EARLY LIFE HISTORY
OF WILLAMETTE RIVER SPRING CHINOOK SALMON

Chester R. Mattson

FISH COMMISSION OF OREGON

Portland, Oregon

January 1962

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Early Life History of Willamette River Spring Chinook Salmon

Chester R. Mattson 1/

ABSTRACT

The early fresh-water phases of the life cycle of spring chinook salmon (Oncorhynchus tshawytscha) of the Willamette River system were investigated during the period 1947-51. Under normal conditions the adults spawn between August 29 and October 15; however, abnormal conditions, introduced by recently constructed large dams, have caused a delay in spawning below such structures that extends into November. Egg incubation periods have ranged from 58 to 150 days, but the normal has been 65 to 80 days. Fry normally emerge from the gravel in February and March unless extreme temperatures cause earlier or later emergence.

Below normal temperatures appeared to lengthen the period of incubation, causing a later fry emergence and restricted rate of growth. Fresh-water residency of young ranged from 3 to 18 months following spawning.

Three distinct periods of fingerling seaward migration were observed: (1) a late winter-spring movement; (2) a late fall-early winter movement; and (3) a second-spring migration. The lengths of migrants ranged from 33 to 140 mm. The earlier migrants were invariably larger in size than those still resident within their parent streams, thus indicating that size may be a factor influencing seaward movement.

Scales, which appeared between fork lengths of 37 and 41 mm., formed first immediately above and below the lateral line, and later ones formed progressively outward from this line. The formation of an annulus, which normally was found between the 10th and 20th circuli, may occur at any time between October and March. Definite relationships were found between fork lengths and number of circuli and length of anterior radius of the scale. Downstream migrant fingerlings invariably possessed more circuli and had faster rates of growth than fish remaining in their parent streams.

The number of circuli formed on active seaward migrants was 0 to 29, depending upon their size at time of movement. Some migrants exhibited accelerated scale growth, comparable to brackish or marine growth found on adult scales; this has been termed "superior fresh-water growth". Comparisons were made of migrant and adult scale growth patterns to show similarities, which were striking in many cases.

1/ Formerly a biologist with the Oregon Fish Commission; now with the U. S. Bureau of Commercial Fisheries, Juneau, Alaska.

INTRODUCTION

Several studies of the life history of spring chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia and Willamette River systems have been conducted, notably by Rich (1920), Rich and Holmes (1929), and Craig and Townsend (1946).

Natural salmon spawning and rearing areas in the Willamette River basin are being rapidly reduced by construction of multiple-purpose dams on the major tributaries. As a result, the survival of spring chinook stocks in this basin will depend more and more upon artificial propagation. It is believed that some of the knowledge gained in the present study can be applied to improvements in fish cultural practices, particularly in regard to length of rearing and time of liberation.

During the 5-year study, various aspects of the fresh-water life of immature salmon were investigated: egg deposition, length of incubation period, time of emergence from the gravel, length of residence in parent stream, time of seaward migration, and abundance and size of migrants. Scale studies of immature salmon involved the age and size of fish at formation of the scale platelet; size of fish in relation to number of circuli; increase in number of circuli during fresh-water residence; formation of winter check on scales; scale formation in various types of stream growth; and the results of a method of growth interpretation by graphing the distances between scale circuli.

METHODS OF COLLECTING AND ANALYZING DATA

Basic information was sought concerning young salmon, both as residents in the parent river system and as seaward migrants. Two sampling stations were established: on a spawning tributary to obtain resident data and on the lower main stem of the Willamette River to obtain active migrant data. The station for residents was located on the Molalla River, a minor salmon-producing tributary of the Willamette, designated as "upper Molalla station" about 2 miles below the mouth of the North Fork (Figure 1). Although fish from this station were considered primarily "resident" stocks, some fish were migrating at time of capture. The second station was on the lower main Willamette just above Oswego, Oregon, and designated as the "Oswego station." Since this station is below all spawning tributaries utilized, the salmon obtained here were regarded as migrants en route to the ocean. However, some of the fish undoubtedly were residents in the vicinity for short periods of time.

The sampling program began February 7, 1947 and ended July 6, 1951. All specimens were collected by means of a 1/4-inch mesh, 70-foot beach seine and preserved in 10 per cent formalin.

Collecting of scale samples from individual young salmon was localized between imaginary perpendicular lines drawn from the anterior and posterior insertions of the dorsal fin to the lateral line, and confined to the first two rows above the lateral line, preferably under the anterior insertion of the dorsal fin.

In the following discussion, downstream migrants less than 1 year of age from the time of spawning are called fingerling or "0-plus" migrants, while those over 1 year are termed yearling or "1-plus" migrants. October 1 was selected as the division point between fish less than 1 year of age and those over 1, since by this date most spring chinook spawning is complete. Thus, the basis for determining age was the time of egg deposition rather than hatching.

A method of measuring distances between circuli and presenting the data in graphic form was first devised from adult salmon scales, but later juvenile salmon scales were also used. The basic requirement of the graphic method is a projected enlargement of a scale image to about 100 times, so that distances

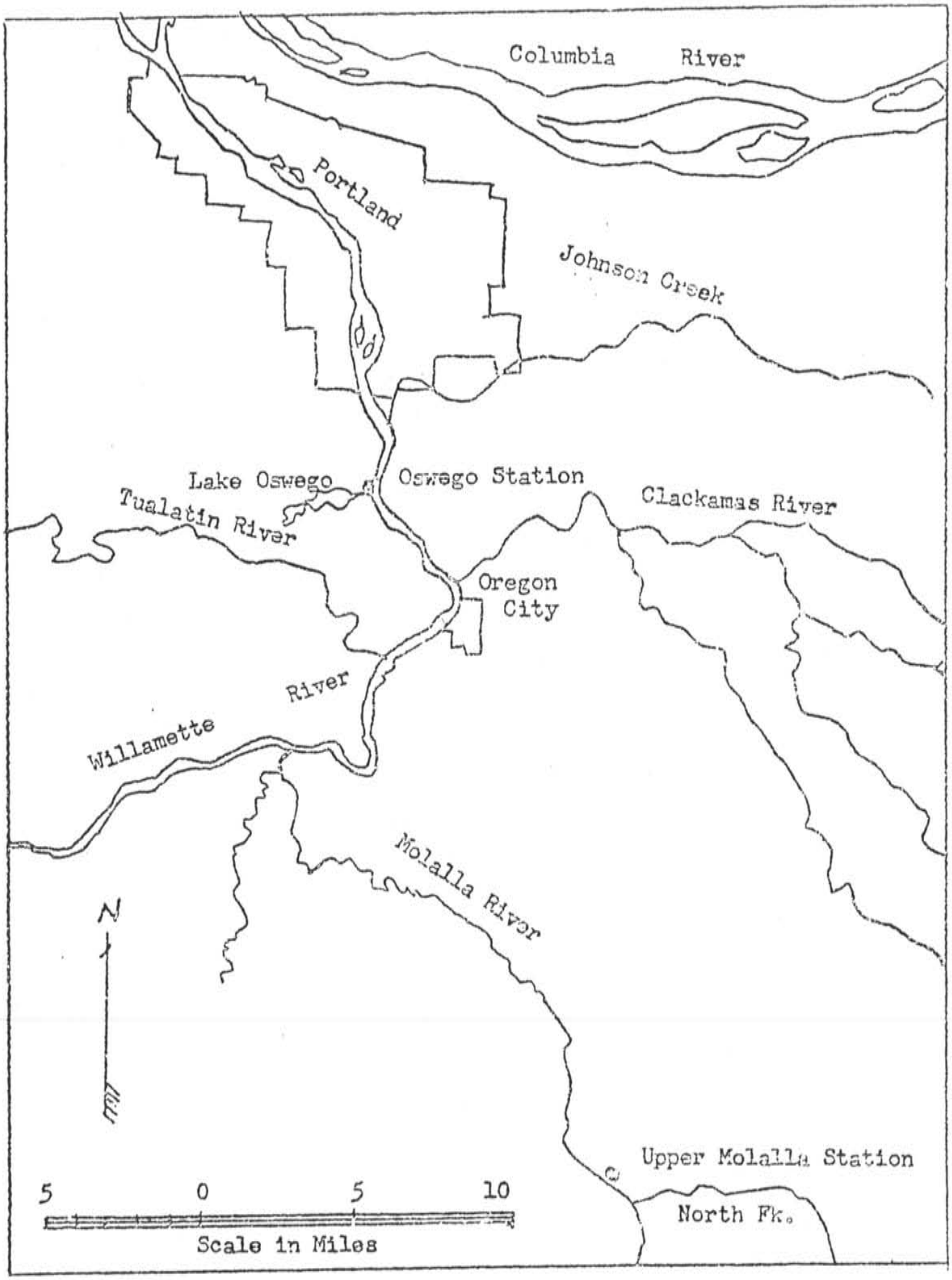


Figure 1. Map of Lower Willamette River Showing Sampling Stations.

between the circuli can be accurately measured. A suitable projection machine was found in the Rayoscope, mounted on a wall bracket in a darkroom, with the scale image projected onto the middle of a table. A magnification of 108 diameters was obtained with a Bausch and Lomb bifocus objective with a 16 mm.-0.25 N a-10 X lens. A standardized procedure for obtaining measurements from specific sections of the scale image was devised by means of a special scale mask consisting of a white piece of cardboard about 2 feet square with guide lines marked in black ink (Figure 2). The mask was placed on the table top under the projector and the scale image was then focused on its surface.

The true anterior radius of many scales was unsatisfactory for accurate measurement because the circuli, especially those comprising the annuli, were irregular, deformed, or broken where the anterior radius crossed. Therefore, it was desirable to choose a more satisfactory radial line to replace the true anterior radius. In order to determine a suitable radius, a group of 50 adult scales was selected at random. The limits of broken circuli areas in the anterior quadrant of the scales were pin-pointed on a sheet of paper with the center of the scale image focused upon the intersection of lateral and anterior radial lines. Certain angles from the true anterior radius were formed by lines drawn through these points, and the percentage of points within the angles was computed. It was found that within the arc covered by 40 degrees to either side of the true anterior radius, nearly all the scale samples could be utilized and the radial lines would also include a maximal number of circuli. The true lateral radi would produce minimal numbers of circuli. At the same time, two lines were drawn in the posterior lateral fields where the posterior portion of the scale is exposed externally and individual circuli are not discernible. Angles of 19 degrees toward the posterior field of the scale from the true lateral radii were found most suitable for fitting the mask to the image. In most cases,

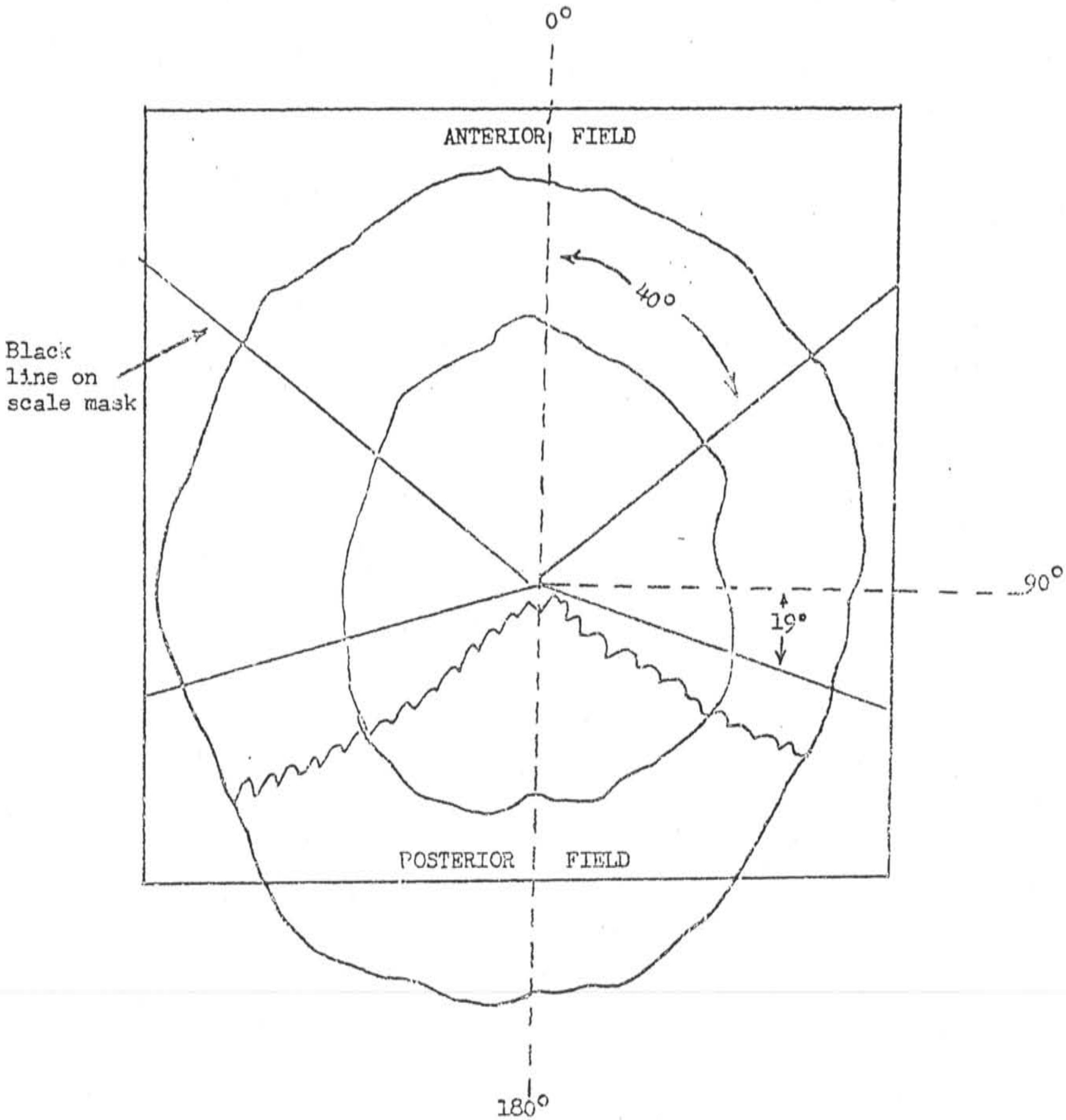


Figure 2. Scale Mask Showing a Projected Scale Image and Arrangement of Scale Measurement Lines.

there are definite lines where the circuli became indistinct on the posterior field of the scale, so it is rather simple to fit the lateral mask lines to the image by eye. References to anterior radii pertain to those selected at an angle of 40 degrees from the true anterior radius. In order to avoid confusion, each will be called a "selected anterior radius." In general, the longer of the two selected anterior radii on a scale image was selected for use unless it passed through an area of broken or disfigured circuli, in which case the other line was used.

After the mask had been fitted to the scale image and the selected anterior radius chosen, a strip of transparent celluloid tape, 0.01 inch thick, 0.5 inch wide, and 18 inches long, was laid over the black guide line so that one end was fitted to the inner edge of the first circulus (also the outer edge of the scale platelet) and the other extended beyond the periphery of the scale image. Then the inner edge of every circulus, where it crossed the black line of the selected anterior radius, was lightly marked on the tape with a sharp scalpel, thus including the thickness of one circulus and interspace. A binocular dissecting microscope was used to obtain measurements from the tape. The distances between circuli were read to the nearest 0.25 mm. with a rule that had 0.5 mm. intervals. Pertinent data on each specimen were also printed on the tape by means of the scalpel point.

The graph resulting from plotting the data obtained represented the distances between circuli, and a picture of the differences in growth rate of each specimen was obtained. In the following discussions, all references to distances between circuli are at a magnification of 108 X.

SPAWNING AND INCUBATION

Time of Spawning

The spawning period of spring chinook in the Willamette River system generally ranges from August 25 through October 15, although at the higher elevations it is completed as early as September 15. Spawning operations at the various hatchery egg-collection sites are normally conducted during September, with a peak between September 10 and 25. The latest date on which spawning has been observed under natural conditions was October 22 on the lower McKenzie River. October 1 has been selected as the date for egg deposition for computing the age of fish.

During recent years, abnormally late spawning has occurred on the North Santiam and Middle Willamette Rivers, where newly constructed dams have prevented the fish from reaching natural spawning grounds. The bulk of the salmon in these two rivers are now taken for hatchery propagation. During the fall of 1952, spring chinook were spawned at an egg-collection site below Detroit Dam on the North Santiam River until November 10 and stragglers were reported until Thanksgiving. In 1953, salmon from the Middle Willamette, below Dexter Dam were spawned from October 1 through November 10.

Length of Incubation Period

The most important factor controlling length of incubation is water temperature. During years of abnormally warm fall weather, the period is reduced, and conversely, with early onset of cold weather and resultant cooler water, incubation time is considerably lengthened. In an experiment conducted in 1948-49 on the North Santiam River (McKee, 1950) incubation began September 24 and 29 and hatching occurred from January 15 to February 28, a range of 113 to 151 days. More normal incubation was observed at the McKenzie River Hatchery where, over a 30-year period, it has ranged from 58 to 105 days. The usual period is 65 to 80 days.

Time of Emergence from Gravel

The exact time of emergence of young spring chinook has not been conclusively established. The earliest date a 0-age-group fish was taken in a seine haul at Oswego station was January 16, 1949 (Table 1). This alevin, 33 mm. long, had less than half its yolk sac absorbed. Since heavy rains and slight flood conditions prevailed in Willamette tributaries prior to capture, it is possible that the young chinook had been uncovered prematurely and swept downstream. The earliest capture of young chinook at upper Molalla station was on March 14, 1950 when several fingerlings between 37 and 38 mm. long were taken.

The first appearance of wild fish in the experiment on the North Santiam River was on June 5, 1949 (McKee, 1950). They had been spawned a short distance above the station and, it is assumed, had recently emerged from the stream bed. It is quite probable that some fish will not emerge from the redds until late spring.

RESIDENCE AND MIGRATION

Length of Residence in Parent Stream

Upper Molalla station was utilized to determine the length of residence of young spring chinook in the parent stream. Figure 3 shows the average number of salmon caught per seine haul at this station for 3 years. Since data were meager for the 1947 year class, there is little merit in discussing this group. However, the 1948 and 1949 year classes were represented by greater numbers. In both cases fingerling salmon were most abundant during May. The rapid decline in numbers caught in June was possibly because: (1) the young fish apparently had begun a downstream migration, and (2) natural mortality may have reduced the abundance of small fingerlings. It was not possible to determine the relative effects of these two factors.

Table 1. Time of First Appearance and Size of Spring Chinook Fingerling Caught at Oswego and Upper Molalla Sampling Stations, 1948-51.

Oswego Station				Upper Molalla Station			
Date Caught	Number Specimens	Length (mm.) Average	Length (mm.) Range	Date Caught	Number Specimens	Length (mm.) Average	Length (mm.) Range
March 1, 1948	3	39.7	38-41	-	-	-	-
January 16, 1949	1	33.0	33	April 5, 1949	4	41.5	37-48
February 7, 1950	1	38.0	38	March 14, 1950	7	37.7	37-38
March 3, 1951	2	50.5	46-56	April 17, 1951	9	38.0	36-39

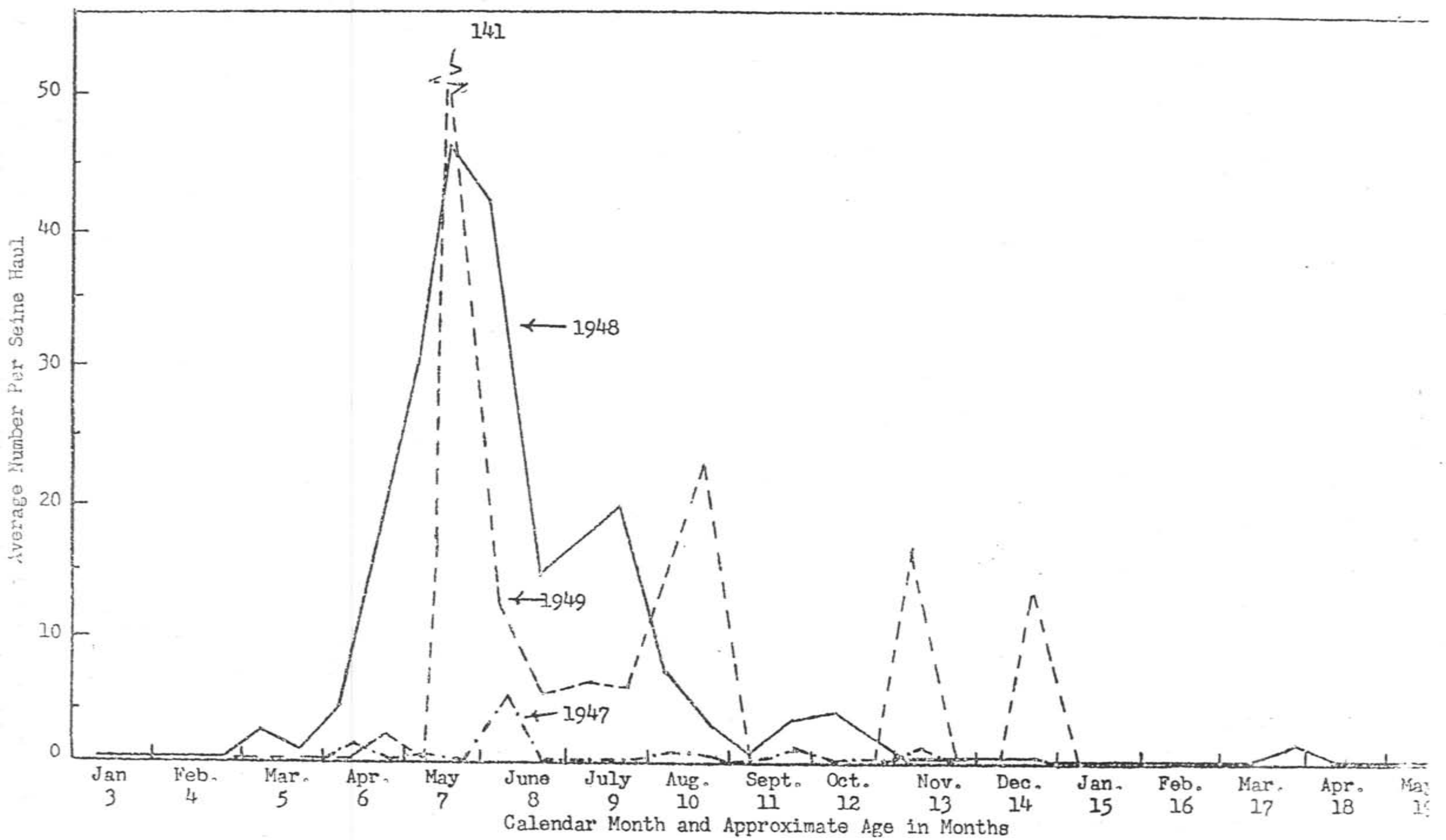


Figure 3. Average Numbers of Spring Chinook Salmon Caught Per Seine Haul at the Upper Molalla Seining Station, 1947-49 Year Classes.

Young salmon of both the 1948 and 1949 year classes were observed at the upper Molalla station during the fall and early winter. Limited observations indicated a downstream movement of spring chinook yearlings during October and November in other Willamette tributaries, especially during high stream flows.

At upper Molalla station, yearling salmon of the 1948 year class were taken as late as mid-March of 1950. Thus, some spring chinook remain in the parent stream for at least 17 months subsequent to egg deposition.

Time of Seaward Migration

Although juvenile spring chinook salmon may be found every month of the year at the Oswego station on the lower Willamette River, where the bulk of the fish are presumably migratory rather than resident, there appears to be three periods of heaviest migration (Figure 4 and Table 2). It is readily evident from the data presented that the migration patterns vary in magnitude and timing with different year classes. Many factors influence the migration of young fish, including major factors like water temperatures and flows, availability of food, rate of growth, and crowding. As these factors vary from year to year they will affect the migration timing of juvenile salmon.

The first distinct migration period occurs during the first spring and summer after the young have emerged from the spawning gravels and are from 8 to 10 months in age. Although fry have been observed as early as January, the migration peaks have ranged from April 17 for the 1949 year class to as late as August 17 for the 1947 year class. Sampling operations were briefly interrupted by flood conditions during the spring migrations of the 1947 and 1949 year classes, and the peak migrations may have been missed. However, seining results prior to and after these interruptions failed to produce large numbers of migrants, thus indicating a small fingerling migration during this period for these years.

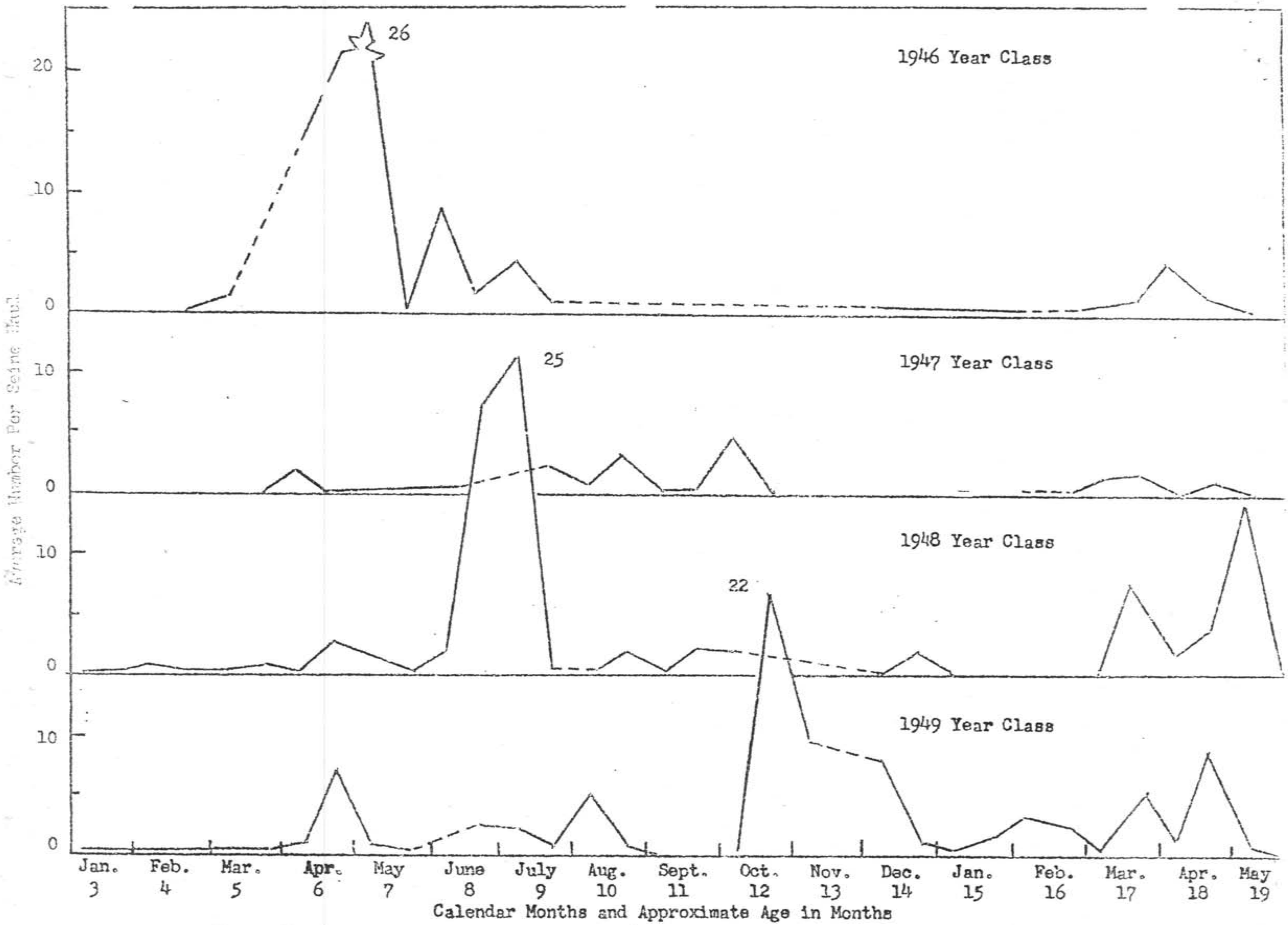


Figure 4. Average Numbers of Spring Chinook Salmon Caught Per Seine Haul at Oswego Station, 1946-49 Year Classes. (Dotted line indicates periods of no sampling)

Table 2. Seasonal Migration Periods of Spring Chinook Salmon in Lower Willamette River at Oswego, 1946-49 Year Classes.

Timing and Catch	Year Class			
	1946	1947	1948	1949
1st Spring Migration				
Period of Migration	March-July	January-August	February-August	April-August
Date of Peak Catch	May 13, 1947	August 17, 1948	July 6, 1949	April 17, 1950
Average Number of Salmon Per Seine Haul during Peak Catch	26.0	3.0	25.0	7.0
Total Catch for Period	181	24	115	51
Per Cent of Complete Sample of Year Class	91.0	49.0	55.3	18.8
1st Fall Migration				
Period of Migration	No Sampling	October	September-Dec.	Oct.-December
Date of Peak Catch		October 15, 1948	October 10, 1949	Oct. 20, 1950
Average Number of Salmon Per Seine Haul during Peak Catch		4.6	8.0	22.0
Total Catch for Period		15	25	132
Per Cent of Complete Sample of Year Class		30.5	12.0	48.7
2nd Spring Migration				
Period of Migration	March-April	March-April	March-May	January-May
Date of Peak Catch	April 5, 1948	March 28, 1949	May 5, 1950	April 30, 1951
Average Number of Salmon Per Seine Haul during Peak Catch	4.0	1.6	14.5	9.0
Total Catch for Period	18	10	68	88
Per Cent of Complete Sample of Year Class	9.0	20.5	32.7	32.5

During the late summer months young salmon were found to be very scarce and migration was reduced or even eliminated by severe pollution in the Oswego area. 1/ Prior to the occurrence of an annual pollution barrier, the young salmon may have continued migrating throughout the entire summer.

The second period of migration occurs during the fall and winter months after the fish have reached a year or more in age. The fall movements have generally been of lesser magnitudes than those of the first spring and summer, although the 1949 year class migrated in greatest numbers during this period. Generally this period of movement is occasioned by the heavy fall rains that sharply increase stream flows and reduce temperatures. The peak movements occurred during the month of October for the 3 years when sampling was conducted. With the approach of winter with colder temperatures and freezing conditions, migratory movements are definitely curtailed.

The third and final migration of spring chinook salmon has been found to occur in the spring of their second year, between January and May, when the fish are between 15 and 19 months of age. The magnitude of the final migration has always been a third or less of an entire year class. The migration peaks were found to range from March 28 (1947 year class) to May 5 (1948 year class).

Length data on 4 year classes of downstream migrant spring chinook were obtained at the Oswego station. Since the collections could contain fish from 8 river systems, differences in size of fish would be expected. The collections were grouped into 2-week intervals, and the points represented mean fork lengths of the catches plotted in Figure 5. Each year class has been traced from the time of the first appearance of the 0-age group until the last yearlings disappeared.

1/ Since 1954 pollution has been reduced, but it is not known what effect, if any, this has had on downstream migration.

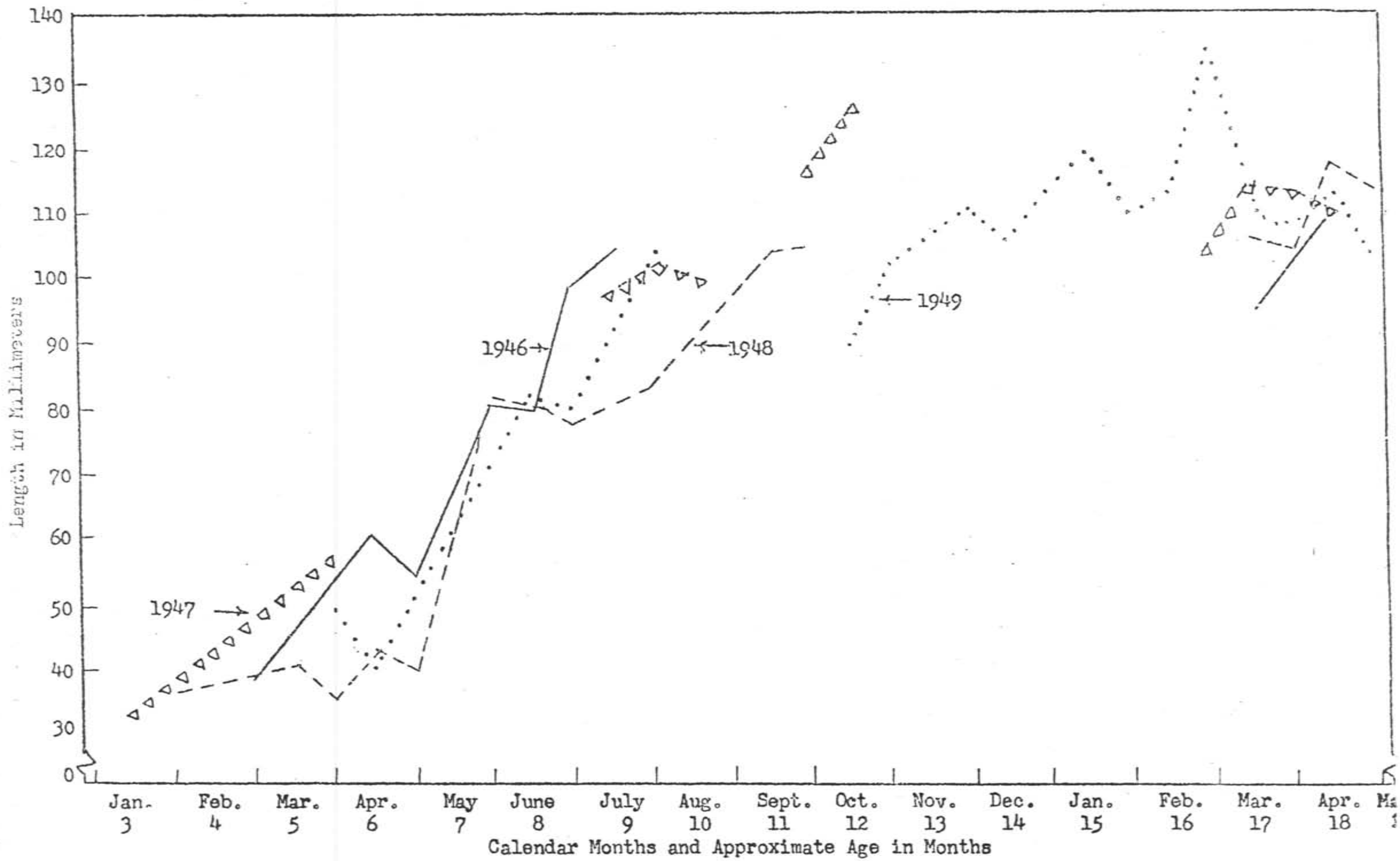


Figure 5. Average Fork Lengths of Spring Chinook Salmon Caught at Oswego Station by Two-Week Intervals, 1946-49 Year Classes.

Normally during March the first migrants were taken, although the 1947 year class appeared in January. The fish averaged between 35 and 40 mm. in fork length between January and March. Growth during the spring and early summer months generally was very rapid and by the end of July the migrants averaged approximately 100 mm. Migrants of the 1948 and 1949 year classes were found to average smaller during the months of March, April, and May than fish of the 1946 and 1947 classes. The differences were believed to result from the rather severe winters that delayed the growth and development of the young fish of these year classes.

The average size of the migrants increases very little after mid-summer and they range from 100 to 130 mm. during the remainder of the time they are present in the river. The largest yearling migrant taken in the Willamette River was 140 mm. in length when captured in May 1950.

Table 3 contains water temperatures taken at the two points of sampling as well as the average sizes of the fish. Note that during May, June, and July, a period of rapid growth for the Oswego migrants in contrast to slower growth at Molalla, the water temperatures in the lower Willamette River were considerably above those on the Molalla River. Another interesting point is apparent lack of growth for Molalla fish of the 1948 year class during the months of March, April, May, and early June, when the average lengths fluctuated rather than increasing gradually as would be normal. This was believed due to the larger fish migrating downstream as they increased in size and being replaced by small fry from spawning areas above the station.

Comparison of Migrant and Resident Populations

Some authorities believe that the larger spring chinook tend to move out of a river system earlier than the smaller; the tendency to migrate is at least partly a function of size (Rich, 1920). If this assumption were true

Table 3. Water Temperatures and Average Lengths of Spring Chinook Downstream Migrants at Oswego and Upper Molalla Stations, 1948-49 Year Classes.

1948 YEAR CLASS						
	Oswego			Upper Molalla		
Date	Temperature (°F.)	Average Length (Mm.)	Number of Fish	Temperature (°F.)	Average Length (Mm.)	Number of Fish
1949						
Feb. 7	36	38.0	1	34	--	0
March 14	45	--	0	42	37.7	7
28	45	43.5	7	42	40.0	3
April 11	52	37.0	1	46	38.4	13
28	52	43.9	9	47	39.5	20
May 11	56	41.3	3	45	41.0	55
23	57	---	0	49	38.6	92
June 8	63	82.3	2	46	40.6	84
20	64	81.4	44	57	48.4	34
July 6	67	79.5	55	59	55.0	1
15	73	--	0	63	67.7	39
Aug. 1	71	--	0	72	73.2	23
16	70	84.8	4	66	76.4	8
Sept. 26	62	104.5	4	57	92.6	8
Oct. 10	54	106.0	17	50	93.9	9
1949 YEAR CLASS						
	Oswego			Upper Molalla		
1950						
April 3	48	50.5	4	44	--	0
17	48	41.0	36	44	38.0	9
May 5	42	--	0	40	--	0
22	58	--	0	46	45.3	142
June 5	64	--	0	49	47.4	24
19	63	--	0	50	49.9	11
26	61	83.8	6	--	--	0
July 5	66	81.3	6	60	55.0	13
18	68	--	0	61	61.9	19
Aug. 2	69	104.5	15	63	--	0
19	74	97.0	1	65	84.7	45
Sept. 6	69	--	0	59	---	0

one would expect fingerling and yearling fish in the parent stream to be smaller in size, on the average, at any given time of year than those en route to the ocean. Such a comparison was made of salmon taken at upper Molalla and Oswego stations (Figure 6).

In late winter and early spring there was little difference between average lengths of fingerlings from the two stations. Beginning in May, however, Oswego fingerlings were decidedly larger. This differential was evident through the following year, and perhaps can be interpreted as the result of both accelerated growth and an early migration of the larger fish.

Table 3 shows the average size of the 1948 and 1949 year classes of Molalla salmon sampled during their fresh-water residency. The 1948 year class first appeared in March as fingerlings approximately 38 mm. in length; 12 weeks later, their average size was still barely 40 mm. Either these fish grew very slowly or there was a migration of the larger salmon downstream and an influx of small, newly emerged fry from areas above the sampling station. It is believed that the latter was the major contributing factor to this phenomenon.

Comparisons were also made of young salmon taken at Oswego and those reared at Willamette system hatcheries. Figure 7 shows average lengths for fish collected in the summer of 1947 from the 1946 year class at the Oswego station and the McKenzie and Willamette Hatcheries. There is great variation in size among Oswego migrants and the other salmon. In the first spring the 0-plus migrants were much larger than the hatchery fish from tributary rivers. This graph lends support to the theory that larger fish migrate to the ocean sooner than smaller fish. In mid-July the wild fish at Oswego averaged slightly under 110 mm., while McKenzie Hatchery salmon several months later were only 77 mm. and Willamette Hatchery fish 90 mm.

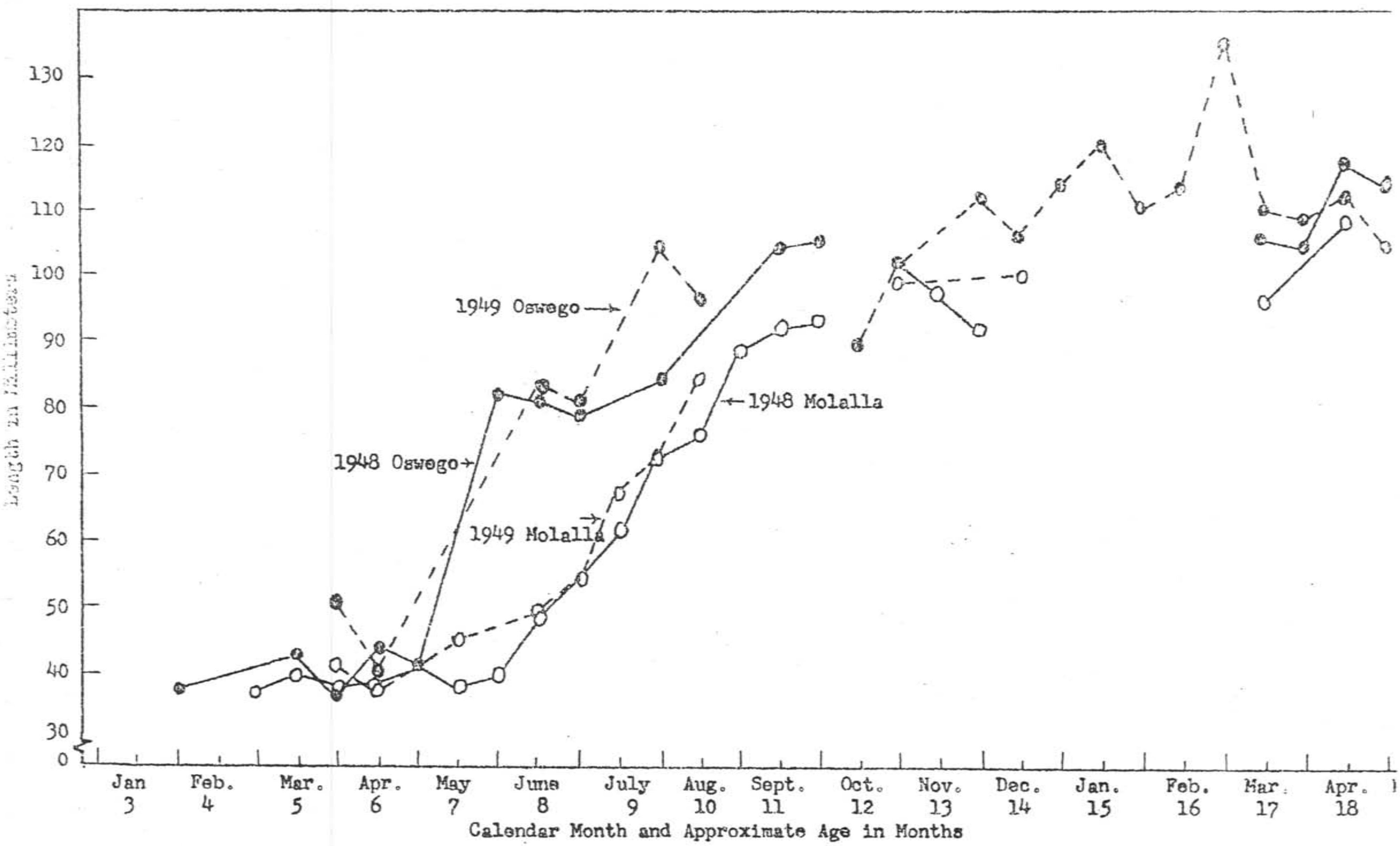


Figure 6. Comparison of the Average Fork Lengths of Young Spring Chinook Salmon Caught at the Oswego and Upper Molalla Seining Stations, 1948-49 Year Classes.

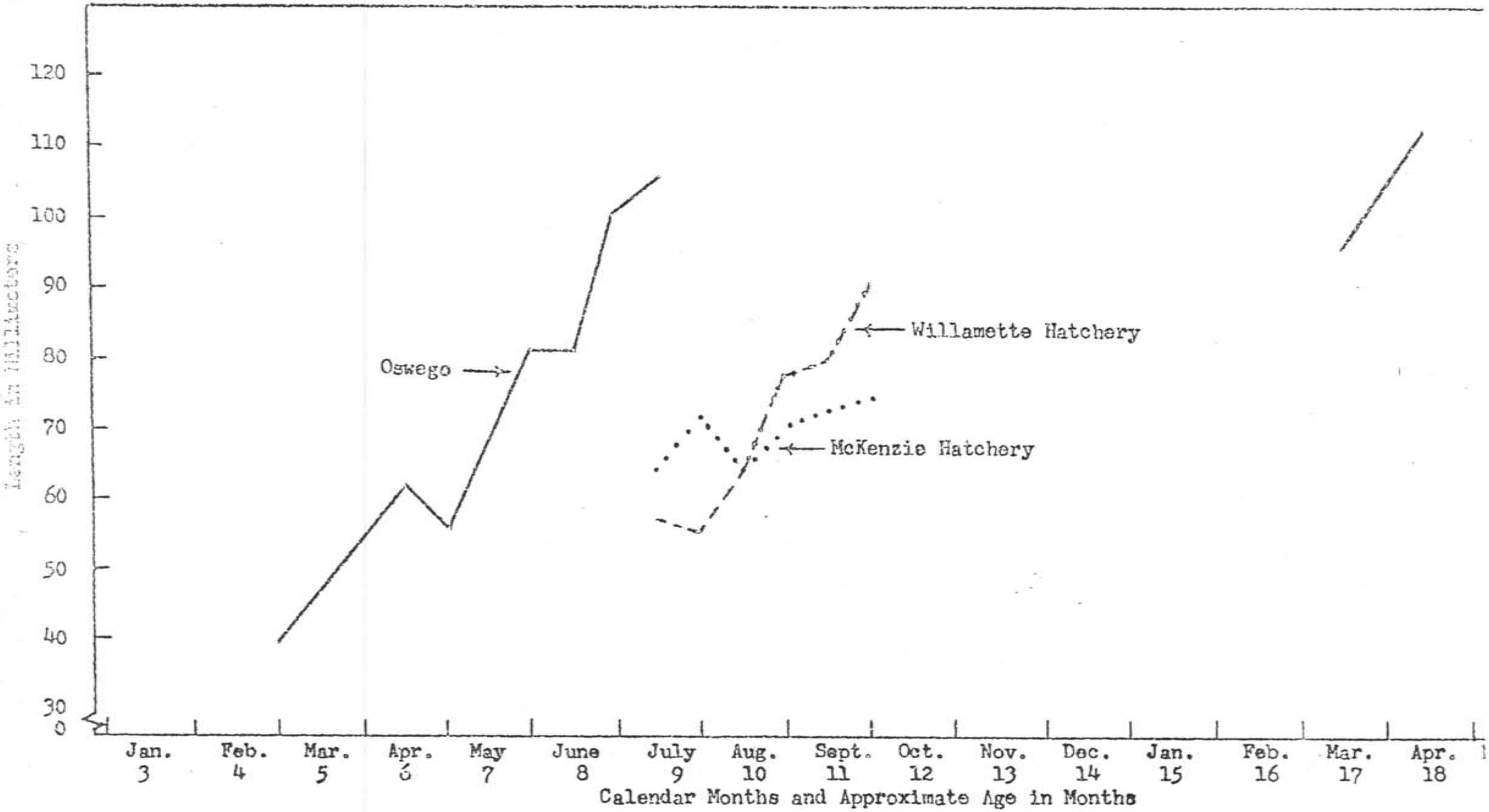


Figure 7. Fork Lengths of Wild Fish From Oswego Station and of Hatchery Fish From the McKenzie and Middle Willamette Rivers.

Data gathered in the Willamette River system strongly suggest that a differential migration of large fish occurs among young spring chinook. At any given time after the advent of warm spring weather, fish in the lower Willamette can be expected to average larger than those remaining behind in the parent river systems or fish being reared in hatchery ponds.

GROWTH PATTERNS AND RELATIONSHIPS

Observations on Circuli Formation

Platelets from which the scales ultimately develop have been observed to form first on the scale rows immediately above and below the lateral line, with succeeding rows following. This phenomenon was noted and photographed by Rich (1920).

At first in the present study, scales were removed from the side of a fish in an area between the lateral line and dorsal fin, without reference to specific scale rows. This method was changed in 1950, when over 100 fish were examined to determine growth patterns of scales from various parts of the body. Figure 8 shows a typical example showing the greatest circuli count near the lateral line. Thereafter, scale samples were restricted to the first or second row above the lateral line beneath the origin of the dorsal fin.

Formation of the first scale platelets was observed when the young fish averaged 37 to 41 mm. in length. Some formation of the platelet had occurred on more than half of the salmon with a length of 39 mm. Only a few fish were found without any formation at 42 mm.

Relationship Between Number of Circuli and Fork Length

The relationship between number of circuli and fork length was determined from 445 Oswego and 320 Molalla fish from the 1946 through 1949 year classes. Figure 9 shows mean fork lengths for various numbers of circuli in both groups.

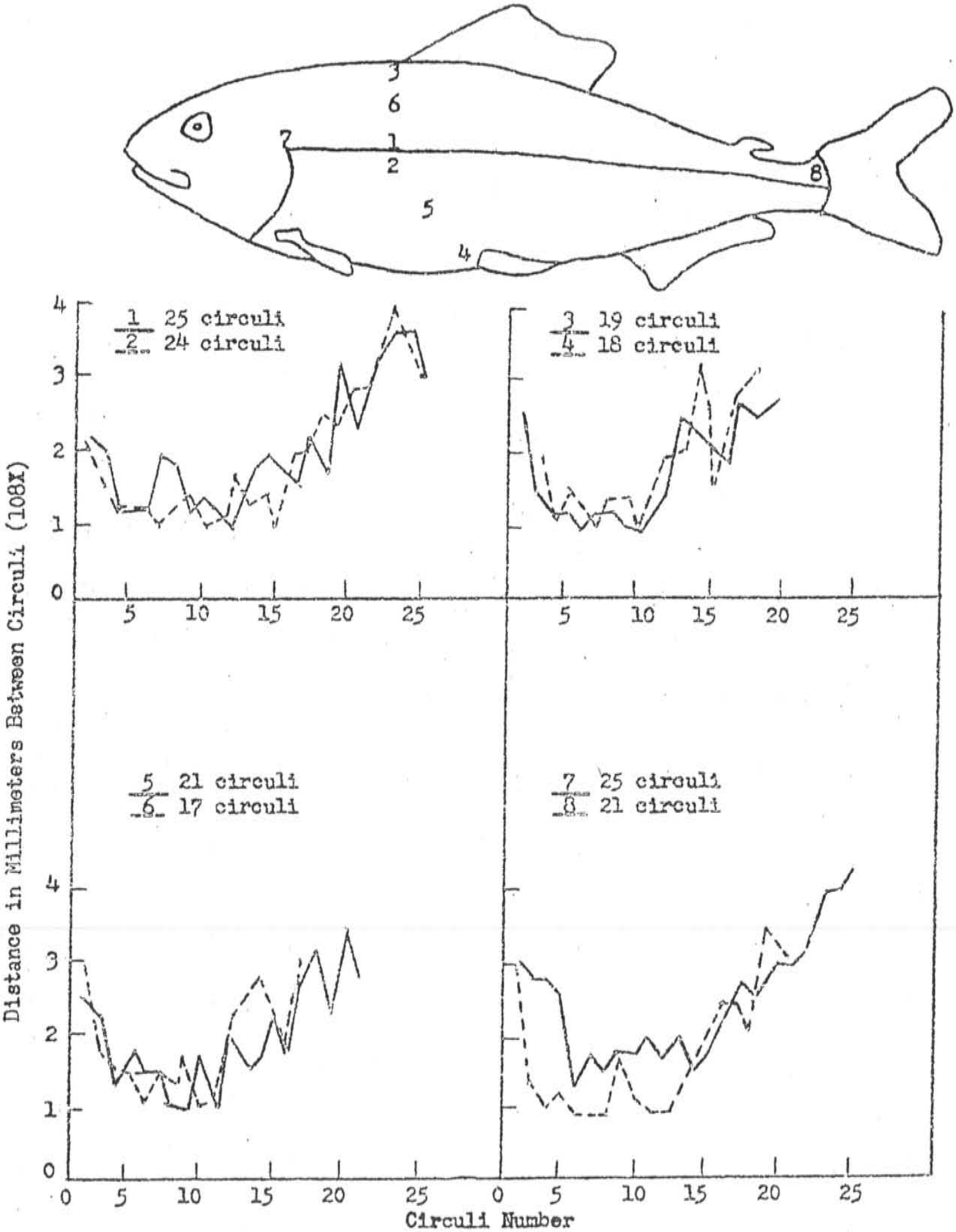


Figure 8. Variations in Numbers of Circuli on Scales from Different Parts of the Body of a Spring Chinook Salmon 125 mm. in Length Taken at Oregon Station in May 1950.

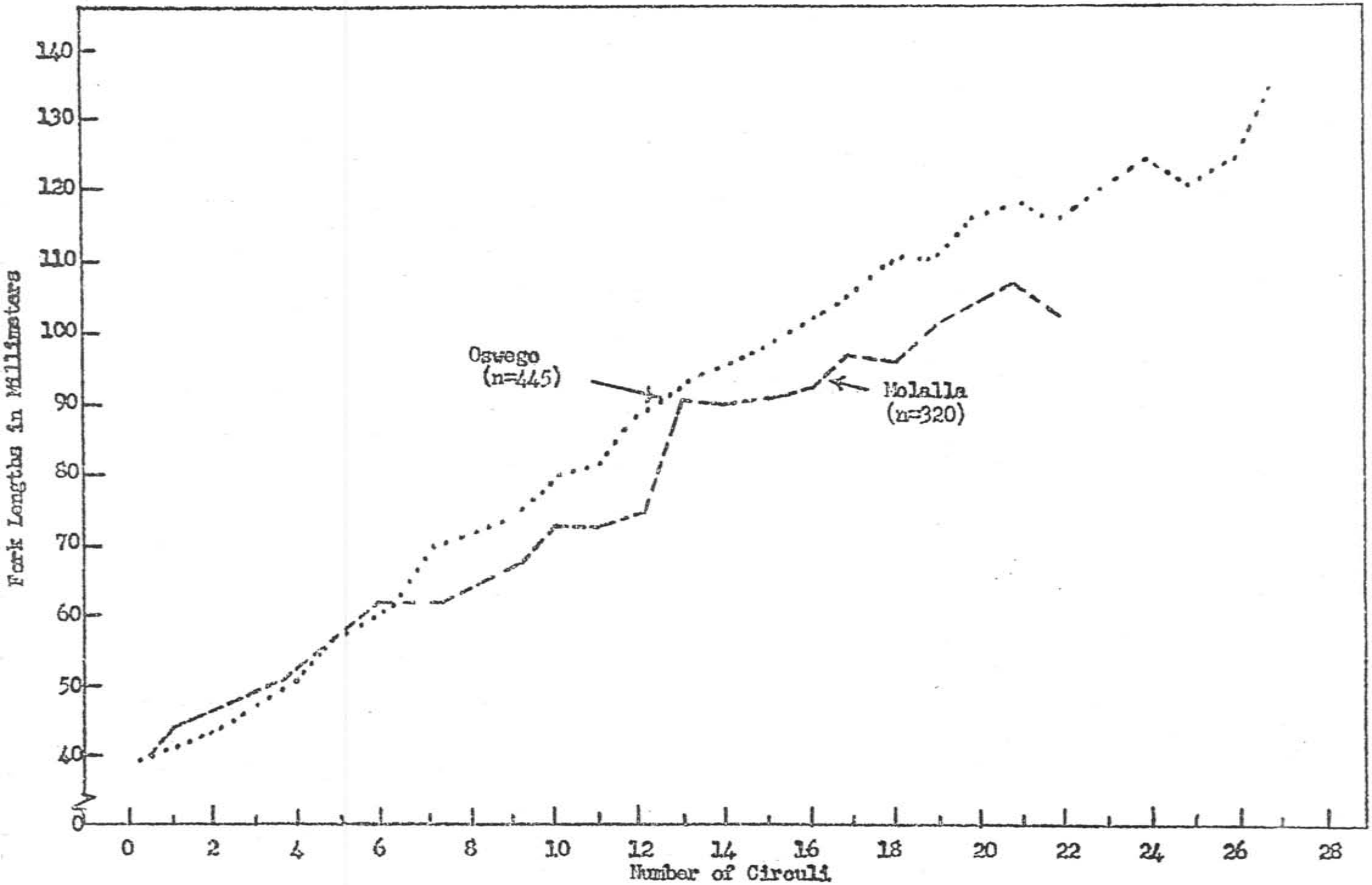


Figure 9. Number of Scale Circuli and Mean Fork Lengths of Spring Chinook Caught at Oswego and Molalla Stations, 1946-49 Year Classes.

For the first 6 circuli there is a distinct similarity, indicating nearly identical growth rates. With increasing numbers of circuli, however, the Oswego salmon exhibit greater lengths than the Molalla salmon for any given number of circuli.

This relationship between body length and number of circuli for spring chinook in a fresh-water environment is not linear, although some segments of the data are nearly so. A close relationship was found when data for Oswego salmon between 0 and 19 circuli were used in calculating a line by the least squares method. However, inclusion of additional circuli (20 to 27), which generally represent winter growth and include annuli, resulted in a poorer correlation due to decreased growth rate in winter.

The transition from one environment to another, as from fresh to salt water, as well as seasonal changes, presumably affects the rate of circuli deposition and type of circuli formed. Ocean growth is recognized by the larger and thicker circuli formed, and also by the greater distance between circuli, than with typical fresh-water growth. Unfortunately, data from young salmon that have entered salt water and show early ocean growth were not available; hence, the curve could not be continued to show changes with environmental transition.

Relationship Between Fork Length and Length of Anterior Radius of Scales

The relationship between fork length and length of anterior radius of scales was also examined. The main objective was to determine the type of relationship and possible application of the data to adult scales in order to calculate approximate lengths when the salmon entered brackish or salt water.

A total of 345 young spring chinook collected at the Oswego station was used in compiling the data presented in Figure 10. The selected anterior radius was used rather than the true radius.

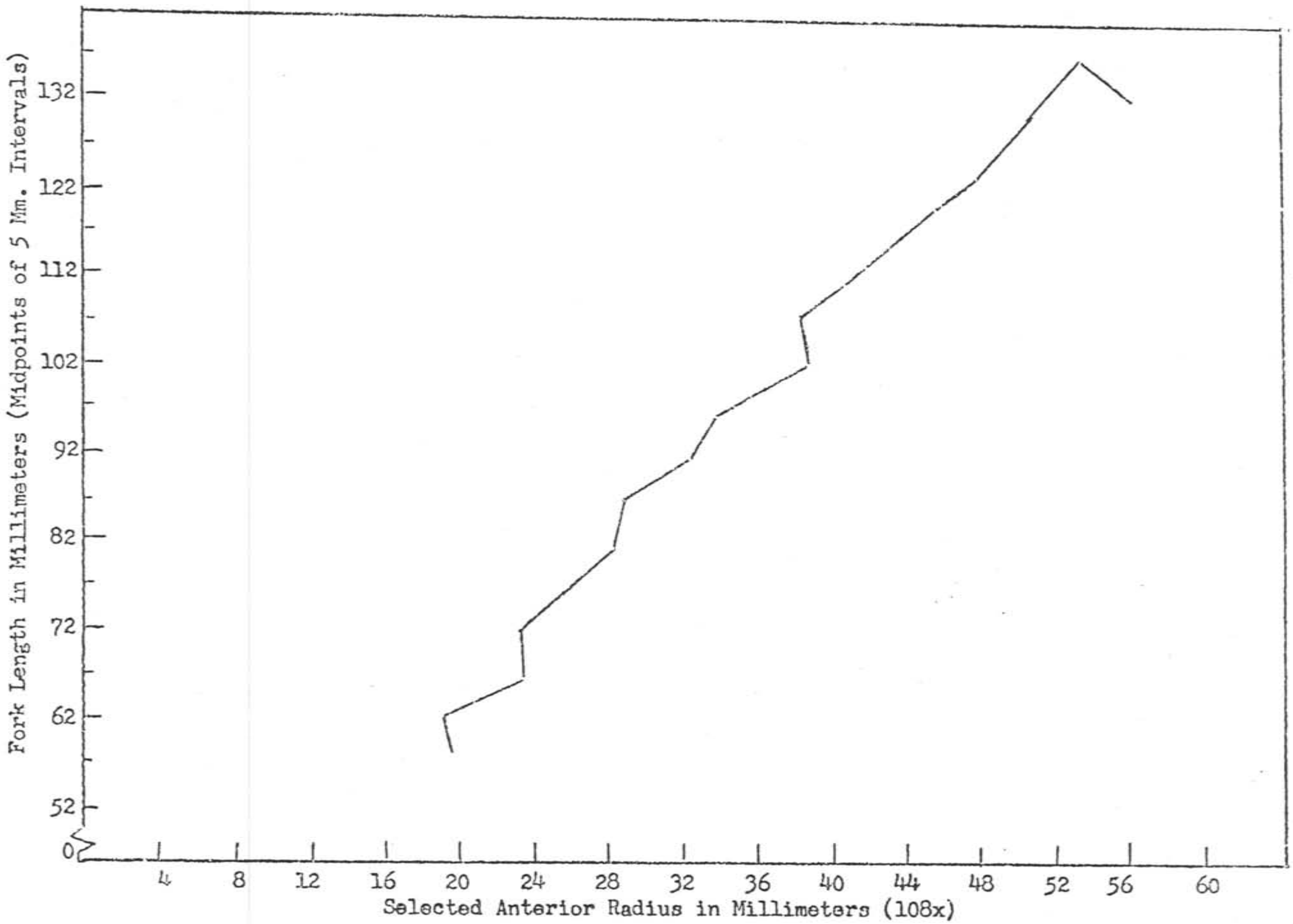


Figure 10. Relationship of Fork Length to Selected Anterior Radius of Scale of 345 Spring Chinook Salmon Caught at Oswego Station, 1947-50.

Data from upper Molalla station were quite similar to those from Oswego station, but the individual means and regression line fell slightly beneath those for the data presented in Figure 10. This indicated that the relationship between fork length and anterior radius may vary, depending on environment and growth rate.

Relationship Between Number of Circuli and Age

The number of circuli present upon the scales of a salmon will be dependent upon the age and rate of growth. Although the age may be the same, the rates of growth differ with the environment, and environments are unlike for resident fish in a parent stream and migratory fish enroute to the ocean.

Figure 11 presents data for the four year classes 1946-49, from Oswego station, where salmon were regarded as active seaward migrants since there was little possibility that they resided in the lower Willamette the entire summer. Except for the relatively small Clackamas River population, spawning areas are from 40 to well over 100 miles away. Thus, by the time downstream migrants reach Oswego the yolk sacs have been "buttoned up", and in most cases scale development has begun. Only small numbers of scaleless fingerlings were taken.

The first migrants of a new year class generally appear at Oswego either in March or April, although a few were taken in January and February. The mean number of circuli found in these salmon generally was only 1 to 2 per scale. The 1947 year-class fingerlings had regular circuli development, indicating a normal growth pattern. In contrast, the 1949 year-class migrants made their first appearance in April, but with a definitely retarded rate of circuli deposition probably reflecting the severe winter of 1949-50, as compared

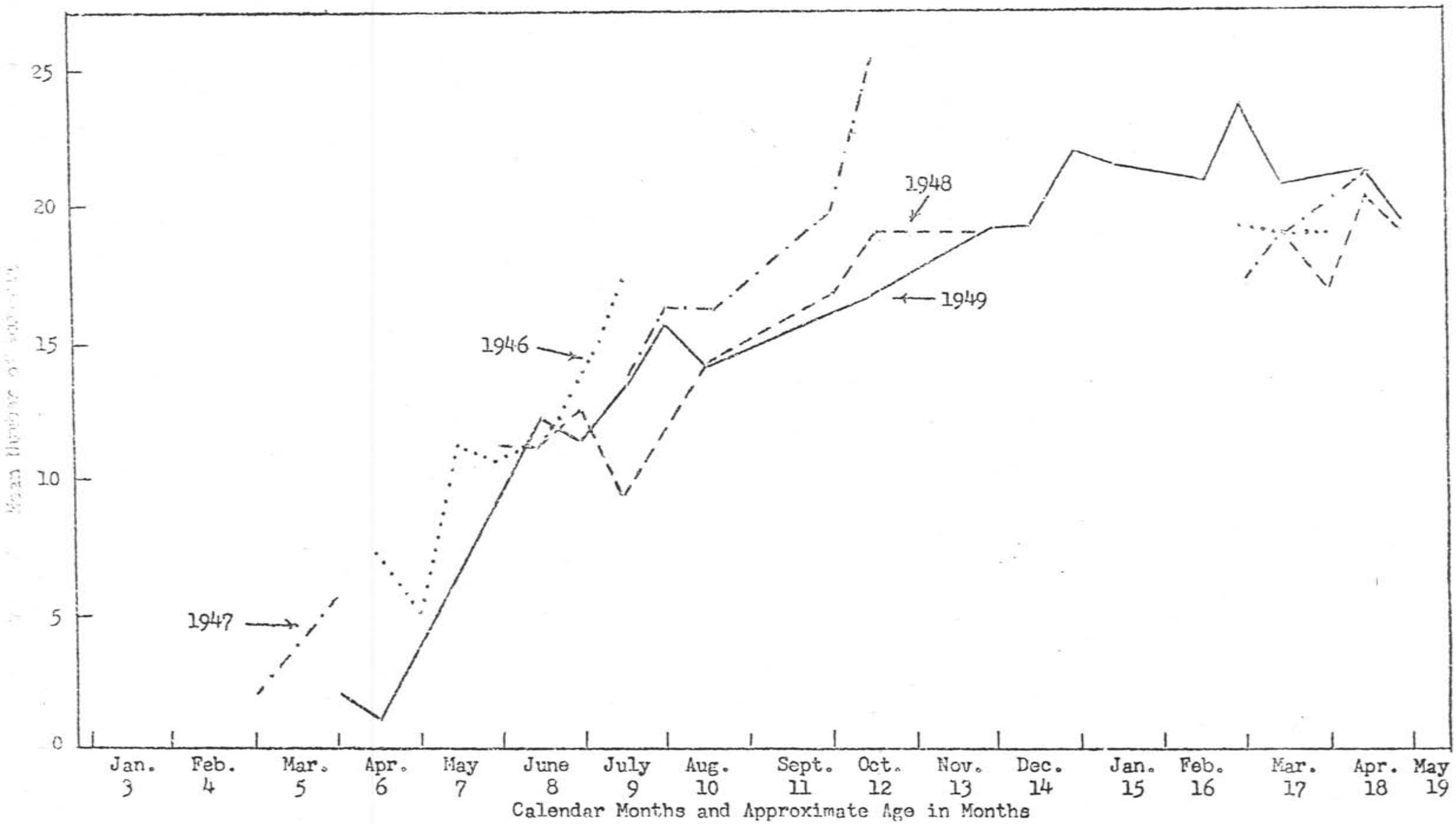


Figure 11. Mean Number of Circuli of Spring Chinook Salmon by Semi-Monthly Intervals Caught at Oswego Station, 1946-49 Year Classes.

to the relatively mild winter of 1947-48. During the spring and summer months there is a rapid rate of growth and circuli deposition, from approximately 2 in mid-March to a mean of 16 or more by mid-August and up to 19 by mid-October, when the fish is about one year from the time of spawning. The numbers of circuli at the beginning of the second year in October were as follows: 1948, mean 19.4, range 12 to 23; 1949, mean 18.9, range 16 to 22; 1950, mean 16.6, range 14 to 22.

There is a reduced rate of growth and circuli development in late summer and fall. The most complete series of collections is shown by the 1949 year class that had catches continued through the winter. Collections of salmon exhibit much slower rates of circuli deposition in winter than in spring and early summer. It is of interest that the mean number of circuli on yearling migrants moving through the Oswego area during March, April, and May is nearly the same for all four year classes. The means of these samples are 16 to 19 circuli, but ranges within a sample were 15 to 28. The effects of abnormal winters, such as those in 1948-49 and 1949-50, are evident to some extent. Fingerlings of the 1946 and 1947 year classes had slightly more circuli than those of the 1948 and 1949 year classes during the spring and summer months. However, such a differentiation was not as evident when the fish were over 16 months of age. Thus, the climatic effect is more manifest in the first spring and summer, when the fish are fingerlings, than later.

Data in Figure 11 show an accelerated rate of circuli deposition in spring and summer and retardation in fall and winter. Fewer circuli are formed in periods of reduced growth rate, and a winter check or annulus, characterized by thin, closely grouped circuli, is formed at this time.

A casual glance at Figure 11 might result in the erroneous conclusion that a spring chinook salmon migrating in June (mean number of circuli 11 or 12) may have 17 to 21 circuli the following April, or an increase of only 6 to 9 in the intervening 10 months. However, the following factors should be noted: (1) these salmon are mainly active downstream migrants and not resident stock; (2) migrants from eight river systems may be included in the collections; (3) June migrants continuing seaward would probably have reached a brackish or salt-water environment, which in turn would greatly affect their growth rate and circuli deposition by the following April; and (4) the yearling March, April, and May migrants have had a long fresh-water residence that resulted in slower growth and circuli formation rates compared to earlier downstream migrants.

The Molalla River collections of mixed resident and downstream-migrating spring chinook are represented in Figure 12. At this station, scaleless fry and fingerlings with the first signs of scale formation are readily caught, since the station is in the midst of a spawning area. Scaleless fingerlings have been taken as late as May. With the advent of spring and warmer temperatures, there is a sudden, sharp increase in growth and circuli deposition, continuing through spring and summer, as indicated by the increase in mean number of circuli from 0 to 3 in April and as late as early May to around 15 by early October. Again, the probable reflection of severe winter, in contrast to the mild winter, is shown. The 1947 year class had slightly greater mean growth, as indicated by more circuli, compared to the next two year classes which experienced severe winters in their first year of life.

A leveling off of circuli formation occurs from October through the fall and winter. Only in the case of the 1948 year class were yearlings taken in the spring. These two samples indicate that probably little growth occurs among fish resident in this stream in the fall and winter months. Few specimens

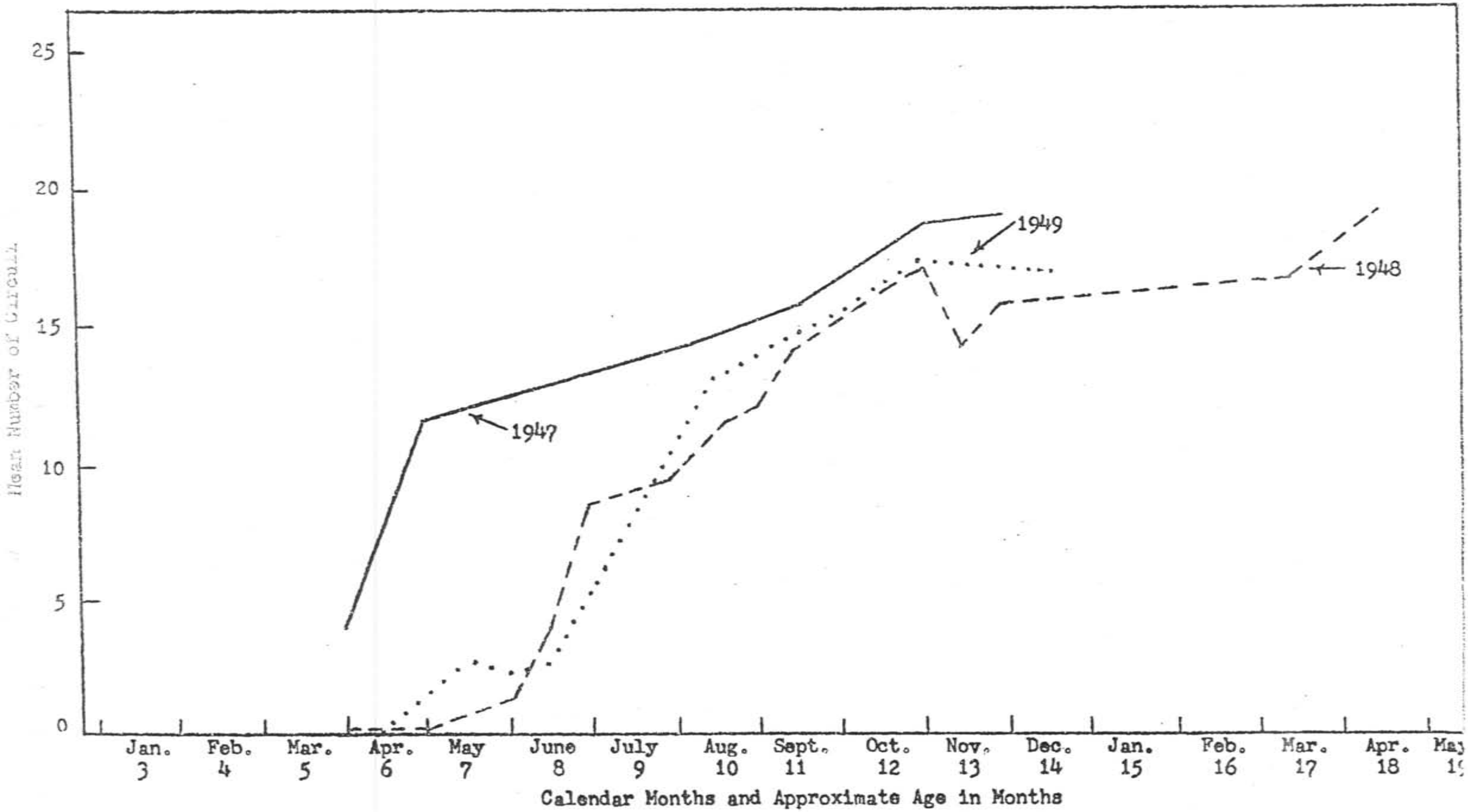


Figure 12. Mean Number of Circuli of Spring Chinook Salmon by Semi-Monthly Intervals Caught at Upper Molalla Station, 1947-49 Year Classes.

have been taken after the last of December, and apparently the bulk of summer residents move toward the ocean during the fall freshets.

That downstream migrant spring chinook are larger than non-migrants at the same time of year has already been shown (Figure 6). Another comparison can be made, indicating differences in number of circuli on fish of approximately the same age, with one group still in the parent stream and the other en route seaward (Figure 13). The mean number of circuli of two comparable year classes (1948 and 1949) have been plotted. The greatest difference is found during the spring and summer periods of accelerated growth and circuli formation, when the Molalla groups invariably showed slower growth rates as reflected by fewer circuli. Thus, it is apparent that rate of growth and circuli deposition are generally slower for salmon remaining in the tributary streams.

Numbers of Circuli on Active Downstream Migrants

Figure 14 shows the numbers of circuli for all Oswego station samples of the 1949 year class. A total of 251 migrants was taken; 51 or 20.3 per cent during the spring and summer migration, when they were less than 1 year of age from time of spawning. The bulk of this year class (79.7 per cent) migrated after reaching 1 year of age.

August migrants have as many circuli as some of the smaller fish migrating 8 or 9 months later. It appears that the older migrants, which remained in the parent streams, were slower growing. In general, there was virtually no increase in numbers of circuli from December until the yearlings leave the parent stream. Unlike fingerling migrants, yearling migrants do not show a sudden increase in circuli counts in the early spring. However, an increase in distance between circuli may appear indicating greater growth rate.

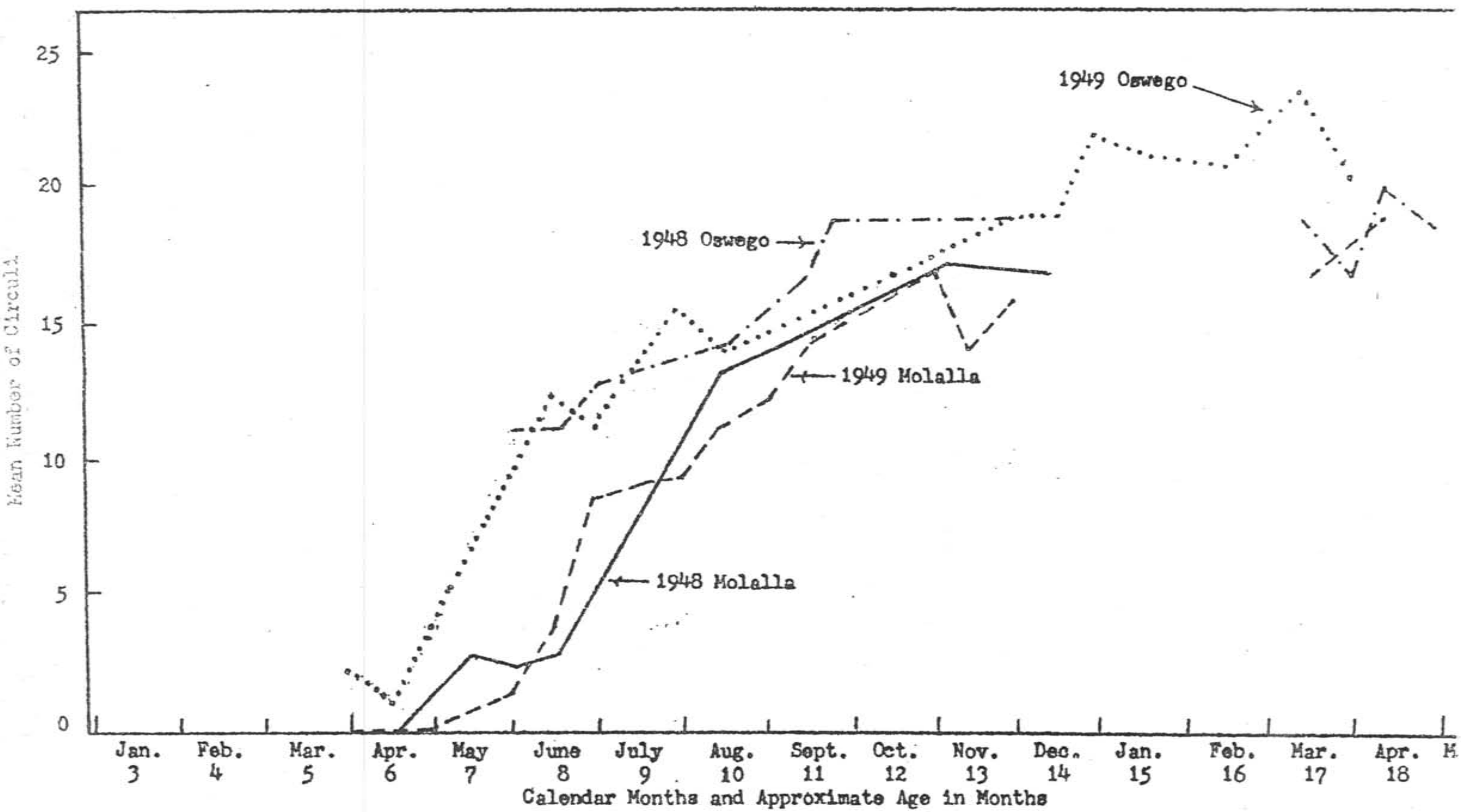


Figure 13. Mean Number of Circuli of Migrant and Resident Chinook Salmon of the Same Age 1948-49 Year Classes from the Oswego and Upper Molalla Stations.

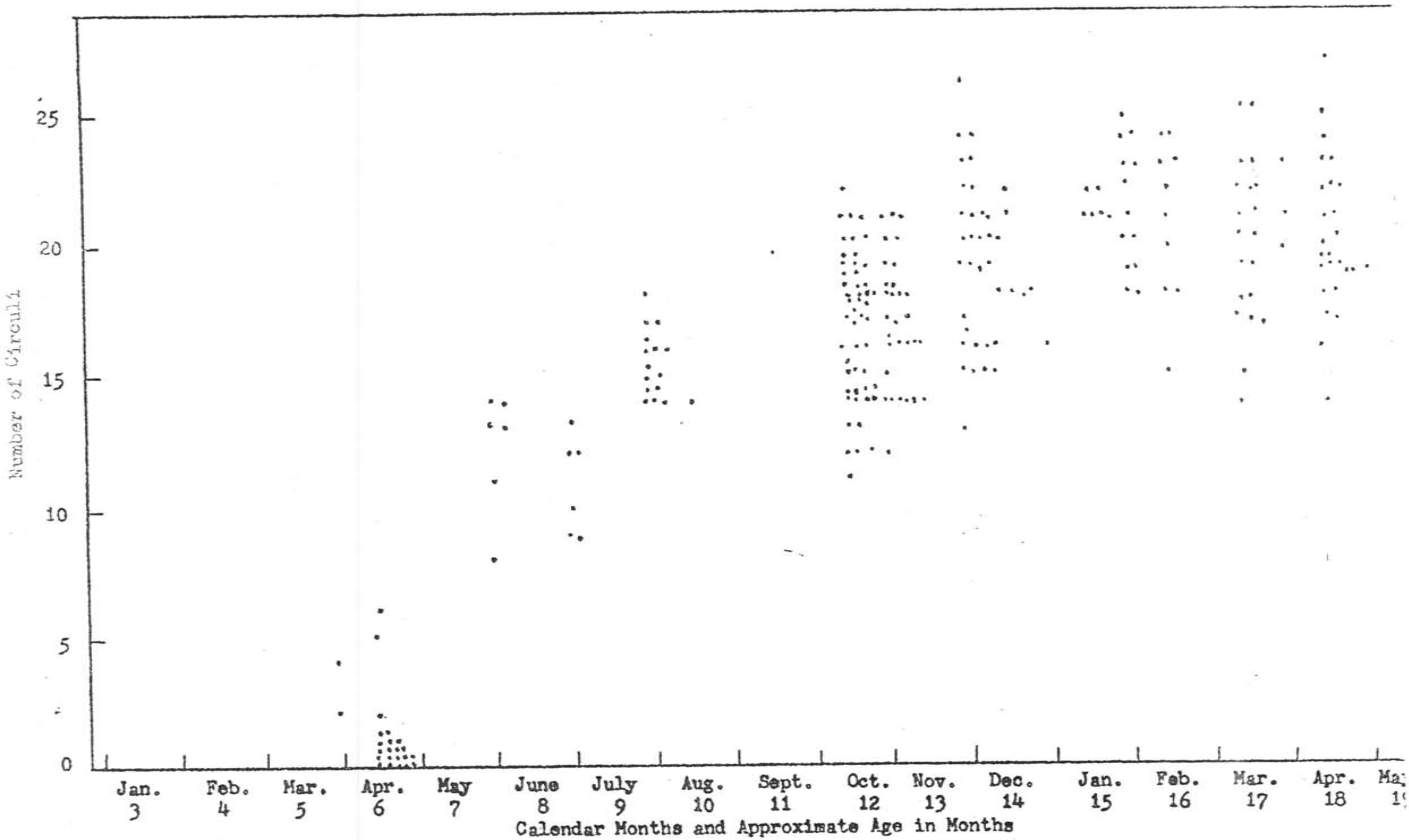


Figure 14. Numbers of Circuli at Time of Downstream Migration, Oswego Station, 1949 Year Class.

Scale Growth Characteristics of Residents

The growth patterns of spring chinook fingerlings and yearlings within their parent stream have been plotted in Figure 15. The method of presentation is by showing the number of circuli and distance between circuli for individual fish. These fish were taken during the months of August, November, and December 1950 to show the various types of growth patterns that can be found within a small river system.

Earlier data presented have shown that the young salmon put on rapid growth during the spring and early summer months as evidenced by increased length and number of circuli. The period of rapid growth on these scales is represented by the first 10 to 12 circuli. When growth is rapid the distance between circuli would be expected to be large and perhaps quite stable between those formed during this period. The trend, however, is generally downward, although sporadic increases do occur, as indicated by scale graphs 6 and 7.

Growing conditions during the summer within a river such as the Molalla should be favorable, yet only a few scale patterns show a stabilization during this period, i. e. scale graph 3. The formation of a distinct winter annulus may occur as early as November as indicated by graphs 6, 7, 9, and 11. The definite grouping of circuli with small interspace distances between the 10th and 20th would be interpreted as winter annuli, as shown by graphs 7, 9, and 11, especially if the following circuli maintained an increased interspace distance.

Except for the first two or three circuli with large interspace distances, which may represent compensatory growth or excellent spring growth, the distance between circuli on scales of fish from a parent stream generally has been found to be less than 3.0 mm. when images are magnified 108 X. Examination of adult scales indicated that almost invariably the interspace distance during ocean growth exceeded 3.0 mm. except during winter annulus formation.

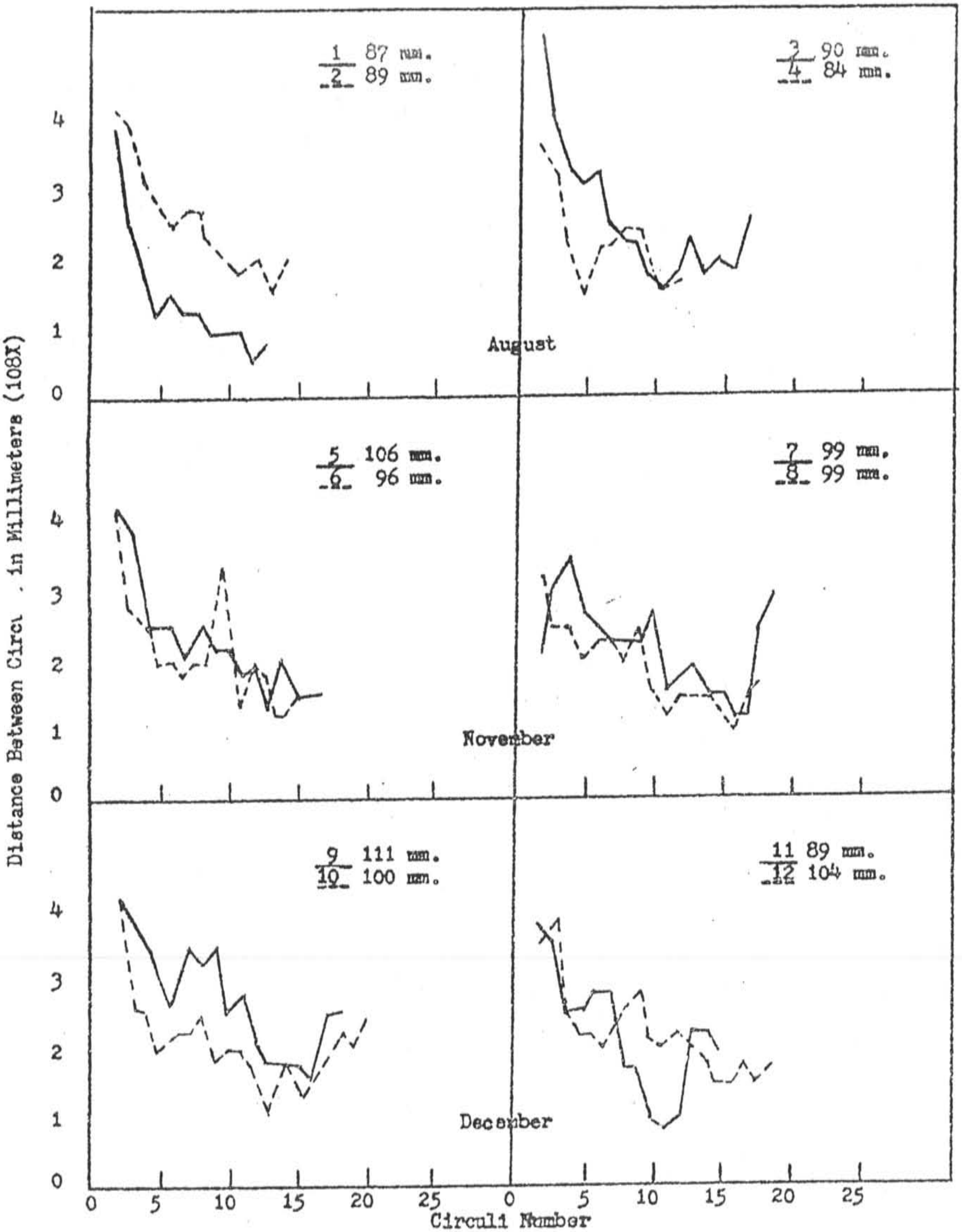


Figure 15. Selected Scale Graphs of 1949 Year Class Molalla River Spring Chinook Fingerlings Collected During the Months of August, November, and December, 1950.

Scale Growth Characteristics of Migrants

Figures 16-18 present scale graphs of the growth patterns of spring chinook fingerlings and yearlings taken at the Oswego station. There are greater variations in growth patterns than on the Molalla River fish because salmon from many river systems are represented. Some patterns show excellent spring and summer growth, some with relatively stable summer growth, others are similar to the Molalla River patterns, where the distance between circuli tends to decrease until a winter annulus is formed. A number of graphs are presented to show the variations and their timing.

Growth patterns of fingerling chinook taken during the months of June, July, and August are presented in Figure 16. In general the first few circuli have large interspace distances, indicating excellent growth, followed by decreasing distances as found among Molalla fish. An unusually rapid rate of growth is shown in graph 11, which averages over 3.0 mm. between interspaces and would be comparable to brackish or ocean growth. These fish show a greater stabilization of growth between the 5th and 15th circuli than was found on Molalla salmon, which appears to indicate better environmental conditions in other streams. A possible change from a parent stream to the warmer Willamette River may have resulted in growth shown by graphs 4, 5, and 12.

In Figure 17, which contains scale graphs of salmon taken during October, November, and December, the same general characteristics are noted for the summer months as in the preceding figure, a similar decline in interspace distances followed by a leveling tendency. Some of the fish encountered relatively good feeding conditions between October and December as indicated by graphs 9 and 12. Graph 9 presents an unusual pattern with a false annulus between the 10th and 17th circuli, a period of increased growth, and the formation of

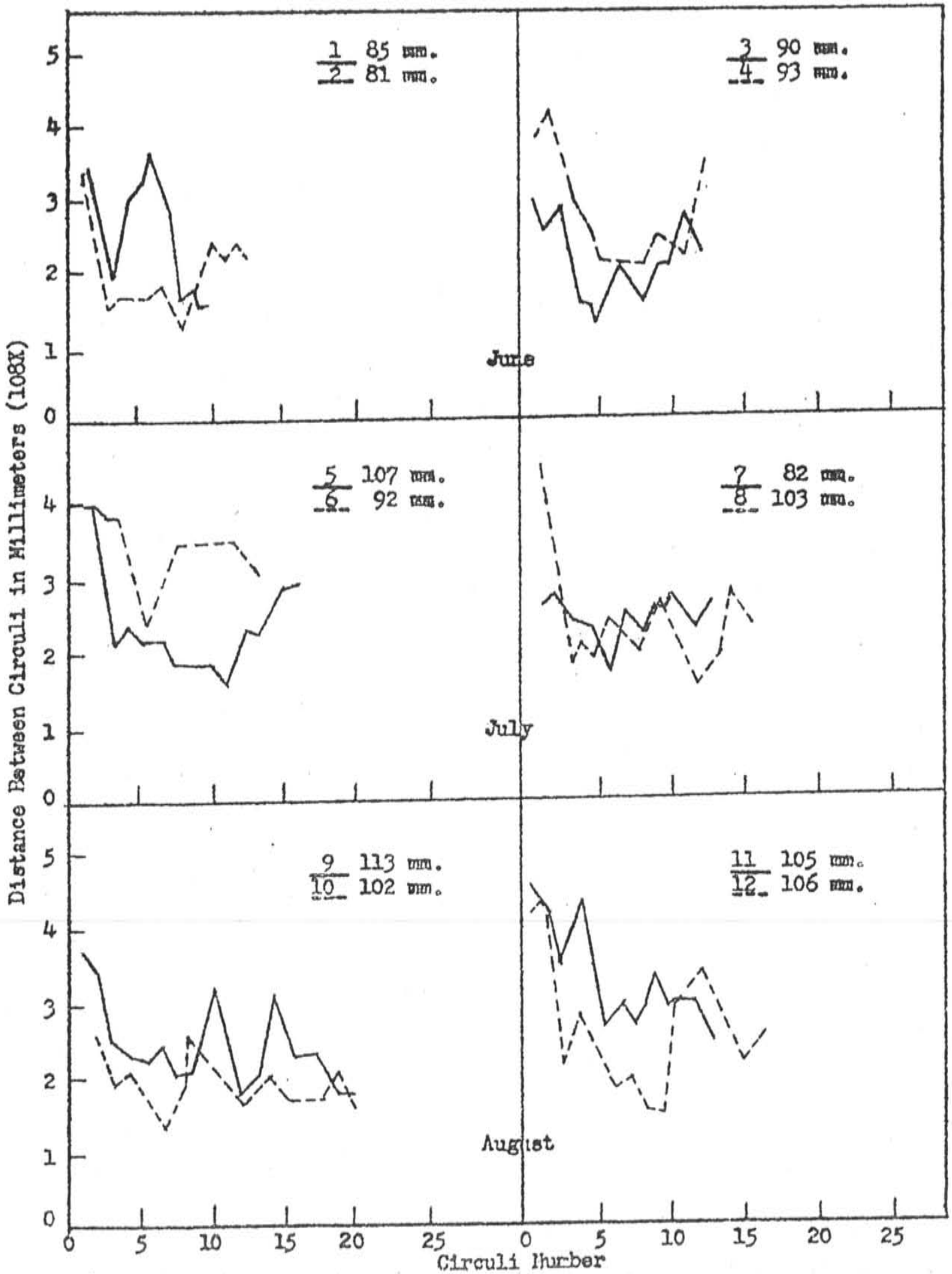


Figure 16. Selected Scale Graphs of Spring Chinook Salmon Less Than One

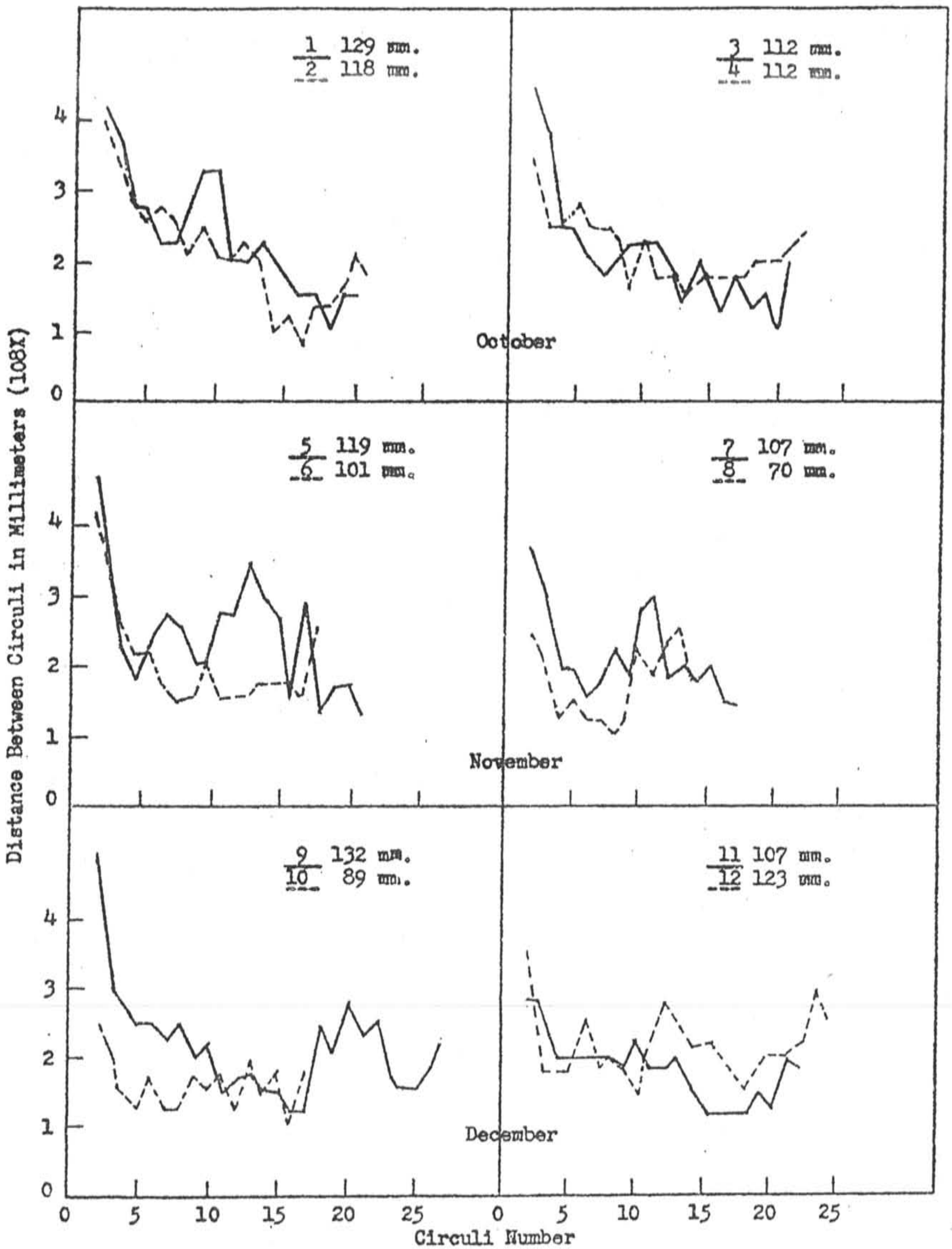
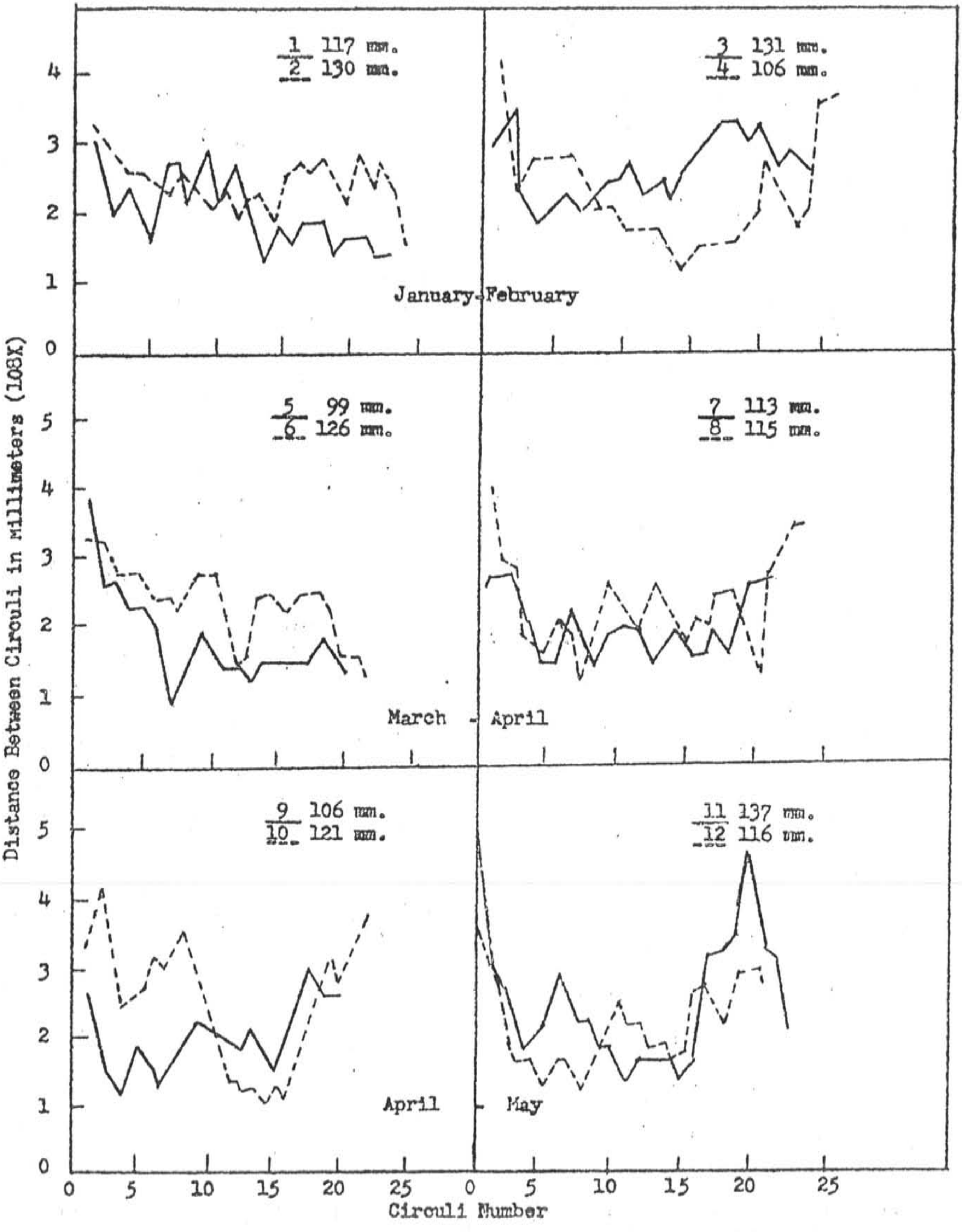


Figure 17. Selected Scale Graphs of Spring Chinook Yearlings Caught at Oswego Station, October, November, and December 1947-50.


1 117 mm.
2 130 mm.
3 131 mm.
4 106 mm.
January-February
5 99 mm.
6 126 mm.
7 113 mm.
8 115 mm.
March - April
9 106 mm.
10 121 mm.
11 137 mm.
12 116 mm.
April - May
Distance Between Circuli in Millimeters (108X)
Circuli Number

a second annulus. It appears doubtful that this fish was in its third year because the period of increased growth between the 18th and 23rd circuli would not be likely to represent one entire year. Definite annuli formations had occurred on some fish as shown by graphs 2, 9, 11, and 12.

The late winter and spring migrating yearling salmon are shown in Figure 18. Again the same general growth characteristics are shown, a rapid growth for the first few circuli, a general decline in circuli spacing, and summer stabilization on some fish. Unusual winter growth patterns without an annulus formation are presented in graphs 2 and 3. Definite winter annuli were present on the migrants represented by graphs 4, 7, 10, and 11, while on others such formations were not nearly as distinct.

An unusual scale pattern was noted on a group of 17 yearling migrants caught at Oswego on May 5, 1950. Following the winter annulus, the interspace distances were significantly greater than normal, and the circuli heavier and thicker. Similar patterns were observed on only a few other occasions, and only once sustained for more than a few circuli (Figure 18, graph 11). This type of growth was comparable to scale patterns generally assumed to be formed during brackish or ocean residences.

In Figure 19 graphs of both adult and young fish are presented for comparison of fresh- and early salt-water growth. Graphs 1, 3, and 7 are typical of greatly accelerated scale growth on yearling migrants; graphs 2, 4, and 8 are from adult scales with similar early-growth rates. Those circuli with interspace distances exceeding 3.0 mm. are assumed to have been formed in brackish or ocean water. Scale photomicrographs of yearling migrants show that the interspaces indicating accelerated growth are wider than normal for fresh water, and are similar to brackish or ocean-growth patterns shown by adult scales. Brackish water growth may be represented by circuli 19-28 on graph 6.

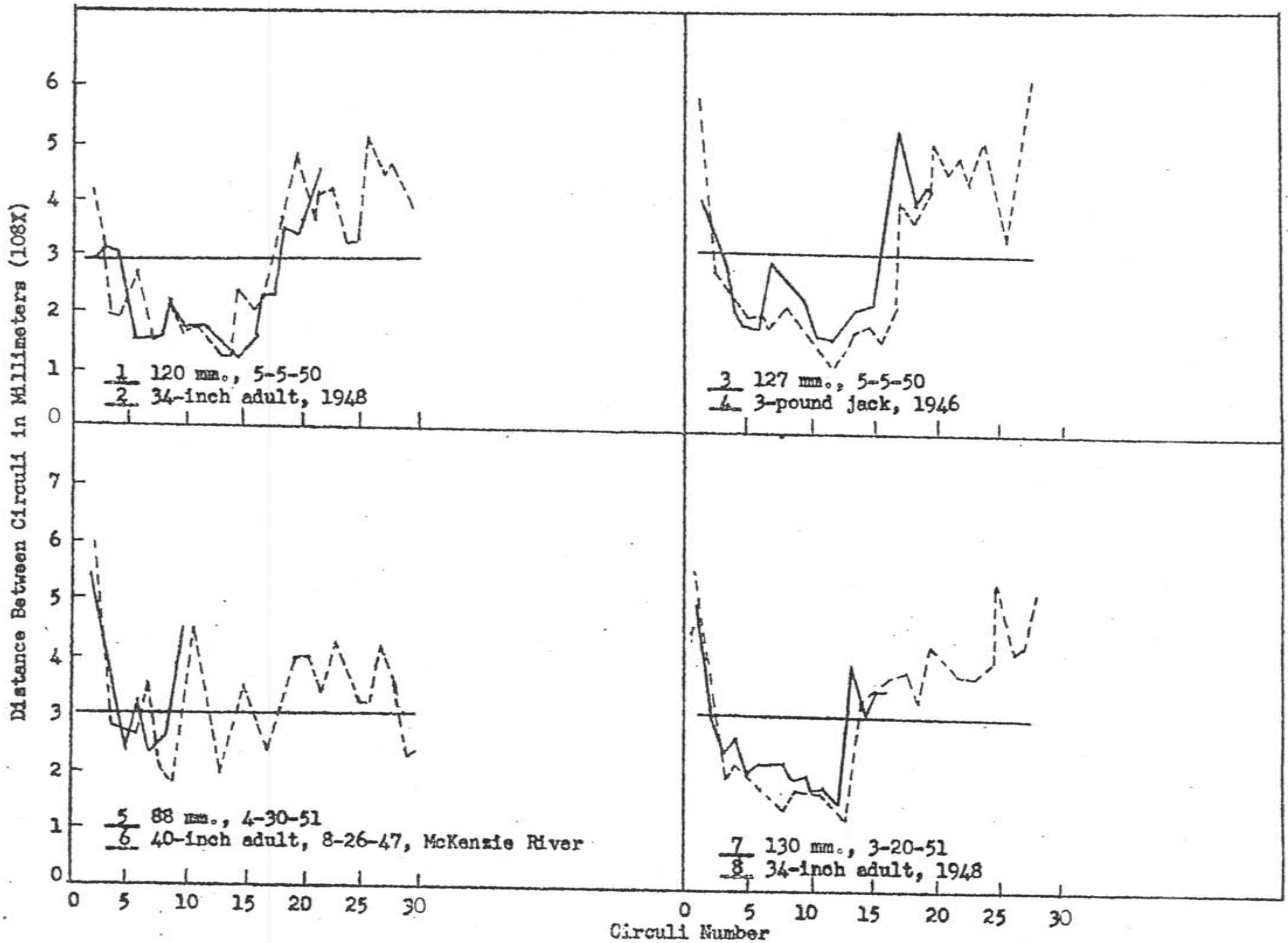


Figure 19. Comparison of Fresh-Water Growth of Yearling Spring Chinook Salmon, Caught at Oswego Station, with Adult Fish. (Scale photographs are presented in the OFC Library copy.)

To avoid confusion with normal, accelerated fresh-water growth following the winter annulus, this type has been called "superior fresh-water growth". Normal distances between fresh-water circuli are rarely 3.0 mm., while on the superior fresh-water type they range from 3.0 to 5.0 mm. and are limited mainly to yearling migrants in April and May, and occasionally to summer fingerlings. In Figure 19, graphs 5 and 6, an April fingerling migrant 88 mm. in length, showing excellent fresh-water growth, is compared with a 5-year-old adult spring chinook. The early patterns of each are strikingly similar. Figure 16, graphs 6 and 11, represent two fingerling migrants with a similar scale pattern. Since these average close to 3.0 mm. they would qualify for superior fresh-water growth and also fulfill the requirements of "intermediate" growth (Rich, 1920).

Rich observed an accelerated type of fresh-water growth on scales of young salmon from the lower reaches of the Columbia which he called "intermediate". These intermediate rings represent a period of growth more rapid than normal growth in fresh water and yet not as vigorous as true ocean growth Intermediate rings were not present on scales of every specimen, but among the larger fry and yearlings taken in the estuary after the first of June some were always found which showed this type of growth at the margins of the scales (Rich, 1920). Among Rich's specimens, those taken from Ilwaco and Point Ellice near the mouth of the Columbia were within the influence of brackish water, and marginal circuli probably represented true intermediate growth. Salmon recovered near Crim's Island, between Clatskanie and Mayger, Oregon, were above the brackish zone, as was a fish taken in the Clackamas River which represented superior fresh-water growth.

Since two greatly accelerated rates of non-ocean growth have been observed, one from the influence of brackish and the other from fresh water, we may regard them as intermediate and superior fresh-water growth, respectively. As both types are similar, the problem of differentiating them will arise when adult salmon scales are examined. Assuming that superior fresh-water growth is due to temporary environmental conditions, there should logically be a return to normal fresh-water growth pattern when the fish have left the favorable habitat. In support of this, Figure 18, graph 11, shows a 137 mm. yearling migrant which enjoyed exceptional growth for a time followed by normal fresh-water scale growth. This fish was taken at Oswego station, far above the influence of brackish water; hence such growth can only be considered as superior rather than intermediate.

Figure 20 compares scale patterns of yearling migrants and adult salmon. Adult graphs 2 and 4 have bands of accelerated growth believed to have been completed in fresh water; graphs 1 and 3 are similar. The possibility that the first checks represent winter annuli is unlikely since the entire spring and summer growth would than consist of only 4 or 5 circuli. Early accelerated growth rates on these adult scales indicate superior fresh-water growth.

Figure 20, graphs 5, 6, 7, and 8, also show superior fresh-water growth on scales of migrant and adult fish. The pronounced second-winter annulus on the adult in graph 8 is believed to be composed of fresh-water circuli, while adult graph 6 may represent intermediate growth. All adult scales were obtained from salmon returning to spawn.

Formation of First Winter Annulus in Spring Chinook

The appearance of an annulus defined as an aggregation of closely-grouped circuli occurring once a year usually in winter has been previously mentioned. The following observations were made during the present study; (1) annulus formation does not occur simultaneously on all young salmon; (2) the annulus

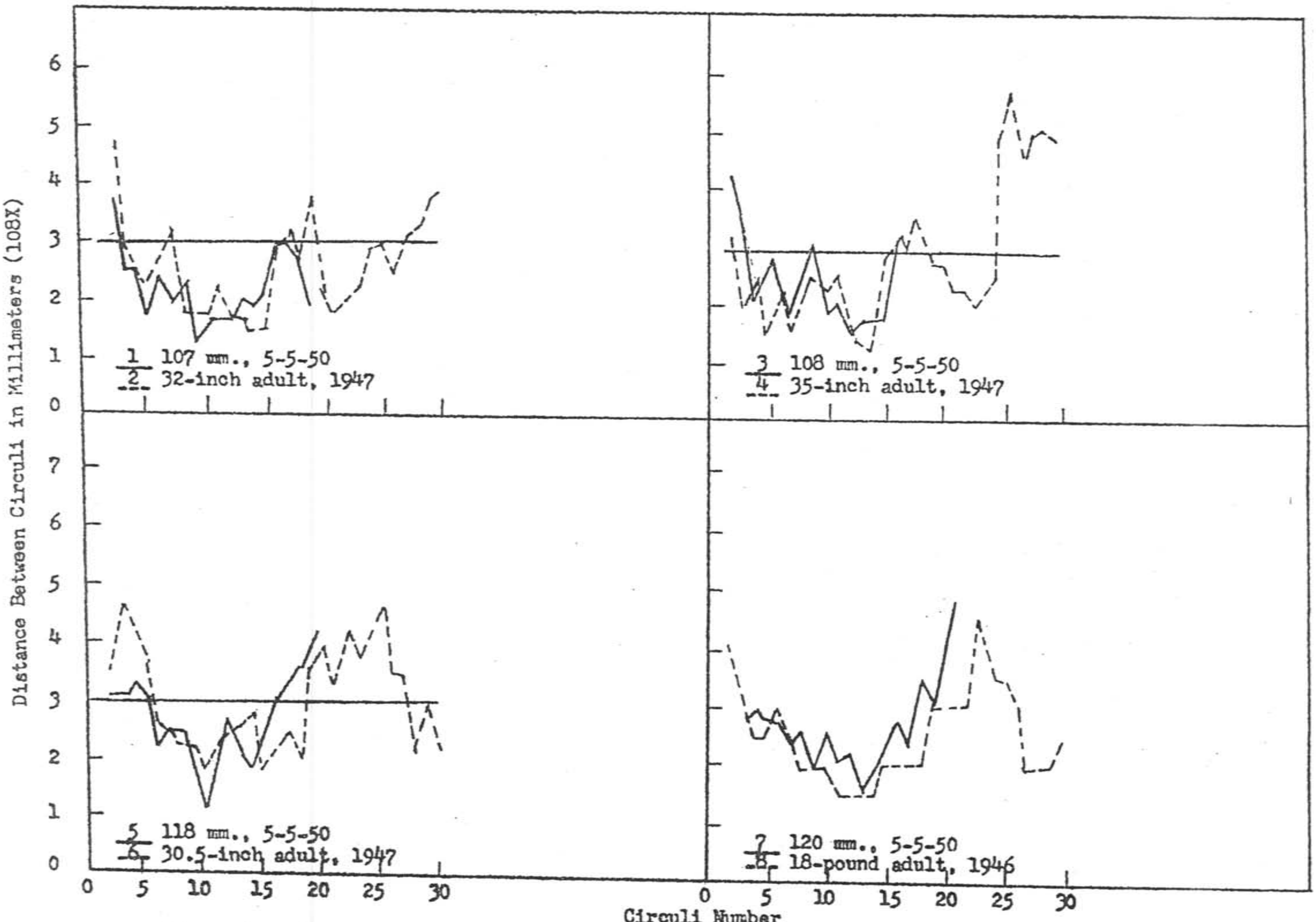


Figure 20. Comparison of Yearling Downstream Migrants Caught at Oswego Station, with Adult Fish Having a Similar Type of Accelerated Fresh-Water Growth. (Scale photographs are presented in the OFC Library copy.)

may be formed in any month between October and May; and (3) fresh-water annuli generally are found between the 10th and 20th circuli and are recognized as a band of 4 to 6 closely grouped circuli.

In Figures 15, 17, and 18 the scale patterns that compose the annulus show wide variation in time of formation, resulting possibly from differences in environmental conditions among river systems where the fish originate. Variations among fish in the same system can also account for differences in timing. Table 4 contains data on time of annulus formation based on scale samples of fish taken at Oswego in the years 1947-51. The earliest completed annuli found were in October, when some fish had fully formed and distinguishable winter checks. In general, by the end of December approximately 50 per cent of the fish examined had completed annuli. The majority of specimens from April catches had completed annulus formation.

The distance between circuli forming an annulus ranged from 1.5 to 2.3 mm. (108 X). Normally, the number of circuli within a check was between 4 and 6, and the check occurred most frequently between the 15th and 20th circuli.

SUMMARY

Under normal conditions, spring chinook salmon of the Willamette River spawn between August 25 and October 5. Abnormal environmental conditions have resulted in exceptionally late spawning that has continued until late November.

The length of egg-incubation ranges from a minimum of 58 to a maximum of 150 days.

Young fry normally emerge from the gravel during February or March, occasionally in mid-January, and as late as the first week of June.

Table 4. Annulus Formation of Yearling Spring Chinook Salmon Caught at Oswego Station, 1947-51.

Date Caught	No. Fish in Sample	Mean No. Circuli	Fish With No Annuli Formation (Number)	Fish With No Annuli Formation (Per Cent)	Fish With Formation Occurring (Number)	Fish With Formation Occurring (Per Cent)	Fish With Formation Completed (Number)	Fish With Formation Completed (Per Cent)
ctober								
5, 1948	14	19.5	1	7.1	6	42.9	7	50.0
0, 1949	17	16.0	4	23.5	10	58.8	3	17.7
20, 1950	51	16.5	16	31.4	24	47.0	11	21.6
ovember								
2, 1950	30	17.4	5	16.6	22	73.4	3	10.0
ecember								
30, 1949	5	19.0	2	40.0	1	20.0	2	40.0
7, 1950	30	10.0	4	13.3	10	33.4	16	53.3
18, 1950	6		0	0	3	50.0	3	50.0
anuary								
5, 1951	4	21.7	0	0	2	50.0	2	50.0
7, 1951	6	21.3	0	0	1	16.7	5	83.3
ebruary								
8, 1947	17	20.0	0	0	11	65.0	6	35.0
5, 1951	4	21.0	0	0	2	50.0	2	50.0
21, 1951	10	20.8	0	0	4	40.0	6	60.0
arch								
1, 1947	6	20.5	0	0	2	33.3	4	66.7
23, 1948	2	19.0	0	0	0	0	2	100.0
14, 1949	3	17.7	0	0	3	100.0	-	
28, 1949	2	23.0	0	0	1	50.0	1	50.0
22, 1950	25	19.0	0	0	15	60.0	10	40.0
28, 1951	21	20.4	0	0	7	33.3	14	66.7
pril								
5, 1948	7	18.8	0	0	2	28.5	5	71.5
19, 1948	3	19.0	0	0	0	0	3	100.0
28, 1949	1	21.0	0	0	0	0	1	100.0
4, 1950	2	17.0	0	0	2	100.0	-	0
17, 1950	13	20.0	0	0	2	15.4	11	84.6
13, 1951	3	21.3	0	0	0	0	3	100.0
30, 1951	24	20.3	0	0	2	8.3	22	91.7
ay								
5, 1950	17	18.8	0	0	1	5.9	16	94.1
17, 1951	1	19.0	0	0	0	0	1	100.0

Length of residence in a spawning tributary of the Willamette may range from 3 to 18 months after spawning.

There are three distinct periods of downstream migration: (1) a late winter-early spring fingerling movement, which is frequently the largest in numbers of fish from a given year-class; (2) a fall-early winter migration (October through December), which in some years may exceed in numbers the later yearling migration: (3) a late winter-spring yearling movement (February through the first of May).

The fork lengths of migrating fish range from 33 to 140 mm.--from 37 to 100 mm. for the fingerling late winter-early spring group; 100 to 130 mm. for the late fall-early winter yearling group; and 100-140 mm. for the yearlings in their second spring.

Growth rates vary for fish from different river systems, probably due to variations in water temperature and food availability. Accelerated growth in the spring occurs up to 2 months earlier for fish in the lower main Willamette compared with fish in the upper tributaries.

Abnormally cold winters appeared to restrict the growth of young salmon.

Scale formation begins on the first scale rows immediately above and below the lateral line and moves progressively outward from this line. The first scale platelets form on fish between 37 and 41 mm. in length.

Formation of the winter annulus may occur any time between October and April on Willamette salmon, although by January approximately half the fish in the samples have some stage of annulus formation underway.

The relationship between number of circuli and fork length on yearlings is best represented by a slightly sigmoid curve.

The relationship between the number of circuli and age of yearlings is non-linear. A slightly curved line again provides the best fit.

The number of circuli on downstream migrants ranges from 0 to 29. In general, the youngest migrants have 0 to 15 circuli, the first fall-early winter fish 13 to 16, and the yearling group, 14 to 29.

There were more circuli invariably on seaward migrants than on fish remaining in their parent streams, at the same time of year, thus indicating that size was a factor influencing time of migration.

A greatly accelerated type of growth, referred to as superior fresh-water growth, is found on only a small number of yearling fish in the lower Willamette River that apparently have experienced exceptionally good environmental conditions. When graphed, this growth is identical with brackish or even salt-water growth.

Fresh-water scale growth patterns show considerable variation, but only rarely, except on scales with superior fresh-water growth, do the circuli interspace distances exceed 3.0 mm. at 108X.

In general, fresh-water spring and summer growth is between 2.0 to 3.0 mm. at 108 X, and winter-annulus circuli distances 1.3 and 2.0 mm.

ACKNOWLEDGMENTS

Donald L. McKernan, Director of the Bureau of Commercial Fisheries, Washington, D. C. and Donald R. Johnson of the Bureau of Commercial Fisheries, San Diego, California, both formerly with the Oregon Fish Commission, contributed materially during the course of the study and assisted in the analysis.

Assistance in the collection and preparation of material was given by Theodore R. Merrell, Robert W. Schoning, Melvin D. Collins, Ernest R. Jeffries, Harry L. Reitze, George F. Slusser, John P. Weise, and John G. Hewston.

LITERATURE CITED

Craig, Joseph, and Lawrence D. Townsend.

1946. An investigation of fish maintenance problems in relation to the Willamette Valley Project. U. S. Fish and Wildlife Serv., Spec. Sci. Rep.: Fish. No. 33, 78 pp.

McKee, Thomas B.

1950. A study of the water supply of the new Marion Forks Hatchery on the North Santiam River. Fish Comm. Oreg., Res. Briefs, Vol. 3, No. 1, pp. 22-32.

Rich, Willis H.

1920. Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. Bull. U. S. Bur. Fisheries, Vol. XXXVII, 1919-20 (1922), pp. 1-74.

Rich, Willis H., and Harlan B. Holmes.

1929. Experiments in marking young chinook salmon on the Columbia River, 1916 to 1927. Bull. U. S. Bur. Fish., Vol. XLIV, 1928, pp. 216-264.