

# IDENTIFICATION OF COLUMBIA BASIN SCKEYE SALMON STOCKS BASED ON SCALE PATTERN ANALYSES, 1987

*Technical Report 88-2*

Matthew Schwartzberg  
Jeffrey Fryer

February 25, 1988



COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION  
975 S.E. Sandy, #202, Portland, OR 97214, (503) 238-0667

**IDENTIFICATION OF COLUMBIA BASIN  
SCKEYE SALMON STOCKS BASED ON  
SCALE PATTERN ANALYSES, 1987**

*Technical Report 88-2*

**Matthew Schwartzberg  
Jeffrey Fryer**

**February 25, 1988**

**COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION  
975 S.E. SANDY BLVD., SUITE #202  
PORTLAND, OREGON 97214  
(503) 238-0667**

## ACKNOWLEDGEMENTS

We would like to sincerely thank the following individuals for their assistance in this project: Benjamin Van Alen and Scott McPherson of the Alaska Department of Fish and Game; Mike Cuenco, Al Debrot, Alex Heindl, Paul Lumley, Dale McCullough, Mike Matylewich, Phil Mundy, Phil Roger, Howard Schaller, and Earl Weber of the Columbia River Inter-Tribal Fish Commission; Yvonne Yole of the Department of Fisheries and Oceans, Canada; Lyle Gilbreath of the National Marine Fisheries Service; Craig Foster, Howard Jensen, and Steve King of the Oregon Department of Fish and Wildlife; Betty Tasaka of the Pacific Salmon Commission; Adam Heineman, Gary Johnson, and Jim Kuskie of the United States Army Corps of Engineers; Nancy Davis, Robert Walker, and Katherine Myers of the Fisheries Research Institute of the University of Washington; and John DeVore, 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.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	i
TABLE OF CONTENTS .....	ii
LIST OF TABLES.....	iii
LIST OF FIGURES.....	iv
INTRODUCTION .....	1
METHODS .....	4
Sampling.....	4
Age Determination and Scale Measurements.....	5
Character Selection .....	8
Statistical Analyses .....	8
Visual Separation of Scales.....	10
Testing for Bias in Scale Measurement.....	11
RESULTS.....	12
Age and Length Composition.....	12
Classification Procedure Using Known-stock Samples.....	17
Classification of Unknown Mixed-stock Samples.....	19
Visual Scale Classification .....	21
Testing for Bias in Scale Measurement.....	21
DISCUSSION.....	23
LITERATURE CITED .....	25

## LIST OF TABLES

1. Variables tested and used in discriminant analyses .....	9
2. Total and weekly age composition (percent) of Columbia Basin sockeye salmon sampled at Bonneville Dam in 1987.....	13
3. Age composition of Wenatchee and Okanogan sockeye salmon stocks sampled in 1987.....	14
4. Classification using linear discriminant analyses of age 1.2 Columbia Basin sockeye salmon stocks (knowns) sampled in 1987.....	18
5. Classification using linear discriminant analyses of age 1.2 Columbia Basin sockeye salmon stocks (unknowns) sampled at Bonneville Dam in 1987.....	20
6. Classification using visual separation of age 1.2 Columbia Basin sockeye salmon stocks (knowns) sampled in 1987 .....	22

## LIST OF FIGURES

1. The Columbia Basin showing Bonneville and McNary dams and the two present sockeye salmon production areas..... 2
2. Age 1.2 Okanogan-stock sockeye salmon scale showing growth and measurement zones..... 6
3. Length-at-age composition of Columbia Basin sockeye salmon stocks..... 15
4. Length distribution of Okanogan-stock sockeye salmon sampled in 1987..... 16

## INTRODUCTION

Sockeye salmon (*Oncorhynchus nerka* Walbaum) is one of five species of Pacific salmon native to the Columbia River Basin. Before white settlers developed the region, the Columbia Basin supported a sockeye salmon run estimated to have averaged more than three million fish annually (Northwest Power Planning Council 1986). Since the mid-1800s, however, this sockeye population has suffered a severe decline. Annual runs now average only about 90,000 fish (Oregon Department of Fish and Wildlife and Washington Department of Fisheries 1987).

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).

Limited harvest of these fish still takes place, with fisheries held in the mainstem Columbia River between the mouth and McNary Dam (river mile 246). Sockeye salmon stocks are mixed in these harvest areas. However, stock-specific management strategies have not been established, because dependable stock-identification techniques have not been developed. In addition, reliable information providing a more complete understanding of the life histories and basic biological attributes of the two stocks has not been available.

Accurate stock-identification information would offer a variety of benefits to fisheries managers. Uses of such information include development of spawner-recruit models to estimate optimum spawning escapements and generation of run-reconstruction studies permitting population size predictions. Identification of Columbia Basin sockeye salmon stocks is also needed to help estimate the proportion and absolute number of Canadian-origin sockeye harvested within the United States. Some Okanogan-stock sockeye salmon originate in Canadian waters but migrate through, and are harvested in, the United States' portion of the Columbia River. Such *transboundary* stocks are subject to the jurisdiction of the Pacific Salmon Commission under the terms of the Pacific

Figure 1. The Columbia Basin showing Bonneville and McNary dams and the two present sockeye salmon production areas.





Salmon Treaty ratified by the United States and Canada in 1985 (Pacific Salmon Treaty 1985).

The 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. Analysis of scale pattern characteristics is the current method of study. This report describes 1987 research on Columbia Basin sockeye salmon, including investigations of life histories and population structures of separate stocks, as well as potential techniques for stock identification.

## METHODS

Scale pattern analysis (SPA) is a well-established stock identification technique (Clutter and Whitesel 1956, Henry 1961, Mosher 1963, Anas and Murai 1969). Use of SPA as a tool for stock identification depends on the fact that in many species of fish, including Pacific salmon, individual fish growth is highly correlated with 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 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 Columbia Basin sockeye salmon spawning and rearing areas. Lake Wenatchee is oligotrophic with deep, cold, and relatively unproductive waters, while Osoyoos Lake has shallow, warm, and agriculturally enriched waters characteristic of eutrophic lake habitats (Allen and Meekin 1980, Mullan 1986). Therefore, it is probable that scales from the two stocks will reflect these differences in freshwater conditions.

### Sampling

Scales from mixed sockeye salmon stocks (*unknowns*) were obtained from 392 fish sampled at the Bonneville Dam Fisheries Engineering and Research Laboratory, located at river mile 146 on the mainstem Columbia River. Over a period of six weeks, live fish were trapped, sampled, and returned to fishway ladders.

Each stock was also sampled in terminal areas to obtain representative scale samples of the two groups (*knowns*). Wenatchee-stock scales were collected from a Lake Wenatchee sport fishery, while Okanogan-stock scales were obtained from Okanogan River spawning-ground carcass recoveries. Target sample sizes were 200 fish of each known group (Conrad 1985). This goal was surpassed for the Okanogan-stock sample (581 fish), although the Wenatchee-

stock sample totaled only 143 fish. Scales were collected and mounted according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963).

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 carcass samples but not for Bonneville Dam samples, because of the absence of morphological characteristics necessary for identification of sex in live fish. Otoliths were collected from 24 Okanogan-stock sockeye. All field sampling procedures followed established guidelines for this project (Schwartzberg 1987).

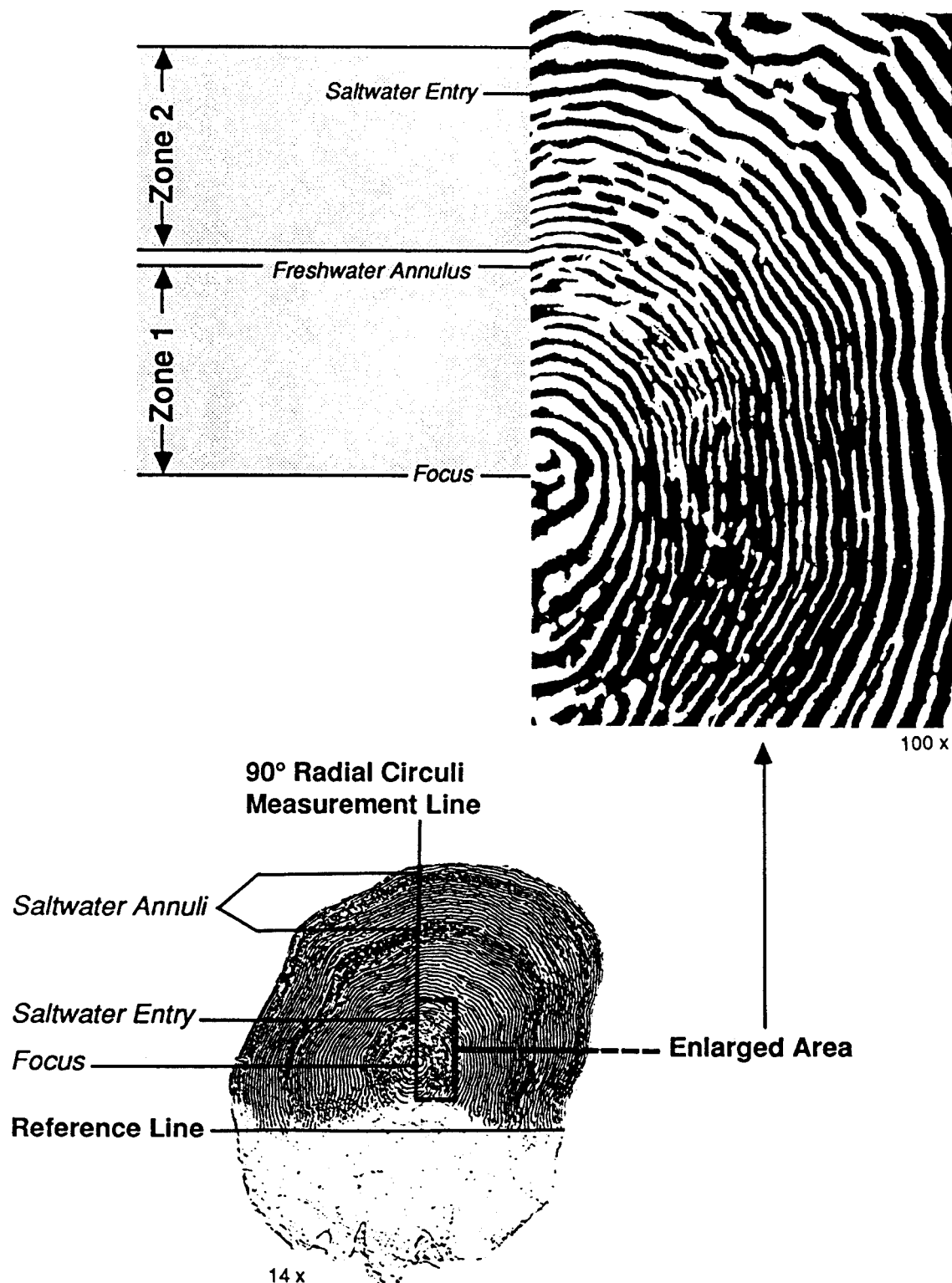
### Age Determination and Scale Measurements

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 well-established methods (Johnston 1905, Gilbert 1913, Van Oosten 1929). Fish age is reported here using the European method (Koo 1955), in which the number of winters spent in freshwater (not including the winter of egg incubation) is described by an Arabic numeral followed by a dot. The numeral following the dot indicates the number of winters a fish spent in the ocean. Total fish age is equal to one plus the sum of both numerals.

Scales were used to estimate the age compositions of Bonneville Dam mixed-stock and Wenatchee known-stock samples. Length-at-age relationships were also established. Scales were used to estimate the freshwater age composition of the Okanogan-stock sample. However, ocean age was, in most

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



cases, impossible to determine from these highly resorbed scales. Okanogan-stock age composition is reported by estimated freshwater age only (combining fish of different ocean ages). The notations used are "1.x" and "2.x." For SPA of all stocks, an attempt was made to separately compare and categorize like-age fish. Therefore, length-at-age frequency histograms for Okanogan-stock samples were used to roughly estimate ocean age and to develop a subsample of age 1.2 fish. Otoliths were also used to verify length-at-age estimates.

SPA of circuli in freshwater and, in some cases, early ocean-growth zones was used to identify each known-stock sample and to classify mixed-stock samples. The methodology was applied to age 1.2 samples from all stocks. The Wenatchee-stock sample contained 100 age 1.2 scales. A subsample of 217 scales was randomly selected from Okanogan-stock scales estimated to be age 1.2. A subsample of 104 age 1.2 scales was randomly selected from the Bonneville Dam mixed-stock group. SPA was not used to classify fish of other age-classes. However, age 1.1 and 2.1 fish in the mixed-stock sample were classified by stock based on age compositions observed in the Wenatchee and Okanogan known-stock samples. The remainder of the Bonneville Dam sample was not classified by stock.

A computer and video camera were used to measure, or *digitize*, scale features (BioSonics 1985). One scale from each fish was selected and projected, and a reference line was drawn along its base. The reference line was placed in the clear (posterior) field of the scale such that it bridged the end points of circuli in the first ocean 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. All measurements were made to the outermost marginal edges of circuli. Measurements of the number of circuli and inter-circuli spacing were obtained from two zones designated in each scale. Zone 1 represented freshwater growth from scale focus through the last circulus in the freshwater annulus. Zone 2 represented either freshwater *plus-growth* (the area representing spring growth prior to ocean entry) or freshwater plus-growth and early ocean growth. Zone 2 measurements were made from the inside focal edge of the first circulus of freshwater plus-growth to the last complete circulus visible on the monitor screen. Depending on the scale, Zone 2 incorporated from six to twelve circuli.

## Character Selection

Variables, or *scale characters*, composed of selected scale measurements from within the two designated zones, were tested to find those that most effectively characterized differences in growth between the two stocks. These variables, used in statistical analyses, included linear measurements between circuli in the two zones, as well as between-zone ratios of circuli-group measurements. In our experiments, we chose not to include variables developed from circuli lying beyond number nine in Zone 1 or number six in Zone 2, because all scales measured contained at least nine Zone 1 and six Zone 2 circuli.

More than 50 potential variables were tested for their effectiveness in discriminating stocks (Table 1). Ten ratio variables were tested that described growth during the first year of a fish's freshwater life proportional to growth during its second year.

## Statistical Analyses

A linear discriminant analysis technique developed by Fisher (1936) was used to differentiate stocks and classify unknown mixed-stock samples. 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). Linear discriminant analysis permits the simultaneous use of many variables to form discriminant functions that typify and identify groups.

A linear 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:

$$Y = m_1x_1 + m_2x_2 + \dots + m_nx_n$$

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

Table 1. Variables tested and used in discriminant analyses.

Test Set	Variables Used		Description of Variables
	Subset 1	Subset 2	
1			Number of circuli in zone 1
2	x	x	Size of zone 1
3			Distance from focus to circulus 1 in zone 1
4			Distance from circulus 1 to circulus 2 in zone 1
5			Distance from circulus 2 to circulus 3 in zone 1
6			Distance from circulus 3 to circulus 4 in zone 1
7			Distance from circulus 4 to circulus 5 in zone 1
8			Distance from circulus 5 to circulus 6 in zone 1
9			Distance from circulus 6 to circulus 7 in zone 1
10			Distance from circulus 7 to circulus 8 in zone 1
11			Distance from circulus 8 to circulus 9 in zone 1
12			Distance from focus to circulus 2 in zone 1
13			Distance from circulus 1 to circulus 3 in zone 1
14			Distance from circulus 2 to circulus 4 in zone 1
15			Distance from circulus 3 to circulus 5 in zone 1
16			Distance from circulus 4 to circulus 6 in zone 1
17			Distance from circulus 5 to circulus 7 in zone 1
18			Distance from circulus 6 to circulus 8 in zone 1
19			Distance from circulus 7 to circulus 9 in zone 1
20	x	x	Distance from focus to circulus 3 in zone 1
21			Distance from circulus 1 to circulus 4 in zone 1
22			Distance from circulus 2 to circulus 5 in zone 1
23			Distance from circulus 3 to circulus 6 in zone 1
24			Distance from circulus 4 to circulus 7 in zone 1
25			Distance from circulus 5 to circulus 8 in zone 1
26			Distance from circulus 6 to circulus 9 in zone 1
27			Distance from circulus 0 to circulus 1 in zone 2
28			Distance from circulus 1 to circulus 2 in zone 2
29			Distance from circulus 2 to circulus 3 in zone 2
30			Distance from circulus 3 to circulus 4 in zone 2
31			Distance from circulus 4 to circulus 5 in zone 2
32			Distance from circulus 5 to circulus 6 in zone 2
33			Distance from circulus 0 to circulus 2 in zone 2
34			Distance from circulus 1 to circulus 3 in zone 2
35			Distance from circulus 2 to circulus 4 in zone 2
36			Distance from circulus 3 to circulus 5 in zone 2
37			Distance from circulus 4 to circulus 6 in zone 2
38	x	x	Distance from circulus 0 to circulus 3 in zone 2
39			Distance from circulus 1 to circulus 4 in zone 2
40			Distance from circulus 2 to circulus 5 in zone 2
41	x	x	Distance from circulus 3 to circulus 6 in zone 2
42			Distance from focus to circulus 6 in zone 1 divided by the distance from circulus 1 to circulus 5 in zone 2
43			Distance from focus to circulus 6 in zone 1 divided by the distance from circulus 0 to circulus 5 in zone 2
44	x		Distance from focus to circulus 6 in zone 1 divided by the distance from circulus 0 to circulus 3 in zone 2
45			Distance from focus to circulus 6 in zone 1 divided by the distance from circulus 0 to circulus 4 in zone 2
46			Distance from focus to circulus 6 in zone 1 divided by the distance from circulus 1 to circulus 6 in zone 2
47			Distance from focus to circulus 6 in zone 1 divided by the distance from circulus 2 to circulus 6 in zone 2
48			Distance from focus to circulus 3 in zone 1 divided by the distance from circulus 0 to circulus 3 in zone 2
49			Distance from focus to circulus 3 in zone 1 divided by the distance from circulus 0 to circulus 4 in zone 2
50			Distance from focus to circulus 3 in zone 1 divided by the distance from circulus 0 to circulus 5 in zone 2
51			Distance from focus to circulus 4 in zone 1 divided by the distance from circulus 0 to circulus 3 in zone 2

The frequency distribution of Y was determined, and mean values of Y computed for the two populations. The critical value for separating the two populations was a function of the average of the two means,  $\overline{Y}_A$  and  $\overline{Y}_B$ , expressed as:

$$Y_C = \frac{\overline{Y}_A + \overline{Y}_B}{2}$$

An observation was then classified to one of the two populations based on whether the application of the discriminant function to that observation produced a value greater than, or less than,  $Y_C$ .

Accuracy of the discriminant analysis was determined by classifying the known samples. A jackknife 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 100%, 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 us to enter and/or remove variables 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 are 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 Bias in Scale Measurement

Because obvious differences between Wenatchee- and Okanogan-stock sockeye scales were often apparent, we were unsure if prior knowledge of stock scale-origin would bias the operator's ability to locate scale features and measure scale zones.

A test was made to determine whether such a bias was present. Sub-samples of 35 Wenatchee-stock scales and 43 Okanogan-stock scales were selected (with origin unknown to the operator), measured, and compared to those scales previously digitized. A paired t-test of annulus position and number of circuli in Zone 1 was made. This test was designed to detect a difference of one circulus in Zone 1 measurements at a significance level of .05 and a power of .90 (Snedecor and Cochran 1980).

## RESULTS

### Age and Length Composition

Age 1.2 fish were estimated to comprise 66% of the Columbia Basin sockeye salmon of unknown origin sampled at Bonneville Dam (Table 2). Significant portions of the mixed stocks sampled there returned as age 1.1 (22%) and 2.2 (9%), while small numbers returned as age 2.1 and 1.3 (1% and 2%, respectively).

Age 1.2 fish were estimated to comprise 79% of the Wenatchee-stock sample (Table 3). Significant proportions of this known stock were estimated to be age 2.2 (16%) and 1.3 (5%). None of the Wenatchee-stock fish sampled were estimated to be age 1.1 or 2.1.

It was estimated that 97% of Okanogan known-stock sockeye spent one complete year in freshwater (Table 3) and thus were designated as age 1.x. Only 3% were estimated to have spent an additional full year in freshwater (age 2.x).

Mean fork-lengths of Bonneville Dam mixed-stock samples for the two principal age classes (1.1 and 1.2) were 40.1 and 52.2 cm, respectively; and 90% confidence intervals for these lengths were from 35.5 to 44.8 cm and from 48.3 to 56.1 cm, respectively (Figure 3).

The mean fork-length of age 1.2 Wenatchee-stock sockeye salmon was 52.8 cm, with a 90% confidence interval from 47.9 to 57.7 cm (Figure 3). For age 2.2 fish, mean length was 53.9 cm, with a 90% confidence interval from 48.2 to 59.6 cm. Age 1.3 fish averaged 60.1 cm in length, with a 90% confidence interval from 56.6 to 63.6 cm.

Unless positively identifiable scales or otoliths indicated otherwise, Okanogan-stock sockeye between 48.0 and 56.0 cm in fork length were classified as being age 1.2 (Figure 4).

Table 2. Total and weekly age composition (percent) of Columbia Basin sockeye salmon stocks sampled at Bonneville Dam in 1987.

Statistical Week	Sample Size	<u>Brood year and age class</u>				
		<u>1984</u>	<u>1983</u>		<u>1982</u>	
		1.1	1.2	2.1	1.3	2.2
25	32	9	56	3	3	28
26	106	22	70	3	3	3
27	130	21	69	0	2	8
28	76	17	70	0	1	12
29	31	36	58	3	0	3
30	17	53	35	0	0	12
Total	392	22	66	1	2	9

Table 3. Age composition of Wenatchee and Okanogan sockeye salmon stocks sampled in 1987.

Wenatchee sockeye sampled in the Lake Wenatchee sport fishery in 1987

Sample Size	Brood Year and Age Class				
	<u>1984</u> 1.1	<u>1983</u> 1.2	<u>1983</u> 2.1	<u>1982</u> 1.3	<u>1982</u> 2.2
143	0	79	0	5	16

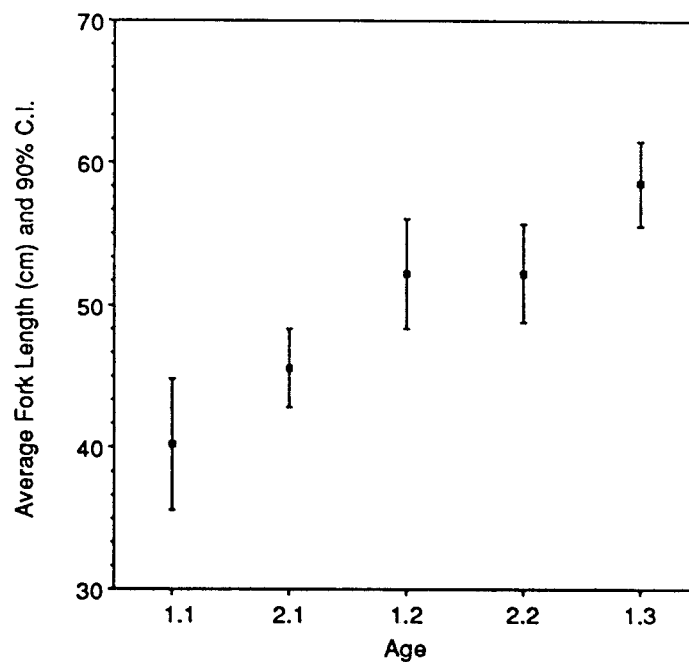
Okanogan sockeye sampled on the Okanogan River spawning grounds in 1987

Sample Size	Age Class	
	1.x <sup>1</sup>	2.x <sup>1</sup>
581	97	3

1. Ocean age was impossible to determine for most Okanogan-stock scale samples. Notations "1.x" and "2.x" are used to report age composition by estimated freshwater age only (combining scales of different ocean ages).

Figure 3. Length-at-age composition of Columbia Basin sockeye salmon stocks sampled in 1987.

Length-at-age composition of Bonneville Dam mixed-stock samples



Length-at-age composition of Wenatchee-stock samples

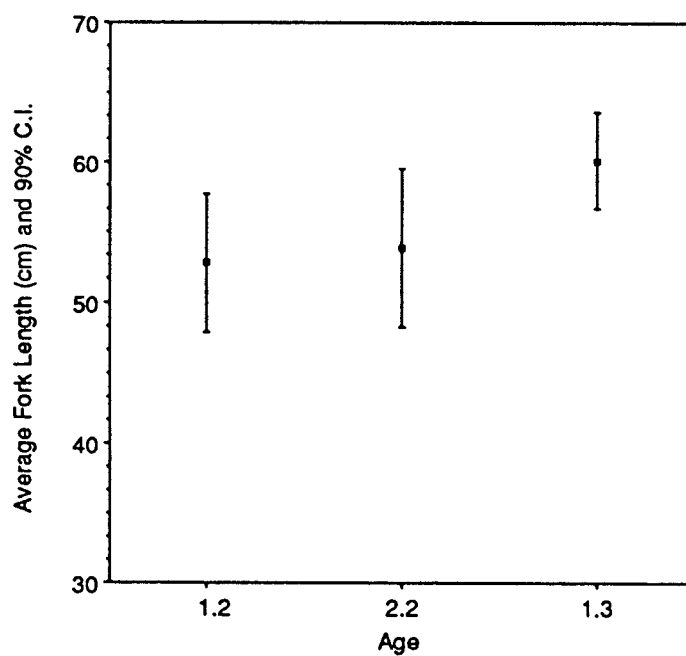
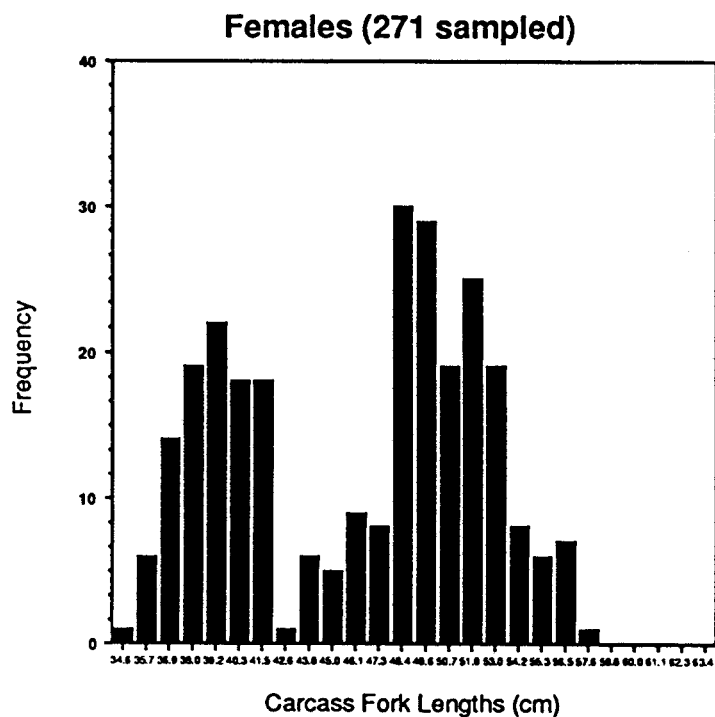
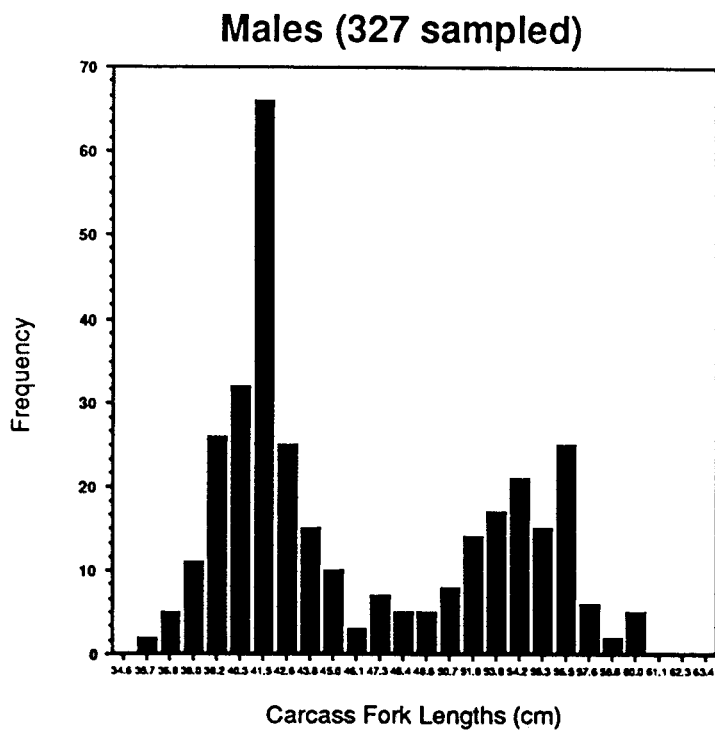


Figure 4. Length distribution of Okanogan-stock sockeye salmon sampled in 1987.



## Classification Procedure Using Known-stock Samples

Distances measured between non-adjacent circuli gave higher classification accuracies than distances measured between adjacent circuli. Using these larger spacings tended to smooth random variations between scales, emphasizing actual differences in scales of different groups. This result was consistent with those determined by Davis (1987) in a study of significant scale-characters found in different chinook salmon stocks harvested in the North Pacific high-seas fishery.

The stepwise variable-selection procedure selected variables having a partial  $F$  statistic with a value greater than four. From 51 variables tested, two subsets were used for the actual analyses, each containing scale characters with the highest partial  $F$  values (Table 1). Variable subset 1, containing five scale characters, was selected for the first analysis. A second analysis was made using variable subset 2, a set of four scale characters, none of which were ratio type. Ratio characters tend to be non-normally distributed and are often difficult to understand biologically (Davis 1987).

Classification accuracy achieved using subset 1 was 93% (Table 4). Only 10 Wenatchee scales were misclassified as being of Okanogan stock, while 12 Okanogan scales were misclassified as Wenatchee stock. The jack-knife procedure had no affect on results.

Classification accuracy achieved using variable subset 2 produced one additional misclassification compared to the previous analysis (Table 4). Using the jackknifed classification in this analysis reduced accuracy to 91%, with a total of 17 Okanogan scales and 10 Wenatchee scales incorrectly classified. Reducing the number of scale characters by eliminating ratio measurements therefore resulted in a total of five additional misclassifications and a decrease of 2% in the accuracy level.

Table 4. Classification using linear discriminant analyses of age 1.2 Columbia Basin sockeye salmon stocks (knowns) sampled in 1987.

Stock classification using variable subset 1  
(containing ratio variables)

Correct Group	Percent Correct	Number of Samples Classified Into Group	
		<i>Okanogan</i>	<i>Wenatchee</i>
<i>Okanogan</i>	95	205	12
<i>Wenatchee</i>	90	10	90
Classification Accuracy	93		

Jackknifed Stock Classification

Correct Group	Percent Correct	Number of Samples Classified Into Group	
		<i>Okanogan</i>	<i>Wenatchee</i>
<i>Okanogan</i>	95	205	12
<i>Wenatchee</i>	90	10	90
Classification Accuracy	93		

Stock classification using variable subset 2  
(without ratio variables)

Correct Group	Percent Correct	Number of Samples Classified Into Group	
		<i>Okanogan</i>	<i>Wenatchee</i>
<i>Okanogan</i>	94	204	13
<i>Wenatchee</i>	90	10	90
Classification Accuracy	92		

Jackknifed Stock Classification

Correct Group	Percent Correct	Number of Samples Classified Into Group	
		<i>Okanogan</i>	<i>Wenatchee</i>
<i>Okanogan</i>	92	200	17
<i>Wenatchee</i>	90	10	90
Classification Accuracy	91		



## Classification of Unknown Mixed-stock Samples

Variable subset 2 was used to classify unknown mixed-stock scales sampled at Bonneville Dam. Variable subset 1 was not used in this analysis, because the small increase (2%) in known-stock classification accuracy it provided did not justify the potential problems created by use of ratio variables. The linear discriminant function classified 36% of the age 1.2 unknown-origin sockeye scale subsample as Okanogan stock and the remaining 64% as Wenatchee stock (Table 5). Because classification accuracy indicated by analysis of known scales was not 100%, a bias occurred in estimating stock sizes (Cook and Lord 1978). After correction for bias, 33% of the sample was classified as Okanogan stock and the remaining 67% as Wenatchee stock. Confidence intervals (90%) ranged from 25% to 42% for the Okanogan group and from 58% to 75% for the Wenatchee group.

No sockeye scales of either age 1.1 or age 2.1 were estimated to be present in the Wenatchee-stock sample (Table 3), although scales of these ages were present (22% and 1%, respectively) in the Bonneville Dam mixed-stock sample (Table 2). We therefore classified fish of these age classes sampled at Bonneville Dam as Okanogan stock.

Classification of age 2.2 and 1.3 sockeye salmon in the mixed-stock sample was not attempted. Although fish of these age classes appeared disproportionately in the two known-stock samples, we did not feel confident enough in sample sizes, representativeness of sampling, or ocean-age estimation of Okanogan-group samples to attempt classification on this basis.

Combining the results of SPA classification of age 1.2 unknowns and classification of the remaining unknowns by age alone, we estimated that the entire run at Bonneville Dam was composed of 45% Wenatchee and 45% Okanogan stock. The remaining 10% were considered of undetermined origin.

Table 5. Classification using linear discriminant analyses of age 1.2 Columbia Basin sockeye salmon stocks (unknowns) sampled at Bonneville Dam in 1987.

Stock classification using variable subset 2  
(without ratio variables)

	<u>Classification into Groups</u>	
	<i>Wenatchee</i>	<i>Okanogan</i>
Number	66	38
Percentage	64	36
Bias Corrected Percentage	67	33
90% Confidence Interval for Bias Corrected Percentage	(58, 75)	(25, 42)

## **Visual Scale Classification**

Sample identification and separation, attempted strictly on the basis of the visual appearance of scale patterns, resulted in a classification accuracy of 90% (Table 6).

## **Testing for Bias in Scale Measurement**

No significant bias was found when this test was applied to Wenatchee-group scales ( $p > .48$ ). A significant bias did appear to be present in tests of Okanogan-stock scale measurements. The t-statistic for the difference between the two measurements of number of circuli in Zone 1 was significant at the .05 level ( $p = .032$ ). The test for the measurement of the size of Zone 1 was highly significant ( $p < .0001$ ). The two measurements of the size of Zone 1 varied by more than 20% for a small number (14%) of these scales. However, the difference between the mean number of circuli and mean size of Zone 1 for the two sets of measurements was insignificant ( $p = .335$  and  $.309$ , respectively).

Table 6. Classification using visual separation of age 1.2 Columbia Basin sockeye salmon stocks (knowns) sampled in 1987.

Stock classification using visual separation techniques

Correct Group	Percent Correct	Number of Samples Classified Into Group	
		<i>Okanogan</i>	<i>Wenatchee</i>
<i>Okanogan</i>	100	44	0
<i>Wenatchee</i>	79	7	27
Classification Accuracy	90		

## DISCUSSION

This study has shown that Wenatchee-stock and Okanogan-stock Columbia Basin sockeye salmon can be separated with a high degree of accuracy by digitizing scales and using a linear discriminant analysis procedure. Our study also indicated that highly accurate visual scale separation is possible. Further experiments will be made both to refine this technique and to study its application to the classification of unknown scales.

SPA was only used to classify age 1.2 sockeye scales. However, the Okanogan sample almost certainly contained scales of both age 1.1 and 1.2. High classification accuracies using pooled age classes suggested that it may be possible to use age 1.2 known samples for stock classification of other-age fish. It may also be possible to classify scales from adult sockeye in other years using 1987 age 1.2 samples. This pooling of data across age classes, both within and between years, will be tested in future studies. Future research will also examine how the proportional representation of the two stocks in mixed-stock areas varies with migration time.

In 1987, known-stock samples were probably sufficient for developing only the conservative age-class composition estimates we made and the subsequent mixed-stock composition estimates based on those age-class representations. Wenatchee-stock samples, collected from a Lake Wenatchee sport fishery, totaled only 143 fish. This sample may have biased estimates of stock age-composition by overestimating the proportion of larger and older fish. A larger and possibly more representative sample will be obtained for this stock in future years. The high proportion of one-ocean fish (both males and females) in the Okanogan-stock sample was questioned, as well as the absence of age 1.x fish in the Wenatchee sample. However, earlier research by Major and Craddock (1962) confirmed the high incidence of one-ocean Okanogan sockeye in certain years, as well as the rarity of age 1.x Wenatchee-stock sockeye.

Additional biases may have existed in the Okanogan sample, which was obtained from two Okanogan River spawning-ground surveys. The first survey

was made early in the spawning season, and samples collected consisted primarily of smaller (and thus, presumably younger) male fish. In the second survey, we noted the presence of a higher proportion of females and larger males. A more-random sample of the entire Okanogan stock will be obtained in future studies.

The results of the test for bias in scale-measurement procedures highlighted problems arising from attempts to digitize poor-quality Okanogan-stock scales. The difficulty of correct reference-line placement on highly resorbed scales appeared to be a primary cause of the significant test results. In the future, marginal-quality scales will be eliminated from samples before data acquisition, and better-quality scales from fish in earlier stages of maturation will be obtained. This will also improve the accuracy of Okanogan-stock ocean-age estimation.

The bias test also indicated that operator variability in precise freshwater annulus location may result in scale data-acquisition errors. In future research, a single-zone scale digitizing method will be tested that may eliminate this problem by removing qualitative decisions concerning scale-feature location from the scale-measurement process.

## LITERATURE CITED

- Allen, R.L., and T.K. Meekin. 1980. Columbia River sockeye salmon study, 1971-1974. State of Washington, Department of Fisheries Progress Report 120.
- Anas, R.E., and S. Murai. 1969. Use of scale characteristics and a discriminant function for classifying sockeye salmon *Oncorhynchus nerka* by continent of origin. International North Pacific Fisheries Commission Bulletin 26.
- Bethe, M.L., and P.V. Krasnowski. 1977. Stock separation studies of Cook Inlet sockeye salmon based on scale pattern analysis. Alaska Department of Fish and Game Informational Leaflet 180.
- Bethe, M.L., P.V. Krasnowski, and S. Marshall. 1980. Origins of sockeye salmon in the Upper Cook Inlet fishery of 1978 based on scale pattern analysis. Alaska Department of Fish and Game Informational Leaflet 186.
- BioSonics Inc. 1985. Optical pattern recognition system. Data acquisition program manual. 4520 Union Bay Place NE, Seattle, Washington 98105.
- Clutter, R., and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission Bulletin 9.
- Conrad, R. 1985. Sample sizes of standards and unknowns for a scale pattern analysis. (Unpublished memorandum) Alaska Department of Fish and Game, Sports Fishery Division, 333 Raspberry Road, Anchorage, Alaska 99502.
- Cook, R.C., and G.E. Lord. 1978. Identification of stocks of Bristol Bay sockeye salmon *Oncorhynchus nerka*, by evaluating scale patterns with a polynomial discriminant method. United States Fish and Wildlife Service, Fishery Bulletin 76(2):415-423.
- Davis, N.D. 1987. Variable selection and performance of variable subsets in scale pattern analysis. (Document submitted to annual meeting of the International North Pacific Fisheries Commission 1987.) FRI-UW-8713. Fisheries Research Institute, University of Washington.
- Dixon, W.J., M.B. Brown, L. Engelman, J.W. Frane, M.A. Hill, R.I. Jennrich, and J.D. Toporek. 1983. BMDP Statistical Software. University of California Press.
- Fisher, R.A. 1936. The use of multiple measurements in taxonomic problems. Annals of Eugenics 7:179 -188.

- Fulton, L.A. 1970. Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River Basin — past and present. National Marine Fisheries Service Special Scientific Report (Fisheries) 618.
- 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.
- Henry, K.A. 1961. Racial identification of Fraser River sockeye salmon by means of scales and its applications to salmon management. International Pacific Salmon Fisheries Commission Bulletin 12.
- 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.
- 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.
- McPherson, S.A., and E.L. Jones. 1987. Contribution, exploitation, and migratory timing of returns of sockeye salmon (*Oncorhynchus nerka*) stocks to Lynn Canal in 1986 based on analysis of scale patterns. Alaska Department of Fish and Game Technical Data Report 220.
- Major, R.L., and D.R. Craddock. 1962. Influence of early maturing females on reproductive potential of Columbia River blueback salmon (*Oncorhynchus nerka*). United States Fish and Wildlife Service, Fishery Bulletin 61 (194):429-437.
- Major, R.L., J. Ito, S. Ito, and H. Godfrey. 1978. Distribution and origin of chinook salmon (*Oncorhynchus tshawytscha*) in offshore waters of the North Pacific Ocean. International Northern Pacific Fish Commission Bulletin #38.
- Mosher, K.H. 1963. Racial analysis of red salmon by means of scales. International North Pacific Fisheries Commission Bulletin 11.
- Mullan, J.W. 1986. Determinants of sockeye salmon abundance in the Columbia River, 1880s—1982: a review and synthesis. United States Fish and Wildlife Service Biological Report 86 (12).
- Northwest Power Planning Council. 1986. Council staff compilation of information on salmon and steelhead losses in the Columbia River Basin. 850 SW Broadway, Portland, Oregon 97205.
- Oregon Department of Fish and Wildlife and Washington Department of Fisheries. 1987. Columbia River Fish Runs and Fisheries, 1960-86.



- 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.
- Pella, J.J., and Robertson, T.L. 1979. Assessment of composition of stock mixtures. United States Fish and Wildlife Service, Fishery Bulletin 77(2):387-398.
- Schwartzberg, M. 1987. Columbia upriver salmon stock identification project — Field operations guide. Columbia River Inter-Tribal Fish Commission Technical Report 87-1.
- Snedecor, G.W. and W.C. Cochran. 1980. Statistical methods. Iowa State University.
- 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.
- Worlund, D.D., and R.A. Fredin. 1960. Differentiation of stocks. Symposium on Pink Salmon. University of British Columbia.