OBJECTIVE STUDIES OF SCALES OF COLUMBIA RIVER CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA* (WALBAUM)[1]

BY

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ABSTRACT

This study uses an objective method that measures and graphs the spacings of circuli. It also introduces a new method of differentiating ocean nucleus from stream nucleus. Four groups of chinook salmon scales were studied, each with a specific purpose.

First, scales from recoveries of two kinds of marked fall chinook at Spring Creek National Fish Hatchery were compared: one kind was from fish released as fry, and the other from fish released as fingerlings. In the nuclear part of scale growth, the group released as fry showed a larger variance in spacing of circuli than the group released as fingerlings but the difference in the mean values between these two groups was not significant. In the first marine part of scale growth, circulus spacing was significantly wider in the group released as fry than in the group released as fingerlings. It was not possible, however, to identify individual scales as coming from fish released as fry or as fingerlings.

Second, scales from marked and unmarked fall chinook salmon at Spring Creek Hatchery were compared to see if any effect of marking could be detected. Significant differences in circulus spacing in marine growth existed between marked and unmarked fish, the latter having wider spacings. Marking was in the removal of adipose and right pectoral fins from chinook fingerlings. This technique was therefore regarded as having unfavorably affected the growth of marked fish.

Third, scales from marked fall chinook that had been released at various times of the year at Little White Salmon National Fish Hatchery were studied. The scales showed that young chinook salmon released in May and July of the first year grew an ocean nucleus typical of fall chinook; those released in February of the second year grew a stream nucleus typical of spring chinook; and those released in September and October of the first year grew a nucleus intermediate in character.

Fourth, scales of fall and spring chinook salmon were studied to see how these two groups could be identified by their scales. Measurements of circulus spacing in the first and second summer of marine growth revealed that, in the spring chinook, marine circuli in both summers were about equally wide; whereas, in the fall chinook, marine circuli of the second summer were nearly one and one-half times wider than those of the first summer. Thus, these scales can be distinguished, not by nuclear growth as is normally done by subjective judgment, but by relative marine growth as measured by objective means.

Since the early studies on the scales of chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), by Gilbert (1914), Rich (1922), Rich and Holmes (1929), and others, little has been published on the subject. Many problems still deserve further study. The most important and interesting problem is the classification and identification of nuclear growth zones, the central part of scale growth. Gilbert (1914) classifies chinook scales into two types: those with an ocean nucleus and those with a stream nucleus. The ocean nucleus type originates from fish that migrate seaward in their first year and thus has the first annulus at the end of the first year's marine growth; the stream nucleus type originates from fish that do not migrate seaward until the early months of the second year and thus has the first annulus at the end of fresh-water growth. To the former group belongs the fall run of chinook, which enters the river from July through November; to the latter, the spring run, which enters the river from March to June.

Classification of nuclear growth zones is very useful and today still serves as the foundation of age study of chinook salmon. This method is most useful when only two groups of chinook salmon are involved and their nuclear zones

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are clearly defined. Its application becomes limited, however, when the boundaries of nuclear growth are not clear-cut. The chinook salmon young of the Columbia River, for instance, migrate seaward throughout most of the year (Rich, 1922); consequently, the first year's growth is subject to numerous variations that intergrade so completely that it is impossible to draw any sharp line of distinction (Rich and Holmes, 1929). Most Columbia River chinooks, according to Rich and Holmes (1929), have neither typical stream nor typical ocean nuclei, but apparently have spent part of the first year in fresh water and part in the ocean. The result has been a nuclear area composed in part of stream growth with narrowly spaced circuli and in part of ocean growth with widely spaced circuli to form what these authors term "composite nucleus."

The composite nucleus makes age determination difficult. In a composite nucleus, the amount of stream growth varies inversely with the amount of ocean growth. At one extreme is the type with only a small amount of stream growth accompanied by a large amount of ocean growth. At the other extreme is the type with a great amount of stream growth accompanied by a small amount of ocean growth. The first type of nuclear growth approaches the ocean nucleus, and the second type approaches the stream nucleus. Between these two extremes there are complete intergradations. This poses the question: "Where should the annuli be placed, and how many?"

The question is further complicated by the formation of the so-called "intermediate growth," that is, growth of circuli in the estuary while the fish is migrating seaward. Circuli of this growth cannot be distinguished with certainty from either the stream or the ocean circuli, and they often form a check which, in the words of Rich and Holmes, "might easily be mistaken for an annulus by an inexperienced observer." These same authors maintain that with experience this kind of error may be eliminated almost completely, and that their own experience with the scales of fish of known history has provided sufficient information for correct age determination.

The prerequisite of experience in scale reading cannot be denied, but the dependence upon experience can be lessened and the accuracy of age determination improved if some mechanical method in scale work can be developed so that the scale growth and marks can be interpreted more objectively. The development of an objective method is the major purpose of the present work. From a large number of scales collected from chinook salmon of known ages through recoveries of marked fish, we were able to establish some definite criteria and methods whereby one can objectively interpret scale marks with a minimum amount of guess work.

The present study comprises four parts. First, scales from adult fall chinook that have migrated seaward as unfed fry and as fed fingerlings [4] were compared in an attempt to find characteristics that might serve to identify fish of unknown origin; i.e., whether they come from fry migrants or from fingerling migrants.

Second, comparative studies were made between scales from fall chinook that had been fin-clipped when released as fingerlings and those that had not been marked. This was to see if marking had any adverse effect on growth that could be detected by scale measurements.

Third, marking experiments on young fall chinook performed by U.S. Fish and Wildlife Service personnel at the Little White Salmon Hatchery provided an unusually valuable series of adult scale samples for age and growth study. Young chinook salmon were released over a wide range of time (May to February), and each release had a different mark. Scales from returned adults originating from different releases were studied to gain insight into the formation of a fresh-water annulus and to assess the relative amount of first and second year's ocean growth due to different release dates. This provided valuable information for understanding scale growth patterns in fall and spring chinooks.

Fourth, the relative amount of the first and second year's ocean growth on scales in known stocks of fall and spring chinooks was studied and compared. An objective method of determining the presence or absence of an an-

[4] "Fed fingerlings" refers to young chinook salmon that have been fed for about 3 months.

nulus in nuclear growth and therefore in distinguishing fall and spring chinooks was developed, independent of fresh-water growth itself.

MATERIALS AND METHODS

Materials for the present study were supplied by the Fish Commission of Oregon and by the Portland Program Office of the Bureau of Commercial Fisheries of the U.S. Fish and Wildlife Service. Scale impressions on cellulose acetate cards of the following were available for study.

1. Returns of marked fall chinook to Spring Creek Hatchery:
   a. 1958 returns—released as fry, 1 fish; released as fingerlings, 8 fish.
   b. 1959 returns—released as fry, 8 fish; released as fingerlings, 173 fish.
   c. 1960 returns—released as fry, 28 fish; released as fingerlings, 158 fish.
2. Returns of unmarked fall chinook to Spring Creek Hatchery:
   a. 1959 returns—925 fish.
   b. 1960 returns—898 fish.
3. Returns of marked fall chinook to Little White Salmon Hatchery:

Mark*	Date released	*Fish returns in 1959*			*Fish returns in 1960*		
		Male	Female	Total	Male	Female	Total
		No.	*No.*	*No.*	*No.*	*No.*	*No.*
LP	May 8-9 (1957, 1958)	10	3	13	12	6	18
RP	July 1-2 (1957, 1958)	27	6	33	28	18	46
D-LP	Sept. 4 (1957, 1958)	3	....	3	4	2	6
D-RP	Oct. 15 (1957, 1958)	6	1	7	2	2	4
An-RP	Oct. 15 (1957, 1958)	20	....	20	20	11	31
An-LP	Feb. 13-15 (1958, 1959)	43	10	53	48	24	72
Total		109	20	129	114	63	177

*L=left; P=pectoral; R=right; D=dorsal; An=anal.

4. Returns of unmarked spring chinook to Carson National Fish Hatchery: Samples of several hundred scales (one from each fish) each year collected during 1955–57 and 1959–60.

In addition to the above impressions of scales of adult chinooks, specimens of young fall chinook, preserved at the time of release at several Federal hatcheries, were also available. Scales from these young fish were studied for comparison with the nuclear zone of adult scales.

The study was based on objective means as much as possible. Scales were studied under a microprojector at magnifications of 92, 140, or 400 times, depending on the magnification desired. The image of a scale was projected directly on millimeter graph paper, and the positions of circuli along the antero-lateral radius of the scale were marked on the paper. The center of the central plate was always used as the starting point, and the edge of the central plate became the first mark. In counting and measuring the circuli, we regarded the mark next to the central plate as the first circulus.

All subsequent studies of the scale growth were made from the markings on the graph paper. Distances were measured in terms of millimeters, and the actual dimensions determined by the magnifications used. The various methods of counting, measuring, and graphing will be described under individual sections.

SCALE GROWTH IN FALL CHINOOK SALMON RELEASED AS FRY AND FINGERLINGS

Spring Creek Hatchery (fig. 1), a Federal installation located about 175 miles from the mouth of the Columbia River on the Washington side, produces primarily fall chinook salmon. In the past, young chinooks were released either as unfed fry during the first week of February or as fed fingerlings during the first week of May. To evaluate the relative merits of fry and fingerling releases, the Bureau of Commercial Fisheries marked young chinook salmon of brood years 1956, 1957, and 1958. Among the young released each year during 1957–59, some fish were marked, consisting of about equal numbers of fry and fingerlings. Two combinations of fin marks were used: adipose and left pectoral fins on fry and adipose and right pectoral on fingerlings.

Fish with both marks were recovered in years 1958–60,[5] and scales were collected from all returned fish. An interesting question here is: "Can the scales of adults that were released as fry be differentiated from those that were released as fingerlings?" This problem is of both theoretical and practical importance.

[5] Later recoveries are not included in the present study.

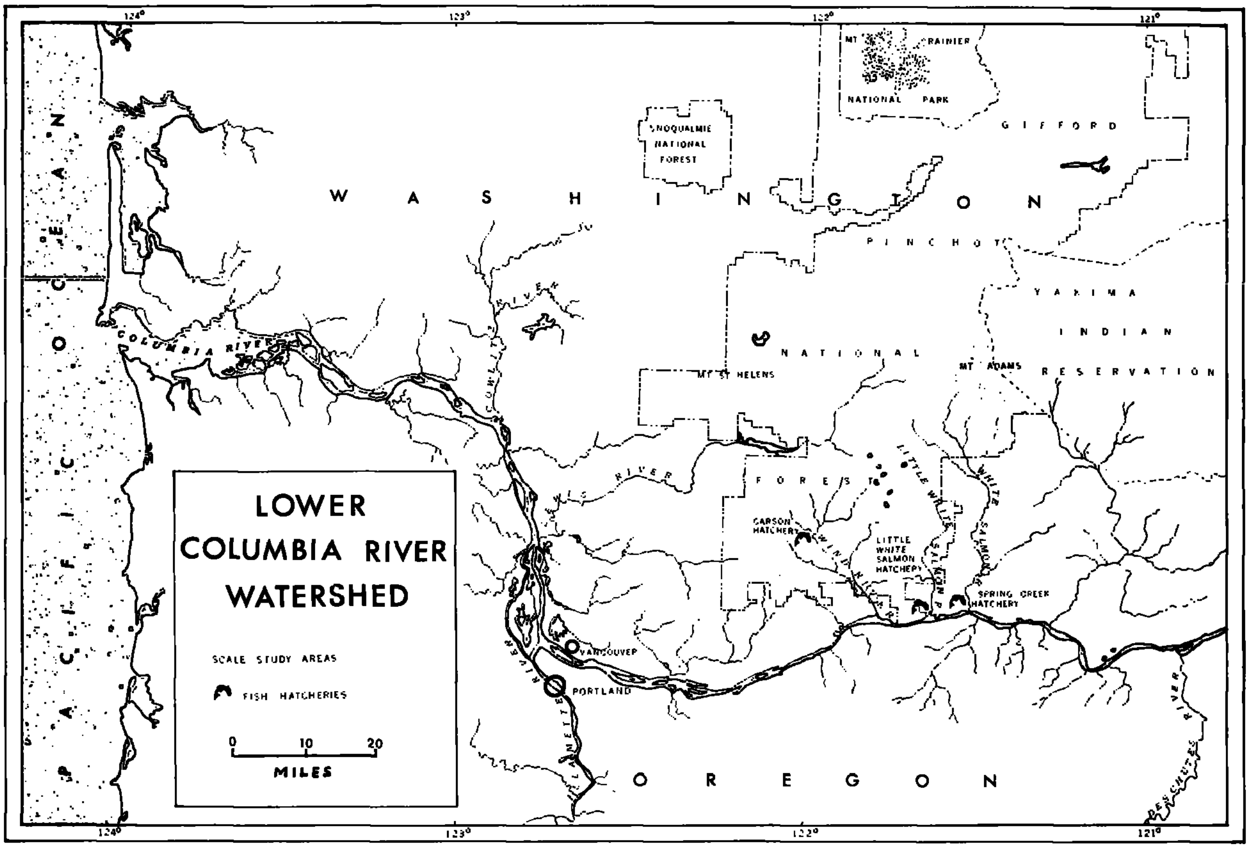

FIGURE 1.—Map of lower Columbia River watershed, showing locations of the three National Fish Hatcheries from which study materials were obtained.

Theoretically speaking, these two groups of fish should have differences in the growth pattern of scales, because at the time of release the fry have not started to grow scales, whereas the fingerlings have already grown scales with circuli. The nuclear area (the central portion of the scale), or at least the initial part of it, of adult scales originating from these two groups of fish must have then grown under different conditions: that from the fry group in river water under lower but variable temperature [6] and feeding conditions, and that from the fingerling group in hatchery water with higher and nearly constant temperature [7] and ample food. It may be expected then that scales from fish released as fry should have more closely spaced circuli in the nuclear zone than those released as fingerlings. Further, because the fry were released 3 months before the fingerlings, they should reach the ocean earlier and consequently may have a different pattern of ocean growth than have the fingerlings.

Practically speaking, if the origin of release — whether fry or fingerling — of returning adults can be identified through scale characters, then the two methods of release can be evaluated without having to mark young fish. Junge and Phinney (1963) indicate that fish released as fingerlings have a much greater survival rate than have fish released as fry. Therefore, the elimination of marking would not only save the costs of marking but also eliminate any possible harm that marking may cause the fish.

[6] Water temperatures of Columbia River at Bonneville Dam in February were 2.8–4.4°C. (1957); 6.1–8.3°C. (1958); 3.9–5.0°C. (1959). U.S. Army Corps of Engineers, Annual Fish Passage Reports.

[7] Water temperature in Spring Creek Hatchery is about 7.8°C. year-round.

To find out whether actual differences existed between scales of adult fish released as fry and those from adults released as fingerlings, we selected scale samples from brood year 1956 because that year had the largest number of specimens that were released as fry. Returns of fish released as fingerlings are plentiful for analyzing this group in any brood year.

In 1959, eight fall chinook salmon with Ad–LP mark (released as fry) were recaptured. Of these, seven were 3 years old and therefore came from 1956 brood. In 1960, 28 such marked chinooks were recaptured and 16 of these were 4 years old and of the 1956 brood. This total of 23 scales that belonged to the 1956 brood, plus 102 3-year-olds that were recaptured in 1959 with Ad–RP marks (released as fingerlings) and 167 4-year-olds that were recaptured in 1960 with the same mark, provide the samples for the following study.

Based on theoretical considerations given earlier, we used two purely objective methods aimed at detecting any difference these two groups of scales might have in growth in fresh water or the first year of growth in the sea.

The first objective method was that of comparing growth patterns revealed by scale graphs based on spacing of circuli. Under a magnification of 140 times, the circuli were marked along the antero-lateral radius on a millimeter graph paper. We then divided the radius into 20-mm. units and calculated the mean spacing of circuli of each unit. For each group of scales, the means of circulus spacing of a unit were summed and averaged to give the mean of the group. When the group means were plotted on the ordinate against the radius units on the abscissa, we obtained a scale graph which shows the growth pattern.

Figure 2 shows information on groups released as fry and as fingerlings.

The fresh-water growth part of figure 2 shows a similar pattern for the two groups, namely, circuli are wide at the start but rapidly narrow down; the extent of growth covers about the same distance on scale radius. Also, there is only a slight difference in the mean spacing of circuli. Such difference, as will be shown in the second method, is not statistically significant.

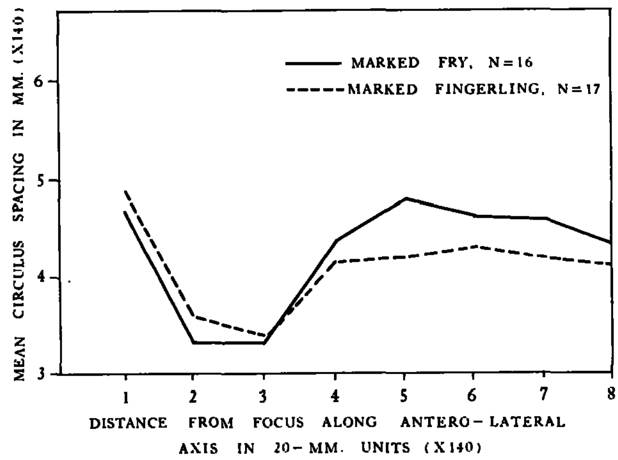

FIGURE 2

FIGURE 2.—Spring Creek Hatchery chinook salmon: Mean scale graphs showing pattern of fresh-water growth and the major portion of first year's marine growth of group marked as fry (solid line) and of group marked as fingerlings (dash line).

Marked difference, however, is evident in the marine growth section of figure 2 (units 4 to 8). The group released as fry has much wider circuli at every unit than has the group released as fingerlings. This is, of course, only a reflection of group difference, as the values plotted are mean widths. At each unit, the mean circulus widths of the two groups of scales overlap widely so that we could not identify the group origin of individual scales on that basis. Examples of scales of adults that were released as marked fry and as marked fingerlings are shown in figures 3 and 4.

The second objective method, aimed at detecting differences in first year growth of fish released as fry and as fingerlings, was to measure and compare the total distance of the first 5 circuli, of the first 10 circuli, and of 10 circuli counted from the 16th through 25th circulus.

The reasons for the selection of these three measurements are as follows: Fish released as fingerlings have developed, in the hatchery, the first 5 circuli and most, if not all, of the first 10 circuli; but the fry that are released develop all circuli in the natural environment. We measured the first 5 and first 10 circuli, therefore, to detect differences in initial fresh-water growth. The third measurement, distance from the 16th through 25th circulus, was made to

FIGURE 3.—A scale of Spring Creek Hatchery chinook salmon that was released as marked fry. Note the relatively wider spacing between circuli in the first year of marineg rowth.

FIGURE 4.—A scale of Spring Creek Hatchery chinook salmon that was released as a marked fingerling. Note the relatively narrower spacing between circuli in the first year of marineg rowth.

study first-year marine growth, because these 10 circuli always represent the major but not the entire part of the first summer growth in the ocean. Using the 10 circuli enables us to have more consistent measurements than we would obtain by measuring the entire first summer growth, because we cannot delimit exactly the first and last circuli of summer growth. Circuli 11 through 15 were purposely skipped, for they may represent some transitional growth and therefore are quite variable as a group.

In reference to scale graphs, the initial 10 circuli are represented by the first two and a half units on the abscissa; and circuli 16 to 25, by units 4 to 6. In essence, the measuring method enables us to check on the graphing method, for we can tabulate the data and subject the results to statistical tests.

The results of the measurements and statistical tests are shown in table 1. In all the tests between the paired sample means, we first tested for the variances (s^2) and then applied the appropriate t-test.

In the comparisons of the first 5 circuli and of the first 10 circuli, the variances of the paired samples are significantly different, and t-test shows that the sample means are not significantly different. This is to say that although circulus spacing in the initial 5 or 10 circuli is more variable in the group released as fry (larger variance) than in the group released as fingerlings, the average values do not differ significantly between these two groups. The latter point confirms the results of the scale graph method

In the comparison of the 10 circuli counted from 16th to 25th circulus, the variances are not significantly different, and t-test shows that the sample mean of "A" (fry releases) is significantly larger than that of "B" (fingerling releases). This is to say that the groups released as fry and as fingerlings have a similar amount of variation in circulus spacing for circuli 16 to 25, but that the average spacing of circuli in the group released as fry is larger than that in the group released as fingerlings. The latter point also confirms the results of the scale graph method.

TABLE 1.—*Frequency and statistics of total distance of circuli of two groups of scales from salmon returning to Spring Creek Hatchery: A—adult chinooks that were marked and released as fry; B—adult chinooks that were marked and released as fingerlings*

Distance	First 5 circuli		First 10 circuli		Circuli 16-25	
	A	B	A	B	A	B
Mm. x 140	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
12–14		2				
14–16	6	12				
16–18	5	66				
18–20	6	70				
20–22	0	74				
22–24	4	31	1			
24–26	1	10		1		2
26–28	1	3		3		1
28–30		1	4	14	1	9
30–32			4	22	1	13
32–34			5	47	2	36
34–36			2	57	1	41
36–38			1	47	5	45
38–40			1	43	3	36
40–42			2	22	1	35
42–44			1	7	3	24
44–46			2	4	2	14
46–48				1	3	10
48–50				1		
50–52					1	2
52–54						
54–56						1
N	23	269	23	269	23	269
$\overline{x}$	18.8	19.6	34.3	35.8	39.8	37.7
s^2	12.69	6.94	32.58	14.97	32.63	23.12
95% confidence limits for ratio of population variances.	$1.09<\frac{s_A^2}{s_B^2}<3.66$		$1.31<\frac{s_A^2}{s_B^2}<4.36$		$0.84<\frac{s_A^2}{s_B^2}<2.82$	
t-statistic	−1.05		−1.24		2.10*	
d.f.	53		24		290	
Value of $[t]$ at 0.05 significance level.	2.01		2.06		1.96	
95% confidence limits for difference between population means.	$-2.34<\mu_1-\mu_2<0.74$		$-3.99<\mu_1-\mu_2<0.99$		$0.14<\mu_1-\mu_2<4.01$	

That the variances of circulus spacing in both the first 5 circuli and the first 10 circuli are significantly greater for the fry-released group than for the fingerling-released group is as we expected, because the fry group grows the first 5 to 10 circuli in the river or estuary, where food and temperature conditions can be highly variable, while the fingerling group grows these same circuli in the hatchery, where the conditions are fairly uniform. Both groups form circuli 16 to 25 in the ocean, which explains why there is no significant difference between the two variances. Why the group released as fry grows more widely spaced circuli than does the group released as fingerlings is not understood. Perhaps it is due to the earlier entry into the ocean by the fry.

SCALE GROWTH IN MARKED AND UNMARKED FALL CHINOOK SALMON

During the 3 years 1957–59 when the Bureau of Commercial Fisheries marked the fall chinook salmon at the Spring Creek Hatchery, both marked and unmarked fish were released simultaneously. When the fish returned, the unmarked fish had a much greater rate of return than the marked fish. Also, at the same age the unmarked chinook were consistently larger than the marked. Examples are given in figure 5 in which the modal length of female unmarked fish is 2 inches, or 6 percent, larger

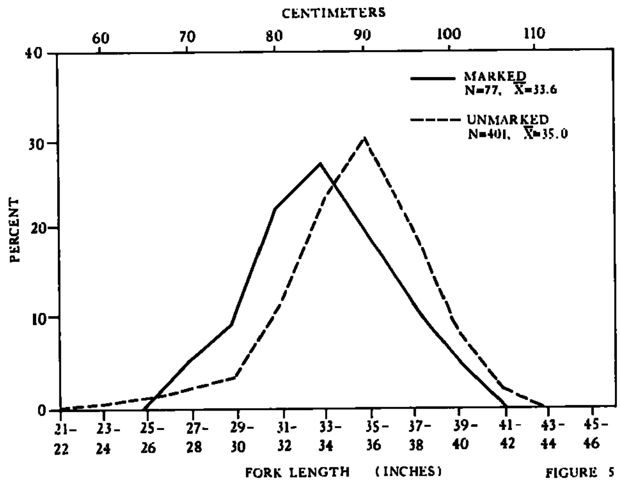

FIGURE 5.—Size frequencies of female 4-year-old Spring Creek Hatchery marked and unmarked chinooks that were released as fingerlings (1956 brood) returned in 1960.

than that of female marked fish, which had their adipose and right pectoral removed. Male chinook salmon exhibited similar differences.

To see if the difference in size between returns of marked and unmarked chinook is manifested in scale growth, we studied the returns of 4-year-old females in 1960. We first compared scales from fish of modal length in each group (33–34 inches in the marked group and 35–36 inches in the unmarked group). Then, we studied unmarked fish 33 to 34 inches long. To do this objectively, we constructed and compared mean scale graphs showing circulus spacing and growth pattern. Of the marked fish returns, only the group released as fingerlings were studied for very few returns were available from fish released as fry.

The three mean scale graphs for the marked and unmarked female fall chinook salmon that returned to the Spring Creek Hatchery in 1960 as 4-year-olds are shown in figure 6. These graphs show the growth period from the beginning of scale growth toward the end of the first summer in the ocean. They represent, therefore, only part of the antero-lateral radius. The initial part of the graphs (units 1–4), which represents fresh-water and intermediate growth, is very similar among the three groups. The remaining part of the graphs (units 5–8), which represents the major part of first marine growth, becomes divergent in that the mean circulus spacing of the marked group is consistently smaller than that of either of the two unmarked groups (33–34 inches, 35–36 inches), with greater difference shown between the marked and the larger unmarked fish.

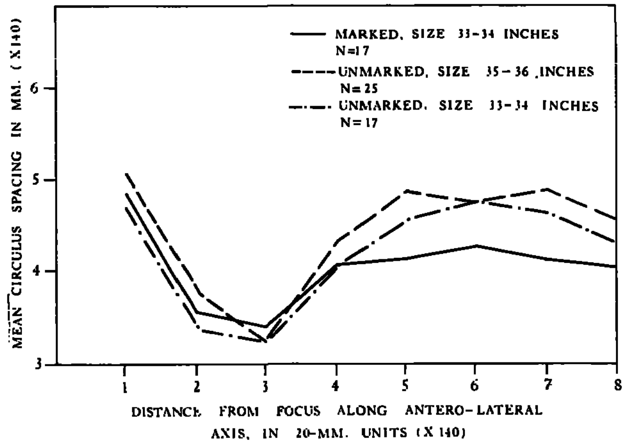

FIGURE 6

FIGURE 6.—Mean scale graphs of marked and unmarked female fall chinooks of three selected size groups that returned to Spring Creek Hatchery in 1960 as 4-year-old fish.

The fact that the initial part of the scale graphs is similar among the three groups of chinook salmon is easily understood, because marking is applied during the fingerling stage after the fish have grown the initial part of the scale. The difference in the remaining part of the scale graphs between the marked and unmarked groups, especially between those of the same size, strongly suggests that marking has slowed down the fish's growth rate, at least during the first summer in the ocean.

To verify the results revealed by the scale graphs, the total distance from the 16th to 25th circulus, which represents the major part of the first year's marine growth, was measured and a t-test applied (table 2). We first tested sample variances, and in both pairs equality can be accepted; therefore, a simple t-test was used. The width of ten marine circuli was significantly greater in the unmarked groups than in the marked group, compared either between two modal lengths of fish or between fish of the same length. These tests thus confirm the results obtained by the scale graph method.

TABLE 2.—*Frequency and statistics of measurements of scale growth during first year's marine life in marked and unmarked fall chinook salmon that returned in 1960 to Spring Creek Hatchery as 4-year-olds*

Distance of 10 circuli (16th–25th)	Marked fish 33-34 inches long	Unmarked fish 33-34 inches long	Marked fish 33-34 inches long	Unmarked fish 35-36 inches long
	A	B	A	B
Mm. x 140	*Number*	*Number*	*Number*	*Number*
31	1	----	1	----
32	0	----	0	----
33	0	----	0	----
34	1	----	1	----
35	0	----	0	----
36	1	1	1	----
37	2	0	2	----
38	2	0	2	1
39	1	0	1	0
40	0	2	0	0
41	2	1	2	4
42	0	1	0	0
43	1	1	1	2
44	3	2	3	1
45	0	2	0	2
46	1	0	1	0
47	0	1	0	3
48	0	0	0	1
49	0	0	0	1
50	0	2	0	4
51	2	2	2	1
52	----	2	----	3
53	----	----	----	1
54	----	----	----	1
55	----	----	----	1
N	17	17	17	26
$\bar{X}$	40.88	45.47	40.88	47.27
s^2	30.23	23.89	30.23	22.12
95 percent confidence limits for ratio of population variances.	$0.29<\frac{s_A^2}{s_B^2}<2.19$		$0.28<\frac{s_A^2}{s_B^2}<1.74$	
t-statistic	−3.58*		4.12*	
d.f.	32		41	
Value of $[t]$ at 0.05 significance level.	2.04		2.02	
95 percent confidence limits for difference between population means.	$-9.95<\mu_1-\mu_2<-2.73$		$3.25<\mu_1-\mu_2<9.53$	

Growth rates of fishes are reflected in the spacing of scale circuli: the faster the growth rate, the wider the spacing between circuli. The present findings, therefore, suggest that marking through the excision of adipose and right pectoral fins in chinook salmon may have been responsible for the slower growth rate of the marked fish. Biologists, using various fin marks, working on various species of fish, and experimenting under various conditions, have obtained contradictory results in this respect. Ricker (1949), for instance, excised the pectoral, both ventrals, or one pectoral and both ventrals of the largemouth bass and found that recoveries of these and unmarked fish indicated that the marked fish were significantly smaller than the unmarked ones. He believes that marking possibly affected the growth rate directly; however, when he marked 2-year-old bluegills, the growth of marked and unmarked fish was the same. Armstrong (1949) studied lake trout fingerlings and found no appreciable difference in length and weight between those that were unmarked and those that had had the adipose removed. Shetter (1951) also shows that removal of the dorsal and adipose fins, right pectoral fin, or right pelvic fin from the fingerling lake trout had no effect on the growth of the marked fish but that removal of the left pectoral appeared to have slowed the growth of the fish. Again, on a study of growth of marked and unmarked lake trout fingerlings in the presence of predatory fish, Shetter (1952) found no significant difference in the growth rate between marked and unmarked groups.

In the Cultus Lake experiments on the sockeye salmon, Foerster (1934, 1936a, 1936b) shows that unmarked smolts had a return rate two and one-half times greater than marked smolts that had both pelvics and adipose or both pelvics and dorsal removed. He shows further that this differential mortality was due to the effect of marking upon marine survival, since marking did not affect lake survival. No data on fish length or scale growth were given, however, so it is not known whether marking did have an adverse effect on growth.

The reasons for the apparent paradoxical results on the effect of marking on the growth rate of fish by various workers may be quite varied. The different results could be due to different fins being clipped, different species being experimented on, different techniques being applied, or different conditions under which the experiments were made.

SCALE GROWTH OF FALL CHINOOK SALMON, RELEASED BETWEEN MAY AND FEBRUARY

At Little White Salmon Hatchery (fig. 1), another Federal installation some 10 miles downriver from the Spring Creek Hatchery, the Bureau of Commercial Fisheries has conducted further marking experiments on fall chinook salmon. Here, for the brood years 1956–58, young chinook salmon were reared for various lengths of time and released at five different times of the year from May to February (see under "Materials and Methods"). A different mark was applied for each release, so that at return a marked fish could be positively identified as to its date of release.

The returns from these experiments offer excellent scale samples for studying the growth of nuclear zones. Fish released earliest (May) should go to sea during the first year, and their scales should show a typical ocean nucleus. Those released latest (February of the following year) spent the first winter in the hatchery, and their scales should therefore have a stream nucleus. Fish released between the above pe-

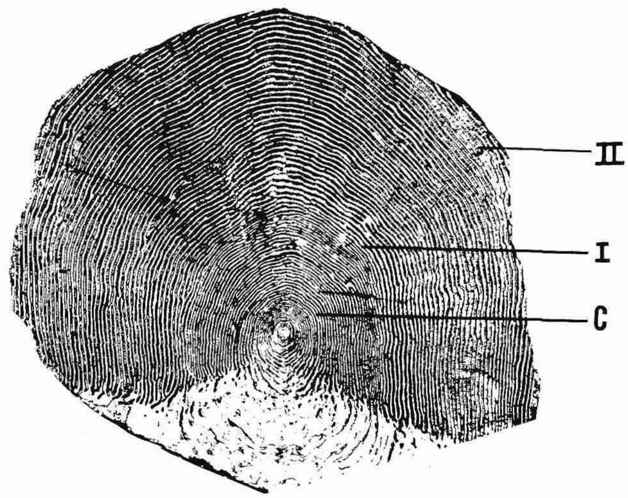

FIGURE 7.—A scale of adult chinook salmon that was released as a fingerling in May at the Little White Salmon Hatchery (May 1957 release, 1959 return).

riods (July, September, and October) should have scale growth of intermediate nature.

First, let us examine a typical scale of an adult chinook that originated from May release (fig. 7). At the center of the scale, there are 14 closely placed fine circuli, which are followed by more widely spaced coarser circuli. A check-like structure (C) is present at the border between the two zones. Most of the fine circuli represent intermediate growth that took place after the fish was released, because young chinook released in May average only two to three circuli on their scales. The zone of more widely spaced coarser circuli that follows the check represents what is generally regarded as marine growth. It is bounded by a distinct band of closely placed circuli (fig. 7, I). Both the check (C) and the band (I) have the appearance of an annulus. But since this is known to be an age II fish (1957 release, 1959 returns), and since the second annulus (II) is evident near the resorbed margin of the scale, only one of the two marks can be regarded as a genuine annulus. Based on relative distance, the band (I) should be regarded as the first annulus. "C," therefore, is a sort of migration check. The entire growth up to and including the band (I), forms what is known as the ocean nucleus. In the ocean nucleus, then, an annulus in the fresh-water growth part is lacking, and that gives rise to the age terminology of "sub-one" for this group,[8] or "O.", to use the terminology of Koo (1962).

Next, let us examine a tipical scale of an adult chinook that returned in 1960 from a February 1958 release (fig. 8). Here, there is also the central crowded area of fine circuli (I) and the surrounding wide marine growth that is bounded by a band of closely placed narrow circuli (II). Although "I" and "II" in this figure appear to be corresponding respectively to "C" and "I" in figure 7, they are different in significance. Because the fish was held in the hatchery over the winter and was not released until February, "I" in figure 8 is a true annulus, not a mere check, as the "C" in figure 7. The central area up to "I" forms what is known as the stream nucleus and because the young fish

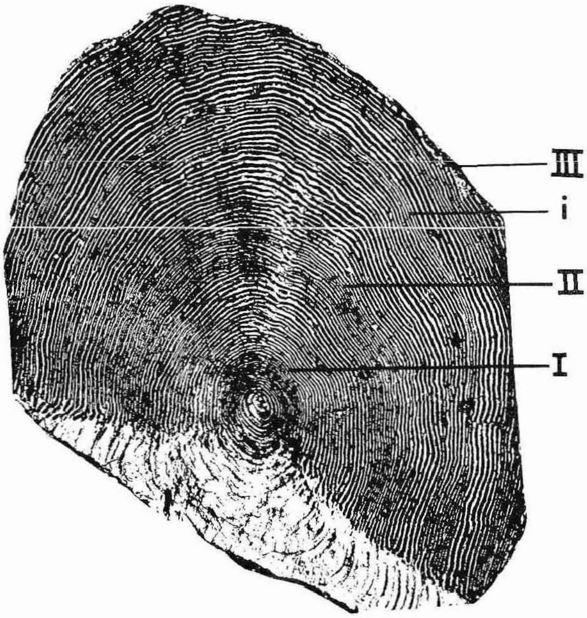

FIGURE 8.—A scale of adult chinook salmon that was released as a fingerling in February at the Little White Salmon Hatchery (February 1958 release, 1960 return).

left fresh water during its second year, it is also referred to as "sub-two age," or "1.", meaning one annulus in fresh-water growth. This fish is known to be age III, so there can be only two marine annuli, which are labeled as II and III in figure 8. The narrow band (i) between these two annuli must therefore be regarded as an incidental check.

From the standpoint of age determination, it is imperative that an ocean nucleus and a stream nucleus can be positively identified, for it will make a difference of 1 year in age, depending upon whether an annulus or a check is assigned to the central fine circuli area. No definite criteria can be found in literature that positively differentiate a mere check from a genuine annulus in this nuclear area of growth in chinook scales. Determination of age is usually based on the appearance of the nuclear zone and is highly dependent upon personal judgment. Thus, a stream nucleus has been described as an area of many closely placed circuli bounded by a distinct narrow band of more

[8] The term "sub-one" is derived from the subscript of Gilbert-Rich's (1927) scale formula, for example, 3_1, 4_1.

closely spaced circuli, the annulus. An ocean nucleus, on the other hand, is recognized when the nuclear zone consists of relatively few but wider circuli that are not marked off by a distinct check from the ensuing widely spaced marine growth.

Unfortunately, nuclear zones of many chinook salmon scales are not clearly defined so that the morphology of the nuclear zones alone does not enable us always to differentiate with certainty the ocean nuclei from the stream nuclei. If, for example, the scales in figures 7 and 8 had come from fish of unknown age, we would have no real basis for calling one mark a mere check (C) and the other a true annulus (I).

Obviously, something other than visual determination must be devised. As we had available a large number of scale samples from recaptured marked chinook salmon comprising both the stream type and the ocean type of nuclear growth, we were able to compare the characters of these two groups of scales on a quantitative basis. Because the nuclear zones of circuli failed to show significant differences, our study was extended to cover marine growth as well, and we have developed some criteria that help to guide the chinook scale reader to differentiate ocean from stream nuclei on a more objective basis.

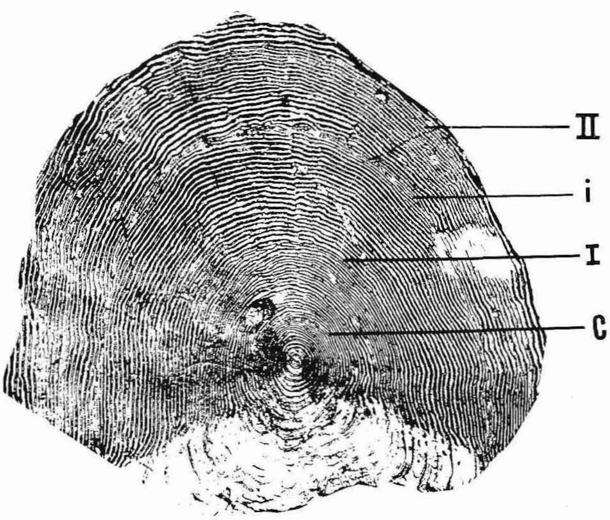

FIGURE 9.—A scale of adult chinook salmon that was released as a fingerling in July at the Little White Salmon Hatchery (July 1957 release, 1959 return.

Before we discuss quantitative measurements, let us examine some scales of adult chinook that originated from releases during the intermediate period between May of the first year and February of the next year, to observe the transition from ocean nucleus growth type to stream nucleus growth type.

A scale of a July release origin is shown in figure 9. Being similar to the scale of a May release origin (fig. 7), it also shows an ocean nucleus (I) and a strong check (C) for the nuclear area. Based on the known age of this

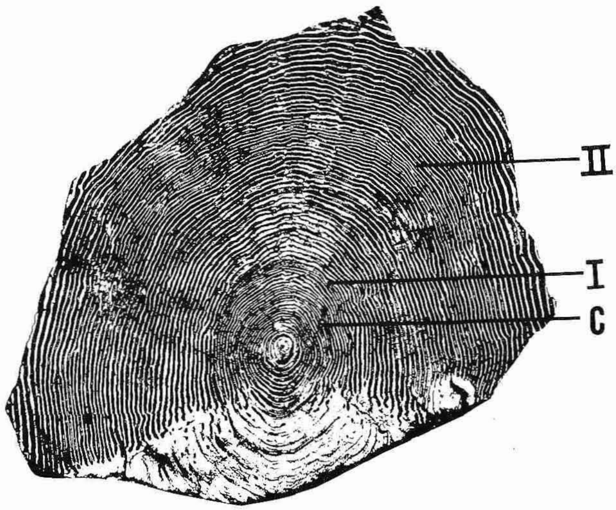

FIGURE 10.—A scale of adult chinook salmon that was released as a fingerling in September at the Little White Salmon Hatchery (September 1958 release, 1960 return).

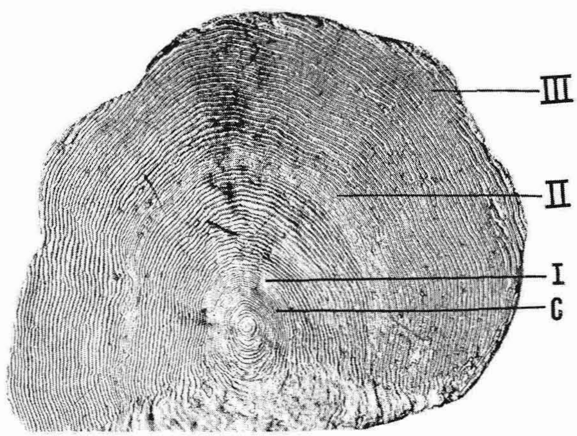

FIGURE 11.—A scale of adult chinook salmon that was released as a fingerling in September at the Little White Salmon Hatchery (September 1957 release, 1960 return).

fish, we know that "I" marks an annulus and "C" is merely a check. An incidental check (i) is also present between annuli I and II.

Two scales of adults that came from September release are shown in figures 10 and 11. In figure 10, the marine growth of the first year (C to I) is much reduced as compared with the scale of May or July release origin (figs. 7 and 9). Consequently, the annulus (I) is getting closer to the check (C), and the entire ocean nucleus becomes much smaller in size. Because of this, it is easy to determine that the check (C) here is *not* an annulus. Further reduction in the first year's marine growth is seen in the second example of a September release (fig. 11). Here the entire nuclear zone assumes the appearance of a stream nucleus. Indeed, it is questionable whether there is any amount of true marine growth inside the first annulus (I).

A scale of the October release origin (fig. 12) shows the same characteristics, i.e., a much reduced zone between "C" and "I," and a nuclear zone that assumes the look of a stream nucleus. At least, as far as age determination is concerned, because the total age of this fish is known to be III, it is certain that "I" is the first and only annulus up to that point, much as "I" in a typical stream nucleus such as that

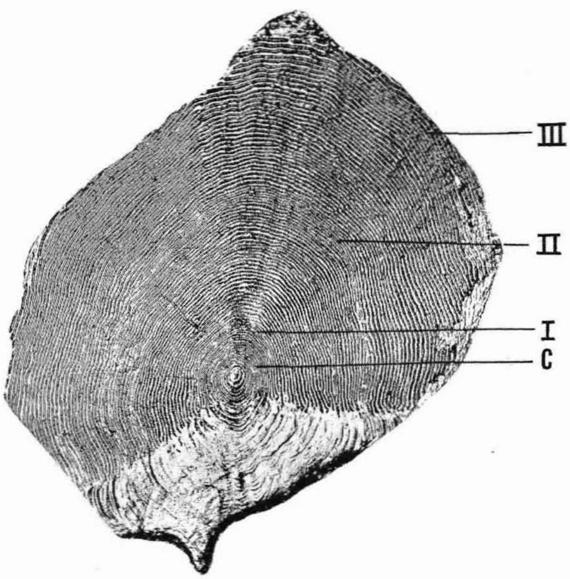

FIGURE 12.—A scale of adult chinook salmon that was released as a fingerling in October at the Little White Salmon Hatchery (October 1957 release, 1960 return).

of a February release origin (fig. 8).

From the above series of examples, it is evident that when the young chinook salmon were released as hatch-of-the-year from May through July, they entered the ocean during the growing season of the first year after some sojourn in the river. As a result, there was a large number of wide marine circuli outside the central zone of narrow fresh-water circuli, resulting in a large ocean nucleus. As the release date became later and later in the year (September and October), however, the chinook salmon would miss more and more of the current season's marine growth, and the result was a nuclear type similar in appearance to a stream nucleus. Finally, when the young chinook salmon were reared in fresh water over winter and were not released until February of the second year, the nuclear zone was composed solely of fresh-water growth, and any marine growth belonged to the following year. For all practical purposes, scales from September and October releases should be treated as stream nucleus type, for there is no way of knowing that "I" is not a stream annulus without the knowledge of release date.

Because the fresh-water growth part in an ocean nucleus may not be distinguishable from that of a stream nucleus, we extended our study into the marine growth of the first and second years of ocean life to find differences between these two types. In this study, 72 returns from May and July releases were treated as one group representing the ocean nucleus type, and 85 returns from October and February releases were treated as another group representing the stream nucleus type.

The method consists of first locating the apparent first marine annulus, i.e., a band of narrow circuli after a zone of wide circuli. This is "I" in figures 7 and 9 and "II" in figures 8, 11, and 12. Then, from the midpoint of this annulus band 20 circuli were counted outward toward the edge of the scale along an antero-lateral radius, and the total distance of these 20 circuli was measured and represented by "A." This represents the major part of the second year growth in ocean for both groups of scales. Similarly, 20 circuli were counted inward toward the focus and the total distance was measured as "B" (fig. 13), which represents the first year growth in ocean for both groups of scales. Then we computed the ratio of A/B, which is the ratio of second year marine growth to the first year marine growth.

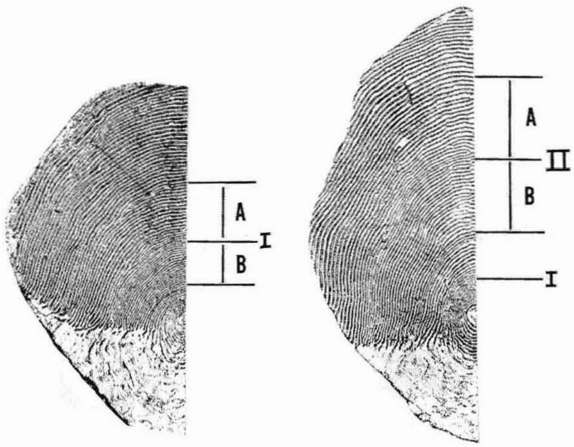

FIGURE 13.—The measurement of circulus spacing. Left, chinook scale with an ocean nucleus; right, chinook scale with a stream nucleus.

We found that in the May to July release group, circuli of the second year marine growth (A) were, on the average, nearly 50 percent wider than the first year marine growth (B); whereas in the October to February release group, "A" was only 22 percent wider than "B". The frequency distribution of the ratio A/B of these two groups of scales is shown in figure 14. It is obvious that the two groups are distinctly different in the value of A/B, but there is also enough overlap so that not all scales can be identified to their nuclear growth type on this character alone.

DIFFERENTIATION OF FALL CHINOOK AND SPRING CHINOOK SCALES BY MARINE GROWTH

The fall chinook scales normally have a typical ocean nucleus (sub-one age), and the spring chinook scales normally have a typical stream nucleus (sub-two age). The nuclear growth part of these two types of scales cannot always be distinguished. So in order to identify these two groups of fish, we applied the method of comparing first and second year's marine

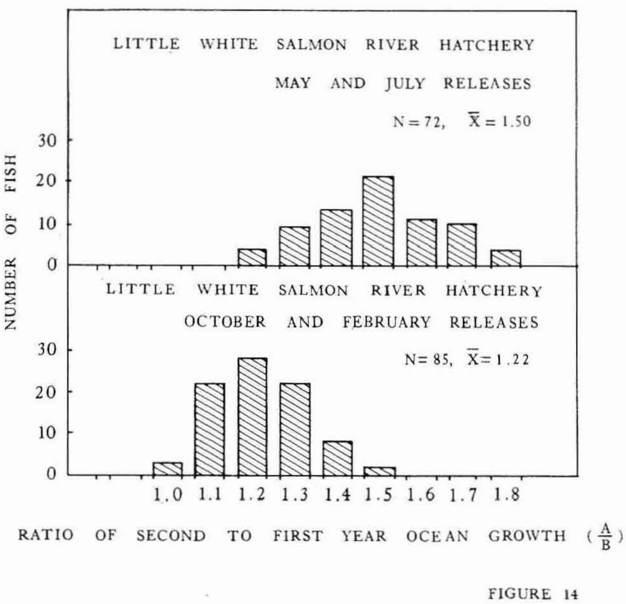

FIGURE 14.—Frequency distribution of the ratio of second to first year marine growth (A/B) of little white salmon Hatchery recaptures of May and July releases, and October and February releases.

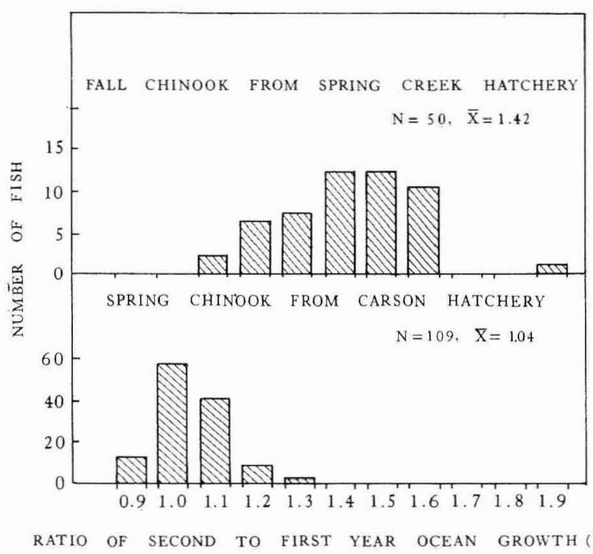

FIGURE 15.—Frequency distribution of the ratio of second to first year's marine growth (—A/B) of fall chinook and spring chinook.

growth as developed from the study of Little White Salmon Hatchery mark recovery specimens. For study material, we used scales collected from unmarked fall chinook at Spring Creek Hatchery and those collected from unmarked spring chinook at Carson Hatchery.

Scales of 50 fall chinook and 109 spring chinook were measured. The frequency distributions of the ratio of second year's to first year's marine growth A/B of these two groups of fish are shown in figure 15. These distributions show clearly that fall and spring chinooks are distinctly separate groups as far as the character of marine growth is concerned. The difference between the two groups is similar to that between May to July release group and October to February release group of Little White Salmon Hatchery fall chinook. In other words, the fall chinook are similar to May to July release group in having a large A/B ratio, and the spring chinook are similar to October to February release group of fall chinook in having a small A/B ratio.

The outstanding feature of spring chinook scales is that the marine growth of the first year is nearly as good as that of the second year, so that its A/B ratio approximates 1.0, as compared with 1.2 for the fall chinook released in October to February. In fact, this character alone is often sufficient to distinguish a spring run from a fall run of chinook salmon. An example of a spring chinook scale is shown in figure 16, in which the circuli inside of the first marine annulus (II) are as widely spaced as circuli outside of it.

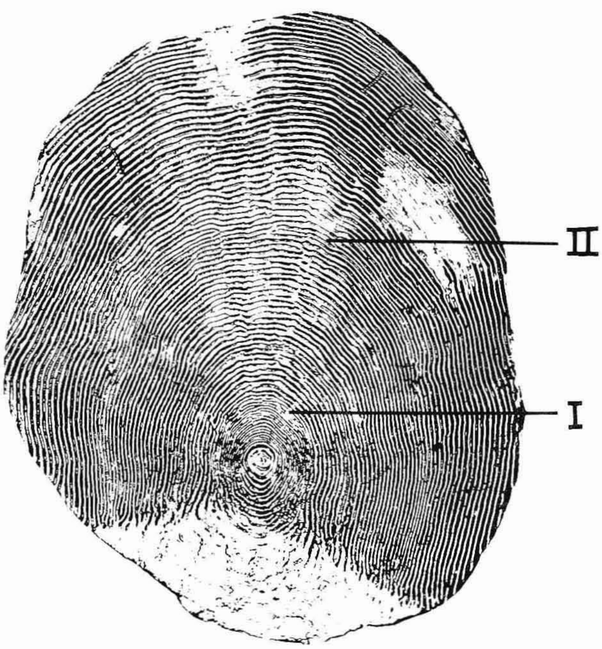

FIGURE 16.—A scale of a spring chinook salmon.

SUMMARY AND CONCLUSIONS

Scales of Columbia River chinook salmon were studied to find answers to the following questions:

1. Is it possible, from structures of adult chinook scales, to identify whether a fish has originated from fry or fingerling migrant?

The answer is negative. Scales from marked fish recoveries showed that there was no significant difference in the mean values of circulus spacing in nuclear growth part between chinook salmon released as fry and those released as fingerlings, although the spacing is more variable in the fry than in the fingerling group. In the first marine growth, circuli in the group released as fry are more widely spaced than in the group released as fingerlings. While the difference is statistically significant, there was too much overlap so that identification of individual scales was not possible.

2. Can the effect of marking, if any, on growth of chinook salmon be detected by scale studies?

The answer is positive. At the Spring Creek Hatchery, fall chinook fingerlings were marked by removal of adipose and right pectoral fins. When scales from marked fish recoveries were compared with those from unmarked fish returns, circulus spacing in marine growth of the marked group was found narrower than the unmarked group.

3. How do the scales of early season (May-July) releases of fall chinook differ from those of later season (October-February) releases?

In answering the above question, we found some interesting relations between scale growth patterns and times of release. Early season releases of fall chinook resulted in an ocean nucleus type (sub-one age) that is typical of fall chinook scales. Late season releases, however, resulted in a stream nucleus type (sub-two age) resembling that of spring chinook scales. Moreover, these two groups of scales are different in marine growth patterns. When circulus spacing in the second year marine growth is compared with that in the first year marine growth, the ratio is far greater for the sub-one group than for the sub-two group.

4. Can fall chinook scales be separated from spring chinook scales by objective means?

The answer is positive. Fall and spring chinooks can be differentiated by their scales. Differentiation, however, is not made from nuclear growth patterns as is usually done visually, but is achieved objectively by comparing marine growth circuli of the first 2 years, the same technique as used for early-season and late-season releases of fall chinook. In the spring chinook, circuli in the second year of marine growth are nearly 50 percent more widely spaced than those in the first year; whereas in the fall chinook, they are about the same.

ACKNOWLEDGMENTS

The most important ground work in connection with the present paper had been done before we started our studies, for marking experiments on the Columbia River chinook salmon and collecting scale samples and pertinent data had been performed by the Bureau of Commercial Fisheries of the U.S. Fish and Wildlife Service. Paul Zimmer, Harlan E. Johnson, and Roy Wahle of the Bureau provided the study material and data. The Fish Commission of Oregon and the Washington State Department of Fisheries, which are also studying the Columbia River chinook salmon, supplied additional material and information, and in this connection, I was assisted by Sigurd J. Westrheim, Raymond A. Willis, and Robert N. Thompson of the former organization and Peter Bergman of the latter agency. Charles E. Walker of the Canadian Department of Fisheries in Vancouver, British Columbia, sent us some duplicate scale impressions of Big Qualicum chinook salmon for our study, and Gerald J. Paulik of the Fisheries Research Institute of the University of Washington advised us on the statistical treatment of the data.

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