EXPERIMENTS IN IDENTIFYING HATCHERY AND NATURALLY SPAWNING STOCKS OF COLUMBIA BASIN SPRING CHINOOK SALMON USING SCALE PATTERN ANALYSES

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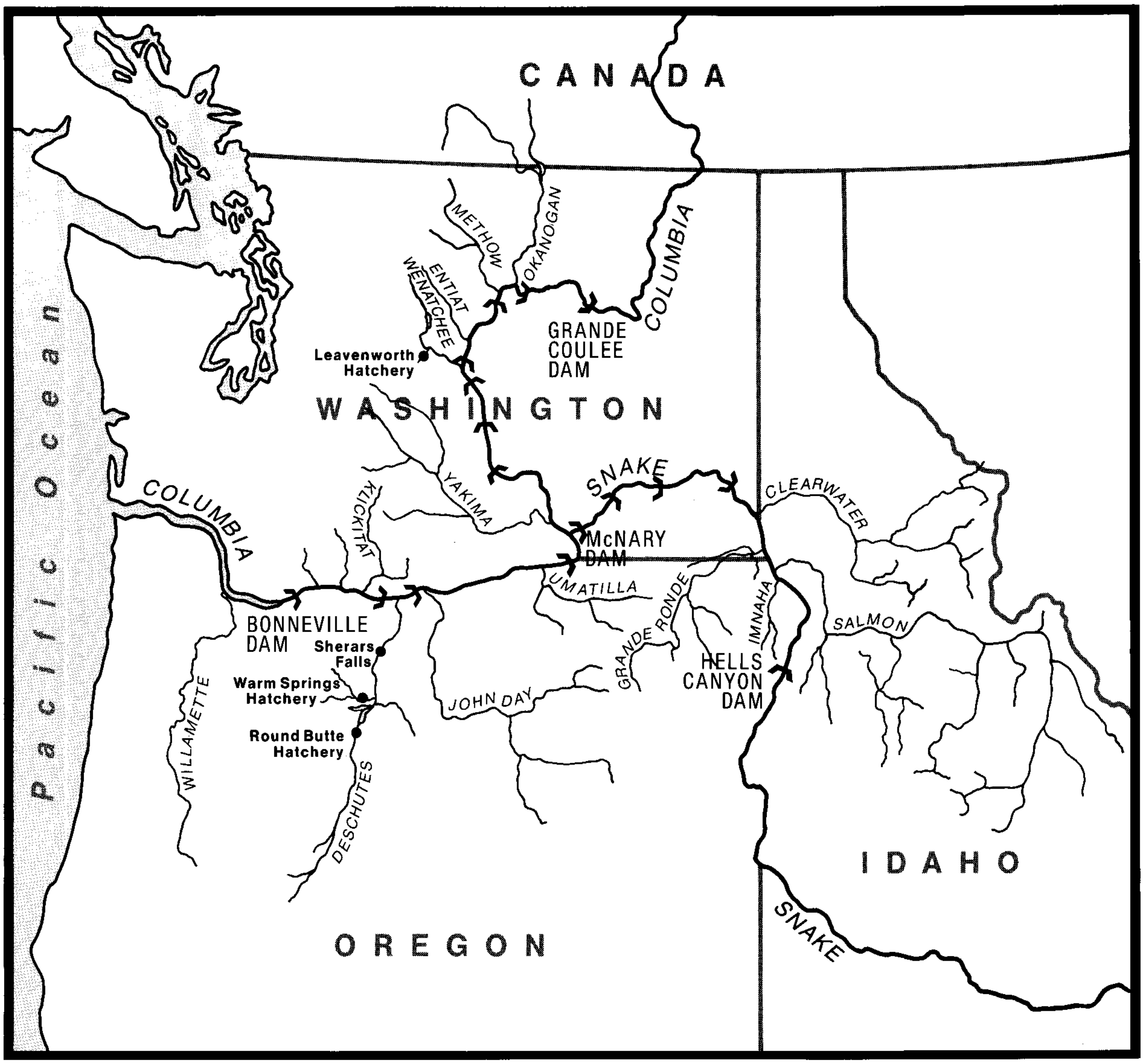
INTRODUCTION

The Columbia River Basin (Figure 1) once supported the largest population of chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the world (Fulton 1968). Based on early harvest records, estimates have been made of annual runs averaging over nine million fish (Northwest Power Planning Council [NPPC], 1986). In recent years (1978-1987), runs have averaged only about 660,000 fish, with a majority of these being hatchery produced (Bohn and McIssac 1988). Biologists recognize three races (spring, summer, and fall) and two major geographic groupings of chinook salmon in the Columbia Basin. These geographic groups are known as *upriver,* composed of fish originating upstream of Bonneville Dam (river km 225), and *lower river,* composed of fish originating downstream of Bonneville Dam. Historically one of the most important Columbia Basin salmon to Indian tribes and early white settlers of the region, upriver spring chinook salmon runs once may have averaged nearly two million fish per year (NPPC 1986). A ten-year average for this population in recent years (1978-1987) indicates a present population size of only about 81,000 fish per year (Bohn and McIssac 1988).

Because salmon return to their natal streams (or hatcheries) to spawn, different discrete groups or *stocks* have evolved, generally based on area of origin (Scheer 1939, Rich 1939). An understanding of the stock composition of fish populations enables fisheries resource managers to optimize the utilization of fisheries resources by treating individual stocks as discrete management units (Ricker 1954, MacLean and Evans 1981, McDonald 1981). One fundamental strategy of this management technique is the proportional distribution of harvest relative to individual stock health and abundance. To be applied effectively, this form of fisheries management requires dependable methods for stock recognition and mixed-stock run composition estimation as well as an understanding of the biological and migratory characteristics of each stock or stock group. Such information, at the present time, does not exist for Columbia Basin upriver spring chinook salmon stocks. In addition, the proportion of hatchery and naturally produced fish in the mixed-stock population is not presently known.

It is expected that reliable stock identification procedures would be specifically useful in a variety of Columbia Basin upriver spring chinook salmon management applications, including escapement monitoring, spawner-recruit modeling to estimate

Figure 1. Map of the Columbia Basin showing Bonneville Dam; the principal (upriver) spring chinook salmon natural production areas; Sherars Falls; Round Butte and Warm Springs hatcheries on the Deschutes River; and Leavenworth Hatchery on the Wenatchee River.



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. The monitoring program established contains provisions for estimating the escapement and status of key Columbia Basin salmon stocks, one of these being upriver spring chinook. In addition, although no mainstem Columbia River commercial fishery now exists for these stocks, potential future in-river harvest management would benefit from an established data base that includes such information as stock composition and stock-specific escapement.

The purpose of this study, a part of the Columbia River Inter-Tribal Fish Commission Stock Identification Project, is to explore the feasibility of Columbia Basin spring chinook salmon stock identification through the use of scale pattern analyses. This report summarizes the results of 1988 research in two major Columbia River subbasins, the Deschutes and Wenatchee, where use of this technique to differentiate hatchery and naturally spawning stocks in each system was tested. A long-term goal of the project is to develop hatchery/natural stock composition estimation techniques for application in mixed-stock areas. Data from the two study areas was therefore pooled to test the subsequent effects on scale-variable dispersion and on group classification accuracy. This study was begun in 1988 and research is expected to continue in 1989 with the possible addition of other stock samples to test area variability in scale pattern characteristics and to further experiment with aggregate stock identification.

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.

Fish reared in hatcheries generally grow faster than those produced in natural habitat. In addition, growth is generally more uniform, with less pronounced growth retardation during winter and early spring periods (Peck 1970). We assumed that these differences might be reflected in scales of hatchery and naturally produced fish and that these differences would be detectable and classification possible using SPA.

Both hatchery and naturally spawning spring chinook populations are found in each of the two Columbia River subbasins selected for this study, the Deschutes and Wenatchee rivers. Two spring chinook hatcheries are located in the Deschutes subbasin. They are Round Butte Hatchery, operated by Portland General Electric Corporation (at river km 175 on the Deschutes River), and Warm Springs National Fish Hatchery, operated by the U.S. Fish and Wildlife Service (at river km 11 on the Warm Springs River). One spring chinook hatchery is located in the Wenatchee subbasin. It is Leavenworth National Fish Hatchery, operated by the U.S. Fish and Wildlife Service and located at river km 4 on Icicle Creek. At all of these hatcheries, a variety of rearing and release strategies are employed. For this study, however, all release groups from within a particular hatchery were treated as a single stock. All natural production from within a particular subbasin was also treated as a single stock. In total, three hatchery and two natural stocks were sampled. In various combinations, data acquired from these samples provided the data used in the following stock-identification feasibility analyses:

Test A. A three-stock identification test of the two hatchery and one natural Deschutes spring chinook stocks.

Test B. A two-stock identification test of hatchery and natural stock separability in the Deschutes subbasin. Both Round Butte and Warm Springs hatchery stock samples were combined and compared to the Deschutes natural stock sample.

Test C. A two-stock identification test of hatchery and natural stock separability in the Wenatchee subbasin. The Leavenworth Hatchery stock sample was compared to the Wenatchee natural stock sample.

Test D. A two-stock identification test in which the three hatchery stock samples from the Deschutes and Wenatchee subbasins were pooled and compared to the two pooled natural stock samples.

Sampling

The five hatchery and natural stocks were sampled in terminal areas to obtain representative scale samples. Deschutes subbasin stocks were sampled at the Sherars Falls sport and tribal-dipnet fisheries (Figure 1). All adult returns from both Deschutes hatchery stocks were uniquely marked with fin clips while natural stock fish carried no artificial external marks. Identity of stock origin was, therefore, easily determined. In the Wenatchee subbasin, hatchery fish were sampled at the Leavenworth National Fish Hatchery, and natural stock samples were collected from carcasses on Wenatchee River tributary spawning grounds.

Target sample sizes were 200 fish from each known stock (Conrad 1985). Actual sample sizes obtained (after adjustment for unusable specimens) were 163 Deschutes natural stock, 252 Round Butte stock, 60 Warm Springs stock, 156 Leavenworth stock, and 168 Wenatchee natural stock. Scales were collected and mounted according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963). Six scales were selected from each fish sampled, except in the Leavenworth Hatchery stock sample, where three scales per fish were collected.

Fork lengths were measured to the nearest 0.5 cm and recorded for each fish along with sex and mark or tag information. All field sampling procedures for this project followed previously established guidelines (Schwartzberg 1987).

Age Determination and Scale Measurements

Under magnification, salmon scales 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 saltwater growth circuli in scales of all Columbia Basin spring chinook salmon, which typically spend one complete year 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.

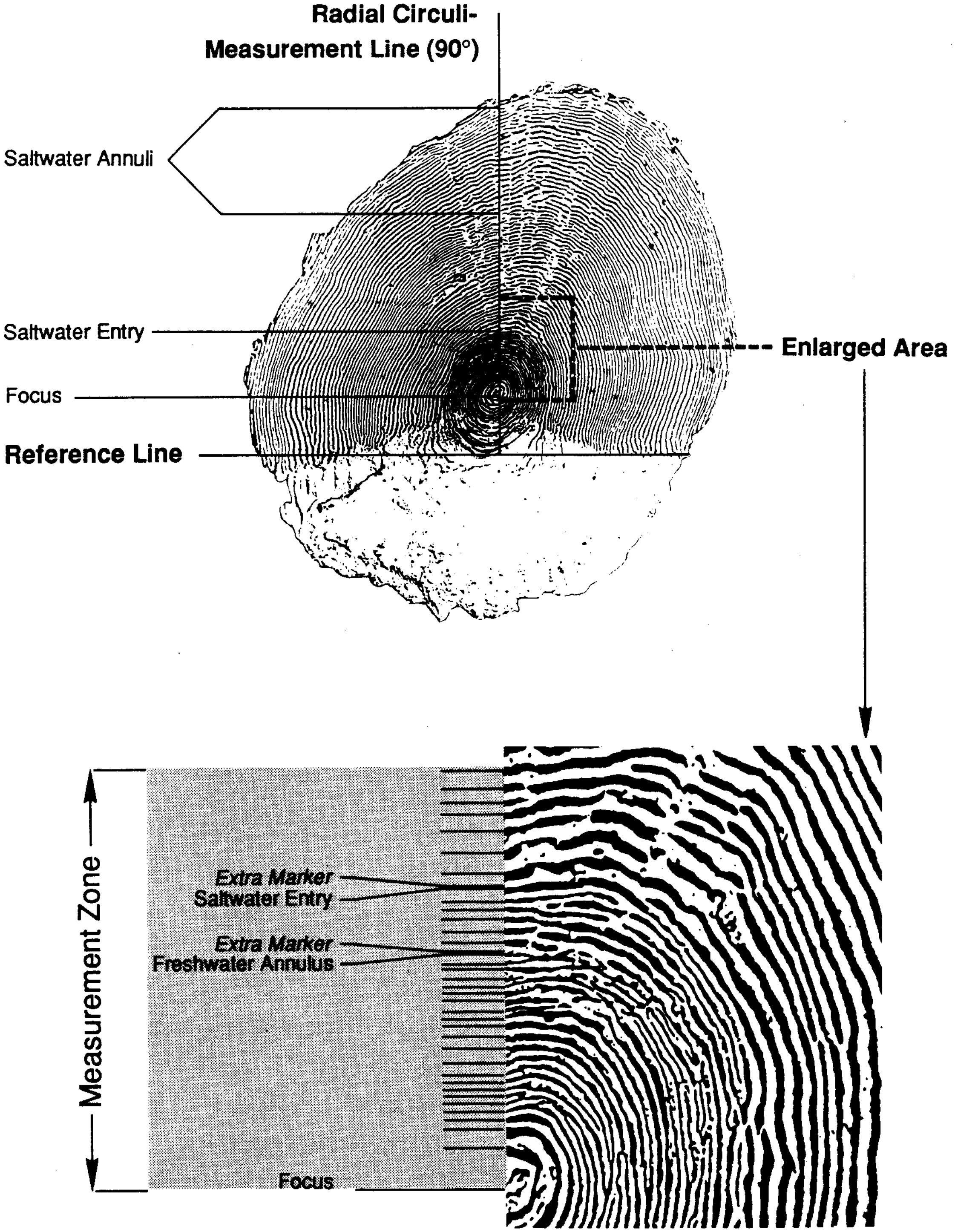
All scales were examined visually and were categorized by age using previously studied techniques (Johnston 1905, Gilbert 1913, Borodin 1924, Van Oosten 1929). The method used for fish-age description is that recommended by Koo (1955), which is sometimes referred to as the *European* method. The number 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 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 composition of each stock. Because of a large amount of scale *resorbtion* (the eroding of a salmon scale as the fish approaches sexual maturity), age composition of the Wenatchee natural stock sample was somewhat more difficult to reliably estimate. Length-at-age relationships were also established for each stock.

SPA of circuli in freshwater and, in some cases, early saltwater growth zones formed the basis for categorization of samples by stock. Within each stock sample, different age-class groups were pooled for SPA stock identification experiments.

A computer and video camera were used to measure, or *digitize*, scale features (BioSonics 1985). The system used consisted of a microscope (2x, 4x, and 10x

Figure 2. Age 1.2 Round Butte stock spring chinook salmon scale showing growth and measurement zones.



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 the 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. Over 20 different variables were tested to determine those most effective in classifying different known-origin samples. Test variables were selected and used in discriminant analyses, and classification accuracies were noted. Variables tested included those made up of measurements among groups of four non-adjacent circuli, or *triplets* (containing three distinct intervals), as well as variables made up of distances measured between three adjacent circuli, or *doublets*. Distances and number of circuli from scale focus to saltwater entry point were also used in variable development. Distances and number of circuli from scale focus to freshwater-annulus margin (anterior) were not used as variables because we believed operator subjectivity played too great a part in the identification of these scale features.

Statistical Analyses

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

A linear function of a set of different scale measurements was computed to maximize the variance among stocks compared to the variance 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 (in the case of a two-stock test) was determined, and mean values of y computed for the two groups. The critical value for separating the groups 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 stocks depending on whether their y values were greater or less than Y.

Accuracy of the discriminant analyses was determined by classifying samples from a particular analysis and then comparing results to actual known-stock identities. 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 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.

Testing for Precision in Scale Feature Measurement

Identification of such scale features as annulus position and saltwater entry point may be a highly subjective process, raising questions about biases associated with their use in stock classification variables. A test was, therefore, conducted to determine whether a single operator could repeatedly locate these two scale features with consistency using samples from all five stock samples. A test of the variability in measurements between different operators was also performed using samples from the Wenatchee naturally spawning stock. Freshwater annulus and saltwater entry locations were both estimated and marked in the initial scale data acquisition process. Subsamples were selected from each sample group, measured, and compared to those previously measured 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 point. The test was designed to detect a difference of 1.5 circuli at a significance level of 0.10 and a power of 0.90 (Snedecor and Cochran 1980).

RESULTS

Age and Age-at-Length Composition

All but one of the five Columbia basin spring chinook stocks sampled included fish of ages 1.1, 1.2, and 1.3 (Table 1, Figure 3). Among the different stocks, variability in age composition was high. Between the subbasins, variability in grouped stock age-composition was also apparent. Fish from both Wenatchee stocks were generally older and larger than fish from the three Deschutes stocks.

The Deschutes natural stock sample was primarily composed of age 1.2 fish (0.85). Age 1.3 fish were present in significant proportion (0.14), while only 0.01 of the sample included age 1.1 fish. Mean fork-lengths for age 1.1, 1.2, and 1.3 fish were, respectively, 52.5, 71.4, and 85.5 cm (Figure 4). The 0.90 confidence intervals for these lengths were, respectively, 51.7, 53.3; 63.8, 79.0; and 77.2, 93.8 cm.

The Deschutes Round Butte Hatchery-stock sample was primarily composed of age 1.2 fish (0.77). Age 1.1 fish were present in significant proportion (0.20), while only 0.04 of the sample included age 1.3 fish. Mean fork-lengths for age 1.1, 1.2, and 1.3 fish were 53.6, 74.5, and 84.9 cm, respectively. The 0.90 confidence intervals for these lengths were, respectively, 44.6, 62.7; 66.5, 82.4; and 77.1, 92.7 cm.

The Deschutes Warm Springs Hatchery stock sample composition included 0.55 age 1.1 and 0.43 age 1.2 fish. Only 0.02 of this sample was age 1.3 fish. Mean fork-lengths for age 1.1 and 1.2 fish were, respectively, 50.1 and 71.0 cm. The 0.90 confidence intervals for these lengths were, respectively, 41.0, 59.2; and 63.5, 78.6 cm. Only one age 1.3 fish was present in this sample.

The Wenatchee natural stock sample composition included 0.61 age 1.3 and 0.39 age 1.2 fish. Only 0.01 of this sample was age 1.1 fish. Mean fork-lengths for age 1.1, 1.2, and 1.3 fish were, respectively, 48.0, 75.2, and 91.1 cm. The 0.90 confidence intervals for these lengths were, respectively, 45.7, 50.3; 66.7, 83.7; and 79.9, 102.4 cm.

The Wenatchee Leavenworth Hatchery stock sample composition included 0.56 age 1.3 and 0.44 age 1.2 fish. No age 1.1 fish were present in this sample. Mean fork-

Table 1. Age composition of Columbia basin spring chinook salmon stocks sampled in 1988.

		Brood Year And Age Class		
		1985	1984	1983
Stock	Sample Size	1.1	1.2	1.3
Deschutes				
Natural	163	0.01	0.85	0.14
Round Butte Hatchery	252	0.20	0.77	0.04
Warm Springs Hatchery	60	0.55	0.43	0.02
Wenatchee				
Natural	156	0.01	0.39	0.61
Leavenworth Hatchery	168	0.00	0.44	0.56

Figure 3. Age composition of Columbia basin spring chinook salmon stocks sampled in 1988.

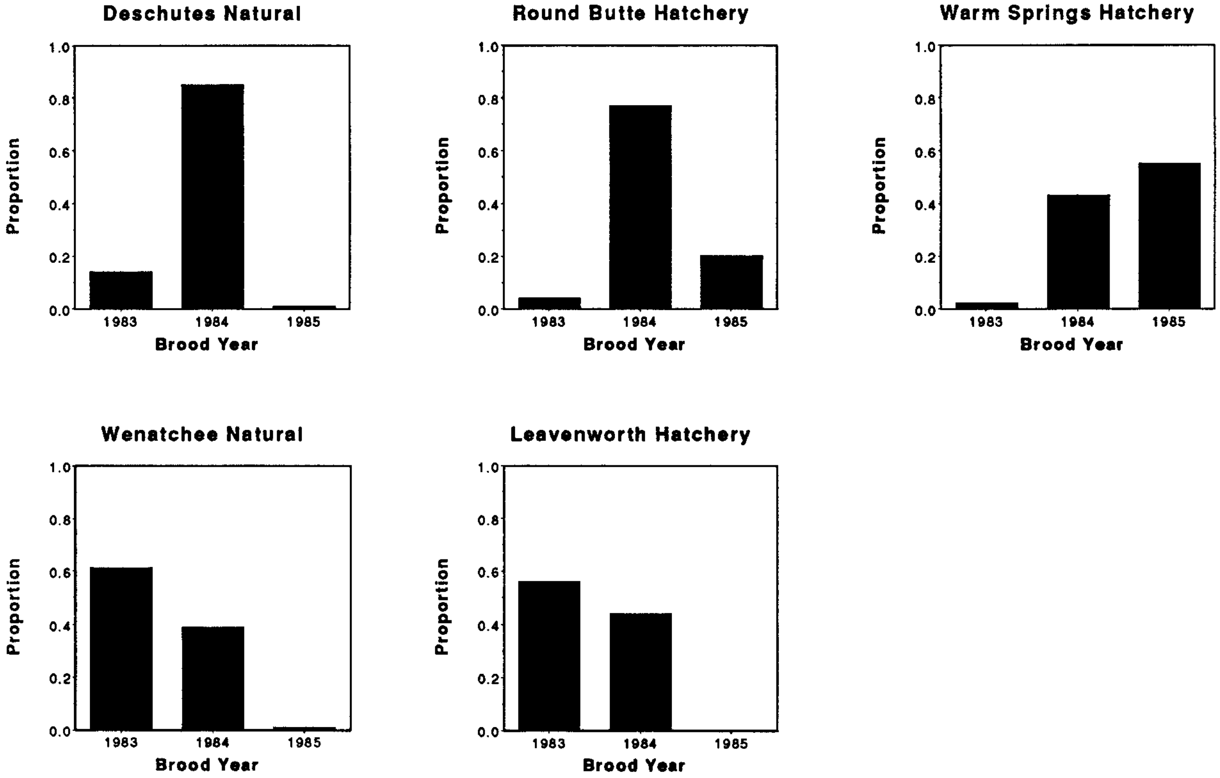
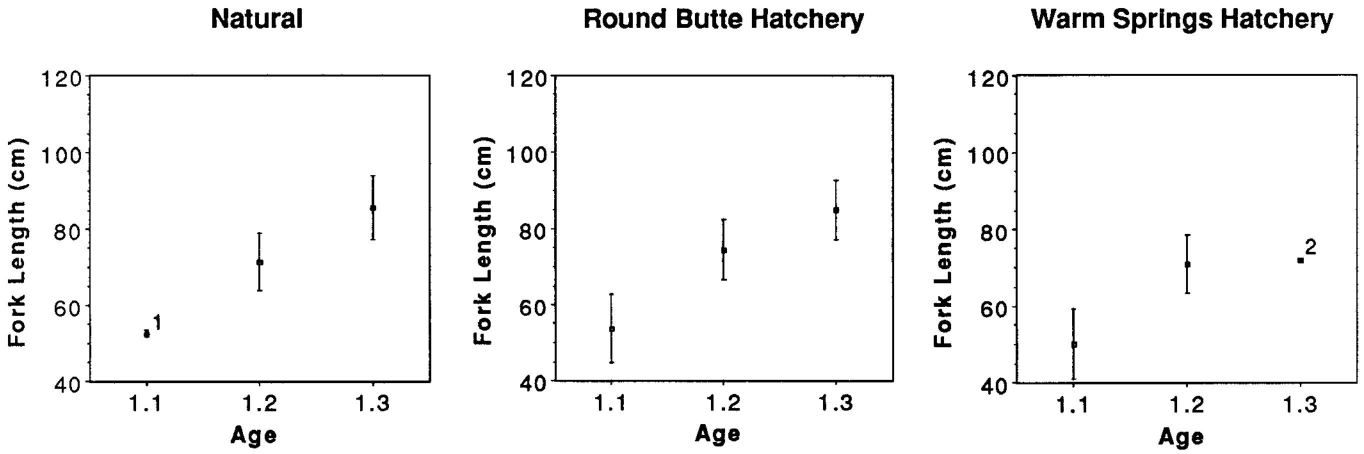
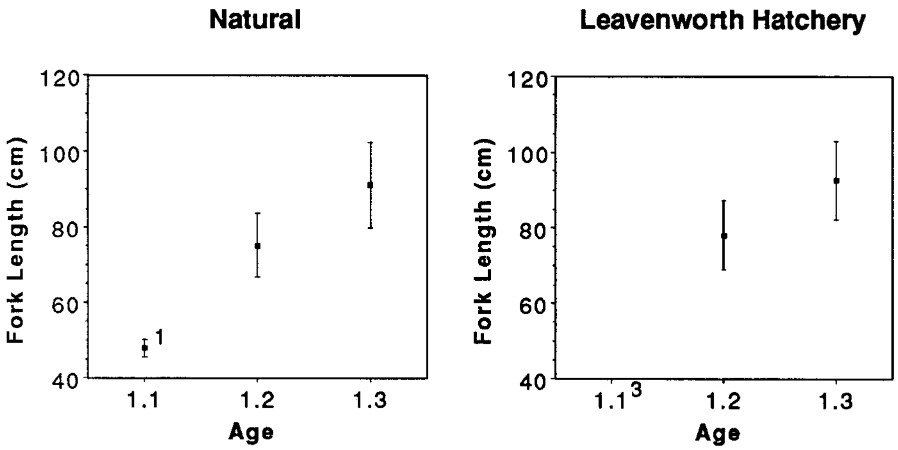


Figure 4. Length-at-age composition of Columbia basin spring chinook salmon stocks sampled in 1988 showing mean fork-lengths and the 0.90 confidence interval for each age class.

Deschutes Stocks



Wenatchee Stocks



1. Only two fish of this age class were sampled.
2. Only one fish of this age class was sampled
3. No fish of this age class was sampled.

lengths for age 1.2 and 1.3 fish were, respectively, 78.1 and 92.6 cm. The 0.90 confidence intervals for these lengths were, respectively, 68.9, 87.3 and 82.2, 102.9 cm.

Classification Feasibility Tests

A subset of 10 variables (Table 2) was selected and used in all reported discriminant analyses. Each test, however, produced a specific model made up of different significant variables. The model used in Test C required the fewest variables (three), while the Test D model used the most variables (eight).

Models containing triplet variables produced higher classification accuracies than those containing doublet variables. The relatively larger triplet spacings tended to smooth random variations among samples of the same stock and to emphasize differences among stocks. Also, using triplets, fewer variables were ultimately required in the final classification model. These findings were consistent with those from our previous stock identification studies (Schwartzberg and Fryer 1988) of Columbia Basin sockeye salmon, *Oncorhynchus nerka* (Walbaum), as well as with the work of Davis (1987) in her study of different Pacific chinook salmon stocks.

Test A

The three-stock identification test of the two Deschutes hatchery stocks and one Deschutes natural stock resulted in an overall classification accuracy of 0.81 (Table 3). The natural stock samples were correctly classified with 0.87 accuracy. Round Butte and Warm Springs hatchery stock samples were correctly classified with 0.75 and 0.80 accuracy, respectively.

Test B

The two-stock identification test of pooled Deschutes hatchery stocks compared with one Deschutes natural stock resulted in an overall classification accuracy of 0.93. Both the combined hatchery and natural stock samples were correctly classified with over 0.90 accuracy.

Table 2. Variables used in discriminant analyses.

Variables	Analyses				Description of Variables
	A	B	C	D	
1	●	●		●	No. of circuli from focus to saltwater entry
2			●	●	Distance from focus to saltwater entry
3				●	Distance from focus to circulus 3
4					Distance from circulus 3 to circulus 6
5	●	●		●	Distance from circulus 6 to circulus 9
6	●	●	●	●	Distance from circulus 9 to circulus 12
7	●	●		●	Distance from circulus 12 to circulus 15
8	●		●	●	Distance from circulus 15 to circulus 18
9	●	●		●	Distance from circulus 18 to circulus 21
10	●	●			Distance from circulus 21 to circulus 24

Table 3. Classification using linear discriminant analyses of Columbia Basin spring chinook salmon stocks sampled in 1988.

Test A (Deschutes subbasin three-stock analysis)

	Stock			
	Natural	*Round Butte*	*Warm Springs*	*Composite*
Sample Size	163	250	60	473
Classification Accuracy	0.87	0.80	0.75	0.81

Test B (Deschutes subbasin two-stock analysis)

	Stock		
	Natural	*Hatchery*	*Composite*
Sample Size	163	310	473
Classification Accuracy	0.91	0.94	0.93

Test C (Wenatchee subbasin two-stock analysis)

	Stock		
	Natural	*Hatchery*	*Composite*
Sample Size	156	168	324
Classification Accuracy	0.80	0.90	0.85

Test D (Deschutes and Wenatchee subbasin pooled two-stock analysis)

	Stock		
	Natural	*Hatchery*	*Composite*
Sample Size	319	478	797
Classification Accuracy	0.87	0.92	0.89

Test C

The two-stock identification test of Wenatchee hatchery and Wenatchee natural stock samples resulted in an overall classification accuracy of 0.85. Hatchery and natural stock samples were correctly classified with 0.80 and 0.90 accuracy, respectively.

Test D

The two-stock identification test of the three pooled hatchery stock samples from the Deschutes and Wenatchee subbasins compared with the two pooled natural origin stock samples from the two subbasins resulted in an overall classification accuracy of 0.89. Hatchery and natural stock samples were correctly classified with 0.92 and 0.87 accuracy, respectively.

Precision in Scale Feature Measurement

The tests for operator consistency and inter-operator variability in locating scale features produced no significant differences when applied to both the number of circuli counted and to the distance measurements within the scale area from focus to freshwater annulus. P-values were above 0.57 for all tests.

DISCUSSION

This study has shown that hatchery and naturally spawning stocks of Wenatchee River and Deschutes River spring chinook salmon can be identified with a relatively high degree of accuracy by digitizing scales and using a linear discriminant analysis procedure. Three of the four feasibility tests performed (Tests B through D) were two-stock analyses comparing hatchery and natural stock samples. These tests achieved classification accuracies of 0.85 or better, while the three-stock analysis (Test A) produced an accuracy of 0.81.

The high classification accuracy levels achieved in Tests B and C, each being a two-stock analysis within a single subbasin, suggest that this technique could be usefully applied to the management of Columbia Basin tributaries where both hatchery and natural spring chinook stocks are present. In such areas, separate management strategies for each stock are generally advantageous. This methodology could most immediately be applicable in those subbasins containing mixed stock fisheries. Emphasis in these cases is usually placed on measuring and insuring desired escapement levels for natural stock fish.

The high classification accuracy obtained in Test D, which compared pooled hatchery stocks from two Columbia River subbasins with two pooled natural stocks from the same subbasins suggests it may be possible to identify hatchery or natural stock composition for the entire aggregate stock population of Columbia Basin upriver spring chinook salmon. Management opportunities for this potential research include evaluation of the degree to which stock-specific escapement goals are being met and, in mixed-stock harvest areas, the assessment and regulation of fisheries. At the present time, separate escapement goals do exist for hatchery and natural Columbia Basin upriver spring chinook stocks, but accuracy of the run-reconstruction methods now used for monitoring and estimation of annual stock abundance could be greatly improved.

A further application of this methodology is in evaluation of Pacific Salmon Treaty impacts (or other ocean harvest control measures) on key indicator-stock populations. Abundance of stocks and knowledge of their biological characteristics will give an indication of the success of the Treaty implementation process. For example, changes in overall hatchery and natural stock age composition and in mean length-at-age composition may reflect the effects of minimum size-limit restrictions in particular ocean fisheries.

Associated with the above-described research, other analyses were performed to explore possibilities for future study. A four-stock analysis comparing each of the two natural stocks with the Wenatchee hatchery stock and the pooled Deschutes hatchery stocks resulted in a 0.69 classification accuracy. This reasonably high accuracy level (for a four-stock analysis) indicates that, in given circumstances, multi-stock classification of Columbia Basin upriver spring chinook salmon may be possible. We also performed an analysis of Wenatchee natural stock samples compared with Deschutes natural stock samples producing an 0.82 classification accuracy. Further study will help determine the feasibility of identifying—under given circumstances—different natural stocks, pooled stocks from different subbasins, and different hatchery stocks.

The results of the precision in scale feature measurement test indicated that both the location of saltwater entry and freshwater annulus could be accurately determined by the operator for all samples. We intend to further explore the importance of precision in scale feature location and whether, in SPA, a maximum permissible variance limit exisits.

In future work, analyses will be expanded by including additional stocks to test the assumption that hatchery and natural stocks can be identified on a broader scale. Including in the study those stocks that may potentially increase the overlap of variables used in the discriminant analyses (such as highly productive natural or unproductive hatchery stocks) will permit a stringent test of the applied SPA methodology. If classification accuracies remain high after performance of these additional feasibility tests, we ultimately hope to include enough known stocks in the analysis to attempt to estimate the proportion of all hatchery and natural upriver spring chinook salmon in the Columbia River (Schwartzberg 1989).

LITERATURE CITED

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.

Bohn B., and D. McIssac (with 15 additional contributing authors). 1988. Columbia River fish runs and fisheries, 1960-1987. Oregon Department of Fish and Wildlife and Washington Department of Fisheries Status Report.

Borodin, N. 1924. Age of shad *Alosa sapidissima* (Wilson) as determined by the scales. Transactions of the American Fisheries Society 54:178-184.

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). Fisheries Research Institute, University of Washington, Report FRI-UW-8713.

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, Berkeley, California.

Fisher, R.A. 1936. The use of multiple measurements in taxonomic problems. Annals of Eugenics 7:179-188.

Fulton, L.A. 1968. Spawning areas and abundance of chinook salmon *Oncorhynchus tshawytscha* in the Columbia River Basin - past and present. U.S. Fish and Wildlife Service Special Scientific Report - Fisheries.

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, Washington.

MacLean, J.A., and D.O. Evans. 1981. The stock concept, discreteness of fish stocks, and fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 38:1889-1898.

McDonald, J. 1981. The stock concept and its application to British Columbia salmon fisheries. Canadian Journal of Fisheries and Aquatic Sciences 38:1657-1664.

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.

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.

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.

Peck, T. H. 1970. Differentiation of hatchery and stream juvenile coho salmon *Oncorhynchus kisutch* from Washington and Oregon by the use of scales and otoliths. M. S. thesis, University of Washington, Seattle, Washington.

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.

Rich, W.H. 1939. Local populations and migration in relation to the conservation of Pacific salmon in the western states and Alaska. American Association for the Advancement of Science 8:45-50.

Ricker, W.E. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11:559-623.

Scheer, B.T. 1939. The homing instinct in salmon. Quarterly Review of Biology 14:408-430.

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

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. 1988. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses, 1987. Columbia River Inter-Tribal Fish Commission Technical Report 88-2.

Snedecor, G.W. and W.C. Cochran. 1980. Statistical methods. Iowa State University, Iowa City, Iowa.

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, Vancouver, British Columbia, Canada.

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 anterior freshwater annulus margin 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.

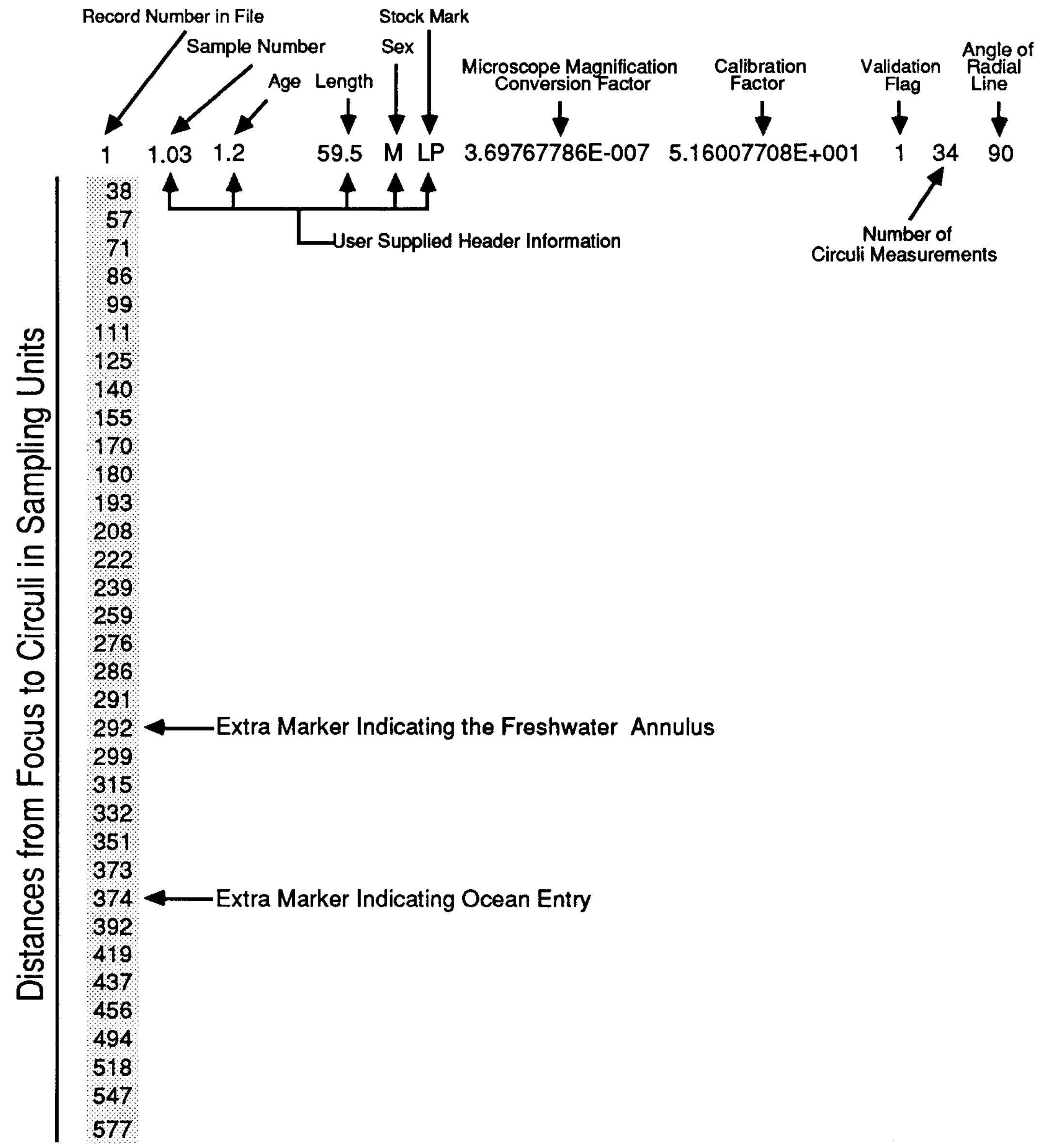
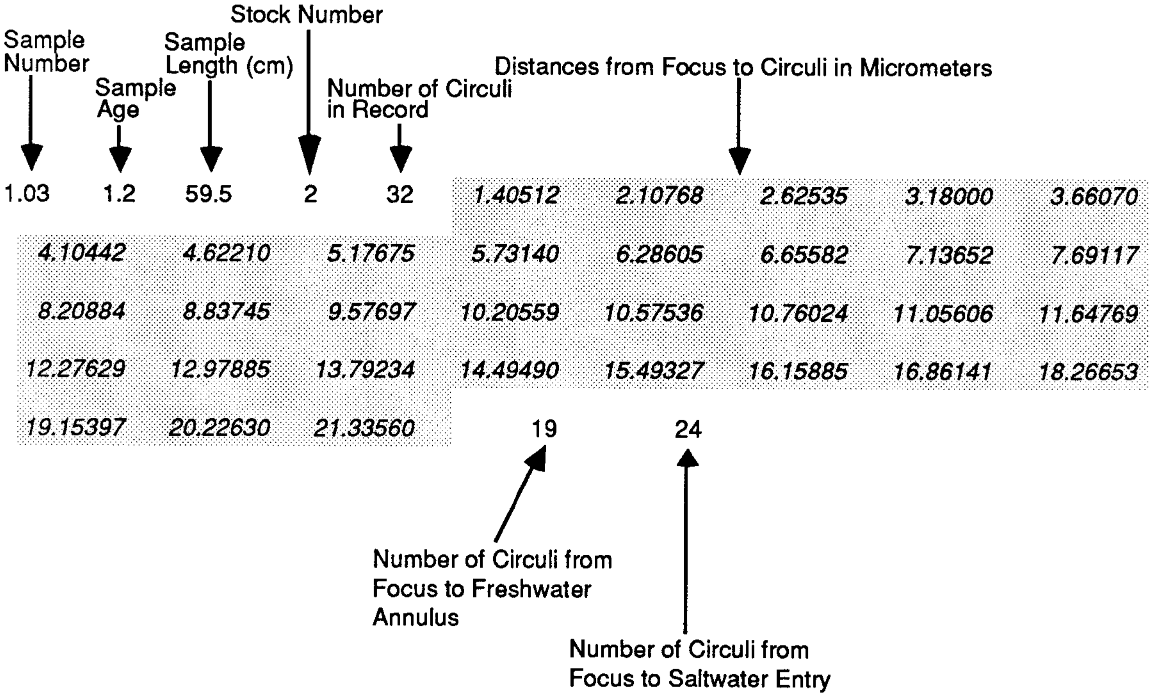


Figure A2. **A sample compact format data record for a single spring chinook salmon scale freshwater-growth-zone measurement.**



```
1.03     1.2      59.5     2        32        1.40512   2.10768   2.62535   3.18000   3.66070
  4.10442  4.62210  5.17675  5.73140   6.28605   6.65582   7.13652   7.69117
  8.20884  8.83745  9.57697  10.20559  10.57536  10.76024  11.05606  11.64769
 12.27629 12.97885 13.79234  14.49490  15.49327  16.15885  16.86141  18.26653
 19.15397 20.22630 21.33560  19        24
```

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. Salmon has always been at the center of their diet and their religious lives; as a valued trade item, it has also been of great economic importance to these Native Americans.

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 their 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.

For a free subscription to ***CRITFC News***, the commission's newsletter, and information on other publications, please write to the Public Information Office, Columbia River Inter-Tribal Fish Commission, 975 S.E. Sandy, Blvd. Suite 202, Portland, OR 97214.