AGE AND LENGTH COMPOSITION OF COLUMBIA BASIN SPRING CHINOOK SALMON SAMPLED AT BONNEVILLE DAM IN 1989

Technical Report 90-1

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February 15, 1990

ACKNOWLEDGEMENTS

We sincerely thank the following individuals for their assistance in this project: Paul Lumley, Mike Matylewich, Phil Mundy, Phil Roger, and Howard Schaller of the Columbia River Inter-Tribal Fish Commission; Lyle Gilbreath of the National Marine Fisheries Service; Curt Melcher of the Oregon Department of Fish and Wildlife; Gary Johnson and Jim Kuskie of the U.S. Army Corps of Engineers; and Curt Knudsen and John Sneva of the Washington Department of Fisheries.

This report is the result of research funded by U.S. Government (Bureau of Indian Affairs, Department of Interior) Contract No. P00C1409445 for implementation of the U.S.-Canada Pacific Salmon Treaty.

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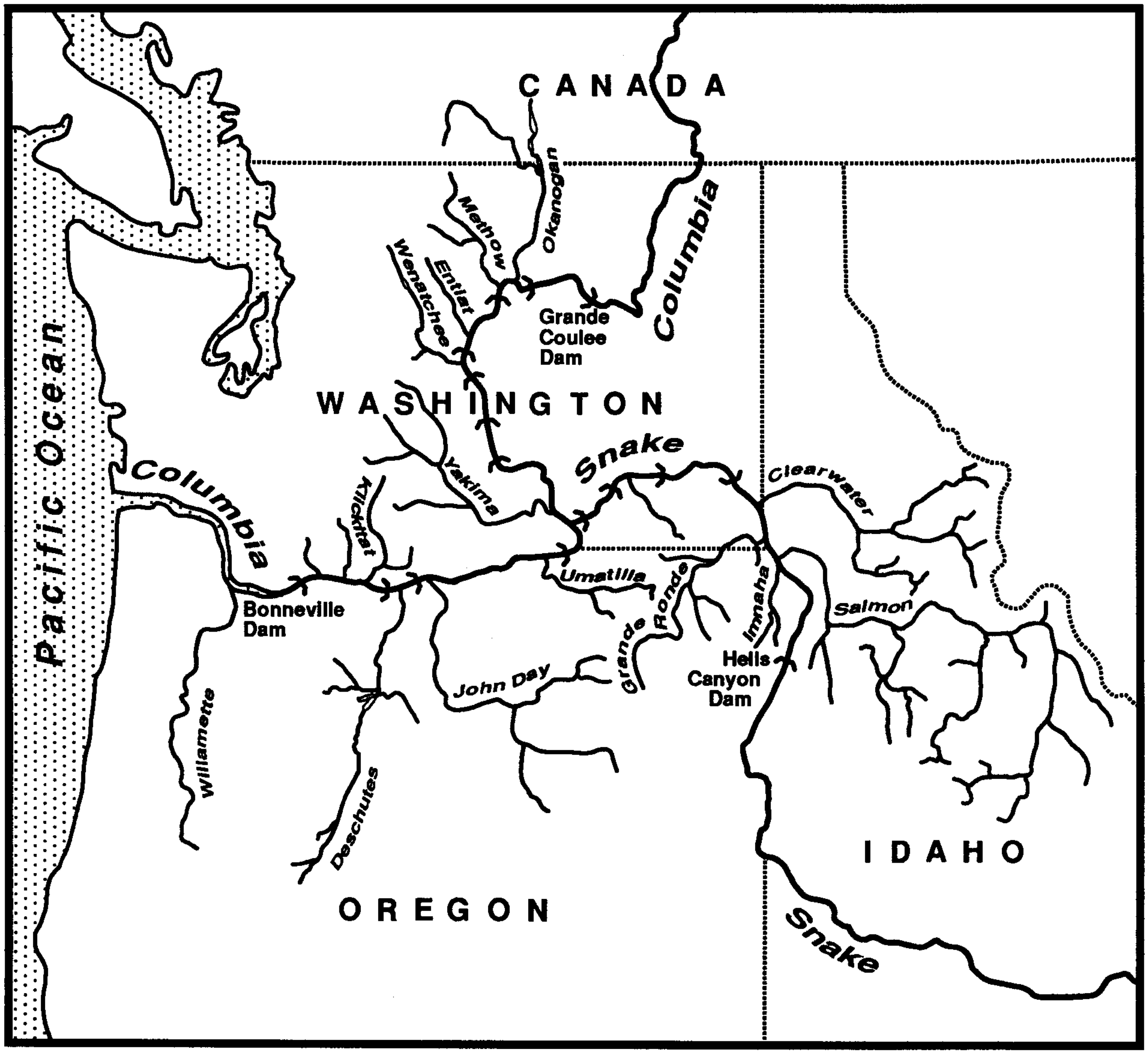
INTRODUCTION

The Stock Identification Project of the Columbia River Inter-Tribal Fish Commission (CRITFC) is a part of the U.S.-Canada Pacific Salmon Treaty spawning escapement monitoring program (Pacific Salmon Treaty 1985). The project is designed to develop and apply identification techniques to individual stocks or groups of stocks of Columbia Basin salmon originating above Bonneville Dam. At the present time, scale pattern analysis is the primary study method.

This report summarizes age and length-at-age composition estimates for spring chinook salmon, (*Oncorhynchus tshawytscha* Walbaum), sampled at Bonneville Dam in 1989. Bonneville Dam is located on the Columbia River at river kilometer 235 (Figure 1). At this sampling location, the spring chinook salmon population is composed of a mixture of both hatchery and natural origin stocks. This research was begun in 1986, and reports of both 1987 and 1988 results are available (Schwartzberg 1988, 1989).

Figure 1. Map of the Columbia Basin showing principal (upriver) spring chinook salmon spawning and rearing tributaries and Bonneville, Grand Coulee, and Hells Canyon dams.



METHODS

Sampling

To collect a representative sample of the spring chinook salmon population, fish were trapped at the Fisheries Engineering and Research Laboratory (FERL) located beside the Second Powerhouse (north side) at Bonneville Dam. Work was done with the assistance and cooperation of the U.S. Army Corps of Engineers, the National Marine Fisheries Service, and the Oregon Department of Fish and Wildlife.

Fish were trapped, anesthetized, quickly sampled for scales and biological data, allowed to recover, and then returned to the exit fishway leading to a main fish ladder. Six scales per fish were collected to minimize the sample rejection rate. Length measurements were recorded, as were observed mark and/or tag information. No live fish were sacrificed in the study. Consequently, sex of collected specimens, all in the earliest stages of sexual maturation, could not be determined. Field sampling procedures followed guidelines established for this project (Schwartzberg 1987).

Sample Design

The sample was composed of 560 fish (Table 1). This sample size was based on desired levels of precision and accuracy (p = 0.05, c.i. = 0.90; Bernard 1982). Weekly sample sizes initially were based on the average weekly proportion of the total annual run estimated from counts made at Bonneville Dam during the previous ten years (Columbia River Inter-Tribal Fish Commission 1989).

In both study years 1987 and 1988, no corrections were made to account for deviations in actual run timing from ten year averages. In 1989, actual run timing was determined from post season analysis of 1989 Bonneville Dam fish counts where all upstream migrating fish are counted visually in counting stations at each fish ladder. If actual run timing differed significantly from that predicted by the ten year average, the (uncorrected) total age and length-at-age composition estimates would thus contain a time related bias. An approach was used to correct for potential bias that was based on a stratified sampling method (Cochran 1977). A corrected and unbiased stratified

Table 1. Weekly and cumulative sample sizes for Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1989.

Date	Statistical[1] Week	10 yr. Avg.[2] (Cum.%)	Samp. Size (Cum. No.)	Samp./Wk. (Desired)	Samp./Wk. (Actual)
4/05,06/89	14[3]	0.07	40	40	42
4/10,14/89	15	0.20	112	72	67
4/17,19/89	16	0.38	214	102	91
4/24/89	17	0.56	313	99	90
5/01/89	18	0.72	406	93	80
5/09/89	19	0.85	474	68	60
5/15/89	20	0.93	521	47	45
5/22/89	21	0.98	548	27	25
5/30/89	22	1.00	560	12	11
Total				**560[4]**	**511[5]**

1. Statistical weeks are sequentially numbered calendar-year weeks. Excepting the first and last week of most years, weeks are seven days long, beginning on Sunday and ending on Saturday. In 1989, for example, Statistical Week 14 began on April 2 and Statistical Week 22 began on May 28.
2. The cumulative percentage was based on the proportional weekly migration rate for previous years' spring chinook counts at Bonneville Dam (ten year average, 1979 -1988).
3. The ten year average and sample sizes for Statistical Week 14 were calculated to include spring chinook fish counts at Bonneville Dam prior to week 14.
4. The total sample size (560) was based on the number of samples necessary to obtain a population composition estimate (p = 0.05, c.i. = .90) given three primary age categories within the population, an infinite estimated population size, and a 0.15 rate of unusable samples.
5. Differences between the number of samples desired and the number of samples collected and analyzed reflects over or under sampling during certain weeks and the rejection of unusable scale samples.

estimate of the total proportion of fish in a given age class, p_{st}, can be calculated as:

$$p_{st} = \frac{\sum_h (N_h p_h)}{N}$$

where h is the statistical week, N_h the total number of spring chinook migrating over Bonneville Dam during that week, p_h the proportion of fish belonging to the given age class in the sample for week h, and N the total count for the season. The quantity in the parentheses, the estimated number of fish of a given age class in week h, is summed over all weeks. The average length by age class, $\overline{y_{st}}$, was computed as:

$$\overline{y_{st}} = \frac{\sum_h (N_h \overline{y_h})}{N}$$

where $\overline{y_h}$ is the average length by age class for a given week. The quantity in the parentheses, the average length weighted by the weekly population size for a given age class, is summed over all weeks. The variance for this estimate was calculated as:

$$V(\overline{y_{st}}) = \sum_h \left(\frac{N_h}{N}\right)^2 V(\overline{y_h})$$

with the quantity in the parentheses, a weighting factor which weights the variance of the length for a given week by the size of the run for that week, again being summed over all weeks.

The 1989 results were corrected using this stratified sampling method. These corrections were also made to previous years' results from 1987 and 1988 and are reported herein.

Age Determination

Scales were prepared and mounted according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963). Individual samples were visually examined by CRITFC staff and were categorized using well established scale age-estimation methods (Johnston 1905, Gilbert 1913, Van

Oosten 1929). Age estimates were corroborated by personnel at the Harvest Management Division of the Washington Department of Fisheries. Validation of ages (Beamish and McFarlane 1983) was not extensive because very few known age fish were present in the sample.

The method used for fish age description is that recommended by Koo (1955), which is sometimes referred to as the *European* method. The number of winters a fish spent in freshwater (not including the winter of egg incubation) is described by an Arabic numeral followed by a dot. The number of winters a fish spent in the ocean is indicated by the numeral following the dot. Total fish-age is equal to one plus the sum of both numerals.

Comparison of Age Composition Estimates

Age composition estimates obtained from Bonneville Dam scale samples were compared to estimates obtained from two different and independent sources. The first comparison was made to visual fish counts from Bonneville Dam. Spring chinook salmon estimated to be less than approximately 61 cm (24 in) in overall length are counted separately as *jacks*, typically of age 1.1. An estimate of the proportion of jacks passing Bonneville Dam was made by dividing the number of visually counted spring chinook jacks by the total number of adult and jack chinook counted.

An additional estimate of age composition was obtained from scales collected from a spring chinook test fishery located approximately 32 km downstream from Bonneville Dam, called the *Corbett fishery*. The Corbett fishery is conducted annually by the Washington Department of Fisheries to collect spring chinook age-specific population abundance data (Dammers 1989). The data are then used in linear forecasting run-size prediction models based on sibling age-class returns. The sampling period is limited to April 1 through April 30, and 18.42 cm (7.25 in.)-mesh gillnets are used.

Length Measurements

Fork lengths were measured to the nearest 0.5 cm. Mean lengths and measurements of variability were calculated for each age class and brood year, by weekly sampling period, and for the entire sample.

RESULTS

Run Timing and Sampling Accuracy

Post season analysis of the 1989 sample design disclosed a time related bias because an averaged run timing prediction based on the previous ten years' Bonneville Dam fish counts differed from the actual 1989 run timing. This bias was a result of spring chinook returning in much larger proportions during the earlier part of the 1989 migration (Statistical weeks 15 through 18) than was predicted by the ten year average on which weekly sample sizes were based (Table 2). The proportion of the entire run passing Bonneville Dam during this period was predicted to be 0.65. Post season analysis, however, showed that 0.80 of the 1989 run passed Bonneville Dam during this time period. The resulting difference in run timing created a bias in uncorrected total sample age and length-at-age estimates. This bias proved to be most significant in estimates of age composition. Corrected estimates of total age and length-at-age compostion will therefore be reported.

Age Composition Estimates

Four-year-old fish (ages 1.2 and 0.3 - 1985 brood) were estimated to compose 0.70 (Figure 2) of the total sample. (Known age fish composed only a portion of the sample. Therefore all scale age and length-at age-composition results reported could not be validated and must be considered estimates.) This age class was predominant in eight of the nine weekly 1989 samples (Table 3, Figure 3), ranging between 0.42 (Statistical Week 19) and 0.86 (Statistical Week 17). Five-year-old fish (ages 1.3 and 0.4 - 1984 brood) were next highest in abundance, comprising 0.18 of the total sample. Weekly proportions of five-year-old fish ranged between 0.08 (Statistical Week 19) and 0.45 (Statistical Week 14).

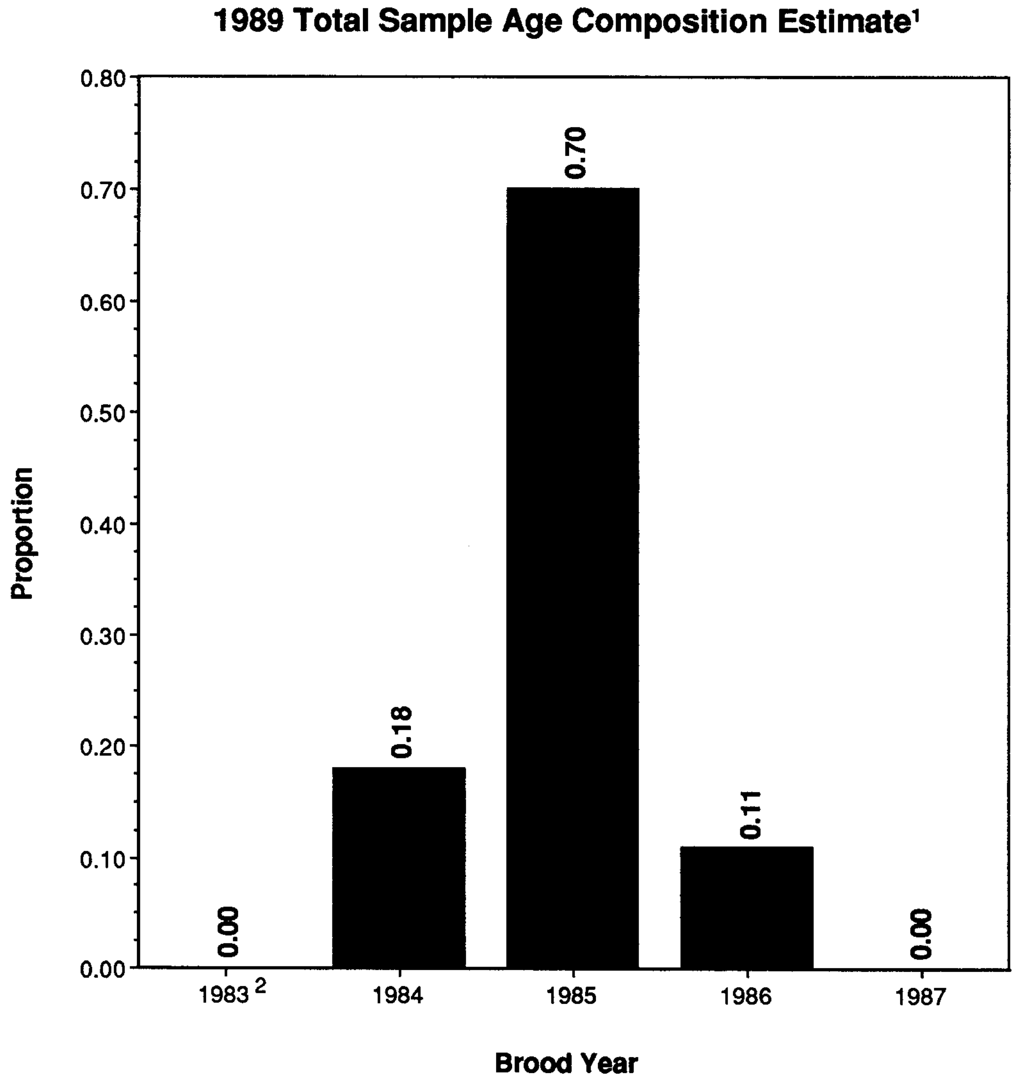
Three-year-old fish (ages 1.1 and 0.2 - 1986 brood) made up 0.11 of the total sample. Weekly proportions ranged between 0.00 (Statistical Week 14) and 0.50 (Statistical Week 19). One six-year-old fish (age 1.4 - 1983 brood) was observed in Statistical Week 16.

Table 2. Actual 1989 run timing of Columbia Basin spring chinook salmon compared with that predicted by a ten year average of Bonneville Dam visual fish ladder counts.

Statistical[1] Week	1989[2] (Weekly %)	1989 (Cum. %)	10 Yr. Avg.[3] (Weekly %)	10 Yr. Avg. (Cum. %)
14 or before	0.02	0.02	0.07	0.07
15	0.16	0.18	0.13	0.20
16	0.20	0.38	0.18	0.38
17	0.24	0.62	0.17	0.56
18	0.19	0.81	0.17	0.73
19	0.09	0.90	0.12	0.85
20	0.05	0.95	0.08	0.93
21	0.03	0.98	0.05	0.98
22	0.02	1.00	0.02	1.00

1. Statistical weeks are sequentially numbered calendar-year weeks. Excepting the first and last week of most years, weeks are seven days long, beginning on Sunday and ending on Saturday. In 1989, for example, Statistical Week 14 began on April 2 and Statistical Week 22 began on May 28.
2. The proportional weekly migration rate for 1989 was based on post season analysis of Bonneville Dam fish ladder counts (Columbia River Inter-Tribal Fish Commission 1989).
3. The proportional weekly migration rate was based on previous years' spring chinook counts at Bonneville Dam (ten year average, 1979-1988).

Figure 2. Age composition estimates of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1989.



1. Rounding errors caused sample proportions to not total 1.0.
2. Estimated proportion was 0.002

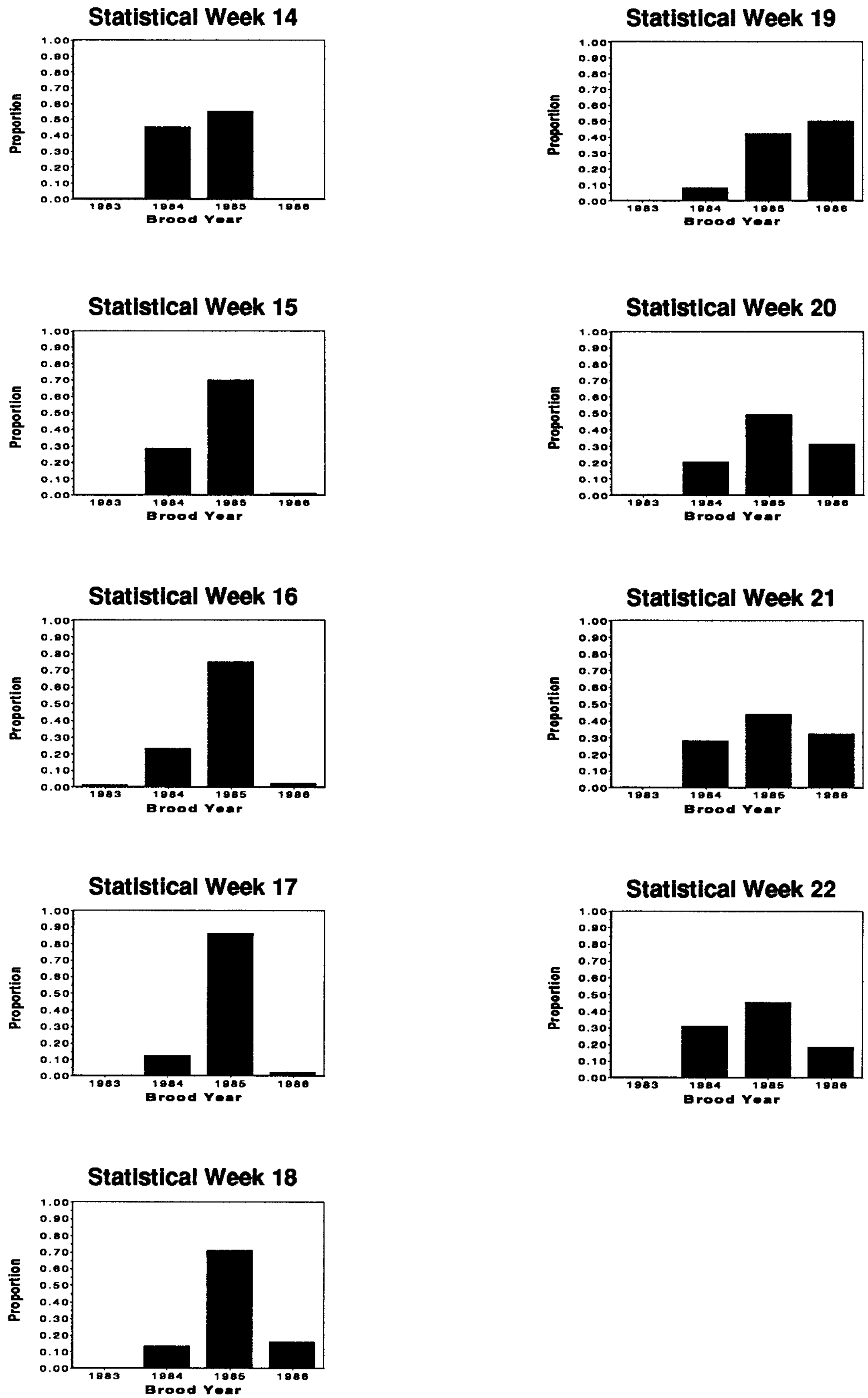
Table 3. Weekly age composition estimates of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1989.

Brood Year and Age Class[1]

Statistical[2]	1986		1985		1984		1983
Week	0.2	1.1	0.3	1.2	0.4	1.3	1.4
14				0.55		0.45	
15		0.01		0.70		0.28	
16		0.02		0.75		0.22	0.01
17		0.02		0.86		0.12	
18	0.01	0.15	0.01	0.70		0.13	
19	0.02	0.48	0.02	0.40		0.08	
20		0.29	0.02	0.47	0.01	0.20	
21		0.28	0.04	0.40		0.28	
22		0.18		0.45	0.04	0.27	
Total Sample	0.00[3]	0.13	0.01	0.64	0.00[3]	0.20	0.00[4]
Corrected[6]	0.00[3]	0.11	0.01	0.69	0.00[5]	0.18	0.00[4]

1. Rounding errors caused sample proportions to occasionally not total 1.0.
2. Statistical weeks are sequentially numbered calendar-year weeks. Excepting the first and last week of most years, weeks are seven days long, beginning on Sunday and ending on Saturday. In 1989, for example, Statistical Week 14 began on April 2 and Statistical Week 22 began on May 28.
3. Estimated proportion was 0.004.
4. Estimated proportion was 0.002.
5. Estimated proportion was 0.003.
6. Corrected to account for differences between actual run timing and that assumed in the sample design.

Figure 3. Weekly age composition estimates of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1989.



Eight fish, or 0.02 of the total sample, were judged to be age 0-plus (four age 0.3, two age 0.2, and two age 0.4). These fish are believed to have originated at the Little White Salmon National Fish Hatchery and to be a result of that hatchery's accelerated rearing program. Age 0-plus fish are combined with their respective brood-year cohorts in the above summaries.

Eight percent of the total sample was rejected and not classified by age because of unreadable scales.

Annual age composition estimates for 1987-1989 are provided in Figure 4.

Comparison of Age Composition Estimates

The proportion of spring chinook jacks in the entire 1989 sample was estimated to be 0.11. This compares to 0.07 based on visual fish counts made at Bonneville Dam fish ladders. In 1987 and 1988, corrected results from our studies estimate that jack abundance was 0.04 and 0.06, respectively. Visual fish counts estimated jack abundance to be 0.03 and 0.04 during those years, respectively.

The 1989 Corbett test fishery age composition estimates agreed closely with those of our study correcting for the fact that Corbett gear does not effectively catch smaller spring chinook (Dammers 1989). Removing jacks from our estimates yields an age-composition profile of 0.78 four-year-old and 0.22 five-year-old spring chinook compared to the Corbett estimate of 0.77 four-year-old, 0.22 five-year-old, and 0.01 six-year-old fish.

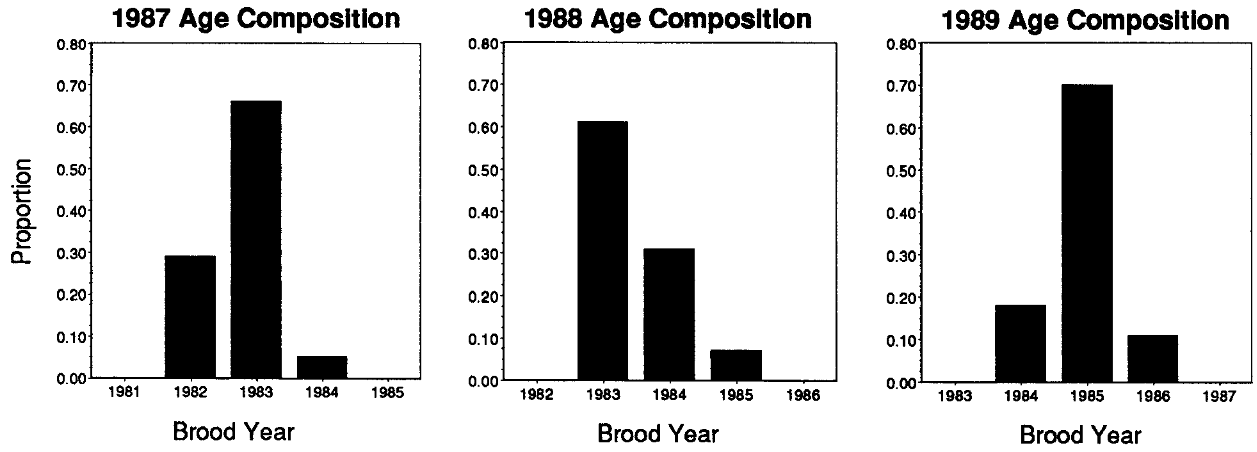
Length-at-Age Composition

The average length of three-year-old fish (1986 brood) in the total sample was 48.6 cm (Table 4, Figure 5). The 0.90 confidence interval was 39.7 to 57.6 cm (n = 70). The average length of four-year-old fish (1985 brood) was 72.1 cm, with a 0.90 confidence interval of 64.3 to 80.0 cm (n = 335). The average length of five-year-old fish (1984 brood) was 87.5 cm with a 0.90 confidence interval of 77.5 to 97. 5 cm (n = 105).

Figure 4. Age composition estimates of Columbia Basin spring chinook salmon sampled at Bonneville Dam from 1987–1989.[1]

Age Class[2]

Year	0.1	0.2	1.1	0.3	1.2	0.4	1.3	1.4
1987	0.00	0.01	0.04	0.00[3]	0.66	0.00	0.29	0.00[3]
1988	0.00[4]	0.01	0.06	0.01	0.31	0.00[4]	0.61	0.00
1989	0.00	0.00[5]	0.11	0.01	0.69	0.00[6]	0.18	0.00[4]

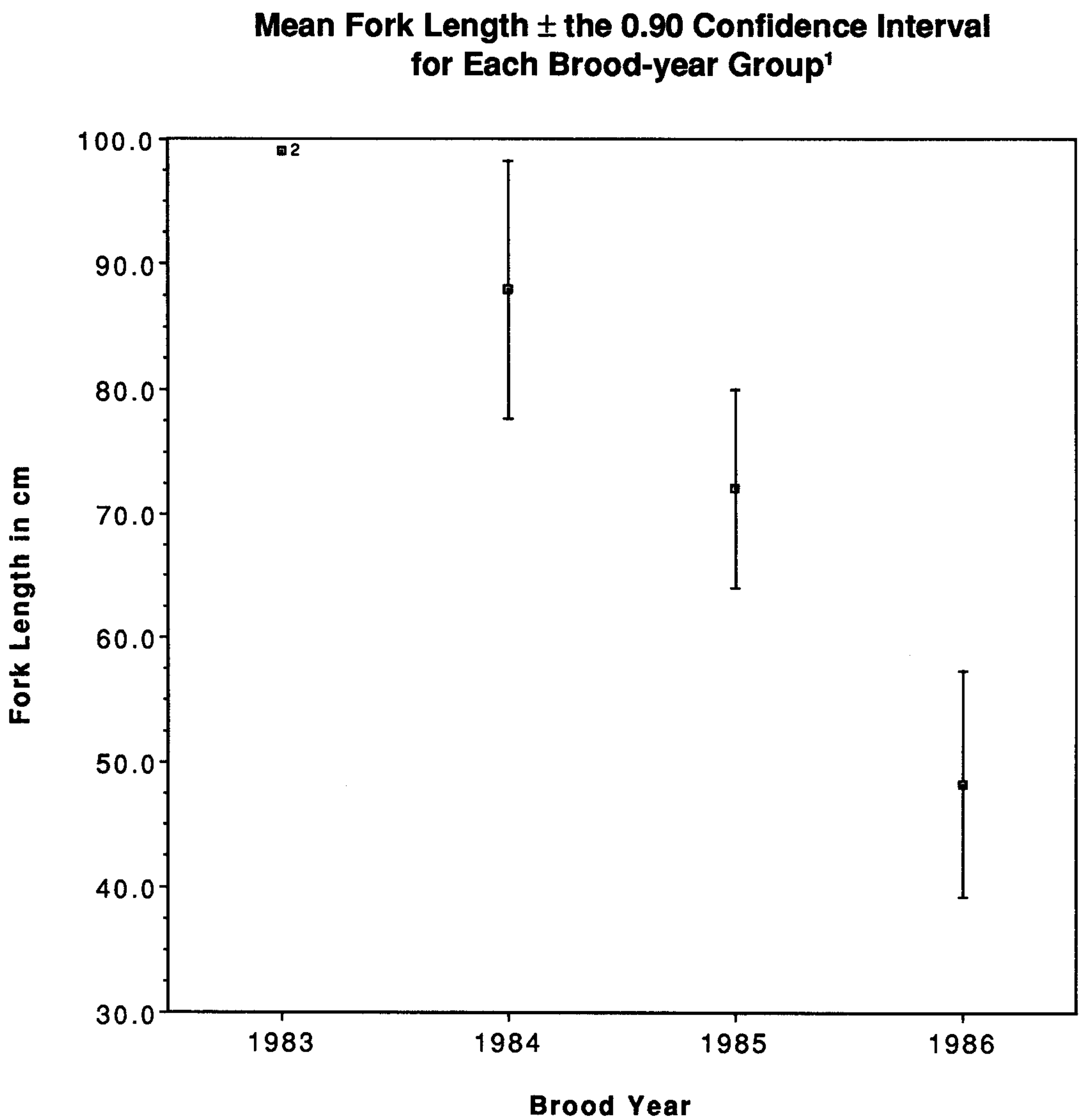


1. Estimates differed slightly from previously reported data (Schwartzberg 1988, 1989) because of adjustments made to account for differences between actual and predicted run timing.
2. Rounding errors caused sample proportions to occasionally not total 1.0.
3. Estimated proportion was 0.001.
4. Estimated proportion was 0.002.
5. Estimated proportion was 0.004.
6. Estimated proportion was 0.003.

Table 4. Weekly and total length-at-age composition estimates of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1989.

	Brood Year and Age Class						
	1986		1985		1984		1983
	0.2	1.1	0.3	1.2	0.4	1.3	1.4
Stat. Wk. 14							
Avg. Fk. Len. (cm)				70.5		91.4	
Min.				53.0		83.0	
Max.				78.0		102.0	
Std. Error				4.4		5.2	
N in Group				23		19	
Stat. Wk. 15							
Avg. Fk. Len. (cm)		45.0		72.3		86.7	
Min.		45.0		61.0		71.5	
Max.		45.0		79.0		99.0	
Std. Error		—		4.4		5.5	
N in Group		1		47		19	
Stat. Wk. 16							
Avg. Fk. Len. (cm)		49.7		71.5		87.6	99.0
Min.		47.0		63.0		76.5	99.0
Max.		52.5		80.0		99.0	99.0
Std. Error		2.7		3.9		5.5	—
N in Group		2		68		20	1
Stat. Wk. 17							
Avg. Fk. Len. (cm)		43.7		72.1		87.9	
Min.		43.0		49.0		79.0	
Max.		44.0		84.0		99.5	
Std. Error		0.2		5.3		6.7	
N in Group		2		77		11	
Stat. Wk. 18							
Avg. Fk. Len. (cm)	71.5	50.3	82.0	73.1		87.9	
Min.	71.5	42.5	82.0	61.0		75.5	
Max.	71.5	64.0	82.0	81.5		99.5	
Std. Error	—	5.9	—	4.7		7.5	
N in Group	1	12	1	56		10	
Stat. Wk. 19							
Avg. Fk. Len. (cm)	56.0	46.6	75.0	70.9		89.0	
Min.	56.0	39.0	75.0	54.0		78.5	
Max.	56.0	58.5	75.0	77.5		101.0	
Std. Error	—	4.0	—	5.4		9.3	
N in Group	1	29	1	24		5	
Stat. Wk. 20							
Avg. Fk. Len. (cm)		47.8	65.0	72.2	92.5	83.6	
Min.		40.5	65.0	60.5	92.5	77.5	
Max.		60.5	65.0	80.5	92.5	89.5	
Std. Error		4.8	—	4.7	—	4.0	
N in Group		13	1	21	1	9	
Stat. Wk. 21							
Avg. Fk. Len. (cm)		49.6	67.5	71.3		86.9	
Min.		43.0	67.5	59.5		76.0	
Max.		53.0	67.5	79.5		95.0	
Std. Error		3.5	—	6.1		5.5	
N in Group		7	1	10		7	
Stat. Wk. 22							
Avg. Fk. Len. (cm)		50.0		73.0	94.0	89.0	
Min.		47.0		66.5	94.0	82.0	
Max.		53.0		78.0	94.0	93.0	
Std. Error		3.0		4.0	—	5.0	
N in Group		2		5	1	3	
1989 COMPOSITE							
Avg. Fk. Len. (cm)	63.7	48.0	72.1	72.0	93.2	87.4	99.0
Min.	56.0	39.0	65.0	49.0	92.5	71.5	99.0
Max.	71.5	64.0	82.0	84.0	94.0	102.0	99.0
Std. Error	7.7	4.5	4.7	4.8	0.7	6.1	—
N in Group	2	68	4	331	2	103	1

Figure 5. Length-at-age composition estimates of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1989.



1. Age 0-plus fish were included with their respective brood year cohorts.
2. Only one fish was sampled of this brood year group (age 1.4).

DISCUSSION

Comparison of the above results to those obtained in 1987 and 1988 study years shows variability with no trends yet discernable in composite sample age compositions. Age 1.2 fish have gone from their lowest level in three years, at 0.31 of the run in 1988, to their highest level in three years of 0.69 in 1989. Conversely, in 1989 the numbers of age 1.3 fish dropped to their lowest level in three years at 0.18 of the run. The proportion of age 1.1 fish reached the highest level in three years at 0.11 of the1989 run. Age 0-plus fish have composed 0.01 of the run in 1987 and 0.02 in 1988 and 1989.

Predominance of age 1.2 fish in 1989 was also noted in known-stock samples of Columbia Basin spring chinook salmon from the Deschutes, Wenatchee, and Snake subbasins (Fryer and Schwartzberg 1990). Similarly, results of a 1989 Columbia Basin sockeye salmon stock identification study (Schwartzberg and Fryer 1990) estimate the highest proportion of age 1.2 fish in the past three years. This tendency for different stocks and species of salmon to show parallel age changes was also noted in 1988 (Schwartzberg 1989).

A salmon population spawning in a given year produces progeny that will return as adult spawners in several different years. All progeny of a given year's spawning population are known as a *brood*. Many salmon population size prediction techniques are based on an understanding of patterns in age compositions from successive broods. Although it is not possible at the present time to make any comparisons in age distribution by brood, the database that this study is creating may make such analyses possible in future years.

Length-at-age composition has remained relatively stable over the three study years for both four- and five-year-old fish with mean fork-lengths differing by less than 1.0 cm. However, three-year-old fish have steadily decreased in size. In 1987, the mean fork-length for this age class was 52.4 cm. In 1988 this decreased to 49.6 cm, and in 1989 became 48.6 cm. No explanation is apparent for this decline.

Analysis of the sample designs for 1987, 1988, and 1989 disclosed a time-related bias because an average run timing prediction based on the previous ten years' migration data differed from the actual run timing for each of these years. In each year, spring

chinook actually returned in larger proportions during the earlier part of the migration than was predicted by the ten year average upon which weekly sample sizes were based. We have noticed a similar trend towards earlier migration in the case of sockeye returning during 1987 and 1988 (unpublished data). Since spring chinook jacks tended to arrive later in the migration, the most consistent bias was the overestimation of the number of jacks in the uncorrected results for each of the three years (by percentage increases of 0.42 in 1987, 0.43 in 1988, and 0.23 in 1989). Among other age classes, the biases expressed as percentages are not nearly as large. In 1989, the proportion of age 1.2 spring chinook was underestimated by 0.07, and the proportion of age 1.3 fish overestimated by 0.10. In 1988, the proportion of age 1.2 spring chinook was overestimated by 0.15, while that of age 1.3 fish was underestimated by 0.13. In 1987, the proportion of age 1.2 chinook was underestimated by 0.01, while that of age 1.3 chinook was underestimated by 0.06.

For each of the past three study years, the estimated proportion of jacks in the entire population was greater based on scale analysis than that based upon Bonneville Dam visual fish ladder counts. However, only in 1989 was this difference statistically significant ($p<0.01$). The proportion of jacks visually counted at other dams agrees with Bonneville Dam jack counts suggesting the possibility that either this study overestimates jack abundance or that lower Columbia River dam counts systematically underestimate jack abundance. We intend to conduct a closer examination of the sampling methods used in this study in 1990 to determine if the number of jacks sampled represents the entire population.

Age-composition estimates obtained from the Corbett test fishery provide a measure of corroboration of our age composition estimates. Since Corbett gear does not effectively capture jacks, this group was not accurately represented. However, after jacks were removed from our study sample, the 1989 Bonneville Dam sampling program age composition estimates were almost identical to those obtained in the test fishery.

In 1989, 0.08 of the samples proved unreadable due to scale regeneration. This was an increase over the 0.05 judged unreadable in 1988 but a decrease from the 0.20 rejected in 1987 when only three scales per fish were collected. In 1988 and 1989, six scales per fish were obtained. Increasing the number of scales collected per fish has resulted in many fewer samples being rejected as unreadable due to scale regeneration.

Also, it has presumably limited potential sampling biases related to stock-specific differences in scale regeneration rates (Knudsen 1988).

This program will be continued in future years to develop an accurate age- and length-at-age composition database for the Columbia Basin spring chinook salmon population. This information will aid fisheries managers in detecting and possibly explaining changes in the composition of stocks. Patterns detectable in age and length-at-age composition of successive brood groups may allow managers to more accurately monitor the effects of ocean harvest restrictions imposed by the Pacific Salmon Treaty. As this study progresses, the database being created may also provide a basis for future population size prediction models.

LITERATURE CITED

Beamish, R.J. and G.A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. Transactions of the American Fisheries Society 112:735-743.

Bernard, D.R. 1982. Statewide standards for sampling sizes for AWL (unpublished memorandum). Alaska Department of Fish and Game, Sports Fishery Division, 333 Raspberry Road, Anchorage, Alaska 99502.

Clutter, R., and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission Bulletin 9.

Columbia River Inter-Tribal Fish Commission. 1989. FISHCOUNT, a computerized database of Columbia Basin fish counts made at mainstem hydroelectric dams.

Cochran, W.G. 1977. Sampling Techniques. John Wiley and Sons. New York.

Dammers, W. 1989. Run size forecast for Columbia River upriver adult spring chinook, 1990. Progress Report 89-26. Washington Department of Fisheries, Columbia River Fisheries Laboratory, 16118 N.E. 219th St., Battle Ground, Washington 98604.

Fryer, J. and M. Schwartzberg. 1990. Experiments in identifying hatchery and naturally spawning stocks of Columbia Basin spring chinook salmon using scale pattern analysis (in preparation). Columbia River Inter-Tribal Fish Commission Technical Report 90-3.

Gilbert, C.H. 1913. Age at maturity of the Pacific coast salmon of the genus *Oncorhynchus.* United States Bureau of Fisheries Bulletin 32:1-22.

International North Pacific Fisheries Commission. 1963. Annual Report — 1961.

Johnston, H.W. 1905. The scales of Tay salmon as indicative of age, growth, and spawning habitat. Scotland Fishery Board Annual Report 23(2):63-79.

Knudsen, C. 1988. Bias in stock separation analyses using scale patterns due to unequal scale regeneration rates. Paper submitted for publication to the International Symposium and Educational Workshop on Fish Marking Techniques, June 27 - July 1, 1988, University of Washington, Seattle, Washington.

Koo, T.S.Y. 1955. Biology of the red salmon, *Oncorhynchus nerka* (Walbaum), of Bristol Bay, Alaska, as revealed by a study of their scales. Ph.D. thesis, University of Washington, Seattle.

Pacific Salmon Treaty. 1985. Treaty between the government of the United States of America and the government of Canada concerning Pacific salmon. Treaty document 99-2.

Schwartzberg, M. 1987. Columbia upriver salmon stock identification project — Field operations guide. Columbia River Inter-Tribal Fish Commission Technical Report 87-1.

Schwartzberg, M. 1988. Age and length composition of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1987. Columbia River Inter-Tribal Fish Commission Technical Report 88-1.

Schwartzberg, M. 1989. Age and length composition of Columbia Basin spring chinook salmon sampled at Bonneville Dam in 1988. Columbia River Inter-Tribal Fish Commission Technical Report 89-1.

Schwartzberg, M., and J. Fryer 1990. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses, 1989 (in preparation). Columbia River Inter-Tribal Fish Commission Technical Report 90-2.

Van Oosten, J. 1929. Life history of the lake herring (*Leucichthys artedi* Le Sueur) of Lake Huron as revealed by its scales, with a critique of the scale method. United States Bureau of Fisheries Bulletin 44:265-428.