IDENTIFYING HATCHERY AND NATURALLY SPAWNING STOCKS OF COLUMBIA BASIN SUMMER CHINOOK SALMON USING SCALE PATTERN ANALYSES IN 1990

Technical Report 93-4

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February 22, 1993

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ABSTRACT

Scales were sampled from Columbia Basin summer chinook salmon from different Snake and Mid-Columbia basin tributaries. Spring, summer, and fall chinook salmon races were also sampled at Bonneville Dam on the lower Columbia River. The age composition for each sample group was estimated. We found that both hatchery and natural origin Mid-Columbia Basin summer chinook stocks included significant proportions of yearling and subyearling juvenile outmigrants. Snake Basin summer chinook were composed entirely of yearling juvenile outmigrants. Scale pattern analysis (SPA) was used both to identify hatchery and natural origin stocks of summer chinook salmon from the Snake and Mid-Columbia basins, as well as to identify the different Columbia Basin chinook salmon races. A linear discriminant analysis procedure was used that indicated hatchery and natural origin summer chinook salmon stocks could be identified with a minimum accuracy of 72%. Pooled stocks of Snake and Mid-Columbia basin salmon were identified with a minimum accuracy of 81%. Relatively high classification accuracies (76-91%) were achieved identifying spring and summer chinook salmon races but classification of summer and fall chinook salmon races resulted in lower classification accuracies (59%). A sample of Age 1.2 summer chinook salmon collected at Bonneville Dam was estimated to be 86% hatchery origin and 14% natural origin. The same sample was estimated to be 72% Snake Basin origin and 28% Mid-Columbia origin. A mixed stock sample collected in the Snake Basin at the South Fork Salmon Weir was estimated to be 69% hatchery origin and 31% natural origin.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

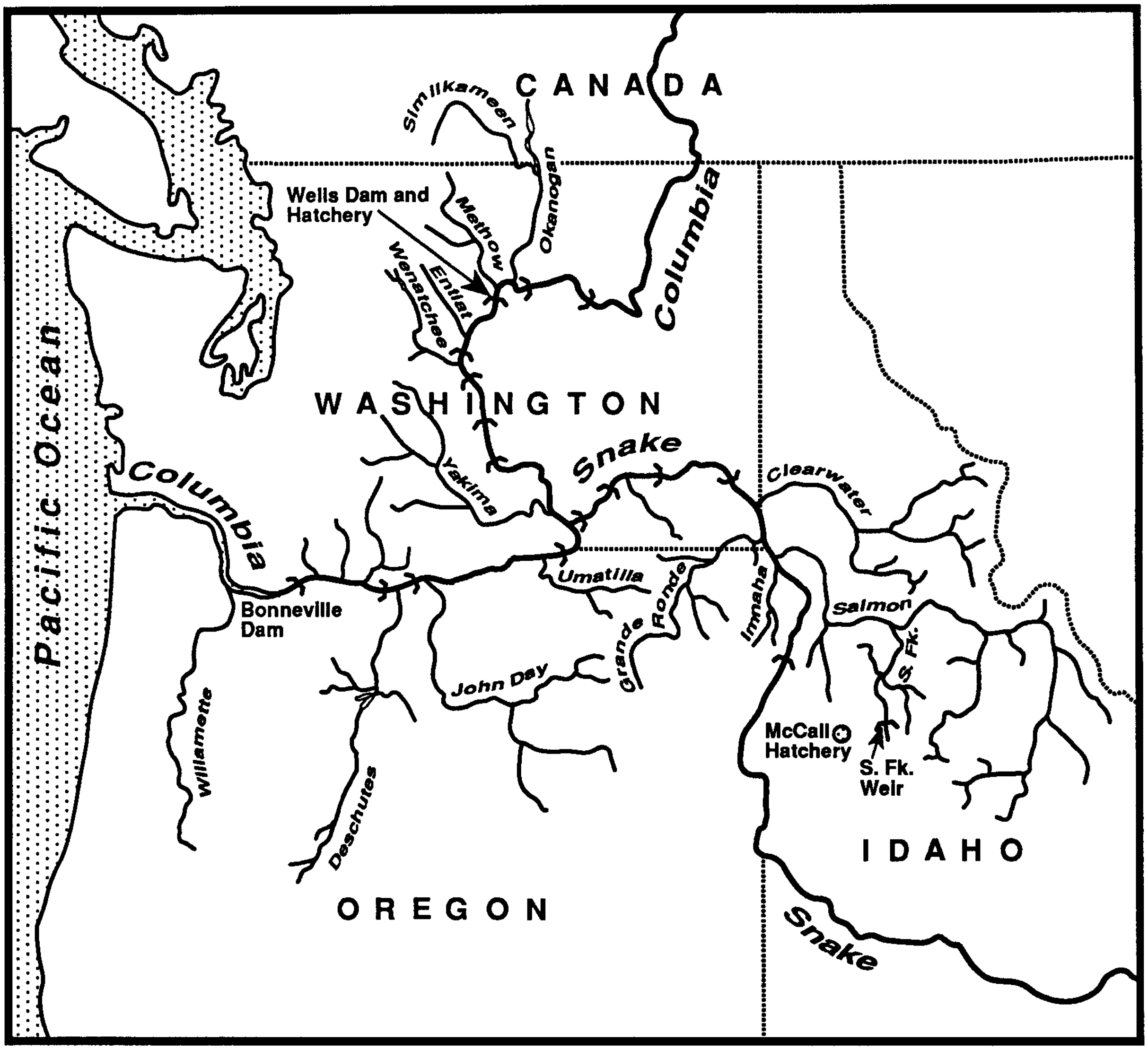
INTRODUCTION

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 adult fish (Northwest Power Planning Council 1986). In recent years (1982-1991), runs have averaged only about 800,000 fish, with a majority of these being hatchery produced (Washington Department of Fisheries and Oregon Department of Fish and Wildlife 1992). Biologists recognize three races of chinook salmon in the Columbia Basin based run timing. At Bonneville Dam (Columbia River km 235) spring chinook salmon are defined to be those chinook salmon passing the dam before June 1 (U.S. v. Oregon Technical Advisory Committee 1991). Summer chinook salmon pass between June 1 and July 31, while fall chinook salmon pass Bonneville Dam after July 31. Although there is almost certainly some overlap between the different chinook salmon races, they are managed separately, depending on their migratory timing. This could result in over- or under-harvest of certain stocks or the incorrect assessment of stock abundances. One of the goals of this project is the search for criteria other than migratory timing for identifying summer chinook salmon.

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). The Pacific Salmon Treaty, ratified by the United States and Canada in 1985 (Pacific Salmon Treaty 1985), requires that certain Pacific salmon stocks be monitored to determine the influence of Treaty-imposed ocean harvest regulations. Consequently, the Pacific Salmon Commission established a monitoring program containing provisions for estimating the escapement and status of key Columbia Basin salmon stocks. Columbia Basin summer chinook salmon are one of these indicator stocks and the work described in this report forms a part of the Pacific Salmon Treaty monitoring program.

Understanding the stock composition of fish populations enables fisheries resource managers to better utilize fisheries resources by treating individual

Figure 1. Map of the Columbia Basin showing summer chinook salmon spawning areas, Wells and Bonneville dams, Wells and McCall hatcheries, and the South Fork Salmon River Weir.



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 for run composition estimation of mixed stocks, as well as the need for greater understanding of the biological and migratory characteristics of each stock or stock group. Such information does not exist for Columbia Basin summer chinook salmon stocks. The proportional composition of hatchery and naturally produced fish in the mixed stock population is also not known. Although the mainstem Columbia River commercial fishery for summer chinook salmon has been suspended since 1965, future in-river harvest management will require an established database that includes such information as stock composition and the level of escapement for each distinct stock.

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 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 an entire group or stock of fish. In the Columbia Basin, SPA has been used in spring chinook stock identification studies (Schwartzberg and Fryer 1989b, 1993; Fryer and Schwartzberg 1990) and in sockeye salmon stock identification studies (Schwartzberg and Fryer 1988, 1989a, 1990; Fryer and Schwartzberg 1991a, 1993; Fryer et al. 1992) .

Fish reared in hatcheries generally grow faster than those produced in natural habitat. In addition, hatchery growth is generally more uniform with less pronounced growth retardation during winter and early spring periods (Peck 1970). Throughout this study an operative hypothesis has been that these differences in growth would be reflected in scales of hatchery and naturally produced fish and that the differences could be detected and stocks classified by SPA. It was also hypothesized that differences in the freshwater growth of the three races of chinook salmon, as well as fish of the same race but located in different basins, would also be reflected in scales of these fish and that these differences could be detected and different stocks or races classified by SPA.

In this two-year study, performed in 1990 and 1991 as a part of the Columbia River Inter-Tribal Fish Commission Stock Assessment Project, a series of tests were performed to study the accuracy of classifying hatchery and natural origin summer chinook salmon both within the same basin and between the Snake and Mid-Columbia river basins. Other tests examined the feasibility of using SPA to differentiate the spring, summer, and fall races of Columbia Basin chinook salmon.

METHODS

Sampling

The hatchery and natural stocks sampled in terminal areas represented *known stock* scale sample groups (Table 1, stocks 1-6). Other stocks of unknown origin (called *unknown* or *mixed stocks*) were also sampled in areas where several known stocks mixed as they migrated upstream (Table 1, stocks 7-11). One mixed-race stock, believed to consist of both spring and summer chinook, was also sampled (Table 1, stock 12).

For SPA studies, target sizes for the mixed-stock samples from Bonneville Dam and all known stock sample groups were 50 scales per group. The preferred sample size per group for unknown and known groups is generally considered to be 100 and 200, respectively (Conrad 1985). However, because a limited amount of personnel time was available, we used smaller sample sizes in this study, although in some cases sample sizes were larger than 50 per group.

To ensure that mixed-stock samples from Bonneville Dam were representative of different racial groups (spring, summer, and fall runs), samples were selected for SPA to minimize the effects of overlap between groups. Consequently, spring chinook salmon scale samples were selected from the earliest portion of their migration (April through mid-May) while summer chinook salmon samples were selected from the middle range of their migration (mid-June to mid-July).

Age Determination

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 summer chinook salmon. Fish age can be determined by counting *annuli,* which are zones of closely spaced circuli formed yearly during periods of slow growth

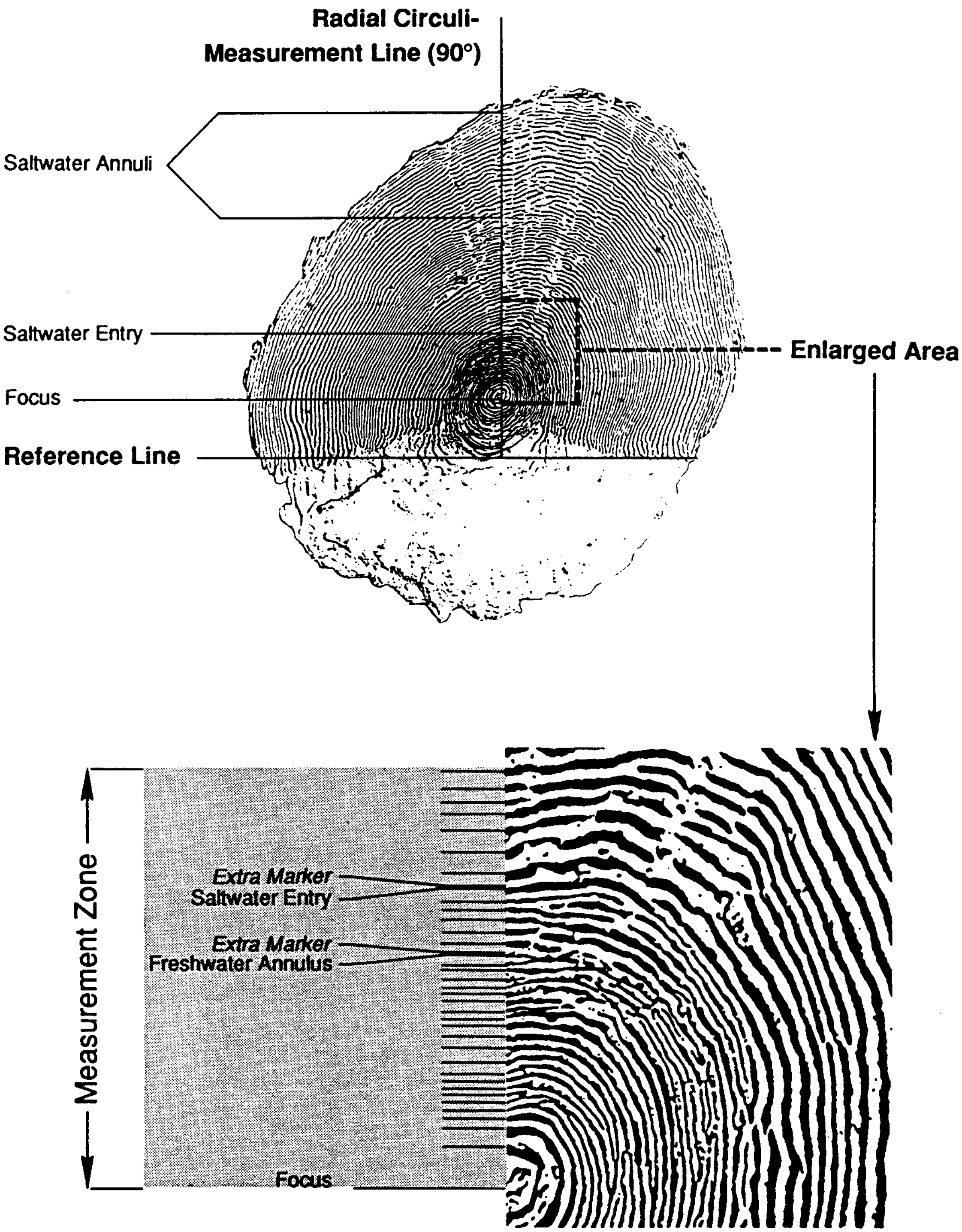
Table 1. Columbia Basin chinook salmon stocks sampled and used in stock identification tests.

Stock	Stock Name	Type	Race	Basin	Juvenile Age	Sample Size
1	McCall Hatchery	Hatchery	Summer	Snake	1.x	158
2	S. Fk. Salmon	Natural	Summer	Snake	1.x	50
3	Methow River	Natural	Summer	Mid-Columbia	0.x, 1.x	17
4	Similkameen River	Natural	Summer	Mid-Columbia	0.x	12
5	Wells Hatchery	Hatchery	Summer	Mid-Columbia	0.x, 1.x	58
6	Wenatchee River	Natural	Summer	Mid-Columbia	0.x, 1.x	57
7	S. Fk. Salmon Weir	Mixed	Summer	Snake	1.x	289
8	Bonneville Dam	Mixed	Summer	Columbia	0.x,1.x	132
9	Bonneville Dam	Mixed	Spring	Columbia	1.x[a]	57
10	Bonneville Dam	Mixed	Fall	Columbia	0.x[b]	56
11	Wenatchee River	Natural	Spring	Mid-Columbia	1.x	57
12	Wenatchee River (Tumwater Dam)	Natural	Spring/ Summer	Wenatchee	0.x, 1.x	14

a. A very small percentage of spring chinook salmon sampled at Bonneville Dam are products of accelerated hatchery rearing program. These fish outmigrated at Age 0.x.

b. Small percentages of Columbia River fall chinook salmon sampled at Bonneville Dam outmigrated at age 1.x (Fryer and Schwartzberg 1991b).

Figure 2. Columbia Basin chinook salmon scale showing growth and measurement zones.



that occur once per year. Summer chinook salmon either outmigrate in the same year as they hatch (called *subyearling* outmigrants) or outmigrate after spending one complete year in freshwater after hatching (called *yearling* outmigrants). Columbia River spring chinook salmon are typically yearling outmigrants, with the exception of the small number of adults produced in certain accelerated hatchery rearing programs and released as subyearlings. Fall chinook salmon are almost entirely subyearling outmigrants. Snake Basin summer chinook salmon are believed to be entirely yearling outmigrants while Mid-Columbia summer chinook salmon are typically subyearling outmigrants (U.S. vs. Oregon Technical Advisory Committee 1991).

All scales were examined visually and were categorized by estimated 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 saltwater. Total age, therefore, is equal to one plus the sum of both numerals. In this report, chinook salmon that outmigrated as yearlings are designated Age 1.x while those that outmigrated as subyearlings are designated Age 0.x.

Scales were used to estimate the age composition of most stocks on a return year basis. Because of a large amount of scale *resorbtion* (the eroding of a salmon scale as the fish approaches sexual maturity), age composition of all known stock samples was difficult to reliably estimate. Age validation (Beamish and McFarlane 1983) was not possible for any stock.

Summer Chinook Known Stock Classification Feasibility Tests

Both hatchery and natural origin known-stock summer chinook samples were used in stock identification tests to determine the ability of SPA to accurately classify samples. These tests were labeled Tests A through H (Table 2). Test A compared several natural stocks in the Mid-Columbia Basin. Tests B, C, and F were two-stock tests of hatchery versus natural origin fish. Tests D, E,

Table 2. Summer chinook salmon known-stock classification feasibility tests.

Test	Description	Stocks[a]
A.1[b]	Methow Natural vs Similkameen Natural vs Wenatchee Natural	3 vs 4 vs 6
A.2[c]	Methow Natural vs Wenatchee Natural	3 vs 6
B.1[b]	Mid-Columbia Hatchery vs Mid-Columbia Natural	5 vs 3, 4, & 6
B.2[c]	Mid-Columbia Hatchery vs Mid-Columbia Natural	5 vs 3 & 6
C	Snake Basin Hatchery vs Snake Basin Natural	1 vs 2
D[d]	Snake Basin Natural vs Mid-Columbia Natural	2 vs 3 & 6
E[d]	Snake Basin Hatchery vs Mid-Columbia Hatchery	1 vs 5
F[d]	Snake Basin and Mid-Columbia Hatchery vs Snake Basin and Mid-Columbia Natural	1 & 5 vs 2, 3, & 6
G[d]	Snake Basin Hatchery and Natural vs Mid-Columbia Hatchery and Natural	1 & 2 vs 3, 5, & 6
H[c]	Snake Basin Hatchery vs Snake Basin Natural vs Mid-Columbia Hatchery vs Mid-Columbia Natural	1 vs 2 vs 5 vs 3 & 6

a. For description of stock sample groups, see Table 1.

b. Age 0.x only.

c. Age 1.x only.

d. Only Age 1.x fish were classified in this test. Since no Age 0.x fish were present in the Snake Basin sample, Age 0.x fish could be classified by age alone as being of Mid-Columbia stock.

and G were two-stock tests of Snake Basin versus Mid-Columbia Basin fish. Test H was a four-stock test of Mid-Columbia Basin natural origin versus Mid-Columbia Basin hatchery versus Snake Basin natural origin versus Snake Basin hatchery stocks. Hatchery stock groups were represented by samples from Stocks 1 and 5 (Table 1). Natural origin stock groups were represented by samples from Stocks 2, 3, 4, and 6 (Table 1).

Spring, Summer, and Fall Chinook Known-Race Classification Feasibility Tests

Tests I through K (Table 3) determined the ability of SPA to accurately classify samples of different races of Columbia Basin chinook salmon. Known race scale samples of the three races (but of mixed hatchery and natural origin) were compared and accuracy of classification determined. Stocks 6 and 8-11 were used in these tests (Table 1).

Classification of Unknown Mixed-Stock and Mixed-Race Samples

The classification function developed in Test C was used to classify unknown Snake Basin summer chinook samples as hatchery or natural origin (Table 4, Test L). The classification function developed in Test F was used to classify the unknown Bonneville Dam summer chinook samples as hatchery or natural origin (Table 4, Test M). The classification function developed in Test G was used to classify the unknown Bonneville Dam summer chinook samples as Snake Basin or Mid-Columbia Basin origin (Table 4, Test N). The classification function developed in Test K was used to classify the unknown Wenatchee Basin mixed race samples as spring or summer chinook race (Table 4, Test O). Samples from stocks 7, 8, and 12 were used as unknowns in these tests (Table 1).

Scale Collection and Measurement

Scales were collected and mounted according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Com

Table 3. Spring, summer, and fall chinook salmon known-race classification tests.

Test	Description	Stocks[a]
I[b]	Bonneville Summer vs Bonneville Spring	8 vs 9
J[c]	Bonneville Summer vs Bonneville Fall	8 vs 10
K[b]	Wenatchee Summer vs. Wenatchee Spring	6 vs 11

a. For description of sample groups, see Table 1.

b. Age 1.x only.

c. Age 0.x only.

Table 4. Mixed stock and mixed-race classification tests to identify proportions of an unknown sample in each component group.

Test	Description	Unknown Stock or Race[a]	Classification Function[b]
L	Snake Basin hatchery/wild	7	C
M	Columbia Basin hatchery/wild	8	F
N	Columbia Basin Mid-Columbia/Snake	8	G
O	Wenatchee River spring/summer	12	K

a. For a description of the sample groups, see Table 1.
b. For a description of the classification functions, see Tables 2 and 3.

mission (1963). Six scales were selected from each fish sampled from Stocks 8, 9, 10, and 12 (Knudsen 1990). Approximately eight scales were selected from each fish sampled from Stocks 2, 3, 4, 6 and 11; and four scales from each fish sampled in Stocks 1, 5, and 7 (Table 1).

In our previous SPA studies with sockeye and spring chinook salmon, a single age group was used in stock identification tests (Schwartzberg and Fryer 1988, 1989a, 1989b, 1990, 1993; Fryer and Schwartzberg 1990, 1991a, 1993; Fryer et al. 1992). However, in this study sample sizes of known stocks were small and saltwater life histories difficult to accurately determine because of scale resorbtion. Samples with similar freshwater ages, but different saltwater life histories, were pooled for all known stock samples. Age determination was easier with Bonneville Dam mixed stock samples and sample sizes were sufficiently large so that only the two predominant age groups (1.2 and 0.4) were studied.

A computer and video camera were used to measure scale features (BioSonics 1985). The system consisted of a microscope (2x, 4x, 6.3x, and 10x objectives; a 1.0x, 1.25x, and 1.5x magnification changer; and a 2.5x photo compensation adapter), a monitor (33cm), and a digitizing tablet connected to a personal computer (AT) with a video frame-grabber board. Acetate impressions of scales were placed in the microscope and projected onto the monitor. Using a keyboard and digitizing tablet, distances were measured along a radial line drawn through the scale. These measurements were then stored in a computer file. An acetate impression of 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 (6.25x final microscope magnification and 82x 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 (20x final microscope magnification and 256x projection magnification). All measurements were made to the marginal (outermost) 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 saltwater zone.

Variable Selection

Variables, composed of selected scale-measurements from within a single zone (from scale focus to approximately circulus 33, usually located in the saltwater area), were tested to find those that most effectively characterized differences in growth among the stocks. A large number of different variables were tested to determine those most effective at classifying different known origin samples. Variables tested included those made up of measurements among groups of three non-adjacent circuli or *doublets*, four non-adjacent circuli or *triplets*, and five non-adjacent circuli or *quadruplets* (Davis 1987). Test variables were selected and used in discriminant analyses and classification accuracies were noted. We used triplets for variables in the analyses because accuracies achieved in preliminary tests were similar to those achieved using other test variables. Triplets also permitted consistency with our previous work. Distances and number of circuli from scale focus to saltwater entry point were also used in initial variable development. However, they were omitted from reported results because their inclusion resulted in little or no improvement in classification accuracy. Distances and number of circuli from scale focus to freshwater annulus margin (anterior) were not used as variables because it was felt that operator subjectivity played far too great a part in the identification of these scale features, especially in hatchery origin scale samples.

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 been applied and proven useful in determining the origin of individual fish stocks from mixed stock samples (Bethe and Krasnowski 1977, Bethe et. al. 1980, Major et. al. 1978).

Accuracy of the discriminant analyses was determined by classifying the pooled known stock samples from a particular analysis and then comparing results to actual (verifiable) known stock identities. A jackknife procedure (Lachenbruch 1975, Dixon et. al 1983) was employed to correct for systematically biased results that are created in known stock classification when the same samples are used for both calculating the discriminant function and determining its accuracy.

The discriminant function was then used to classify unknown mixed stock samples. To correct for misclassification, the method developed by Cook and Lord (1978) was employed. Variances on estimates were also computed (Pella and Robertson 1979).

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

RESULTS

Age and Length-at-Age Composition

Age compositions, determined on a return year basis, varied considerably among the different stocks studied as well as among the different subbasins (Table 5). The Snake Basin natural stock samples were Age 1.2 and 1.3. All Similkameen River natural stock samples were Age 0.3 and 0.4. The Wenatchee River summer chinook salmon natural stock sample primarily included Age 1.3, 1.2, 0.4, and 0.3 fish, although Age 0.2 and 1.1 fish were also present. The Methow River natural stock, Wells Hatchery, and Wenatchee mixed race samples also included fish of different age classes and fish of both subyearling and yearling juvenile life histories.

All samples from the Snake Basin hatchery and Snake Basin mixed stocks were estimated to be yearling outmigrants. No saltwater age composition estimates were made for these samples.

Summer Chinook Known Stock Classification Feasibility Tests

Test A.2 indicated that Methow and Wenatchee Age 1.x fish could be identified with 80% classification accuracy (Table 6). However, later analyses were little affected by pooling these samples. Thus to achieve a larger Mid-Columbia natural stock sample size for use in later analyses, we subsequently pooled both stocks into a single stock.

Tests B, C, and F indicated that relatively high accuracies could be achieved in two-stock tests of hatchery versus natural origin fish. For all three tests, fish were classified with accuracies of at least 72%. Tests D, E, and G indicated that a minimum 82% accuracy could be achieved in two-stock tests of Snake Basin versus Mid-Columbia Basin fish. Test H, a four stock test, classified three of the stocks with relatively high accuracies (a minimum of 70%), but performed poorly in classification of the fourth stock (Mid-Columbia Hatchery). The resulting overall classification accuracy for this test was 62%.

Table 5. Age composition estimates of Columbia Basin chinook salmon stocks sampled in 1990.

Stock	Sample Size	Age Class 0.2	1.1	0.3	1.2	0.4	1.3	0.5	1.4
SUMMER CHINOOK									
Mid-Columbia									
Wenatchee	65	3	2	12	22	28	34	0	0
Similkameen	12	0	0	67	0	33	0	0	0
Methow	19	0	0	11	21	26	37	0	5
Wells Hatchery	114	0	1	9	27	24	38	0	2
Snake Basin									
S. Fk. Salmon Natural	56	0	0	0	70	0	30	0	0
Mixed Stock									
Bonneville	569	1	4	11	27	22	26	1	7
MIXED RACE									
Wenatchee									
Tumwater	28	0	14	7	14	25	39	0	0

Table 6. Classification accuracies achieved in Columbia Basin summer chinook salmon known-stock feasibility tests.

Test	Description	Stock	n[a]	CA[b]	Composite n[a]	Composite CA[b]
A.1	Methow Natural vs Similkameen Natural vs Wenatchee Natural Age 0.x	Methow	7	c		
		Wenatchee	26	c		
		Similkameen	12	c		
A.2	Methow Natural vs Wenatchee Natural Age 1.x	Methow	9	89	40	80
		Wenatchee	31	71		
B.1	Mid-Columbia Hatchery vs Mid-Columbia Natural Age 0.x	Mid-Columbia Hatchery	29	78	74	75
		Mid-Columbia Natural	45	72		
B.2	Mid-Columbia Hatchery vs Mid-Columbia Natural Age 1.x	Mid-Columbia Hatchery	29	78	69	72
		Mid-Columbia Natural	40	66		
C.	Snake Hatchery vs Snake Natural	Snake Basin Hatchery	158	94	208	87
		Snake Basin Natural	50	80		
D.	Snake Basin Natural vs Mid-Columbia Natural	Snake Basin Natural	50	92	90	92
		Mid-Columbia Natural	40	92		
E.	Snake Hatchery vs Mid-Columbia Hatchery	Snake Basin Hatchery	158	82	187	83
		Mid-Columbia Hatchery	29	83		
F.	Snake and Mid-Columbia Hatchery vs Snake and Mid-Columbia Natural	Hatchery	187	84	277	81
		Natural	90	78		
G.	Snake Hatchery and Natural vs Mid-Columbia Hatchery and Natural	Snake Basin	208	88	277	84
		Mid-Columbia	69	80		
H.	Snake Basin Hatchery vs Snake Basin Natural vs Mid-Columbia Hatchery vs Mid-Columbia Natural	Snake Basin Hatchery	158	80	277	62
		Snake Basin Natural	50	76		
		Mid-Columbia Hatchery	29	21		
		Mid-Columbia Natural	40	70		

a. Sample size.
b. Classification accuracy (%).
c. The stocks were too similar to allow a classification function to be developed.

Spring, Summer, and Fall Known Race Classification Feasibility Tests

Tests I and K, both tests of spring versus summer chinook salmon resulted in classification accuracies of at least 76% (Table 7). Test J, a classification test of summer versus fall chinook salmon resulted in a classification accuracy of only 59%.

Classification of Unknown Mixed Stock and Mixed Race Samples

Both the Bonneville Dam and Snake Basin (Salmon River Weir) mixed summer chinook stock samples were classified as being primarily hatchery origin (Table 8). The mixed-race Wenatchee River (Tumwater Dam) sample was classified as entirely summer chinook salmon.

Table 7. Classification accuracies achieved in Columbia Basin spring, summer, and fall chinook known-race feasibility tests.

Test	Description	Stock	n[a]	CA[b]	Composite n[a]	Composite CA[b]
I.	**Bonneville Spring vs Bonneville Summer Chinook[c]**	Spring Summer	50 56	78 73	106	76
J.	**Bonneville Summer vs. Bonneville Fall Chinook[d]**	Summer Fall	76 56	61 57	132	59
K.	**Wenatchee Spring vs. Wenatchee Summer Chinook[d]**	Spring Summer	47 31	85 97	78	91

a. Sample size.

b. Classification accuracy (%).

c. Age 1.x only. Since few Age 0.x fish were present in the spring chinook salmon samples, fish of this age class could be classified as summer chinook salmon by age alone.

d. Age 0.x only. Since few Age 1.x fish were present in the fall chinook sample, fish of this age class could be classified as summer chinook by age along.

Table 8. **Classification of Columbia Basin summer chinook salmon mixed stocks and mixed races[a] in 1990 showing the percentage of each unknown sample classified to component stocks or races.**

Test	Mixed Stock or Race	Classification	
		Hatchery Origin	Natural Origin
L	Snake Basin (Salmon River Weir)	69	31
M	Bonneville Dam	86	14
		Snake Basin	Mid-Columbia Basin
N	Bonneville Dam	72	28
		Spring Chinook	Summer Chinook
O	Wenatchee River (Tumwater Dam)	0	100

a. Only Age 1.x fish were used in all analyses.

DISCUSSION

Columbia Basin fisheries managers have considered that all natural stocks of Mid-Columbia summer chinook salmon generally follow a subyearling freshwater outmigration life history (Park 1969, U.S. v. Oregon Technical Advisory Committee 1991). However in our study, we estimated a large proportion of the Methow and Wenatchee natural stocks (as well as the Wells Hatchery stock) to be yearling outmigrants. The only stock we sampled which consistently exemplified a subyearling life history was the Similkameen natural stock.

A change over the past several years in the outmigration patterns of Mid-Columbia natural stocks may possibly be explained by the effects of mainstem Columbia River hydroelectric dam construction and operations on juvenile salmon migration. Park (1969) found that the downstream migration of Mid-Columbia summer chinook salmon through Priest Rapids Dam occurred considerably later in 1965-1967 than 1954-1955 (Mains and Smith 1964) and that some fish overwintered in lower Columbia River reservoirs. Park attributed changes in migratory timing to a decrease in flows in Columbia River impoundments. Two additional mainstem dams, Wells and John Day, have been completed since Park's study. Additional dams have been constructed in Columbia River headwaters in Canada. These projects have, no doubt, further reduced spring and summer flows and altered downstream migration timing. Raymond (1988) concluded that mid-Columbia summer chinook migrating to the sea as subyearlings in July and August, times of low river flows and relatively warm water, have lower survival than those fish migrating as yearlings in April and May, when river flows are higher and temperatures lower. Predation is also higher in late summer months and disease more prevalent (Park 1969).

Smolt bypass systems have been fitted to Columbia River mainstem dams since the late 1970s (Giorgi et al. 1988). Subyearling outmigrants are guided into these bypass systems with much lower efficiencies than yearling fish. Therefore, subyearling outmigrants more frequently pass through dam turbines and generally suffer greater mortalities (Raymond 1988). In the Similkameen River, poor rearing conditions (Washington Department of Wildlife 1990) may

may encourage outmigration at an earlier age than in other Mid-Columbia tributaries. This may result in most Similkameen River fish outmigrating to the ocean as subyearlings.

A second possible explanation for the high proportion of yearling outmigrants among Mid-Columbia summer chinook salmon is the straying of hatchery returns into natural spawning areas. Since 1980, Wells Hatchery has been producing, in most years, yearling, as well as subyearling summer chinook salmon (Howell et al. 1985). We estimated that 68% of our 1990 Wells Hatchery adult sample were yearling outmigrant fish. Yearling summer chinook salmon were also released from Winthrop Hatchery on the Methow River in 1979 and 1982 as well as from Rocky Reach Hatchery (Columbia River km 752) in 1982 and 1983 (ibid.) If age among these fish is a genetically determined stock characteristic (Ricker 1972), straying of adult hatchery fish into nearby rivers could be influencing natural stocks and might help to explain our observations of a large yearling component to the Methow and Wenatchee natural stocks. We found a higher proportion of yearling fish in those rivers (Methow and Wenatchee) located nearest hatcheries that have released yearling summer chinook salmon since 1979. No yearling fish were found in the river most distant from these hatcheries, the Similkameen.

Further changes in the biological characteristics of Mid-Columbia summer chinook salmon stocks are likely in the near future. In 1991, the Eastbank Hatchery (Columbia River km 720) began production of summer chinook salmon and yearling juveniles were released in the Methow, Similkameen and Wenatchee basins. Adult spawners from these releases are expected to begin returning in significant numbers in 1993.

Using SPA, we were able to identify several hatchery and naturally spawning stocks of Mid-Columbia and Snake basin summer chinook salmon with relatively high accuracies. Three of the eleven feasibility tests performed (Tests B, C, and F) were two-stock analyses testing classification accuracies using samples of hatchery and naturally spawning stocks. In these tests, scale samples were correctly identified according to their place of origin with accuracies of 72% or greater. This suggests that SPA could be used in enhancement programs that may require differentiation of adult hatchery and natural origin fish for hatchery broodstock collection. SPA may also be useful to accurately estimate the ratio of hatchery to natural fish in potential future lower river fisheries or for other study purposes at locations such as Bonneville Dam.

Tests of Mid-Columbia hatchery versus Mid-Columbia natural stocks (Test B) produced the lowest classification accuracies among the hatchery versus natural stock tests. Wells Hatchery obtained 40% of its 1990 summer chinook broodstock from the Wells Dam west bank fish ladder[1]. (The remaining 60% voluntarily entered the hatchery immediately downstream of this fish ladder.) It is likely that our Wells Hatchery stock sample included many fish of Methow or Similkameen river origin whose scale patterns would be similar to specimens in the natural stock samples. This likely explains the results of Test H, the four-stock classification test, which produced relatively high classification accuracies (for a four-stock analysis) for three of the four stocks. The Mid-Columbia hatchery stock was identified with lowest accuracy in Test H, being commonly misclassified as Mid-Columbia natural origin.

High classification accuracies were obtained in Test F which compared pooled hatchery stocks from Snake and Mid-Columbia basins with pooled natural stocks from those same basins. This suggests that a composite mixed-stock analysis of unknown origin samples might be possible using a classification function based on a limited set of known stock samples. This analysis could be used to estimate the percentage of Snake and Mid-Columbia summer chinook salmon in the mixed stock population in any potential future lower river fisheries or for other study purposes at locations such as Bonneville Dam. We conducted such a test (Test N) using the classification function derived from Test F to obtain a composition estimate for Snake Basin and Mid-Columbia components of the summer chinook population at Bonneville Dam. After adjustment for bias, 28% of the Age 1.2 samples were estimated to originate from the Mid-Columbia Basin. Among Age 0.x samples, we assumed all (36% of the total population) originated from the Mid-Columbia Basin. Therefore we estimated that the Bonneville Dam summer chinook salmon population included 54% Mid-Columbia and 46% Snake Basin stocks.

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1 Beginning in 1991, Wells Hatchery broodstock were collected at a new fish trap on the east bank fish ladder and use of the trap at the west bank ladder was phased out.

Counts made at Columbia Basin hydroelectric dams (CRITFC 1992) suggest that only 26% of the summer chinook salmon at McNary Dam (river km 463) originate in the Snake Basin. Possible explanations for the difference between this and our SPA based estimate of the abundance of Snake Basin fish in the lower Columbia River include the high variation inherent in the SPA estimate resulting from small sample sizes, the relative abundance of other yearling age classes in the two basins differing from that represented by Age 1.2 samples (only Age 1.2 samples were used in the analysis), inaccuracies in dam counts, poorly representative samples from the two basins, and a differential mortality rate for adult fish from the two basins as they migrate from Bonneville Dam to the Snake River. An unknown percentage of what is being called summer chinook salmon at Bonneville Dam may be late migrating spring chinook salmon (Fryer and Schwartzberg 1991b).

Two stock classification tests of the Mid-Columbia versus Snake Basin natural stocks (Test D) and Mid-Columbia versus Snake Basin hatchery stocks (Test E) both classified fish with relatively high accuracies. Results of these tests indicate that, if all hatchery fish were externally marked (they are not at this time), it might be possible to use SPA to accurately identify Mid-Columbia Natural, Mid-Columbia hatchery, Snake Natural, and Snake Hatchery stocks of summer chinook at any mixed-stock lower Columbia River site. One test (using the discriminant function derived in Test E) could be conducted to differentiate marked (hatchery) fish as Mid-Columbia hatchery or Snake Basin hatchery origin while the other test (using the discriminant function derived in Test D) could differentiate unmarked (natural) fish as Mid-Columbia natural or Snake Basin natural origin. A sampling program at a site such as Bonneville Dam could then be used to determine migratory timing of the Snake Basin natural stock. Since Snake Basin natural-origin chinook salmon are listed as threatened under the Endangered Species Act (1973), information on migratory timing of this stock is particularly important.

Three tests (Tests I, J, and K) were conducted to examine the accuracy of SPA in identifying different races of chinook salmon. High classification accuracies were achieved using known samples of spring and summer chinook salmon races in the Wenatchee Basin. Relatively high classification accuracies were also achieved identifying known yearling spring- and summer-race chinook salmon samples from Bonneville Dam. Considering that both races are a mixture of natural and hatchery stocks, this was unexpected. This suggests SPA could be used to differentiate spring versus summer chinook specimens more accurately during times of potential overlap in the migratory timing of the two races than by using migratory timing alone. A similar analysis does not appear to be possible to differentiate summer from fall chinook salmon, as poor classification accuracies were achieved in Test J.

The classification of the Wenatchee River mixed-race sample at Tumwater Dam (Test O) indicated that all chinook salmon sampled at that location were summer race fish. All Age 1.x chinook salmon were so classified using SPA while Age 0.x fish were assumed to be summer chinook salmon since no subyearlings were found in the Wenatchee River spring chinook salmon sample. Samples were collected relatively late in the spring chinook migratory period and the possibility exists that our unknown-race sample did not represent a mixture of the two races. Based on our findings in Tests O and K, we believe that accurate spring versus summer chinook race identification is possible at Tumwater Dam for fish migrating above that point. Almost all natural origin spring chinook salmon in the Wenatchee Basin spawn upstream of Tumwater Dam[2] (Peven 1992) and fish are counted at this site (Hatch et al. 1992). We believe SPA could be used as a management tool to accurately estimate the number of spring and summer chinook salmon spawning above Tumwater Dam in the Wenatchee River[3]. Wenatchee River natural origin spring and summer chinook are both listed as stocks of *high concern* in the Columbia Fish and Wildlife Program Integrated System Plan (Northwest Power Planning Council 1990).

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2. Some spring chinook salmon spawn naturally in the 4.4 km of Icicle Creek between Leavenworth Fish Hatchery and the confluence of Icicle Creek with the Wenatchee River. These fish are most likely strays from Leavenworth Hatchery. In some years, a small amount of spawning is also observed in Peshastin Creek.
3. Presently, Wenatchee spring chinook natural-stock salmon abundance can only be estimated by subtracting the Rocky Reach Dam spring chinook salmon visual count from the Rock Island Dam count (CRITFC 1992). From this spring chinook *interdam* count, the harvest in sport and tribal fisheries, as well as the return to Leavenworth National Fish Hatchery, is subtracted .

Many fisheries research and management opportunities exist for application of SPA-based stock identification in the Columbia Basin. The ability to distinguish hatchery and naturally spawning stocks within mixed stock areas would permit much more comprehensive monitoring, evaluation, and management of many salmon stocks. For example, SPA could be used to evaluate stock-specific escapement goals and the degree to which they are being met. This is important because of the need to assess the status and monitor the recovery of stocks listed under the Endangered Species Act (1973). In mixed stock harvest areas, SPA could be used in the assessment and regulation of fisheries to protect stocks in low abundance and to target stocks of larger population sizes.

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APPENDIX A. DATA HANDLING AND MANIPULATION FOR SCALE PATTERN ANALYSIS.

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. This command creates an ASCII file that 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 statistical software.

Figure A1. A sample OPRS data record for a single sockeye salmon scale freshwater-growth-zone measurement.

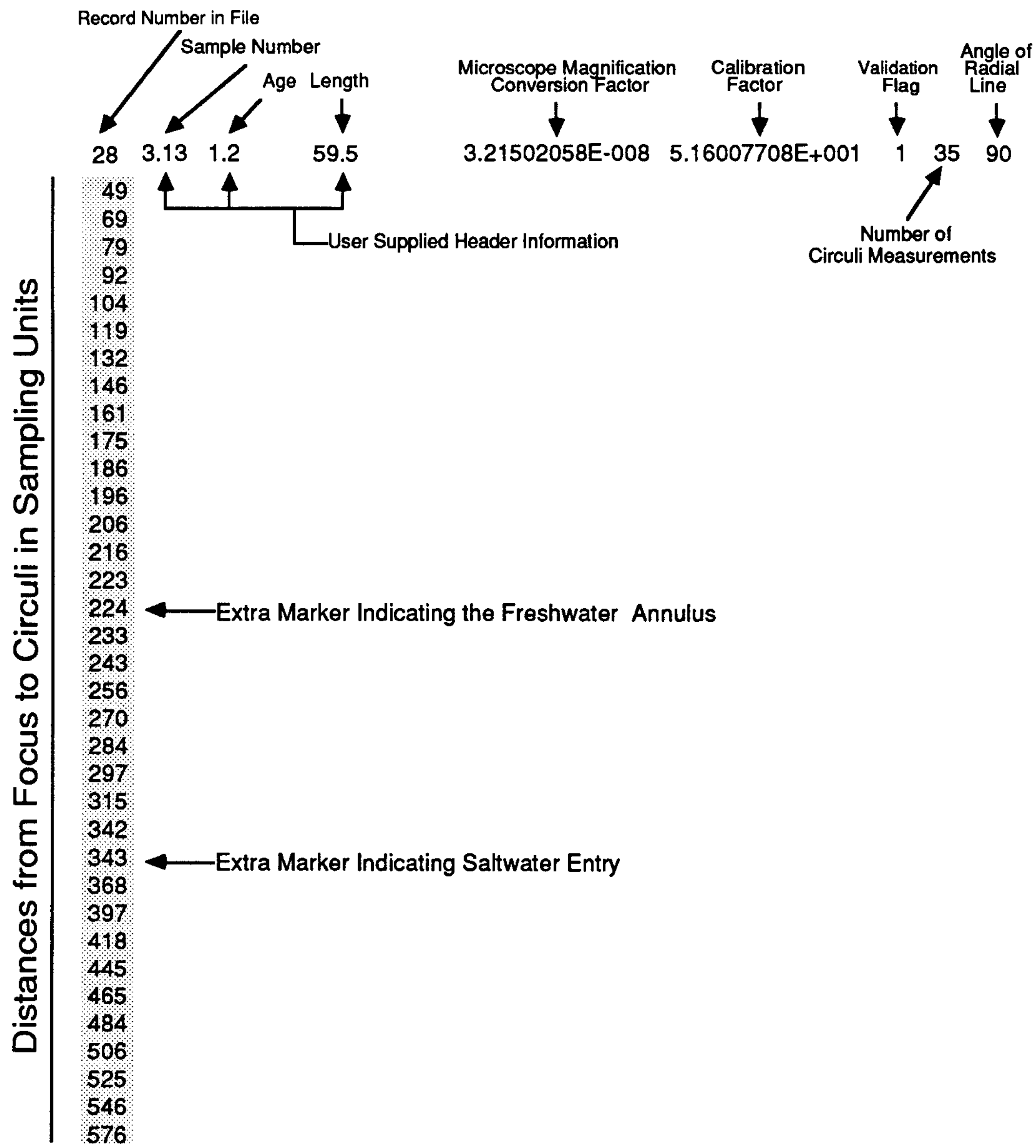

Figure A2. A sample compact-format data record for a single sockeye salmon scale freshwater-growth-zone measurement.