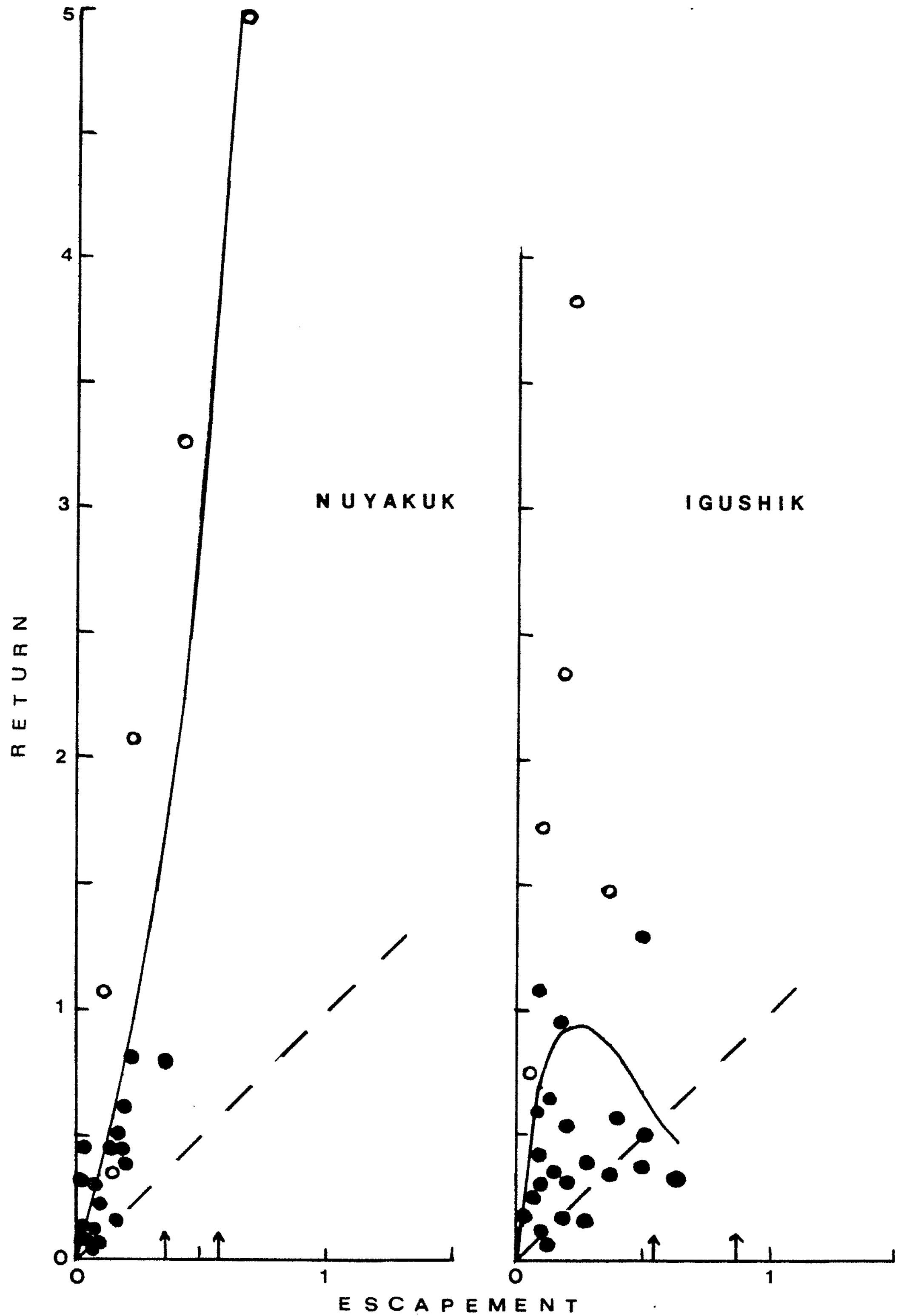

Fig. 14. Escapements and returns of sockeye salmon to the Nuyakuk and Igushik systems for the 1952-77 brood years with least-squares curves. Arrows indicate escapements in 1978-79. Escapements in 1980 were 3 million (Nuyakuk) and 2 million (Igushik).

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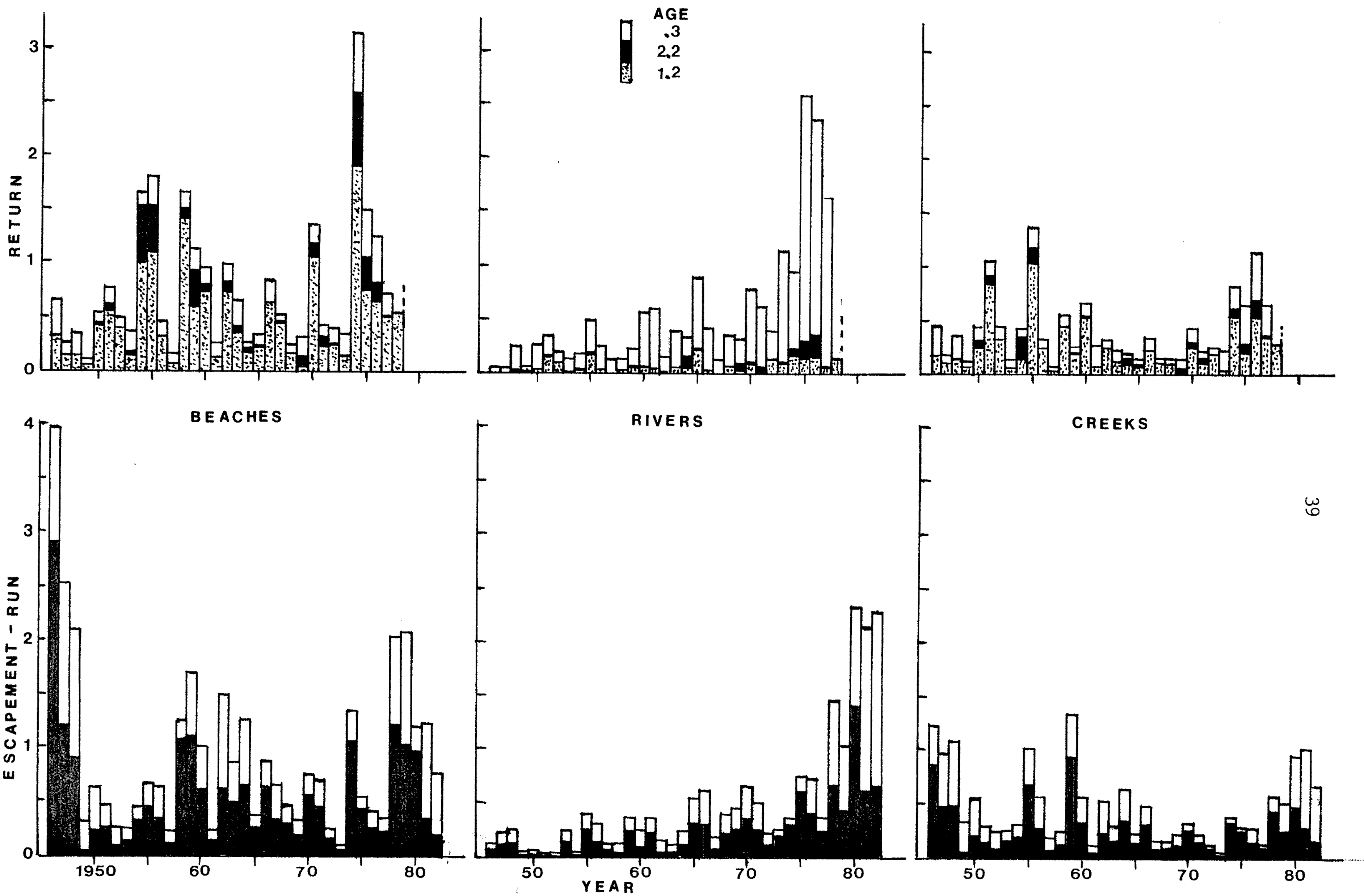

Fig. 15 Escapements, runs and returns (in millions) of sockeye salmon to the Wood River lake system by type of spawning ground.

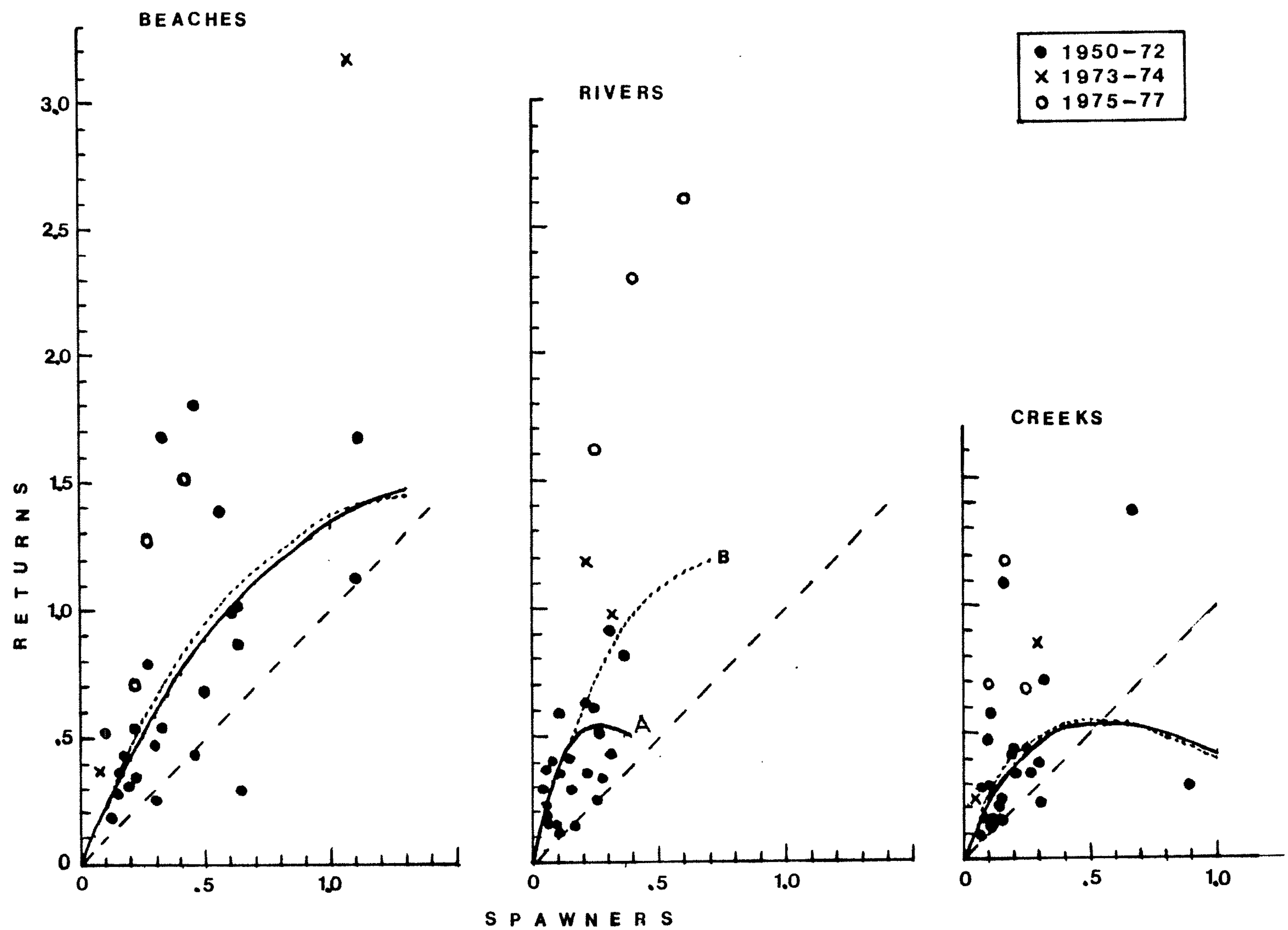

Fig. 16. Spawner-return relationships by type of spawning ground in the Wood River lake system. Simple Ricker-type curves; (A) 1950-74 brood years and (B) 1950-77 brood years.

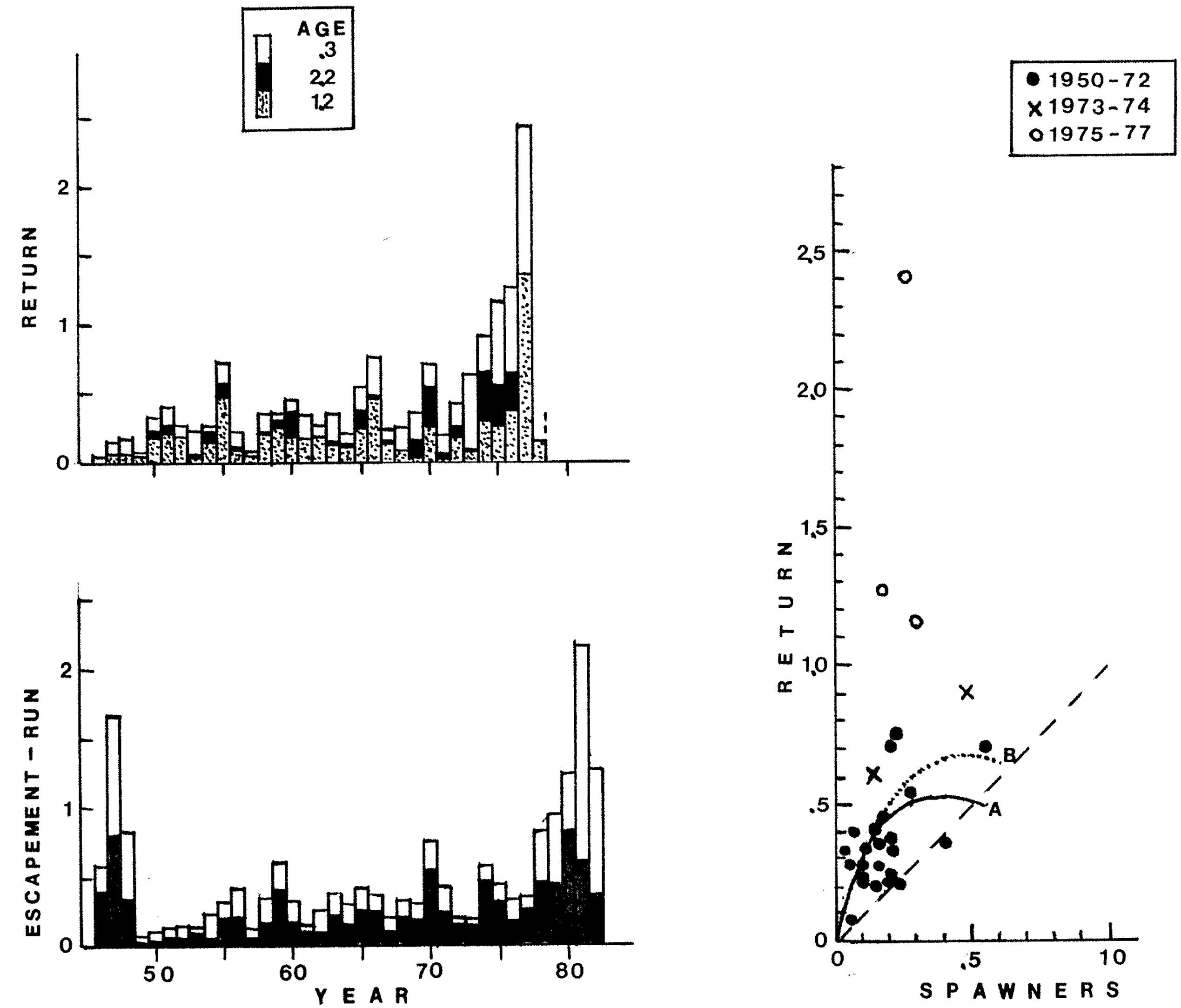

Fig. 17. Escapement, run and return statistics for Little Togiak Lake (number x 10^5).

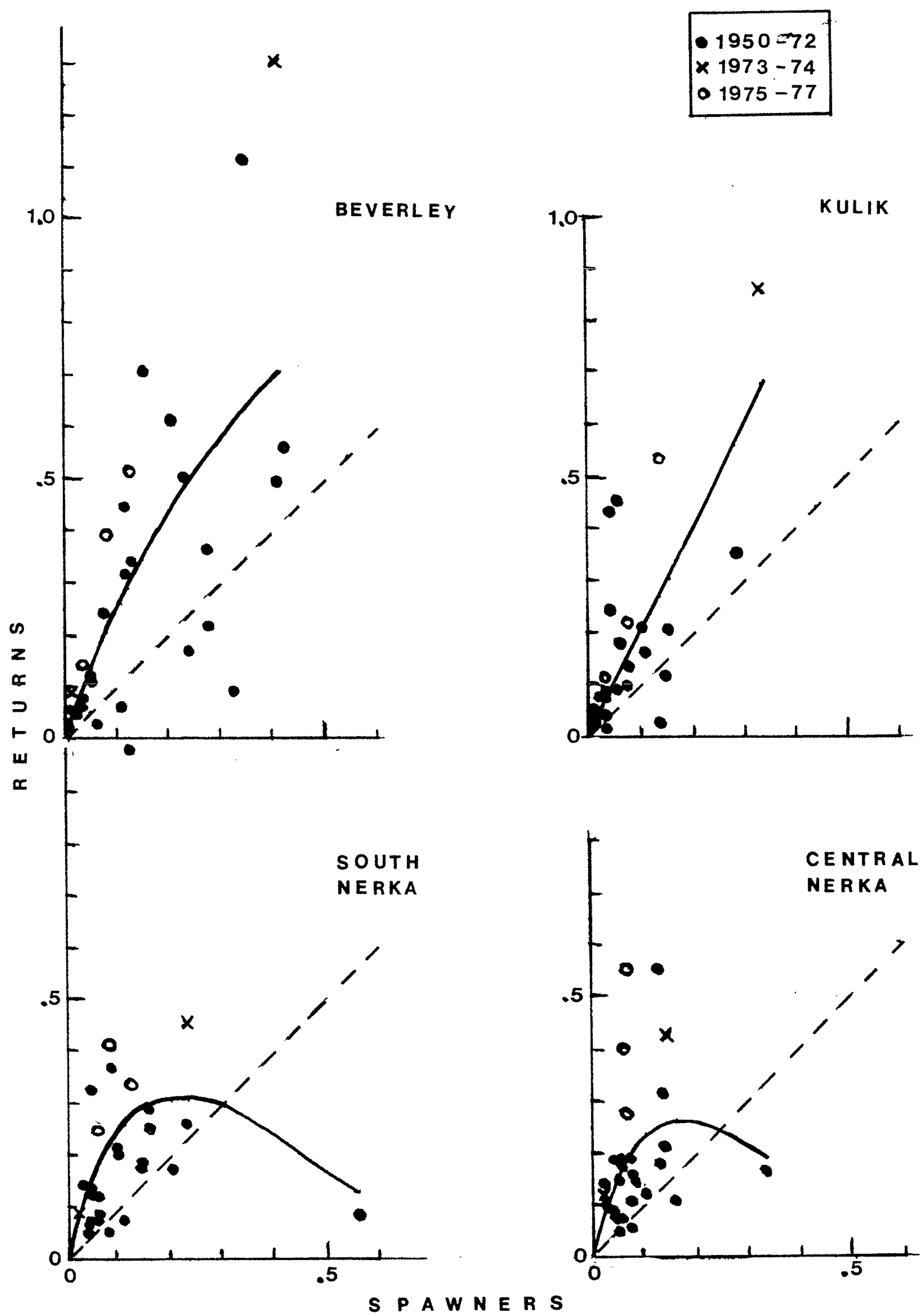

Fig. 18. Least-squares spawner-return curves for sockeye salmon from Lakes Beverley, Kulik, South Nerka and Central Nerka; 1950-77 brood years (numbers x 10^6).

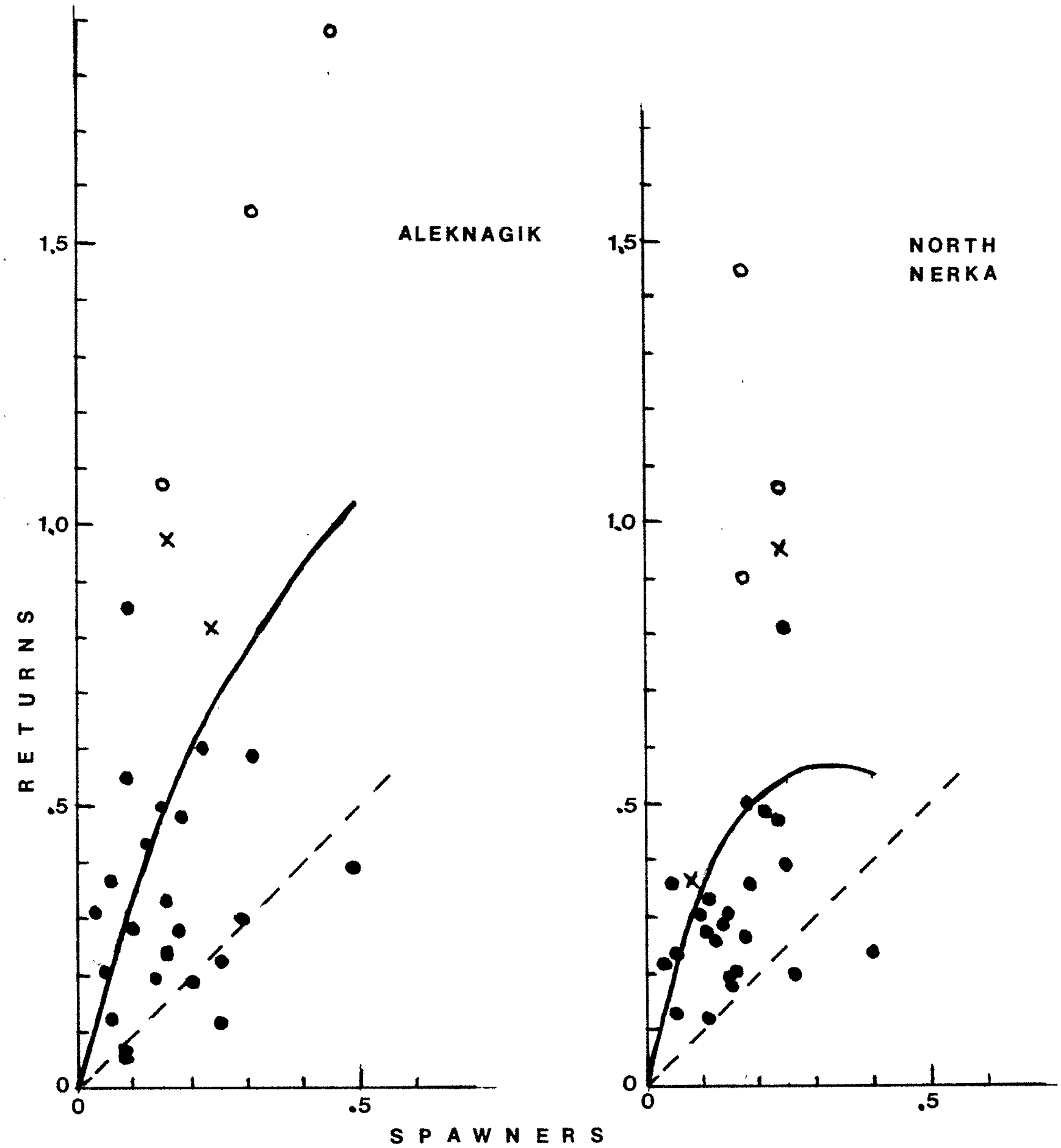

Fig. 19. Least-squares spawner-return curves for sockeye salmon from Lake Aleknagik and North Nerka, 1950-77 brood years (numbers x 10^6).

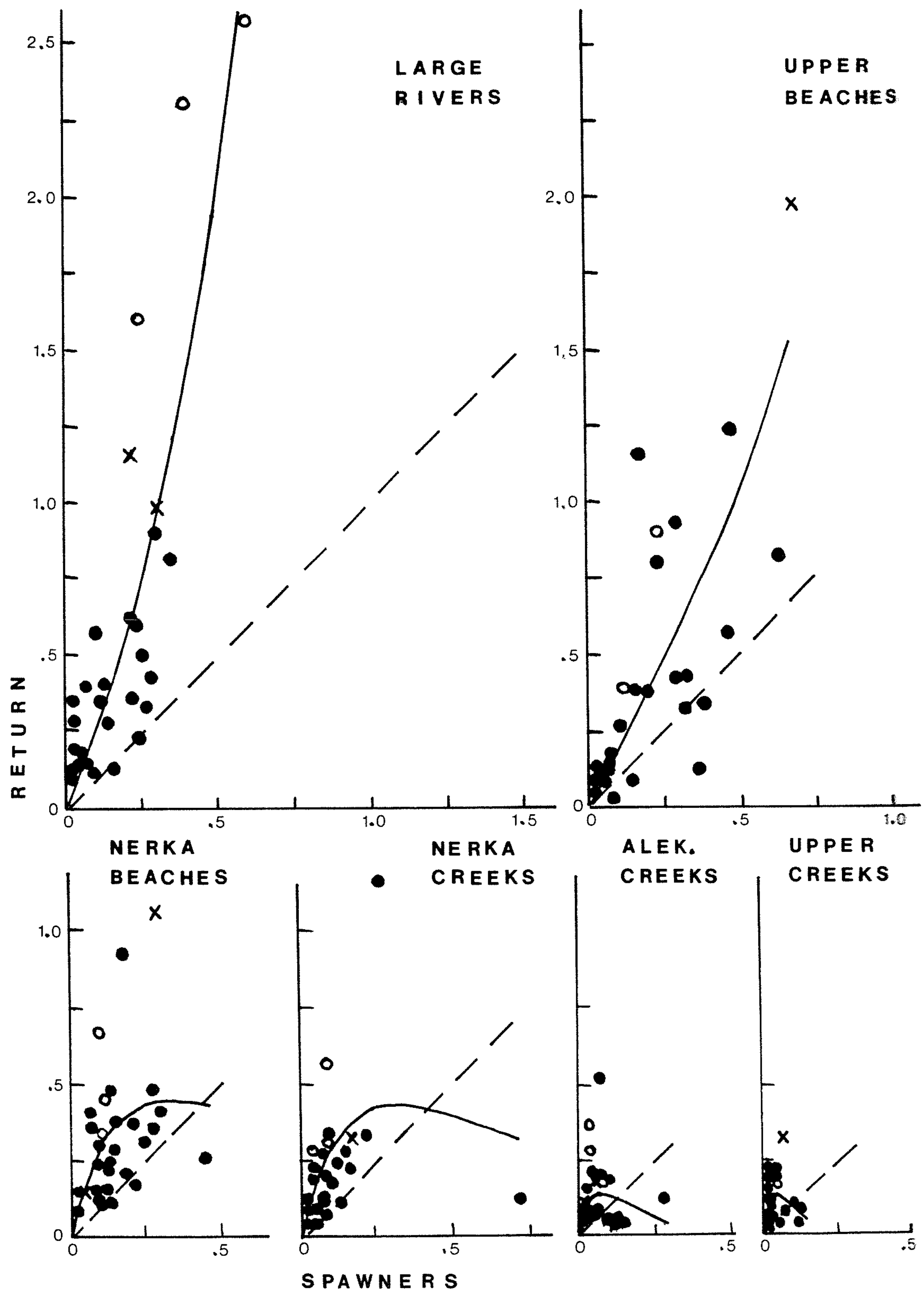

Fig. 20. Least-squares spawner-return curves by type and location of spawning ground in the Wood River lake system (numbers x 10^6).

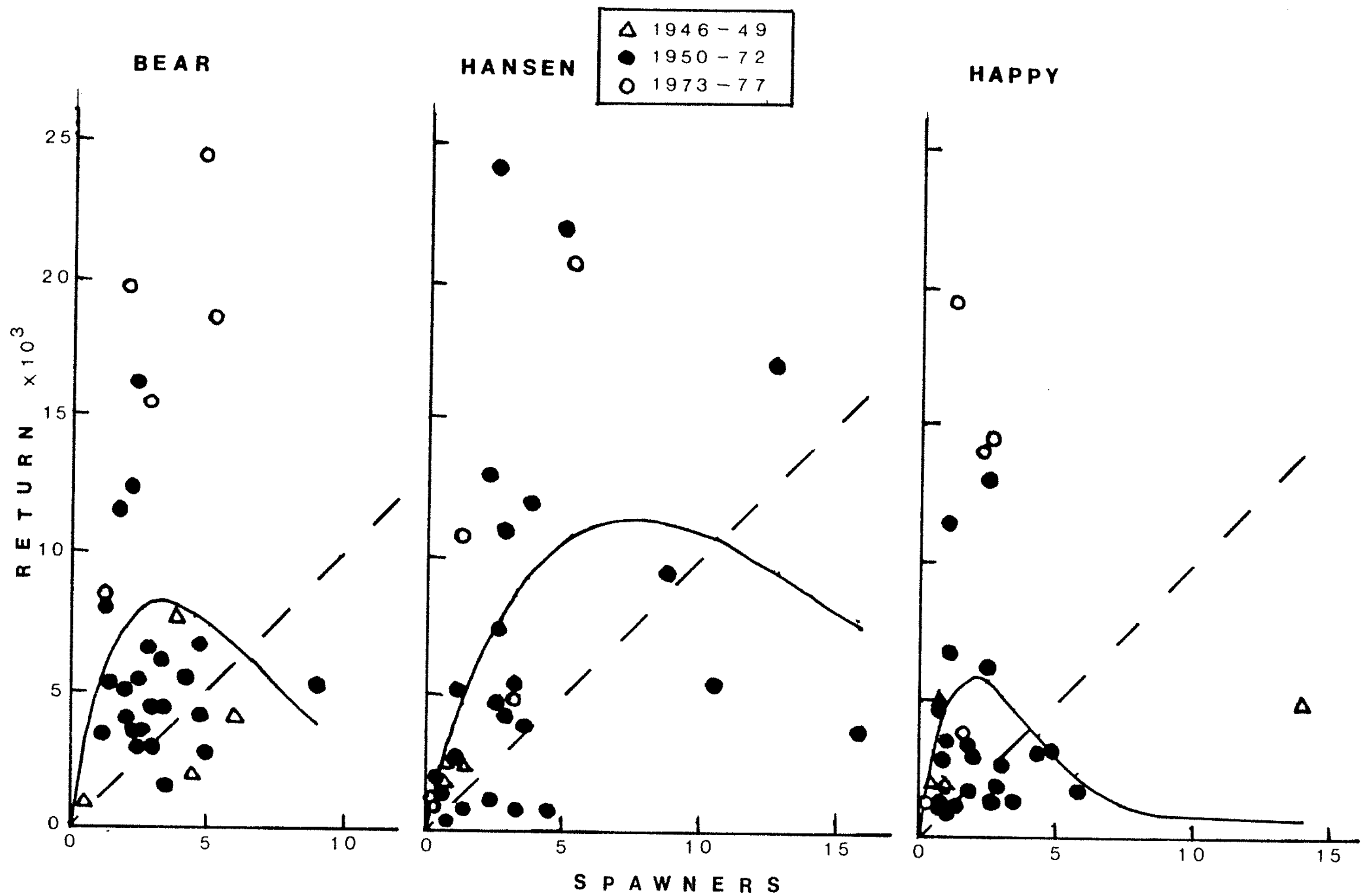

Fig. 21. Spawner-return curves for three creeks on Lake Aleknagik.

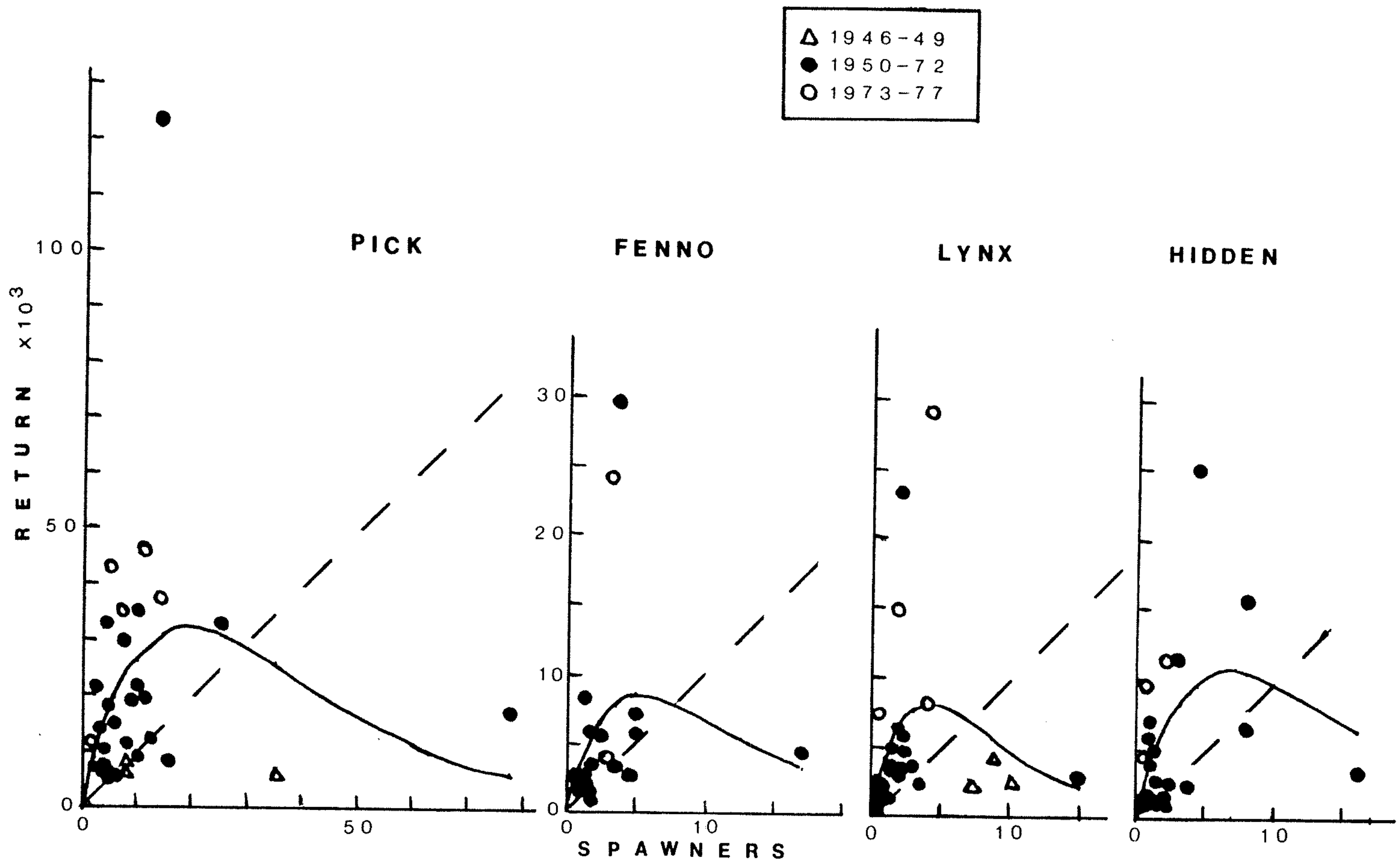

Fig. 22. Spawner-return curves for four creeks on Lake Nerka.

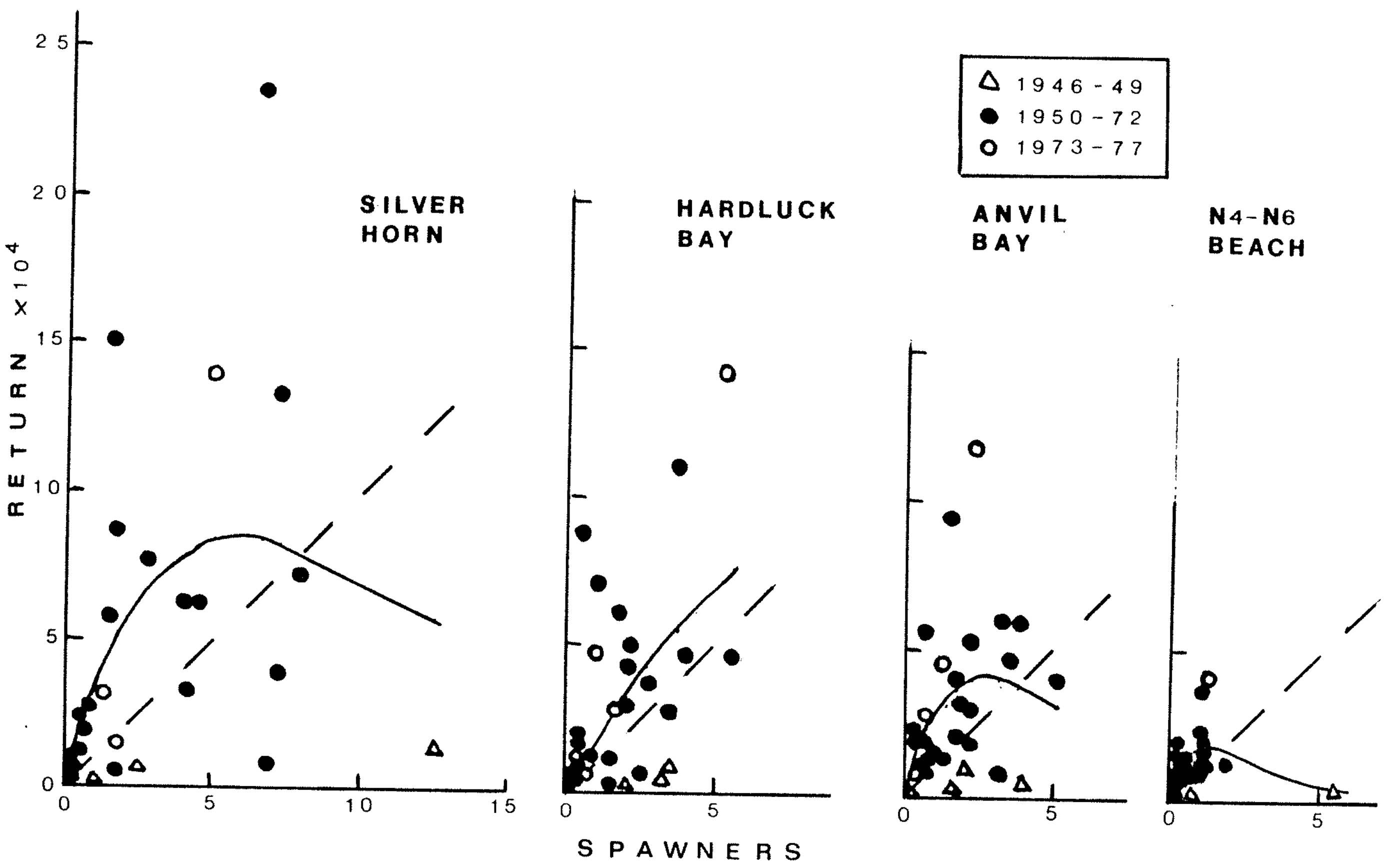

Fig. 23. Spawner-return curves for four beach spawning areas.

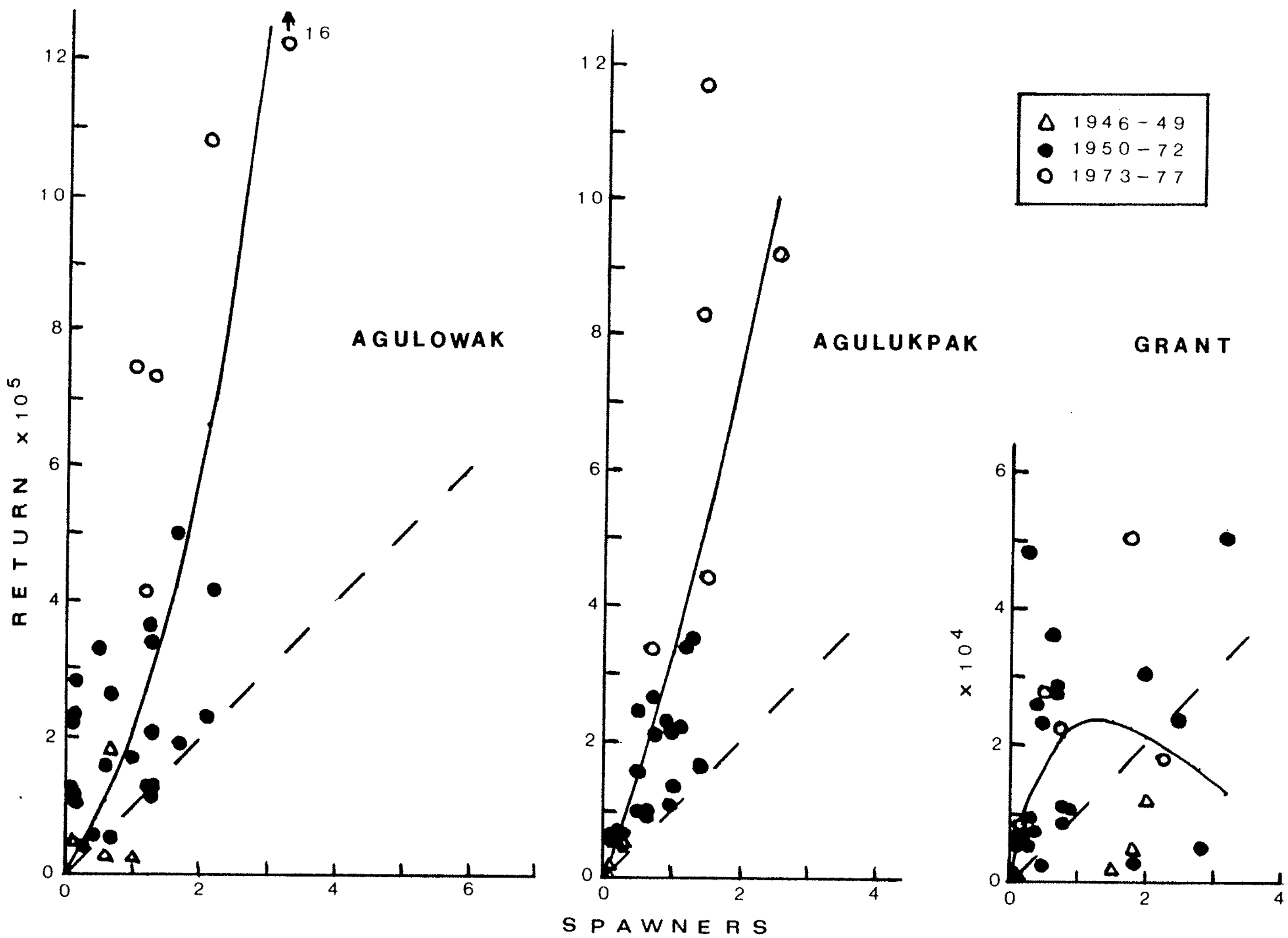

Fig. 24. Spawner-return curves for three rivers.

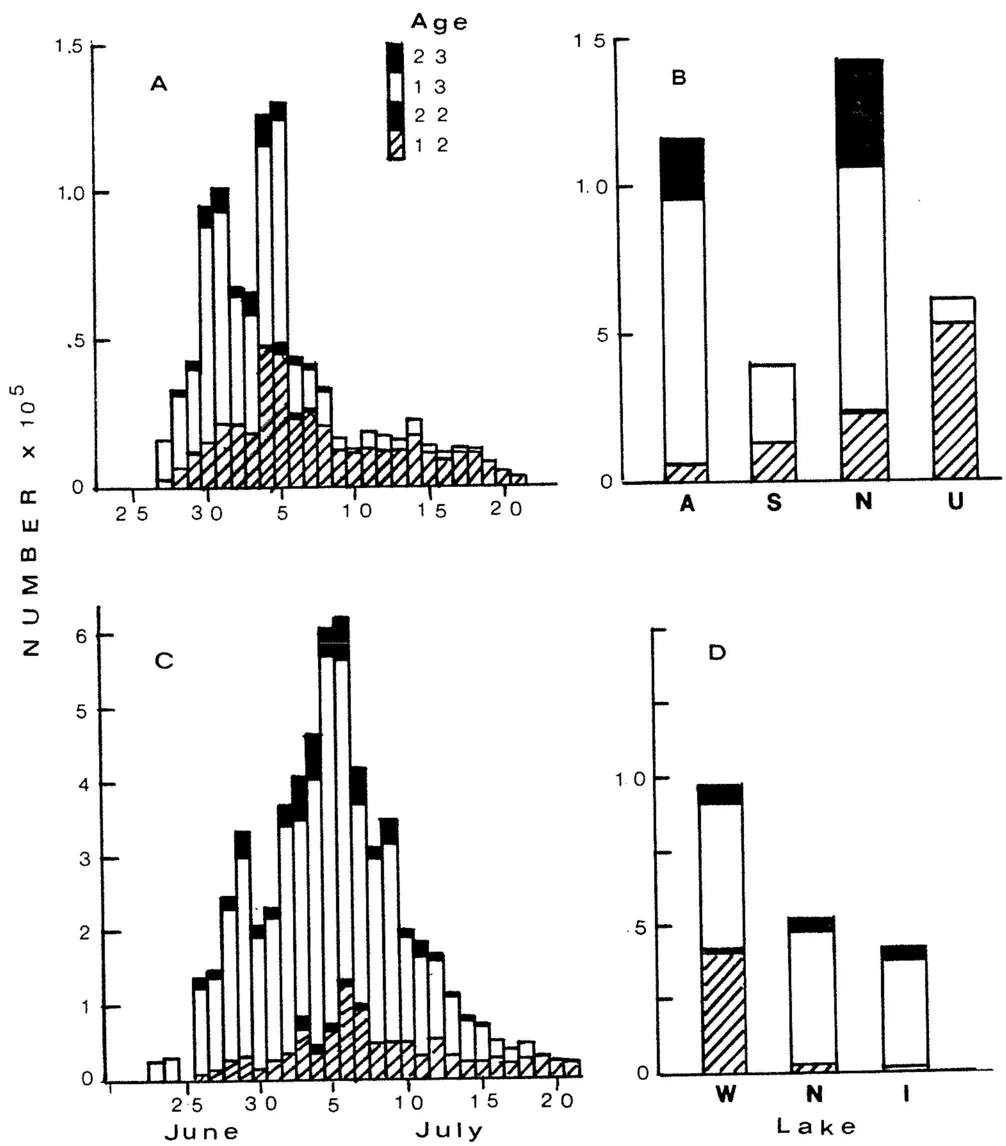

Fig. 25. Timing and distribution of the Wood River escapement and Nushagak catch of sockeye salmon in 1982. A) Daily Wood River escapement; B) escapements to Lakes Aleknagik (A) South and Central Nerka (S), North Nerka (N), and the upper lakes (U); C) daily Nushagak catches; and D) escapements to the Wood River (W), Nuyakuk (N) and Igushik (I) systems.

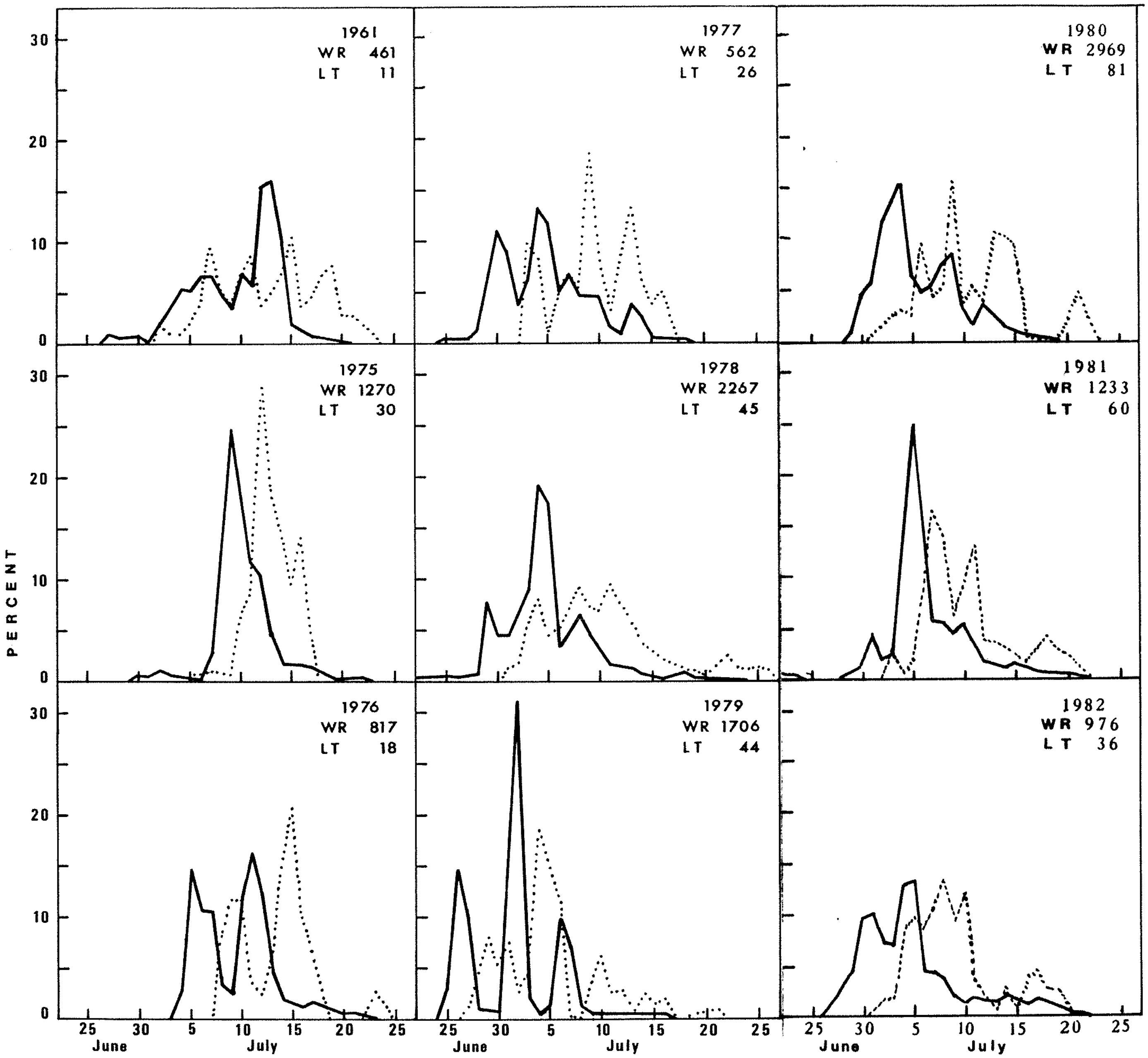

Fig. 26. Daily escapements (percent of total) to the Wood River Lakes and Little Togiak Lake (dotted), 1961, 1975-82. Total escapements (in thousands) are given under each year.

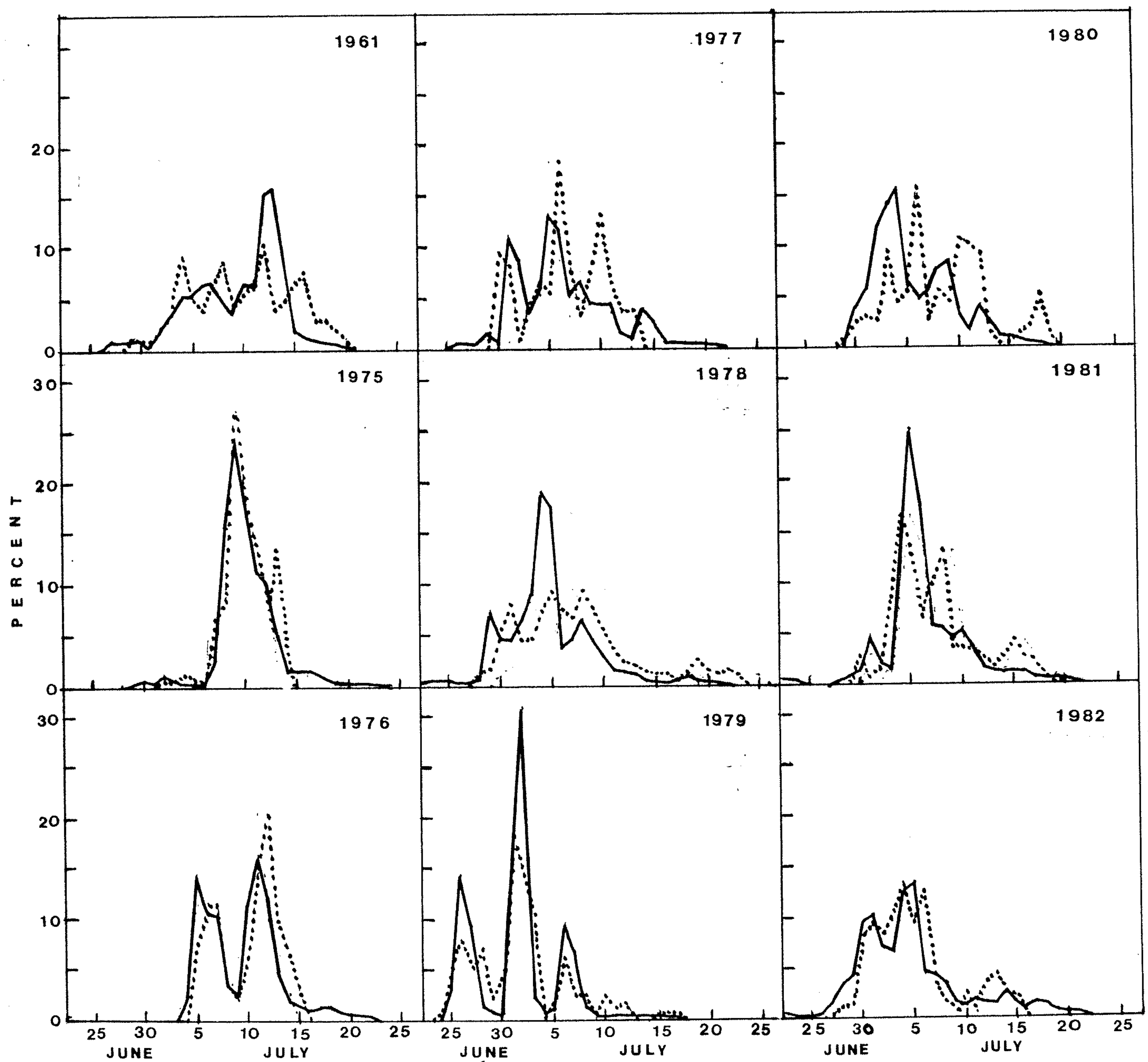

Fig. 27. Daily escapements (percent of total) to the Wood River Lakes with escapements to Little Togiak Lake lagged 3 days (4 days for 1982).

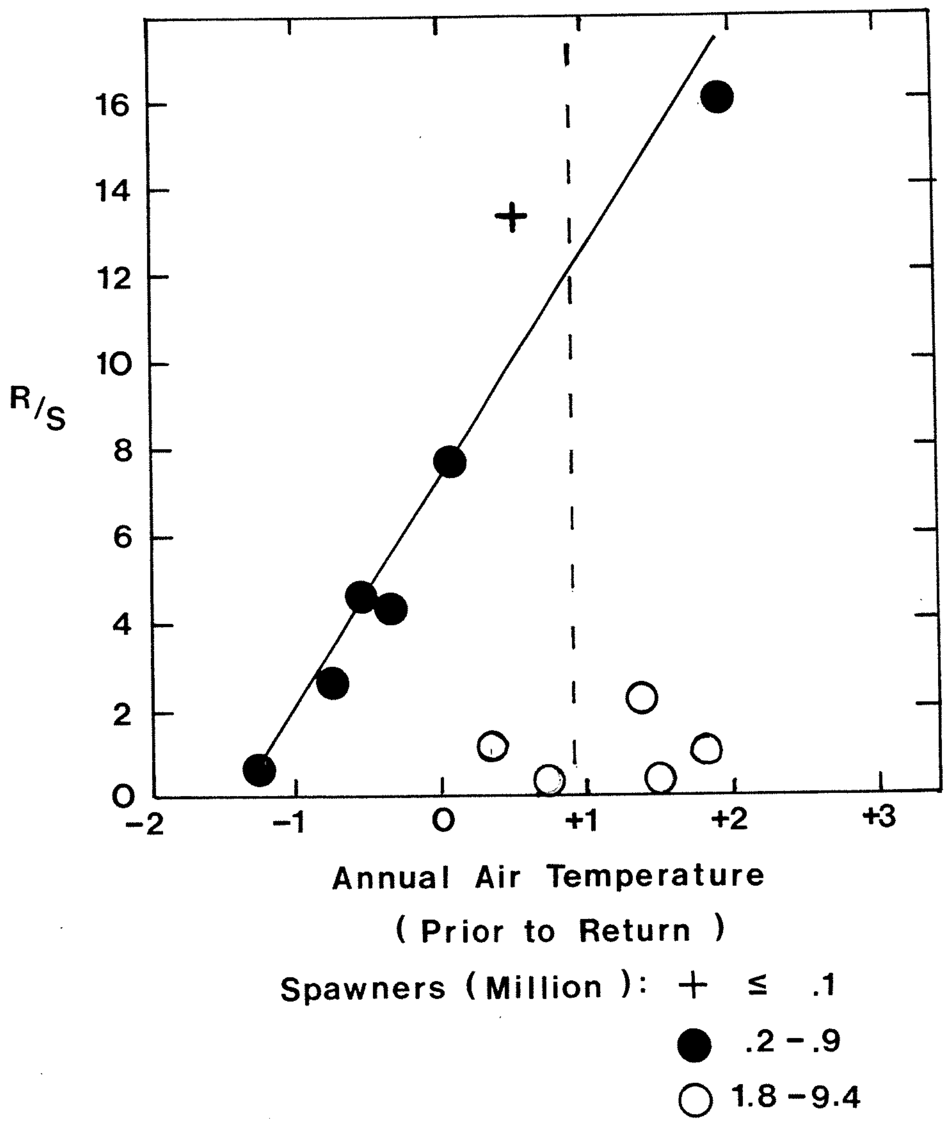

Fig. 28. Relationship between return per spawner for Nushagak pink salmon and annual air temperature in Bristol Bay.

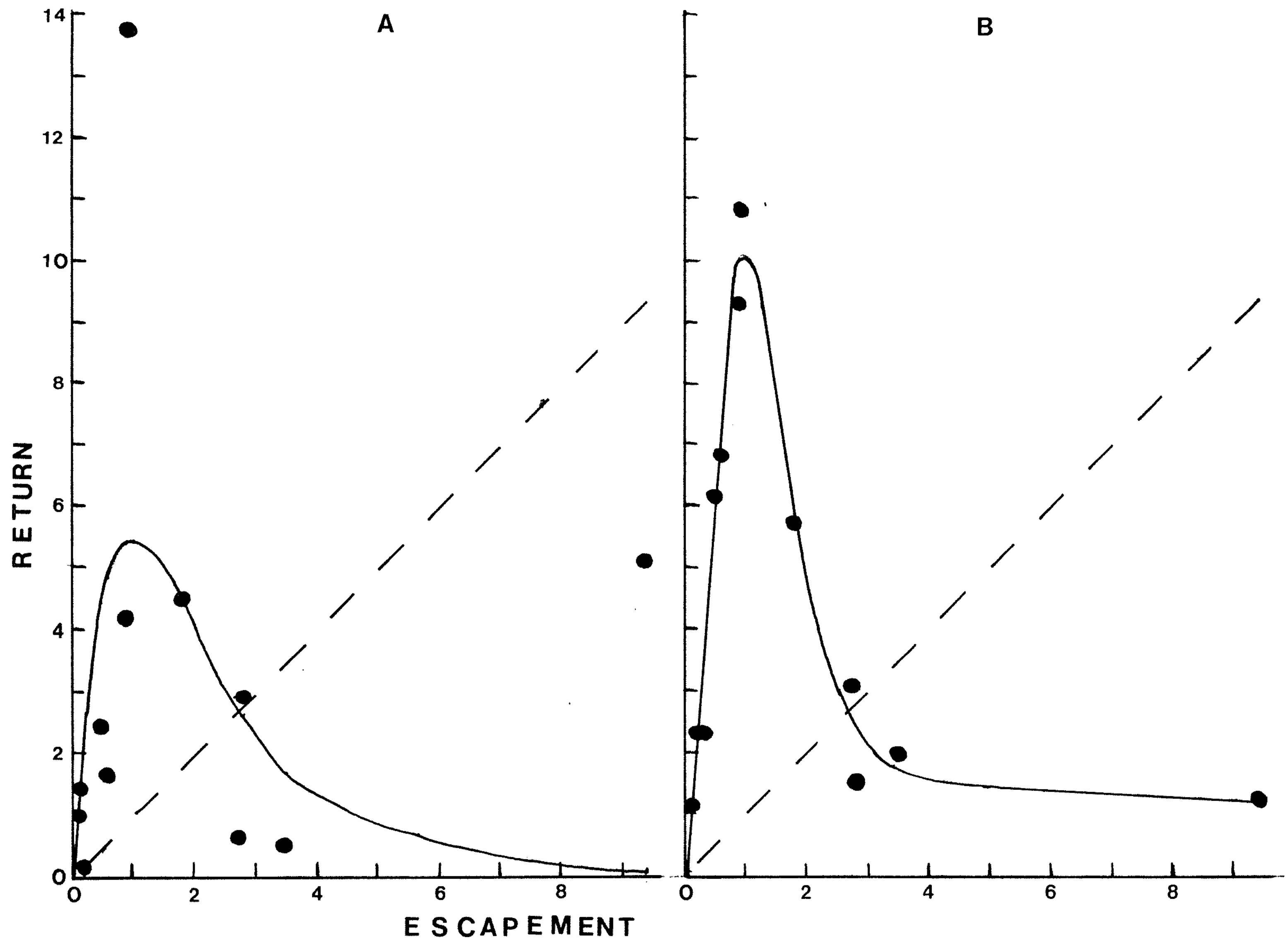

Fig. 29. Escapement-return relationships for Nushagak pink salmon; (A) unadjusted, least squares curve and (B) temperature adjusted curve fitted by eye.