AN ABSTRACT OF THE THESIS OF

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Title: Influence of Marine Environment on Age and Size at Maturity, Growth, and Abundance of Chum Salmon, <u>Oncorhynchus keta</u> (Walbaum), from Olsen Creek, Prince William Sound, Alaska.

Abstract approved: Redacted for Privacy

John D. McIntyre

Effects of the marine environment on age and size at maturity, early marine growth, and abundance of chum salmon, <u>Oncorhynchus keta</u>, were studied at Olsen Creek during 1959-77.

Chum salmon returned to Olsen Creek as predominately 3-, 4-, and 5-year fish; however, age composition varied from year to year. The mean age composition for the brood years 1956-72 for males was 15%, 66%, and 19% for 3-, 4-, and 5-year fish, respectively. Mean age composition for females of the same broods showed slightly higher percentages of older fish: 9%, 67%, and 23% for 3-, 4-, and 5-year fish, respectively. Some 6-year chum salmon returned to Olsen Creek between 1968 and 1975; but, only in 1973 did the number of 6-year fish (3%) represent more than 1% of the returns. Population sizes tended to be larger during these years, and mean age increased as the number of fish in a brood increased. Intraseasonally, age of new chum salmon spawners at Olsen Creek decreased as the season progressed. Mean size of older spawners was greater than the mean size of younger spawners; but, the ranges in

size of the three age groups overlap each other so size is not a good criterion for estimating age of chum salmon.

Measurement of circuli and distances on adult scales were used to estimate growth of chum salmon during their first two years of marine life. Both number of circuli and distances on scales of juvenile chum salmon after their first summer in Prince William Sound were shown to be related to length of the fish. Growth during the first season at sea was not related to age at maturity; however, amount of growth acquired during the second marine season was negatively related to age at maturity. Growth during the first summer at sea was related to sea surface temperatures and marine weather parameters in Prince William Sound and in the northern Gulf of Alaska. Location of chum salmon from Olsen Creek during their second year at sea is unknown.

Fluctuations in size (length) at maturity were more similar between fish from different broods returning during the same year than they were for fish that matured at different ages from the same broods. Length at maturity was related to marine weather factors during their last summer at sea in the northern Gulf of Alaska and Prince William Sound. Length at maturity was also related to mean summer sea surface temperature in Prince William Sound during the year of return.

Total survival of each brood was estimated from the ratio of number of progeny (returns) to number of parents (spawners). No direct relationships were found between survival and growth during the first or second season in the sea, sea surface temperatures, or upwelling indices along the coast. However, a highly significant relationship was found between the survival of progeny and mean length of the parents.

Influence of Marine Environment on Age and Size at Maturity, Growth, and Abundance of Chum Salmon, *Oncorhynchus keta* (Walbaum), from Olsen Creek, Prince William Sound, Alaska

by

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I. INTRODUCTION

In North America, chum salmon (_Oncorhynchus keta_) spawn in streams and rivers that drain into the Arctic Ocean and Pacific Ocean from the Mackenzie River in northern Canada southward to the Klamath River in northern California (Atkinson et al., 1967). However, only small numbers of chum salmon are found in streams north of Kotzebue Sound on the northwestern Alaska coast or south of Tillamook Bay on the central Oregon coast. On the eastern coast of Asia, the range of spawning chum salmon extends from the Lena River in the USSR on the Arctic Ocean to northern Kyushu, Japan (Sano, 1966). Based on latitude, the northern and southern limits of chum salmon spawning streams in Asia are slightly greater than the range of chum salmon spawning in North American streams.

Chum salmon return to their natal streams to spawn as 2-6 year fish, but 3-, 4-,and 5-year fish are predominant. Age composition of mature chum salmon in both Asia and North America varies greatly between areas and between years (Bakkala, 1970). Mean age at maturity tends to increase from the southern to the northern limits of their geographical range. This tendency is evident in both North American stocks (Marr, 1943; Pritchard, 1943; Helle, in press) and Asian stocks (Kobayashi, 1961; Sano, 1966). I use the term "stock" as defined by Ricker (1972) to refer to a group of chum salmon that spawn in a particular stream, "which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season." Higher percentages of older chum salmon spawners in the northern areas might indicate that slower growth rates associated with colder sea temperature in the north may cause later maturity. The association between faster growth and earlier maturity has been documented extensively for freshwater, marine, and anadromous fishes (see Alm, 1959). Nevertheless, at least some portion of the variation in age and size at maturity of anadromous fishes may be attributable to additive genetic effects (see Godfrey, 1958; Ricker, 1972; Schaffer and Elson, 1975; Gardner, 1976; and Ricker et al., 1978).

In 1959, I observed abundance, age, and size of adult chum salmon in seven streams along the eastern shore of Prince William Sound, Alaska (Helle, 1960). More than 50% of the chum salmon that returned to these streams were 3-year fish. Studies on age composition of chum salmon in Prince William Sound prior to 1959 had shown 4-year fish, never 3-year fish, to be the predominate age group (Kirkwood, 1962; Thorsteinson et al., 1963). Examination of growth on the scales of adult chum salmon that spawned in Prince William Sound in 1959 showed that 3-year fish grew significantly more during their first marine season than 4- and 5-year fish grew during their first season at sea (Helle, 1960). Three-year chum salmon that spawned in 1959 would have entered Prince William Sound as juveniles during the spring and summer of 1957 which were very unusual in that clear skies and warm temperatures prevailed instead of the more usual damp weather associated with this area.

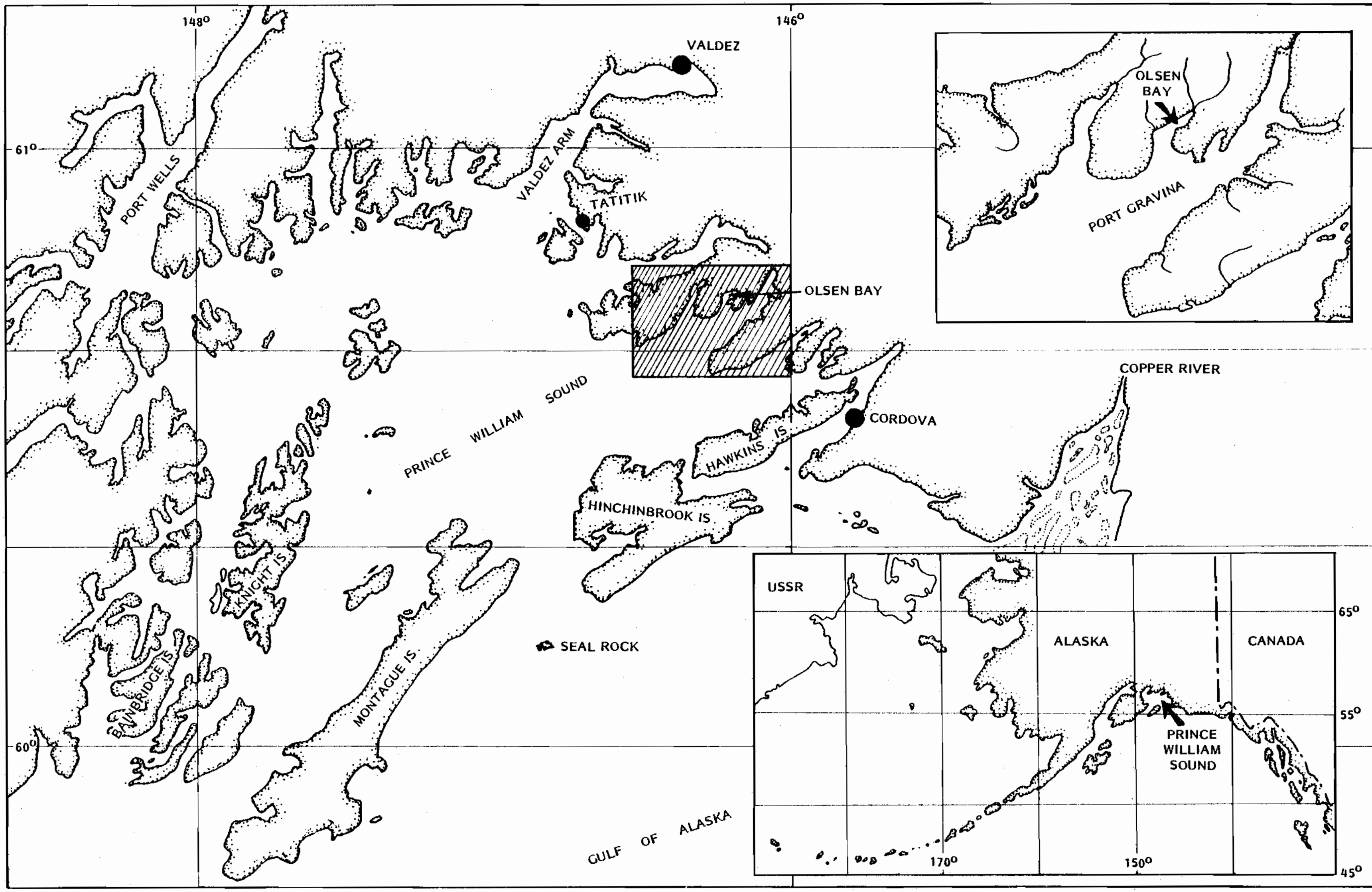

Figure 1. Index map of Alaska, showing the location of Prince William Sound and Olsen Bay.

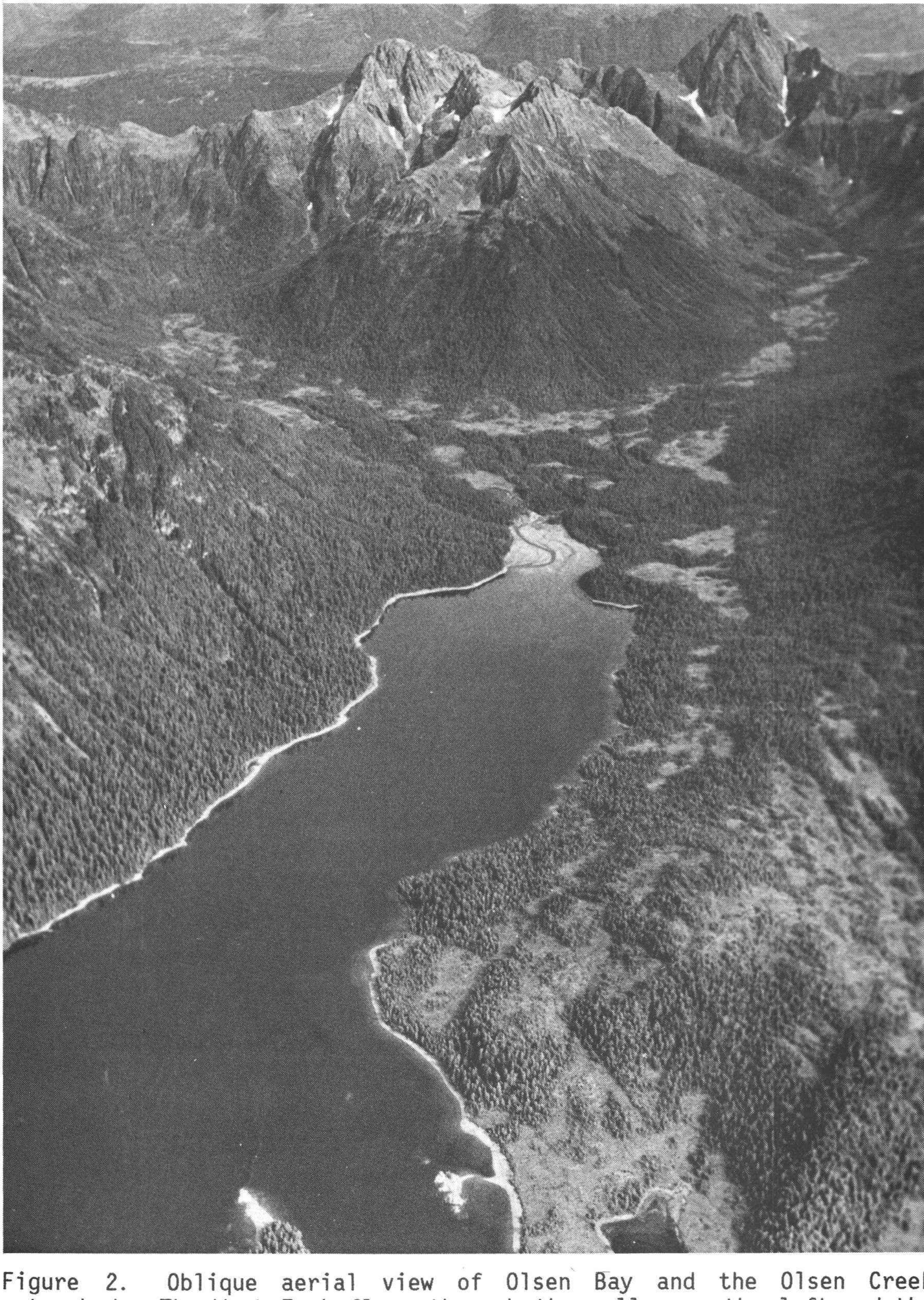

Figure 2. Oblique aerial view of Olsen Bay and the Olsen Creek watershed. The West Fork flows through the valley on the left and the East Fork flows through the valley on the right. The common intertidal channel is visible where it drains into the bay.

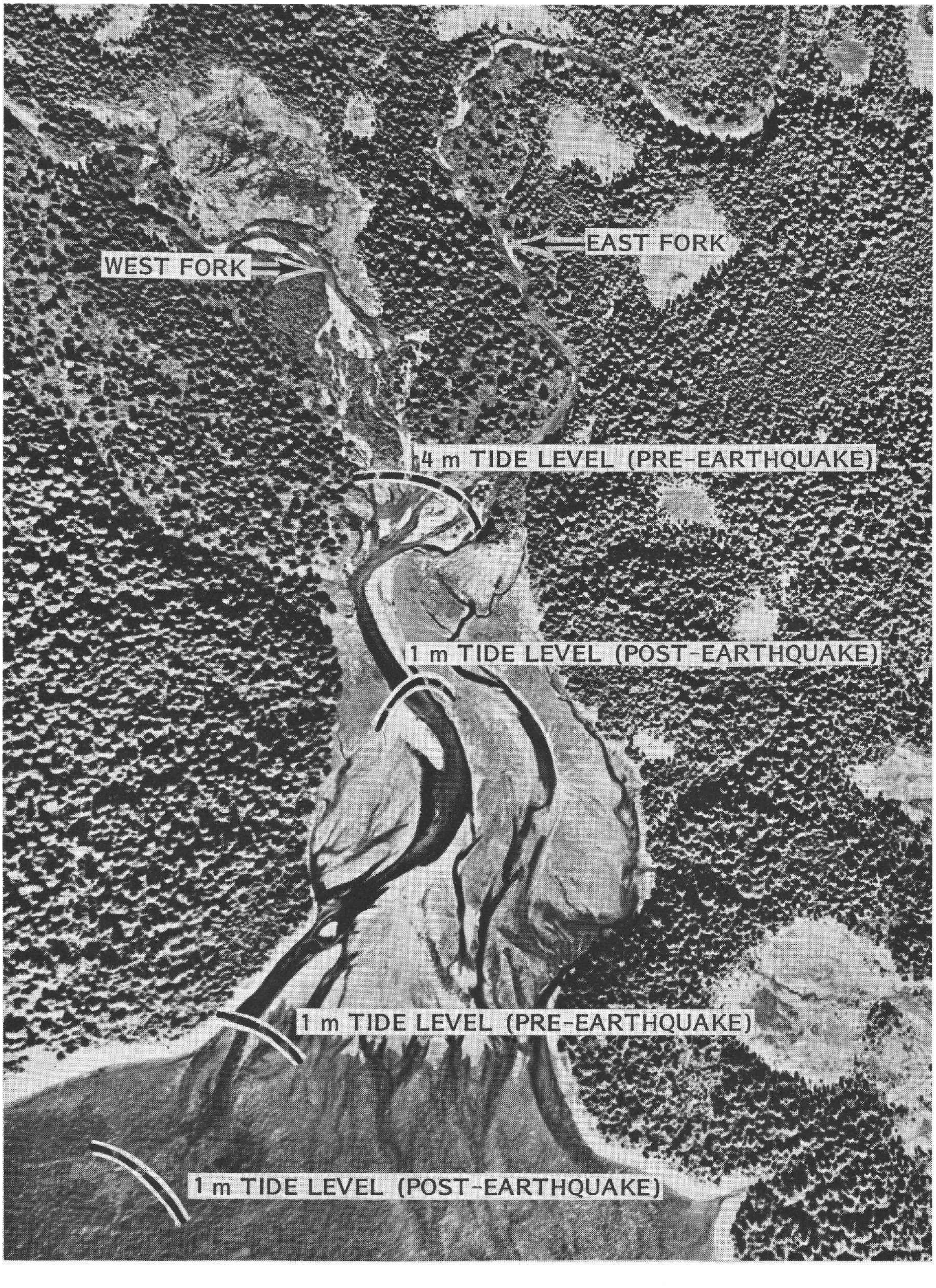

Figure 3. Vertical aerial view of the lower portion of Olsen Creek, including the intertidal stream channel and the West and East Forks (1 km = 15.6 cm).

In spite of this available spawning area, less than five percent of the spawning by chum salmon takes place above the 4-m tide level. Chum salmon spawn predominantly in the area of open stream from the tree line down to the 1-m tide level (Fig. 3). Occasional spawning occurs below the 1-m tide level in years of high population abundance, but the eggs do not survive.

The epicenter of a major earthquake in March 1964 was located in Prince William Sound. Changes in land elevation associated with this earthquake caused severe displacement and instability of the spawning habitat (Noerenberg, 1971; Roys, 1971; Thorsteinson et al., 1971). The land mass in the Olsen Bay area was uplifted about 1.2 m during the earthquake and this changed the elevation of the intertidal zone (Fig. 3). A new intertidal zone was created downstream.

More detailed physical and ecological descriptions of the Olsen Creek area and descriptions of the pink salmon spawning populations were reported by Helle et al. (1964) and Helle (1966, 1970).

III. METHODS

A. Abundance of Spawners

Several different methods of estimating abundance of spawners were tried and evaluated at Olsen Creek (Helle, 1970). The most practical of these methods was one based on periodic foot-survey counts and this method was used to estimate the number of chum salmon and pink salmon that spawned at Olsen Creek from 1959 to 1977.

During a foot survey, an observer walked along the stream bank and counted the spawners by species. Polaroid glasses were worn by the observer to reduce surface glare on the water. Fish schooled in pools were excluded from the counts because they would be counted on the riffles during the next survey. Periodic counts were made throughout each season. These counts were plotted and the area within the curve was calculated. This figure was divided by a mean "redd life" factor to obtain an estimate of the total number of spawners for the season.

Stream life for an individual salmon is defined as the period of time between stream entry and death after spawning. Riffle life or redd life is defined as the stream life minus time spent in pools. Redd life is used in the calculations because fish in pools were excluded from the foot-survey counts.

Redd life for chum salmon at Olsen Creek was determined from tagging experiments. Fish were captured with a seine in the bay and marked with large numbered Petersen disk tags (Fig. 4). The locations of individual tagged fish were observed daily.

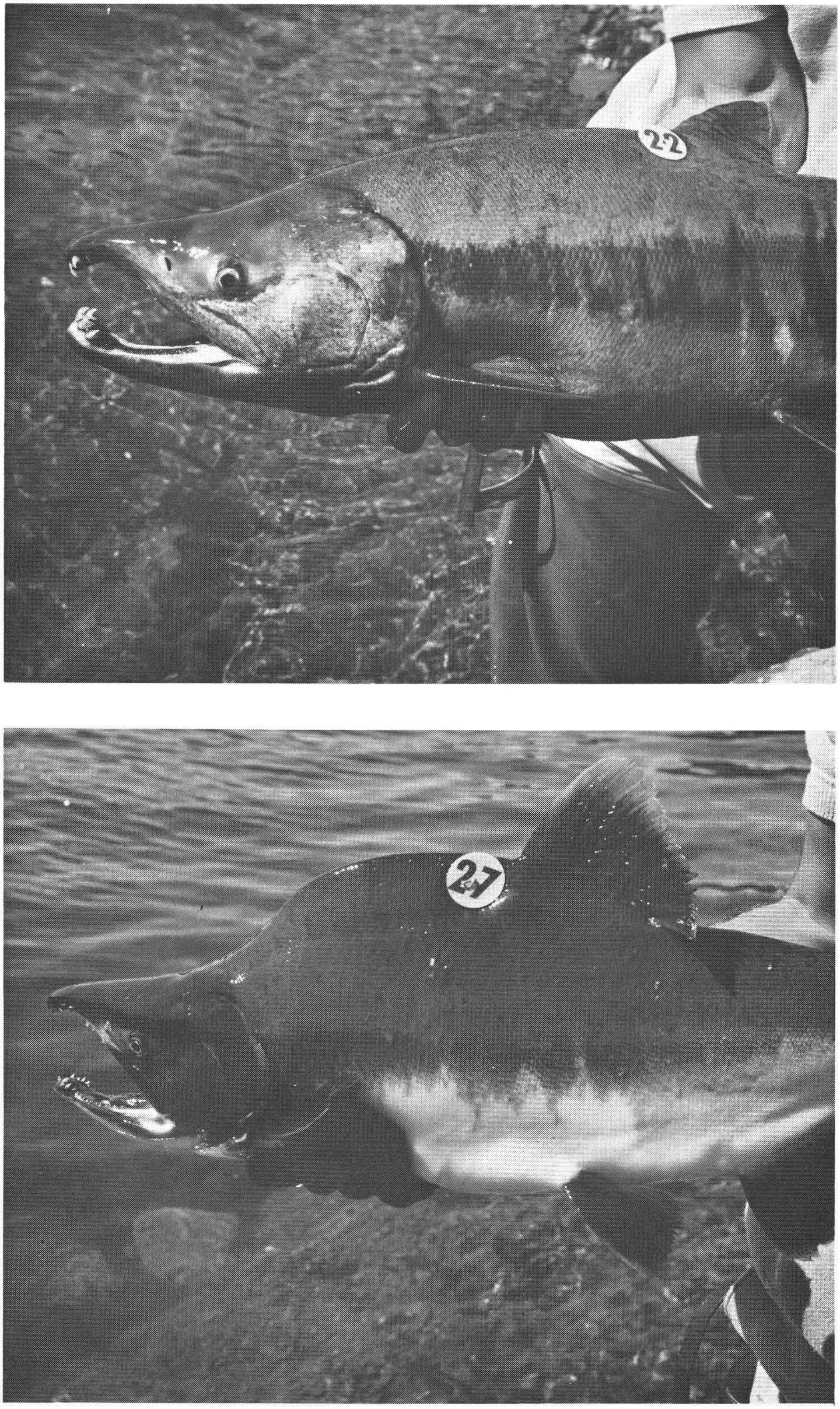

Figure 4. Male chum salmon (top) and male pink salmon (bottom) with large numbered Petersen disk tags attached.

Because of the difference in mean redd life between early- and late-run chum salmon (Table 1), the area under the curve of the foot-survey counts was separated into early and late segments. Salmon in the stream before 5 August were considered early-run fish. Late-run fish were those counted after 5 August.

Table 1. Mean redd life of early- and late-run chum salmon at Olsen Creek as determined from daily observations of tagged fish.

	Early run				Late run			
	Males		Females		Males		Females	
Year	Number	Redd life (days)	Number	Redd life (days)	Number	Redd life (days)	Number	Redd life (days)
Chum salmon:								
1963	--	--	17	11	--	--	20	7
1966	3	13	--	--	10	8	3	6
1967	71	9	10	10	56	8	44	8
1968	88	12	25	11	29	11	8	9
1969	25	9	21	8	--	--	3	8
Mean		10.8		10.0		9.0		7.5

Each segment was divided by the proper redd-life factor to estimate total number of spawners. There were also differences between years in mean redd life. A mean of all the available data was used in the calculations for years when no tagging experiments were conducted. Salmon were not counted by sex on the foot surveys and the sex ratio was assumed to be 50:50 for each season.

B. Age of Spawners

Age of chum salmon spawners was determined from scales collected from carcasses that were randomly sampled throughout each season. If enough carcasses were available, scales were collected from at least 100 fish of each sex during each sample. A single scale was removed from the carcass with a forceps from the left side of the fish in an area approximately four scale rows above the lateral line between the posterior insertion of the dorsal fin and the lateral line. Impressions were made of scales on a sheet of acetate plastic pressed under heat in a hydraulic press (Arnold, 1951; Koo, 1962a).

Chum salmon are aged from conception, not from birth or hatching. The time from fertilization to development of scales plus the growth beyond the last annulus equals about one year. Therefore, age of an individual fish was the number of annuli on the scale plus one year. This method of aging allows direct comparison to the brood year, e.g., 4-year-old progeny of parents that spawned in 1960 would return to spawn in 1964. This age designation is the same as the Gilbert-Rich method with the subscript dropped (Gilbert and Rich, 1927). Other methods of aging chum salmon (Koo, 1962b) and their equivalents are listed in Appendix Table 1.

Scales from carcasses of Pacific salmon often have resorbed edges (Clutter and Whitesel, 1956; Tesch, 1970). The validity of using scales from chum salmon carcasses for aging was tested at Olsen Creek in 1966, 1967, and 1968. Live chum salmon were captured in Olsen Bay with a seine, scales were removed, and each fish was tagged with a numbered

Petersen disk tag on each side. Scales were collected from the tagged carcasses recovered on the spawning grounds. Scales from live fish and carcasses were aged independently. The age determined from the scale from the carcass was then compared to the age determined from scales of the same fish captured in the bay before it entered the stream.

Scale samples taken from carcasses periodically each season were combined into two groups--early (fish that spawned prior to 5 August) and late (fish that spawned after 5 August). The estimated number of fish in the early and late runs were assigned to age groups based on the percentage age composition of each segment of the run. Then the age composition for the whole year was determined by combining the numbers of fish in the early and late age groups. Sexes were calculated separately because their age composition is different. No scale samples were taken during the 1965 season; therefore, the mean age composition of all the years was used to estimate numbers in each age group in 1965.

C. Size of Spawners

Common measurements of fish length could not be used on chum salmon in this study. The enormous elongation of the jaws of mature male chum salmon makes measurements that use the tip of the snout subject to additional variation. Because length was going to be compared to environmental parameters, I felt that this additional variation could reduce the sensitivity of the comparisons. Measurements of fish length often extend to the fork of the caudal fin. Spawned carcasses were sampled in this study and usually the caudal fin of both sexes was eroded. This erosion was especially noticeable in female carcasses which often had no caudal fin remaining--just a nub. For these reasons the length measurement used on carcasses throughout this study was from the middle of the eye to the end of the hypural plate (MEHP). This measurement (MEHP) was made with a caliper rule to the nearest millimeter. In order that other length measurements can be compared to MEHP, I took paired measurements on the same fish. At least 50 paired measurements were made for each comparison of different lengths. A linear regression analysis was used to obtain a conversion formula (Ricker, 1973). These conversion formulas are listed in Table 2.

Analysis of length data by sex and age groups was greatly simplified by use of a special computer program written by DiCostanzo (1965). Length data were summarized by the modification of the graphic method of Dice and Leraas (1936) described by Simpson et al. (1960). No overlap of 95% confidence intervals in these graphs usually indicates significant differences.

D. Measurement of Scale Characters

The line of count used to measure growth was a line through the center of the focus of the scale at a 75° angle with a line drawn between the center of the focus and point on the closest side where the first annulus ends in the transition zone of the scale (see Fig. 31, on p. 120 of LaLanne, 1963). Counts and measurements were made along this line directly on the magnified (80X) image on the screen of an Eberbach scale projector.

Because Olsen Creek chum salmon go to sea shortly after emergence from the stream gravels before the fish have developed scales, all the

Table 2. Conversion formulas based on linear regression analysis for comparison of mid-eye to end of hypural plate length (MEHP) of chum salmon with various other length measurements by sex.

Sex	Conversion Formula	r^2
Male	MEFT*= -0.242 + 1.118 MEHP	0.99
Female	MEFT = 38.441 + 1.049 MEHP	0.94
Male	TSFT†= 132.669 + 1.038 MEHP	0.94
Female	TSFT = 49.148 + 1.123 MEHP	0.91
Male	ESHP§= -1.316 + 0.979 MEHP	0.99
Female	ESHP = -8.537 + 0.994 MEHP	0.99

* MEFT--distance between the middle of the eye and the fork of the tail;

† TSFT--distance between the tip of the snout and the fork of the tail;

§ ESHP--distance between the posterior edge of the eye socket and the end of the hypural plate.

growth on the scales represents growth in the marine environment. The following circuli counts and measurements were made to examine early marine growth:

L_1--The length or distance between the center of the focus and the middle of the first annulus.

L_2--The length between the middle of the first annulus and the middle of the second annulus.

C_a--The number of circuli in the first half of the first marine growth period (L_1).

C_1--The number of circuli from the focus to and including the last wide dark, continuous circulus before the annulus.

C_2--The number of wide dark, continuous circuli between the first and the second annuli.

A circulus had to be continuous for 10 mm on each side of the line of count on the projected image to be counted. Branched circuli, then, would count as two circuli if the branch started outside the 10-mm space on each side of the line of count. If a circulus branched within this space, it was counted as one.

I measured up to 30 scales in each age and sex category for each year. I made all the scale counts and measurements using the same scale projector and lenses. Initial summaries of the scale measurements were facilitated by use of a computer program, BMD02D (Dixon, 1974).

E. Environmental Data

Unpublished environmental data were acquired from sources in several federal agencies within the U.S. departments of Commerce and Interior. Monthly means of sea surface temperature (SST), cloud cover, air temperature, wind speed, and dew point by 5° quadrants for quarters 4 (195-4) and 3 (195-3) of Marsden Square 195 (Fig. 5) from 1957 to 1978 were provided by the National Marine Fisheries Service (U.S. Department of Commerce), Monterey, California. Seasonal means from the monthly means for the two quadrants were calculated as follows:

Season	Months
winter	December-February
spring	March-May
summer	June-August
fall	September-November

Months were combined in these combinations to match the estimated time when juvenile chum salmon were present in certain areas.

Unpublished monthly means of sea surface temperature and seawater density from 1957 through 1974 at Cordova were obtained from the National Ocean Survey (U.S. Department of Commerce), Washington, D.C. Observations for certain months were missing, so seasonal means could not be calculated for 1958, 1960, 1962, 1963, and 1964.

Unpublished data from 1967 through 1976 on air temperature at the 1000 m elevation on Wolverine Glacier which is on the mountain range west of Prince William Sound was provided by the Geological Survey (U.S.

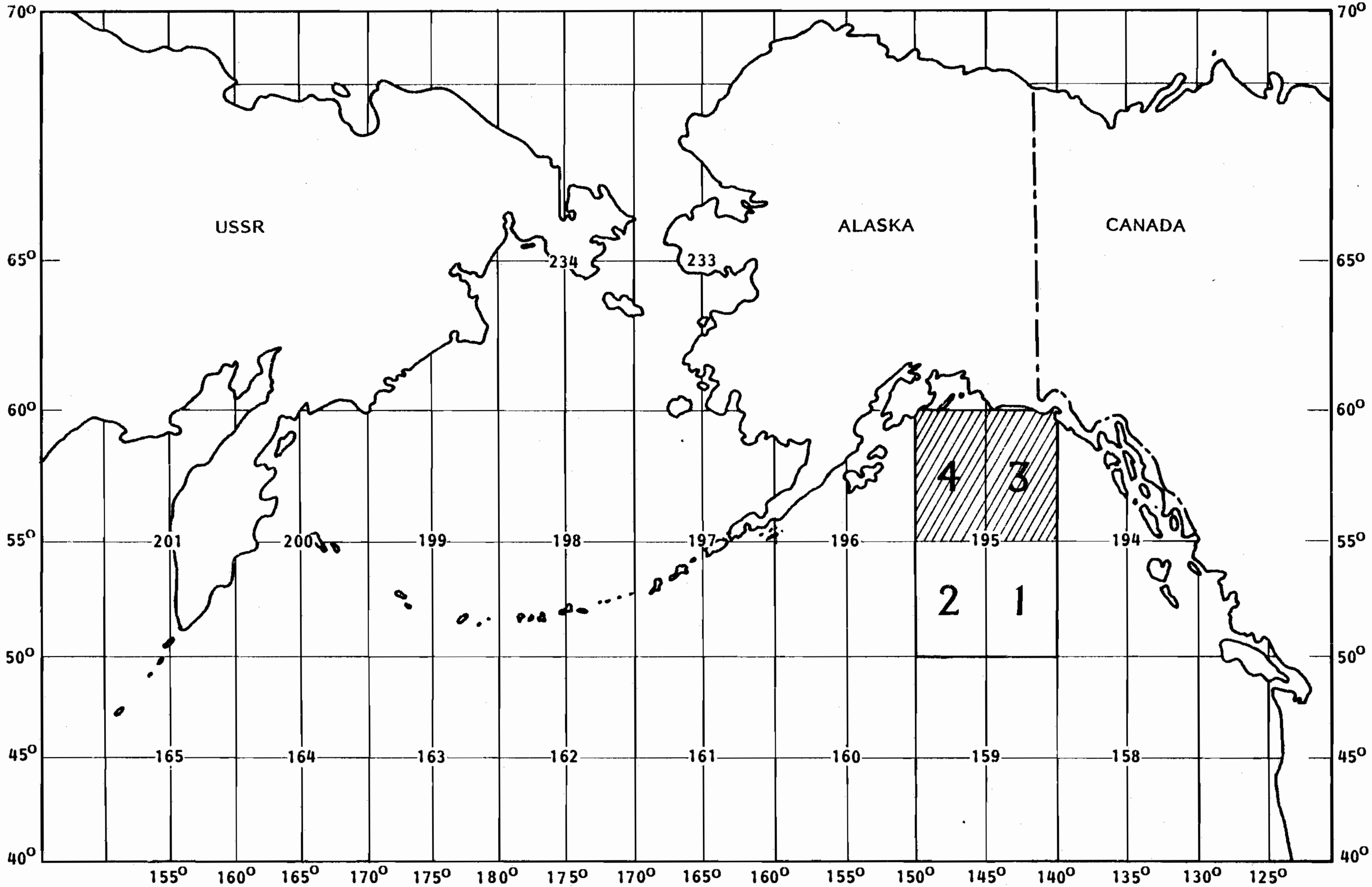

Figure 5. Location of the quarters 4 and 3 of Marsden Square 195 in the northern Gulf of Alaska south of Prince William Sound.

Department of the Interior), Fairbanks, Alaska. I converted these data to seasonal means. Mean summer flows were calculated from yearly streamflow summaries for West Fork of Olsen Creek, Power Creek, and Copper River (east of Cordova), and Wolverine Creek which drains from Wolverine Glacier (U.S. Department of the Interior, 1957-77).

Seasonal means were calculated for ocean upwelling indices from data presented by Bakun (1973) at locations near Prince William Sound (60°N, 149°W and 60°N, 146°W) and additional locations along the outside coasts of southeastern Alaska (57°N, 137°W), British Columbia (54°N, 134°W and 51°N, 13°W), and Washington (48°N, 125°W). The units of these indices are cubic meters per second per 100 meters of coastline.

The National Weather Service (U.S. Department of Commerce) regularly publishes data on air temperature, precipitation, cloud cover, and barometric pressure taken at the Cordova airport which is 21 km east of Cordova (National Weather Service, 1957-75). Seasonal means were calculated from their published data to compare with growth of chum salmon from Olsen Creek. Original units of measure for temperature (°F) and precipitation (inches) were retained to preserve original accuracy.

The relationship between biological measurements and environmental parameters was measured by regression and correlation analyses (Draper and Smith, 1966). Significance of correlation coefficients (r) was determined from tables in Snedecor and Cochran (1968). A highly significant (>0.01) correlation coefficient is identified by two asterisks. A significant correlation coefficient (>0.05) is identified by one asterisk.

IV. RESULTS

A. Abundance of Spawners

Maturing chum salmon return to Prince William Sound to spawn in streams from June through September. The commercial fishery in this area is regulated for the more abundant pink salmon. Most of the chum salmon harvest occurs incidentally (Fig. 6). Reliable estimates for the harvest of Olsen Creek chum salmon were not available, so no adjustments were made to account for fish returning to Olsen Creek that were taken in the fishery. I have assumed that the catch of Olsen Creek chum salmon each year is in direct proportion to their total abundance and that the age composition of those caught is not different from the age composition of the escapement.

In Olsen Creek, chum salmon spawners start entering the stream in late June, and they occur in peak numbers in late July. Additional spawners continue to enter the stream during August and early September. By the middle of September, only a few live chum salmon remain in the stream. Few chum salmon spawn above the high tide mark. The few that do go up the West and East forks, ascend each fork less than 100 m.

The relations between the numbers of chum salmon spawners and the return of their progeny are shown in Figure 7. A spawner-recruit curve (Ricker, 1954) was fitted to the data (Tables 3 and 4) from Olsen Creek, using procedures described by Ricker (1958) with the modified notation described by Paulik and Greenough (1966). A regression of $\log_e$ [Return (R)/Spawners (S)] against S yielded the linear equation: $y = 0.5647 - 0.0427x$. The slope and Y-axis intercept from this equation were used to

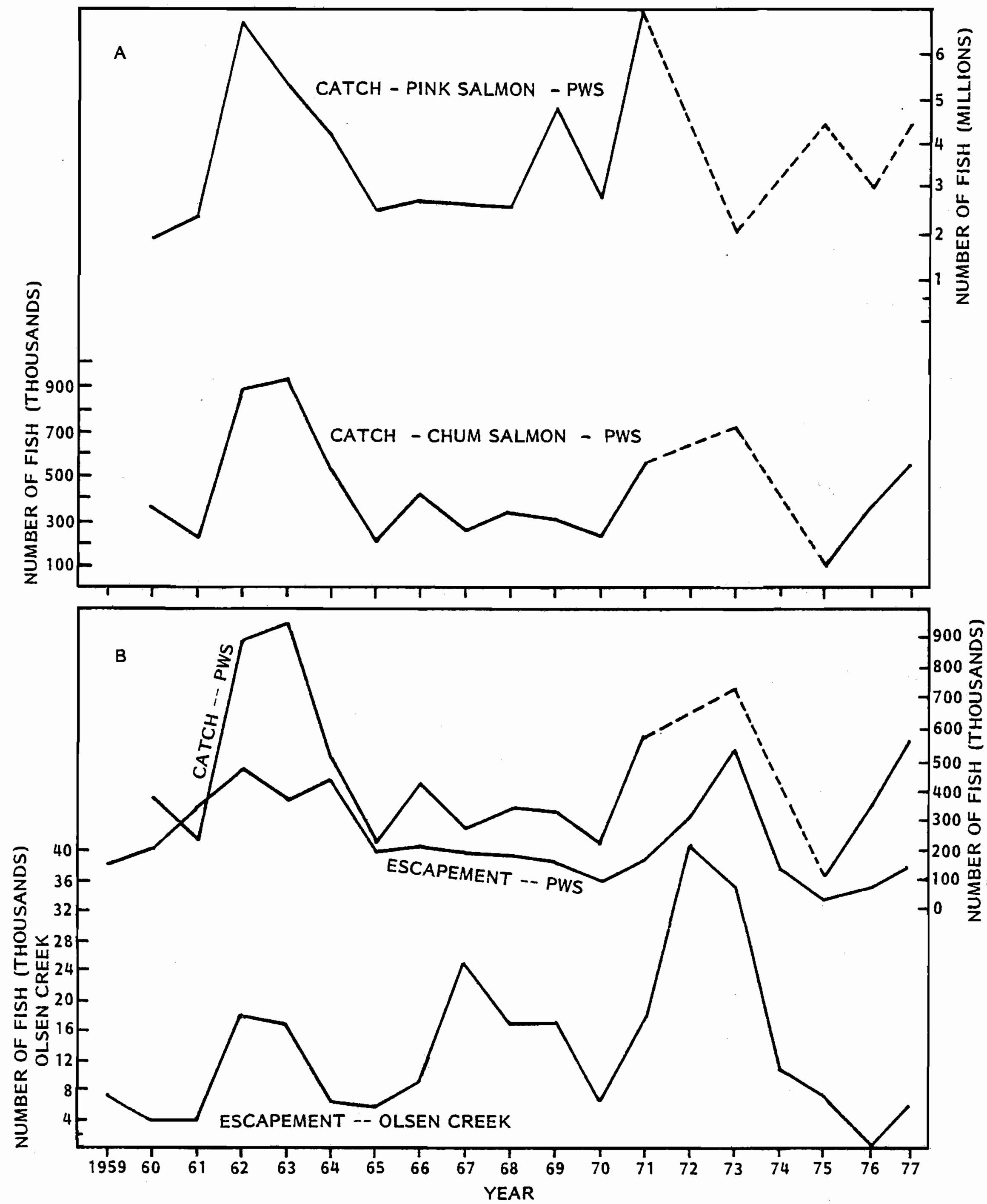

Figure 6. The number of chum salmon and pink salmon that were caught in the commercial fishery in Prince William Sound (PWS) Alaska (A), and the catch and the number of chum salmon that spawned (escapement) in streams of Prince William Sound and in Olsen Creek during 1959-77 (B). The commercial fishery was closed during 1959, 1972, and 1974. (Data from Prince William Sound from R. B. Pirtle, Alaska Department of Fish and Game, Cordova, Alaska.)

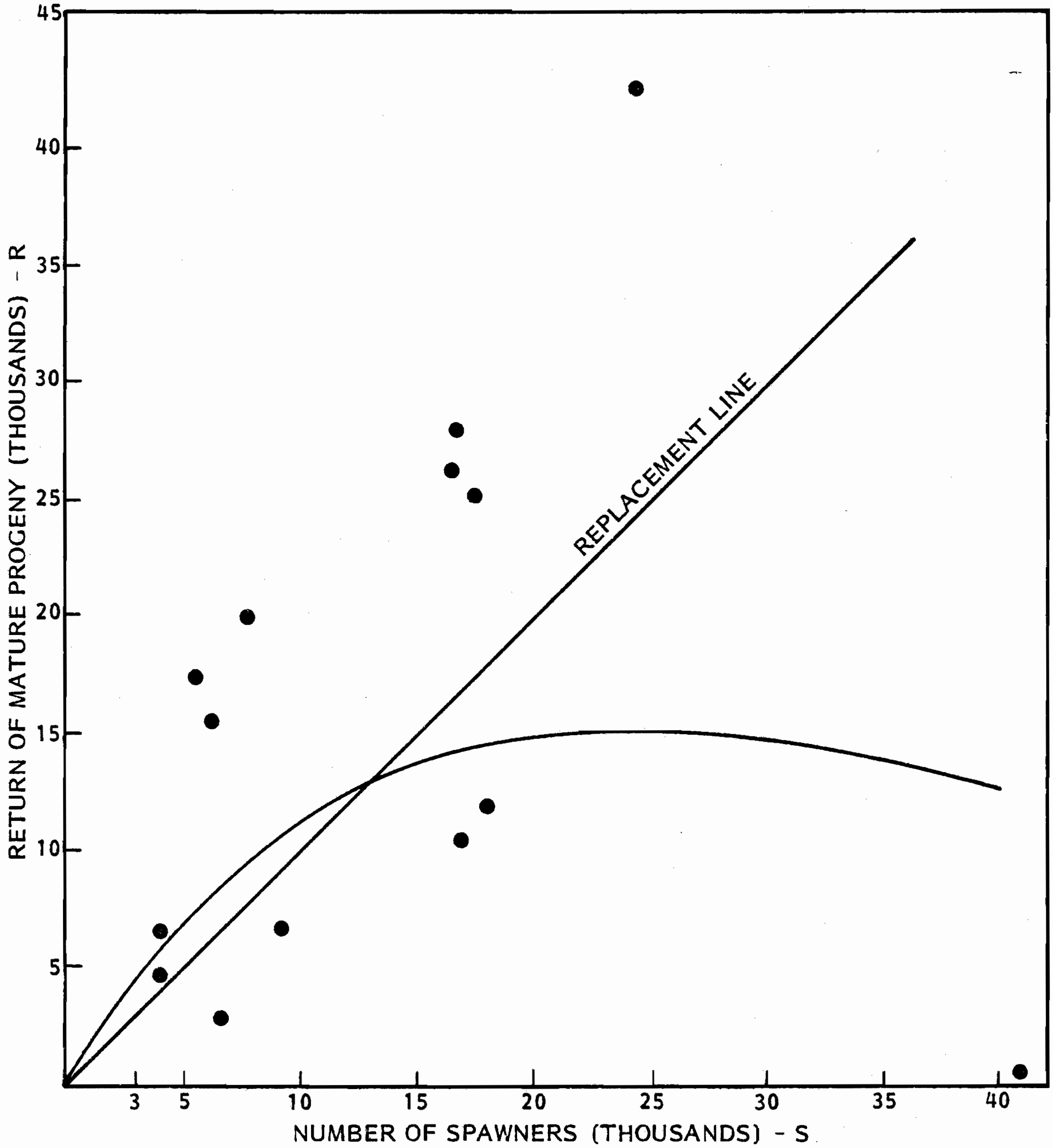

Figure 7. Relation between return of mature chum salmon progeny (R) of a brood and the number of parent spawners (S) that produced the brood at Olsen Creek. Brood years 1959-72. The replacement line bisects the y- and x-axes. The spawner-recruit curve (Ricker, 1954) is described by $\hat{R} = 1.76\ Se^{-0.0427(S)}$.

Table 3. The number and percentage of 3-, 4-, 5-, and 6-year male and female chum salmon that spawned at Olsen Creek from 1959 through 1977.

Return year	Males: Age (years) 3 No.	%	4 No.	%	5 No.	%	6 No.	%	Total no.	Females: Age (years) 3 No.	%	4 No.	%	5 No.	%	6 No.	%	Total no.	Total run (no.)
1959	3,565	91	157	4	196	5	0	0	3,918	2,507	64	1,175	30	235	6	0	0	3,917	7,835
1960	0	0	2,024	100	0	0	0	0	2,024	20	<1	2,004	99	0	0	0	0	2,024	4,048
1961	737	37	1,072	54	188	9	0	0	1,997	450	22	1,315	66	238	12	0	0	2,003	4,006
1962	2,858	32	6,042	67	66	1	0	0	8,966	1,527	17	7,060	78	443	5	0	0	9,030	17,996
1963	888	11	6,539	79	830	10	0	0	8,257	523	6	6,868	83	865	10	0	0	8,256	16,513
1964	123	4	1,908	62	1,046	34	0	0	3,077	61	2	1,846	60	1,169	38	0	0	3,076	6,153
1965	457	16	1,798	63	599	21	0	0	2,854	257	9	1,884	66	713	25	0	0	2,854	5,708
1966	907	20	3,262	71	447	10	0	0	4,616	263	6	4,030	87	325	7	0	0	4,618	9,234
1967	425	3	10,039	79	2,221	18	0	0	12,685	212	2	10,753	86	1,591	13	0	0	12,556	25,241
1968	1,029	12	5,522	64	2,116	24	22	<1	8,689	624	7	5,990	69	2,051	24	22	<1	8,687	17,376
1969	423	5	6,360	77	1,501	18	19	<1	8,303	331	4	6,046	72	1,972	24	0	0	8,349	16,652
1970	147	4	1,922	58	1,217	37	0	0	3,286	79	2	1,054	32	2,165	66	0	0	3,298	6,584
1971	164	2	7,236	85	1,074	13	0	0	8,474	39	<1	6,702	79	1,691	20	0	0	8,432	16,906
1972	663	3	5,965	29	13,770	67	46	<1	20,444	153	1	6,373	31	13,796	68	46	<1	20,368	40,812
1973	242	1	10,352	59	6,352	36	471	3	17,417	125	1	10,795	62	6,199	35	346	2	17,465	34,882
1974	1,819	32	1,028	18	2,725	48	64	1	5,636	998	18	1,314	23	3,316	58	64	1	5,692	11,328
1975	30	1	3,763	98	23	0.5	23	0.5	3,839	15	0.3	3,685	96	117	3	23	0.5	3,840	7,679
1976	57	19	171	57	72	24	0	0	300	9	3	207	69	84	28	0	0	300	600
1977	164	6	2,653	94	20	1	0	0	2,837	67	2	2,723	96	47	2	0	0	2,837	5,674
Mean		16		64		20		<1			9		68		23		<1		

Table 4. The number and percentage of 3-, 4-, 5-, and 6-year male and female chum salmon that returned to Olsen Creek to spawn from the 1956-72 broods.

Brood year	Males: Age (years) 3 No.	%	4 No.	%	5 No.	%	6 No.	%	Males Total no.	Females: Age (years) 3 No.	%	4 No.	%	5 No.	%	6 No.	%	Females Total no.	Total return (no.)
1956	3,565	62	2,024	35	188	3	0	0	5,777	2,507	53	2,004	42	238	5	0	0	4,749	10,526
1957	0	0	1,072	94	66	6	0	0	1,138	20	1	1,315	74	443	25	0	0	1,778	2,916
1958	737	10	6,042	79	830	11	0	0	7,609	450	5	7,060	84	865	10	0	0	8,375	15,984
1959	2,858	27	6,539	63	1,046	10	0	0	10,443	1,527	16	6,868	72	1,169	12	0	0	9,564	20,007
1960	888	26	1,908	56	599	18	0	0	3,395	523	17	1,846	60	713	23	0	0	3,082	6,477
1961	123	5	1,798	76	447	19	0	0	2,368	61	3	1,884	83	325	14	0	0	2,270	4,638
1962	457	8	3,262	55	2,221	37	22	<1	5,962	257	4	4,030	68	1,591	27	22	<1	5,900	11,862
1963	907	7	10,039	77	2,116	16	19	<1	13,081	263	2	10,753	82	2,051	16	0	0	13,067	26,148
1964	425	6	5,522	74	1,501	20	0	0	7,448	212	3	5,990	73	1,972	24	0	0	8,174	15,622
1965	1,029	12	6,360	74	1,217	14	0	0	8,606	624	7	6,046	68	2,165	25	0	0	8,835	17,441
1966	423	12	1,922	55	1,074	31	46	1	3,465	331	11	1,054	34	1,691	54	46	1	3,122	6,587
1967	147	1	7,236	33	13,770	64	471	2	21,624	79	<1	6,702	32	13,796	66	346	2	20,923	42,547
1968	164	1	5,965	48	6,352	51	64	<1	12,545	39	1	6,373	50	6,199	49	64	<1	12,675	25,220
1969	663	5	10,352	75	2,725	20	23	<1	13,763	153	1	10,795	76	3,316	23	23	<1	14,287	28,050
1970	242	19	1,028	80	23	2	0	0	1,293	125	8	1,314	84	117	8	0	0	1,556	2,849
1971	1,819	32	3,763	67	72	1	0	0	5,654	998	21	3,685	77	84	2	0	0	4,767	10,421
1972	30	14	171	77	20	9	0	0	221	15	6	207	77	47	17	0	0	269	490
Mean		15		66		19		<1			9		67		23		<1		

fit the Ricker curve from the formula $\hat{R} = 1.76\ Se^{-0.0427S}$. The optimum number of spawners can be estimated from the spawner-recruit curve (Fig. 7) at the point where the curve has a positive slope of 45°. Because the curve was broad, I calculated the optimum number of spawners to be approximately 6,000 fish from procedures described by Dahlberg (1973). The slope (0.0427) and Y-axis intercept (0.5647) were used to calculate the number of spawners (S_m) which produces the most returns (S_m = 10,200) and the replacement size (S_r) or the number of spawners that on the average just replaces itself (S_r = 13,200). All of these parameters could be estimated directly from the curve on the graph (Fig. 7).

The extreme point (S = 40,812) on the graph (Fig. 7) represents the 1972 brood year. The spawning escapement of chum salmon at Olsen Creek in 1972 was the largest observed during this study and the returns from this record spawning were the smallest (<500)--45 in 1975 as 3-year fish, 378 in 1976 as 4-year fish, and 67 as 5-year fish in 1977 (Table 4). The 1967 brood of chum salmon produced the most returns at Olsen Creek during this study--25,241 spawners produced 42,547 returns (Fig. 7).

Chum salmon returns to Olsen Creek exhibited three progressively larger periods of abundance from 1960 to 1973 (Fig. 8). Peaks of abundance between these three periods occurred every five years. In contrast, both even- and odd-year lines of pink salmon returns declined sharply after 1965 and remained at low levels through 1973. The decline of pink salmon returns to Olsen Creek after 1965 was primarily caused by stream instability following changes in land elevations associated with the 1964 earthquake (Thorsteinson et al., 1971). Why chum salmon

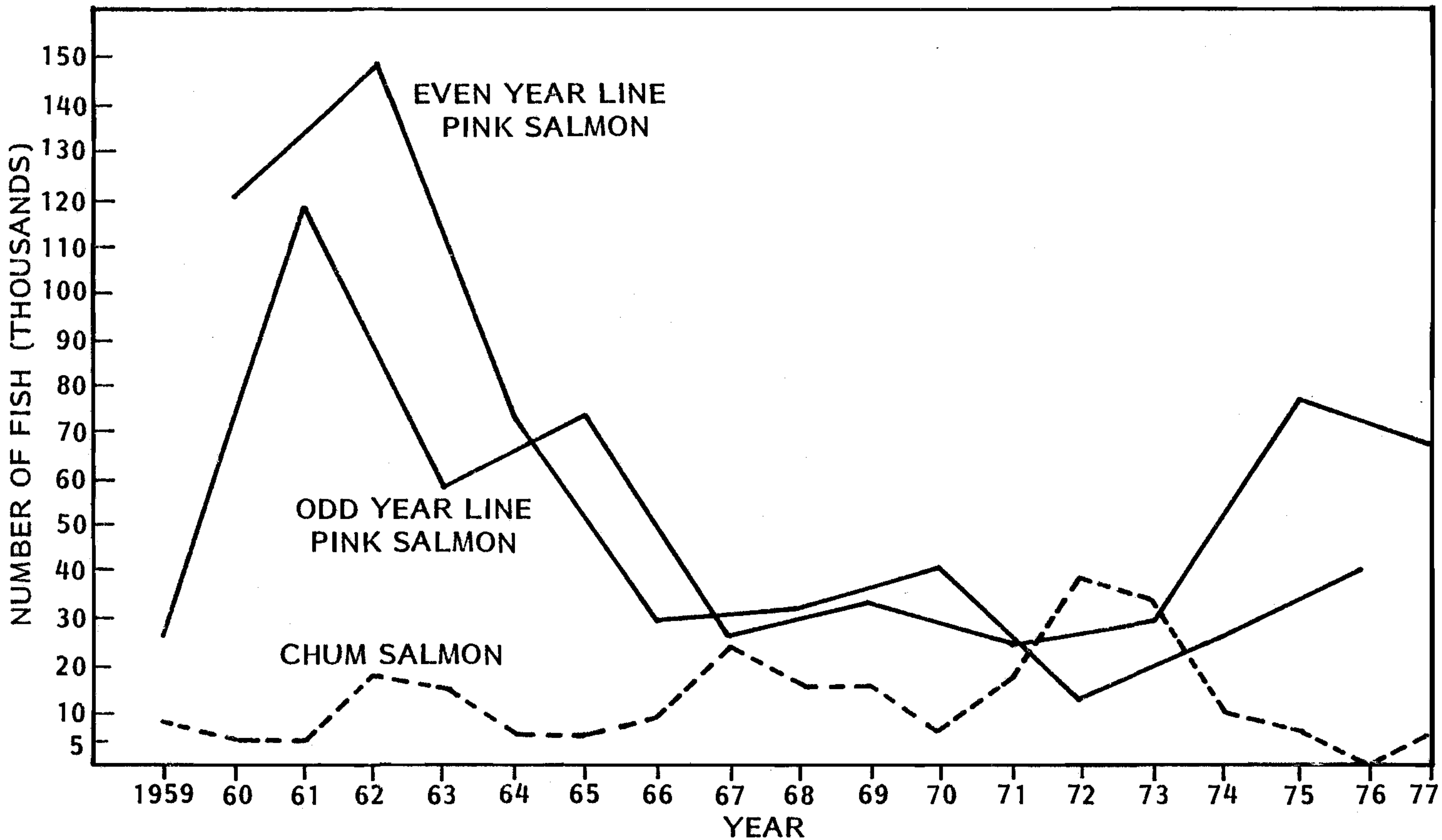

Figure 8. Number of chum salmon and even- and odd-year-line pink salmon that spawned at Olsen Creek, 1959-77.

returns to Olsen Creek increased during this same period is not definitely known; however, most chum salmon spawn in areas of the stream where ground water upwells into the intragravel water. The streambanks in these upwelling areas were more stable than the streambanks in the rest of the intertidal stream channel where most of the pink salmon spawned, also, chum salmon redds are deeper than pink salmon redds (Table 5). Perhaps eggs deposited at greater depths in the unstable portion of the streambed were affected less by scouring associated with floods.

Table 5. Depth in the streambed of redds of chum salmon and pink salmon measured just prior to egg deposition at Olsen Creek, 1969.

	Depth of Redds	
Species	Mean (cm)	Number measured
Chum	21.5	26
Pink	17.3	30

The possibility exists that the increasing abundance of chum salmon at Olsen Creek may have had a negative effect on the abundance of pink salmon. When the number of chum salmon spawners is compared to the number of pink salmon spawners from the same brood year, no relationship is apparent (Fig. 9A). However, when the numbers of chum salmon and pink salmon spawners are compared that returned during the same year, an apparent relation exists (Fig. 9B). Explanations for this relation could involve some competitive factor between chum salmon and pink

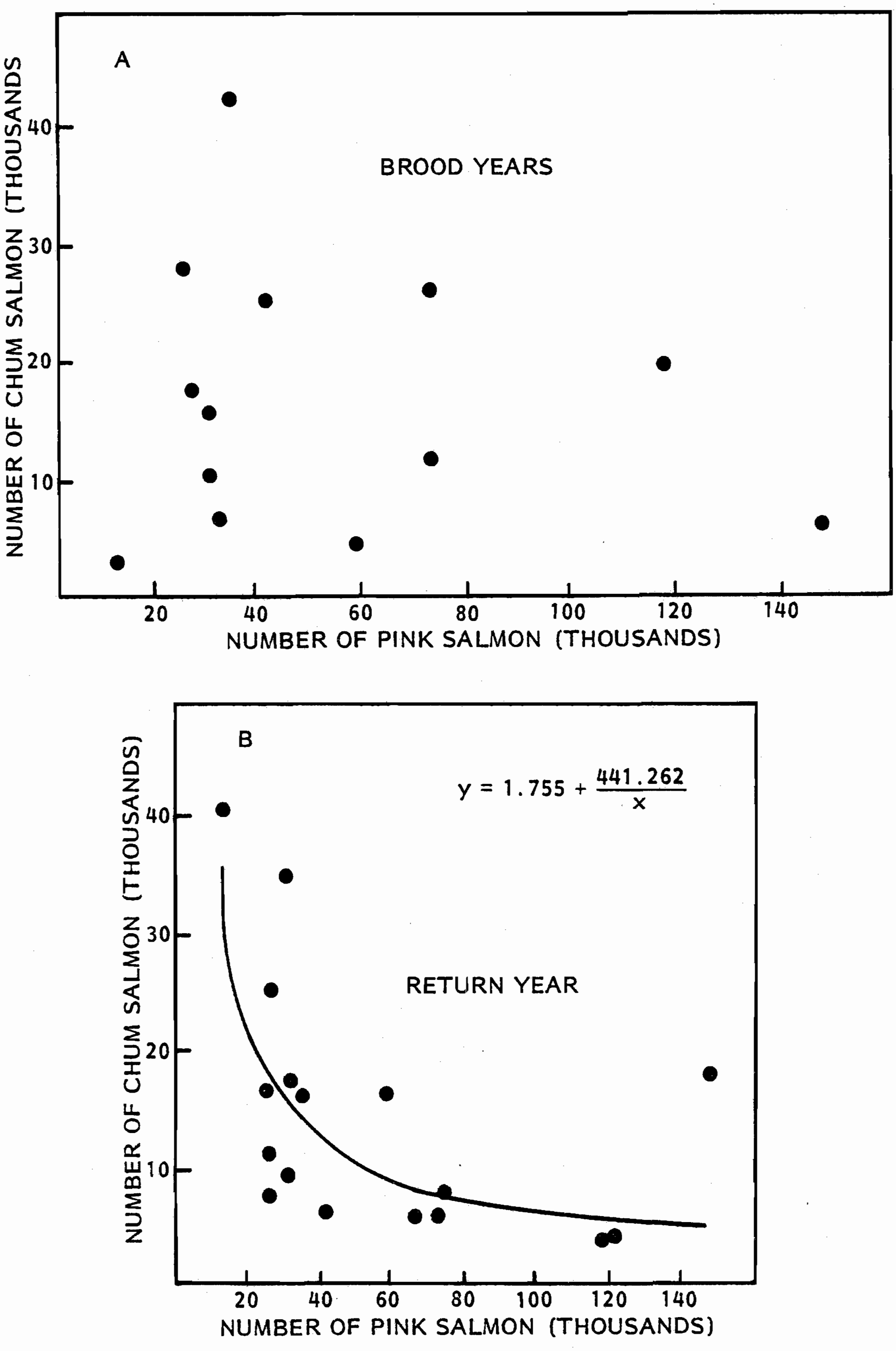

Figure 9. Comparison between numbers of chum salmon and pink salmon spawners at Olsen Creek from the same brood years, 1959-72, (A) and during the same return years, 1959-75, (B).

salmon for food and space or possibly some selective predation factor during their final year in the ocean.

If the number of pink salmon that returned in one year was related to the number of 3-year chum salmon that returned the following year and/or the number of 4-year chum salmon that returned two years later, a useful predictive relationship could be established. Unfortunately, there is no relation (Fig. 10A and 10B). Likewise, if the number of 3-year chum salmon that spawned in one year was indicative of the number of 4-year chum salmon that would return the following year and the number of 4-year chum salmon that returned in one year was indicative of the number of 5-year chum salmon that would return the following year, useful predictive equations could be established. Especially useful would be a reliable prediction of the return of 4-year chum salmon because they are usually the most abundant age group. Unfortunately, no relationships are apparent in these comparisons (Fig. 10C, 10D).

B. Age Composition of Spawners

The validity of using scales of chum salmon before spawning for age determination has been verified by analysis of scales of known-age fish (LaLanne, 1963; Bilton and Ricker, 1965). The validity of using scales from carcasses for aging was tested at Olsen Creek during 1966-68. Scales were removed from a total of 548 chum salmon that were captured and tagged in Olsen Bay in for this special study. Thirty percent (163) of these fish were recovered as spawned carcasses and scales were removed for aging again (Table 6). Only one disagreement out of 163 paired comparisons occurred when the two independent age determinations

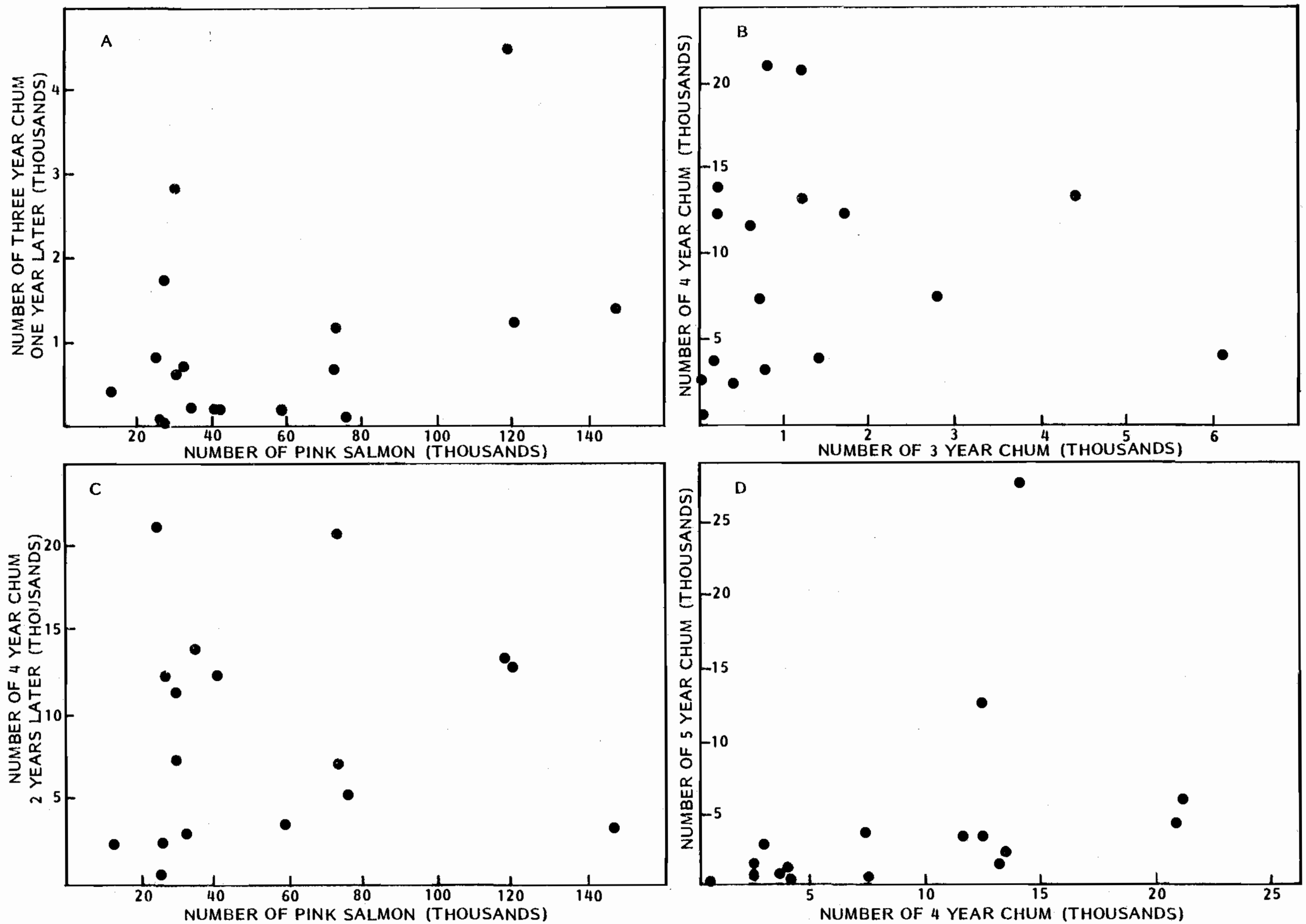

Figure 10. Comparison between numbers of pink salmon spawners and the numbers of 3-year chum salmon spawners one year later (A) and the numbers of 4-year chum salmon two years later (C); and the comparison between the numbers of 3-year and 4-year chum salmon spawners of the same brood (B) and the numbers of 4-year and 5-year chum salmon spawners from the same brood (D), 1959-76.

Table 6. Comparison between number and age of male and female chum salmon captured and marked in Olsen Bay and the number and age of the recovered marked carcasses that spawned in Olsen Creek during 1966, 1967, and 1968.

	Males				Females				Grand total
	Age				Age				
	3	4	5	Total	3	4	5	Total	
1966:									
Marked (no.)	2	82	13	97	2	52	3	57	154
Recovered (no.)	1	17	2	20	0	12	1	13	33
Recovered (%)	50	21	15	21	0	23	33	23	21
Days out ($\bar{X}$)*	--	--	--	19	--	--	--	21	20
Disagreements (no.)	0	0	1	1	0	0	0	0	0
1967:									
Marked (no.)	4	174	22	200	3	74	7	84	284
Recovered (no.)	0	28	6	34	1	41	0	42	76
Recovered (%)	0	16	27	17	33	55	0	50	27
Days out ($\bar{X}$)*	--	20	18	20	--	18	--	18	19
Disagreements (no.)	0	0	0	0	0	0	0	0	0
1968:									
Marked (no.)	24	50	12	86	8	8	8	24	110
Recovered (no.)	14	19	3	36	4	7	7	18	54
Recovered (%)	58	38	25	42	50	88	88	75	49
Days out ($\bar{X}$)*	20	21	20	21	21	20	20	20	20
Disagreements (no.)	0	0	0	0	0	0	0	0	0

* Mean number of days between marking live fish in bay and recovery of marked carcass.

from the same fish were compared. This specimen was aged a tentative 4-year fish from the scale taken when the fish was captured in the bay. Scales taken from the carcass indicated it was a 5-year fish. Obviously, this error was not caused by loss of an annulus due to resorption of the edge of the scale. This study confirms that age can be successfully determined from the scales of chum salmon carcasses at Olsen Creek. Oakley (1966) also verified that scales from chum salmon carcasses could be used for age determinations in Tillamook Bay, Oregon, by comparing scale characteristics of chum salmon caught in the commercial fishery with scales from carcasses recovered on the spawning grounds. LaLanne and Safsten (1969) suggest that new growth should be evident on the margin of resorbed scales if they are used for age determination.

Chum salmon scales (and pink salmon scales) are not as "complex" as scales from the other species of Pacific salmon because usually no freshwater growth is represented on the scales of these two species. Chum salmon fry generally have migrated to the marine environment before circuli are formed on the scale. However, there are some exceptions. I have seen freshwater growth on some scales from chum salmon that spawned in the Kluane River, a tributary of the Yukon River in Yukon Territory, Canada, about 2,700 km upstream from tidewater. Roslyy (1972) reports freshwater growth on the scales of some chum salmon that spawn in the Amur River in the USSR.

Occasionally, a supplementary check or estuary check was seen between the focus and the first annulus on scales from chum salmon at

Olsen Creek. This check has been frequently reported on scales of chum salmon and it does not represent an annulus (Bilton and Ricker, 1965).

1. Intraseasonal Changes in Age Composition

I determined the age from scales of more than 10,000 chum salmon that spawned at Olsen Creek from 1959-78. With one exception, scale samples were taken from chum salmon carcasses periodically during each season from 1959-75 (Appendix Table 2). No scale or length samples were taken during the 1965 spawning season. Only one sample was taken during each season in 1976, 1977, and 1978.

A clear intraseasonal trend in age composition of both male and female chum salmon spawners occurs at Olsen Creek. The percentage of 5-year fish decreases as the season progresses, and the percentage of 3-year fish increases during this time (Fig. 11). Usually, 4-year fish are strongly represented throughout the season. Data for this graph were selected for years when the three major age groups were adequately represented by early (spawned before 5 August) and late spawners (spawned after 5 August).

Female chum salmon tend to be slightly older than males at Olsen Creek. During each season, the age composition of the females shows a higher percentage of older fish, and the males show a higher percentage of younger fish (Table 3).

2. Interseasonal Changes in Age Composition

Age composition of the chum salmon spawners that returned to Olsen Creek varied widely from year to year (Table 3). Only one chum salmon

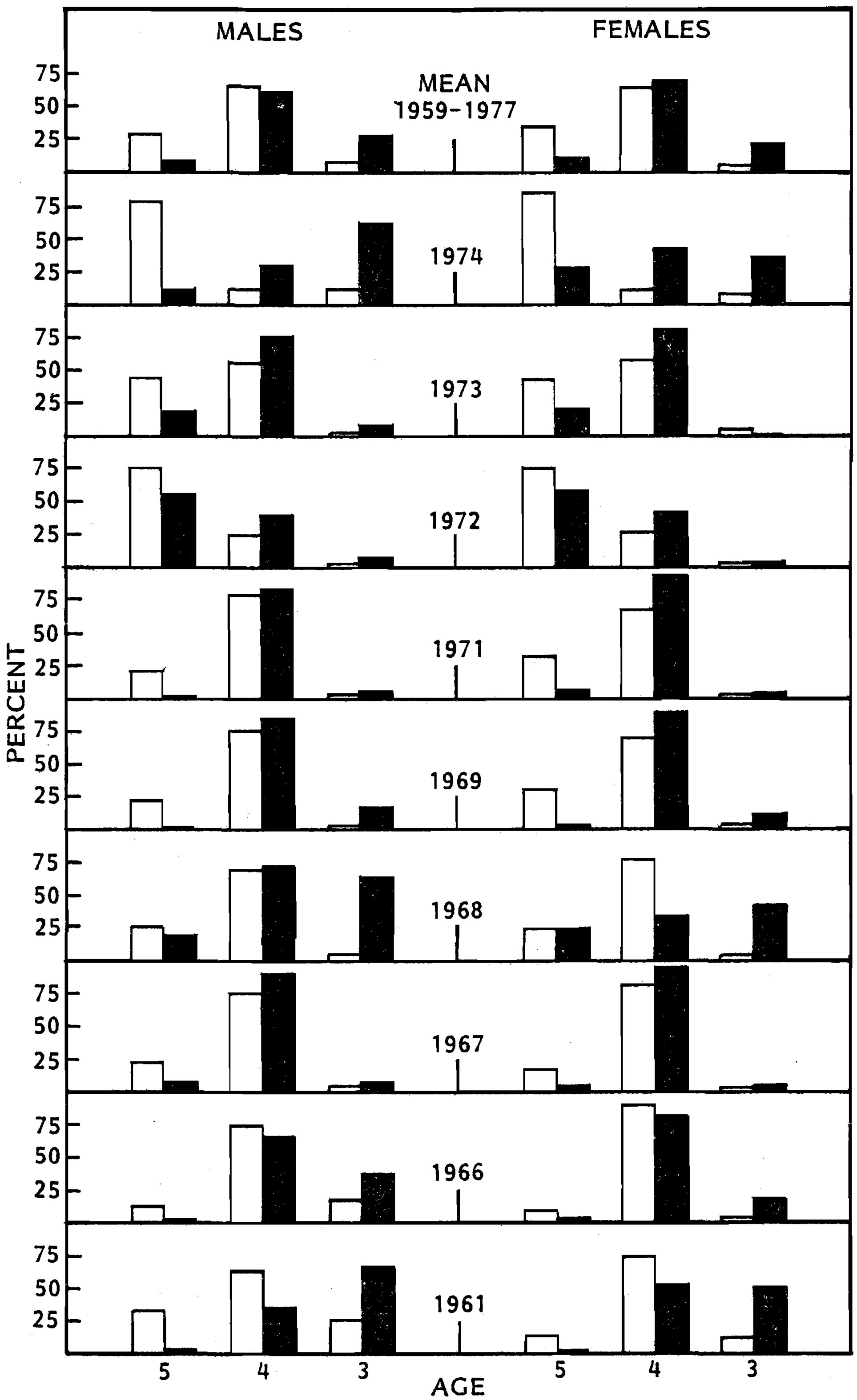

Figure 11. Mean age composition of early- and late-spawning male and female chum salmon at Olsen Creek. White bars represent early spawners and black bars represent late spawners. Return years were excluded that had low returns of one or more age groups.

was determined to be a 2-year fish during the 19 years of observations. This fish was a male sampled in 1961. Six-year chum salmon were first observed in 1968, but in only one year (1973) did they comprise more than 1% of the total run (Table 3). Usually 4-year fish comprised more than 50% of the total returns in each year, but major exceptions to this trend occurred in 1959, 1970, 1972, and 1974 (Table 4). Returns in 1959, 1960, 1975, and 1977 were unusual because the total season's run in each of these years was dominated by a single age class. The run in 1959 was unique--the only year that more than 50% of the run was 3-year fish. The commercial fishery was closed in Prince William Sound in 1959, 1972, and 1974 so the returns during these years should reflect only natural mortalities.

Usually, chum salmon have been spawning in Olsen Creek for two weeks or more when the commercial season opens. These early-spawning fish are predominantly 5-year and 4-year chum salmon and the majority of 5-year fish that return in any one year return early in the season (Appendix Table 2). Therefore, if the commercial fishery was selective for certain age groups, there would probably be less selective pressure on the 5-year fish. During years when there was no commercial fishery, the percentages of 4-year and 3-year fish could be slightly higher than they would be in years when the commercial fishery was open.

Strength of age groups returning from different brood years probably is more important in determining age composition within any year than selection of age groups by the fishery, however, because the fishery operates primarily on pink salmon. Chum salmon are caught incidentally. The large percentage of 3-year chum salmon that returned in 1959 was probably the result of better survival of the 1956 brood when compared to the survival of age groups in the 1955 brood (4-year chum salmon returned in 1959) and 1954 brood (5-year chum salmon returned in 1959). The age composition of 17 complete brood years from 1956 to 1972 is shown in Table 4.

The disproportionate survival of progeny of different ages from consecutive broods was almost certainly responsible for the lower percentage of 4-year chum salmon in the closed seasons of 1972 and 1974. The very high survival of older age groups from the 1967 brood resulted in a large return of 5-year fish in 1972 (Tables 3 and 4). Conversely, the low survival of the 1970-brood progeny resulted in a low return of 4-year chum salmon in 1974 (Tables 3 and 4).

Age composition varied widely between brood years; however, a distinct trend in the production of 5-year fish is evident (Fig. 12). The percentage of the total progeny from a brood that returned as 5-year fish increased greatly from 1956 to 1967. The percentage of 5-year fish in brood years 1968-71 declined sharply.

C. Size Composition of Spawners

Considerable variation in mean length exists within the same age group for males and females between years (Tables 7, 8, and 9). Occasionally, mean size of later-spawning fish of the same age and sex is greater than the mean size of earlier-spawning fish; but this relation is not consistent from year to year (Appendix Tables 3 and 4). The calculated mean length of males is always slightly greater than the calculated mean length of females of the same age during the same year.

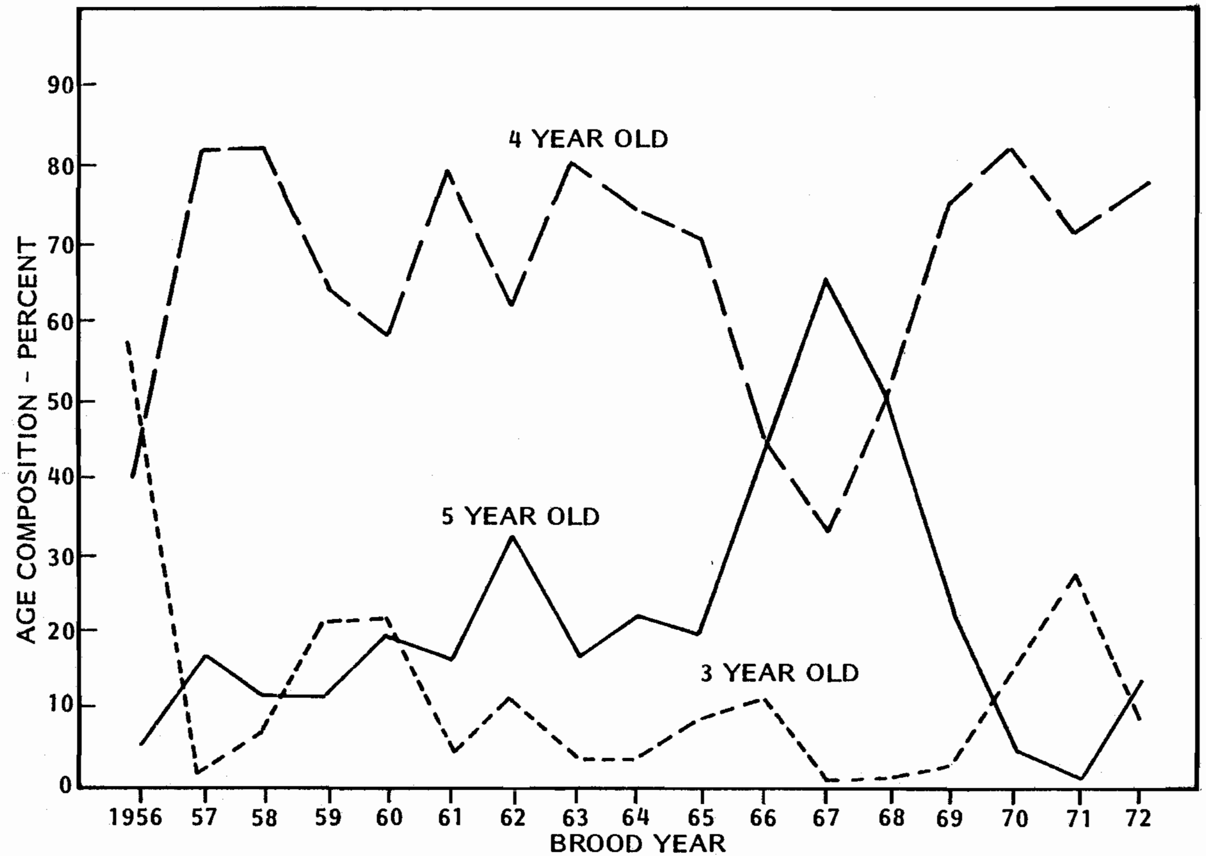

Figure 12. Percentage age composition (sexes combined) of chum salmon from brood years 1956-72 that spawned at Olsen Creek.

Table 7. The mean length (MEHP), 95% confidence interval (CI), standard deviation (S.D.), and range in length of 3-, 4-, and 5-year male chum salmon that spawned at Olsen Creek from 1959 through 1978.

MALES

	Age 3				Age 4				Age 5			
Year	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1959	129	460-595	25.0	532± 4	6	505-615	45.9	577±46	7	525-630	33.0	592±30
1960	0	--	--	--	91	500-690	27.0	561± 6	0	--	--	--
1961	147	420-595	29.4	515± 5	193	475-640	26.0	556± 4	33	495-645	33.9	571±12
1962	85	415-570	27.4	508± 6	190	490-620	26.4	551± 4	3	585-615	17.3	595±32
1963	28	485-560	23.0	520± 9	200	500-635	26.5	568± 4	26	505-675	33.5	583±14
1964	11	480-560	22.0	534±15	101	510-670	33.6	591± 7	55	540-695	33.7	615± 9
1965	--	--	--	--	--	--	--	--	--	--	--	--
1966	38	450-585	31.1	513±10	81	485-605	27.1	548± 6	3	550-605	30.4	570±56
1967	14	430-580	40.1	508±23	294	450-645	25.2	559± 3	59	505-650	26.8	579± 7
1968	168	460-575	22.2	513± 3	287	485-615	24.7	563± 3	132	510-655	28.2	595± 5
1969	48	445-565	27.3	504± 8	465	430-660	29.6	565± 3	79	515-660	30.4	588± 7
1970	18	475-555	24.6	509±12	130	450-640	29.4	536± 5	11	535-690	43.6	612±29
1971	7	435-515	34.6	486±13	300	450-600	25.7	520± 3	42	485-585	27.6	546± 9
1972	13	440-565	30.6	490±19	110	485-605	25.1	545± 5	243	500-645	27.1	573± 3
1973	11	470-580	36.2	518±24	233	470-670	28.0	561± 4	92	525-665	28.6	588± 6
1974	99	455-575	25.0	511± 5	60	505-610	26.6	565± 7	191	515-665	30.5	596± 4
1975	2	495-515	--	--	234	470-625	31.9	548± 4	1	555	--	--
1976	11	445-525	25.3	487±17	33	510-630	26.1	565±12	14	520-630	28.3	583±16
1977	4	475-590	54.6	510±87	105	430-615	26.3	559± 5	1	575	--	--
1978	14	460-555	27.6	498±16	93	445-615	26.5	553± 5	7	525-620	33.0	583±31

Table 8. The mean length (MEHP), 95% confidence interval (CI), standard deviation (S.D.), and range in length of 3-, 4-, and 5-year female chum salmon that spawned at Olsen Creek from 1959 through 1978.

FEMALES

	Age 3				Age 4				Age 5			
Year	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1959	34	485-575	23.2	524± 8	16	515-600	23.0	569±12	3	490-595	54.1	550±99
1960	1	500	--	--	92	505-605	19.8	554± 4	0	--	--	--
1961	89	465-555	22.0	509± 5	262	470-610	23.6	544± 3	48	525-610	19.5	562± 6
1962	48	470-575	21.6	506± 6	226	480-620	21.1	541± 3	15	540-600	19.5	568±11
1963	20	470-555	29.2	515±14	221	495-615	23.3	556± 3	22	535-610	21.9	577±10
1964	7	530-595	21.8	552±19	97	515-645	24.7	579± 5	63	535-665	29.7	596± 8
1965	--	--	--	--	--	--	--	--	--	--	--	--
1966	13	490-545	18.4	519±11	87	480-605	22.2	541± 5	5	520-575	27.6	545±32
1967	6	460-550	32.7	508±33	275	440-645	22.7	552± 3	37	520-625	26.0	570± 9
1968	97	465-555	19.3	506± 4	319	450-615	21.8	551± 2	129	515-650	24.0	578± 4
1969	32	480-565	22.9	523± 8	420	455-615	23.6	550± 2	98	505-630	26.6	573± 5
1970	10	460-525	21.5	493±15	139	460-600	27.0	530± 4	10	525-650	36.0	573±25
1971	2	500-530	21.2	--	240	460-580	20.2	514± 5	53	475-600	25.5	529± 7
1972	3	480-515	17.6	498±44	92	475-590	23.0	537± 5	176	490-615	19.7	564± 3
1973	1	540	--	--	199	485-615	22.9	548± 3	79	510-615	21.6	573± 5
1974	40	455-590	27.9	510± 9	53	520-605	19.3	559± 5	189	475-640	24.1	575± 3
1975	1	530	--	--	177	465-620	27.5	538± 4	5	530-605	29.8	570±34
1976	2	505-520	--	--	40	480-580	23.8	542± 8	16	530-620	26.1	574±14
1977	1	530	--	--	93	490-610	22.4	547± 5	0	--	--	--
1978	20	460-545	21.4	502±10	100	490-600	22.4	535± 4	11	505-590	30.2	541±20

Table 9. The mean length (MEHP), 95% confidence interval (CI), standard deviation (S.D.), and range in length of 6-year male and female chum salmon that spawned at Olsen Creek from 1969 to 1976.

Length (MEHP)

	Males				Females			
Year	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1968	1	652	--	--	1	614	--	--
1969	1	654	--	--	0	--	--	--
1972	1	555	--	--	1	594	--	--
1973	8	580-620	20.2	603±17	4	570-606	16.8	593±27
1974	5	592-619	10.8	609±13	4	569-598	13.4	578±21
1975	2	624-656	--	--	1	617	--	--

This relation is shown for 4-year chum salmon in Figure 13. Actually, the mean length of 4-year males is significantly larger than the mean length for 4-year females 10 out of 18 times.

Mean length of older fish is always greater than the mean lengths of younger fish (Fig. 14). However, the range in length overlaps in all three age groups for each sex within each year (Fig. 14). Larger 3-year fish are larger than the smaller 5-year fish. This overlap in size between age groups makes any judgments about age based on length unreliable. This relationship has also been observed between different age groups of chum salmon in Oregon (Henry, 1954), Japan (Kobayashi, 1961), Canada (Palmer, 1972), and various locations in Alaska (Thorsteinson et al., 1963).

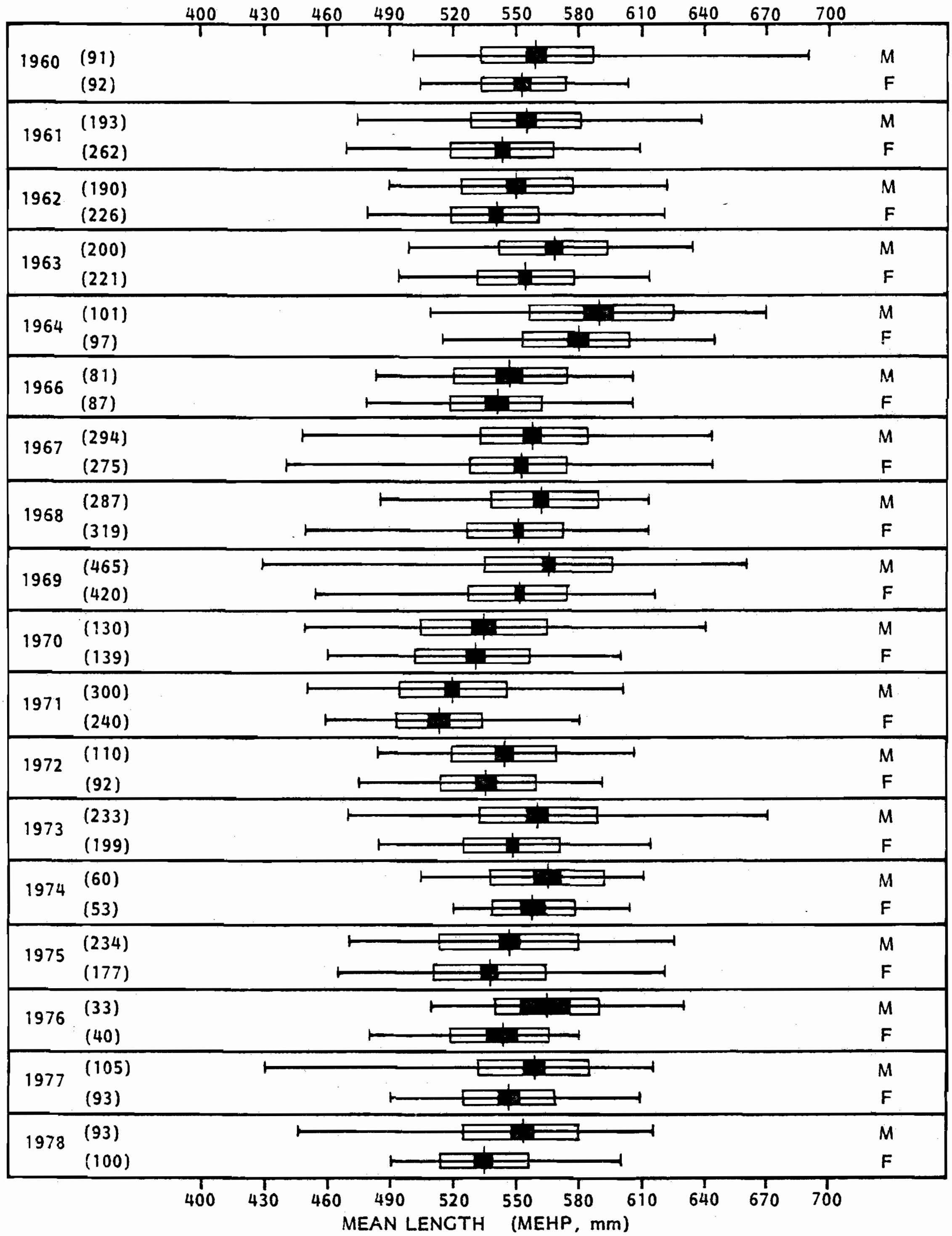

Figure 13. Comparison of length (MEHP) between sexes of 4-year chum salmon at Olsen Creek, 1960-78. Horizontal lines represent range in lengths; short vertical lines represent mean length; white bars represent one standard deviation on each side of mean; black bars represent 95% confidence interval of the means. No overlap of the black bars usually indicates significant differences. Numbers in parentheses indicate the number of specimens in each sample.

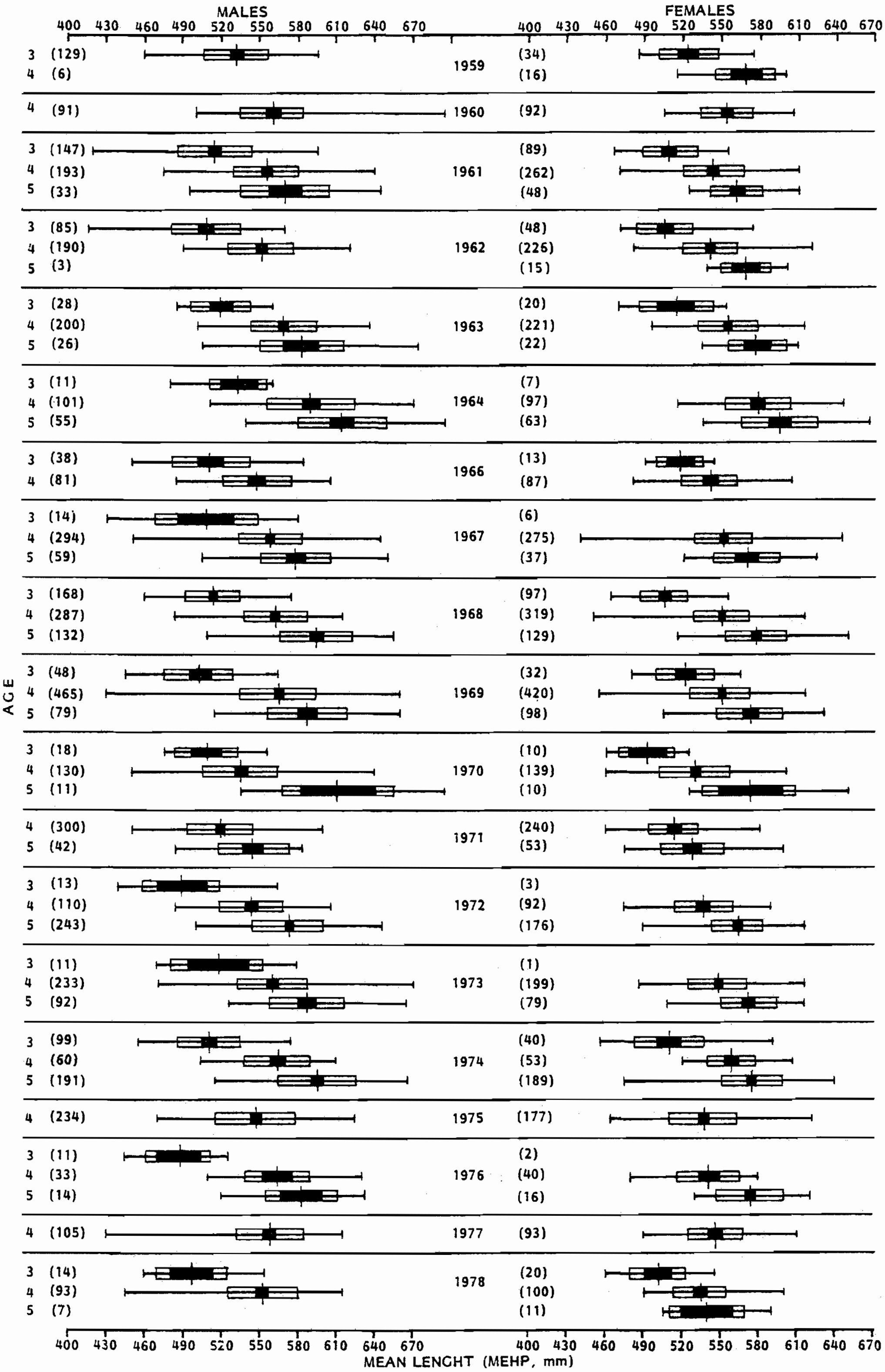

Figure 14. Comparison of length (MEHP) and age of male and female chum salmon that spawned at Olsen Creek from 1959 through 1978. Sample sizes less than 10 were excluded. See legend of Figure 13 for explanation of symbols.

Comparison of mean length at maturity of 3-, 4-, and 5-year chum salmon from the same brood year shows some parallel trends in changes in size (Fig. 15). In many cases, yearly changes in mean length of 5-year fish are followed by similar changes in mean length of 4-year fish from the next brood and in a few cases by similar changes in 3-year fish from the next brood (Fig. 15).

Comparison of mean length of males and females from the three age groups that returned to spawn during the same year (different broods) are shown in Figure 16. Changes in mean length tend to coincide during the same years. Correlation coefficients for the comparisons between mean length of 4-year and 5-year males and 4-year and 5-year females that returned during the same year were significant ($r = 0.590$, $n = 16$; $r = 0.613$, $n = 17$). Correlation coefficients for the comparisons between mean length of 3-year and 4-year males and 3-year and 4-year females that returned during the same year were also significant ($r = 0.691$, $n = 17$; $r = 0.844$, $n = 13$). Because changes in mean length of the three age groups tend to be more similar during year of return than changes in mean length among fish maturing at different ages from the same brood, conditions during the final growing season are very important in determination of size at maturity.

D. Early Marine Growth Estimated from Scales of Adults

Counts of circuli and measurements on the scales are summarized in Appendix Table 5. Differences in circuli counts and scale measurements between sexes of the same age and brood year are neither consistent nor significant; therefore, these data were combined for further

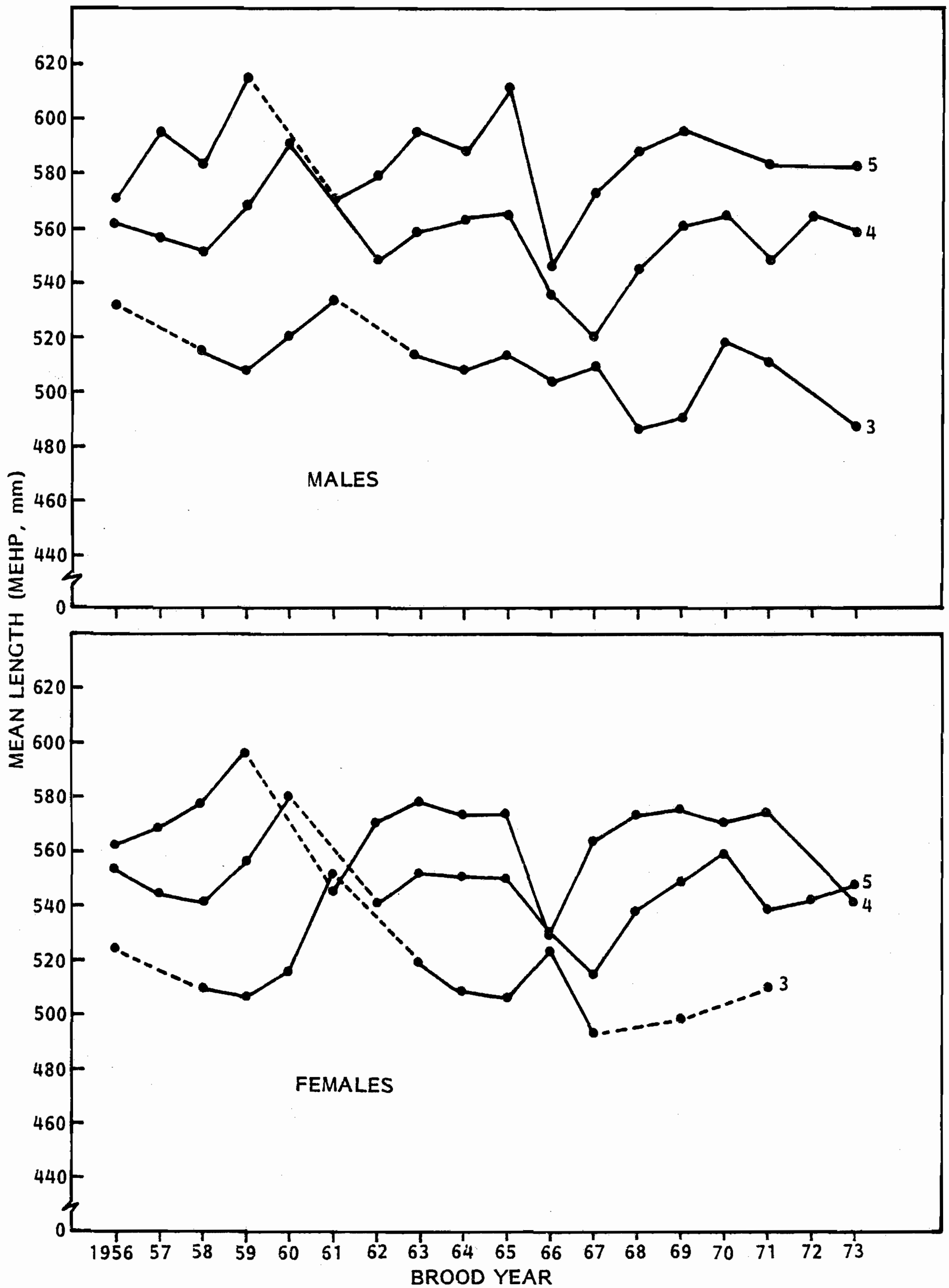

Figure 15. Comparison between mean length (MEHP) of 3-, 4-, and 5-year male and female chum salmon from the same brood year (1956-73) that spawned at Olsen Creek. Dashed lines indicate missing data points.

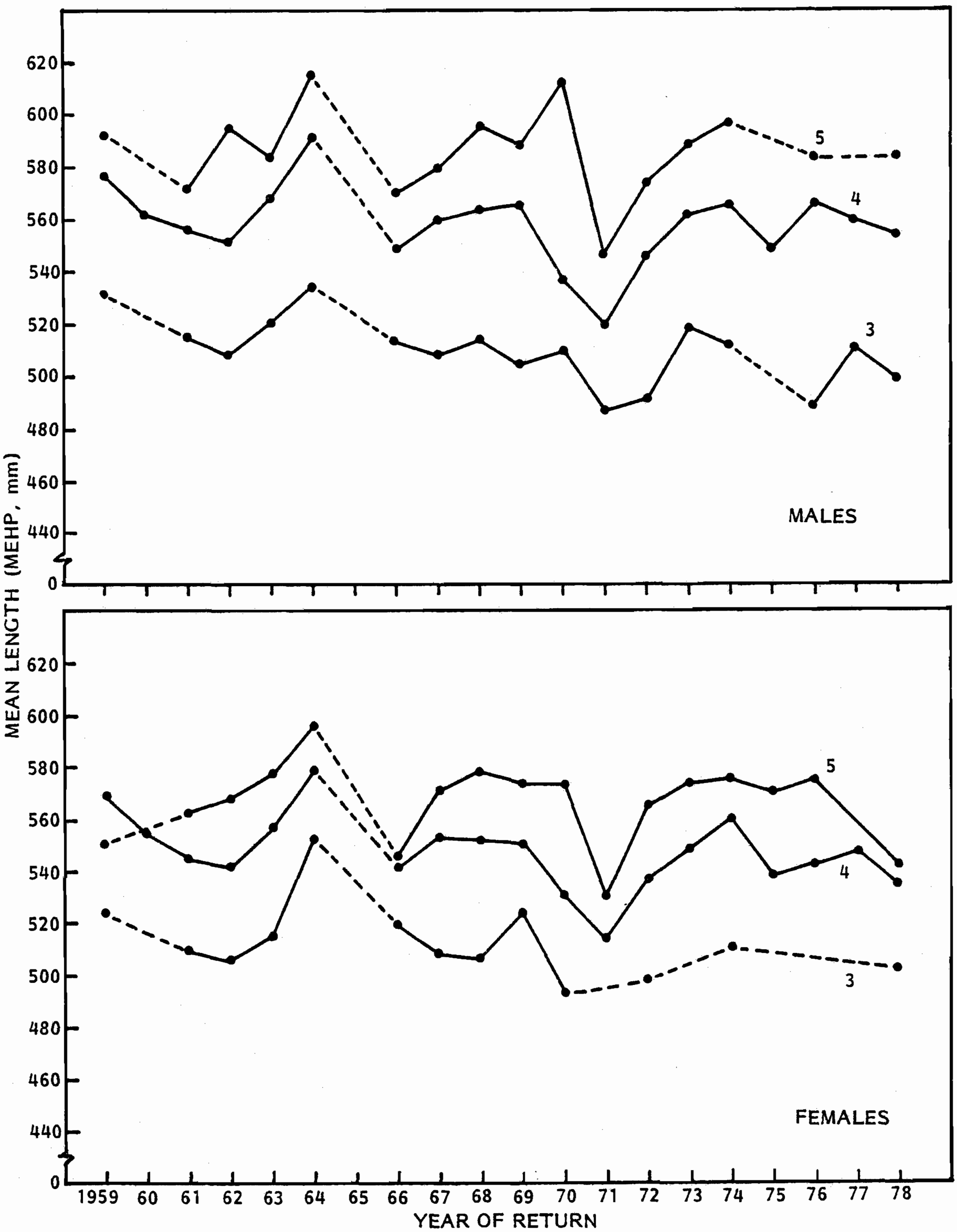

Figure 16. Comparison between mean length (MEHP) of 3-, 4-, and 5-year male and female chum salmon that spawned during the same year (1959-78) at Olsen Creek. Dashed lines indicate missing data points.

comparisons. The correlations between the scale characters and length at maturity (MEHP) and between the scale characters themselves are shown in Tables 10-13. There appears to be only a weak relationship in some years between length at maturity and the number of circuli in the first marine growth period (C_1) or the distance measurement (L_1) on the scale for this period. The correlation between the number of circuli in the second marine growth period (C_2) or the distance on the scale for this period (L_2) and length at maturity shows a stronger relationship and is highly significant in some years (Tables 10-12).

The correlation coefficients between circuli counts and distance measurements for the same growth zone are usually high, e.g., C_1 vs. L_1, C_2 vs. L_2 (Tables 10-12). The correlation between growth in the first marine growth period and growth in the second marine growth period of fish of the same age was weak in most cases (Tables 10-13).

Scale characteristics of progeny of the same brood year that matured at different ages are shown in Figure 17. Data for these Figures were selected for brood years that had sufficient sample sizes in three age groups (Appendix Table 6). Sample sizes were small for 6-year fish from the 1967 and 1968 brood years; however, this age group was included to learn whether any trends in scale characters extended another year because this age group is somewhat rare at Olsen Creek. The mean number of circuli in the first half of the first marine growth period (C_a) and the mean number of circuli in the first marine growth period (C_1) were not significantly different between age groups within a brood year. However, there are significant differences for these circuli counts between brood years (Appendix Table 6).

Table 10. Correlation between length (MEHP) at maturity, circuli counts (C_1, C_2), and distance measurements (L_1, L_2) on the scales of 3-year chum salmon at Olsen Creek. See METHODS for definition of scale characters. Significance of correlation coefficients (r) was determined from tables in Snedecor and Cochran (1968).

3-year chum salmon (sexes combined)

Return year	Correlation between:								Samples (no.)
	MEHP,C_1 r	MEHP,C_2 r	MEHP,L_1 r	MEHP,L_2 r	C_1,L_1 r	C_2,L_2 r	C_1,C_2 r	L_1,L_2 r	
1959	0.148	0.216	0.026	0.423**	0.453**	0.721**	0.009	0.331**	59
1960	--	--	--	--	--	--	--	--	0
1961	0.186	0.279*	0.027	0.421**	0.470**	0.609**	0.042	0.014	61
1962	0.059	0.458**	0.190	0.618**	0.460**	0.668**	0.078	0.067	60
1963	0.400*	0.021	0.237	0.038	0.064	0.616**	0.096	0.027	27
1964	0.591	0.208	0.099	0.312	0.698	0.518	0.032	0.314	8
1965	--	--	--	--	--	--	--	--	0
1966	0.197	0.177	0.189	0.121	0.696**	0.667**	0.136	0.562**	33
1967	0.318	0.443	0.109	0.705*	0.093	0.488	0.253	0.377	11
1968	0.062	0.346**	0.197	0.448**	0.485**	0.656**	0.075	0.233	60
1969	0.248	0.223	0.020	0.161	0.380**	0.635**	0.464**	0.190	49
1970	0.059	0.314	0.124	0.327	0.826**	0.524*	0.250	0.558*	19
1971	--	--	--	--	--	--	--	--	0
1972	0.048	0.359	0.576	0.492	0.312	0.979**	0.793	0.352	5
1973	0.242	0.054	0.535	0.380	0.293	0.871*	0.330	0.280	6
1974	0.130	0.313*	0.056	0.323*	0.307*	0.805**	0.054	0.111	55
1975	--	--	--	--	--	--	--	--	0
1976	0.578	0.383	0.103	0.083	0.223	0.744	0.576	0.538	6
1977	--	--	--	--	--	--	--	--	0
1978	0.024	0.278	0.087	0.061	0.340	0.643**	0.042	0.563*	21

* = Significant at 0.05.
** = Significant at 0.01.

Table 11. Correlation between length (MEHP) at maturity, circuli counts (C_1, C_2), and distance measurements (L_1, L_2) on the scales of 4-year chum salmon at Olsen Creek. See METHODS for definition of scale characters. Significance of correlation coefficients (r) was determined from tables in Snedecor and Cochran (1968).

4-year chum salmon (sexes combined)									
	Correlation between:								
Return year	MEHP,C_1 r	MEHP,C_2 r	MEHP,L_1 r	MEHP,L_2 r	C_1,L_1 r	C_2,L_2 r	C_1,C_2 r	L_1,L_2 r	Sample (no.)
1959	--	--	--	--	--	--	--	--	0
1960	0.206	0.268*	0.234	0.395**	0.425**	0.744**	0.042	0.262*	61
1961	0.071	0.173	0.173	0.184	0.283*	0.643**	0.029	0.162	60
1962	0.226	0.248	0.311*	0.290*	0.337**	0.776**	0.108	0.159	60
1963	0.128	0.036	0.257*	0.233	0.521**	0.647**	0.015	0.245	60
1964	0.007	0.372**	0.101	0.292*	0.479**	0.652**	0.015	0.210	61
1965	--	--	--	--	--	--	--	--	0
1966	0.174	0.095	0.020	0.141	0.409**	0.770**	0.180	0.329*	60
1967	0.119	0.291*	0.066	0.229	0.397**	0.645**	0.184	0.411**	60
1968	0.076	0.198	0.030	0.355**	0.289*	0.595**	0.141	0.227	60
1969	0.090	0.108	0.119	0.194	0.392**	0.745**	0.050	0.231	60
1970	0.087	0.260*	0.260*	0.213	0.425**	0.598**	0.103	0.180	59
1971	0.008	0.023	0.280*	0.185	0.534**	0.677**	0.001	0.111	61
1972	0.089	0.097	0.122	0.175	0.171	0.678**	0.122	0.316*	59
1973	0.086	0.106	0.042	0.128	0.250	0.697**	0.062	0.134	60
1974	0.075	0.154	0.019	0.293*	0.450**	0.699**	0.065	0.252	56
1975	0.200	0.428**	0.303*	0.513**	0.421**	0.587**	0.259*	0.337**	60
1976	0.030	0.241	0.063	0.276	0.361*	0.723**	0.009	0.293	29
1977	0.178	0.051	0.173	0.036	0.428**	0.785**	0.094	0.142	59
1978	0.037	0.125	0.160	0.063	0.225	0.788**	0.096	0.075	59

* = Significant at 0.05.
** = Significant at 0.01.

Table 12. Correlation between length (MEHP) at maturity, circuli counts (C_1, C_2), and distance measurements (L_1, L_2) on the scales of 5-year chum salmon at Olsen Creek. See METHODS for definition of scale characters. Significance of correlation coefficients (r) was determined from tables in Snedecor and Cochran (1968).

5-year chum salmon (sexes combined)

Return year	Correlation between								Samples (no.)
	MEHP,C_1 r	MEHP,C_2 r	MEHP,L_1 r	MEHP,L_2 r	C_1,L_1 r	C_2,L_2 r	C_1,C_2 r	L_1,L_2 r	
1959	--	--	--	--	--	--	--	--	0
1960	--	--	--	--	--	--	--	--	0
1961	0.082	0.048	0.105	0.063	0.434**	0.608**	0.191	0.051	56
1962	0.492	0.253	0.350	0.016	0.374	0.603*	0.114	0.130	15
1963	0.354	0.169	0.011	0.025	0.453*	0.772**	0.371	0.042	27
1964	0.045	0.103	0.053	0.155	0.452**	0.624**	0.108	0.175	60
1965	--	--	--	--	--	--	--	--	0
1966	0.850*	0.771	0.297	0.506	0.035	0.277	0.877*	0.802	6
1967	0.052	0.007	0.183	0.090	0.260	0.610**	0.242	0.312*	49
1968	0.118	0.180	0.128	0.134	0.464**	0.386**	0.004	0.416**	62
1969	0.066	0.156	0.127	0.105	0.488**	0.758**	0.043	0.170	60
1970	0.201	0.266	0.104	0.441	0.425	0.885**	0.096	0.201	18
1971	0.338**	0.189	0.018	0.069	0.343**	0.589*	0.403**	0.377**	59
1972	0.075	0.103	0.144	0.029	0.217	0.601**	0.100	0.014	60
1973	0.028	0.266*	0.108	0.140	0.241	0.615**	0.156	0.170	60
1974	0.067	0.253	0.225	0.283*	0.399**	0.792**	0.037	0.037	60
1975	--	--	--	--	--	--	--	--	0
1976	0.098	0.101	0.133	0.077	0.003	0.613**	0.108	0.085	18
1977	--	--	--	--	--	--	--	--	0
1978	--	--	--	--	--	--	--	--	0

* = Significant at 0.05.
** = Significant at 0.01.

Table 13. Correlation between length (MEHP) at maturity, circuli counts (C_1, C_2), and distance measurements (L_1, L_2) on the scales of 6-year chum salmon at Olsen Creek. See METHODS for definition of scale characters. Significance of correlation coefficients (r) was determined from tables in Snedecor and Cochran (1968).

6-year chum salmon (sexes combined)

	Correlation between								
Return year	MEHP,C_1 r	MEHP,C_2 r	MEHP,L_1 r	MEHP,L_2 r	C_1,L_1 r	C_2,L_2 r	C_1,C_2 r	L_1,L_2 r	Samples (no.)
1973	0.194	0.682*	0.833**	0.441	0.195	0.719*	0.295	0.317	10
1974	0.353	0.334	0.228	0.503	0.588	0.781*	0.255	0.144	9

* = Significant at 0.05.

** = Significant at 0.01.

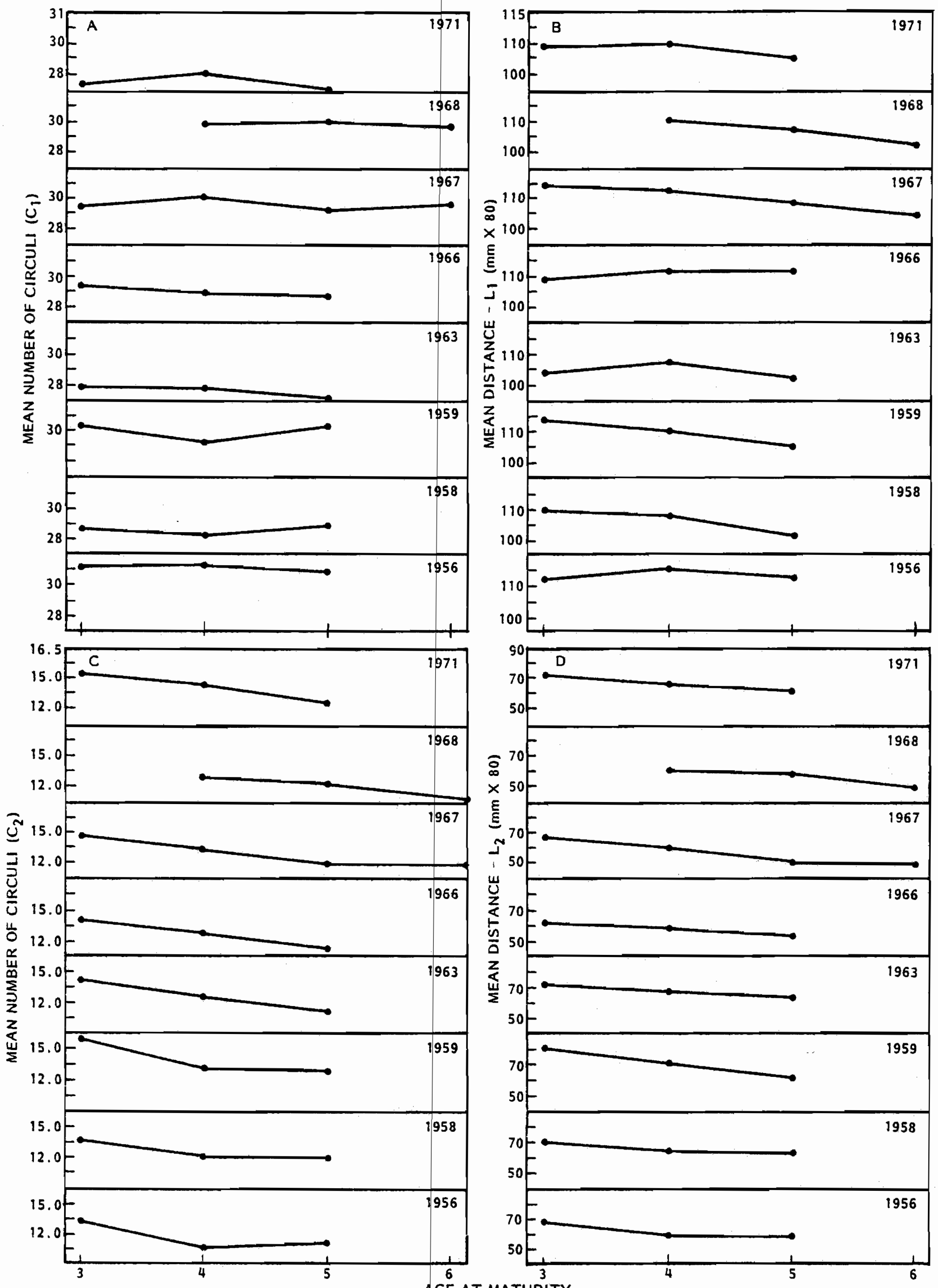

Figure 17. Mean number of circuli (C_1 and C_2) and distances (L_1 and L_2) on scales of chum salmon from the same brood year at Olsen Creek that matured at different ages. Brood years with small sample sizes in some age groups were excluded. See Methods section for explanation of scale characters.

The mean number of circuli in the second marine growth period (C_2) of progeny from the same brood year show a tendency to decline with age at maturity (Figure 17). The mean distance of the first marine growth period (L_1) of progeny from the same brood year also shows a tendency to decline with increasing age at maturity (Figure 17). This decline in mean distance (L_1) is more consistent between the 4-, 5-, and 6-year fish than it is between the 3- and 4-year fish. The mean distance of the second marine growth period (L_2) of progeny from the same brood year shows a strong tendency to decline with increasing age at maturity (Figure 17).

E. Early Marine Growth on Scales of Juveniles

The peak of the chum salmon fry outmigration at Olsen Creek occurs during mid-May and by early July very few fry are captured in the stream (Kirkwood, 1962). Migrating fry at Olsen Creek are less than 40 mm in length (TSFT) and the scale has not formed. Some chum salmon fry can be seen feeding in small sloughs in the intertidal zone at Olsen Bay until as late as mid-July in some years. On two occasions, I sampled these late-remaining chum salmon fry to check for formation of scales. On 19 June 1970, I examined 29 fry. The mean length (TSFT) and 95% confidence interval were 42±1. On 14 July 1971, I examined 27 fry whose mean length and 95% confidence interval were 46±1. In both cases the scale was still being formed and no recognizable circuli were present.

Chum salmon fry in the Chitose River on Hokkaido Island, Japan, in 1953 started to show circuli forming on their scales when their length (TSFT) was about 43 mm (Kobayashi, 1961). The winters in 1970 and 1971 in Prince William Sound were very cold so the development of the fry that I examined may have been retarded.

Crewmen on the research vessel R.V. John N. Cobb (U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries) captured juvenile chum salmon in a mid-water trawl in Knight Island Passage in southwestern Prince William Sound on 11 September and 24 October 1961. Some of these fish were preserved in the museum collection at the Auke Bay Fisheries Laboratory (presently, National Marine Fisheries Service, formerly Bureau of Commercial Fisheries). I took scales and length measurements from these 37 specimens. The September and October samples were mixed. The mean length (TSFT) and 95% confidence interval for these fish were 166±4 mm. Mean number of circuli on the scales was 19. Correlations between number of circuli and scale radius and length, number of circuli and scale radius, and TSFT length and MEFT length were all significant at >0.01 (Fig. 18). These significant correlations confirm that number of circuli and scale distance can be used to represent growth in length of chum salmon.

F. Effects of Environmental Factors on Early Marine Growth

The amount of time that juvenile chum salmon from Olsen Creek or juvenile chum salmon from other streams remain in Prince William Sound before entering the Gulf of Alaska is not definitely known. The juveniles caught by crewmen of the R.V. John N. Cobb in southwestern Prince William Sound in September and October of 1961 provide some evidence that at least some juveniles remain in the sound until fall.

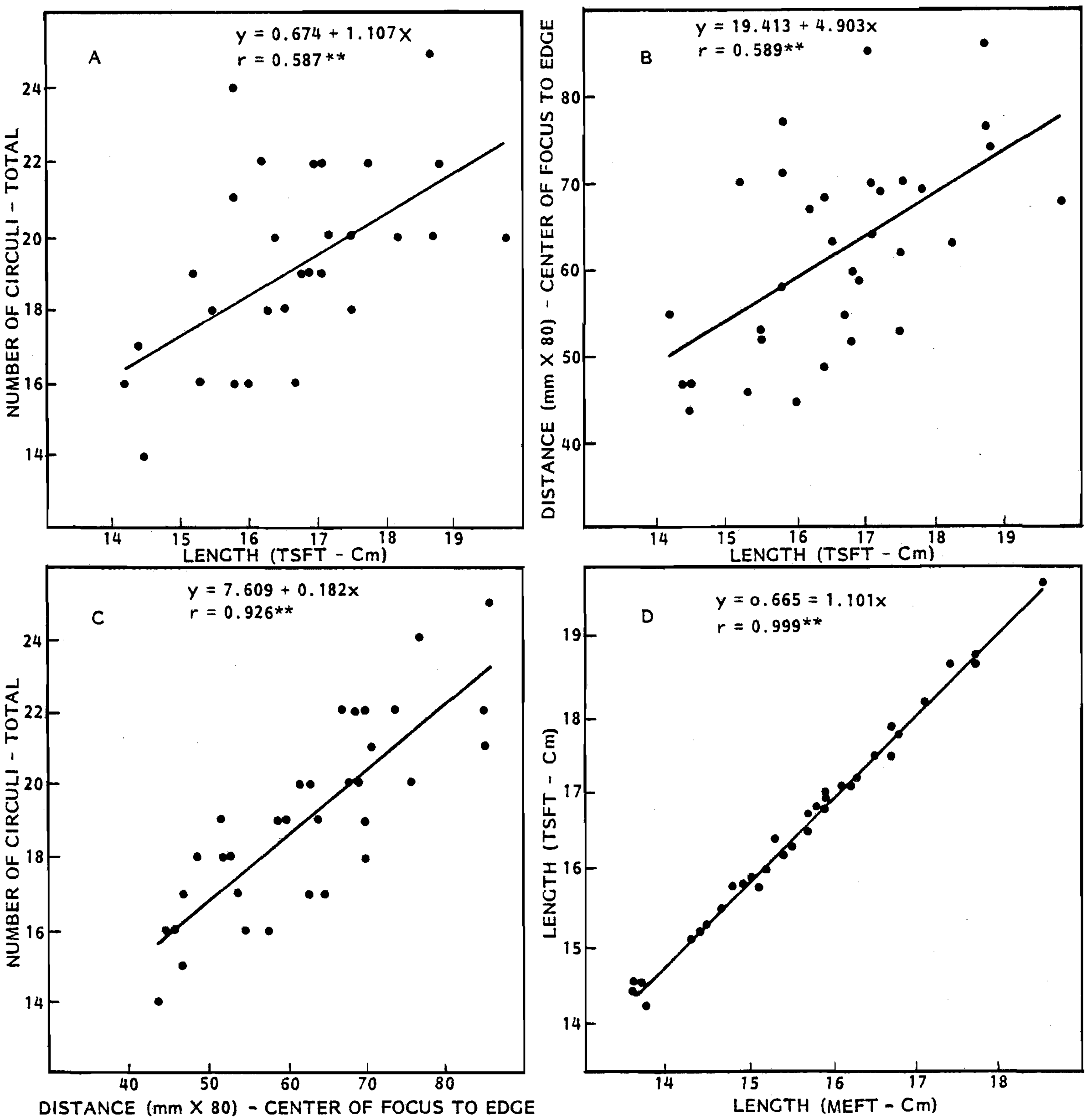

Figure 18. Relations between numbers of circuli and distances on the scales between the center of the focus to the edge and length (TSFT) of juvenile chum salmon caught in southwestern Prince William Sound in September and October 1961. A regression between the lengths TSFT and MEHP of these juvenile chum salmon is provided for conversion of the two lengths.

According to Shepard et al. (1968), juvenile chum salmon (15-20 cm) may remain in coastal waters until mid-summer.

If early marine growth of chum salmon from Olsen Creek is similar to the growth measured on the scales of the juveniles captured in September and October of 1961, then at least 63% (19 circuli) of the circuli in the first year of the 1960 brood represents growth in Prince William Sound (Appendix Table 6). Measurement of scale characters on these juvenile chum salmon captured in southwestern Prince William Sound showed that number of circuli and scale distance are clearly related to length of the fish (Fig. 18). Number of circuli and scale distance also are strongly correlated (Fig. 18C). Therefore, either of these two characters is a good indicator of marine growth. Reimers (1973) also found the total number of circuli on scales of juvenile king salmon (O. tshawytscha) at Sixes River, Oregon, to be directly related to length of the fish. Henry (1954) showed that the scale radius was directly related to length of adult chum salmon at Tillamook Bay, Oregon. In comparisons between early marine growth of Olsen Creek chum salmon and environmental data, both mean number of circuli and mean scale distance were used, but to avoid repetition only the comparisons using circuli are shown unless further comparisons seemed important. Also, mainly data from 4-year chum salmon were used in the comparisons because more data were available for 4-year fish and also there were no significant differences between the mean number of circuli between age groups of the same brood (Appendix Table 6).

No relation was found between precipitation, air temperature, cloud cover, and atmospheric pressure during the summers of 1957-75 measured at the Cordova Airport (National Weather Service, 1957-75) and marine growth during the first marine year of chum salmon from Olsen Creek (Table 14). Weather at the Cordova Airport can be very different from weather in Prince William Sound, but similar data for the sound are unavailable.

A highly significant relation exists between the first marine growth period of Olsen Creek chum salmon and the mean summer sea surface temperature (SST) measured at Cordova (Fig. 19A). No relation exists between the first marine growth period and mean density of seawater during the summer at Cordova (Fig. 19B).

Air temperature measured at high elevations in the coastal range may provide a more regional representation of air temperature than measurements taken at shore stations. Mean summer air temperature at the 1,000 m level on Wolverine Glacier is correlated with the first half of the first marine growth period of Olsen Creek chum salmon (Fig. 20A) but the relation is not quite significant for the total first marine growth period (Fig. 20B). Temperature data for only nine seasons were available for comparisons. Perhaps more data and/or similar comparisons in other areas would provide a more reliable estimate of this potentially useful relationship. Also, use of correlation analyses to compare environmental and biological data may result in significant correlation coefficients that represent chance relationships (Gulland, 1953; Sutcliffe et al., 1977). Large sample sizes would reduce the likelihood of obtaining spurious relationships.

The comparison between growth of chum salmon in their first marine season (C_1) and mean surface temperature during the summer and fall in

Table 14. Correlation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and the summer mean values for precipitation, air temperature, cloud cover and atmospheric pressure measured at the Cordova airport.

Environmental parameter	Correlation coefficient *r*	Number of comparisons *n*
Mean precipitation	-0.285	18
Total precipitation	-0.282	18
Mean maximum air temperature	0.343	18
Mean minimum air temperature	-0.289	18
Mean cloud cover	-0.342	18
Mean pressure at sea level	0.164	18

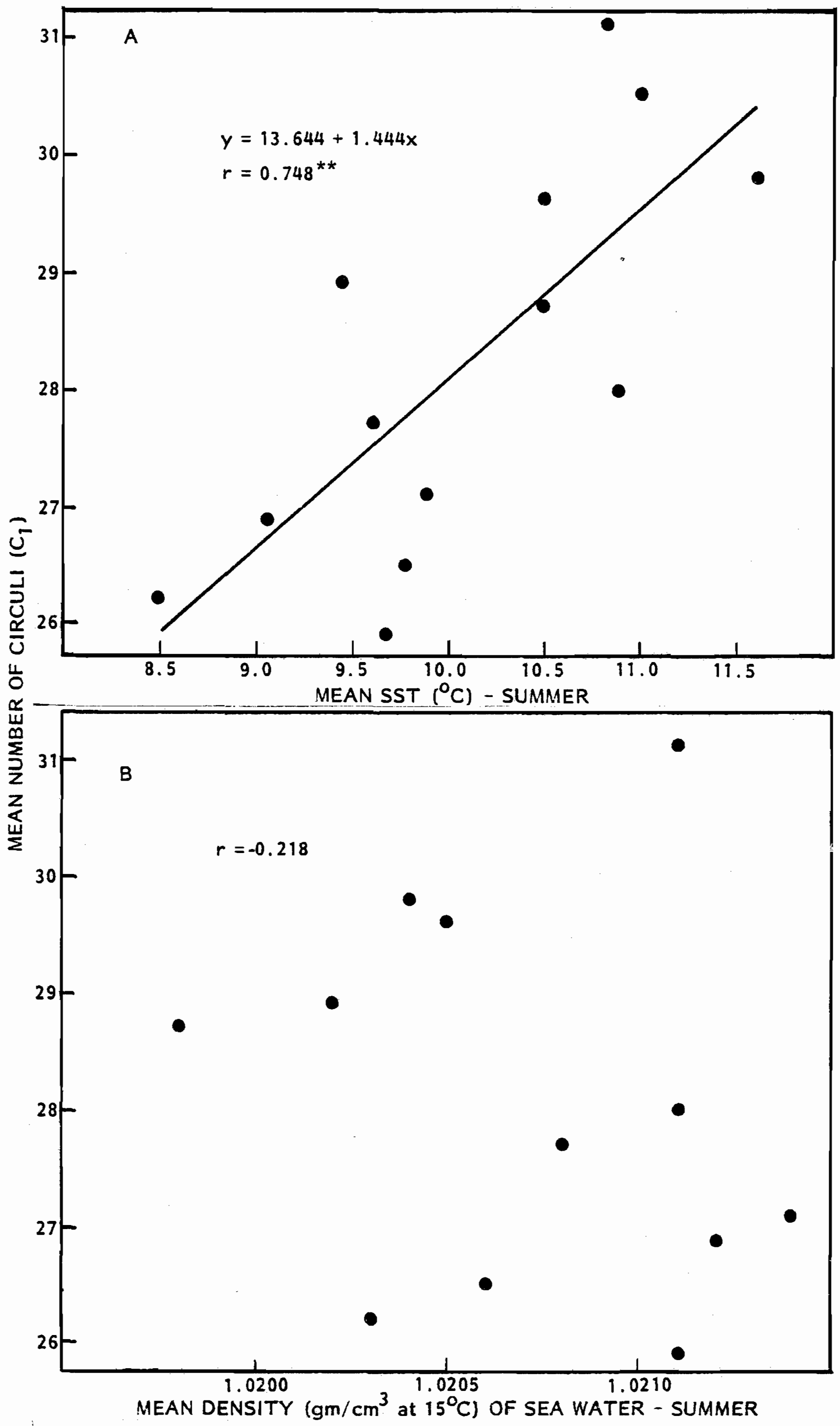

Figure 19. Relation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and mean sea surface temperature (SST) and mean seawater density during the corresponding summers at Cordova. See Methods for missing years.

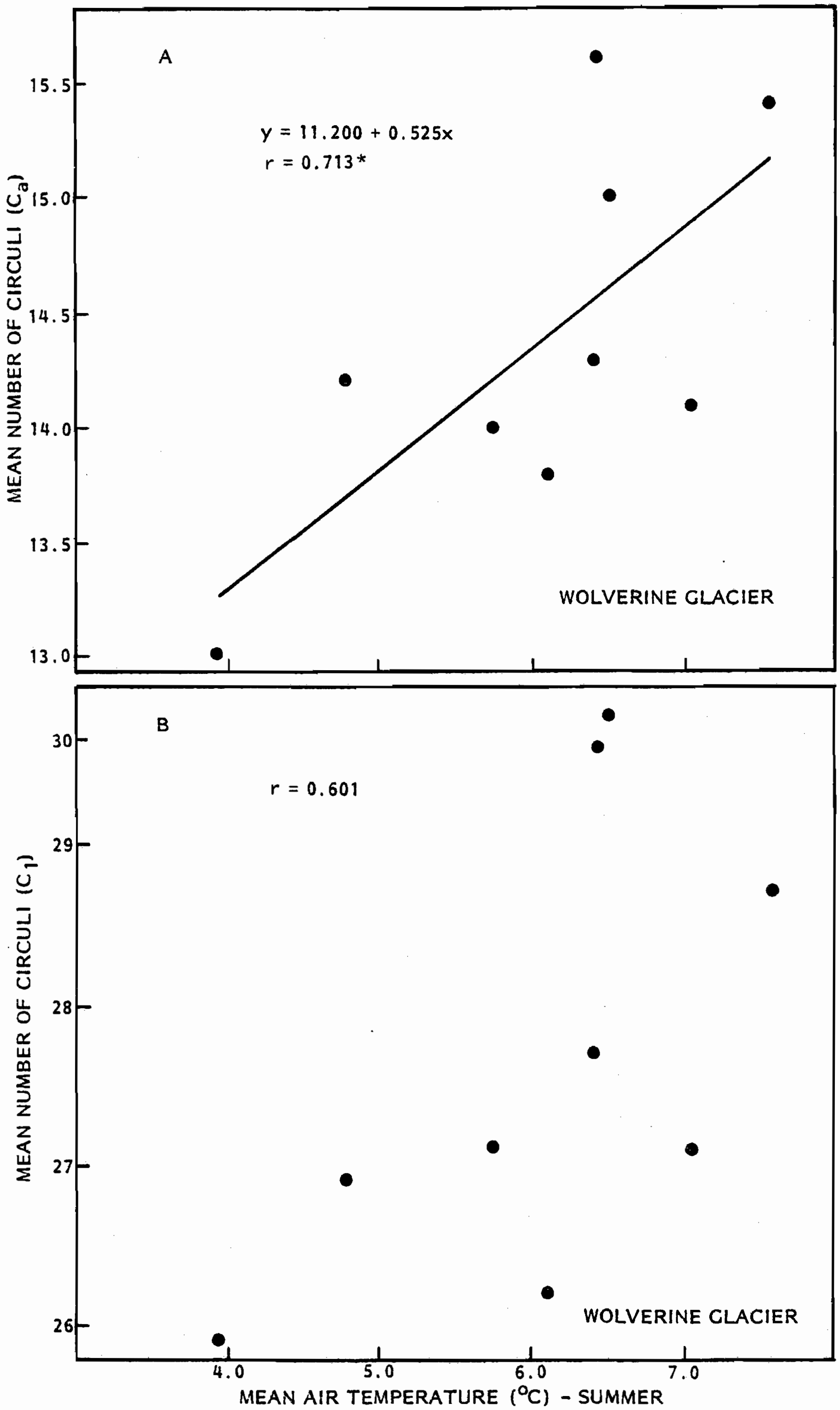

Figure 20. Relation between mean number of circuli (C_a and C_1) representing the first half of the first marine growth period and the total first growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and mean air temperature at 1000 m altitude on Wolverine Glacier during the corresponding summer, 1967-76.

Marsden Squares 195-4 and 195-3 (See Fig. 5) is shown in Figure 21. The four comparisons are all highly significant but the correlation coefficients are higher for the comparisons within Marsden square 195-4. Manzer et al. (1965) and Shepard et al. (1968) observed that juvenile chum salmon migrate westward along the coast of the Gulf of Alaska during summer and fall. Therefore, environmental conditions within Marsden Square 195-4 should be more relevant than those within Marsden Square 195-3 to growth of juvenile chum salmon from Olsen Creek.

Other environmental data available for the area within Marsden Square 195-4 are cloud cover, wind speed, air temperature, and dew point. Mean summer air temperature is significantly correlated with mean sea surface temperature ($r = 0.859$, $n = 16$) and mean summer dew point ($r = 0.974$, $n = 16$). However, mean summer cloud cover is not significantly correlated with mean summer air temperature ($r = -0.418$, $n = 16$) or mean summer dew point ($r = -0.477$, $n = 16$). Even though some of these environmental parameters are interrelated, comparisons were made of each individually with growth measurements to learn which of the comparisons showed the strongest relationships. The relation between growth of chum salmon during their first marine season and mean summer cloud cover is inverse and highly significant (Fig. 22A). In the fall, the same relationship is not significant (Fig. 22B). No apparent relation exists between early marine growth of chum salmon and mean summer or mean fall wind speed (Fig. 22C, 22D). There is a significant positive relation between early marine growth and mean summer and mean fall air temperature within Marsden Square 195-4 (Fig. 23A, 23B). The

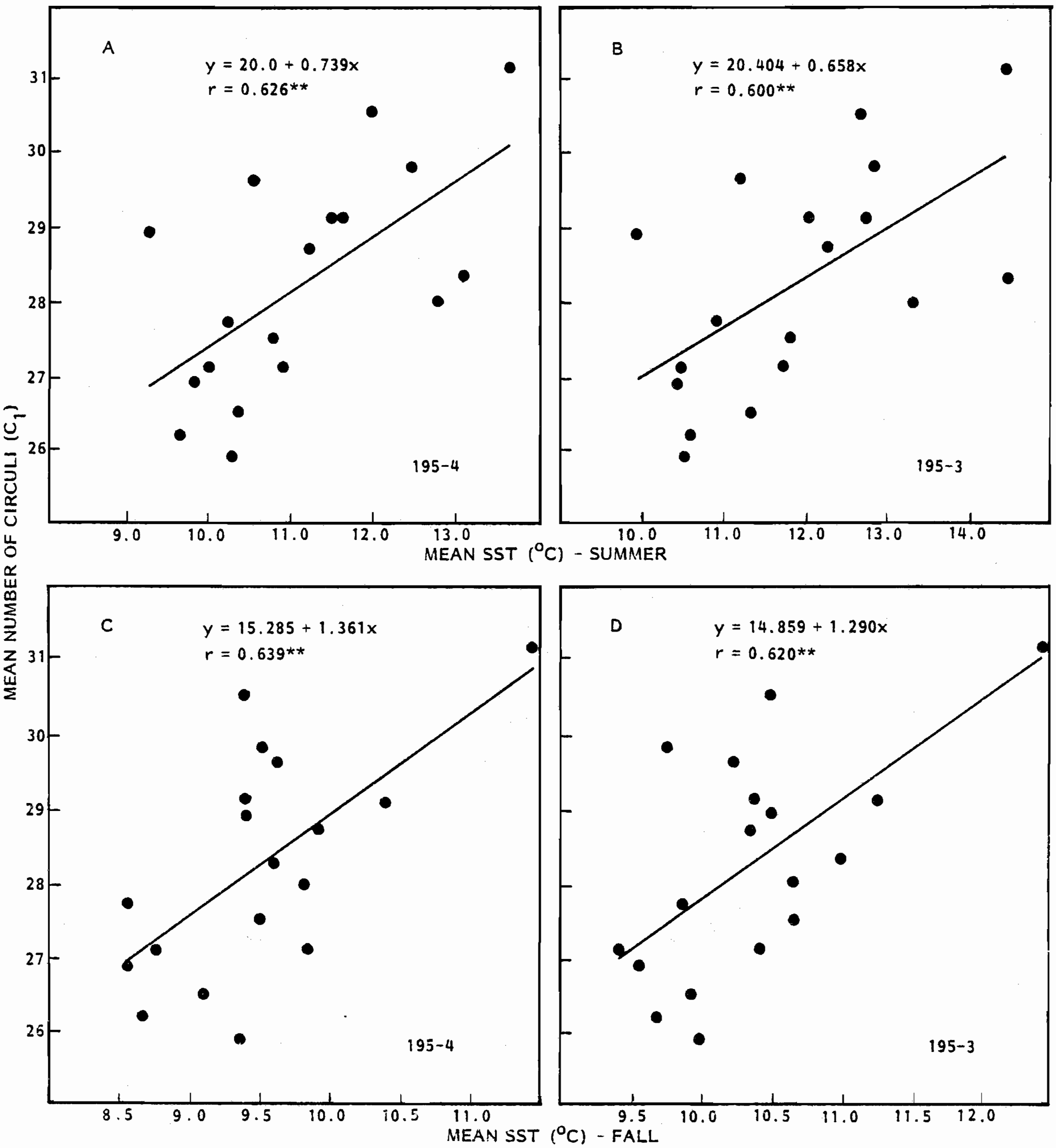

Figure 21. Relation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year (sexes combined) chum salmon from Olsen Creek and mean sea surface temperatures (SST) within Marsden Squares 195-4 and 195-3 during the corresponding summer and fall, 1957-75.

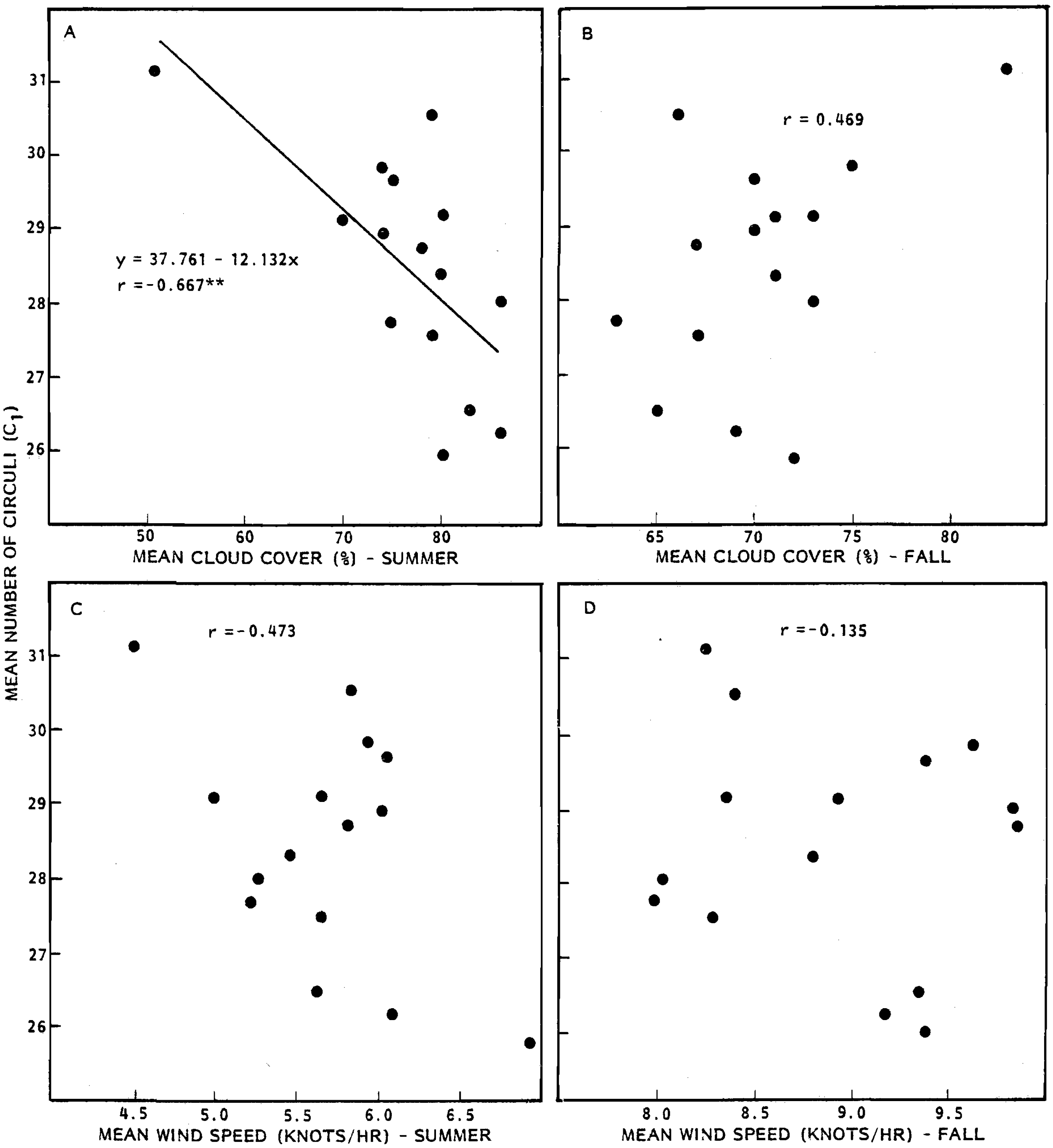

Figure 22. Relation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and mean cloud cover and mean wind speed during the corresponding summer and fall within Marsden Square 195-4, 1957-72.

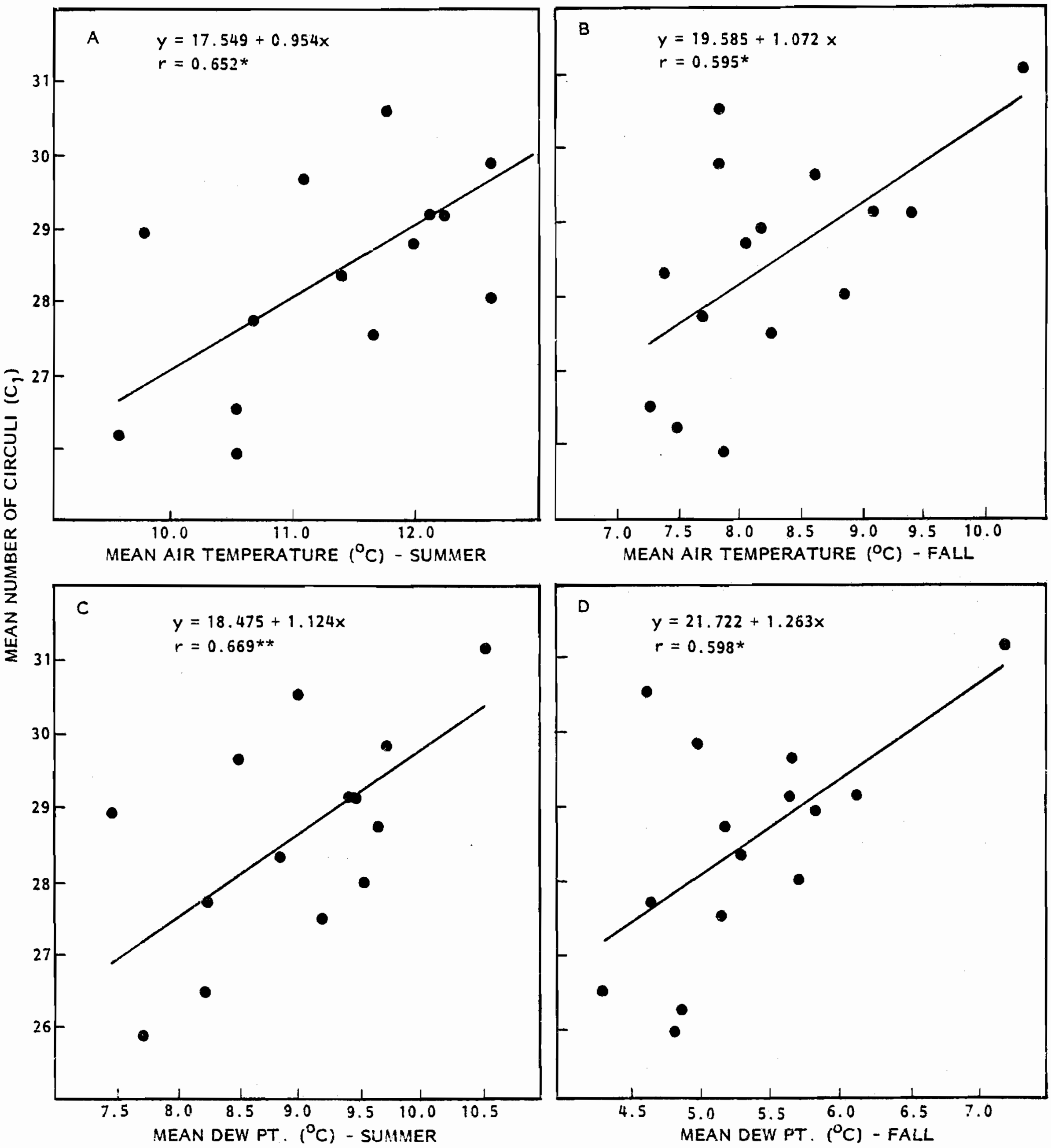

Figure 23. Relation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and mean air temperature and mean dew point during the corresponding summer and fall within Marsden Square 195-4, 1957-72.

relation between growth and dew point during the summer and fall is also significant (Fig. 23C, 23D).

Bakun (1973) has calculated upwelling indices for two locations near Prince William Sound (see Methods). The correlations between early marine growth (C_1) of chum salmon and yearly and mean summer upwelling indices are not significant; however, the comparisons with yearly indices have higher correlation coefficients than the comparisons with mean summer indices (Table 15).

Table 15. Correlation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and the mean yearly and mean summer upwelling indices at 60°N 146°W and 60°N 149°W.

Upwelling index (location)	Correlation coefficients (r)	Number of comparisons (n)
60°N 146°W		
yearly	-0.488	14
summer	-0.210	16
60°N 149°W		
yearly	-0.504	14
summer	-0.138	15

The general lack of correlation between early marine growth of chum salmon and upwelling indices and the significant correlations between early marine growth and sea surface temperature, air temperature, cloud cover, and dew point during the summer within Marsden Square 195-4 suggest that weather conditions may be a major factor in determining events that affect marine growth of chum salmon during their first summer in the sea. I mentioned previously that weather conditions at Cordova Airport are not necessarily indicative of weather conditions in Prince William sound. However, streamflow could be an indirect measure of weather conditions in Prince William Sound. Olsen Creek is a run-off type stream and flow is closely related to precipitation (Helle, 1970). Therefore, during clear dry weather conditions, streamflows would be reduced. Streams or rivers whose major source is runoff from glaciers would have opposite flow characteristics. The flow in these systems would increase during clear dry weather conditions due to glacial melting. The Copper River is a large river that drains many large glaciers and enters the Gulf of Alaska near Prince William Sound. Power Creek is a run-off type system that flows into the Gulf of Alaska near the Cordova Airport between the Copper River and Prince William Sound. Wolverine Creek drains primarily from Wolverine Glacier to the west of Prince William Sound. Comparisons between early marine growth of chum salmon and mean summer flow of these four systems is shown in Figure 24. A significant negative relation is shown between early marine growth (C_1) and the mean summer streamflow at Olsen Creek (Fig. 24A). The same comparison with streamflow at Wolverine Creek is not significant (Fig. 24B). A significant positive relation is shown for the comparison with flow of the Copper River (Fig. 24C). No relationship exists between early marine growth and mean summer flow of Power Creek (Fig. 24D). The significant negative correlation coefficients between growth

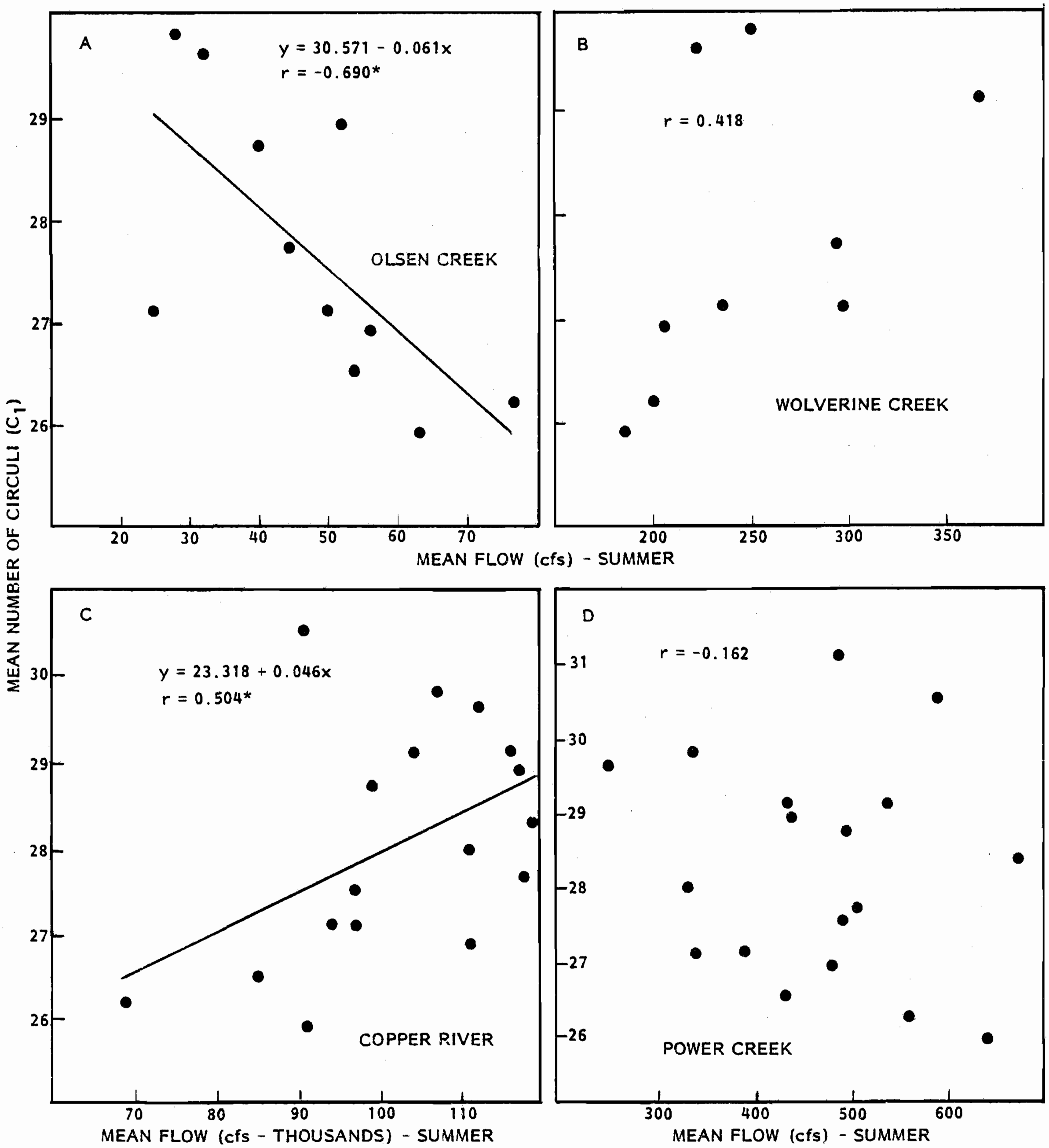

Figure 24. Relation between mean number of circuli (C_1) representing the first marine growth period on the scales of 4-year chum salmon (sexes combined) from Olsen Creek and mean stream flow at Olsen Creek (1965-76), Wolverine Creek (1967-76), Copper River (1958-77), and Power Creek (1957-76) during the corresponding summer.

and mean summer streamflow at Olsen Creek and the significant positive correlation coefficient between growth and mean summer flow in the Copper River support the hypothesis that weather conditions may be a major factor in determining events that influence early marine growth.

The location of Olsen Creek chum salmon in the ocean during their second summer at sea is unknown. Shepard et al. (1968) state that chum salmon in their second summer at sea are "distributed broadly throughout the subarctic waters of the North Pacific Ocean and adjacent seas." It is unlikely that Olsen Creek chum salmon are within the area bounded by Marsden Square 195-4 or 195-3 at this time as no relationship is apparent between growth during the second marine season (C_2) and sea surface temperature within Marsden Squares 195-4 ($r = -0.141$, $n = 18$) and 195-3 ($r = -0.157$, $n = 18$). I also compared the growth during the second season (C_2) at sea with yearly, spring, and summer upwelling indices at locations along the coast of Alaska and British Columbia at six coordinates listed by Bakun (1973) between 60°N 149°W and 48°N 125°W (off the state of Washington coast). Again, no significant relationships were found.

G. Effects of Environmental Factors on Size at Maturity

The similarity in changes in length at maturity between 3-, 4-, and 5-year chum salmon from different broods that returned to spawn during the same year suggests that events in the last growing season are very important in determination of length at maturity (Fig. 16). Maturing chum salmon returning to Prince William Sound and to Olsen Creek through the Gulf of Alaska spend an unknown amount of time in the area within

Marsden Squares 195-4 and/or 195-3. Comparisons were made between length (MEHP) at maturity and various environmental factors in these areas during the year of maturity to learn what relationships might exist. Again, 4-year males are used for the comparisons because the sample sizes in this age group were consistently large (Table 7).

Comparison of mean length at maturity and mean summer sea surface temperature at Cordova yielded a significant relationship (Fig. 25). Correlations between mean length at maturity and mean sea surface temperature (SST) during the winter, spring, and summer in Marsden Squares 195-4 and 195-3 during the year of return were not significant Table 16.

Table 16. Correlation between mean length (MEHP) of 4-year male chum salmon from Olsen Creek and mean sea surface temperatures during the winter, spring, and summer within Marsden Squares 195-4 and 195-3 during the year of spawning.

	Marsden Square		
Season	195-4 r	195-3 r	Number n
Winter	0.350	0.343	17
Spring	0.225	0.225	17
Summer	0.378	0.450	17

Comparisons between mean length at maturity and cloud cover, air temperature, and dew point during the spring and summer within Marsden Square 195-4 are shown in Fig. 26. Correlation coefficients were

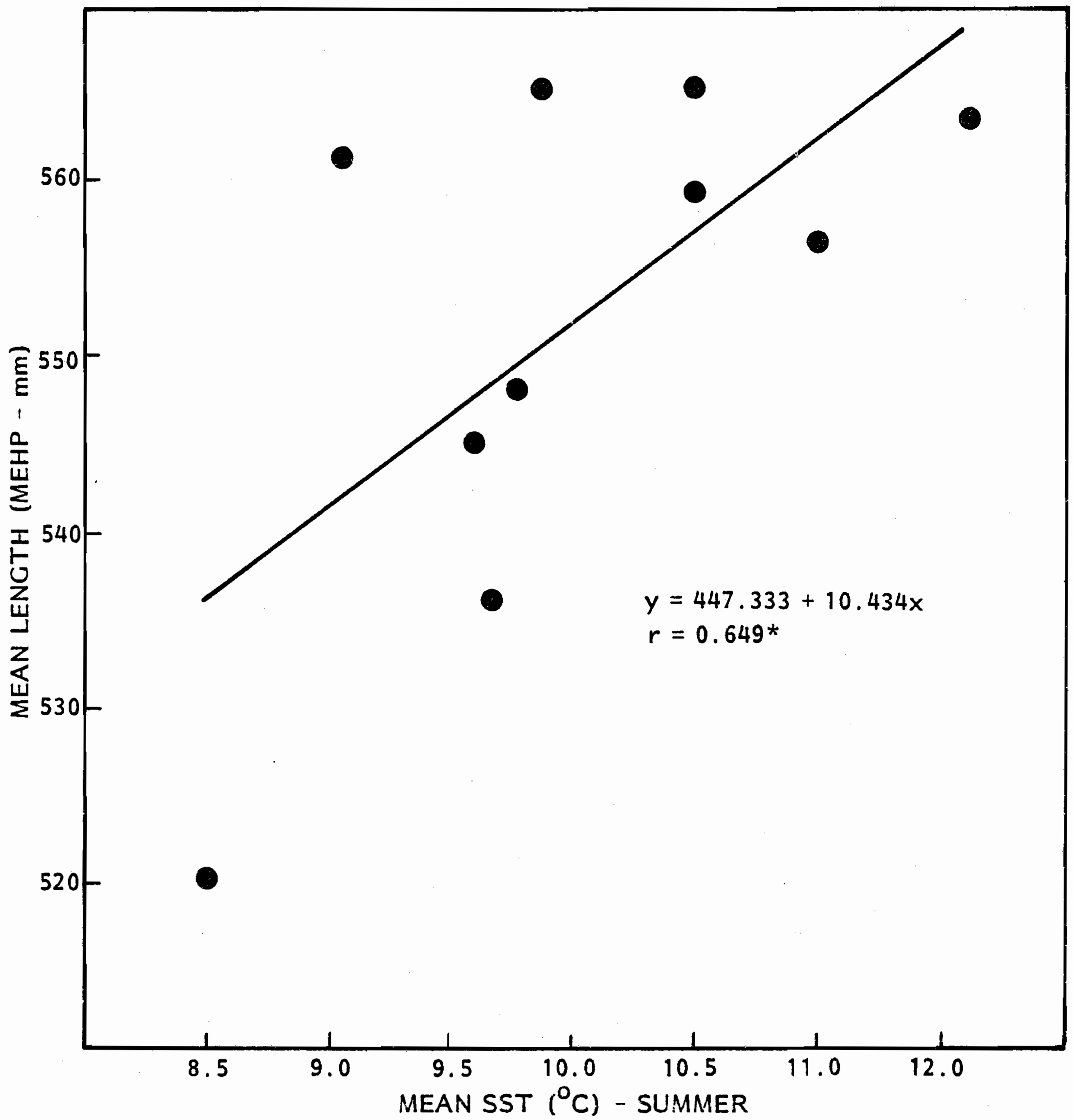

Figure 25. Relation between length (MEHP) of 4-year male chum salmon from Olsen Creek and mean sea surface temperature (SST) during the summer at Cordova, 1957-74. See Methods for missing years.

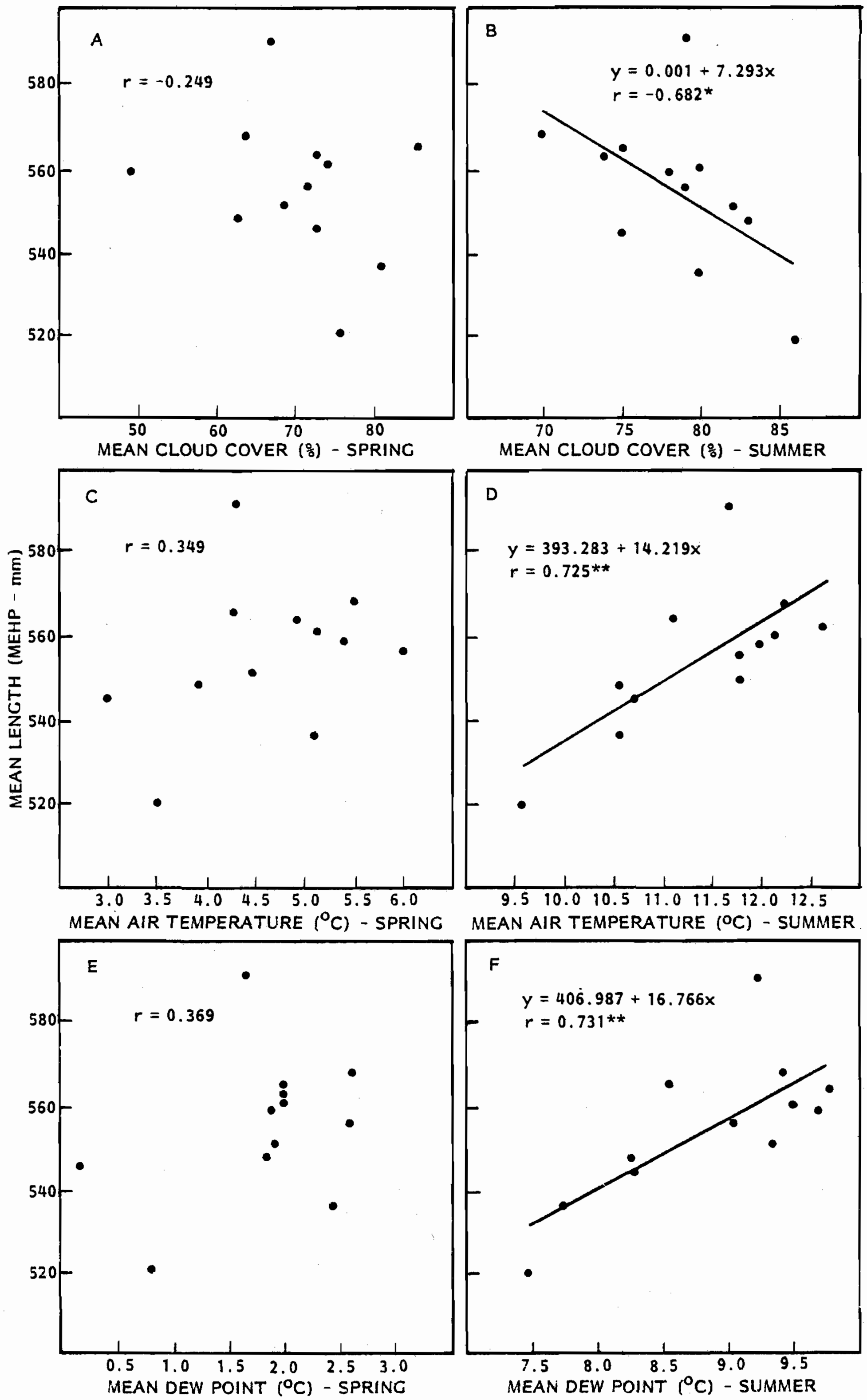

Figure 26. Relation between mean length (MEHP) of 4-year male chum salmon from Olsen Creek and mean spring and summer values for cloud cover, air temperature, and dew point within Marsden Square 195-4 during the year of spawning (1957-72).

significant and negative between length and cloud cover during the summer and highly significant (positive) for air temperature and dew point during the summer (Fig. 26). The relations were not significant for these comparisons during the spring.

Comparisons between length and upwelling indices at 60°N 149°W and 60°N 146°W near Prince William Sound and at the four additional locations between 57°N 137°W and 48°N 125°W along the coast of Alaska, British Columbia, and Washington listed by Bakun (1973) showed no significant relationships. Likewise, comparisons between mean length at maturity and various weather observations at the Cordova airport showed no significant relationships.

Comparisons were made between length and mean summer flows at Olsen Creek, Copper River, Wolverine Creek, and Power Creek. A highly significant negative correlation was shown for the Olsen Creek comparison, and the Copper River comparison was positively significant (Fig. 27A, 27B). The comparisons of length with summer flow at Wolverine Creek and Power Creek were not significant. The trends fit the hypothesis mentioned before for early marine growth and flow where a glacial stream should show a positive correlation coefficient and a runoff stream should show a negative correlation coefficient.

H. Effects of Early Marine Growth on Age at Maturity

Mean number of circuli (C_1) in the first marine growth zone on scales of different-age fish from the same brood was shown previously to be similar (Fig. 17). Mean scale distance (L_1), during the first marine

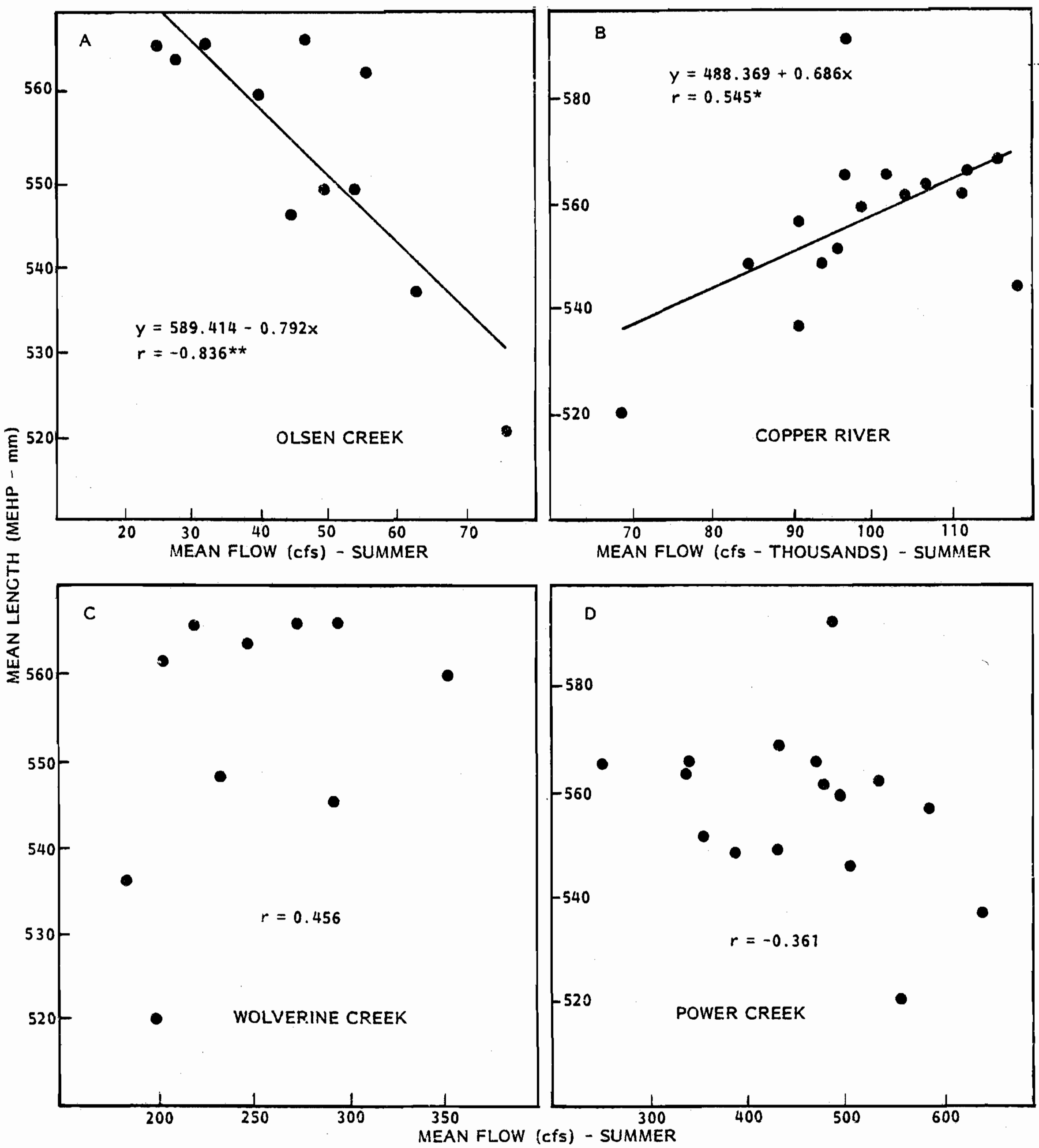

Figure 27. Relation between mean length (MEHP) and 4-year male chum salmon from Olsen Creek and mean summer flow in Olsen Creek, Copper River, Wolverine Creek, and Power Creek during the spawning year. See Figure 24 for years.

growth zone, however, showed a tendency in some brood years to decline with age at maturity (Fig. 17). During the second marine growth zone, both mean number of circuli (C_2) and mean distance (L_2) on scales of fish from the same brood showed a clear trend of decreasing with increasing age at maturity (Fig. 17). These data support the conclusions based on summaries of various studies by Ricker (1964) that faster-growing chum salmon tend to mature earlier. These observations do not answer the question of why chum salmon mature at different ages. Younger, faster-growing individuals may be the progeny of younger fish and, therefore, could be exhibiting a genetic tendency to grow faster. Observations by Childs and Law (1972) on coho salmon (O. kisutch) suggest that progeny of faster-growing parents show similar tendencies for fast growth.

Mean values for scale characters (C_1, L_1, C_2, L_2) from fish of the same age varied considerably between brood years (Appendix Table 6). Much of this variation in marine growth during the first year at sea has been shown to be related to environmental factors. What environmental factors influence growth during the second season at sea are unknown because the location of chum salmon during this time is not known. A comparison between mean growth of a brood during the first and second marine seasons and mean age at maturity of that brood should give an estimate of the relationship between growth and age at maturity (Fig. 28). Correlation coefficients are negative but not significant when mean age at maturity of the brood is compared to mean number of circuli and mean scale distances of the brood during the first marine growth period (Fig. 28A, 28B). The comparisons of mean age at maturity of the

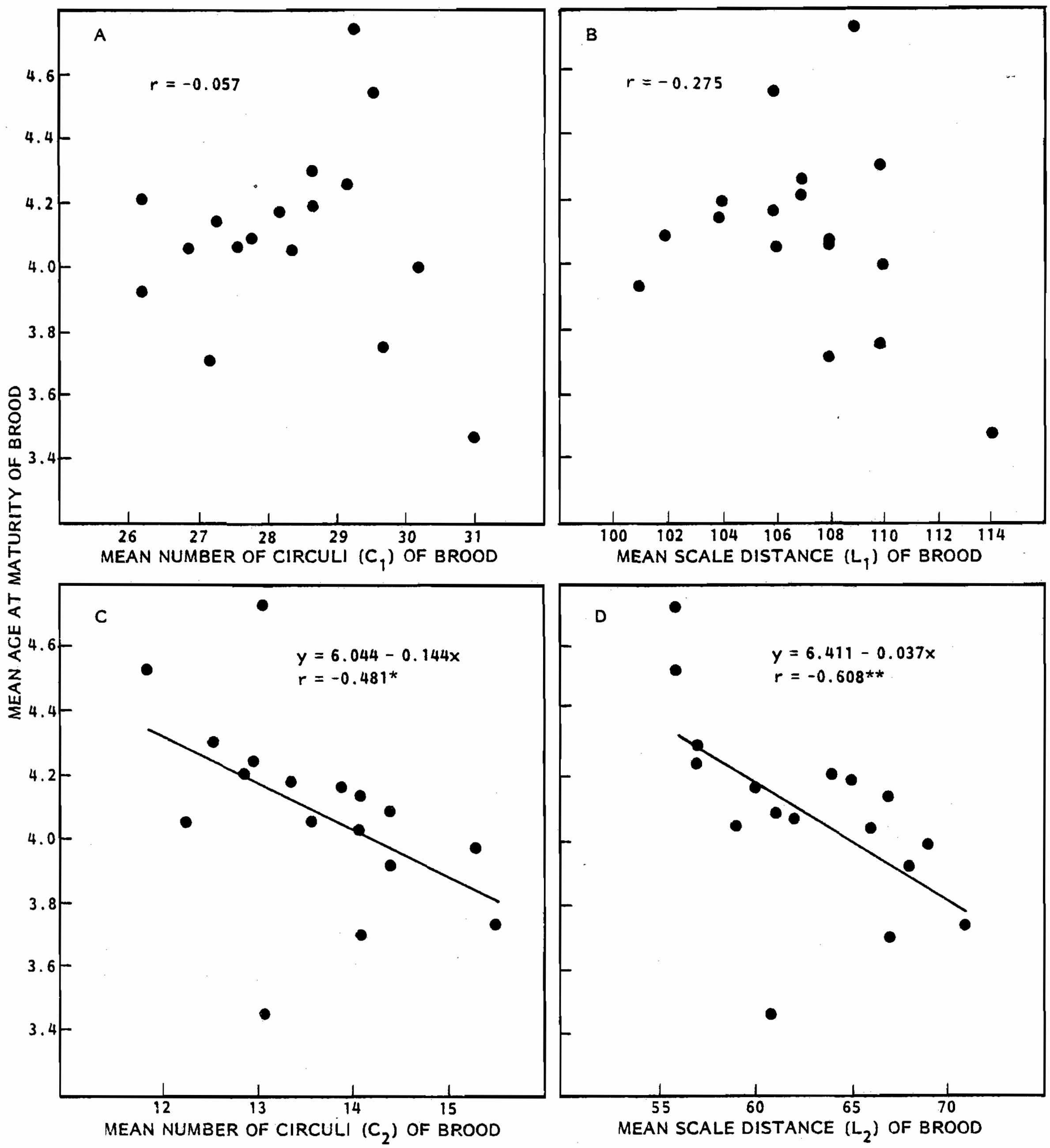

Figure 28. Relation between mean age at maturity of broods (1956-72) of chum salmon that returned to Olsen Creek and scale characters (C_1, C_2, L_1, L_2) representing the first and second marine growth periods of each brood.

brood and growth during the second marine season of the brood are clearly related (Fig. 28C, 28D). The correlation coefficients for the comparison with mean number of circuli (C_2) was significant and the comparison with mean scale distance (L_2) was highly significant. These observations provide evidence that amount of growth acquired by juvenile chum salmon during their second marine season has a strong influence on their age at maturity.

I. Relationships between Population Abundance, Age and Size at Maturity, Environment, and Survival

The number of chum salmon returning to spawn in Olsen Creek fluctuated greatly from year to year, but overall, a trend of increasing peaks of abundance was evident from 1960-73 (Fig. 8). Concurrent with the increase in population size was an increase in the age at maturity (Fig. 12). A comparison of age at maturity and population abundance by brood year shows a significant relationship (Fig. 29). Mean age at maturity of each brood tends to increase as the total number of spawners from each brood increases. Birman (1951) and Birman and Levanidov (1954) reported larger percentages of older age groups associated with larger population sizes in chum salmon from the Amur River in the USSR. Contrarily, chum salmon from southern Sakhalin Island and western Kamchatka in the USSR showed no relation between age and abundance (Semko, 1954; Volovik and Landyshevskaya, 1968).

Environmental conditions during the final year at sea were previously shown to be correlated with length at maturity of spawners at Olsen Creek. Correlation coefficients between mean length and

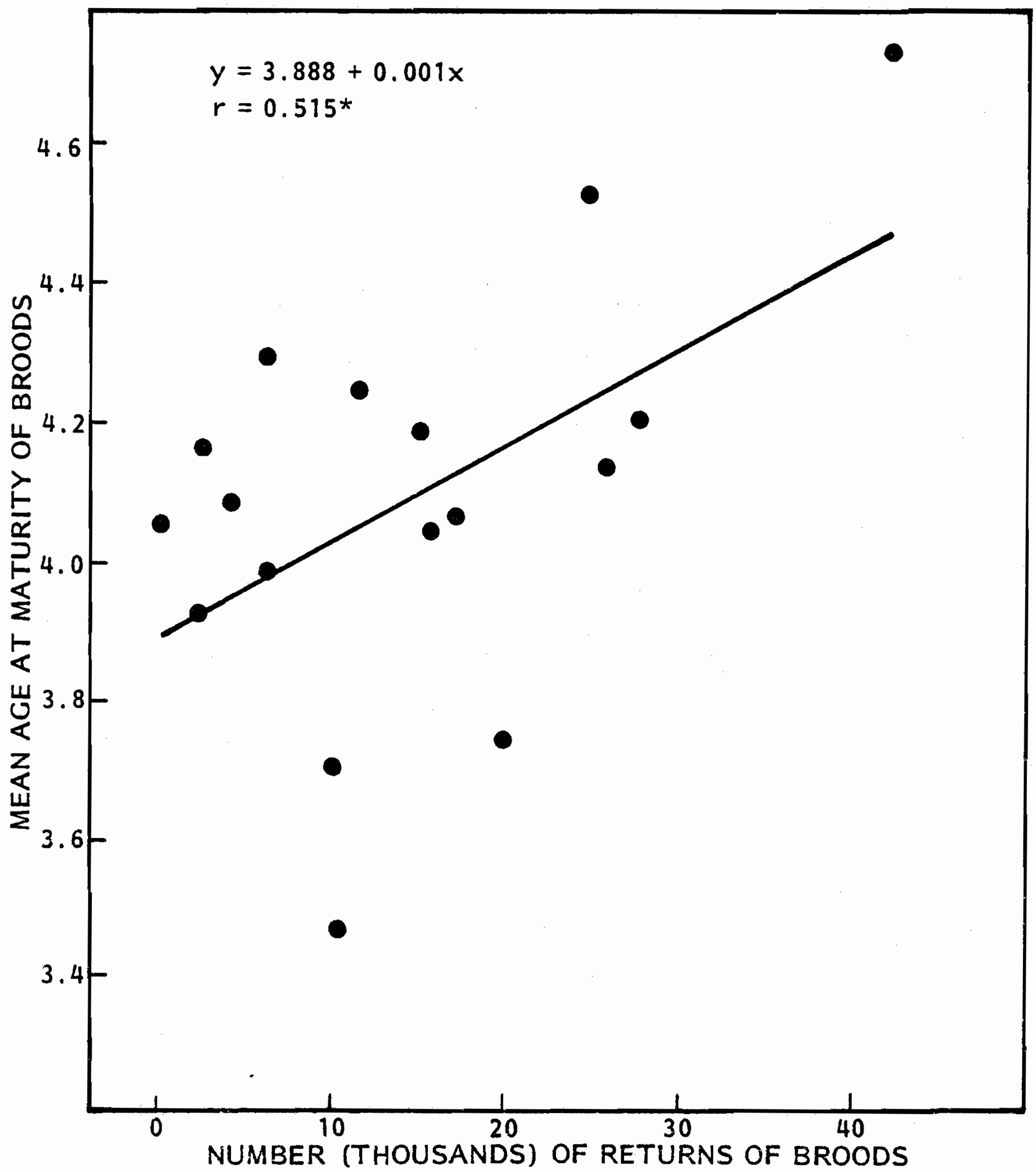

Figure 29. Relation between mean age at maturity of broods of chum salmon (sexes combined) at Olsen Creek and the total number of spawners in the same broods, 1956-72.

population abundance during the year of return (r = -0.204, n = 18) and for the brood year (r = -0.476, n = 16) were not significant; however, plots of these comparisons indicate that from 1960-71, while the population abundance shows an overall increasing trend , the mean length shows an overall decreasing trend (Fig. 30). During this time the smallest 4-year fish were from the 1967 brood which produced the largest number of individuals (Fig. 30B). This occurrence could have been coincidental because mean length was shown to be significantly related to sea surface temperatures and weather factors during the last season in the sea (Figs. 25, 26, 27).

The largest 4-year fish (1964) returned after the warmest mean winter sea surface temperature occurred within Marsden Square 195-4 (Fig. 30C). The next year (1965) mean winter sea surface temperature in Marsden Square 195-4 was the lowest during this study; unfortunately, I was unable to sample the return of chum salmon to Olsen Creek in 1965. The coldest mean summer sea surface temperature during this study also occurred during 1965. Regardless, the effect of population abundance on mean length appears in this study to be slight. Other environmental factors were shown to account for most of the variation in mean length.

Soviet data on the relationship between size of chum salmon and abundance is contradictory. Birman (1951) and Petrova (1964) reported larger size was associated with declining abundance in the Amur River and the Bolshaya River. Semko (1954) had reported that earlier runs of chum salmon in the Bolshaya River were larger in size when numbers of fish were abundant.

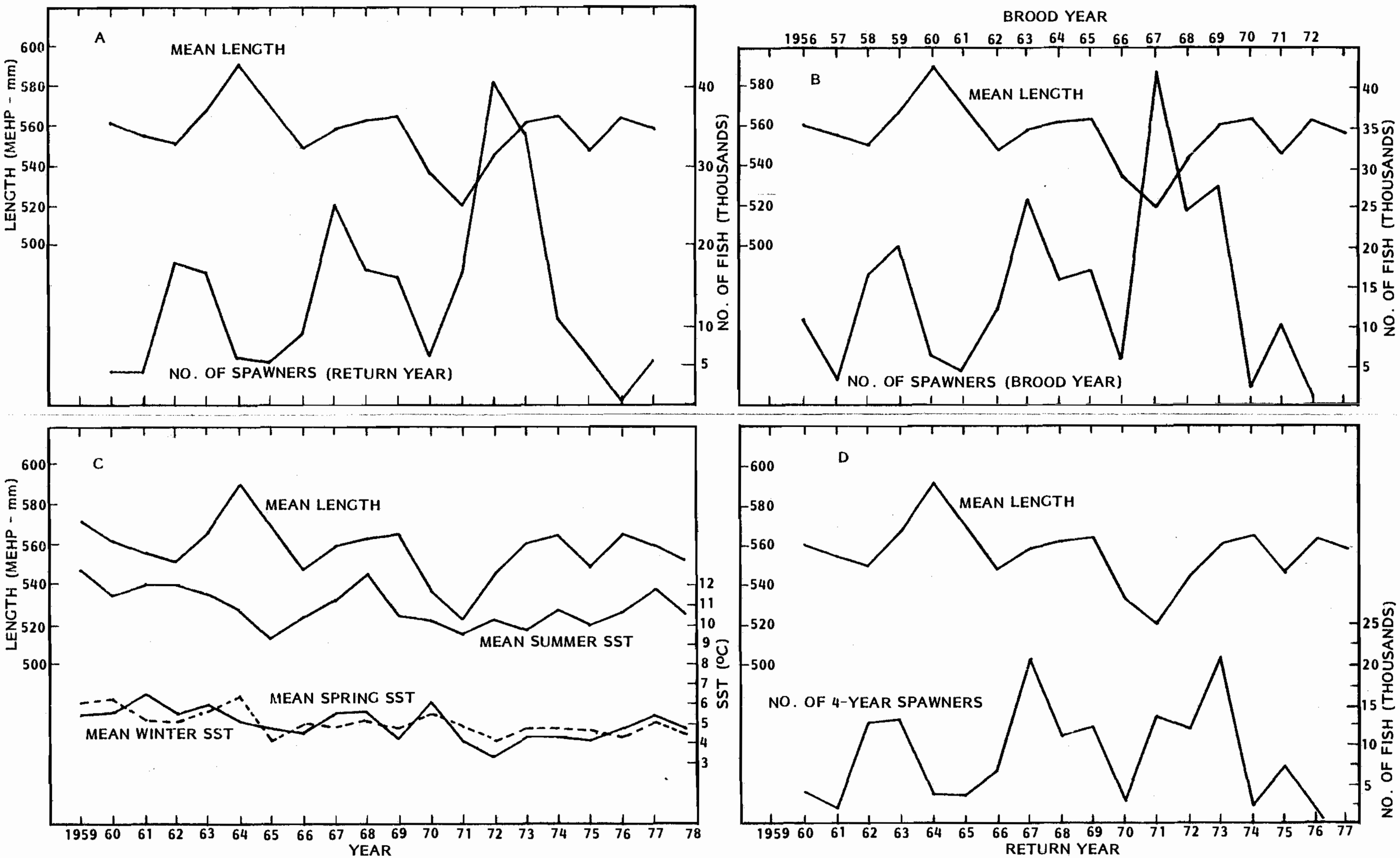

Figure 30. Comparison of mean length (MEHP) of 4-year male chum salmon with abundance of spawners in the same year, with abundance of spawners of same brood year, with abundance of 4-year fish of the same brood year, and with mean sea surface temperature (SST) in Marsden Square 195-4 during winter, spring, and summer of the year of return. Brood years 1956-72, return years 1959-77.

A comparison between the residuals or deviations from the spawner-recruit curve (Fig. 7) and environmental factors should provide estimates of variation in the spawner-recruit relationship minus density-dependent factors. Correlations were made between the residuals and: summer sea surface temperatures, summer air temperatures, and summer cloud cover within Marsden Square 195-4 during the first and last summers at sea; upwelling indices during the first and last years at sea; and mean length of progeny. None of these comparisons were significant and all of the r^2 values were less than 0.13.

An estimate of the total survival of a brood can be obtained from the ratio of the number of returns (progeny) to the number of spawners (parents). This estimate combines freshwater mortality during the spawning and incubation period and marine mortality including fishing mortality. Ratios of number of progeny/number of parents ranged from 0.01 to 3.1 during brood years 1959-72. No significant correlation was found between the survival of a brood (ratio of progeny/parents) and growth of the progeny during the first ($r = 0.147$, $n = 13$) and second ($r = 0.300$, $n = 13$) seasons in the sea.

Correlation of survival of broods with various weather parameters and sea surface temperature within Marsden Square 195-4, and upwelling indices during the first and the last summers at sea are shown in Table 17. No significant relationships are shown; however, paired correlation coefficients are largest for comparisons during the last summer at sea within Marsden Square 195-4. Juvenile chum salmon during their first summer at sea would seem to be more vulnerable than adults in their last summer at sea to the effects of environmental changes. Paired correlation coefficients were larger for the comparison during the first summer at sea for the upwelling indices (Table 17).

Table 17. Correlation between the ratio of number of progeny to number of parents of chum salmon at Olsen Creek and mean values for cloud cover, dew point, and sea surface temperatures within Marsden Square 195-4, and yearly upwelling indices during the fishes' first and last summers in the ocean.

Environmental parameter	Period in ocean	Correlation coefficient (r)	Number of comparisons (n)
Cloud cover	First summer	0.117	12
	Last summer	-0.555	10
Dew point	First summer	-0.093	13
	Last summer	0.511	10
Sea surface temperature	First summer	0.067	12
	Last summer	0.368	14
Yearly upwelling index at 60°N 146°W	First summer	0.273	12
	Last summer	0.015	9
Yearly upwelling index at 60°N 149°W	First summer	0.217	12
	Last summer	-0.077	9

The relation between survival (ratio of progeny/parents) of a brood and mean length at maturity of the 3-, 4-, and 5-year male and female parents is shown in Figure 31. A strong relation between survival and mean length of parents is evident. Only the correlation coefficient for the comparison with the 5-year males was not significant (Fig. 31E). The higher values of the correlation coefficients for 4-year males and females probably reflects the consistently larger sample sizes for this

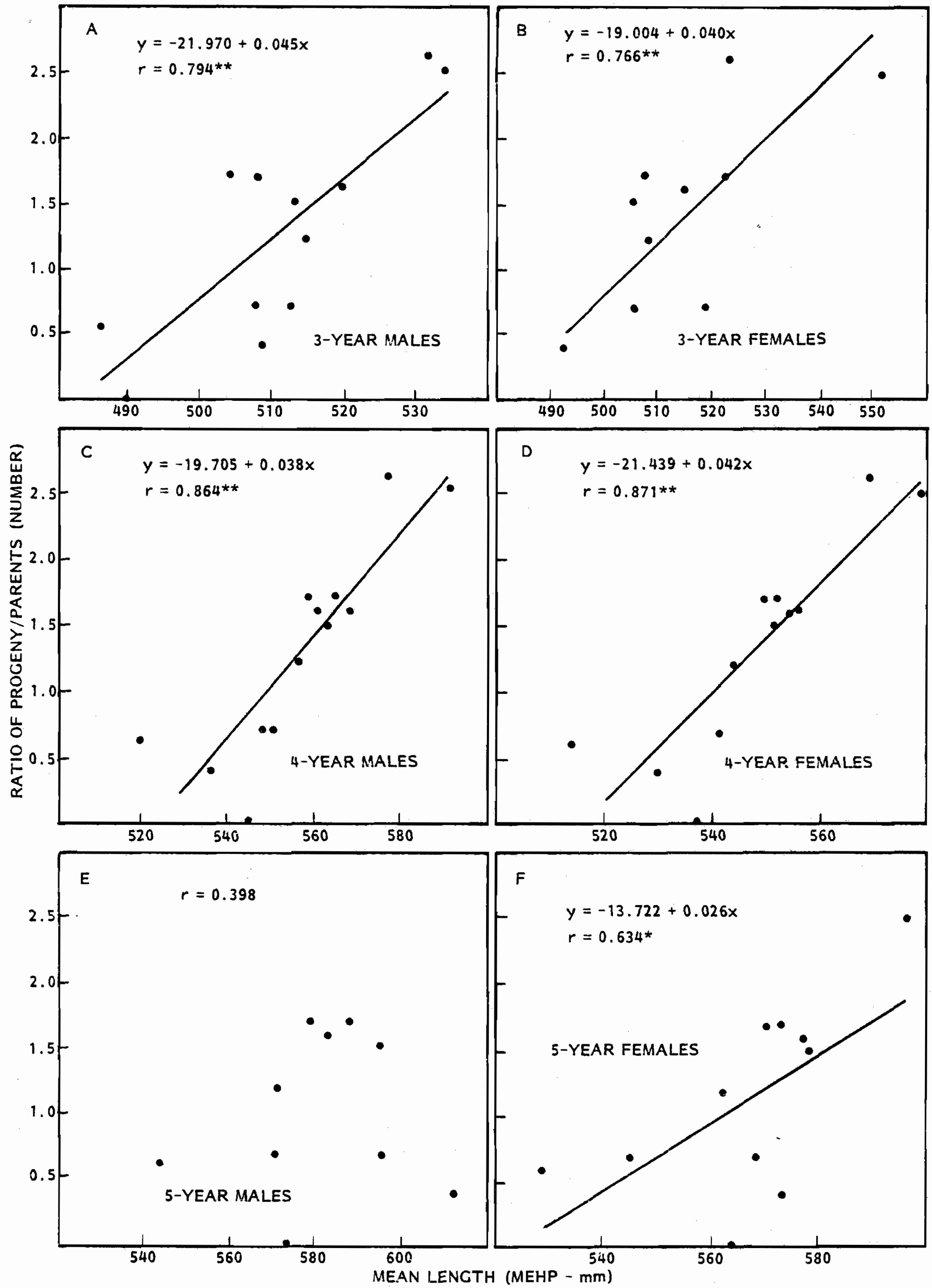

Figure 31. Relation between the ratio of the number of progeny/number of parents of chum salmon spawners at Olsen Creek and the mean length (MEHP) of 3-, 4-, and 5- year males and females, 1959-72.

age group compared to sample sizes of the 3-and 5-year fish (see Tables 7 and 8). Skud (1958, 1973) has reported a relation between size of adult pink salmon and time of their migration and freshwater survival at Sashin Creek in southeastern Alaska. Skud (op. cit.) concluded that in years when adult pink salmon entered the stream to spawn early, they tended to be large and the freshwater survival was higher than it was in years when smaller adults entered the stream later. Merrell (1962), McNeil (1969), and Ellis (1969) verified the negative relation between time and freshwater survival of pink salmon at Sashin Creek that was described earlier by Skud (1958).

At Olsen Creek there is not a clear distinction between time of spawning and size of spawners between years. True, older fish (5-year fish) are generally larger and they tend to spawn early, and younger fish (3-year fish) are generally smaller and they tend to spawn late (Fig. 11). However, size within each age group did not change intraseasonally (Appendix Tables 3 and 4). During years when the mean size of all age groups was larger than average (or smaller), timing of the runs was not associated with size.

Why is the survival of progeny high during years when the size of the parents is large? And why is survival low for progeny of smaller parents? Some of the variation in survival can be explained by the relationship between size and fecundity. Number of eggs per female at Olsen Creek was determined in 1966 by counting individual eggs on a special board (see Helle et al., 1964). The significant relation ($r = 0.508^{**}$, $n = 45$) between number of eggs and length (MEHP) was:

Least Squares Regression Formula

$$\text{Number of eggs} = -567.48 + 6.65\ (\text{length})$$

Functional Regression Formula

$$\text{Number of eggs} = -4004.59 + 13.09\ (\text{length}).$$

Ricker (1973) argues that the functional regression may be more appropriate than the more commonly used least squares regression in this type of comparison.

Mean length of 4-year female chum salmon ranged from 591 mm in 1964 to 520 mm in 1971 (Table 8). Differences in mean number of eggs per female during these two years was estimated from the least squares equation and functional equation to be 472 and 929 eggs per female, respectively. Therefore, on the average, females 591 mm in length would have 1.2 to 1.3 times more eggs than females 520 mm in length would have. However, the difference in survival rate between females 591 mm in length and females 520 mm in length is estimated to be about 5 times (Fig. 31D). The advantage in survival of progeny of larger fish must be due to other factors (or factor) in addition to greater fecundity of larger fish.

Koski (1975) showed that not only is there a positive relation between size and number of eggs in chum salmon but also that larger females tend to have larger eggs. Perhaps larger eggs provide an additional advantage in survival over smaller eggs in some circumstances. Larger fish may also deposit their eggs deeper in the streambed. Eggs deposited deepest in the streambed could be less susceptible to dislodgement by scouring of floods or to excavation by other spawners. Chum salmon redds are deeper than pink salmon redds at Olsen Creek (Table 5). Chum salmon are also larger than pink salmon. If egg depth in the streambed was size dependent as well as species dependent, eggs deposited by large fish might have a higher survival rate than eggs that were deposited in shallower redds by smaller fish.

V. DISCUSSION

The number of chum salmon spawners that returned to Olsen Creek varied widely from year to year; but, it could be argued that major periods of abundance follow a five-year cycle (Fig. 8). Only one of the years (1972) of peak abundance (1962, 1967, 1972) had a large percentage of 5-year-old fish in the return (Table 3). Therefore, strength of return of 5-year fish does not explain the occurrence of a 5-year cyclic trend in abundance. These periods of peak abundance do roughly correspond to the solar activity cycle (Favorite and Ingraham, 1976).

The solar activity cycle (approximately 11 years) has been thought to be related to abundance of fish stocks for 50 years or more (see Birman, 1973). Birman (1966, 1973) discusses similarities between peaks of solar activity and peaks of abundance of Pacific salmon, herring (*Clupea* sp.), and other species. Driver (1978) has shown that shrimp (*Crangon crangon*) abundance can be predicted several years in advance by a direct relation with sunspot number. Cycles of sunspot number seem to be related to sea surface temperature data in the North Pacific Ocean and in some cases to commercial landings of sockeye salmon (*O. nerka*), herring, and Dungeness crab (*Cancer magister*) in Alaska (Favorite and Ingraham, 1976).

Evidence for a strong environmental component in determination of age at maturity in chum salmon was presented in this study. The amount of growth of a brood during their second season at sea was shown to be significantly related to age at maturity (Fig. 28). Increasing growth during the second season at sea resulted in earlier maturity. Also, a significant positive relationship was shown between number of chum salmon in a brood and mean age at maturity (Fig. 29).

The 1956 brood of chum salmon had an unusually high percentage of 3-year fish (Table 4). These fish experienced unusually fair weather conditions during their first summer at sea in Prince William Sound and unusually high sea temperatures in their first (1957) and second (1958) seasons at sea (Fig. 32C). That sea surface temperatures in the North Pacific Ocean were anomalously warm during these years has been well documented (Favorite and McLain, 1973). Barracuda (<u>Sphyraena</u> sp.) were captured in Prince William Sound during the summer of 1958 and bluefin tuna (<u>Thunnus</u> sp.) were reported near Kodiak Island in 1958 (Quast, 1964). These two warm-water species are seldom captured in Alaskan waters.

A comparison of all the broods studied (1956-1972) showed that rate of growth during the first year at sea was not significantly related to age at maturity (Fig. 28). In addition to the 1956 brood, the 1967-brood chum salmon also experienced very warm sea surface temperatures during their first summer at sea in 1968 (Fig. 32C) but only one percent of the brood returned as 3-year fish. In fact, the mean age at maturity of the 1967 brood was the oldest of all the broods studied at Olsen Creek (Table 4). The 1967 brood was also the most abundant and a significant relation was shown between mean age at maturity of a brood and abundance of the brood (Fig. 29).

Perhaps some threshold size needs to be attained by the second season at sea if chum salmon are to mature at 3 years and population density may influence the attainment of this size. That mean age at

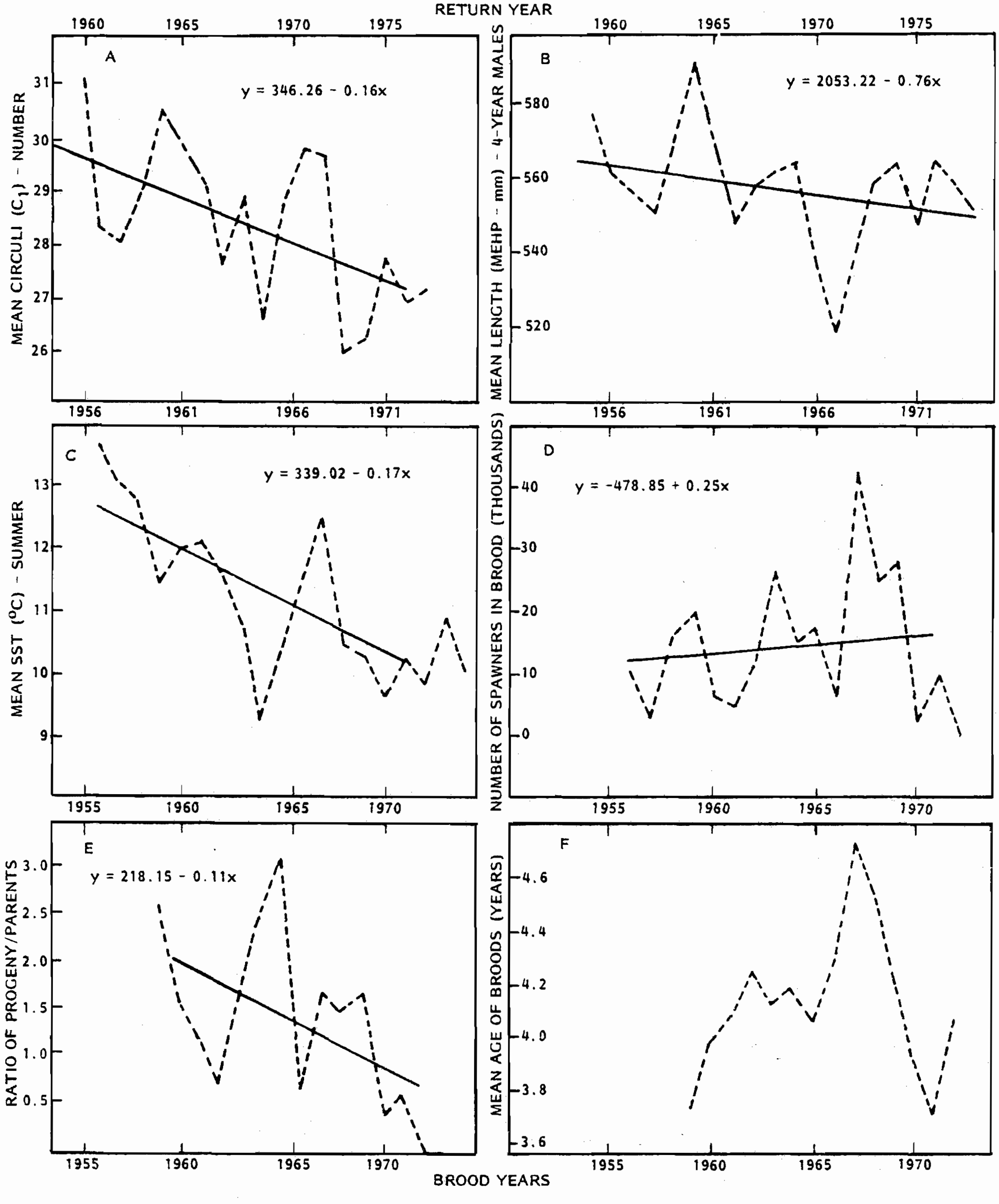

Figure 32. Trend lines for mean length, mean number of circuli (C_1), mean sea surface temperature (SST) in Marsden Square 195-4, number of spawners produced by each brood, mean age at maturity of each brood (trend line omitted), and ratio of number of progeny/number of parents for return years 1959-77 and brood years 1956-72.

maturity is related to population abundance suggests that Olsen Creek chum salmon may stay together during their stay in the ocean. What other species of salmon or other species of marine fish may be competitive with chum salmon during different population densities is not known.

A comparison of mean length of 3-, 4-, and 5-year chum salmon from the same brood year and same return year indicated that the last season at sea has a strong influence on final size at maturity (Figs. 15 and 16). Environmental factors during the last season at sea were shown to be significantly related to length at maturity (Figs. 25-27). Population abundance and mean length at maturity were not directly related (Fig. 30). Certainly other populations of chum salmon are mixed with or adjacent to Olsen Creek chum salmon in the ocean so if these factors were known, it is possible there could be a relationship between mean length and total number of chum salmon per unit area of ocean.

An estimate of the percentage of variation in length due to environmental influences can be made from the coefficients of determination (r^2). The r^2 values for the relationships between mean length and mean air temperature, mean cloud cover, and mean dew point in the summer within Marsden Square 195-4 were 0.53, 0.47, and 0.53, respectively. The r^2 values for the relationships between mean length and mean summer streamflow at Olsen Creek and mean summer sea surface temperatures in Prince William Sound at Cordova were 0.70 and 0.42, respectively. Therefore, approximately 40-70% of the variation in length at maturity was associated with these environmental parameters.

The relation between growth and survival is complex. In studies of the population dynamics of fishes, growth is often assumed to be a sensitive measure of survival, e.g., Ricker (1958), Vladimirov (1973), Walters et al. (1978). Cushing and Dickson (1976), Sutcliffe et al. (1977), Sjöblom (1978) and Parrish and MacCall (1978) relate variations in survival of marine species to variations in the marine environment. Henry (1961) found a relation between early marine growth on the scales of sockeye salmon and survival of adults returning to the Fraser River in British Columbia. I found no direct significant relationships between survival and growth of broods of chum salmon from Olsen Creek during the first season at sea ($r = 0.147$, $n = 13$) or during the second season at sea ($r = 0.300$, $n = 13$). Correlations between survival and various environmental parameters during the first and last seasons at sea also were not significant (Table 17). I had expected to see a strong positive relationship between growth and survival during the early marine period. Actually, the correlation coefficients, although not significant for the comparisons between survival and growth during the first and second seasons in the sea, were higher for the comparison during the second season. Correlation coefficients for the comparisons between survival and environmental parameters during the chum salmons' first and last seasons in the sea were also generally higher for the later comparisons. Similarly, there was an apparent relationship between the abundance of chum salmon and pink salmon during the year of return, but no relationship was evident for the period when chum salmon and pink salmon broods were together during their early marine experience (Fig. 9). In studies based on returns, we are measuring growth of the survivors, not the fish that died. Perhaps relationships between growth and survival would be more direct if we could also estimate growth rates of the fish that died.

My estimates of survival were made from the ratio of number of progeny/number of parents. This ratio combines mortalities during spawning and incubation in freshwater and mortalities during the marine phase of their life history. Separate estimates of freshwater survival and marine survival would certainly strengthen the results of comparisons of growth and marine survival. Also, maybe, in the absence of separate freshwater and marine mortality estimates, direct comparison of survival by regresson analysis could be too restrictive. Comparisons of the trend lines for mean growth during the first season at sea (Fig. 32B), mean sea surface temperatures during the summer within Marsden Square 195-4 (Fig. 32C), and total survival (Fig. 32E) show very similar rates of decline during this study. The slopes, 0.16, 0.17, and 0.11 for growth during the first season at sea, SST, and survival, respectively, are very similar. Even though there is no direct relation, growth during the first season at sea, sea surface temperatures, and total survival have declined precipitously at similar rates. During the same time, mean length at maturity has declined more moderately (Fig. 32D). Mean population abundance of the brood shows a slight increasing trend or positive slope (Fig. 32D). However, population abundance and mean age at maturity of later broods (1970-72) declined sharply (Figs. 32D and 32F).

The precipitous declines in early marine growth, mean summer sea surface temperatures, survival, and length at maturity seem to be starting to show more positive trends in the mid-1970's (Fig. 32). The good return of 4-year fish in 1977 from the 1973 brood (Table 3) exhibited a vast improvement in survival over the disastrous survival of the 1972 brood (Table 4).

Mean length at maturity of parents was shown to be strongly related to the survival of their progeny (Fig. 31) and mean length was shown to be related to environmental factors during the last season in the sea (Figs. 25-27). The winters of 1971-75 in the North Pacific Ocean were very cold (especially the winter of 1971-72) and resulted in anomalously low sea-surface temperatures (McLain and Favorite, 1976). Mean lengths at maturity of chum salmon at Olsen Creek were smaller than normal during the seasons of 1970-72, and survival of their progeny was lower than survival of broods when the mean size of the parents was larger.

The strength of the correlations between mean length of parents and survival of progeny for Olsen Creek chum salmon is especially significant because they represent total (freshwater plus marine) survival of the broods. Vladimirov (1973) using data from Skud (1958) for pink salmon at Sashin Creek in southeastern Alaska showed that size of parents (independent of timing) was significantly related to the freshwater survival of their progeny. Vladimirov (1973) has shown that similar relations between size of parents and survival of progeny also exists for several other species of fish.

Ricker et al. (1978) present a strong argument that size-selective commercial fishing gear has significantly reduced the size of pink salmon returning to British Columbia. If there is a relation among pink salmon in British Columbia between size of parents and survival of progeny, then a progressive reduction in mean size of pink salmon could also result in reduced survival of progeny. Evaluations of the size selectivity of commercial gear and the relation of fish size to survival in many fisheries should be investigated.

Commercial fishing for chum salmon and pink salmon in Prince William Sound is mainly accomplished with purse seines which are generally not size selective. The declining trend in size (Fig. 32B) of chum salmon at Olsen Creek was shown to be related to environmental factors.

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APPENDIX

Appendix table 1. Equivalent age designations used in studies of age at maturity of chum salmon.

Method	Age			
This study	3	4	5	6
Gilbert-Rich	3_1	4_1	5_1	6_1
European	0.2	0.3	0.4	0.5
Soviet	2^+	3^+	4^+	5^+

Appendix table 2. Intraseasonal differences in number and percentage of 3-, 4-, and 5-year male and female chum salmon that spawned at Olsen Creek from 1959 through 1977. Letters represent sample periods spaced approximately equidistantly within each 12-week spawning season.

	Males							Females						
	Age							Age						
	3		4		5			3		4		5		
Year	No.	(%)	No.	(%)	No.	(%)	Total	No.	(%)	No.	(%)	No.	(%)	Total
1959														
A	13	(100)	0	(0)	0	(0)	13	7	(64)	2	(18)	2	(18)	11
B	116	(90)	6	(5)	7	(5)	129	27	(65)	14	(33)	1	(2)	42
1960														
A	0	(0)	45	(100)	0	(0)	45	0	(0)	15	(100)	0	(0)	15
B	0	(0)	27	(100)	0	(0)	27	1	(2)	58	(98)	0	(0)	59
C	0	(0)	19	(100)	0	(0)	19	0	(0)	19	(100)	0	(0)	19
1961														
A	7	(12)	33	(59)	16	(29)	56	0	(0)	14	(40)	21	(60)	35
B	31	(33)	56	(59)	8	(8)	95	11	(9)	90	(74)	21	(17)	122
C	22	(25)	58	(66)	8	(9)	88	20	(16)	98	(79)	6	(5)	124
D	34	(52)	31	(47)	1	(1)	66	17	(31)	39	(69)	0	(0)	56
E	53	(78)	15	(22)	0	(0)	68	41	(66)	21	(34)	0	(0)	62
1962														
A	11	(14)	68	(85)	1	(1)	80	1	(2)	61	(92)	4	(6)	66
B	15	(18)	68	(80)	2	(2)	85	6	(8)	62	(83)	7	(9)	75
C	35	(59)	24	(41)	0	(0)	59	27	(32)	55	(65)	3	(3)	85
D	24	(44)	30	(56)	0	(0)	54	14	(22)	48	(76)	1	(2)	63

Appendix table 2. continued.

Year	Males							Females						
	Age							Age						
	3		4		5			3		4		5		
	No.	(%)	No.	(%)	No.	(%)	Total	No.	(%)	No.	(%)	No.	(%)	Total
1963														
A	1	(1)	70	(86)	10	(12)	81	3	(5)	50	(79)	10	(16)	63
B	11	(12)	71	(76)	11	(12)	93	3	(5)	53	(87)	5	(8)	61
C	11	(18)	47	(77)	3	(5)	61	7	(8)	71	(83)	7	(8)	85
D	5	(26)	12	(63)	2	(11)	19	7	(13)	47	(87)	0	(0)	54
1964														
A	0	(0)	23	(49)	24	(51)	47	0	(0)	12	(34)	23	(66)	35
B	1	(1)	38	(58)	27	(41)	66	0	(0)	26	(49)	27	(51)	53
C	2	(5)	36	(86)	4	(9)	42	0	(0)	59	(82)	13	(18)	72
D	8	(67)	4	(33)	0	(0)	12	7	(100)	0	(0)	0	(0)	7
1966														
A	4	(16)	18	(72)	3	(12)	25	1	(3)	32	(89)	3	(8)	36
B	34	(35)	63	(65)	0	(0)	97	12	(17)	55	(80)	2	(3)	69
1967														
A	0	(0)	15	(32)	32	(68)	47	0	(0)	4	(19)	17	(81)	21
B	1	(1)	57	(88)	7	(11)	65	2	(3)	49	(80)	10	(16)	61
C	4	(4)	88	(86)	10	(10)	102	0	(0)	92	(96)	4	(4)	96
D	8	(8)	91	(88)	4	(4)	103	2	(2)	94	(93)	5	(5)	101
E	1	(2)	43	(86)	6	(12)	50	2	(5)	36	(92)	1	(3)	39
1968														
A	1	(1)	72	(74)	24	(25)	97	0	(0)	60	(66)	31	(34)	91
B	0	(0)	75	(74)	27	(26)	102	1	(1)	86	(83)	17	(16)	104
C	11	(8)	94	(67)	35	(25)	140	4	(3)	98	(75)	29	(22)	131
D	34	(35)	34	(35)	28	(29)	96	11	(11)	54	(56)	30	(31)	95

Appendix table 2. continued.

	Males							Females						
	Age							Age						
	3		4		5			3		4		5		
Year	No.	(%)	No.	(%)	No.	(%)	Total	No.	(%)	No.	(%)	No.	(%)	Total
1968														
E	62	(74)	9	(11)	13	(15)	84	39	(54)	19	(26)	14	(19)	72
F	60	(88)	3	(4)	5	(7)	68	42	(81)	2	(4)	8	(15)	52
1969														
A	0	(0)	47	(55)	39	(45)	86	0	(0)	43	(51)	41	(49)	84
B	1	(1)	53	(67)	25	(32)	79	3	(4)	43	(54)	34	(42)	80
C	2	(2)	72	(86)	10	(12)	84	1	(1)	65	(80)	15	(18)	81
D	2	(3)	76	(95)	2	(3)	80	1	(1)	65	(93)	4	(6)	70
E	4	(5)	78	(94)	1	(1)	83	1	(1)	80	(96)	2	(2)	83
F	8	(9)	80	(89)	2	(2)	90	6	(7)	79	(92)	1	(1)	86
G	31	(34)	59	(66)	0	(0)	90	20	(30)	45	(68)	1	(1)	66
1970														
A	0	(0)	7	(44)	9	(56)	16	0	(0)	0	(0)	9	(100)	9
B	14	(30)	30	(65)	2	(4)	46	7	(13)	47	(85)	1	(2)	55
C	4	(4)	93	(96)	0	(0)	97	3	(3)	92	(97)	0	(0)	95
1971														
A	1	(2)	45	(68)	20	(30)	66	0	(0)	23	(66)	12	(34)	35
B	0	(0)	55	(81)	13	(19)	68	0	(0)	39	(59)	27	(41)	66
C	1	(3)	34	(89)	3	(8)	38	0	(0)	31	(89)	4	(11)	35
D	1	(1)	98	(95)	4	(4)	103	0	(0)	83	(95)	4	(5)	87
E	4	(5)	68	(92)	2	(3)	74	2	(3)	64	(89)	6	(8)	72
1972														
A	0	(0)	22	(21)	82	(79)	104	0	(0)	6	(22)	21	(78)	27
B	2	(2)	27	(26)	73	(71)	102	0	(0)	25	(27)	69	(73)	94

Appendix table 2. continued.

	Males							Females						
	Age							Age						
	3		4		5			3		4		5		
Year	No.	(%)	No.	(%)	No.	(%)	Total	No.	(%)	No.	(%)	No.	(%)	Total
1972														
C	3	(3)	29	(30)	66	(67)	98	2	(2)	34	(34)	63	(64)	99
D	8	(13)	32	(52)	22	(35)	62	1	(2)	27	(53)	23	(45)	51
1973														
A	0	(0)	61	(55)	50	(45)	111	1	(1)	59	(57)	44	(42)	104
B	0	(0)	82	(80)	20	(20)	102	0	(0)	83	(78)	23	(22)	106
C	11	(9)	90	(73)	22	(18)	123	0	(0)	57	(83)	12	(17)	69
1974														
A	2	(2)	18	(15)	98	(83)	118	1	(1)	8	(9)	85	(90)	94
B	23	(21)	6	(6)	79	(73)	108	11	(11)	9	(9)	82	(80)	102
C	74	(60)	36	(29)	14	(11)	124	28	(33)	36	(42)	22	(25)	86
1975														
A	0	(0)	124	(99)	1	(1)	125	0	(0)	86	(95)	5	(5)	91
B	2	(2)	110	(98)	0	(0)	112	1	(1)	91	(99)	0	(0)	92
1976														
A	11	(19)	33	(57)	14	(24)	58	2	(3)	40	(69)	16	(28)	58
1977														
A	4	(4)	105	(95)	1	(1)	110	1	(1)	93	(99)	0	(0)	94
1978														
A	14	(12)	93	(82)	7	(6)	114	20	(15)	100	(76)	11	(8)	131

Appendix table 3. Intraseasonal differences in mean length (MEHP), 95% confidence intervals (CI), standard deviation (S.D.), and range in length of 3-, 4-, and 5-year male chum salmon that spawned at Olsen Creek from 1959 through 1978. Letters represent sample periods spaced approximately equidistantly within each 12-week spawning season.

MALES

	Age 3				Age 4				Age 5			
Year	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1959												
A	13	500-595	24.5	533±15	0	--	--	--	0	--	--	--
B	116	460-590	25.2	532± 5	6	505-615	45.9	577±48	7	525-630	33.0	592±31
1960												
A	0	--	--	--	45	500-600	25.0	557± 8	0	--	--	--
B	0	--	--	--	27	520-690	33.4	567±13	0	--	--	--
C	0	--	--	--	19	510-600	19.9	563±10	0	--	--	--
1961												
A	7	465-555	28.8	504±27	33	475-595	23.9	544± 9	16	495-630	33.5	564±18
B	31	420-575	30.0	506±11	56	500-640	28.7	552± 8	8	545-620	27.0	577±23
C	22	480-590	24.8	529±11	58	515-620	24.0	568± 6	8	535-645	40.7	584±34
D	34	470-570	25.2	517± 9	31	505-585	18.8	555± 7	1	545	--	--
E	53	430-595	31.8	515± 9	15	515-585	25.7	556±14	0	--	--	--
1962												
A	11	455-550	23.9	514±16	68	500-615	25.2	551± 6	1	585	--	--
B	15	465-565	23.7	509±13	68	495-620	27.3	554± 7	2	585-615	--	--
C	35	440-550	27.0	508± 9	24	505-590	21.2	557± 9	0	--	--	--
D	24	415-570	32.2	505±14	30	490-600	28.7	539±11	0	--	--	--

Appendix table 3. continued.

MALES

Year	Age 3				Age 4				Age 5			
	Number	Range (mm)	S.D. (mm)	X̄±CI (mm)	Number	Range (mm)	S.D. (mm)	X̄±CI (mm)	Number	Range (mm)	S.D. (mm)	X̄±CI (mm)
1963												
A	1	550	--	--	70	510-635	27.7	570± 7	10	505-635	34.5	578±25
B	11	485-560	22.3	527±15	71	515-615	22.8	570± 5	11	535-675	38.0	587±26
C	11	485-560	23.1	516±16	47	510-625	28.1	570± 8	3	575-625	27.5	593±68
D	5	485-540	20.2	508±25	12	500-570	20.0	541±13	2	565-565	--	--
1964												
A	0	--	--	--	23	510-615	31.8	569±14	24	545-660	28.8	603±12
B	1	--	--	--	38	535-670	31.4	601±10	27	540-675	33.9	621±13
C	2	--	17.7	--	36	520-650	30.4	592±10	4	615-695	33.8	--
D	8	480-560	24.5	--	4	580-650	35.2	--	0	--	--	--
1966												
A	4	455-500	20.2	483±32	18	485-595	28.7	550±14	3	550-605	30.4	570±76
B	34	450-585	30.4	517±11	63	490-605	26.8	547± 7	0	--	--	--
1967												
A	0	--	--	--	15	510-615	28.9	564±16	32	545-650	22.2	581± 8
B	1	430	--	--	57	480-595	27.2	551± 7	7	505-615	37.3	572±34
C	4	465-550	35.8	500±57	88	495-610	23.7	559± 5	10	505-645	38.3	581±27
D	8	470-580	36.7	521±31	91	450-645	25.8	561± 5	4	535-580	18.9	561±30
E	1	515	--	--	43	515-610	21.4	560± 7	6	555-610	19.3	584±20
1968												
A	1	490	--	--	72	500-615	25.9	551± 6	24	510-645	34.3	586±14
B	0	--	--	--	75	510-615	22.6	567± 5	27	535-645	24.2	599±10

Appendix table 3. continued.

MALES

Year	Age 3 Number	Range (mm)	S.D. (mm)	X̄±CI (mm)	Age 4 Number	Range (mm)	S.D. (mm)	X̄±CI (mm)	Age 5 Number	Range (mm)	S.D. (mm)	X̄±CI (mm)
1968												
C	11	470-575	30.7	518±21	94	515-615	20.3	570± 4	35	515-655	30.1	602±10
D	34	475-555	21.0	511± 7	34	485-600	26.0	559± 9	28	540-635	22.8	592± 9
E	62	475-570	22.3	516± 6	9	500-615	33.5	565±26	13	550-630	22.0	592±13
F	60	460-565	20.8	510± 5	3	510-590	40.4	553±99	5	540-655	41.1	595±51
1969												
A	0	--	--	--	47	505-615	24.1	562± 7	39	535-640	25.2	592± 8
B	1	565	--	--	53	430-625	35.0	546±10	25	515-660	33.8	572±14
C	2	500-565	46.0	--	72	500-660	32.0	569± 8	10	570-655	30.8	607±22
D	2	475-545	49.5	--	76	470-630	31.0	562± 7	2	605-610	3.5	--
E	4	460-505	21.2	490±34	78	510-625	25.1	569± 6	1	570	--	--
F	8	470-545	26.4	512±22	80	495-620	23.6	571± 5	2	590-595	3.5	--
G	31	445-545	23.7	500± 9	59	485-630	29.0	573± 8	0	--	--	--
1970												
A	0	--	--	--	7	475-580	34.1	518±32	9	535-690	46.7	616±36
B	14	480-555	23.9	509±14	30	475-640	34.3	538±13	2	575-620	31.8	--
C	4	475-545	31.1	510±49	93	450-590	27.2	537± 6	0	--	--	--
1971												
A	1	440	--	--	45	460-600	29.2	520± 9	20	520-585	16.6	559± 8
B	0	--	--	--	55	455-575	26.0	522± 7	13	485-585	32.7	531±19
C	1	510	--	--	34	450-570	28.3	512±10	3	500-565	33.3	537±83
D	1	435	--	--	98	470-585	24.2	527± 5	4	515-585	31.2	556±50
E	4	485-515	14.4	504±20	68	455-560	21.4	514± 5	2	515-525	7.1	--

Appendix table 3. continued.

MALES

Year	Age 3				Age 4				Age 5			
	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1972												
A	0	--	--	--	22	500-605	26.1	550±12	82	505-645	28.2	569± 6
B	2	440-470	21.2	--	27	490-595	27.3	542±11	73	515-640	27.8	576± 7
C	3	465-565	50.3	512±99	29	485-585	25.4	544±10	66	500-625	25.4	575± 6
D	8	470-520	16.5	490±14	32	500-585	22.7	544± 8	22	520-620	25.3	568±11
1973												
A	0	--	--	--	61	480-620	23.4	549± 6	50	525-635	29.5	590± 8
B	0	--	--	--	82	470-635	30.6	562± 7	20	540-665	29.9	597±14
C	11	470-580	36.2	518±24	90	510-670	26.1	567± 5	22	535-615	22.3	577±10
1974												
A	2	465-535	49.5	--	18	505-610	30.8	559±15	98	515-700	32.8	600± 7
B	23	455-535	19.5	494± 8	6	515-610	32.5	564±34	79	530-650	26.0	591± 6
C	74	460-575	23.6	517± 5	36	510-600	23.3	569± 8	14	520-645	35.6	595±21
1975												
A	0	--	--	--	124	480-625	31.2	561± 6	1	555	--	--
B	2	495-515	--	--	110	470-595	26.6	535± 5	0	--	--	--

Appendix table 4. Intraseasonal differences in mean length (MEHP), 95% confidence interval (CI), standard deviation (S.D.), and range in length of 3-, 4-, and 5-year female chum salmon that spawned at Olsen Creek from 1959 through 1978. Letters represent sample periods spaced approximately equidistantly within each 12-week spawning season.

FEMALES

	Age 3				Age 4				Age 5			
Year	Number	Range (mm)	S.D. (mm)	$\overline{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\overline{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\overline{X}$±CI (mm)
1959												
A	7	530-575	15.7	541±15	2	570-570	--	--	2	470-595	--	--
B	27	485-560	23.0	519± 9	14	515-600	24.7	569±14	1	565	--	--
1960												
A	0	--	--	--	15	505-570	20.9	542±12	0	--	--	--
B	1	500	--	--	58	520-605	18.3	556± 5	0	--	--	--
C	0	--	--	--	19	515-595	20.0	561±10	0	--	--	--
1961												
A	0	--	--	--	14	490-570	21.4	544±12	21	540-585	14.0	566± 6
B	11	470-545	22.4	511±15	90	480-585	22.6	539± 5	21	525-610	24.2	561±11
C	20	465-550	18.4	514± 9	98	490-610	22.9	549± 5	6	530-575	18.3	554±19
D	17	480-555	21.5	512±11	39	485-605	24.2	547± 8	0	--	--	--
E	41	465-550	23.4	504± 7	21	470-590	28.0	541±13	0	--	--	--
1962												
A	1	485	--	--	61	495-620	21.4	544± 5	4	550-600	23.2	579±37
B	6	485-530	14.6	509±15	62	480-585	21.1	540± 5	7	540-575	14.0	561±13
C	27	470-575	23.4	509± 9	55	495-605	20.2	544± 5	3	555-595	20.8	578±52
D	14	470-545	20.3	500±12	48	490-590	21.9	539± 6	1	545	--	--

Appendix table 4. continued.

FEMALES

Year	Age 3				Age 4				Age 5			
	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1963												
A	3	470-535	37.5	492±93	50	500-615	25.5	559± 7	10	535-610	24.5	582±17
B	3	500-545	23.6	527±59	53	520-600	21.0	561± 6	5	555-605	20.1	576±21
C	7	485-555	24.1	533±22	71	495-610	22.7	553± 5	7	550-610	21.0	572±19
D	7	470-535	22.6	501±21	47	500-595	23.7	553± 7	0	--	--	--
1964												
A	0	--	--	--	12	520-600	22.3	571±14	23	535-620	26.9	583±12
B	0	--	--	--	26	515-645	31.6	585±13	27	560-665	24.0	604± 9
C	0	--	--	--	59	520-620	21.4	579± 6	13	545-655	39.0	600±24
D	7	530-595	21.8	552±20	0	--	--	--	0	--	--	--
1966												
A	1	540	--	--	32	480-605	26.8	540±10	3	520-575	29.3	542±73
B	12	490-545	18.0	518±11	55	490-585	19.3	541± 5	2	525-575	35.4	--
1967												
A	0	--	--	--	4	535-555	9.1	545±15	17	535-620	27.0	568±14
B	2	460-495	24.8	--	49	520-645	24.4	554± 7	10	520-595	22.2	577±16
C	0	--	--	--	92	515-635	21.8	557± 5	4	520-575	25.0	556±40
D	2	505-540	24.8	--	94	510-610	19.5	550± 4	5	535-590	21.4	563±27
E	2	500-550	35.4	--	36	440-595	28.2	544±10	1	625	--	--
1968												
A	0	--	--	--	60	510-595	19.3	548± 5	31	520-650	25.5	578± 9
B	1	545	--	--	86	485-610	19.3	551± 4	17	535-625	27.0	583±14
C	4	490-555	26.9	--	98	500-615	23.7	553± 5	29	535-615	18.2	582± 7

Appendix table 4. continued.

FEMALES

Year	Age 3				Age 4				Age 5			
	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1968												
D	11	470-545	21.6	508±14	54	450-600	23.9	553± 7	30	515-615	23.9	575± 9
E	39	465-540	18.1	506± 6	19	500-590	24.6	552±12	14	525-620	25.9	571±15
F	42	465-545	17.7	503± 6	2	545-575	21.2	--	8	540-630	30.1	580±25
1969												
A	0	--	--	--	43	505-605	24.0	550± 7	41	530-610	24.0	568± 8
B	3	555-565	5.0	560±12	43	510-590	20.9	547± 6	34	505-630	28.1	572±10
C	1	490	--	--	65	490-595	24.2	543± 6	15	550-630	24.9	580±14
D	1	520	--	--	65	505-615	24.9	557± 6	4	525-615	38.6	579±61
E	1	540	--	--	80	455-600	23.5	551± 5	2	565-590	17.7	--
F	6	515-560	18.4	532±19	79	490-600	24.9	549± 6	1	615	--	--
G	20	480-550	19.9	516± 9	45	505-590	18.7	551± 6	1	620	--	--
1970												
A	0	--	--	--	0	--	--	--	9	525-600	25.0	564±19
B	7	460-525	24.5	490±23	47	465-600	27.2	539± 8	1	650	--	--
C	3	490-515	13.2	500±33	92	460-595	25.8	526± 5	0	--	--	--
1971												
A	0	--	--	--	23	480-580	25.8	520±11	12	510-600	27.2	550±17
B	0	--	--	--	39	460-550	22.9	498± 7	27	475-565	23.0	524± 9
C	0	--	--	--	31	480-560	20.3	516± 7	4	490-565	31.2	524±50
D	0	--	--	--	83	475-550	16.1	517± 4	4	510-540	12.9	525±21
E	2	500-530	21.2	--	64	475-555	16.4	515± 4	6	490-530	14.0	513±15

Appendix table 4. continued.

FEMALES

Year	Age 3				Age 4				Age 5			
	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)	Number	Range (mm)	S.D. (mm)	$\bar{X}$±CI (mm)
1972												
A	0	--	--	--	6	495-570	27.7	523±29	21	490-605	30.0	562±14
B	0	--	--	--	25	475-590	29.4	538±12	69	520-605	18.7	565± 4
C	2	480-515	24.8	--	34	505-580	22.1	538± 8	63	530-615	19.1	564± 5
D	1	500	--	--	27	505-565	15.8	536± 6	23	540-590	12.3	564± 5
1973												
A	1	540	--	--	59	485-600	23.0	542± 6	44	540-605	18.4	573± 6
B	0	--	--	--	83	490-600	21.8	549± 5	23	510-615	24.9	578±11
C	0	--	--	--	57	500-615	23.5	552± 6	12	520-605	23.5	561±15
1974												
A	1	490	--	--	8	530-585	19.9	549±17	85	510-630	22.5	575± 5
B	11	475-590	34.1	512±23	9	530-595	22.0	559±17	82	475-640	25.8	574± 6
C	28	455-585	26.1	509±10	36	520-605	18.3	562± 6	22	515-610	24.6	575±11
1975												
A	0	--	--	--	86	490-620	26.9	549± 6	5	530-605	29.8	570±37
B	1	530	--	--	91	465-590	24.3	529± 5	0	--	--	--

Appendix table 5. Mean numbers of circuli (C_a, C_1, C_2) and mean distances (L_1, L_2) on the scales of male and female chum salmon at Olsen Creek from the same brood that matured at 3, 4, and 5 years. Distances are in mm x 80. Confidence intervals are at 95%. See METHODS for definitions of scale characters.

Brood		Samples		C_a (circuli)		C_1 (circuli)		C_2 (circuli)		L_1 (distance)		L_2 (distance)	
year	Age	M	F	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
1956	3	30	29	16.4±0.5	16.3±0.4	30.6±0.8	31.5±0.7	14.0±0.9	15.0±0.8	111±4	115±4	68±3	68±4
	4	31	30	16.2±0.5	16.4±0.6	31.0±0.7	31.2±0.8	12.5±0.7	11.9±0.6	118±3	113±3	62±4	56±4
	5	27	29	16.5±0.6	16.5±0.7	30.7±0.9	31.0±0.9	12.6±0.8	12.5±0.9	113±4	113±4	57±3	57±3
1957	3	0	0	--	--	--	--	--	--	--	--	--	--
	4	30	30	14.8±0.7	14.3±0.6	28.4±0.8	28.1±0.8	14.1±0.7	14.7±0.8	106±3	107±3	59±3	61±3
	5	3	12	15.0±4.3	15.5±1.5	27.7±5.2	28.3±1.3	13.0±2.5	13.6±1.5	105±24	105±7	57±8	60±5
1958	3	31	30	14.7±0.4	14.2±0.4	28.5±0.6	28.6±0.6	15.3±1.1	15.0±0.8	109±3	111±4	72±4	69±3
	4	30	30	14.2±0.6	14.5±0.5	27.7±0.9	28.2±0.8	12.8±1.0	14.3±1.4	105±4	108±3	62±4	65±4
	5	13	14	15.5±1.1	15.1±0.7	28.6±1.6	28.6±1.0	13.4±1.3	13.7±1.4	103±6	98±5	62±5	62±6
1959	3	30	30	14.9±0.6	15.2±0.6	30.0±0.9	30.3±0.8	17.2±1.0	17.8±0.9	112±3	116±3	80±4	79±3
	4	30	30	15.3±0.5	14.7±0.5	29.1±0.7	29.1±0.6	14.4±0.9	15.2±0.8	108±4	111±4	70±4	71±3
	5	30	30	16.0±0.6	15.6±0.5	29.7±0.8	30.3±0.6	14.2±0.8	14.4±0.9	103±3	107±3	62±3	61±3
1960	3	19	8	15.6±0.6	16.3±1.1	30.0±0.8	29.7±1.6	15.3±1.0	15.9±1.1	113±4	114±6	72±4	72±4
	4	32	29	16.1±0.7	16.0±0.7	30.2±0.8	30.8±0.9	15.4±1.1	15.0±0.9	110±3	111±3	66±3	65±3
	5	0	0	--	--	--	--	--	--	--	--	--	--
1961	3	7	1	14.0±1.4	--	28.0±1.7	--	14.9±1.6	--	105±6	--	61±5	--
	4	0	0	--	--	--	--	--	--	--	--	--	--
	5	3	3	14.0±5.0	15.6±3.8	27.0±3.2	27.7±1.4	14.0±2.5	13.3±1.4	101±17	97±33	63±5	57±12

Appendix table 5. Continued.

Brood year	Age	Samples M	Samples F	C_a (circuli) Males	C_a (circuli) Females	C_1 (circuli) Males	C_1 (circuli) Females	C_2 (circuli) Males	C_2 (circuli) Females	L_1 (distance) Males	L_1 (distance) Females	L_2 (distance) Males	L_2 (distance) Females
1962	3	0	0	--	--	--	--	--	--	--	--	--	--
	4	30	30	15.0±0.5	15.4±0.5	28.8±0.6	29.4±0.7	13.9±0.8	13.0±0.8	104±3	110±3	60±3	57±3
	5	30	19	14.7±0.4	15.3±0.7	29.1±0.5	29.5±1.1	12.4±0.8	12.5±0.7	104±3	111±4	54±3	56±3
1963	3	24	9	13.3±0.7	14.4±1.1	27.2±1.0	28.4±1.6	15.2±1.0	16.1±1.0	103±5	108±7	70±4	78±9
	4	30	30	14.3±0.5	14.2±0.4	27.5±0.6	27.5±0.5	13.7±0.8	14.2±0.6	106±4	108±3	66±3	67±3
	5	31	31	13.5±0.4	13.7±0.5	26.6±0.6	27.1±0.7	12.8±0.5	12.6±0.5	103±3	101±3	62±2	62±2
1964	3	8	3	15.4±0.8	14.3±1.4	29.0±1.1	28.7±2.9	14.6±1.8	15.7±2.9	103±6	113±16	72±8	75±4
	4	30	30	14.4±0.4	14.3±0.4	28.8±0.6	29.0±0.6	13.8±0.8	12.9±0.7	104±2	107±3	66±3	67±3
	5	30	30	14.7±0.5	14.5±0.6	28.0±0.6	28.4±0.7	12.1±0.6	11.8±0.7	97±3	103±4	56±3	56±3
1965	3	30	30	14.7±0.4	14.8±0.4	28.7±0.7	28.6±0.6	15.2±0.9	14.1±0.6	110±3	113±3	73±5	63±3
	4	30	30	13.3±0.3	13.7±0.4	26.1±0.6	26.8±0.7	14.0±0.9	13.6±0.9	100±3	105±3	61±3	60±3
	5	10	8	13.9±0.9	14.5±1.2	27.1±1.4	28.4±1.5	12.6±1.0	12.2±2.2	107±9	112±5	58±5	57±7
1966	3	30	19	15.4±0.4	15.6±0.7	28.9±0.6	29.4±0.9	13.8±0.8	14.3±0.7	108±3	110±5	61±3	61±3
	4	30	29	15.5±0.5	15.2±0.5	28.3±0.7	29.0±0.8	12.7±0.6	12.5±0.6	110±3	113±3	57±3	56±3
	5	29	30	14.6±0.5	15.1±0.5	27.9±0.7	28.9±0.6	11.1±0.7	11.4±0.6	110±2	111±3	52±3	51±2
1967	3	12	7	15.4±1.1	15.4±0.9	30.5±1.9	29.4±1.8	14.2±1.4	12.9±1.2	116±7	112±11	65±5	55±6
	4	31	30	15.1±0.5	15.0±0.6	29.8±0.7	29.8±0.9	13.0±0.7	13.7±0.8	113±3	111±3	58±3	60±3
	5	30	30	15.0±0.4	14.9±0.6	29.1±0.6	28.9±0.7	12.2±0.9	12.1±0.6	109±3	107±2	51±2	51±2
	6	5	5	14.4±1.9	15.6±1.4	29.0±2.9	29.6±2.3	12.4±1.1	11.6±4.0	104±8	104±7	49±2	52±16
1968	3	0	0	--	--	--	--	--	--	--	--	--	--
	4	30	29	15.7±0.5	15.5±0.5	29.8±0.7	29.4±0.6	13.1±0.6	12.8±0.8	110±3	110±3	62±3	60±3
	5	30	30	16.2±0.4	15.8±0.5	30.0±0.6	29.4±0.8	12.3±0.7	12.0±0.5	107±3	107±3	58±2	57±3
	6	5	4	16.6±1.1	16.0±4.3	30.2±1.0	28.5±4.0	11.2±1.8	9.7±2.0	103±7	101±17	54±7	45±7

Appendix table 5. Continued.

Brood		Samples		C_a (circuli)		C_1 (circuli)		C_2 (circuli)		L_1 (distance)		L_2 (distance)	
year	Age	M	F	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
1969	3	2	3	--	14.3±2.9	--	28.3±5.2	--	12.3±5.7	--	103±29	--	59±34
	4	30	30	13.0±0.5	13.1±0.5	25.9±0.6	25.9±0.6	13.9±0.8	13.1±0.7	105±3	106±3	67±4	64±3
	5	30	30	13.4±0.6	13.6±0.7	26.3±0.9	26.5±0.9	12.6±0.7	11.9±0.8	103±4	104±4	62±3	58±4
1970	3	6	0	14.2±1.0	--	26.8±1.5	--	15.8±2.5	--	99±5	--	69±8	--
	4	30	26	13.9±0.5	13.7±0.5	26.3±0.7	26.1±0.6	14.9±0.9	13.9±0.7	102±3	104±2	68±3	65±3
	5	0	0	--	--	--	--	--	--	--	--	--	--
1971	3	30	25	13.9±0.5	14.4±0.5	27.2±0.7	27.4±0.7	15.9±0.8	15.0±0.9	107±3	111±3	74±4	70±4
	4	30	30	14.3±0.4	14.2±0.4	27.4±0.6	27.9±0.6	14.3±0.6	14.4±0.6	107±3	110±3	67±3	67±4
	5	6	12	13.8±1.0	13.6±0.7	27.0±2.1	26.5±1.0	13.2±1.4	12.2±1.0	106±7	105±5	64±6	61±6
1972	3	0	0	--	--	--	--	--	--	--	--	--	--
	4	10	19	14.5±1.2	14.1±0.4	27.2±1.5	26.7±0.9	12.2±1.6	11.7±1.6	109±5	107±3	57±5	60±5
	5	0	0	--	--	--	--	--	--	--	--	--	--
1973	3	4	2	--	--	--	--	--	--	--	--	--	--
	4	29	31	14.2±0.6	14.4±0.5	27.2±0.9	27.2±1.1	13.2±0.8	13.4±0.9	107±3	106±3	62±4	62±4
	5	0	0	--	--	--	--	--	--	--	--	--	--
1974	3	0	0	--	--	--	--	--	--	--	--	--	--
	4	29	30	13.9±0.5	14.0±0.5	27.2±0.8	27.0±0.6	16.8±0.9	15.3±1.0	102±3	104±2	72±3	67±4
	5	--	--	--	--	--	--	--	--	--	--	--	--

Appendix table 6. Mean number of circuli (C_a, C_1, C_2) and mean distances (L_1, L_2) on the scales of chum salmon from the same brood at Olsen Creek that matured at 3, 4, and 5 years. Counts and measurements for each sex were combined. Distances are in mm x 80. Confidence intervals are at 95%. See METHODS for definition of scale characters.

Brood year	Year of Return	Age	Samples	C_a (circuli)	C_1 (circuli)	C_2 (circuli)	L_1 (distance)	L_2 (distance)
1956	1959	3	59	16.3±0.3	31.1±0.5	14.5±0.6	113±3	68±3
	1960	4	61	16.3±0.4	31.1±0.5	12.2±0.5	116±2	59±3
	1961	5	56	16.5±0.5	30.8±0.6	12.5±0.6	113±3	57±2
1957	1960	3	0	--	--	--	--	--
	1961	4	60	14.6±0.4	28.3±0.5	14.4±0.5	107±2	60±2
	1962	5	15	15.4±1.2	28.2±1.1	13.5±1.2	105±6	60±4
1958	1961	3	61	14.5±0.3	28.5±0.4	15.1±0.6	110±3	71±2
	1962	4	60	14.4±0.4	28.0±0.6	13.6±0.8	107±3	64±3
	1963	5	27	15.3±0.6	28.6±0.8	13.6±0.9	101±4	62±4
1959	1962	3	60	15.1±0.4	30.1±0.6	17.5±0.7	114±2	80±2
	1963	4	60	15.0±0.4	29.1±0.5	14.8±0.6	110±3	71±3
	1964	5	60	15.8±0.4	30.0±0.5	14.3±0.6	105±2	61±2
1960	1963	3	27	15.8±0.5	29.9±0.7	15.4±0.8	113±3	72±3
	1964	4	61	16.0±0.5	30.5±0.6	15.2±0.8	110±2	66±2
	1965	5	0	--	--	--	--	--
1961	1964	3	8	14.1±1.2	28.3±1.5	15.1±1.5	106±6	62±4
	1965	4	0	--	--	--	--	--
	1966	5	6	14.8±1.9	27.3±1.3	13.7±0.9	99±10	60±5

Appendix table 6. Continued.

Brood year	Year of Return	Age	Samples	C_a (circuli)	C_1 (circuli)	C_2 (circuli)	L_1 (distance)	L_2 (distance)
1962	1965	3	0	--	--	--	--	--
	1966	4	60	15.2±0.4	29.1±0.5	13.5±0.6	107±2	59±2
	1967	5	49	14.9±0.4	29.2±0.5	12.4±0.5	107±3	54±2
1963	1966	3	33	13.6±0.6	27.6±0.8	15.5±0.8	104±4	72±4
	1967	4	60	14.2±0.3	27.5±0.4	14.0±0.5	107±2	67±2
	1968	5	62	13.6±0.3	26.8±0.5	12.7±0.3	102±2	62±2
1964	1967	3	11	15.1±0.6	28.9±0.8	14.9±1.3	106±5	73±5
	1968	4	60	14.4±0.3	28.9±0.4	13.3±0.5	106±2	66±2
	1969	5	60	14.6±0.4	28.2±0.5	12.0±0.4	100±2	56±2
1965	1968	3	60	14.8±0.3	28.6±0.5	14.7±0.5	111±2	68±3
	1969	4	60	13.5±0.3	26.5±0.4	13.8±0.6	103±2	61±2
	1970	5	18	14.2±0.6	27.7±1.0	12.4±1.0	109±5	57±3
1966	1969	3	49	15.4±0.4	29.1±0.5	14.0±0.5	109±2	61±2
	1970	4	59	15.4±0.3	28.7±0.5	12.6±0.4	111±2	57±2
	1971	5	59	14.8±0.3	28.4±0.4	11.3±0.4	111±2	52±2
1967	1970	3	19	14.4±1.0	29.2±1.6	14.9±1.2	114±5	66±4
	1971	4	61	15.0±0.4	29.8±0.6	13.3±0.6	112±2	59±2
	1972	5	60	14.9±0.4	29.0±0.4	12.1±0.5	108±2	51±1
	1973	6	10	15.0±1.0	29.3±1.4	12.0±1.6	104±4	50±6
1968	1971	3	0	--	--	--	--	--
	1972	4	59	15.6±0.3	29.6±0.5	12.9±0.5	110±2	61±2
	1973	5	60	16.0±0.3	29.7±0.5	12.2±0.4	107±2	57±2
	1974	6	9	16.3±1.4	29.4±1.4	10.6±1.2	102±6	50±5

Appendix table 6. Continued.

Brood year	Year of Return	Age	Samples	C_a (circuli)	C_1 (circuli)	C_2 (circuli)	L_1 (distance)	L_2 (distance)
1969	1972	3	5	14.6±1.4	28.4±1.9	13.0±2.3	111±17	65±17
	1973	4	60	13.0±0.3	25.9±0.4	13.5±0.5	106±2	66±3
	1974	5	60	13.5±0.5	26.4±0.6	12.2±0.5	104±2	60±2
1970	1973	3	6	14.2±1.0	26.8±1.5	15.8±2.5	99±5	69±8
	1974	4	56	13.8±0.3	26.2±0.4	14.4±0.6	103±2	67±2
	1975	5	0	--	--	--	--	--
1971	1974	3	55	14.1±0.4	27.3±0.5	15.5±0.6	109±2	72±3
	1975	4	60	14.3±0.3	27.7±0.4	14.3±0.4	109±2	67±2
	1976	5	18	13.7±0.5	26.7±0.8	12.6±0.8	105±4	62±4
1972	1975	3	0	--	--	--	--	--
	1976	4	29	14.2±0.5	26.9±0.7	12.3±0.6	108±3	59±3
	1977	5	0	--	--	--	--	--
1973	1976	3	6	13.3±0.5	26.8±1.5	14.8±1.0	110±9	71±5
	1977	4	59	14.1±0.4	27.1±0.5	14.3±0.7	105±2	64±3
	1978	5	0	--	--	--	--	--
1974	1977	3	0	--	--	--	--	--
	1978	4	59	14.0±0.3	27.1±0.5	16.0±0.7	103±2	69±2
	1979	5	--	--	--	--	--	--
1975	1978	3	21	13.4±0.7	27.2±0.9	15.9±1.2	110±5	68±5
	1979	4	--	--	--	--	--	--
	1980	5	--	--	--	--	--	--