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SEPARATING MAJOR RUNS IN THE COPPER-BERING RIVER SOCKEYE SALMON (*Oncorhynchus nerka*) FISHERY WITH SCALE PATTERN ANALYSIS

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ABSTRACT

Data collected in 1980 and 1981 by the Alaska Department of Fish and Game are used to test the power of linear discriminant functions to distinguish runs of sockeye salmon *(Oncorhynchus nerka)* in the Copper-Bering River fishery. Scales were taken from salmon caught in the subsistence fishery near the mouth of the Chitina River (tributary of the Copper River) from spawning salmon in the Copper River Delta, and from the adjacent Bering River drainage. Fifty-five attributes in the freshwater and the first marine zones were measured for each scale. Discriminant functions were based on scales from three groups of fishery samples (Copper River, Delta, and Bering River), and later a combined Bering River and Delta sample was constructed and contrasted singly against the Copper River stock. A jackknife procedure was used to determine the power of the linear functions to classify correctly the origin of individual fish. For data taken in 1980, 81.6% of fish aged 1.2 and 65.9% of fish aged 1.3 are correctly classified as either Copper River or Delta-Bering fish, and when Bering River fish aged 1.3 are separated from other Delta fish aged 1.3, 53.3% are correctly classified into the three groups. For data taken in 1981, 87.1% of fish aged 1.3 are classified correctly as Copper River or Delta-Bering fish, and when Bering River fish are separated from other Delta fish, 75.5% are correctly classified into the three groups. For the 1976 brood year, the size of the freshwater growth zone is considerably larger for Copper River fish than for fish from other areas. For the 1975 brood year, the freshwater growth zones are similar among fish from different areas. For brood years when classification accuracy is good (1976, but not 1975), the technique can be used for in-season catch allocation of fish aged 1.3 based on discriminant functions built in the preceding year for aged 1.2, and post-season catch allocations can be made based on the current year age 1.3 classification models.

INTRODUCTION

Sockeye salmon *(Oncorhynchus nerka)* returning to the Copper and Bering River fishing districts are a mixutre of stocks from the upper Copper River drainage, from the Bering River, and from small watersheds in the Copper River Delta (Figure 1). Stocks from the upper Copper River can be divided into two runs, one which is intercepted by the subsistence fishery at the mouth of the Chitina River and one which is not (Roberson, personal communication). Stocks from the Delta are grouped into many runs: Eyak Lake, McKinley Lake, 27-Mile Slough, Martin River Slough, Clear Creek, Ragged Point Lake, Martin Lake, Little Martin Lake, and Tokun Lake. Stocks from the Bering River can be grouped into runs to Bering Lake, Kushtaka Lake, and Shepard Creek. Aerial surveys and sonar projects indicate that escapements to the Copper River are more numerous than to the Delta and to the Bering River. Based on historic commercial catch data age groups 1.2 and 1.3[1] are predominant in the fishery.

Because the commercial fishery harvests a mixture of stocks from the upper Copper River, Delta, and Bering River, fisheries managers want a technique of estimating the numbers of each of these three runs in the catch. In-season catch allocation may allow selective harvesting of these runs. Post-season catch apportionment coupled with escapement counts would provide estimates of total return by run by brood year, and could also provide information on the spatial and temporal distribution of the runs in the fishery.

Scale pattern analysis based on linear discriminant functions is one possible method for making in-season and post-season allocations of salmon catches. For instance, scale pattern analysis is used to allocate catches in Cook Inlet (Bethe and Krasnowski 1979; Bethe, Krasnowski, and Marshall 1980; Cross et al. 1981) and in Lynn Canal (Marshall, Bergander, and Sharr 1982). The purpose of this study was to test the feasibility of using this technique to identify major runs to the Copper-Bering River commercial fishery.

METHODS AND MATERIALS

Scale Sampling

Fish from the Chitina subsistence fishery, live fish captured on the spawning grounds, and spawned-out carcasses were sampled for scales for stock identification. One scale was collected from each fish from the left side of the body two rows above the lateral line on the diagonal scale row running from the posterior base of the dorsal fin to the anterior base of the anal fin. Scales were mounted on gum cards and impressions made in cellulose acetate. A limited number of otoliths were removed from carcasses and stored on standard plastic otolith trays. Sex and mid-eye to fork-of-tail length were recorded for each fish.

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[1] European Formula - Numerals preceding the decimal refer to the number of freshwater annuli, numerals following the decimal are the number of marine annuli. Total age is the sum of these two numbers plus 1.

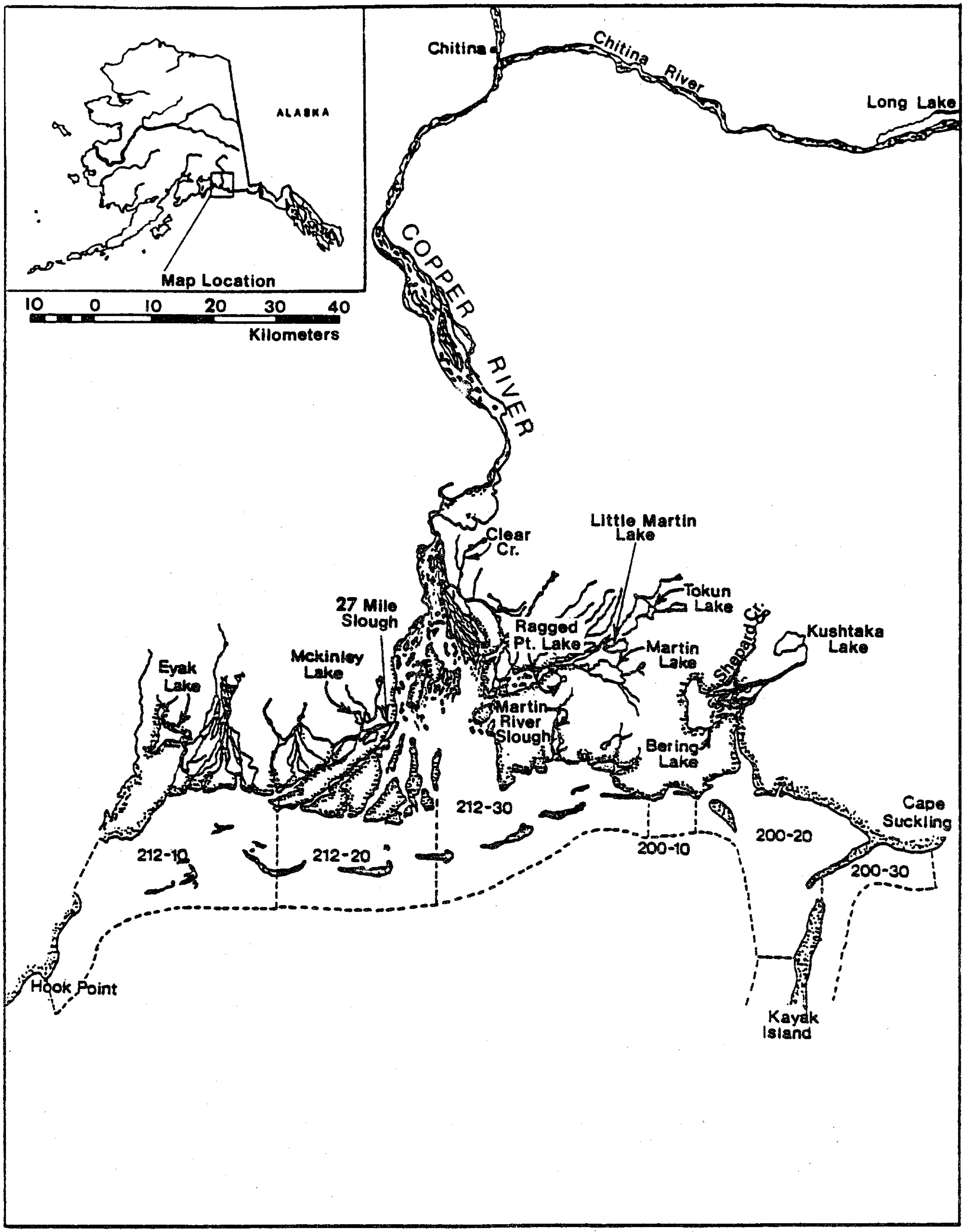

Figure 1. Prince William Sound showing the Copper River and Bering River fishing districts and the sampling locations of major runs of sockeye salmon.

Samples taken at the subsistence fishery at the mouth of the Chitina River are representative of all stocks in the upper Copper River except for stocks from Long Lake in the Chitina River drainage. The subsistence fishery on the Copper River downstream of its confluence with the Chitina River is conducted mostly on the west bank; fish headed for Long Lake orient to the east bank (Roberson, personal communication). In 1981 Long Lake fish sampled on the spawning ground; no sample from Long Lake is available for 1980.

In 1980 one Bering River and four Delta sockeye salmon runs were sampled on the spawning grounds; in 1981 five Delta and two Bering River runs were sampled. Appendix Table 1 provides a summary of the scale samples taken in the 1980 and 1981 field seasons.

Aging

Because resorption in the marine growth zones of some scales made distinguishing two-ocean and three-ocean aged fish very difficult, marine ages were subsequently determined with the Peterson method of length frequency analysis (Tesch 1970). To further substantiate the marine ages of individual fish, otolith samples taken in 1981 were magnified 20x using a dissecting scope and aged according to methods outlined by Kim and Roberson (1968).

Scale Pattern Measurements

Eleven measurements on each of five zones were made on each scale taken in 1980 from fish aged 1.2 and 1.3 and in 1981 from fish aged 1.2 (Figure 2, Table 1). Scale impressions were projected at 100x using equipment similar to that described by Bilton (1970) and modified by Ryan and Christie (1976).

Measurements were taken along the anterior-posterior axis of the scale. Within each zone, circuli were counted, and the distance between adjacent circuli measured. Counts and measurements were taken from the projected image using a Talos Digitizing Tablet connected to a Vector Graphics microcomputer.

Model Design

To test the power of discriminant analysis to distinguish fish from different runs, two-way and three-way models were constructed. Functions for two-way models were derived from standards of equal size that are comprised of selected scales from the Copper River group and from the combined data for the Delta and Bering River groups (Delta-Bering River). For three-way models, standards of equal size were selected for the Copper River, Delta, and Bering River. Inadequate numbers of measurable scales from fish aged 1.2 precluded a three-way model for 1980 data and any model for fish aged 1.2 in 1981.

When standards represent more than one run, the scales were selected according to estimates of run strength by age from escapement enumeration estimates (aerial surveys, sonar projects, or weirs), and from estimates of escapement age composition (Tables 2 and 3). For example, when the Delta-Bering River standard was constructed from the 1980 two-way age 1.2 analysis, 26, 14, 28, 20, and 7 scale samples were randomly selected from Eyak, McKinley, Martin, Tokun, and Bering Lakes scale samples respectively, to develop a 95 scale weighted

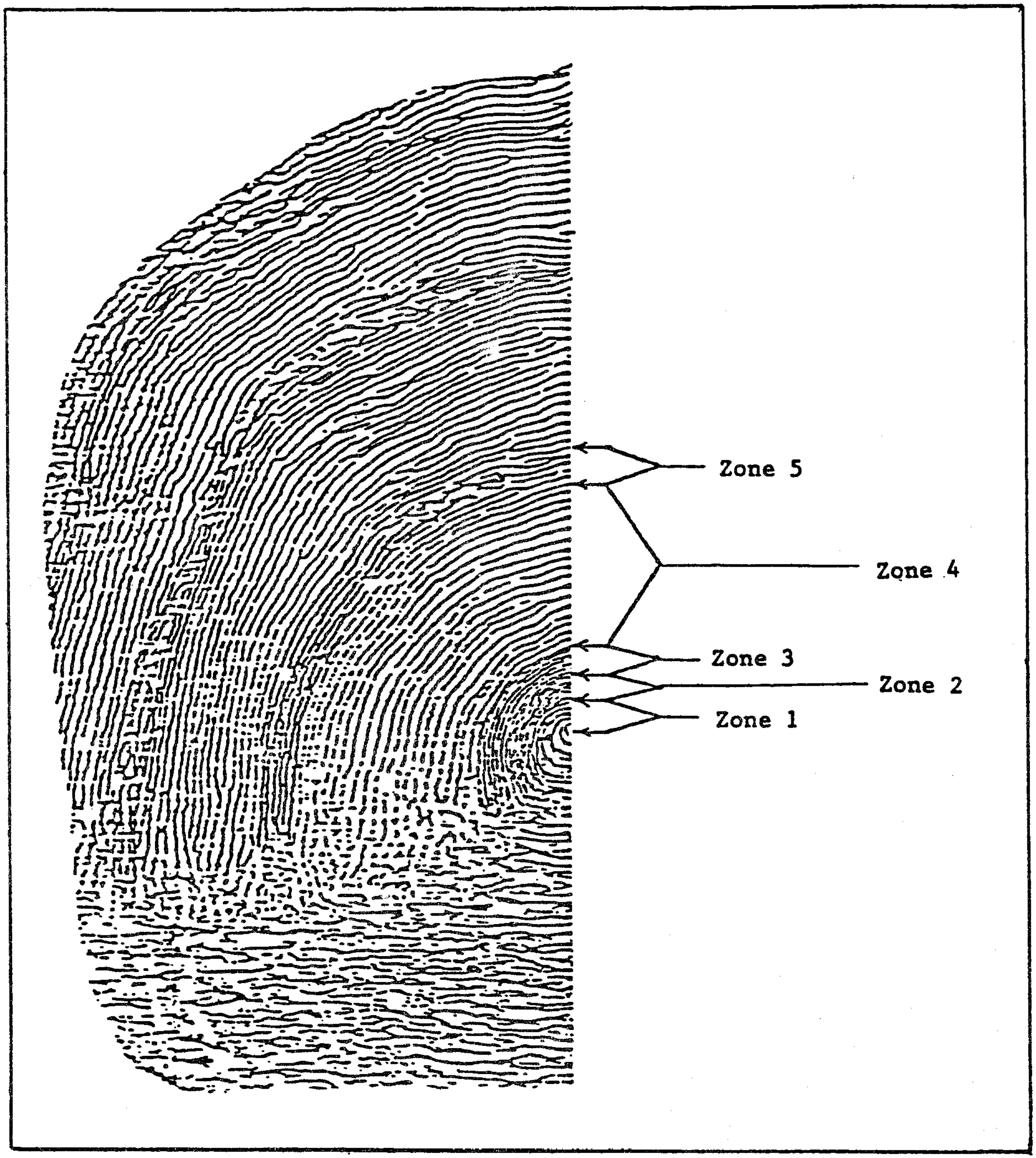

Figure 2. Scale from sockeye salmon aged 1.3 showing zones measured to generate the 55 variables used to build linear discriminate functions.

Table 1. Scale pattern variables used to build linear discriminant functions. Zones are measured along the anterior-posterior axis of the scale. Within each zone a total number of circuli are counted and the distances between pairs of adjacent circuli are measured. Distance measurements are recorded in hundredths of an inch. Transformations on the data measured in each zone generate the following variables.

*Two(n)	=	Distance from the beginning of the zone to the second circulus in the zone.
Four(n)	=	Distance from the beginning of the zone to the fourth circulus in the zone.
Six(n)	=	Distance from the beginning of the zone to the sixth circulus in the zone.
Eight(n)	=	Distance from the beginning of the zone to the eighth circulus in the zone.
Max(n)	=	Maximum distance between any two adjacent circuli in the zone.
Min(n)	=	Minimum distance between any two adjacent circuli in the zone.
Lmax(n)	=	Circuli count for the beginning of the zone to the location of Max(n).
Lmin(n)	=	Circuli count from the beginning of the zone to the location of Min(n).
NC(n)	=	Total circuli count across the zone.
ID(n)	=	Total distance across the zone.
NCH(n)	=	Number of circuli included in the first half of the zone.

* n = The number of the zone

Table 2. Escapement estimates for sampling sites and weighted standards for Copper River, Delta-Bering River, Delta and Bering River groups classified by two- and three-way models for sockeye salmon aged 1.2 and 1.3, 1980.

Two-Way Model for Fish Aged 1.2

Group	Sampling Site	Aerial Survey Index	Percent Fish Aged 1.2 in Sample	Number of Fish Aged 1.2 Returning	Percent of Group Total Return of Fish Aged 1.2	Weighted Sample Contributed to the Group
Copper River	Chitina	276,538	47.0	129,972	100.0	95
Total		276,538	47.0	129,972	100.0	95
Delta-Bering River	Eyak Lake	25,600	68.9	17,638	27.7	26
	McKinley Lake	30,700	31.2	9,578	15.0	14
	Martin Lake	21,150	88.3	18,675	29.4	28
	Tokun Lake	17,000	79.3	13,481	21.1	20
	Bering Lake	23,300	18.7	4,357	6.8	7
Total		117,750	51.7	63,729	100.0	95

Two-Way Model for Fish Aged 1.3

Group	Sampling Site	Aerial Survey Index	Percent Fish Aged 1.3 in Sample	Number of Fish Aged 1.3 Returning	Percent of Group Total Return of Fish Aged 1.3	Weighted Sample Contributed to the Group
Copper River	Chitina	276,538*	44.0	121,677	100.0	113
Total		276,538	44.0	121,677	100.0	113
Delta-Bering River	Eyak Lake	25,600	27.5	5,760	12.5	14
	McKinley Lake	30,700	64.4	19,771	43.0	49
	Martin Lake	21,150	7.0	1,481	3.2	4
	Tokun Lake	17,000	12.9	2,193	4.8	5
	Bering Lake	23,300	72.1	16,799	36.5	41
Total		117,750	40.7	46,004	100.0	113

Three-Way Model for Fish Aged 1.3

Group	Sampling Site	Aerial Survey Index	Percent Fish Aged 1.3 in Sample	Number of Fish Aged 1.3 Returning	Percent of Group Total Return of Fish Aged 1.3	Weighted Sample Contributed to the Group
Copper River	Chitina	276,538	100.0	129,972	100.0	102
Total		276,538	100.0	129,972	100.0	102
Delta	Eyak Lake	25,600	22.5	5,760	19.7	20
	McKinley Lake	30,700	64.4	19,771	67.7	69
	Martin Lake	21,150	7.0	1,481	5.1	5
	Tokun Lake	17,000	12.9	2,193	7.5	8
Total		94,450	30.9	29,205	100.0	102
Bering River	Bering Lake	23,300	72.1	16,799	100.0	102
Total						

Table 3. Escapement estimates for sampling sites and weighted standards for Copper River, Delta-Bering River, Delta and Bering River groups classified by two- and three-way models for sockeye salmon aged 1.2 and 1.3, 1981.

Two-Way Model for Fish Aged 1.3

Group	Sampling Site	Aerial Survey Index	Percent Fish Aged 1.3 in Sample	Number of Fish Aged 1.3 Returning	Percent of Group Total Return of Fish Aged 1.3	Weighted Sample Contributed to the Group
Copper River	Chitina	534,263	72.3	386,272	98.9	115
	Long Lake	12,687	33.3	4,187	1.1	1
Total		546,950	71.4	390,459	100.0	116
Delta-Bering River	Eyak Lake	17,150	66.5	11,405	15.0	17
	McKinley Lake	19,300	31.9	6,157	8.1	9
	Martin Lake	31,550	20.3	6,405	8.4	9
	Tokun Lake	8,500	41.6	3,536	4.6	6
	Clear Creek	11,000	59.9	6,589	8.6	10
	Bering Lake	53,300	72.4	38,589	50.7	59
	Kushtaka Lake	8,000	43.5	3,480	4.6	6
Total		140,300	54.3	76,161	100.0	116

Three-Way Model for Fish Aged 1.3

Group	Sampling Site	Aerial Survey Index	Percent Fish Aged 1.3 in Sample	Number of Fish Aged 1.3 Returning	Percent of Group Total Return of Fish Aged 1.3	Weighted Sample Contributed to the Group
Copper River	Chitina	534,263	72.3	386,272	98.9	115
	Long Lake	12,687	33.3	4,187	1.1	1
Total		546,950	71.4	390,459	100.0	116
Delta	Eyak Lake	17,150	66.5	11,405	33.5	36
	McKinley Lake	19,300	31.9	6,157	18.1	20
	Martin Lake	31,550	20.3	6,405	18.8	21
	Tokun Lake	8,500	41.6	3,536	10.4	11
	Clear Creek	11,000	59.9	6,589	19.3	21
Total		79,000	43.2	34,092	100.0	109
Bering River	Bering Lake	53,300	72.4	38,589	91.7	100
	Kushtaka Lake	8,000	43.5	3,480	8.3	9
Total		61,300	68.6	42,069	100.0	109

weighted standard (Table 2). Similarly in 1981, scale samples were randomly chosen from five separate runs to develop a 109 scale weighted standard for the three-way age 1.3 classification model (Table 3).

Stock identification models were constructed using stepwise linear discriminant function analysis (Dixon and Brown 1979) on combinations of circuli counts and inter-circuli distances. Only those variables normally distributed among scales were used to build discriminant functions.

A jackknife procedure[2] was used to determine how accurately the discriminant functions assign sampled fish to the Copper River versus the Delta-Bering River combined sample in two-way analysis and how accurately it assigned fish to the Copper River, Delta, and Bering River in three-way analysis. The F level for the stepwise procedure was set at 4.0.

Appendix Tables 2 through 6 list the means and standard deviations for all variables included in each set of standards used in the 1980 and 1981 analyses.

RESULTS

Scale pattern analysis based on linear discriminant functions was used for possible identification of the different salmon stocks.

Selection of Variables

Frequency histograms of measurements show that variables SIX1, EIGHT1, FOUR2, SIX2, EIGHT2, FOUR3, SIX3, EIGHT3, SIX5, and EIGHT5 are not normally distributed for both years and that in 1981 three additional variables (FOUR1, LMAX1, and FOUR5) are also not normally distributed.

The distance across the first freshwater summer scale growth zone (ID1) is a strong discriminant variable in 1981 for the 1976 brood year but not in 1980 for the 1975 brood year (Tables 4 and 5). The variable ID1 (F=116.53, Table 4) provides the most power of the three variables selected in the two-way model for fish aged 1.2 in 1980 (the 1976 brood year). The mean value for ID1 is considerably higher for the Copper River fish indicating more growth during their first summer than fish from the Delta-Bering River group. The F values for variables selected in the models for fish aged 1.3 in 1980 (the 1975 brood year) are much lower (Table 4). Of the three variables selected in the two-way model for age group 1.3 the number of circuli in the first half of the first summer growth zone (NCH1)(F=23.54) is most important, and of the seven selected in the three-way model, the number of circuli in the freshwater winter growth zone NC2 (F=26.45) and NCH1 (F=16.96) are most important.

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[2] A jackknife procedure works as follows: (1) for standards with n fish, one fish is selected and a discriminant function is built on information from the remaining $n-1$ scales, (2) the selected scale is assigned to a group with the discriminant function, and (3) the procedure is repeated n times with a different scale selected each time to find the percentage fish correctly assigned an origin.

Table 4. Means and standard deviations of all variables chosen by the linear discriminant analysis stepwise selection procedure, 1980.

Two-way model - Age group 1.2

Variable	F Value	Copper River Mean	Copper River SD	Delta-Bering Mean	Delta-Bering SD
ID1	116.54	135.14	29.08	97.79	17.07
ID5	5.96	73.91	14.88	71.65	11.39
NC1	7.23	9.92	2.46	6.83	1.33

Two-way model - Age group 1.3

Variable	F Value	Copper River Mean	Copper River SD	Delta Mean	Delta SD
NCH1	23.54	2.90	1.34	2.16	0.92
LMIN4	11.93	8.29	6.97	10.21	7.26
LMAX5	11.47	2.72	1.78	3.47	2.13

Three-way model - Age group 1.3

Variable	F Value	Copper River Mean	Copper River SD	Delta Mean	Delta SD	Bering River Mean	Bering River SD
NC2	26.45	3.41	0.97	3.33	1.04	4.29	1.13
NCH1	16.96	2.89	1.33	2.24	0.92	2.07	0.76
TWO1	5.67	40.96	7.94	45.10	6.27	43.41	5.99
TWO3	4.91	16.75	8.04	19.38	6.79	19.55	4.65
NC4	4.39	19.54	3.47	20.01	2.82	21.31	2.49
FOUR1	4.19	66.91	11.59	70.86	8.93	70.13	7.37
TWO1	3.74	40.96	7.94	45.10	6.27	43.41	5.99

Table 5. Means and standard deviations of all variables chosen by the linear discriminant analysis stepwise selection procedure, 1981.

Two-way model - Age group 1.3

Variable	F Value	Copper River Mean	Copper River SD	Delta-Bering Mean	Delta-Bering SD
ID1	195.18	124.92	25.05	85.34	17.42
MIN1	20.50	8.72	1.85	7.41	1.59
ID4	9.02	302.95	54.00	347.53	42.51
MAX1	6.17	29.78	4.85	28.37	5.23
MIN2	4.85	6.99	2.10	5.93	1.28
NC5	4.72	6.47	1.37	6.22	1.06

Three-way model - Age group 1.3

Variable	F Value	Copper River Mean	Copper River SD	Delta Mean	Delta SD	Bering River Mean	Bering River SD
ID1	145.25	125.28	24.29	88.79	17.72	83.16	16.53
NC1	20.44	8.74	1.35	6.26	1.44	6.52	1.44
ID2	13.28	36.19	9.79	28.15	6.92	33.33	6.93
ID4	11.21	304.82	50.69	346.08	47.02	350.31	44.17
MAX1	6.99	29.64	4.73	29.89	4.51	27.55	5.24
NC5	5.17	6.53	1.29	6.37	1.17	5.98	1.27
ID3	6.85	38.12	34.13	52.69	19.83	44.61	19.03
NC4	4.69	18.39	2.98	20.49	2.71	21.17	2.73
TWO2	4.02	18.17	4.14	14.95	2.79	15.15	2.89
LMAX3	4.10	2.38	1.29	2.88	1.58	3.19	1.65

In the 1981 models for fish aged 1.3 (the 1976 brood year), ID1 is again the single most important variable of the six selected in the two-way model and the ten selected in the three-way model (Table 5). The F values for ID1 are high in both models (195.18 and 145.25, respectively) and mean values for ID1 again indicate more growth during their first summer for Copper River fish than for fish from the other two groups.

Classification Accuracy

For data taken in 1980, fish aged 1.2 (1976 brood year), classify in the two-way model with much greater accuracy than fish aged 1.3 or 1975 brood year (Table 6). The Copper River vs Delta-Bering River two-way model classifies fish from the 1976 brood year with an overall accuracy of 81.4%; fish from the 1975 brood year with an overall accuracy of 65.9%. Delta-Bering River fish classify more accurately (87.4%) than Copper River fish (75.8%) from the 1976 brood year; the two groups classify with almost equal accuracy for the 1975 brood year (64.6 and 67.3%). The Copper River vs Delta vs Bering River three-way model for fish from the 1975 brood year achieves an overall accuracy of 53.3%. Classification accuuracies are highest for the Bering River and Copper River groups, respectively, and fish from these two groups most frequently misclassify as Delta fish.

For data taken in 1981, fish aged 1.3 (1976 brood year), classify correctly 87.1% overall in a two-way Copper River vs Delta-Bering model, and 75.5% overall in a three-way Copper River vs Delta vs Bering River model (Table 7). Delta-Bering fish classify correctly (91.4%) more often than Copper River fish (82.8%) in the two-way model but, in the three-way model Copper River fish classify correctly most often (80.7%). The three-way model misclassifies Copper River fish equally to the Delta and Bering River groups, Delta fish most frequently to the Bering River group, and Bering River fish most frequently to the Delta group.

DISCUSSION

For some brood years, catches of sockeye salmon made in the Copper-Bering River fishery can be allocated to their destinations with linear discriminant analysis of scale patterns. Models based on escapement samples from the 1976 brood year can be used with confidence to identify fish aged 1.2 sampled in the 1980 commercial catch and fish aged 1.3 sampled in the 1981 commercial catch. However, classification accuracy for models based on fish returning from the 1975 brood year are low and cannot be used with much confidence to allocate fish aged 1.3 from the 1980 commercial catch.

The accuracy with which models classify fish from Copper River, Delta, and Bering River is directly related to differences in the growth of fry in the rearing areas for the three groups. The variable ID1 is a measure of scale growth for a fish during its first freshwater summer. For the 1976 brood year, ID1 is the most discriminating variable, and values of ID1 are much higher for fish from the Copper River. But for the 1975 brood year, ID1 had little if any discriminating power, and values of ID1 are about the same for fish from all areas. Diminished differences result from decreased growth in the Copper River and greater first summer's growth in the Delta and Bering River. Relative differences in first summer's growth in Delta vs Bering River fish are about the same for fish from both brood years.

Table 6. Classification accuracies for linear discriminant functions, 1980.

Two-way model - Age group 1.2

Group	Percent correct	Number of cases classified into groups	
		Copper River	Delta-Bering
Copper River	75.8	72	23
Delta-Bering	87.4	12	83

Overall accurracy = 81.6

Two-way model - Age group 1.3

Group	Percent correct	Number of cases classified into groups	
		Copper River	Delta-Bering
Copper River	64.6	73	40
Delta-Bering	67.3	37	76

Overall accurracy = 65.9

Three-way model - Age group 1.3

Group	Percent correct	Number of cases classified into groups		
		Copper River	Delta	Bering River
Copper River	52.0	53	33	16
Delta	40.2	27	41	34
Bering River	67.6	12	21	69

Overall accurracy = 53.3

Table 7. Classification accuracies for linear discriminant functions, 1981.

Two-way model - Age group 1.3

Group	Percent correct	Number of cases classified into groups	
		Copper River	Delta-Bering
Copper River	82.8	96	20
Delta-Bering	91.4	10	106

Overall accurracy = 87.1

Three-way model - Age group 1.3

Group	Percent correct	Number of cases classified into groups		
		Copper River	Delta	Bering River
Copper River	80.7	88	12	9
Delta	70.6	9	77	23
Bering River	75.2	4	23	82

Overall accurracy = 75.5

Weather directly affects limnological conditions and may have a strong influence on fry growth in the first summer. Summers with infrequent cloud cover, low precipitation, and small departures from the norm are typical of interior Alaska where fish from the Copper River rear. Summers with frequent cloud cover, high precipitation, and often large departures from the norm are typical for Delta and Bering River. Differences such as these may explain in part the greater growth in Copper River fish in the first summer and suggest greater fluctuations in first summer's growth might be expected for Delta-Bering River fish, but 2 years do not make a trend. A time series of scale growth and weather data for future investigation is needed to test the relationship between weather and first-year growth.

When discriminant models are accurate, they can be used to make post-season allocations of catch and estimates of returns. First, catches of single age group are allocated with linear discriminant models, and secondly, catches of other age groups are allocated with estimated age compositions of catch and escapement (Cross et al. 1973). A catch allocation of all age groups, escapement counts, aerial surveys, and estimates of the age composition of escapements can be fused to estimate total return to the Copper River, the Delta, and the Bering River. As long as the fishery manager is confident of the models for the brood years in the fishery, a post-season allocation can be made. Such allocations can be made for the catch in 1980 and 1981 because the models for the 1976 brood year are accurate.

Because accurate models for fish of the same brood year have the same freshwater variables and similar accuracy, in-season allocation of catches for that brood year are possible. In-season allocation is often not feasible because the fish sampled for escapement standards used to build models do not arrive on the spawning grounds until well past the peak of the fishery and because historical models based on younger fish from the same brood year will have different variables and accuracies. In the Copper River fishery, models for fish aged 1.2 can be used a year later to allocate catches within the fishing season for fish aged 1.3 when these models are highly accurate. Also, if the previous year's models for fish aged 1.2 are accurate, the manager can change his or her catch sampling procedures to procure scale samples appropriate for the in-season allocation of catches. In-season allocation of catches could have been made in 1981, but not in 1980, because the 1976 brood year has accurate models and the 1975 brood year does not.

RECOMMENDATIONS

Start a program to allocate catches in the Copper-Bering River fishery with scale pattern analysis. Build linear discriminate functions on measurements from scales taken on the spawning grounds, then apply them to scales sampled from the fishery. Build models for fish aged 1.2 and for fish aged 1.3 in all years. For a post-season allocation, use models built in the same year the catches are made. For an in-season allocation, use models built in the previous year for a younger age group in the same brood year. For those age groups with poor or no models, allocate catches based on the age composition of the escapements and allocations with strong models of other age groups.

Sample at least 300 fish each fishing period to begin the program. After a few years, determine the rapidity with which the run composition of the catch changes and alter the sampling frequency accordingly. If an allocation of catch within a part of a fishing district is desired, sample at least 300 fish for each period from each part (subdistrict, entrance, etc.).

To improve the accuracy and precision of the linear discriminant functions, I recommend the following:

1) When sampling carcasses, remove some otoliths. Degeneration of scales makes distinguishing fish of differing ocean ages very imprecise. A length-frequency model checked against otolith ages can provide an accurate, rapid means of determining ocean age. Ideally, collect 300 otoliths from each spawning ground.

2) When sampling live fish, take at least 600 (800 is better) scales from each spawning ground. Resorption of scales makes distinguishing fish of different ocean ages very imprecise. Six hundred samples should ensure enough legible scales to estimate the age composition with good accuracy and precision.

3) Because Martin River Slough, Ragged Point Lake, Little Martin Lake, Shepard Creek, and 27-Mile Slough make significant contributions to the Delta-Bering River run, sample fish from these areas in the future.

4) Stratify the samples from the subsistence fishery at Chitina into early, middle, and late to better represent the run to the upper Copper River. Because the migratory timing of groups of stocks through the fishery varies little from year to year (Merritt and Roberson 1983), stratified sampling will cover each major group of stocks in the escapement to the Copper River. Also, investigate the possibility that stratifying samples from other runs will increase the accuracy of scale pattern analysis.

6) Build a time-series data base of weather and scale patterns for Copper River and Delta-Bering River areas.

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APPENDICES

Appendix Table 1. Number of sockeye salmon sampled[1] by age group at each site, 1980 and 1981.

Sampling Site	Sample Sizes Age 1.2	Age 1.3	Other	Total
1980 Samples				
Chitina	238	503	133	874
Eyak Lake	208	68	26	302
McKinley Lake	92	190	13	295
Martin Lake	264	21	14	299
Tokun Lake	233	38	23	294
Bering Lake	51	196	25	272
1981 Samples				
Chitina	43	266	110	419
Long Lake	166	87	43	296
Eyak Lake *	290	427	83	400
McKinley Lake	155	98	100	353
Martin Lake	194	75	131	299
Tokun Lake	99	138	163	400
Clear Creek	73	182	105	360
Bering Lake	67	293	80	440
Kushtaka Lake	110	150	140	400

[1] Samples taken at Hatchery Creek.

Appendix Table 2. Means and standard deviations of scale pattern variables computed for sockeye salmon aged 1.2 and used in the Copper River vs Delta-Bering River model, 1980.

Variable	Copper River		Delta-Bering River	
	Mean	Standard Deviation	Mean	Standard Deviation
TWO1	41.10	7.85	43.97	5.95
FOUR1	67.24	11.64	69.56	10.24
MAX1	28.47	6.50	30.57	4.98
MIN1	7.52	2.05	7.77	1.59
LMAX1	1.06	0.41	1.00	0.00
LMIN1	7.47	3.25	6.45	2.26
NC1	8.97	2.85	7.66	2.03
ID1	120.28	36.23	107.31	25.55
NCH1	2.90	1.34	2.16	0.92
TWO2	15.26	3.16	15.93	3.69
MAX2	9.62	1.54	9.70	1.71
MIN2	6.11	1.51	5.92	1.71
LMAX2	2.20	1.16	2.12	1.26
LMIN2	2.06	1.06	2.23	1.27
NC2	3.42	0.94	3.68	1.12
ID2	26.10	6.99	27.89	8.20
NCH2	1.34	0.59	1.36	0.73
TWO3	16.90	7.92	18.63	7.08
MAX3	12.66	3.42	13.12	2.87
MIN3	8.43	2.60	8.36	2.14
LMAX3	2.44	1.86	2.71	1.79
LMIN3	1.95	2.03	2.09	1.52
NC3	3.43	2.56	4.09	2.21
ID3	36.38	36.19	43.20	24.47
NCH3	1.75	4.78	1.63	1.09
TWO4	29.21	6.38	29.58	5.09
FOUR4	61.60	11.03	61.06	7.57
SIX4	95.15	17.53	94.17	10.44
EIGHT4	129.33	21.50	127.94	11.67
MAX4	23.50	3.59	24.76	13.16
MIN4	10.17	1.89	9.79	1.61
LMAX4	8.15	4.93	8.58	4.74
LMIN4	8.29	6.96	10.21	7.26
NC4	19.60	3.42	20.39	2.69
ID4	318.80	54.59	326.23	43.34
NCH4	9.20	1.92	9.56	1.36
TWO5	25.84	4.00	24.91	4.32
FOUR5	50.24	7.74	48.61	6.14
MAX5	15.73	2.95	15.55	2.33
MIN5	9.70	1.80	9.50	1.57
LMAX5	2.72	1.77	3.47	2.13
LMIN5	3.26	1.55	3.17	1.73
NC5	5.81	1.24	6.09	1.09
ID5	73.74	15.18	74.08	12.34
NCH5	2.93	4.52	2.56	0.64

Appendix Table 3. Means and standard deviations of scale pattern variables computed for sockeye salmon aged 1.3 and used in the Copper River vs Delta-Bering River model, 1980.

Variable	Copper River		Delta-Bering River	
	Mean	Standard Deviation	Mean	Standard Deviation
TWO1	44.79	7.43	43.48	5.98
FOUR1	71.99	11.01	69.14	7.88
MAX1	31.20	5.78	30.13	5.10
MIN1	7.69	1.56	8.22	1.83
LMAX1	1.06	0.43	1.04	0.41
LMIN1	7.45	3.00	5.52	1.82
NC1	9.91	2.46	6.83	1.33
ID1	135.14	29.08	97.79	17.87
NCH1	3.19	1.16	1.97	0.75
TWO2	15.65	3.48	14.74	3.52
MAX2	9.57	1.64	9.21	1.66
MIN2	6.26	1.61	6.16	1.85
LMAX2	1.89	1.09	1.82	1.02
LMIN2	2.22	0.98	1.93	0.96
NC2	3.55	0.95	3.24	0.96
ID2	27.65	7.65	23.93	6.46
NCH2	1.28	0.52	1.17	0.56
TWO3	16.08	8.60	19.98	7.56
MAX3	12.76	3.19	13.97	2.73
MIN3	9.13	2.57	8.94	2.47
LMAX3	2.18	1.36	2.36	1.17
LMIN3	1.43	0.74	1.91	1.31
NC3	2.91	1.75	3.79	1.67
ID3	30.97	19.03	42.57	18.31
NCH3	1.63	5.11	1.48	0.89
TWO4	30.86	5.58	28.17	4.62
FOUR4	65.63	10.07	60.92	7.73
SIX4	102.09	12.62	96.32	10.58
EIGHT4	138.38	14.89	132.21	11.85
MAX4	24.37	3.10	23.67	3.03
MIN4	10.56	1.93	10.24	1.70
LMAX4	8.41	4.73	8.61	4.59
LMIN4	10.08	7.60	9.22	7.49
NC4	20.52	2.70	20.64	3.02
ID4	344.93	45.90	336.47	49.41
NCH4	9.56	1.49	9.57	1.57
TWO5	26.25	4.69	27.03	3.29
FOUR5	52.16	8.83	52.56	5.47
MAX5	15.81	2.71	16.24	1.83
MIN5	10.31	2.11	10.07	1.67
LMAX5	3.06	1.84	2.59	1.63
LMIN5	3.18	1.75	3.26	1.49
NC5	5.66	1.25	5.47	0.89
ID5	73.91	14.88	71.65	11.39
NCH5	2.91	4.93	2.21	0.54

Appendix Table 4. Means and standard deviations of scale pattern variables computed for sockeye salmon aged 1.3 and used in the Copper River vs Delta vs Bering River model, 1981.

Variable	Copper River		Delta		Bering River	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
TWO1	40.96	7.94	45.10	6.27	43.41	5.99
FOUR1	66.91	11.59	70.86	8.93	70.12	7.37
MAX1	28.41	6.47	31.14	5.24	30.24	5.12
MIN1	7.49	2.10	7.72	1.79	7.69	1.66
LMAX1	1.06	0.42	1.00	0.00	1.01	0.10
LMIN1	7.38	3.23	6.58	2.10	6.13	1.96
NC1	8.93	2.82	7.76	1.92	7.43	1.58
ID1	119.42	35.94	109.99	25.94	103.58	17.79
NCH1	2.89	1.33	2.24	0.92	2.07	0.76
TWO2	15.21	3.17	15.27	3.94	15.20	2.93
MAX2	9.65	1.57	9.47	1.74	9.64	1.58
MIN2	6.13	1.49	6.35	1.77	5.71	1.37
LMAX2	2.22	1.18	1.80	1.02	2.33	1.36
LMIN2	2.00	1.06	2.00	1.04	2.55	1.34
NC2	3.41	0.97	3.33	1.04	4.29	1.13
ID2	26.02	7.12	25.48	7.12	31.77	7.89
NCH2	1.33	0.60	1.17	0.65	1.63	0.64
TWO3	16.75	8.04	19.38	6.79	19.55	4.65
MAX3	12.67	3.43	13.36	2.96	12.94	2.29
MIN3	8.38	2.68	8.70	2.18	7.95	2.04
LMAX3	2.43	1.89	2.79	1.77	2.67	1.41
LMIN3	2.02	2.12	2.03	1.47	2.25	1.42
NC3	3.48	2.65	3.93	1.95	4.21	1.55
ID3	36.77	37.60	42.82	22.67	42.90	15.70
NCH3	1.82	5.02	1.56	1.05	1.66	0.85
TWO4	29.10	6.22	29.91	6.01	29.61	5.50
FOUR4	60.94	10.57	62.07	9.44	61.35	8.01
SIX4	94.36	17.25	94.57	11.70	93.75	10.70
EIGHT4	128.32	21.14	127.82	13.32	127.88	12.61
MAX4	23.41	3.57	25.19	13.91	23.30	2.75
MIN4	10.08	1.80	9.82	1.64	9.52	1.70
LMAX4	7.83	4.53	7.50	4.06	9.35	4.97
LMIN4	8.01	6.92	9.89	6.84	10.38	8.44
NC4	19.53	3.47	20.01	2.82	21.31	2.49
ID4	316.14	55.48	319.24	45.11	339.04	42.68
NCH4	9.17	1.92	9.32	1.52	9.92	1.25
TWO5	25.73	4.03	25.71	4.72	24.77	3.94
FOUR5	49.75	7.46	49.25	6.25	48.27	6.08
MAX5	15.59	2.77	15.96	2.75	21.27	60.41
MIN5	9.62	1.76	9.50	1.58	9.40	1.72
LMAX5	2.73	1.81	2.93	2.01	3.55	2.12
LMIN5	3.29	1.53	3.18	1.64	3.36	1.84
NC5	5.86	1.24	6.02	1.05	6.21	1.01
ID5	73.85	14.76	74.29	11.38	80.96	60.75
NCH5	3.00	4.75	2.54	0.70	2.65	0.61

Appendix Table 5. Means and standard deviations of scale pattern variables computed for sockeye salmon aged 1.3 and used in the Copper River vs Delta-Bering River model, 1981.

Variable	Copper River		Delta-Bering River	
	Mean	Standard Deviation	Mean	Standard Deviation
TWO1	43.94	5.77	40.44	6.42
MAX1	29.78	4.85	28.37	5.23
MIN1	8.72	1.85	7.41	1.59
LMIN1	6.95	2.57	5.23	1.84
NC1	8.71	2.07	6.36	1.33
ID1	124.92	25.05	85.34	17.42
NCH1	2.82	0.94	1.66	0.72
TWO2	18.10	4.14	15.33	2.87
MAX2	11.31	2.45	9.84	1.92
MIN2	6.99	2.10	5.93	1.28
LMAX2	2.54	1.49	2.48	1.44
LMIN2	2.36	1.48	2.36	1.15
NC2	4.12	1.40	4.35	1.05
ID2	35.78	9.73	32.44	7.21
NCH2	1.65	0.69	1.72	0.63
TWO3	21.22	7.69	20.06	5.27
MAX3	14.71	3.40	13.98	2.47
MIN3	9.90	3.44	8.51	1.86
LMAX3	2.48	1.43	3.19	1.76
LMIN3	1.71	1.29	2.22	1.56
NC3	3.39	2.64	4.47	1.98
ID3	41.51	44.05	49.12	21.69
NCH3	1.36	1.35	1.89	1.11
TWO4	33.09	5.72	30.19	5.03
FOUR4	67.42	7.92	64.26	8.32
SIX4	103.14	10.14	100.90	11.12
EIGHT4	137.00	21.50	137.25	13.70
MAX4	23.73	3.39	24.17	2.82
MIN4	10.89	1.56	10.51	1.71
LMAX4	7.03	4.68	8.65	4.75
LMIN4	9.75	6.47	10.78	7.52
NC4	18.26	3.13	20.83	2.49
ID4	302.95	54.00	347.53	42.51
NCH4	8.24	1.55	9.60	1.35
LMAX5	3.59	2.31	3.41	2.04
LMIN5	3.09	1.69	3.02	1.53
NC5	6.47	1.37	6.22	1.06
ID5	85.20	16.83	81.66	13.32

Appendix Table 6. Means and standard deviations of scale pattern variables computed for sockeye salmon aged 1.3 and used in the Copper River vs Delta vs Bering River model, 1981.

Variable	Copper River		Delta		Bering River	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
TWO1	43.77	5.70	42.54	5.38	39.24	6.05
FOUR1	29.64	4.73	29.89	4.51	27.55	5.24
MIN1	8.72	1.85	7.97	1.69	7.03	1.46
LMIN1	7.04	2.57	4.93	1.86	5.21	1.73
NC1	8.74	2.00	6.26	1.44	6.52	1.35
ID1	125.28	24.29	88.79	17.72	83.16	16.53
NCH1	2.86	0.90	1.66	0.78	1.67	0.72
TWO2	18.17	4.14	16.95	2.79	15.15	2.89
MAX2	11.29	2.48	9.61	1.75	9.50	1.88
MIN2	6.90	2.11	5.98	1.33	5.89	1.33
LMAX2	2.51	1.52	2.27	1.30	2.41	1.49
LMIN2	2.49	1.51	2.06	1.03	2.55	1.27
NC2	4.19	1.40	3.71	0.97	4.56	0.96
ID2	36.19	9.79	28.15	6.92	33.33	6.93
NCH2	1.66	0.71	1.45	0.59	1.85	0.61
TWO3	21.00	7.68	21.51	5.70	19.21	4.91
MAX3	14.65	3.25	14.28	2.13	13.46	2.40
MIN3	9.88	3.51	9.15	1.92	8.07	1.84
LMAX3	2.38	1.29	2.88	1.58	3.19	1.65
LMIN3	1.66	1.27	2.34	1.56	1.97	1.40
NC3	3.19	2.23	4.57	1.69	4.21	1.77
ID3	38.12	34.13	52.69	19.83	44.61	19.03
NCH3	1.27	1.16	1.89	0.93	1.81	1.00
TWO4	33.05	5.87	31.42	5.31	29.30	5.48
FOUR4	67.49	8.08	66.15	8.68	63.06	8.94
SIX4	103.21	10.42	102.93	11.66	99.21	11.20
EIGHT4	137.84	17.70	139.06	14.08	135.39	13.53
MAX4	23.87	3.35	25.45	11.54	24.28	2.97
MIN4	10.83	1.56	10.64	1.75	10.19	1.96
LMAX4	7.09	4.80	8.78	4.93	8.72	4.83
LMIN4	9.60	6.50	10.70	7.24	10.02	7.56
NC4	18.39	2.98	20.49	2.71	21.17	2.73
ID4	304.82	50.69	346.08	47.02	350.31	44.17
NCH4	8.30	1.49	9.47	1.46	9.83	1.48
LMAX5	3.64	2.29	3.61	2.20	3.35	2.07
LMIN5	3.12	1.68	3.12	1.71	3.10	1.69
NC5	6.53	1.29	6.37	1.17	5.98	1.27
ID5	85.82	14.88	82.22	14.19	78.45	15.15