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Technical Report 89-2

Matthew Schwartzberg
Jeffrey Fryer

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COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION
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INTRODUCTION

Sockeye salmon *Oncorhynchus nerka* (Walbaum) is one of the five species of Pacific salmon native to the Columbia River Basin. Before white settlers developed the region, it is estimated the Columbia Basin supported an annual sockeye salmon run averaging over four million fish (Northwest Power Planning Council 1986). Since the mid-1800s, however, this sockeye population has severely declined. Annual runs now average (1978-1987) only about 90,000 fish (Bohn and McIsaac 1988).

The Columbia Basin sockeye salmon run was once composed of at least eight principal stocks (Fulton 1970). Today, only two major stocks remain (Figure 1). Both stocks are naturally sustaining, originating in the Wenatchee River-Lake Wenatchee system (Wenatchee stock) and in the Okanogan River-Osoyoos Lake system (Okanogan stock).

Optimal management of fisheries resources, particularly in mixed-stock harvest areas, requires that individual stocks be treated as discrete management units (Simon and Larkin 1972, MacLean and Evans 1981, McDonald 1981). A limited harvest of sockeye salmon still occurs in the mainstem Columbia River, with fisheries located between the mouth and McNary Dam (river km 470). Although stocks are mixed in these harvest areas, no stock-specific harvest management strategies presently exist. This is, in part, because dependable methods for individual stock recognition have not yet been developed that would assist managers in determining run composition and the migratory characteristics of each stock.

Reliable stock-identification procedures, once developed, might also be useful in a variety of Columbia Basin sockeye salmon management applications, including escapement monitoring, spawner-recruit modeling to estimate optimum spawning escapements, and in run-reconstruction studies to permit accurate population-size forecasts. The Pacific Salmon Treaty, ratified by the United States and Canada in 1985 (Pacific Salmon Treaty 1985), requires that certain Pacific salmon populations be monitored to determine the influence of Treaty-imposed ocean-harvest regulations on *transboundary* stocks. Some Okanogan-stock sockeye salmon originating in Canadian waters but migrating through, and harvested in, the United States portion of the Columbia River constitute such a stock. Stock-identification research would aid in

Figure 1. Map of the Columbia Basin showing Bonneville, McNary, Rock Island, Rocky Reach, Wells, and Tumwater dams and the two present sockeye salmon production areas.

estimation of the proportion and absolute number of Canadian-origin sockeye caught within the United States.

The Columbia River Inter-Tribal Fish Commission's Stock Identification Project is designed to develop and apply techniques for identification of individual or aggregate stocks of Columbia Basin salmon originating above Bonneville Dam. The collection and dissemination of basic stock-specific biological information is also an important project goal. Analysis of scale pattern characteristics is the method of study we are currently using for stock identification. Research on sockeye salmon was begun in 1986, and a report is available describing 1987 results (Schwartzberg and Fryer 1988). We have expanded the 1987 research to include stock-composition estimates at Bonneville Dam stratified by migratory timing. Between-year stock composition comparisons are also discussed. Sampling was more comprehensive in 1988, and a more objective data-acquisition process was tested and used.

METHODS

Scale pattern analysis (SPA) is a well-established stock identification and classification technique (Clutter and Whitesel 1956, Henry 1961, Mosher 1963, Anas and Murai 1969). In many species of fish including Pacific salmon, the use of SPA as a tool for stock identification depends on a high correlation between individual fish growth and scale growth (Koo 1955, Clutter and Whitesel 1956). Fish growth and scale growth are influenced by genetic factors and by such environmental conditions as water temperature, length of growing season, and food availability. Stock identification based on SPA assumes that genetically or environmentally influenced growth patterns will differ throughout a species' range and that these differences will be exhibited in the scales of entire groups or *stocks* of fish.

Markedly different conditions exist in the two remaining Columbia Basin sockeye salmon spawning and rearing areas. Lake Wenatchee is oligotrophic, with relatively deep, cold, and biologically unproductive waters. Conversely, Osoyoos Lake has the shallow, warm, and agriculturally enriched waters characteristic of eutrophic lake habitats (Allen and Meekin 1980, Mullan 1986). We believed it probable that scales from the two stocks would reflect these differences in freshwater spawning and rearing conditions.

Sampling

Scales from mixed sockeye salmon stocks *(unknowns)* were obtained from fish sampled at the Bonneville Dam Fisheries Engineering and Research Laboratory, located at river kilometer 225 on the mainstem Columbia River. Over a period of six weeks, live fish were trapped, sampled, and returned to fishway ladders. The sample size used for estimating the total-sample age composition was 467, based on the number neccesary to obtain a population age-composition estimate (p= 0.05, c.i.= .90; Bernard 1982) given three primary age categories within the population and an infinite estimated population size. Weekly sample sizes were proportional to Bonneville Dam sockeye counts averaged over the previous ten years (1977-1987). To improve precision in weekly age-composition as well as weekly stock-composition estimates, actual sample sizes were increased in certain weeks. The total of all usable weekly samples collected was 509.

Each stock was also sampled in terminal areas to obtain representative scale samples of each of the two groups *(knowns)*. Wenatchee-stock scales were collected at Tumwater Dam on the Wenatchee River (river km 31), while Okanogan-stock scales were obtained at Wells Dam on the mainstem Columbia River (river km 829). Target sample sizes were 200 samples of each known stock (Conrad 1985). The actual Okanogan-stock sample numbered 523, with 474 usable. The Wenatchee-stock sample was 245, with 195 being usable. Scales were collected and mounted according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963). Otoliths and supplemental scale samples were collected from spawned-out carcasses of 41 Wenatchee- and 45 Okanogan-stock samples. In all cases, at least three scales were selected from each fish sampled.

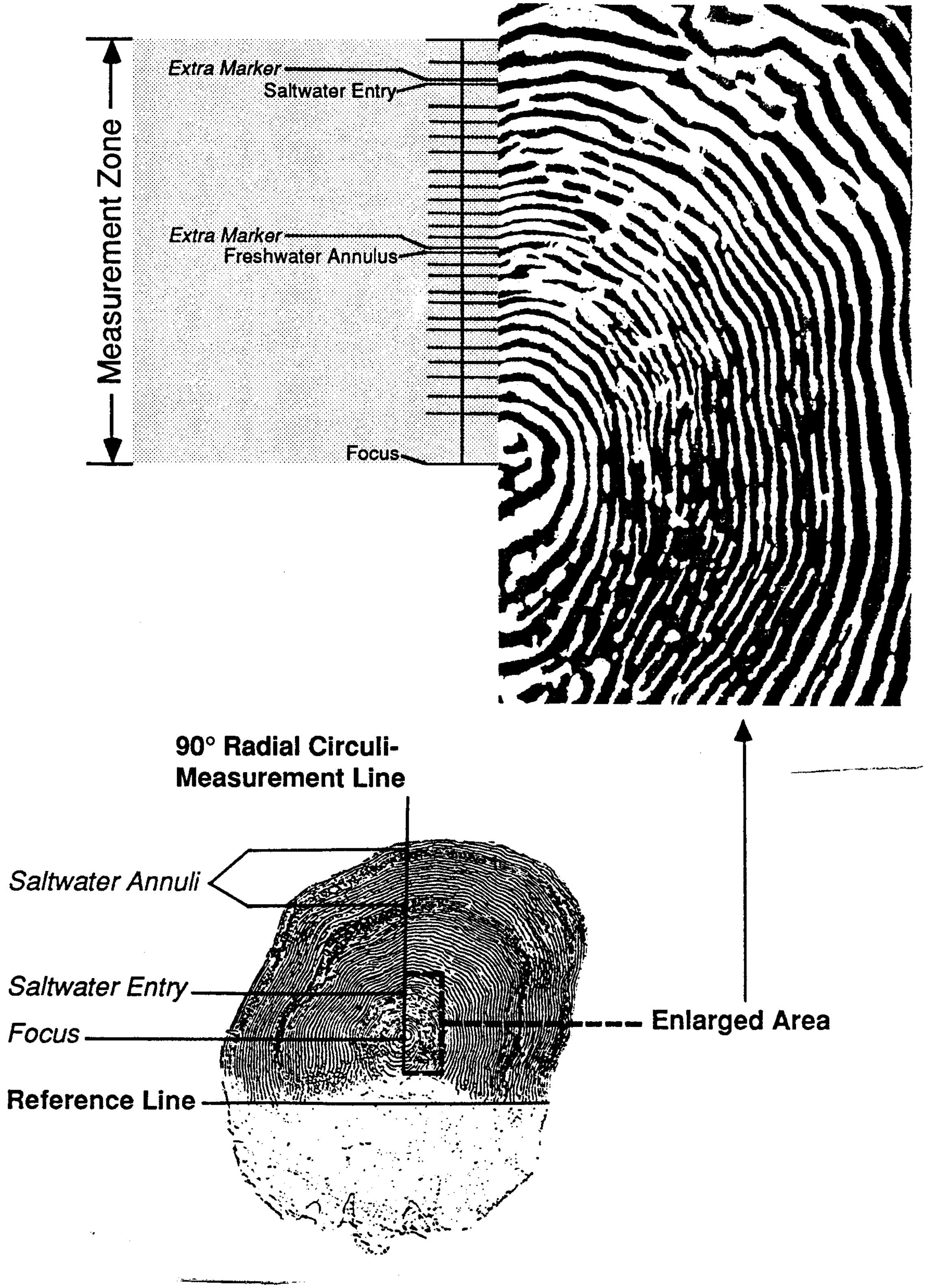
Fork lengths were measured to the nearest 0.5 cm and recorded for each fish along with any observed marks or tag information. Sex was determined for the known-stock samples. Bonneville Dam samples were not categorized by sex because of the absence of necessary external morphological characteristics. All field sampling procedures followed established guidelines for this project (Schwartzberg 1987).

Age Determination and Scale Measurements

Salmon scales, under magnification, display numerous concentric rings *(circuli)* radiating outward from a central focal area. A freshwater-growth zone of narrowly spaced circuli (Figure 2) is clearly distinguishable from a zone of more widely spaced ocean-growth circuli in scales of all Columbia Basin sockeye salmon, which typically spend one or two complete years in freshwater before migrating to the ocean. Fish age can be determined by counting *annuli*, which are zones of closely spaced circuli formed yearly during winter periods of slow growth.

All scales were examined visually and categorized by age using previously studied techniques (Johnston 1905, Gilbert 1913, Borodin 1924, Van Oosten 1929). 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 period. The numeral following the period indicates the number of winters

Figure 2. Age 1.2 Okanogan-stock sockeye salmon scale showing growth and measurement zones.



a fish spent in the ocean. Total age, therefore, is equal to one plus the sum of both numerals.

Scales were used to estimate the age compositions of Bonneville Dam mixed-stock as well as the Okanogan and Wenatchee known-stock samples. Length-at-age relationships were established. Otoliths from each known-stock were also used to support scale-age estimation techniques and to corroborate scale-age estimates.

SPA of circuli in freshwater and, in some cases, early saltwater-growth zones was used to identify each known-stock sample and to also classify mixed-stock samples. The methodology was applied to like-age (age 1.2) samples from all stocks. All Wenatchee-stock age 1.2 scales were used in the analyses. A subsample of 214 scales was randomly selected from Okanogan-stock age 1.2 scales. All Bonneville age 1.2 scales were used in the analysis so that sample sizes would permit more precise weekly age- and stock-composition estimates. SPA was not used to classify fish of age-classes other than 1.2 in the mixed-stock sample. Certain age-classes were found to be overwhelmingly present in only one of the two known-stock samples. We assumed that those age classes were stock specific (at least in this sample year) and used this relationship to categorize mixed-stock samples of given age-groups.

A computer and video camera were used to measure, or *digitize*, scale features (BioSonics 1985). The system employed consisted of a microscope (2x, 4x, and 10x objectives; a 1.0x, 1.25x, and 1.5x magnification changer; and a 2.5x photocompensation adapter), a monitor (13 inch), and a digitizing tablet connected to a personal computer (AT) with a video frame-grabber board. Scales were placed in the microscope, projected onto the monitor and, using keyboard and digitizing tablet, distances were measured along a radial line drawn through the scale. These measurements were then stored in a computer file.

One scale from each fish was selected, oriented diagonally with the clear (posterior) part of the scale in the lower left corner of the screen, and a reference line was drawn along its base (5x final microscope magnification and 65x projection magnification). The reference line was placed in the posterior field of the scale so that it bridged the end points of circuli in the first saltwater annulus (Figure 2). A radial line was then drawn perpendicular to the reference line, and circuli positions were measured at their points of intersection with the radial line (25x final microscope magnification and

325x projection magnification). All measurements were made to the outermost marginal edges of circuli. Additional circuli markers were placed to permit measurement of other key scale-features, specifically, freshwater annulus and saltwater-entry point. These features were respectively indicated by two sets of closely-spaced circuli markers. The 'extra markers' were placed immediately after and adjacent to the original circuli position markers and were interpreted and removed by data-analysis programs used in subsequent procedures (Appendix A). The freshwater annulus-position marker was placed beside the last circulus in the freshwater annulus and the saltwater-entry marker was placed immediately after the first circulus in the ocean zone.

Variable Selection

Variables, composed of selected scale-measurements from within a single zone (from scale focus to approximately circulus 24, usually located in the saltwater area), were tested to find those that most effectively characterized differences in growth between the two stocks. A total of 53 different variables were tested to determine those most effective in classifying known-origin samples. Test variables were selected and used in discriminant analyses, and classification accuracies were noted. Variables tested included distances measured between adjacent circuli, or *pairs,* as well as measurements between three non-adjacent circuli or *triplets*. Distances and number of circuli from scale focus to saltwater-entry and from scale focus to freshwater annulus margin (anterior) were also used.

Statistical Analyses

A linear discriminant analysis technique developed by Fisher (1936) was used to differentiate stocks and classify unknown mixed-stock samples. Linear discriminant analysis permits the simultaneous use of many variables to form classification functions that typify and identify groups. This methodology has proven useful for determining the origins of fish stocks from mixed-stock samples (Bethe and Krasnowski 1977, Bethe et al. 1980, Major et al. 1978).

A linear classification function of a set of different scale measurements was computed that maximized the variance between stocks against that within each stock.

This discriminant function y may be written as:

$$y = m_1x_1 + m_2x_2 + \ldots + m_nx_n$$

for the case where there are n different scale measurements being used in the analysis (Worlund and Fredin 1960). The i^{th} measurement is represented by x_i while m_i represents its coefficient.

The frequency distribution of y was determined, and mean values of y computed for the two populations. The critical value for separating two populations was a function of the average of the two means $\bar{y}_a$ and $\bar{y}_b$, expressed as:

$$Y = \frac{\bar{y}_a + \bar{y}_b}{2}$$

The discriminant function was applied to each sample, producing a y value. Samples were categorized to one of the two populations depending on whether their own y values were greater or less than Y.

Accuracy of the discriminant analysis was determined by classifying the pooled known-stock samples and comparing results to actual known-stock identities. A jack-knife procedure was used to correct for systematically biased results created by using the same set of observations for both calculating the discriminant function and determining its accuracy (Dixon et. al. 1983). To correct for the additional bias occurring when the expected classification accuracy determined from known-stock tests was not 1.00, we used the method developed by Cook and Lord (1978). Variances on estimates were also computed (Pella and Robertson 1979).

A stepwise procedure (Dixon et. al. 1983) was applied in our analyses, allowing variables to be entered and/or removed from a discriminant function at each stage of function development. The steps taken by the procedure were similar to those of a stepwise regression.

Visual Separation of Scales

Visual interpretation of freshwater scale-circuli patterns was studied based on the assumption that differences between Okanogan and Wenatchee sockeye salmon scales were large enough to permit classification through visually observable characteristics alone. A blind experiment similar to one described by McPherson and Jones (1987) was used to test this hypothesis.

Testing for Precision in Scale-Feature Measurement

The identification of such scale features as annulus position and point of saltwater entry may be a highly subjective process. Therefore, we avoided using variables dependent on the location of such features in the discriminant analysis procedures. Freshwater annulus and saltwater-entry locations were, however, estimated and marked in the digitizing process and a test was later conducted to determine whether an operator could consistently locate these two scale features. A subsample of 23 mixed-stock scales were selected, measured, and compared to those same previously digitized scales. A paired t-test was made of the distance and number of circuli from scale focus to freshwater annulus and from scale focus to saltwater entry. The test was designed to detect a difference of one circulus at a significance level of 0.10 and a power of 0.90 (Snedecor and Cochran 1980).

RESULTS

Age and Length Composition

Mixed stocks of Columbia Basin sockeye salmon sampled at Bonneville Dam in 1988 included fish of ages 1.1, 2.1, 1.2, 2.2, and 1.3. Age 1.2 fish composed 0.74 of the sample (Table 1). Age 1.3 and 2.2 were found in significant numbers, 0.13 and 0.08, respectively. A small proportion of age 2.1 and 1.1 fish were present (0.03 and 0.02, respectively).

The Wenatchee-stock sample included fish of ages 2.2, 1.3, and 1.2 in almost equal proportions, 0.37, 0.32, and 0.31, respectively (Table 2). A small proportion of age 2.3 fish were present (0.01). No fish in the Wenatchee-stock sample were estimated to be ages 1.1 or 2.1.

The Okanogan-stock sample was primarily composed of age 1.2 fish, 0.96. Small proportions of age 2.1, 2.2, and 1.3 were present (0.01, 0.01, and 0.02, respectively). Less than 0.01 of the sample consisted of age 1.1 fish.

Mean fork-lengths of Bonneville Dam mixed-stock samples for the three principal age classes present in that sample (1.2, 2.2, and 1.3) were 50.7, 51.8, and 57.3 cm, respectively. The 0.90 confidence intervals for these lengths were 46.9, 54.4; 47.6, 56.0; and 53.9, 60.6; respectively (Figure 3).

Mean fork-lengths of Wenatchee-stock samples for the three principal age classes present in that sample (1.2, 2.2, and 1.3) were 51.9, 51.2, and 57.5, respectively. The 0.90 confidence intervals for these lengths were 46.7, 57.0; 47.2, 55.1; and 52.9, 62.2, respectively.

Mean fork-lengths of Okanogan-stock samples for the three principal age classes present in that sample (2.1, 1.2, and 1.3) were 42.3, 51.5, and 59.1, respectively. The 0.90 confidence intervals for these lengths were 39.7, 44.9; 47.4, 55.6; and 54.3, 64.0; respectively.

Table 1. **Total and weekly age-composition of Columbia Basin sockeye salmon stocks sampled at Bonneville Dam in 1988.**

		Brood year and age class				
Statistical	Sample	1985	1984		1983	
Week[1]	Size	1.1	1.2	2.1	1.3	2.2
25	50	0.00	0.66	0.02	0.22	0.10
26	75	0.00	0.73	0.00	0.19	0.08
27	151	0.00	0.68	0.01	0.25	0.07
28	124	0.01	0.81	0.06	0.07	0.05
29	67	0.06	0.79	0.04	0.07	0.03
30-31	42	0.05	0.71	0.12	0.07	0.05
Total	**509**	**0.02**	**0.74**	**0.03**	**0.15**	**0.06**

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 1988, for example, statistical Week 25 began on June 12 and Week 31 began on July 24.

Table 2. Total age-composition of Wenatchee and Okanogan sockeye salmon stocks sampled in 1988.

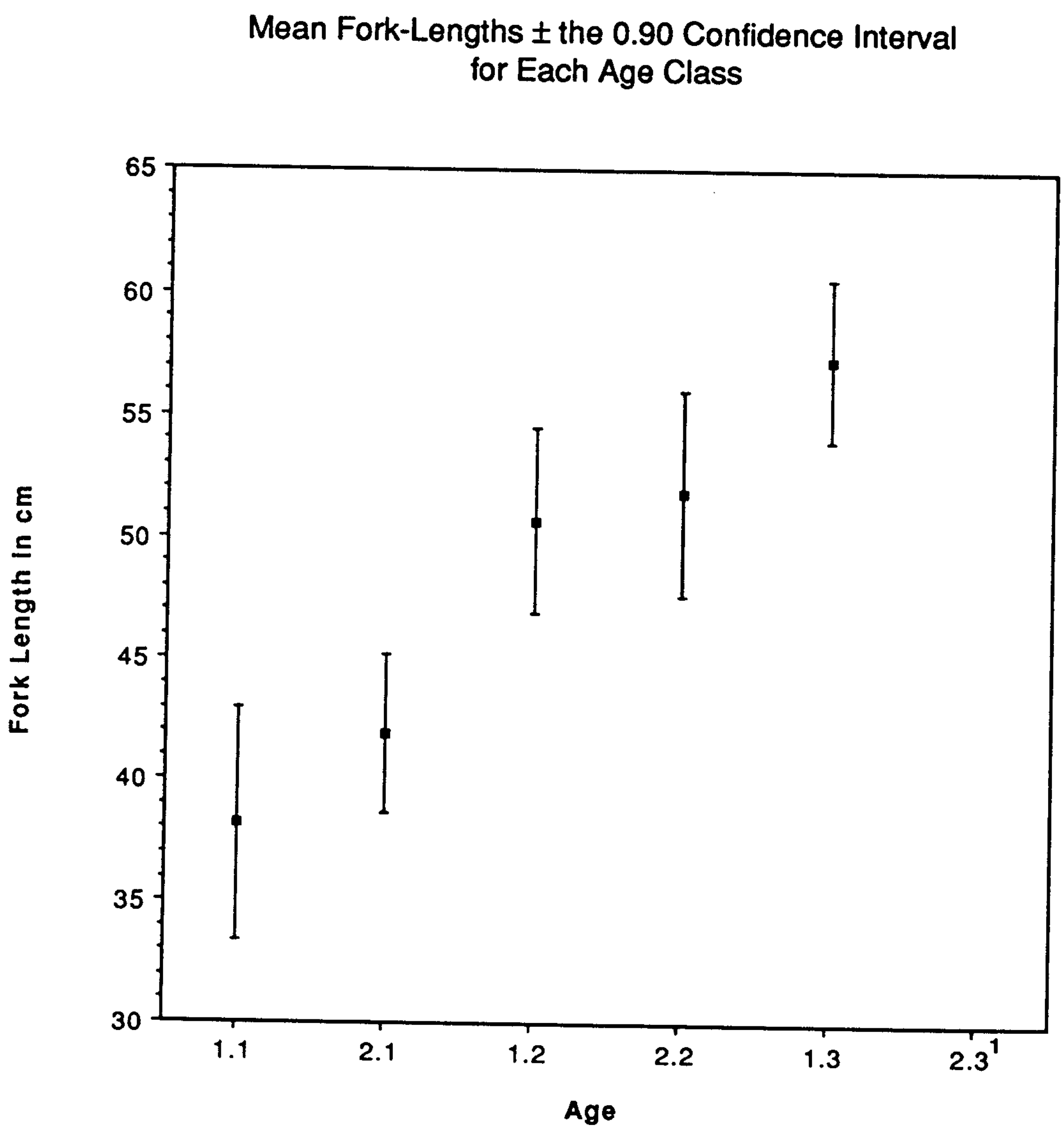
<u>Wenatchee stock sampled at Tumwater Dam</u>

Sample Size	Brood Year and Age Class					
	1985	1984		1983		1982
	1.1	1.2	2.1	1.3	2.2	2.3
195	0.00	0.31	0.00	0.32	0.36	0.01

<u>Okanogan stock sampled at Wells Dam</u>

Sample Size	Brood Year and Age Class					
	1985	1984		1983		1982
	1.1	1.2	2.1	1.3	2.2	2.3
474	0.00	0.96	0.01	0.02	0.01	0.00

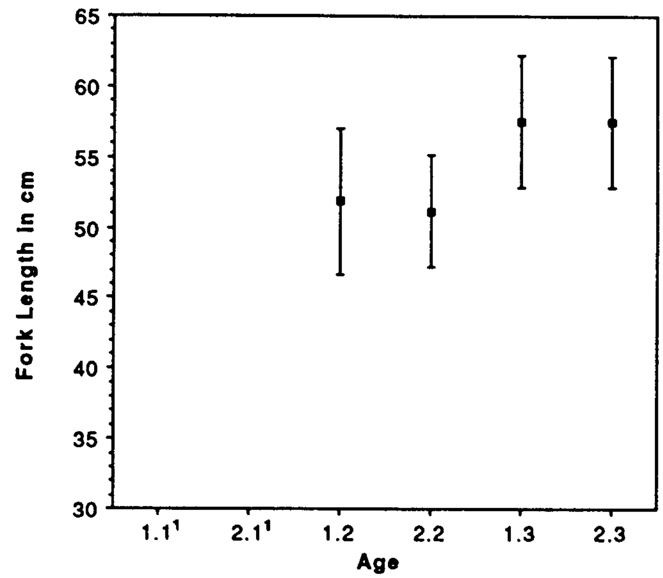
Figure 3. Length-at-age composition of Columbia Basin sockeye salmon stocks sampled at Bonneville Dam in 1988.



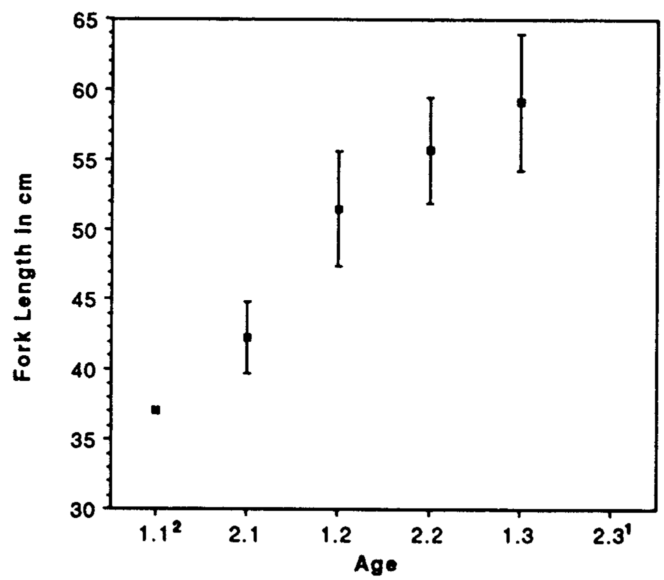
1. No fish estimated to be of this age class was sampled.

Figure 4. Length-at-age composition of Wenatchee and Okanogan sockeye salmon stocks sampled in 1988.

Wenatchee Stock
Mean Fork-Lengths ± the 0.90 Confidence Interval
for Each Age Class



Okanogan Stock
Mean Fork-Lengths ± the 0.90 Confidence Interval
for Each Age Class



1. No fish estimated to be of these age classes were sampled.
2. Only one fish estimated to be of this age class was sampled.

Classification of Known-Stock Samples

Among the 53 variables tested (Table 3), those resulting in the highest classification accuracies were number of circuli and distance measurements from scale focus to saltwater entry (variables 3 and 4). A known-stock classification accuracy of 0.98 was achieved using these two variables alone. However, an attempt was made in this study to limit the degree of subjectivity in the data-acquisition process. Because point of saltwater entry is often difficult to determine in sockeye scales and is highly dependent on individual-operator judgement, those variables directly related to saltwater-entry position were rejected from the final subset. Variables that were directly related to freshwater-annulus location (variables 1 and 2), possibly influenced by operator bias as well, did not prove to be effective discriminators.

A final subset was selected consisting of four groups of triplets (variables 40, 41, 45, and 46). Although in 1988, distance measurements between circuli pairs gave approximately the same classification accuracies as those between triplets, we chose to use triplet variables to provide consistency with last year's procedures. In 1987, it was found that the relatively larger triplet spacings tended to smooth random variations between samples of the same stock, emphasizing actual between-stock scale differences.

The classification accuracy achieved using the final variable subset was 0.86 (Table 4). A total of 10 Wenatchee samples were misclassified as being of Okanogan stock, while 25 Okanogan samples were misclassified as Wenatchee stock. The jackknife procedure was tested but found to have no affect on results.

Classification of Unknown Mixed-Stock Samples

The linear discriminant function classified 0.79 of age 1.2 unknown-origin samples as Okanogan stock and the remaining 0.21 as Wenatchee stock (Table 4). Because classification accuracy indicated by analysis of known samples was not 1.00, a bias was expected in stock-abundance estimation. After correction for bias (Cook and Lord 1978), 0.87 of the sample was classified as Okanogan stock and the remaining 0.13 as Wenatchee stock. Confidence intervals (0.90) ranged from 0.80 to 0.94 for the Okanogan group and from 0.06 to 0.20 for the Wenatchee group.

Table 3. Variables tested and used in discriminant analyses.

Test Set	Model Subset	Description of Variables
1		Number of circuli from focus to freshwater annulus
2		Distance from focus to freshwater annulus
3		Number of circuli from focus to saltwater entry
4		Distance from focus to saltwater entry
5		Distance from circulus 1 to circulus 2
6		Distance from circulus 2 to circulus 3
7		Distance from circulus 3 to circulus 4
8		Distance from circulus 4 to circulus 5
9		Distance from circulus 5 to circulus 6
10		Distance from circulus 6 to circulus 7
11		Distance from circulus 7 to circulus 8
12		Distance from circulus 8 to circulus 9
13		Distance from circulus 9 to circulus 10
14		Distance from circulus 10 to circulus 11
15		Distance from circulus 11 to circulus 12
16		Distance from circulus 12 to circulus 13
17		Distance from circulus 13 to circulus 14
18		Distance from circulus 14 to circulus 15
19		Distance from circulus 15 to circulus 16
20		Distance from circulus 16 to circulus 17
21		Distance from circulus 17 to circulus 18
22		Distance from circulus 18 to circulus 19
23		Distance from circulus 19 to circulus 20
24		Distance from circulus 20 to circulus 21
25		Distance from circulus 21 to circulus 22
26		Distance from circulus 22 to circulus 23
27		Distance from circulus 23 to circulus 24
28		Distance from focus to circulus 2
29		Distance from circulus 2 to circulus 4
30		Distance from circulus 4 to circulus 6
31		Distance from circulus 6 to circulus 8
32		Distance from circulus 8 to circulus 10
33		Distance from circulus 10 to circulus 12
34		Distance from circulus 12 to circulus 14
35		Distance from circulus 14 to circulus 16
36		Distance from circulus 16 to circulus 18
37		Distance from circulus 18 to circulus 20
38		Distance from circulus 20 to circulus 22
39		Distance from circulus 22 to circulus 24
40	x	Distance from focus to circulus 3
41	x	Distance from circulus 3 to circulus 6
42		Distance from circulus 6 to circulus 9
43		Distance from circulus 9 to circulus 12
44		Distance from circulus 12 to circulus 15
45	x	Distance from circulus 15 to circulus 18
46	x	Distance from circulus 18 to circulus 21
47		Distance from circulus 21 to circulus 24
48		Distance from focus to circulus 4
49		Distance from circulus 4 to circulus 8
50		Distance from circulus 8 to circulus 12
51		Distance from circulus 12 to circulus 16
52		Distance from circulus 16 to circulus 20
53		Distance from circulus 20 to circulus 24

Table 4. Classification using linear discriminant analyses of age 1.2 Columbia Basin sockeye salmon stocks sampled in 1988.

Known-stock classification test

Correct Group	Percent Correct	Classification (samples categorized)	
		Wenatchee	*Okanogan*
Wenatchee	83	49	10
Okanogan	88	25	189
Classification Accuracy	86		

Mixed-stock classification

	Run-Composition Estimate	
	Wenatchee	*Okanogan*
Number	78	292
Percentage	0.21	0.79
Bias Corrected Percentage	0.13	0.87
0.90 Confidence Interval for Bias Corrected Percentage	(0.06, 0.20)	(0.80, 0.94)

Although age 1.3 and 2.2 fish were found in both Okanogan and Wenatchee samples, their proportional abundance was quite different in each group. Fish of these age classes composed two-thirds of the Wenatchee-stock sample size (Table 2), while they composed only 0.02 of the Okanogan-stock sample. We therefore classified all age 1.3 and 2.2 fish in the Bonneville Dam mixed-stock sample as Wenatchee stock.

Ages 1.1 and 2.1 fish were similarly treated. No scales of either age 1.1 or 2.1 were estimated to be present in the Wenatchee-stock sample, although scales of these ages were present (0.03 and 0.02, respectively) in the Bonneville Dam sample (Table 1). Although the proportion of these fish was even smaller at Wells Dam, previous studies have found one-ocean fish to be extremely rare in the Wenatchee system (Major and Craddock, 1962). We therefore classified all age 1.1 and 2.1 fish in the Bonneville Dam mixed-stock sample as Okanogan stock.

Combining the results of SPA classification of age 1.2 unknowns and classification of the remaining unknowns by age alone, we estimated the total mixed-stock sample to be composed of 0.69 Okanogan and 0.31 Wenatchee stock.

Weekly stock-composition analysis indicated no significant variation in stock composition through the sampling period.

Visual Scale Classification

Known-stock sample identification and separation, attempted strictly on the basis of the visual appearance of scale patterns, resulted in an 0.80 classification accuracy (Table 5).

Precision in Scale-Feature Measurement

Results of the test for operator consistency in scale-feature location yielded no significant differences found in measurements of variables 1, 2, 3, or 4 (number of circuli from scale focus to freshwater annulus, distance from scale focus to freshwater annulus, number of circuli from focus to saltwater entry, and distance to saltwater entry, respectively). P-values ranged from 0.32 for the test of variable 1 to 0.80 for variable 4.

Table 5. **Classification using visual separation of age 1.2 Wenatchee and Okanogan sockeye salmon stocks sampled in 1988.**

Known-stock classification test using visual-separation techniques

Correct Group	Percent Correct	Classification (samples categorized)	
		Wenatchee	*Okanogan*
Wenatchee	0.85	17	3
Okanogan	0.75	5	15
Classification Accuracy	0.80		

DISCUSSION

This paper reports results from the second year of a Columbia Basin sockeye salmon stock-identification research project (Schwartzberg and Fryer 1988). Again this year, Wenatchee- and Okanogan-stock fish were identified and separated with a high degree of accuracy by digitizing scales and using a linear discriminant analysis procedure. Our study also has indicated that highly accurate visual scale-identification is possible.

A single-zone scale-digitizing process was tested and used in 1988 because it did not require subjective decisions by the operator regarding freshwater annulus and saltwater entry location. The method proved much faster than in 1987 (when two zones were digitized on each scale) and is expected to give more consistent results.

Although not used in final analyses, freshwater annulus and saltwater entry locations were marked in the 1988 data-acquisition process to permit a variety of tests. A test for precision in scale-feature measurement indicated that both freshwater annulus and saltwater entry position could be consistently located. Very high classification accuracies (0.98) were attained this year in tests using variables containing positions of subjectively determined scale features. Nevertheless, we felt it prudent to limit use of these variables in stock-composition estimates, awaiting the results of further study.

The overall classification accuracy achieved in 1988 was 0.86, 0.05 lower than in 1987. While reasons for this have not yet been fully explored, a test of between-year variation in focus-to-freshwater-annulus growth was made for each known stock. The test showed that, in the Wenatchee stock, focus-to-freshwater-annulus growth averaged only 0.04 less in 1988 than 1987 which was not statistically significant ($p=0.15$). In the Okanogan stock, this growth was not as great in 1988 specimens as in 1987 ($p<0.001$) with focus-to-freshwater-annulus growth averaging 0.15 less in 1988 than in 1987. Because variables based on inter-circuli spacing in this growth area are key between-stock discriminators, the relative changes in Okanogan-stock scale characteristics probably caused an overall reduction in 1988 classification accuracy.

Age compositions differed significantly in 1988 from that recorded in 1987 for all three samples. Among mixed stocks sampled at Bonneville Dam, there was a large

increase in the proportion of age 1.3 fish and a corresponding decrease for age 1.1. In the Wenatchee-stock sample, the proportion of age 1.3 and 2.2 fish more than tripled, while the proportion of age 1.2 fish decreased by 0.60. In the 1988 Okanogan-stock sample, 1.2 age fish were estimated to compose 0.98 of the sample. Although we were unable to accurately estimate ocean age in the 1987 Okanogan-stock sample, length-frequency distributions and examination of a sub-sample of better-quality scales indicated that age 1.1 fish constituted over 0.50 of the sample. There appears, therefore, to have been a large decrease in age 1.1 and concurrent increase in age 1.2 Okanogan-stock fish in 1988.

Age-composition variations were consistent among all samples in that, generally, adult sockeye returned to spawn at an older age in 1988 than in 1987. Similar observations were made in both mixed- and known-stocks of Columbia Basin spring chinook salmon *Oncorhynchus nerka* (Walbaum) sampled in 1988 (Schwartzberg 1989, Schwartzberg and Fryer 1989). These findings suggest that observed inter-annual age-compositional changes may be caused by regional and possibly global rather than local factors. There is also evidence that, for different sockeye stocks, certain brood-year groups were much more productive than others. At Bonneville Dam in both 1987 and 1988, sockeye from brood years 1983 and 1984 predominated. However, for the Wenatchee stock during both years, the predominant brood-year was 1983, while for the Okanogan stock, the predominant brood year was 1984 for both years. We believe further investigation of the nature of dominant known-stock brood year patterns is warranted. In addition, we recommend that study be initiated of the possible correlation between known-stock predominant brood-year representation and future population sizes.

Where comparisons were possible, we found sockeye of similar ages to be consistently smaller in 1988 than in 1987. At Bonneville Dam, the average inter-annual difference for age 1.2 sockeye was 0.4 cm ($p = .05$). In the Wenatchee-stock sample, the average difference for age 1.2, 2.2, and 1.3 sockeye was 0.9, 2.7, and 2.6 cm, respectively ($p = .09$, .00, and .02, respectively). No such comparison was possible for Okanogan-stock sockeye because ages could not be accurately estimated in the 1987 Okanogan-stock sample. No explanation is presently available for these changes in inter-annual length-at-age compositions. No significant length-at-age compositional changes were noted between 1988 and 1989 in the above mentioned mixed-stock Columbia Basin spring chinook study.

More precise stock-composition estimates could be made in 1988 than in 1987 because better quality Okanogan-stock scale samples were obtained enabling accurate known-stock age-composition profiles. Mixed-stock composition analysis was then possible based on differential age-class representation combined with linear discriminant analyses. Differences in the age compositions of each stock were used to classify all sockeye except those of age 1.2, which were classified by discriminant analysis. In 1988, the total run (at Bonneville Dam) was estimated to be 0.69 Okanogan stock and 0.31 Wenatchee stock. In 1987 however, the run was classified as 0.45 Wenatchee and 0.45 Okanogan stock, with the remaining 0.10 (age 1.3 and 2.2) considered to be of undetermined origin. The stock origin of age 1.2 sockeye in the mixed-stock sample varied dramatically from 1987 to 1988. In 1987, the discriminant analysis classified 0.64 of these fish as Wenatchee stock, while in 1988 this decreased to 0.13. Changes in known-stock age-class compositions and changes in the relative abundance of each known stock in the mixed-stock sample are probable contributing factors to this observation.

Adult migrating salmon are counted at most mainstem Columbia and Snake river dams. Except for a remnant Snake River stock, all Columbia Basin sockeye salmon pass Rock Island Dam (river km 729) but only Okanogan-stock fish pass Rocky Reach Dam (river km 761). By factoring dam counts, and assuming no significant inter-dam mortality, 0.69 (34,067) of the 1988 escapement may be attributed to Okanogan stock and 0.31 (15,068) to Wenatchee stock. These proportions agree very closely with the results of our mixed-stock classification estimate.

The impact of commercial fisheries on stock composition has yet to be addressed in our reports. In 1987 and 1988, commercial sockeye fisheries were conducted both below and above Bonneville Dam. Thus the Bonneville sample may not necessarily be representative of the run as it enters the Columbia River. Both the above-and below-Bonneville fisheries may be impacting the population in, as yet, undetermined ways. Agreement between our 1988 stock-composition estimate and that based on upper Columbia River dam fishcounts suggests that the Zone 6 treaty fishery (located upstream of Bonneville Dam) had an equal impact on both stocks. Fishery scale samples are available from 1987 and 1988 and we hope to examine these in future studies.

In 1988, sample sizes and quality improved dramatically from 1987, particularly for the Okanogan stock. In 1987, the Okanogan-stock scale samples were resorbed to the extent that saltwater age could not be accurately estimated. In this year's study, we obtained samples from a Wells Dam fish-ladder trap. Because of trap design limitations, the sample obtained possibly underestimated age 1.1 and 2.1 fish (although few fish of these age classes were observed at Bonneville Dam or on the Okanogan spawning grounds). In years when a large proportion of one-ocean fish are present, the Wells Dam trap would probably create sampling biases. However, it is anticipated that the trap will be modified before the 1989 sampling period begins, and that a new trap will be constructed in the near future.

The Wenatchee sample in 1987 came from a Lake Wenatchee sport fishery. Good-quality scales were obtained, but it was suspected that the fishery might be selective for larger fish. In 1988, plans were made to sample sockeye at Tumwater Dam, as well as in the fishery. The fishery was cancelled, however, due to low escapement and sampling at Tumwater Dam was restricted to a short period near the end of the migratory season. As a result, the Wenatchee sample was of lower than desired quality. We hope to obtain a larger and more representative sample at Tumwater Dam next year.

Juvenile scale samples were a great aid in determining the freshwater-growth characteristics and the freshwater age of 1987 adult fish. We intend further study of sockeye smolts sampled at mainstem Columbia River dams and, if obtainable, from juvenile fish sampled in Osooyos Lake and Lake Wenatchee. In addition, we wish to explore the possibility that juvenile scales can be used for adult in-season run composition analyses.

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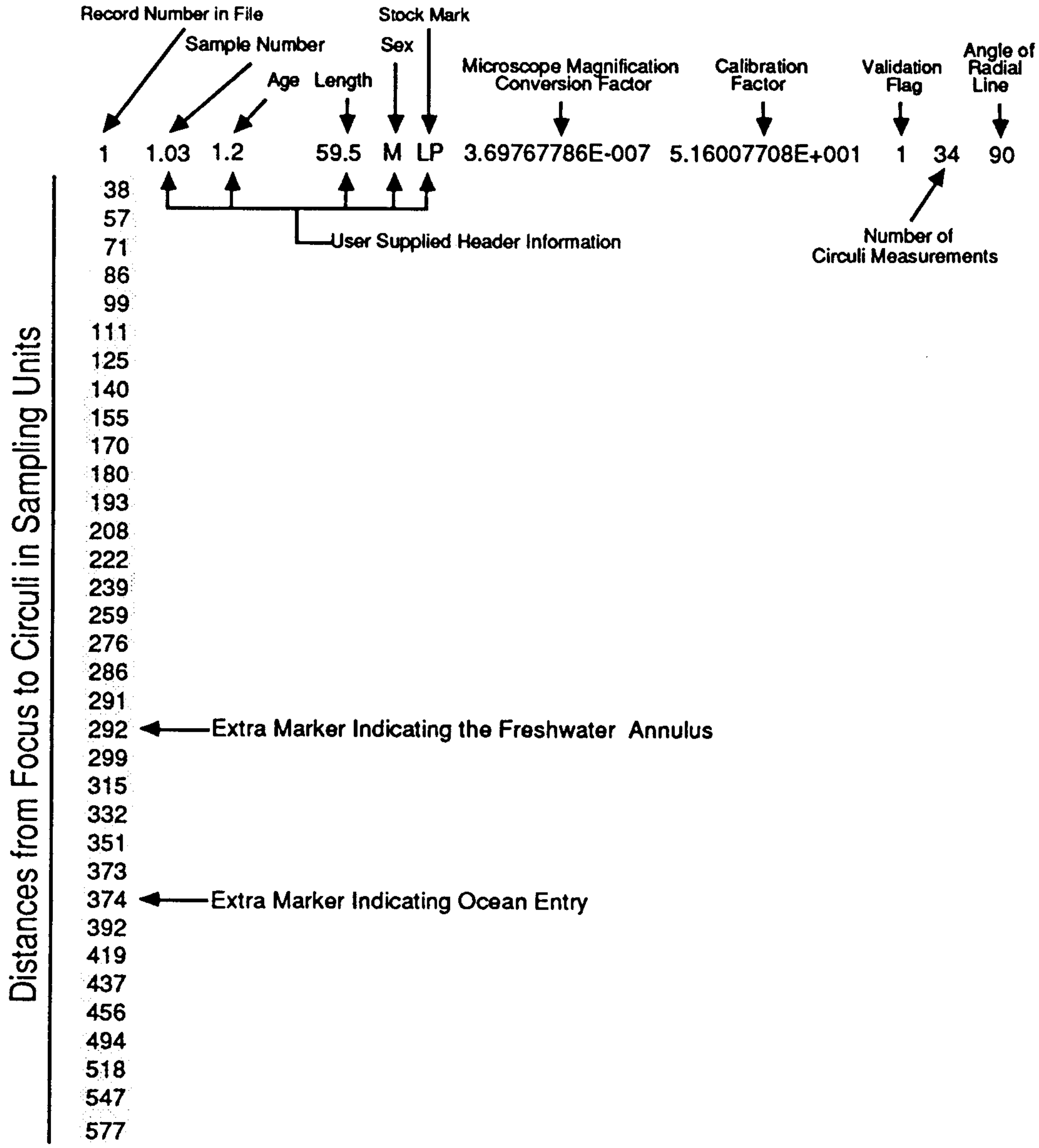
Appendix A. Data handling and manipulation for SPA.

During the scale data-acquisition process, information associated with each scale-data record is stored along with actual scale measurements in four separate fields of the data record *header* (Optical Pattern Recognition System, OPRS; Biosonics Inc. 1985). The sample number, denoted by the appropriate scale-card and the sample-position number (separated by a period) is recorded in the *sample id* field. Thus, sample number 3 on card number 1 would be recorded as 1.03. The estimated age of the fish from which the scale sample was taken is recorded in the *specimen id* field while the length, sex (M, F, or U), and stock (if known) are recorded in the field labeled *other.* In addition to this user-supplied information, the header includes system-supplied data including a sequential record number, the microscope magnification-conversion factor, a microscope lens-calibration factor, a record-validity indicator, the total number of circuli in the record, and the angle of the radial line used.

Once circuli measurements are made and a scale-data record is saved to the computer's hard disk, scale-measurement data cannot be further edited. The operator may, however, edit user-supplied header information. The desired record can be located and displayed (by using the OPRS *EDT* page and the *display data* command). Each record is displayed and contains header information and distance measurements from the scale focus to each circulus measured in *sampling units* (Figure A1). Measurements in sampling units can range from 1 to 700 and must be multiplied by the microscope magnification-conversion factor to determine metric distances from the scale focus to each marked circulus. Each circulus measurement is stored on a separate line.

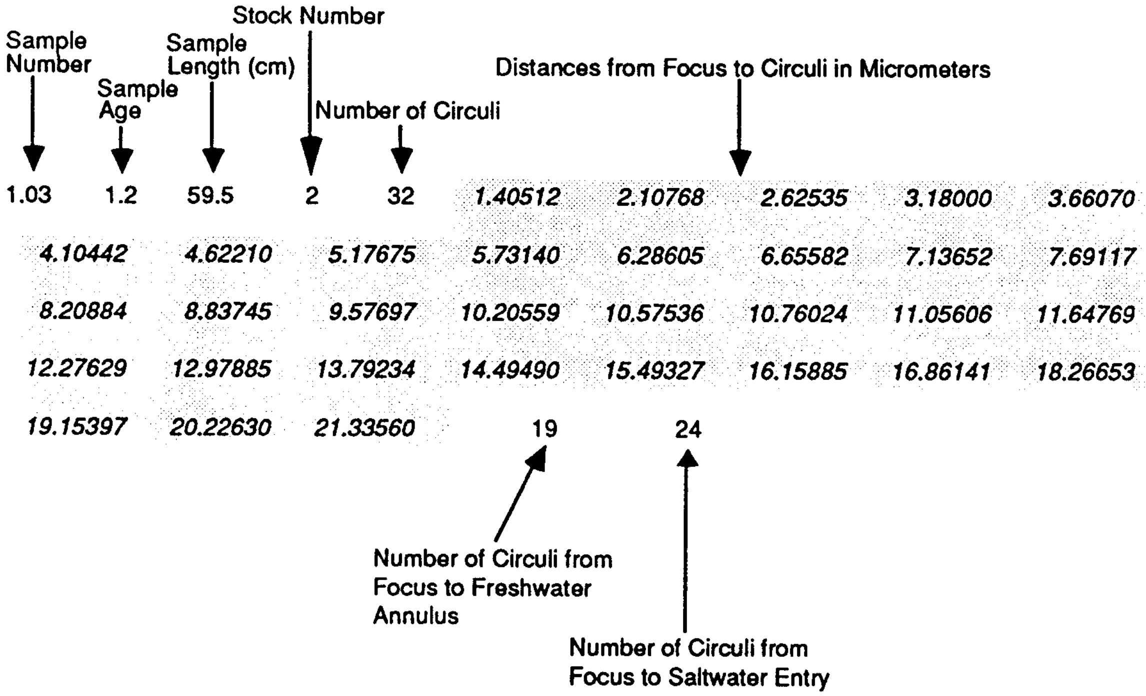
To more effectively edit and prepare data for further statistical analysis, the *convert to ASCII* feature of the EDT page is used. The ASCII file this command creates can be manipulated by a program we have written that detects the extra markers in each record (marking freshwater annulus margin (anterior) and saltwater-entry point), converts scale-data measurements to actual metric distances, and stores this information in a more compact format (Figure A2). Using still another program, the information necessary to perform statistical analyses is extracted from this file and transferred to BMDP statistical software (Dixon et. al. 1983).

Figure A1. A sample OPRS data record for a single spring chinook salmon scale freshwater-growth-zone measurement[1].



1. The data-acquisition process used for sockeye salmon scales was essentially the same as that used for spring chinook salmon scales.

Figure A2. A sample compact-format data record for a single spring chinook salmon scale freshwater-growth-zone measurement[1].



1. The data-acquisition process used for sockeye salmon scales was essentially the same as that used for spring chinook salmon scales.

The **Columbia River Inter-Tribal Fish Commission (CRITFC)** is the coordinating fisheries agency for the Nez Perce, Umatilla, Warm Springs, and Yakima tribes—four Columbia River tribes that **reserved** fishing rights in 1855 treaties with the United States government.

Since time immemorial, Indian people have lived and fished in the Columbia River's vast basin, and salmon and steelhead have always been central to the culture and lifestyles of these Native Americans. Anadromous fish, in addition to being the mainstay of the diet, have great religious significance. Salmon and steelhead, which in prehistoric times were dried for trading to other tribes, have also been of great economic importance.

Court decisions in the 1960s and 1970s reaffirmed not only the tribes' right to fish, but also their right to co-manage this once plentiful renewable resource. To fulfill their responsibilities as co-managers, the Nez Perce, Umatilla, Warm Springs, and Yakima tribes formed CRITFC in 1977 to be these tribes' coordinating technical arm on fisheries issues. CRITFC, through its staff of biologists, policy analysts, law enforcement officers, and other specialists, works closely with state and federal agencies, citizen groups, and other tribes to help restore the Columbia Basin's salmon and steelhead runs.

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