CRITFC

TECHNICAL REPORT 05-2

Identification of Columbia Basin Sockeye Salmon Stocks in 2004

Jeffrey K. Fryer

April 8, 2005

Columbia River Inter-Tribal Fish Commission
729 NE Oregon, Suite 200
Portland, OR 97232
503.238.0667
www.critfc.org

IDENTIFICATION OF COLUMBIA BASIN SOCKEYE SALMON STOCKS IN 2004

Technical Report 05-2

Jeffrey K. Fryer

April 8, 2005

ABSTRACT

In 2004, samples of adult Columbia Basin sockeye salmon, *Oncorhynchus nerka*, were collected at Bonneville Dam as well as at Tumwater Dam on the Wenatchee River and Wells Dam in the mid-Columbia River downstream of the Okanogan River. Tumwater and Wells dams were chosen to provide samples of sockeye salmon from the two principle stocks of Columbia Basin sockeye salmon, which originate from the Wenatchee and Okanogan basins. Age composition was estimated from the sampled sockeye salmon passing the three dams. Four-year-old fish were estimated to comprise 98% of the mixed-stock sockeye salmon migrating past Bonneville Dam, 95% of the Okanogan stock migrating past Wells Dam, and 98% of the Wenatchee stock migrating past Tumwater Dam. Three-year-old fish were estimated to comprise 1% of the Bonneville Dam mixed-stock, 2% of the Okanogan stock and none of the Wenatchee stock. Five-year-old fish were estimated to comprise 1% of the Bonneville Dam mixed-stock, 3% of the Okanogan stock, and 2% of the Wenatchee stock. Scale pattern analysis techniques were used to estimate that 94% of the sockeye salmon passing Bonneville Dam were of Okanogan origin, 5% were of Wenatchee stock, with the remaining 1% of unknown origin. This estimate differed from that derived from fish counts at mainstem dams of 77% Okanogan and 23% Wenatchee stock. Additional scales were measured to investigate the reasons for this difference and it was concluded that it was concluded that low known-stock classification accuracy (73%) is likely responsible.

ACKNOWLEDGMENTS

Bonneville field sampling was supervised by John Whiteaker and assisted by Bobby Begay, and Donette Miranda while Tumwater and Wells field sampling was conducted by Carolyn Pearson of EcoAIM and Rolf Larsen of Snow Creek Environmental Services. John Sneva of Washington Department of Fish and Wildlife provided corroboration of scale age estimates. The following individuals also assisted in this project: Doug Hatch, Denise Kelsey, André Talbot, Rishi Sharma, Stuart Ellis, and Marianne McClure of the Columbia River Inter-Tribal Fish Commission; Chuck Peven of Public Utility District No. 1 of Chelan County; Shane Bickford and Rick Klinge of Public Utility District No. 1 of Douglas County; Tammy Mackey of the US Army Corps of Engineers; Megan Heinrich and Steven Lee of the University of Idaho, and Bob Jateff, Travis Maitland, Andrew Murdoch, Charlie Snow and Rick Stillwater of the Washington Department of Fish and Wildlife.

This report is the result of research funded by US Government (Bureau of Indian Affairs, Department of Interior) Contract No. GTP00X90107 for implementation of the US-Canada Pacific Salmon Treaty.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Sockeye salmon, *Oncorhynchus nerka,* is one of the species of Pacific salmon native to the Columbia River Basin. Before white settlers developed the region, it is estimated the Columbia Basin supported an annual sockeye salmon run averaging over three million fish (Northwest Power Planning Council 1986, Fryer 1995). Since the mid-1800's, however, this sockeye salmon population has severely declined. The estimated number of sockeye salmon entering the Columbia River over the most recent four year period (2001-2004) averaged 82,000 fish per year, though as recently as 1995-1998, the mean escapement was only 24,900 per year (DART 2004).

The Columbia Basin sockeye salmon run was once composed of at least eight principal stocks (Fulton 1970, Fryer 1995). Today, only two major stocks remain[1] (Figure 1). From the 1960's through the early 1990's, both stocks were entirely naturally produced, originating in the Wenatchee River-Lake Wenatchee System (Wenatchee stock) and in the Okanogan River-Osoyoos Lake System (Okanogan stock). In recent years, enhancement programs in both systems have been initiated that capture returning adults, spawn the adults in hatcheries, and raise the offspring in net pens located in the rearing lakes before release (Hays 1992, Wells Project Coordinating Committee 1992). The Okanogan enhancement program was terminated following the 2000 release; however a similar program focusing on restoring sockeye salmon to Skaha Lake upstream of Osoyoos Lake began in 2003. The two remaining Columbia Basin sockeye salmon rearing areas differ markedly (Allen and Meekin 1980, Mullan 1986). Lake Wenatchee is oligotrophic, with relatively deep, cold, and biologically unproductive waters. Conversely, Osoyoos Lake has the shallow, warm, and agriculturally enriched waters characteristic of eutrophic lake habitats.

Reliable estimates of the overall run composition of Columbia Basin sockeye salmon stocks and the biological and migratory characteristics of each

---

1 A small run of sockeye salmon return to the Snake River and are listed as endangered under the Endangered Species Act. These fish are almost entirely hatchery origin and adipose fin clipped. While an estimated 123,291 sockeye salmon passed Bonneville Dam in 2003, only 91 (0.1%) passed Ice Harbor Dam on the Snake River.

Figure 1. Map of the Columbia Basin showing the fishing Zones 1-2, 1-5 and 6, Bonneville, McNary, Ice Harbor, Priest Rapids, Rock Island, Rocky Reach, Tumwater, Wells, and Chief Joseph dams, and the two major sockeye salmon production areas.

stock are useful for run-reconstruction studies permitting accurate population size predictions, escapement monitoring, establishing spawner-recruit relationships, and developing discrete stock approaches to Columbia River mainstem harvest management. The Pacific Salmon Treaty (PST), ratified by the United States and Canada in 1985 (PST 1985), requires that certain Pacific salmon populations be monitored to determine the influence of Treaty-imposed ocean harvest regulations on *transboundary* stocks. Some Okanogan-stock sockeye salmon originating in Canadian waters but migrating through, and harvested in, the United States portion of the Columbia River constitutes such a stock. Stock identification research would aid in estimation of the proportion and abundance of Canadian-origin sockeye salmon caught within the United States. This study, begun in 1987 (Schwartzberg and Fryer 1988), was initiated to provide such information.

Scale pattern analysis (SPA) has been the method of study used for our stock identification research and 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 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. Scale patterns from the Wenatchee and Okanogan sockeye salmon stocks in past years have differed (Schwartzberg and Fryer 1988, 1989, 1990; Fryer and Schwartzberg 1991, 1993, 1994; Fryer et al. 1992; Fryer and Kelsey 2001, 2002, 2003; Fryer 2004), presumably reflecting differences in freshwater rearing conditions. In most years, Okanogan sockeye salmon scale samples have shown greater growth to both freshwater annulus and saltwater entry than have Wenatchee sockeye salmon scale samples.

This report presents estimates of the age and length-at-age composition of adult Columbia Basin sockeye salmon at Bonneville Dam in 2004. This report also presents age and length-at-age composition estimates from the Wenatchee stock collected at Tumwater Dam on the Wenatchee River and the Okanogan stock collected at Wells Dam. Data collected from our mid-Columbia sampling program was used to estimate stock composition of the Bonneville Dam mixed-stock in 2004.

METHODS

Sample Design

Sockeye salmon were sampled at Bonneville Dam (river km 235) one to two days per statistical week[2] in conjunction with a summer chinook salmon sampling program (Miranda et al. 2005). Sockeye salmon were sampled at Wells Dam in conjunction with a Washington Department of Fish and Wildlife (WDFW) summer chinook brood stock collection program, while sampling at Tumwater Dam was done in conjunction with another WDFW research project. The desired total sample size for age composition estimates at each site was a minimum of 500 fish at Bonneville Dam, and 400 fish at Tumwater and Wells dams. In previous study years, these minimum sample numbers have resulted in acceptable levels of precision and accuracy (Fryer 1995) ($d=0.05$, $\alpha=0.10$). Smaller sample sizes are normally sufficient at Tumwater and Wells dams because the age composition tends to be more skewed towards one or two age classes than at Bonneville Dam. Daily counts of 2004 fish passage at fish ladders were obtained from DART (2004) for Bonneville and Wells dams and from WDFW for Tumwater Dam (Travis Maitland, WDFW, March 18, 2005 e-mail).

A stratified sampling method that weighted weekly age and length-at-age estimates by actual migratory timing was used to obtain composite estimates for the Wenatchee and Okanogan known-stocks as well as the Bonneville mixed-stock (Cochran 1977).

Sampling Methods

Data and scales from mixed sockeye salmon stocks (or mixed-stocks) were obtained from fish sampled at the Bonneville Dam Adult Fish Facility,

---

2 Statistical weeks are sequentially numbered calendar-year weeks. Excepting the first and last week of most years, weeks are seven days long, beginning on Sunday and ending on Saturday. In 2004 for example, Statistical Week 24 began on June 6 and ended on June 12.

located on the mainstem Columbia River. Each stock was also sampled in terminal areas to obtain representative scale samples for each of the two Columbia Basin sockeye salmon groups (or known-stocks). Wenatchee stock data and scales were collected at Tumwater Dam on the Wenatchee River (river km 53), and Okanogan stock data and scales were obtained at Wells Dam on the mainstem Columbia River (river km 830).

Fish were trapped and anesthetized. Each fish was then sampled for scales, measured for fork length, inspected for markings and/or tag information and noted for other pertinent biological information (Miranda et al. 2005). At Tumwater and Wells dams, inspection for biological information was not as extensive as at Bonneville Dam due to the need to handle fish quickly to allow our project to be run concurrently with broodstock collection and research projects being conducted by other parties. All fish were revived in freshwater and returned to the exit fishway. Four scales per fish were collected to minimize the sample rejection rate. The gender of specimens collected at Bonneville Dam could not be determined because all were in the earliest stages of sexual maturation. The gender of some specimens collected at Tumwater and Wells dams could be determined, and was recorded but this data is not included in this report.

Length Measurements

Fork lengths were measured to the nearest 0.5 cm at Bonneville, Wells, and Tumwater dams. Mean lengths and standard deviations were calculated for each age class, by weekly sampling period, and for the composite sample. Composite samples were weighted by weekly run size.

Age Determination

Scales were selected, mounted, and pressed according to methods described in Clutter and Whitesel (1956) and the International North Pacific Fisheries Commission (1963). Individual samples were visually examined and categorized using well-established scale age-estimation methods (Gilbert 1913, Borodin 1924, Van Oosten 1929). A sample of scales was brought to John

Sneva of the Washington Department of Fish and Wildlife for corroboration of age estimates.

The European method for fish age description (Koo 1955) is used in this report. 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.

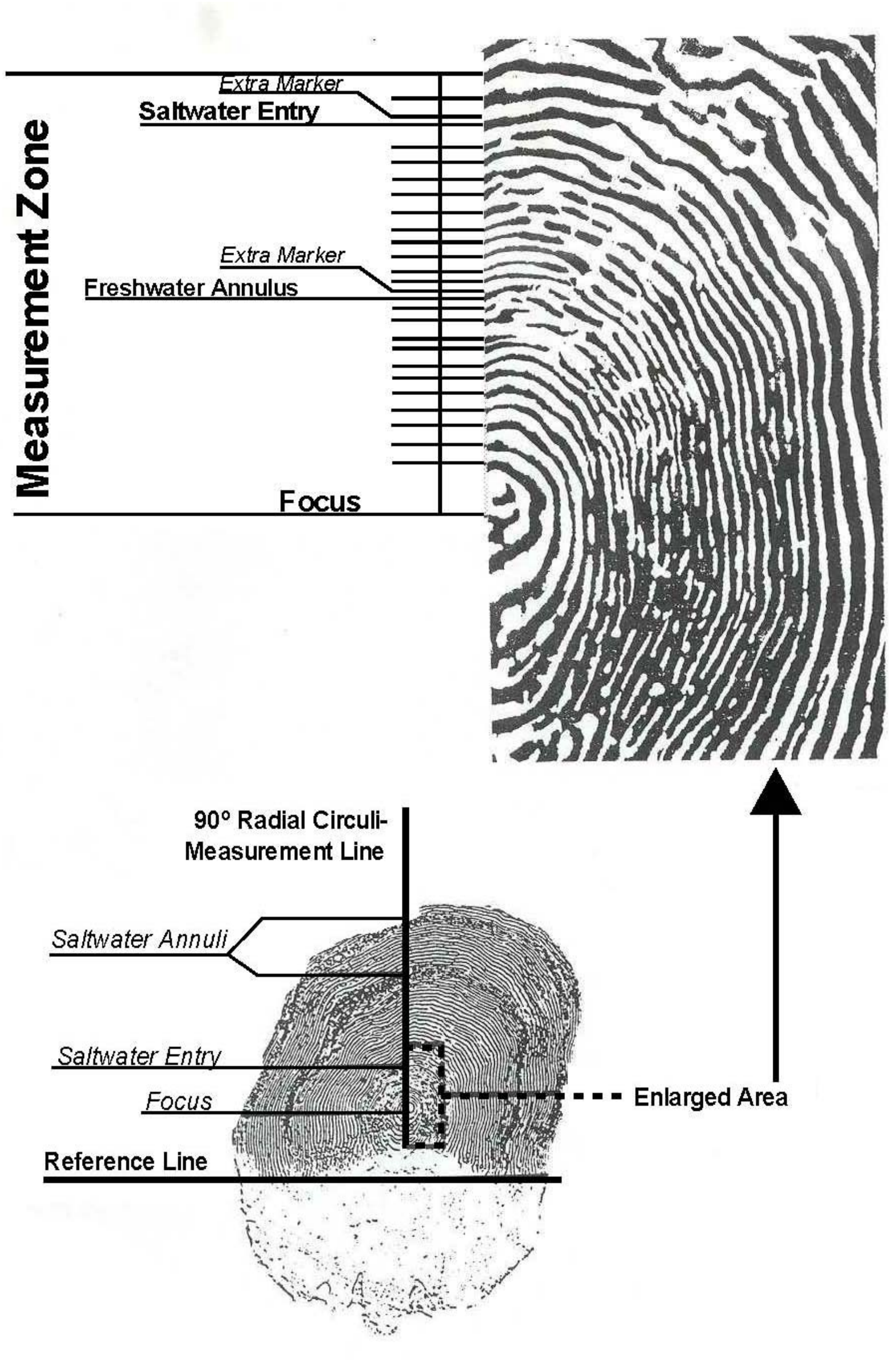
Weekly age composition estimates were compiled and weighted by weekly run size to estimate overall age composition at Bonneville, Wells, and Tumwater dams.

Scale Pattern Analyses

Scale pattern analysis of circuli in freshwater- and early saltwater-growth zones was used to identify each known-stock sample and to also classify mixed-stock samples. The methodology was applied to the predominant Age 1.2 class from all stocks. Scale features were first measured using a computer and video camera based system (BioSonics Optical Pattern and Recognition System [OPRS]) that included a microscope (2x, 4x, 6.3x, and 10x objectives; a 1.0x, 1.25x, and 1.5x magnification changer; and a 2.5x photocompensation adapter), a secondary monitor (53 cm), and a digitizing tablet connected to a personal computer with a video frame-grabber board (BioSonics 1987). Acetate impressions of scales were placed under the microscope and projected onto the monitor using a 4.0x objective, 1.0x magnification changer, and 2.5x photo-compensation adapter. This lens configuration created a scale image initially viewed at 130x actual size.

Working from the top of the scale card, the first scale impression with no focus regeneration and clearly defined circuli was selected and the projected image was oriented diagonally with the clear (posterior) portion of the scale in the lower left corner of the screen. A reference line was drawn along the base of the scale image (Figure 2). The reference line was placed in the posterior field of the scale image so that the line bridged the end points of circuli in the first saltwater annulus (Fryer and Schwartzberg 1994). The objective was then

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



changed to 10x, resulting in a viewed scale image 325x actual size, and a radial line was then drawn perpendicular to the reference line. Circuli positions were marked at the marginal (outermost) edge of their intersection with the radial line. The OPRS software (version 1.0) measured the distance from the scale focus to each circuli marker. The portion of the scale where circuli measurements were made included the entire freshwater zone and part of the early saltwater growth zone.

Additional artificial circuli markers were placed to permit measurement of other key scale-features, specifically, freshwater annulus and saltwater-entry point. These features were respectively indicated by two sets of closely spaced circuli markers. The 'extra markers' were placed immediately after and adjacent to the original circuli position markers and were interpreted and removed by data analysis programs used in subsequent procedures (Fryer and Schwartzberg 1993). 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.

For SPA studies, the desired sample size was approximately 200 from each known-stock group for each age class analyzed (Conrad 1985)[3]. As in most previous years, the only age class with a sufficiently large sample size to justify using SPA was Age 1.2. For SPA analysis of mixed-stocks, 100 was the desired sample size (Conrad 1985), although the actual sample size used for the Bonneville mixed-stock has normally been much larger to permit more precise weekly stock composition estimates. No adipose-fin or ventral fin-clipped sockeye salmon were included in any of the samples studied due to very small sample sizes as well as the fact that these were assumed to be from a hatchery program.

In 2004, approximately half of the known stock scale samples measured for our SPA study were measured a second time using the same techniques. This second set of measurements was completed on every other sample in the

3 In many years, actual sample sizes have been considerably less due to low numbers of fish collected.

original set. These Okanogan and Wenatchee *validation* groups were created because of unanticipated results in the original analyses.

Statistical Analyses

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

Variables, composed of selected scale-measurements within the area from scale focus to Circulus 24, were tested to find those that most effectively characterized differences in growth between the two known stocks as well as between the two validation groups. As in previous years' studies, distances between four adjacent circuli (or triplets) were the primary variable tested (Davis 1987). Distance measurements and number of circuli from scale focus to saltwater-entry and from scale focus to freshwater annulus margin (anterior) were also among the variables tested.

A paired t-test was used to compare triplet measurements between the original and validation groups. For example, the mean distance from focus to third circuli for the Wenatchee known-stock group was tested against the mean distance from focus to third circuli for the Wenatchee validation group. In addition, a paired t-test was used to compare the mean distance and number of circuli to freshwater annulus and saltwater entry between the Wenatchee known-stock and validation group as well as between the Okanogan known-stock and validation group.

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 estimating its accuracy. To correct for misclassification of mixed-stock samples, I used a method developed by Cook and Lord (1978) and Cook (1983). Variances on mixed-stock classification estimates were also computed (Pella and Robertson 1979). The Bonneville mixed-stock sample was classified using both the known stocks and validation groups and the results compared.

RESULTS

Sample Sizes

Final sample sizes used for age and length-at-age composition estimates were 630 Bonneville mixed-stock, 392 Wenatchee known-stock, and 363 Okanogan known-stock. Of the original 650 sockeye salmon sampled at Bonneville Dam, 3% of the total sample was rejected and not classified by age because of unreadable scales. For the same reason, 2% of the 400 Wenatchee, and 2% of the 400 Okanogan samples were rejected.

Age Composition

The predominant age class for the Bonneville mixed-stock as well as for the Okanogan and Wenatchee known stocks was Age 1.2 (Table 1-3). Age 1.2 fish comprised greater than 95% of the run for each of the stocks.

Seventeen of the fish sampled at Bonneville Dam were adipose clipped, which represented 2.8% of the entire run. These fish are most likely from the Wenatchee Eastbank supplementation program, although the remote possibility does exist that fish from the Snake River program may also be included. One fish sampled had a left pectoral fin clipped, while another had both an adipose and left ventral fin clipped. The age of three adipose-only clipped fish could not be determined due to regenerated scales; all other fin-clipped fish were Age 1.2.

Three adipose-clipped and three left ventral clipped fish were sampled at Wells Dam, representing 0.8% and 0.4% of the run, respectively. Six adipose-clipped fish were sampled at Tumwater Dam, representing an estimated 1.5% of the run. Video counts of fish passage at Tumwater Dam estimated that 6.0% of sockeye salmon were adipose-clipped (Travis Maitland, WDFW, March 18, 2005 e-mail).

Table 1. Weekly and cumulative age composition Columbia Basin sockeye salmon sampled at Bonneville Dam in 2004.

Age Composition by Brood Year and Age Class

Statistical Week	Sampling Date	Number Sampled	Number Ageable	Weekly Run Size	2001	2000	1999			1998
					1.1	1.2	1.3	2.2	3.1	2.3
24[a]	6/9	70	68	9997		0.971		0.029		
25	6/15,6/17	140	138	31706		0.978		0.007	0.007	0.007
26	6/22,6/24	160	155	44331	0.013	0.981		0.006		
27	6/29,6/30	140	135	22241	0.000	0.985	0.015			
28	7/6,7/8	100	97	10175	0.052	0.948				
29[b]	7/13,7/15	40	37	4841	0.027	0.973				
Cumulative		**650**	**630**	**123291**	**0.010**	**0.977**	**0.003**	**0.007**	**0.002**	**0.002**

a Weekly run size includes fish numbers from Week 21 - 24. Sampling began in Week 24.
b Weekly run size includes fish numbers from Weeks 29 - 45. Sampling ended in Week 29.

Table 2. Weekly and cumulative age composition of Okanogan sockeye salmon stocks sampled at Wells Dam in 2004.

Age Composition by Brood Year and Age Class

Statistical Week	**Sampling Date**	**Number Sampled**	**Number Ageable**	**Weekly Run Size**	**2001**	**2000**		**1999**		**1998**
					1.1	**1.2**	**2.1**	**2.2**	**3.1**	**4.1**
28[a]	7/6	100	99	46366	0.000	0.970	0.000	0.020	0.010	0.000
29	7/12,7/13	172	167	15560	0.042	0.922	0.006	0.012	0.012	0.006
30	7/19	90	90	11192	0.033	0.922	0.000	0.011	0.033	0.000
31[b]	7/26	38	37	2821	0.054	0.919	0.000	0.027	0.000	0.000
Cumulative		**400**	**393**	**75939**	**0.016**	**0.951**	**0.001**	**0.017**	**0.014**	**0.001**

a Weekly run size includes fish numbers from Weeks 26 – 28. Sampling started in Week 28.
b Weekly run size includes fish numbers from Weeks 31 – 39. Sampling ended in Week 31.

Table 3. **Weekly and cumulative age composition of Wenatchee sockeye salmon stocks sampled at Tumwater Dam in 2004.**

Age Composition by Brood Year and Age Class

Statistical Week	Sampling Date	Number Sampled	Number Ageable	Weekly Run Size	2000	1999	
					1.2	1.3	2.2
28[a]	7/8	92	91	9058	0.978		0.022
29	7/14	160	156	15266	0.981	0.013	0.006
30[b]	7/20,7/21	148	145	8843	0.972		0.028
Cumulative		**400**	**392**	**33167**	**0.978**	**0.006**	**0.016**

a Weekly run size includes fish numbers from Weeks 28 – 30. Sampling started in Week 30.
b Weekly run size includes fish numbers from Weeks 31 – 40. Sampling ended in Week 31.

Length Composition

Mean fork lengths of Age 1.2 sampled at Bonneville, Tumwater, and Wells dams differed by less than 0.8 cm (Tables 4-6). Wenatchee sockeye sampled at Tumwater dam had the greater lengths and this may be a result of the fact that many fish sampled at Tumwater Dam had well-developed secondary sexual characteristics, including the development of an elongated snout in the males, which would result in an increase in fork length. For other age classes with much smaller sample sizes, mean fork lengths varied by up to 1.83 cm for Age 2.2 fish and by 0.81 cm for Age 1.1 fish.

Classification of Known-Stock Samples

Known stock sample sizes for SPA were 200 Okanogan and 209 for the Wenatchee, while the validation groups consisted of 103 Okanogan and 106 Wenatchee. The variable set chosen to classify known- and mixed-stock samples consisted of triplets between focus and circuli 24. As in previous years, distance and number of circuli to saltwater entry variables were felt to be highly dependent on operator judgment as the location of saltwater entry was often difficult to determine. The freshwater annulus, on the other hand, was relatively easy to locate, particularly for Age 1.2 and not nearly as subject to operator judgment. However, the stepwise algorithm did not select these variables. The variables used by the stepwise procedure for classification were distance from focus to third circuli, third to sixth, sixth to ninth, twelfth to fifteenth, and fifteenth to twenty-first. The overall classification accuracy was 72.6% for the original data and 72.5% for the validation data (Table 7). Okanogan classification accuracy was higher using the validation data, while Wenatchee classification accuracy was higher using the original data.

A paired t-test found a significant difference between the mean triplet measurements for the original and validation groups for the Wenatchee stock (p=0.04), but not the Okanogan stock (p=0.15). The mean difference between the sets of triplet measurements was 1.4% for the Okanogan stock and 1.5% for the Wenatchee. There was not a significant difference for the mean

Table 4. Length-at-age estimates for Columbia Basin sockeye salmon stocks sampled at Bonneville Dam in 2004.

Brood Year and Age Class	2001 1.1	2000 1.2	1999 1.3	1999 2.2	1999 3.1	1998 2.3
Statistical Week 24						
Mean Fork Length (cm)		49.54		50.75		
Maximum		54.5		51.5		
Minimum		45.0		50.0		
Standard Deviation		2.01		1.06		
Sample Size		66		2		
Statistical Week 25						
Mean Fork Length (cm)		49.90		54.50	52.50	50.00
Maximum		58.5		54.5	52.5	50.0
Minimum		44.0		54.5	52.5	50.0
Standard Deviation		2.18		-	-	-
Sample Size		135		1	1	1
Statistical Week 26						
Mean Fork Length (cm)	38.75	49.73		52.00		
Maximum	39.0	55.0		52.0		
Minimum	38.5	41.5		52.0		
Standard Deviation	0.35	2.33		-		
Sample Size	2	150		1		
Statistical Week 27						
Mean Fork Length (cm)		50.20	58.75			
Maximum		57.0	64.0			
Minimum		44.5	53.5			
Standard Deviation		2.36	7.42			
Sample Size		132	2			
Statistical Week 28						
Mean Fork Length (cm)	37.50	49.64				
Maximum	40.0	55.0				
Minimum	35.5	44.0				
Standard Deviation	1.77	2.24				
Sample Size	5	92				
Statistical Week 29						
Mean Fork Length (cm)	36.50	49.11				
Maximum	36.5	53.0				
Minimum	36.5	43.0				
Standard Deviation	-	2.23				
Sample Size	1	35				
2004 Composite						
Mean Fork Length (cm)	37.69	49.80	58.75	52.00	52.50	50.00
Maximum	40.0	58.5	64.0	54.5	52.5	50.0
Minimum	35.5	41.5	53.5	50.0	52.5	50.0
Standard Deviation	1.53	2.26	7.42	1.87	-	-
Sample Size	8	610	2	4	1	1

Table 5. Length-at-age estimates for Wenatchee sockeye salmon stocks sampled at Tumwater Dam in 2004.

Brood Year and Age Class	2000 1.2	1999 1.3	1999 2.2
Statistical Week 28			
Mean Fork Length (cm)	50.59		50.00
Maximum	56.0		51.5
Minimum	46.0		48.5
Standard Deviation	1.81		2.12
Sample Size	89		2
Statistical Week 29			
Mean Fork Length (cm)	50.89	56.75	48.50
Maximum	54.5	57.5	48.5
Minimum	45.0	56.0	48.5
Standard Deviation	1.83	1.06	-
Sample Size	153	2	1
Statistical Week 30			
Mean Fork Length (cm)	50.41		51.38
Maximum	55.5		55.0
Minimum	46.0		48.5
Standard Deviation	1.81		3.15
Sample Size	141		4
2004 Composite			
Mean Fork Length (cm)	50.65	56.75	50.57
Maximum	56.0	57.5	55.0
Minimum	45.0	56.0	48.5
Standard Deviation	1.83	1.06	2.64
Sample Size	383	2	7

Table 6. Length-at-age estimates for Okanogan sockeye salmon stocks sampled at Wells Dam in 2004.

Brood Year and	2001	2000		1999		1998
Age Class	1.1	1.2	2.1	2.2	3.1	4.1
Statistical Week 28						
Mean Fork Length (cm)		50.65		52.75	48.50	
Maximum		56.0		53.5	48.5	
Minimum		44.0		52.0	48.5	
Standard Deviation		2.26		1.06	-	
Sample Size		96		2	1	
Statistical Week 29						
Mean Fork Length (cm)	37.36	49.95	40.00	47.25	44.75	49.00
Maximum	39.5	56.0	40.0	48.5	45.5	49.0
Minimum	35.0	42.0	40.0	46.0	44.0	49.0
Standard Deviation	1.68	2.32	-	1.77	1.06	-
Sample Size	7	154	1	2	2	1
Statistical Week 30						
Mean Fork Length (cm)	37.50	49.58		52.50	50.50	
Maximum	38.5	55.5		52.5	52.5	
Minimum	36.5	43.5		52.5	48.5	
Standard Deviation	1.00	2.64		-	2.00	
Sample Size	3	83		1	3	
Statistical Week 31						
Mean Fork Length (cm)	38.00	48.66		48.50		
Maximum	39.5	53.5		48.5		
Minimum	36.5	41.0		48.5		
Standard Deviation	2.12	2.39		-		
Sample Size	2	34		1		
2004 Composite						
Mean Fork Length (cm)	37.50	49.93	40.00	50.17	48.25	49.00
Maximum	39.5	56.0	40.0	53.5	52.5	49.0
Minimum	35.0	41.0	40.0	46.0	44.0	49.0
Standard Deviation	1.48	2.44	-	2.93	3.13	-
Sample Size	12	367	1	6	6	1

Table 7. Known-stock classification resulting from using the linear discriminant analysis with Columbia Basin sockeye salmon stocks sampled in 2004.

Original Data

		Sample Classification	
Stock	**Percent Correct**	***Wenatchee***	***Okanogan***
Wenatchee	73.7	154	55
Okanogan	71.5	57	143
Composite Accuracy	72.6		

Using Validation Data

		Sample Classification	
Stock	**Percent Correct**	***Wenatchee***	***Okanogan***
Wenatchee	72.6	77	29
Okanogan	72.8	28	75
Composite Accuracy	72.7		

distance and number of circuli to freshwater annulus and saltwater entry for either the Wenatchee ($p=0.07$) or Okanogan stock ($p=0.09$). The mean difference between these measurements for of the original and validation groups was 0.9% for the Okanogan stock and 3.4% for the Wenatchee stock.

Classification of Mixed-Stock Samples

After weighting weekly stock composition estimates by weekly run size, the percentage of non-fin-clipped sockeye of Okanogan origin was 98% (σ=6%) for Age 1.2 (Table 8). In an effort to derive a weekly and total stock composition estimate for all age classes, other age classes sampled at Bonneville Dam were allocated to the two stocks (Fryer 1995). Given the fact that no fish of Age 1.1 fish were found in the Wenatchee known-stock sample but were found in the Okanogan known-stock sample, Age 1.1 fish at Bonneville Dam were allocated to the Okanogan stock. All adipose-clipped fish were allocated to the Wenatchee stock as these are most likely fish from a Wenatchee supplementation program[4]. Since no fish in the Wenatchee sample returned after spending only one year in saltwater, or spent more than two years in freshwater, the single Age 3.1 fish was also allocated to the Okanogan stock. The Age 1.3, 2.2 and 2.3 fish as well as the Age 1.2 LP clipped fish were considered to be of unknown origin. Among all sockeye passing over Bonneville Dam in 2004, I estimate that 5% (σ=6%) were of Wenatchee stock, 94% (σ=6%) were of Okanogan stock, and 1% (σ=1%) were of unknown origin (Table 8). Using the validation set of scales, the estimated percentage of Wenatchee stock sockeye was 13% (σ=7%) for Age 1.2 fish and 16% (σ=7%) among all age groups while the estimated percentage of Okanogan stock sockeye was 86% (σ=7%) for Age 1.2 fish and 83% (σ=7%) among all age groups (Table 8).

---

4 Sockeye salmon raised as part of a Snake River captive brood program are also adipose clipped. However, the number of sockeye salmon returning to the Snake River is very small relative to those returning to the Wenatchee River.

Table 8. Weekly and cumulative stock composition estimates (mean and standard deviation) of Columbia Basin sockeye salmon at Bonneville Dam in 2004 using original and validation groups.

Classification of Age 1.2 Sockeye Salmon					
		Sample Classification (%)			
Statistical Week	**Sample size**	**Wenatchee**		**Okanogan**	
		Mean	**St. Dev.**	**Mean**	**St. Dev.**
24	35	0	16	100	16
25	84	3	12	97	13
26	86	2	12	98	12
27	69	4	13	96	13
28	52	0	14	100	14
29	33	0	17	100	17
Population Estimate	**359**	**2**	**6**	**98**	**6**
Validation group	**359**	**13**	**7**	**87**	**7**

Classification of Sockeye Salmon of all ages							
		Sample Classification (%)					
Statistical Week	**Sample size**	**Wenatchee**		**Okanogan**		**Unknown**	
		Mean	**St. Dev.**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**
24	68	9	9	89	14	3	5
25	138	6	7	94	14	1	1
26	155	4	5	95	9	1	1
27	135	5	3	93	7	2	1
28	97	2	2	98	7	0	0
29	37	0	8	100	21	0	0
Population Estimate	**630**	**5**	**6**	**94**	**6**	**1**	**1**
Validation Group	**630**	**16**	**7**	**83**	**7**	**1**	**1**

DISCUSSION

The 2004 Columbia Basin sockeye salmon run of over 123,000 fish at Bonneville Dam was the largest sockeye run since 1987. This run was also notable for being almost entirely of a single age group, Age 1.2. This age group was estimated to comprise at least 95% of the run at Bonneville, Wells, and Tumwater dams. While the tendency for sockeye salmon runs to be overwhelmingly of the same age class is common for some other sockeye runs (e.g., the Fraser [Fryer 1995]), this has not been observed in the Columbia River. In no other year since this study began in 1987 have Age 1.2 fish been estimated to make up more than 84% of the run in the mixed stock as well as both known stocks.

In the report discussing the Columbia Basin sockeye run in 2003 (Fryer 2004), it was noted that the age composition of the run was "unusual in that, like 2002, three- and four-freshwater fish (ages 3.1, 3.2, 3.3, 4.1) were observed at Bonneville and Wells dams. Fish of these age groups comprised an estimated 19.4% of the run at Bonneville Dam and 17.1% of the run at Wells Dam." In 2004, only one three- or four-freshwater sockeye salmon was sampled at Bonneville Dam, while seven fish were sampled at Wells dams. In 2004 genetics samples were collected from all fish sampled at Wells and Tuwmater dams. Future work includes using the genetic samples from these seven fish from Wells Dam to compare the genetic profile with that of Okanogan sockeye as well as kokanee stocks upstream of Wells Dam.

A commonly used method to determine the percentage of Columbia Basin sockeye salmon by stock is to use the split in upstream dam counts. Using the count at Rocky Reach Dam of 81,338 sockeye salmon (which presumably are Okanogan stock), and the difference in Rocky Reach and Rock Island counts of 25,328 fish[5], the proportion of the run in the mid-Columbia of Okanogan origin

5 These are the fish that presumably comprise the Wenatchee stock, however the estimated number of sockeye salmon passing Tumwater Dam on the Wenatchee River in 2004 based on video counts was 33,167 fish (Travis Maitland, WDFW, March 18, 2005 e-mail).

was 77%, compared to 94% estimated by this report. Although these two estimates could differ due to differential mortality on the upstream migration, in most years our stock composition estimate has been very similar to that offered by dam count splits. The estimated 95% confidence interval around my estimate of 94% would range from 82% to 106%. However, given that the percentage of the run of Okanogan origin cannot be above 100%, the true confidence interval would extend lower, and would include the dam count split estimate of 77%.

The 2004 known-stock classification accuracy of 73% was relatively low compared with past years of this study over which the mean two-stock classification accuracy for the predominant age class has been 83.4%. This low accuracy, and the difference between the SPA estimate and the dam count split estimate, led me to measure again approximately half of the known stock samples to create the validation groups. I found the validation data more similar to the original data than I expected. The two models (original data and validation data) used the same variable set, overall classification accuracy was the same, and the mean difference between the two sets of triplet measurements was less than 1.5%. Even the measurements to freshwater annulus and saltwater entry which, in most years, I have not used as variables for classifying unknowns due to their subjectivity in interpretation, differed by an average of 2.2% with a maximum difference of 5.8%.

Despite the similarity in measurements and classifications for the two sets of known stocks, the classification of the mixed stock differed considerably. The validation group had the same overall classification accuracy as the original groups, but Okanogan classification accuracy increased by one percentage point, while Wenatchee classification accuracy decreased by one percentage point. This small change in classification accuracy decreased the estimated percentage of Age 1.2 Bonneville mixed-stock sockeye salmon of Okanogan origin from 97% to 86%, while the percentage of Okanogan origin for all age groups decreased from 94% to 83%. This estimate of 83% is not far from the dam count split estimate of 77%. Because of the low known-stock classification accuracies, a very small difference in the known stock classification (the equivalent of 5 out of 409 fish, or 1.2%, were reclassified), resulted in a 12% difference in the classification of the unknown stock.

The estimated harvest in Zone 1-5 (downstream of Bonneville Dam) was 672 fish, with an additional 1,727 fish harvested in the Zone 6 (between Bonneville and McNary dams) tribal commercial and 2,590 in the Zone 6 tribal ceremonial and subsistence fishery (March 22, 2005 e-mail from Stuart Ellis, CRITFC). No scales were collected in 2004 from any sockeye captured in these fisheries so SPA could not be used to estimate the stock composition of these harvests.

Sockeye salmon are also harvested in tribal fisheries upstream of Wells Dam. In 2004, the estimated number of sockeye salmon harvested in the Chief Joseph Dam snag fishery was 24 (an estimated 4 of these fish were adipose clipped and were described as possible kokanee), while 17 fish were harvested in an Okanogan River sockeye net fishery (March 24, 2005 e-mail from Chris Fisher, Confederated Tribes of the Colville Indian Reservation). An estimated 200-250 sockeye were harvested in Okanagan Band tribal Lake Osoyoos gill net and Okanagan River snag fisheries (Personal Communication, Howie Wright, Okanagan Nation Alliance, March 22, 2005).

The Lake Wenatchee sport fishery harvested an estimated 5410 sockeye salmon, 429 of which were adipose-clipped (Art Viola memo to Andrew Murdoch dated 10/22/04, Washington Department of Fish And Wildlife, Wenatchee, WA.)

Research on Columbia Basin sockeye salmon will continue in 2005 and we will continue to develop an age, length-at-age, and stock composition data-base for this population. Data obtained from this program may be useful to monitor the impact of future main-stem Columbia fisheries, supplementation programs in the Wenatchee basin, as well as sockeye salmon stock recovery efforts in other Columbia River subbasins.

REFERENCES

Allen, R.L., and T.K. Meekin. 1980. Columbia River sockeye salmon study, 1971-1974. State of Washington, Department of Fisheries, Progress Report 120. Olympia.

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. Juneau.

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. Juneau.

BioSonics, Inc. 1987. Optical pattern recognition system. Data acquisition program manual. Seattle.

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.

Cochran, W.G. 1977. Sampling techniques. J.W. Wiley & Sons. New York.

Conrad, R. 1985. Sample sizes of standards and unknowns for a scale pattern analysis. Alaska Department of Fish and Game, Sports Fisheries Division Unpublished Memorandum. Anchorage.

Cook, R.C. 1983. Simulation and application of stock composition estimators. Simulation and application of stock composition estimators. Canadian Journal of Fisheries and Aquatic Sciences. 40: 2113-2118.

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.

DART (Columbia River Data Access in Real Time). 2004. Online at: http://www.cbr.washington.edu/dart/dart.html

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, Seattle.

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.

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

Fryer, J.K. 1995. Columbia Basin sockeye salmon: Causes of their past decline, factors contributing to their present low abundance, and the future outlook. Ph.D. Thesis. University of Washington, Seattle.

Fryer, J. K. 2004. Identification of Columbia Basin sockeye salmon stocks in 2003. Columbia River inter-Tribal Fish Commission Technical Report 04-01, Portland.

Fryer, J.K., and D.A. Kelsey. 2001. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 2000. Columbia River Inter-Tribal Fish Commission Technical Report 01-2, Portland.

Fryer, J.K., and D.A. Kelsey. 2002. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 2001. Columbia River Inter-Tribal Fish Commission Technical Report 02-2, Portland.

Fryer, J.K., and D.A. Kelsey. 2003. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 2002. Columbia River Inter-Tribal Fish Commission Technical Report 03-2, Portland.

Fryer, J.K., C.E. Pearson, and M. Schwartzberg. 1992. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 1991. Columbia River Inter-Tribal Fish Commission Technical Report 92-2, Portland.

Fryer, J.K., and M. Schwartzberg. 1991. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses, 1990. Columbia River Inter-Tribal Fish Commission Technical Report 91-2, Portland.

Fryer, J.K., and M. Schwartzberg. 1993. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses in 1992. Columbia River Inter-Tribal Fish Commission Technical Report 93-2, Portland.

Fryer, J.K., and M. Schwartzberg. 1994. Age and length-at-age composition of Columbia Basin spring and summer chinook at Bonneville Dam, 1993.

Columbia River Inter-Tribal Fish Commission Technical Report 94-1, Portland.

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.

Hays, S. 1992. Rock Island Hatchery evaluation plan and 1992-93 work plan. Memorandum to Rock Island Coordinating Committee, June 5, 1992. Public Utility District No. 1 of Chelan County, Wenatchee, WA.

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. Vancouver, British Columbia.

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.

Lachenbruch, P.A. 1975. Discriminant analysis. Hafner Press, New York, New York.

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 North Pacific Fisheries Commission Bulletin 38.

Miranda, D., J Whiteaker, and J.K. Fryer. 2005. Age and length composition of Columbia Basin Chinook and sockeye salmon and steelhead at Bonneville Dam in 2004. Columbia River Inter-Tribal Fish Commission Technical Report 05-1. Portland.

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 – 1972: 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.

PST (Pacific Salmon Treaty). 1985. Treaty between the government of the United States of America and the government of Canada concerning Pacific salmon. Treaty document Number 99-2, (entered into force March 18, 1985), 16 USC§§3631-3644 (1988).

Pella, J.J., and T.L. Robertson. 1979. Assessment of composition of stock mixtures. United States Fish and Wildlife Fishery Bulletin 77(2):387-398.

Schwartzberg, M., and J.K. 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, Portland.

Schwartzberg, M., and J.K. Fryer. 1989. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses, 1988. Columbia River Inter-Tribal Fish Commission Technical Report 89-2, Portland.

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

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.

Wells Project Coordinating Committee. 1992. Summary of December 1, 1992 Meeting. Public Utility District No. 1 of Douglas County, East Wenatchee, WA.