Agenda Item 10, b
September 1978

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INVESTIGATIONS ON THE CONTINENTAL ORIGIN OF SOCKEYE AND COHO SALMON IN THE AREA OF THE JAPANESE LAND-BASED FISHERY

by

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Quarterly Report No. 3
Due 27 July 1978
North Pacific Fisheries Management Council

Approved:

Submitted: ____________________

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INTRODUCTION

Third quarter (28 April 1978 - 27 July 1978) activities concentrated on preparing a comprehensive report on the fishery (Task 1) and on reading sockeye salmon scales for use in the polynomial discriminant function (PDF) analysis (Task 2). The feasibility of applying the PDF technique to coho salmon scales (Task 3) is temporarily stalled while we await replies to our inquiries of available data for years prior to 1972 and after 1975. Completion of a review of Osako's (1975) paper (Task 4) is scheduled for the fourth quarter. A cost estimate for conducting an intensive three year study in the area of the land-based fishery (Task 5) was reported last quarter.

The purpose of this report is to summarize the methods we are employing to apply the PDF technique to the identification of sockeye salmon intercepted by the Japanese land-based fishery.

REPORT ON METHODS AND FINAL DATA COLLECTION

Scales of sockeye salmon record the growth pattern of the fish, and Mosher (1968) has summarized typical patterns. One to three freshwater growth zones and one to four oceanic growth zones are common, and each zone represents a year's growth (Fig. 1). In addition, a zone of plus or intermediate growth may be present between the freshwater and oceanic zones on some scales; this zone corresponds to growth realized in the year of seaward migration. The use of scales for identifying the racial origins of sockeye salmon depends upon the genetic similarity of a local (or regional) stock of fish acting in conjunction with local (or regional) environmental conditions to produce differences in scale patterns on a local (or regional) basis. Generally, multivariate statistical analysis are used to identify these patterns.

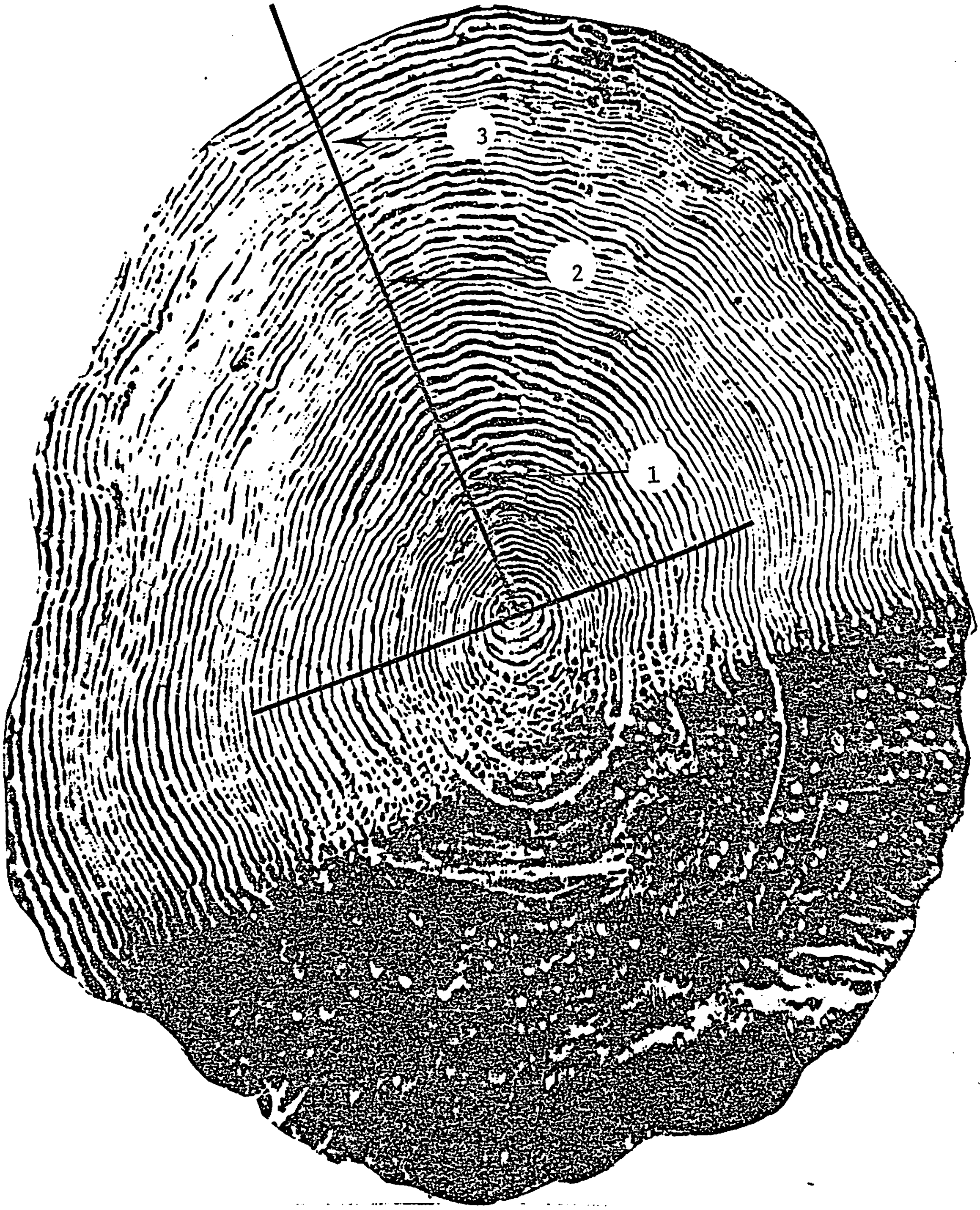

Figure 1. Photograph of age 2.2 sockeye salmon. Line perpendicular to sculptured field illustrates radius along which measurements and counts were made. Arrow No. 1 marks the end of the freshwater zone, Nos. 2 and 3 indicate the end of the first and second ocean zones.

The analytic method

Discriminant function analyses have been used extensively to identify salmon stocks in mixed fisheries. These analyses have been relatively successful because the theory is readily applicable. Early studies by Fukuhara et al. (1962), Amos et al. (1963), Dark and Landrum (1964), Anas (1964), and Mason (1966) used linear discriminant functions with either morphological or scale measurement data. Anas and Murai (1969) used linear and quadratic discriminant functions. Recent studies by Major et al. (1975) and Bilton and Messinger (1975) used unspecified discriminant function techniques. Krasnowski and Bethe (1978) used linear functions. Cook and Lord (1978) applied Specht's (1966) polynomial discriminant function to scale characters and developed a method to correct for classification error rates.

Linear models (Fisher, 1936) assume that the data are multivariate normal with common variance-covariance matrices. Issacson (1954) showed that the assumption of common variance-covariance matrices may be violated when large sample sizes are used. This was confirmed by Anas and Murai (1969). Quadratic models (Smith, 1947) require only that the data be multivariate normal. The polynomial model (Specht, 1966) assumes no underlying distribution. We chose this method as applied by Cook and Lord (1978) because it is distribution-free and because it also performs efficiently with normal data (Specht, 1966). The reader is referred to Specht (1966) and Cook and Lord (1978) for detailed information regarding the analytic procedures. The form of the polynomial discriminant function is:

$$P(x) = D_o + D_1X_1 + D_2X_2 + \ldots + D_pX_p + D_{11}X_1^2 + \ldots + D_{k_1k_2}X_{k_1}X_{k_2} + \ldots$$
$$+ D_{pp}X_p^2 + D_{111}X_1^3 + \ldots + D_{k_1k_2k_3}X_{k_1}X_{k_2}X_{k_3} + \ldots + D_{ppp}X_p^3 + \ldots$$
$$+ D_{k_1 \ldots k_j \ldots k_h}X_{k_1} \ldots X_{k_j} \ldots X_{k_h} \ldots + \ldots,$$

where $1 \leq k_j \leq p$ (k_j = an integer)

$j = 1, 2, \ldots h$

h = the degree of the variable portion of the term.

Three scale sample sets are required to implement the polynomial discriminant method: learning samples, test samples, and unknown samples. The learning and testing samples are collected from each stock when they are segregated (i.e., in the regions of origin). Scale characters to be measured in the unknown sample for the required discrimination are determined by evaluating characters measured in the learning samples. The learning samples and the characters selected are used to calculate the coefficients in the polynomial discriminant functions. The fish comprising the test samples are classified to test the effectiveness of the method, to determine the a priori probablities, and to estimate the classification error rates. Finally, samples collected from the zone of intermingling are classified to determine the racial origins in the area(s) of interest.

These classification results and the composition of the unknown population are not always directly comparable. To make unbiased estimates of the proportion of each stock present in the unknown population, one must correct for classification error rates. This is done with the classification matrix procedure (Cook and Lord, 1978):

$$\hat{U} = (\hat{C})^{-1}\hat{R}$$

where $\hat{U}$ is a vector, the ith element of which is the estimated proportion of class i in the unknown population,

$\hat{C}$ is a matrix where the ijth element is the fraction of the test sample classified as class i that actually belongs to class j,

and $\hat{R}$ is a vector, the ith element of which is the proportion of the unknown sample that classified as class i.

The estimates thus obtained have a variance dependent upon 1) the unknown sample size, 2) the test sample sizes, and 3) the classification accuracy:

$$\text{est. var. } (\hat{U}_i) = \frac{\hat{u}_i(1-\hat{u}_i)}{N_u} + \frac{2\,\hat{u}_i^2\, c_{ii}(1-c_{ii})}{N_i\,(c_{ii}-c_{ij})^2} + \frac{2\,\hat{u}_j^2\, c_{ij}(1-c_{ij})}{N_j\,(c_{ii}-c_{ij})^2}$$

where $\hat{U}_i$ = the estimate of the proportion of class i in the unknown population,

$\hat{u}_i$ = the estimate of the proportion of class i in the unknown sample,

N_u = the size of the unknown sample,

c_{ii} = the fraction of the test sample from class i that classified as class i,

c_{ij} = the fraction of the test sample from class j that classified as class i,

N_i = the size of the ith test sample,

N_j = the size of the jth test sample,

i = the class of concern,

j = all other classes.

A paper is currently being prepared for publication that describes in detail the theory and the variance considerations as related to this problem.

Sample collection, preparation and viewing

Scale samples were provided by various state, provincial, and federal agencies of the United States, Canada, Japan and the Soviet Union. Impressions of scales were made in cellulose acetate (Koo, 1955). Personal communication with biologists of the providing agency (except for those scales provided by the Soviet Union) indicate that scale samples were collected from body areas A or B as established by the International North Pacific Fisheries Commission (INPFC, 1961). This area includes the first four rows of scales above and below the lateral line. The area is bounded anteriorly by an imaginary line dropping ventrally from the middle of the dorsal fin and posteriorly by an imaginary line dropping ventrally from the anterior edge of the adipose fin. Scale scamples within this region from either side of the fish may be used.

Scale images were projected at 100 power using a Bausch & Lomb microprojector.[1] Measurement and count data were recorded directly on a form from this image (Fig. 2). A consistent radius along which measurements and counts were recorded was found by aligning the form so that the radius approximated a perpendicular angle to the sculpture field (Fig. 1), (Mosher, 1959; Narver, 1963). This axis was chosen over the longest axis because of the tendency for sockeye salmon scales from stocks returning to the south side of Alaska Peninsula, Cook Inlet and some rivers of the Kamchatka Peninsula to show broken and irregular circulii along the longest axis (Mosher, 1968).

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[1] Catalog No. 42-63-59

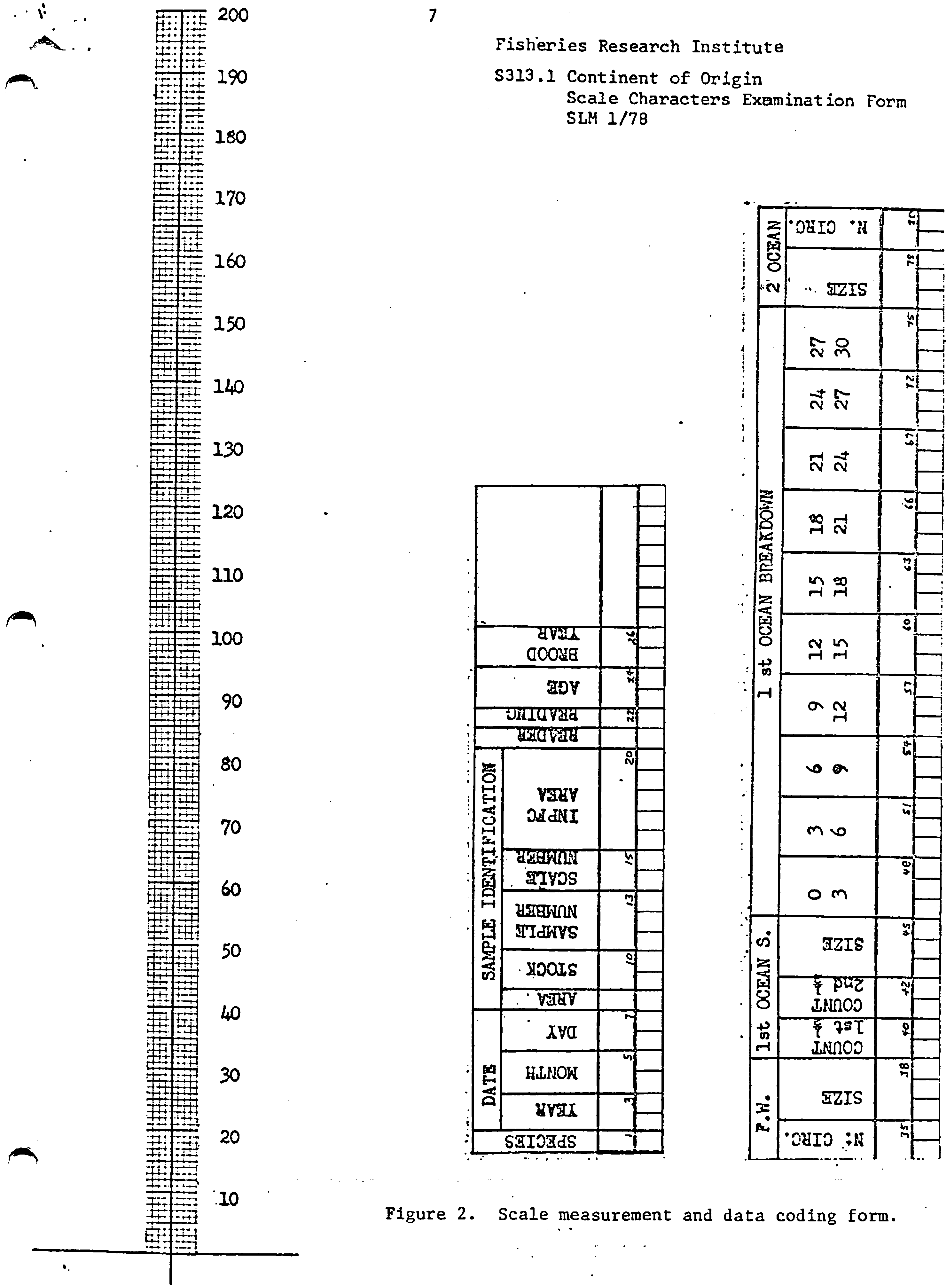

Figure 2. Scale measurement and data coding form.

Aging

Two technicians independently read each scale for age and then compared their readings with that provided by the agency supplying the scale. If all readers agreed, the age was accepted. If a disagreement was found, the scale in question was examined jointly by the two technicians. During these conference readings the pattern in question was identified and an attempt was made to resolve the conflict. If the conflict could not be resolved the biologist in charge read the scale. If after this reading only one in four readings was discrepant, the age determination of the three readers was accepted, if a three-way discrepancy emerged, the scale was rejected. In the case where the agency supplying the scale had not aged the fish a similar procedure was used except that only two rather than three agreements were needed to accept the age reading.

Development of Standards

Results of tagging experiments (French et al., 1976) indicate that Asian sockeye are present in the landbased fishery area. Although there have been no coastal recoveries of sockeye salmon tagged in the landbased fishery area, there have been high seas recoveries (in the years of tagging) in area E 6048 of maturing fish released in areas E 6046 (6 fish), E 6546 (5 fish), and area E 6544 (2 fish), and of immature sockeye released in area E 6048 (2 fish) and area E 6542 (2 fish). These same studies are inconclusive as to the presence of North American stocks, especially in the eastern portion of the fishery. Asian and western Alaska sockeye are known to intermingle extensively in the North Pacific between about 165°E and 175°W north of about 46°N (French et al., 1976) (Figure 3).

In development of continental standards we wished to strike a balance between achieving good classification accuracy by factoring out as many sources of variability as possible and keeping the number of standards that must be developed small. Maximum classification accuracy would be

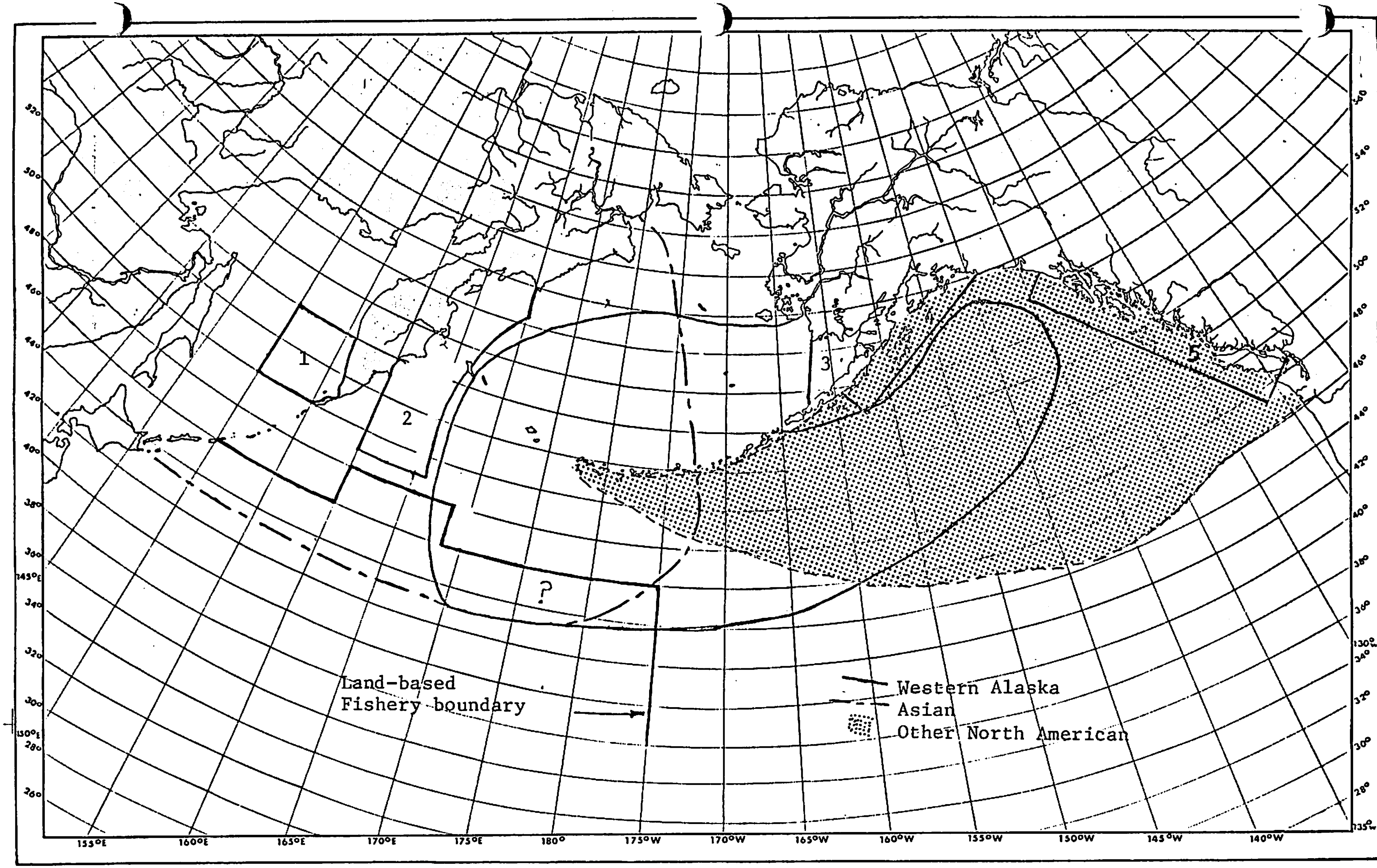

Figure 3. Generalized ocean distribution of Asian and North American sockeye salmon, areas from which regional standards were developed and the area of the Japanese land-based driftnet fishery (after French et al. 1976). (The eastern boundary of the land-based fishery area was moved 10° west to 175°E in 1978 under terms of the new treaty.)

achieved by treating each year class from each brood year by stock separately (Cook and Lord, 1978; Krasnowski and Bethe, 1978; Anas and Murai, 1969). This procedure would result in a overwhelmingly large experimental design and furthermore, scale samples from sockeye when segregated in either terminal fisheries or in the spawning grounds were available from few Asian stocks. These considerations led us to group stocks within regions on either side of the Pacific whose river of origin emptied into similar water masses and to treat year class within brood years separately; therefore, two Asian and three North American standard regions were defined (Figure 3).

For Asia, streams emptying into the Okhotsk Sea on the west side of the Kamchatka Peninsula were separated from those emptying into the North Western Pacific Ocean on the east side of the Kamchatka Peninsula. On the west side the principal producers are the Ozernaia and Bolshaia rivers, on the east side the principal producer is the Kamchatka River. Samples collected aboard Japanese research vessels operating off the southwest coast of Kamchatka were used to develop the West Kamchatka standard, Fig. 3, area 1. An attempt was made to allocate samples based on the catch per tan by age class (gear A only) by INPFC area by month. A dearth of samples in August (Table 1) will require some divergence from this scheme. We will therefore supplement these time x area deficiencies with samples collected from other time x area blocks in which the scale pattern most closely resembles that from the cell that is deficient. The East Kamchatka standard will be developed by combining escapement samples collected in the Kamchatka River, Japanese research vessels' catch samples collected off the southeast coast of Kamchatka

Table 1. Catch per tan, sample size and available scales for age 2.2, 1.3 and 2.3 sockeye salmon intercepted by Japanese research vessels operating on the west side of the Kamchatka Peninsula, Gear A, mature fish, by month and area in 1975.

		2.2			1.3			2.3		
Month	Area	Catch/tan	Sample size	Total available	Catch/tan	Sample size	Total available	Catch/tan	Sample size	Total available
June	E 5052	0.082	10	15	0.034	15	55	0.066	13	106
	E 5050	0.023	3	31	0.066	29	88	0.104	21	140
	E 5552	0.013	2	3	0.017	8*	4	0.014	23	26
	E 5550	0.012	1	5	0.017	8*	7	0.072	15	30
July	E 5052	0.020	2	29	0.057	25	64	0.027	5	40
	E 5050	0.079	9*	6	0.	0	0	0.039	8*	3
	E 5552	0.052	6	21	0.156	69*	66	0.052	11	21
	E 5550	0.280	33	42	0.047	21*	7	0.133	27*	20
August	E 5052	0.029	3*	11	0.	0	0	0.017	3	7
	E 5050	0.437	52	41	0.011	5*	1	0.117	24*	11
	E 5552	0.082	10	58	0.005	2*	1	0.042	9	25
	E 5550	0.576	69*	3	0.040	18*	4	0.199	41*	20
Total			200	265		200	297		200	444

*indicates time x area deficiences in available samples.

and samples collected aboard Japanese motherships further offshore (Fig. 3, area 2). Inclusion of mothership catch samples is required because of a lack of samples from the other sources. Final decisions regarding times and areas for mothership samples are currently being made and will be reported later.

The North American continent was divided into three regions corresponding to the water mass into which the parent streams terminate: the Bering Sea (Fig. 3, area 3) the south coast of Alaska from about 160° W to 145° W (hereafter called the Gulf Standard)(Fig. 3, area 4); and the southeastern coast of Alaska south to the Fraser River, B.C. (Fig. 3, area 5). Standards by age class within these regions were compiled by sampling from the major stocks within the region in proportion to the abundance of each age class by stock. Tables 2 to 4 summarize the run size by stock and age class within each region and the resulting sample sizes. Our first year's report will not include the southeastern Alaska and British Columbia standard due to the extreme unlikliness of the presence of these fish in the area in question (French et al., 1976) and the limited amount of time.

Screening of characters

Some characters selected for screening were identified from previous work. Anas and Murai (1969) reported that: 1) the number of circulii in the first half of the first ocean zone; 2) the measured distance between circulii 1 and 6 of the first ocean zone; and 3) the measured distance between circulii 13 and 18 of the first ocean zone provided good separation of Asian from Bristol Bay sockeye salmon when used in either a linear or quadratic discriminant function. Mosher (1963) used the number of circulii in the total freshwater zone and the first ocean zone for sockeye of age

Table 2. Inshore run of the major stocks of sockeye salmon returning to the Bering Sea region for age classes 2.2, 1.3 and 2.3 and resulting sample sizes.

Stock	Run size (thousands)			Sample size		
	2.2	1.3	2.3	2.2	1.3	2.3
Goodnews & Kwinhok[1]	24.7	3.2	4.1	0	0	0
Togiak	20.2	204.5	4.3	0	18	0
Igushik	90.5	172.7	113.8	1	15	8
Snake	0.3	9.0	<0.1	0	1	0
Wood	193.4	838.6	85.4	2	74	6
Nushagak	3.6	60.8	2.2	0	5	0
Nuyakuk	120.3	567.0	3.9	1	51	0
Kvichak	14,014.5	13.8	520.7	161	1	36
Alagnak	5.7	61.2	20.4	0	5	1
Naknek	1,674.5	275.1	968.8	20	24	66
Egegik	739.5	70.1	961.5	8	6	66
Ugashik	249.0	2.7	21.1	3	0	1
Bear	241.4	<0.1	198.8	3	0	14
Sapsuk	127.0	11.0	25.0	1	0	2
Total	17,506.5	2,289.7	2,930.1	200	200	0

[1] Age composition estimated by using the average age composition for the region because of a lack of samples--run size estimated at 2 times catch because of a lack of data.

Table 3. Inshore run of the major stocks of sockeye salmon returning to the Gulf of Alaska region for age classes 2.2, 1.3 and 2.3 and resulting sample sizes.

Stock	Run size (thousands)			Sample size		
	2.2	1.3	2.3	2.2	1.3	2.3
Chignik	149.2	221.3	540.8	35	41	133
Akalura	12.6	2.6	0.6	3	0	0
Frazer	51.3	1.9	4.5	12	0	1
Upper Station	32.8	6.1	12.1	8	1	3
Red River	49.5	2.9	14.3	11	1	3
Karluk	264.0	7.9	55.2	62	1	14
Cook Inlet	262.9	402.5	93.0	62	74	23
Bering River	no scale samples available					
Copper River	11.4	259.5	80.3	3	48	20
Prince William Sound Management Area	18.6	182.4	13.1	4	34	3
Total	852.4	1,086.9	814.0	200	200	200

Table 4. Inshore run of the major stocks of sockeye salmon returning to British Columbia, for age classes 2.2, 1.3 and 2.3 and resulting sample sizes.

Stock	Run size (thousands)			Sample size		
	2.2	1.3	2.3	2.2	1.3	2.3
Nass	72.9	57.5	7.2	76	16	122
Skeena	21.4	341.6	4.5	22	95	76
Rivers Inlet	0	224.7	0	0	63	0
Fraser	97.0	93.0	0.1	102	26	2
Total	191.3	716.8	11.8	200	200	200

groups 1.- and 2.- and the size of the same two zones for sockeye of age group 3.- in bivariate frequency tables to classify Asian and North American fish. We screened the following characters (Table 5): characters A 1 & A 2 are the same as those of Mosher (1963), character B 1 is the same as Anas & Murai (1969). A combination of characters B 4 & B 5 and B 8 & B 9 are similar to Anas & Murai's character numbers 2 and 3 above, respectively.

Table 5. Scale characters being evaluated.

A	Freshwater Zone	
	1	Number of circulii
	2	measured width
B	First Ocean Zone	
	1.	Number of circulii in first half of zone
	2.	number of circulii in second half of zone
	3.	measured width
	4.	distance between outer edge of last freshwater circulii to the third ocean circulii
	5.	distance between circulii 3 and 6
	6.	" " " 6 and 9
	7.	" " " 9 and 12
	8.	" " " 12 and 15
	9.	" " " 15 and 18
	10.	" " " 18 and 21
	11.	" " " 21 and 24
	12.	" " " 24 and 27
	13.	" " " 27 and 30
C	Second Ocean Zone	
	1.	Number of circulii
	2.	measured width

Unknowns

Scale samples to serve as unknowns were requested from the Fishery Agency of Japan (FAJ). The request was for samples collected aboard research vessels operating in and around the land-based fishery area and for samples collected aboard motherships operating to the north of the land-based area. Scale samples are not collected aboard commercial vessels within the area. A minimum of 40 samples for each age x time x area cell are required to provide reasonably narrow confidence intervals for the proportions of North American vs Asian fish.

Figures 4-7 summarize the number of available scales from age 2.2 mature sockeye salmon by INPFC statistical area by 10-day periods from May 1 to June 10, 1975. Adequate samples are available from 4 areas within the land-based area and from two areas to the north for the period May 1 - May 10. During the second ten days in May adequate sample sizes are present from two areas within the land-based area. For the period May 21-31 one area within the land-based area has adequate samples, however, six areas to the north have adequate samples. No adequate sample sizes exist after May 31. Regarding age 1.3 mature sockeye, adequate sample sizes do not exist within the land-based area during the entire season. Adequate samples do exist in one area to the north of the fishery during the period May 11 - May 20 and from four areas to the north during the period May 21-31. No adequate sample sizesare available for age 2.3 mature fish from within the area. Adequate samples are available from one area to the north of the fishery during the period May 11-21 and from three areas to the north of the fishery during the period May 21-31.

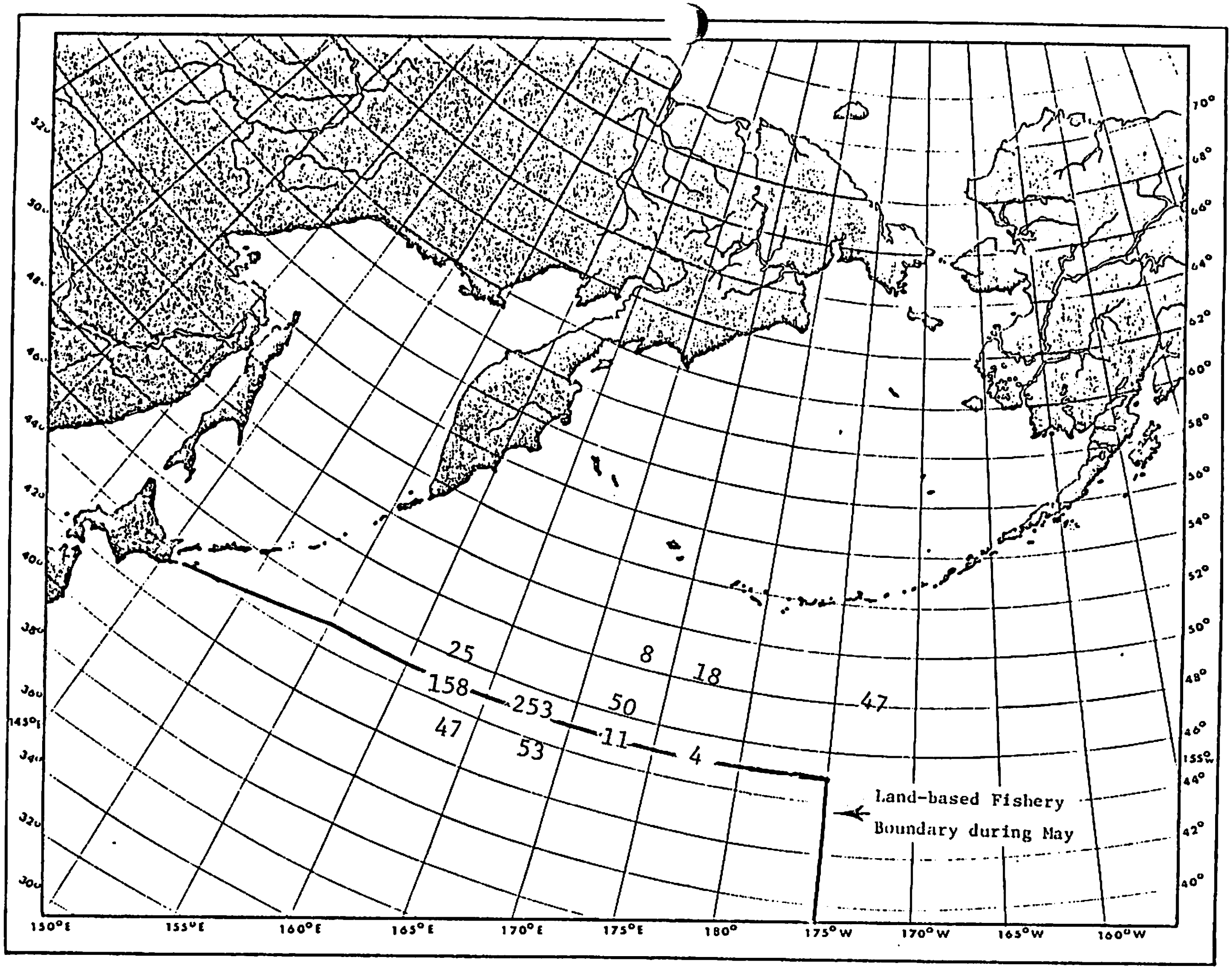

Figure 4. The number of available scales from age 2.2 mature sockeye salmon by INPFC statistical area for the period May 1 - May 10, 1975.

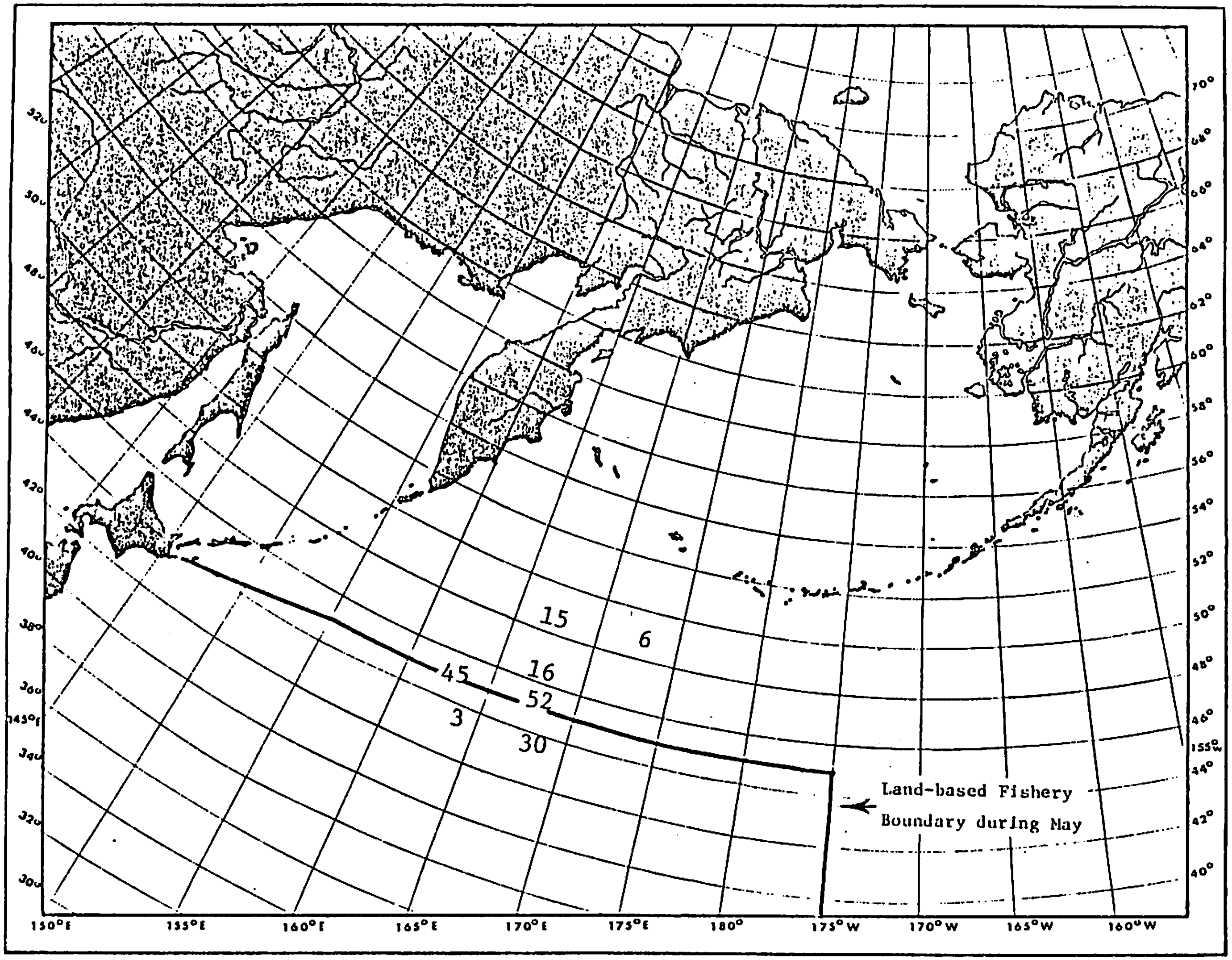

Figure 5. The number of available scales from age 2.2 mature sockeye salmon by INPFC statistical area for the period May 11 - May 20, 1975.

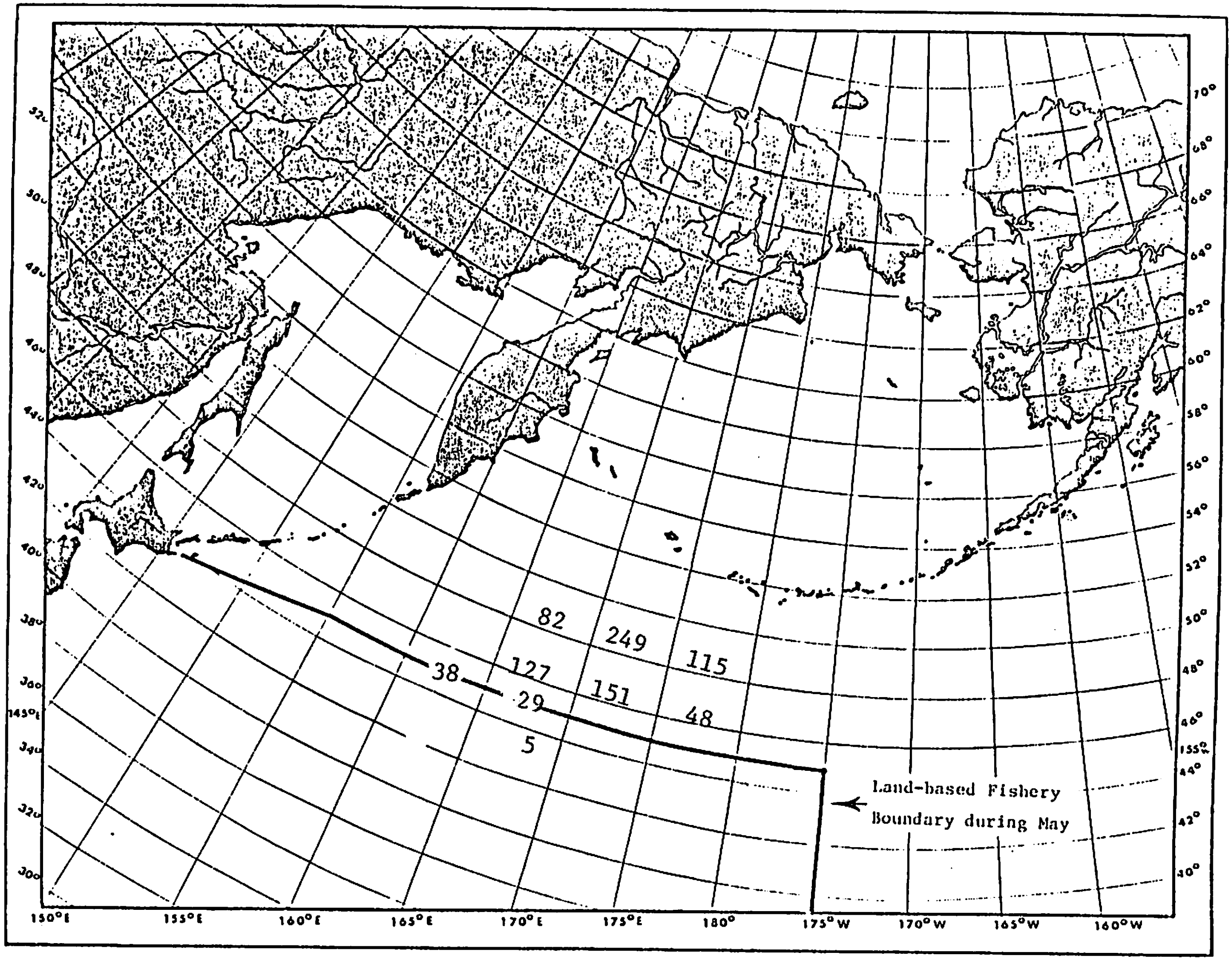

Figure 6. The number of available scales from age 2.2 mature sockeye salmon by INPFC statistical area for the period May 21-May 31, 1975.

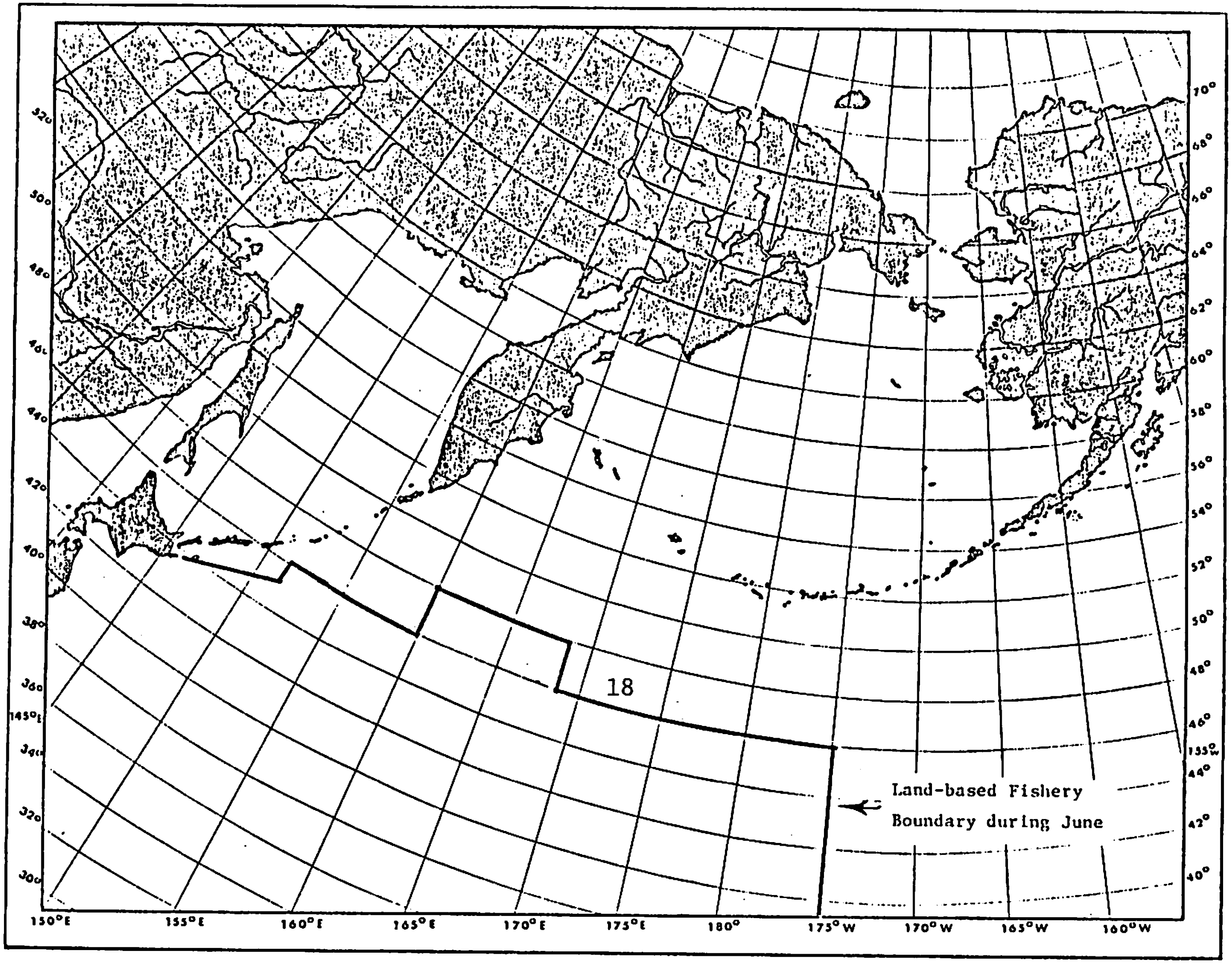

Figure 7. The number of available scales from age 2.2 mature sockeye salmon by INPFC statistical area for the period June 1 - June 10, 1975.

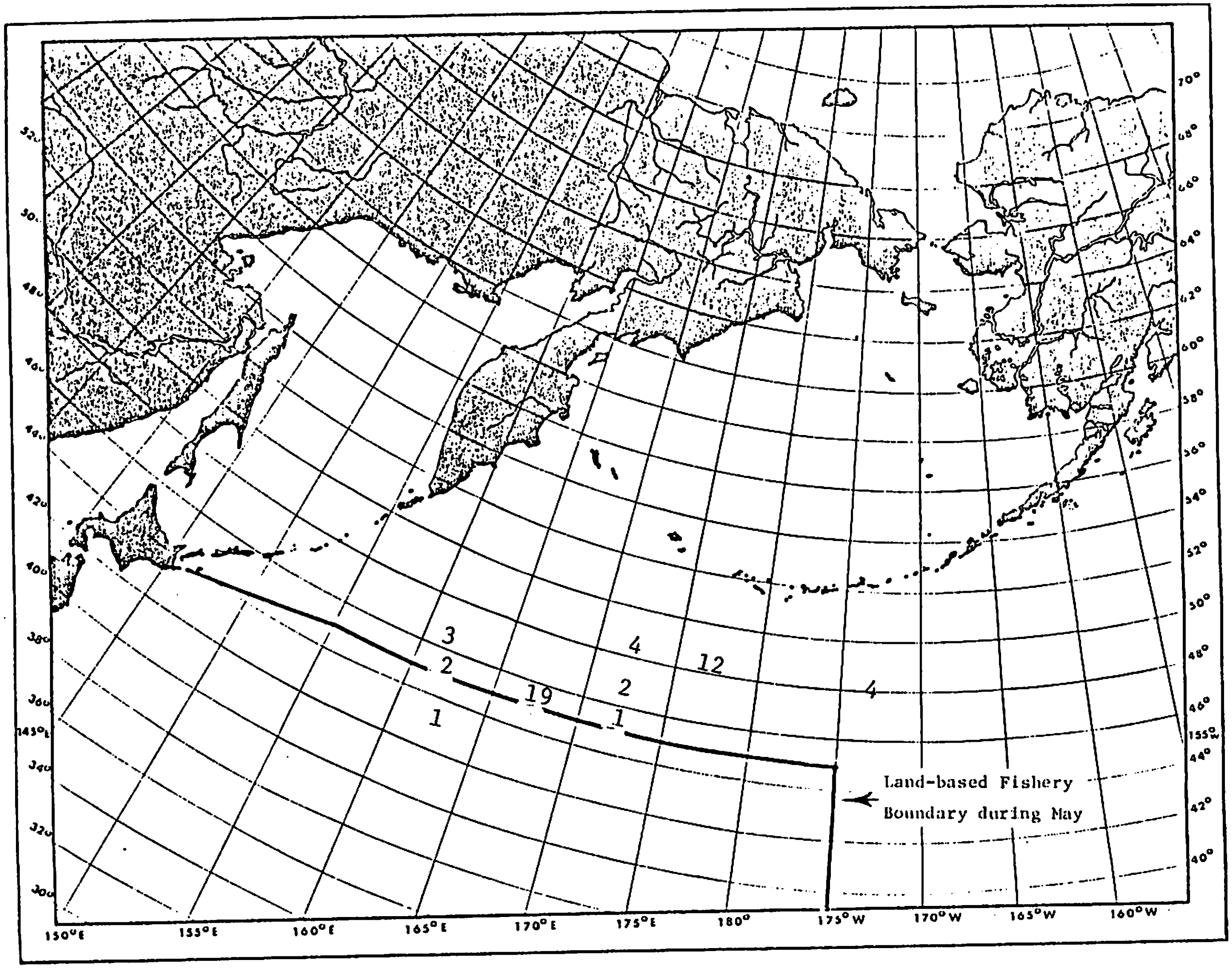

Figure 8. The number of available scales from age 1.3 mature sockeye salmon by INPFC statistical area for the period May 1 - May 10, 1975.

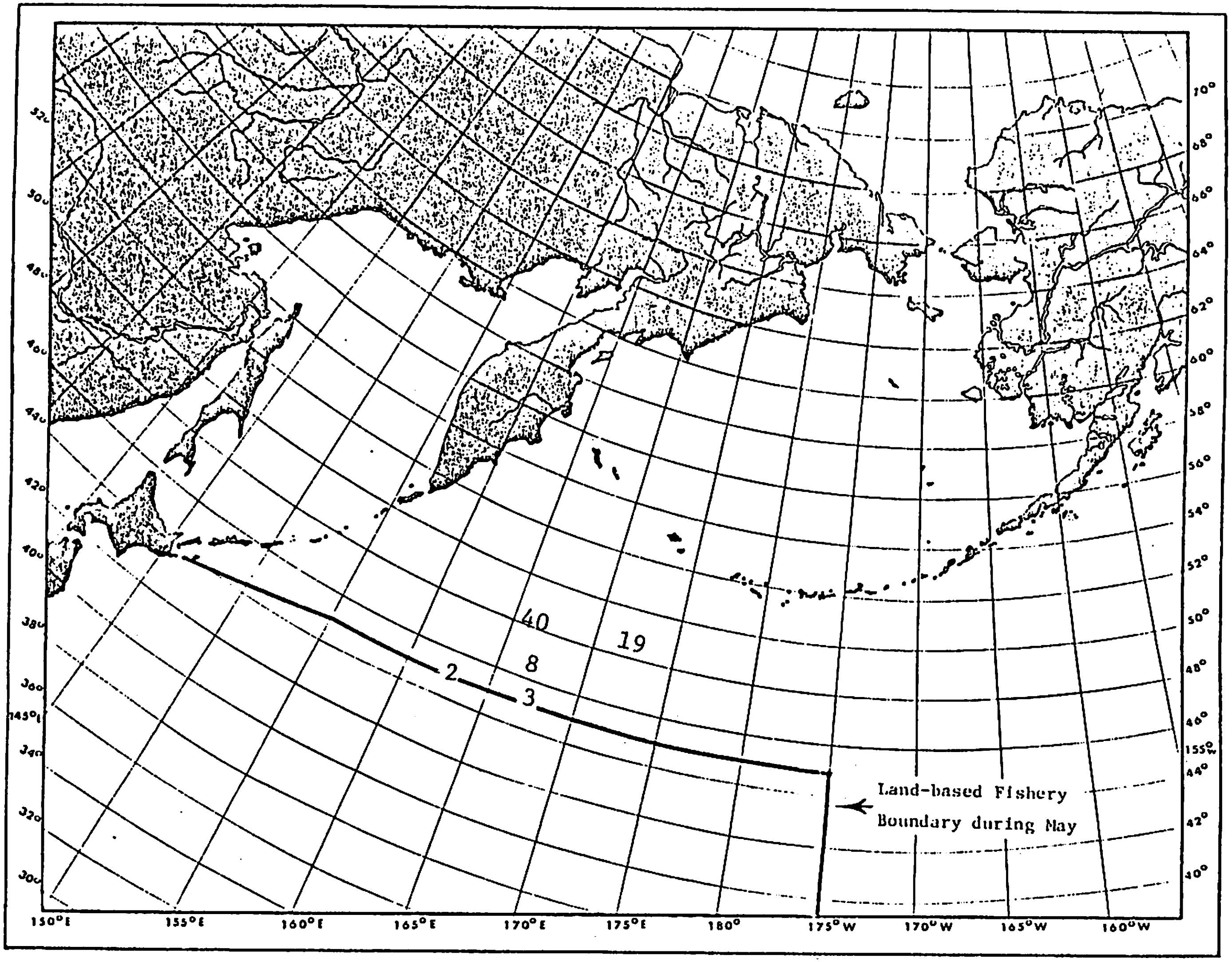

Figure 9. The number of available scales from age 1.3 mature salmon by INPFC statistical area for the period May 11 - May 20, 1975.

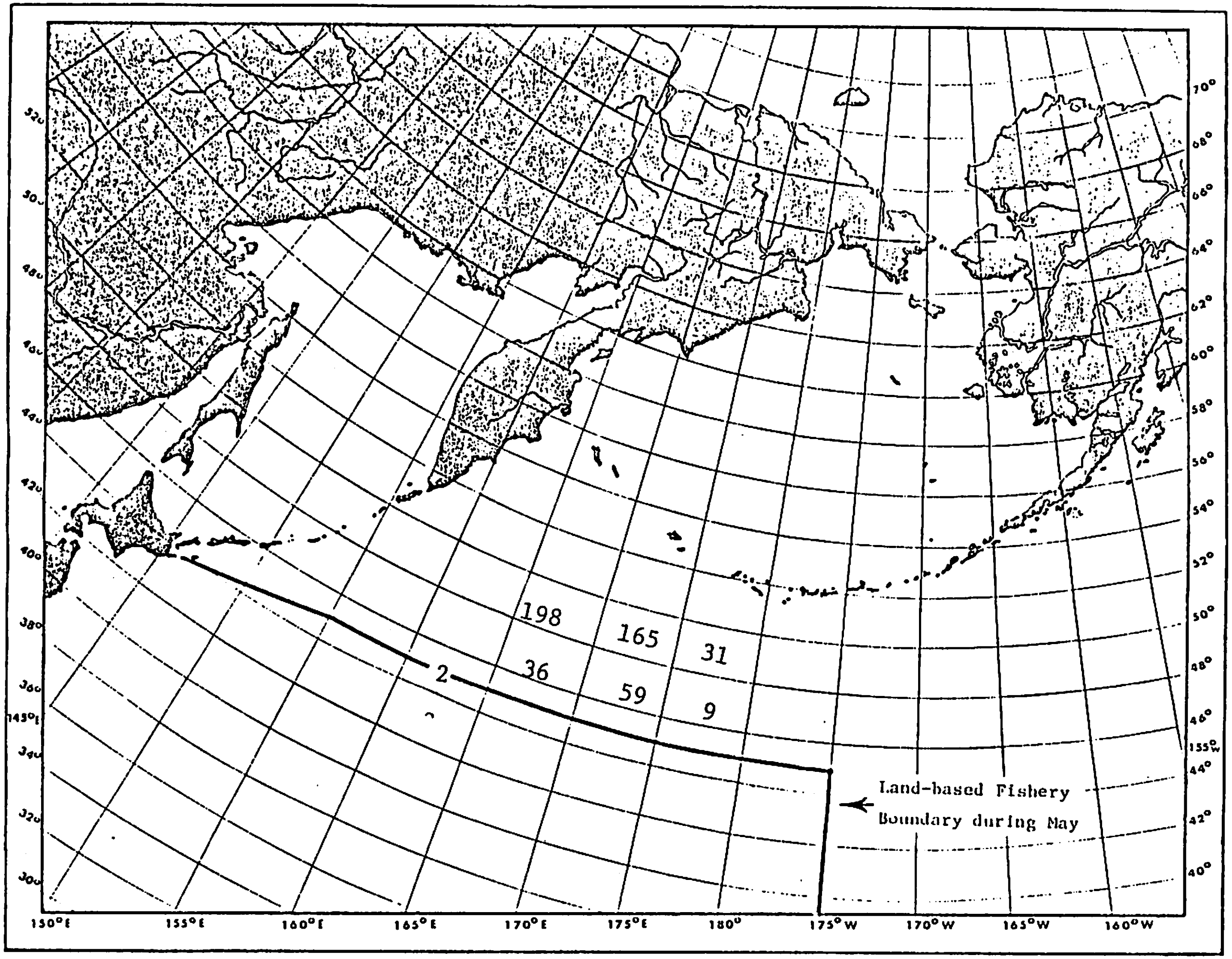

Figure 10. The number of available scales from age 1.3 mature sockeye salmon by INPFC statistical area for the period May 21 - May 31, 1975.

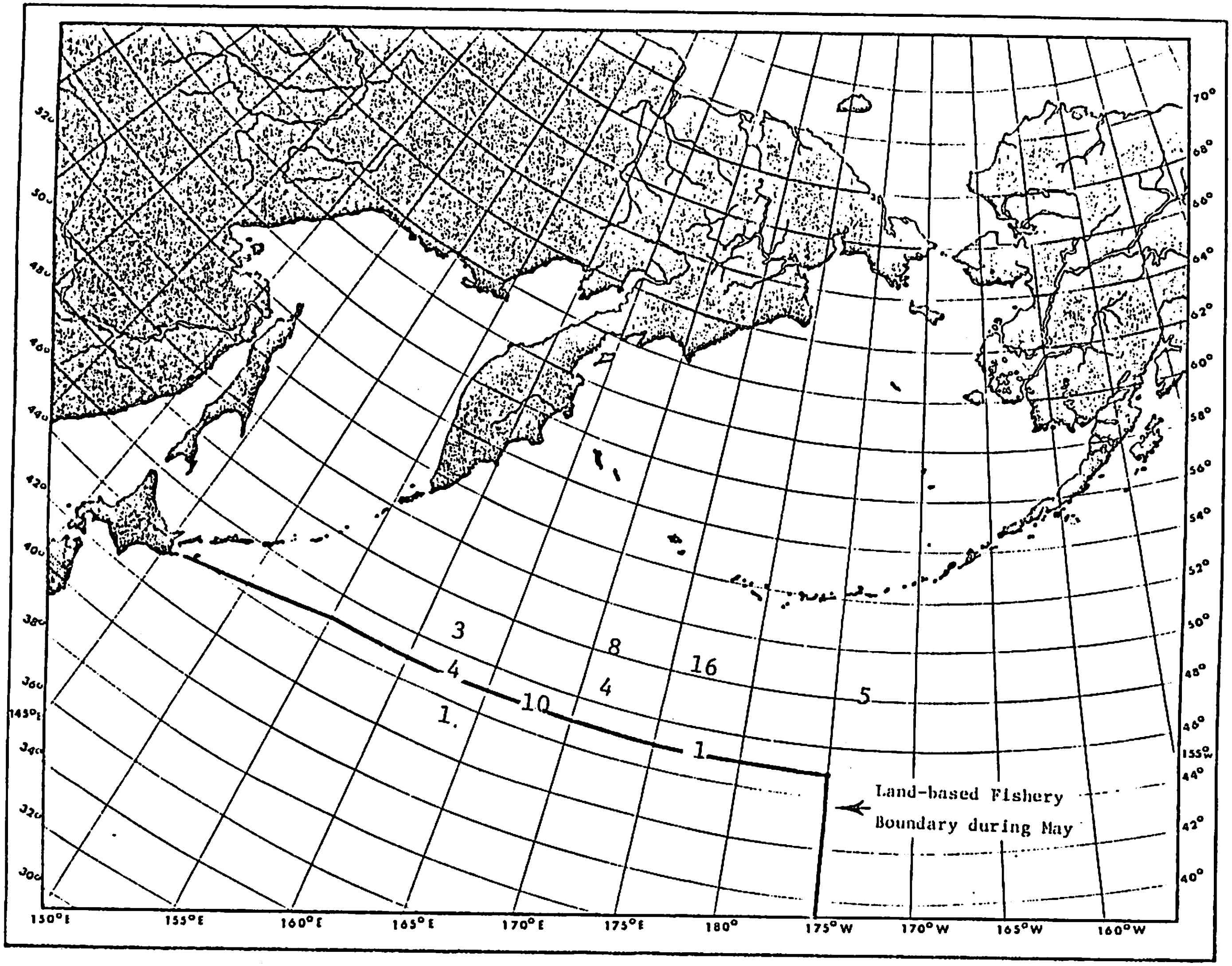

Figure 11. The number of available scales from age 2.3 mature sockeye salmon by INPFC statistical area for the period May 1 - May 10, 1975.

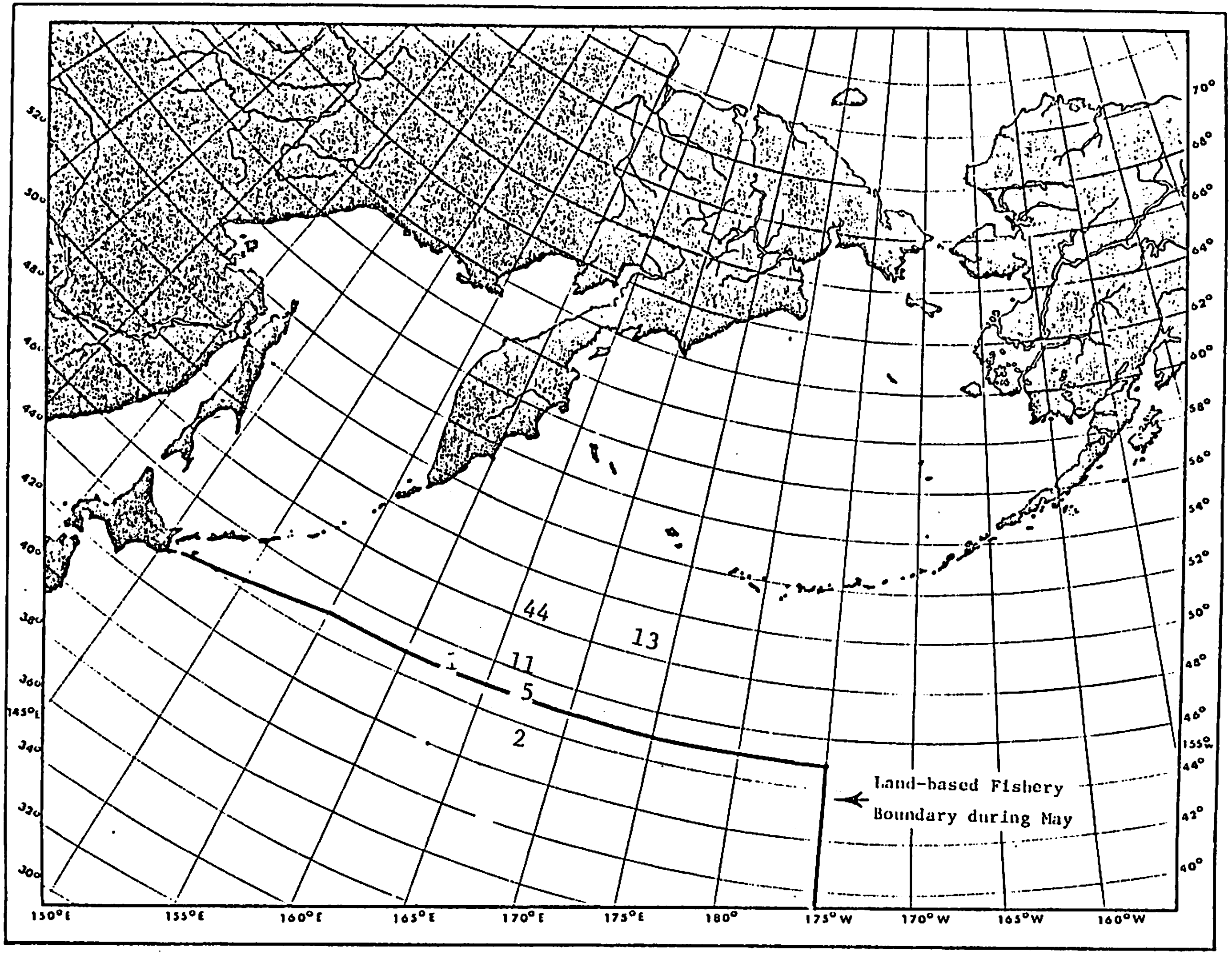

Figure 12. The number of available scales from age 2.3 mature sockeye salmon by INPFC statistical area for the period May 11 - May 20, 1975.

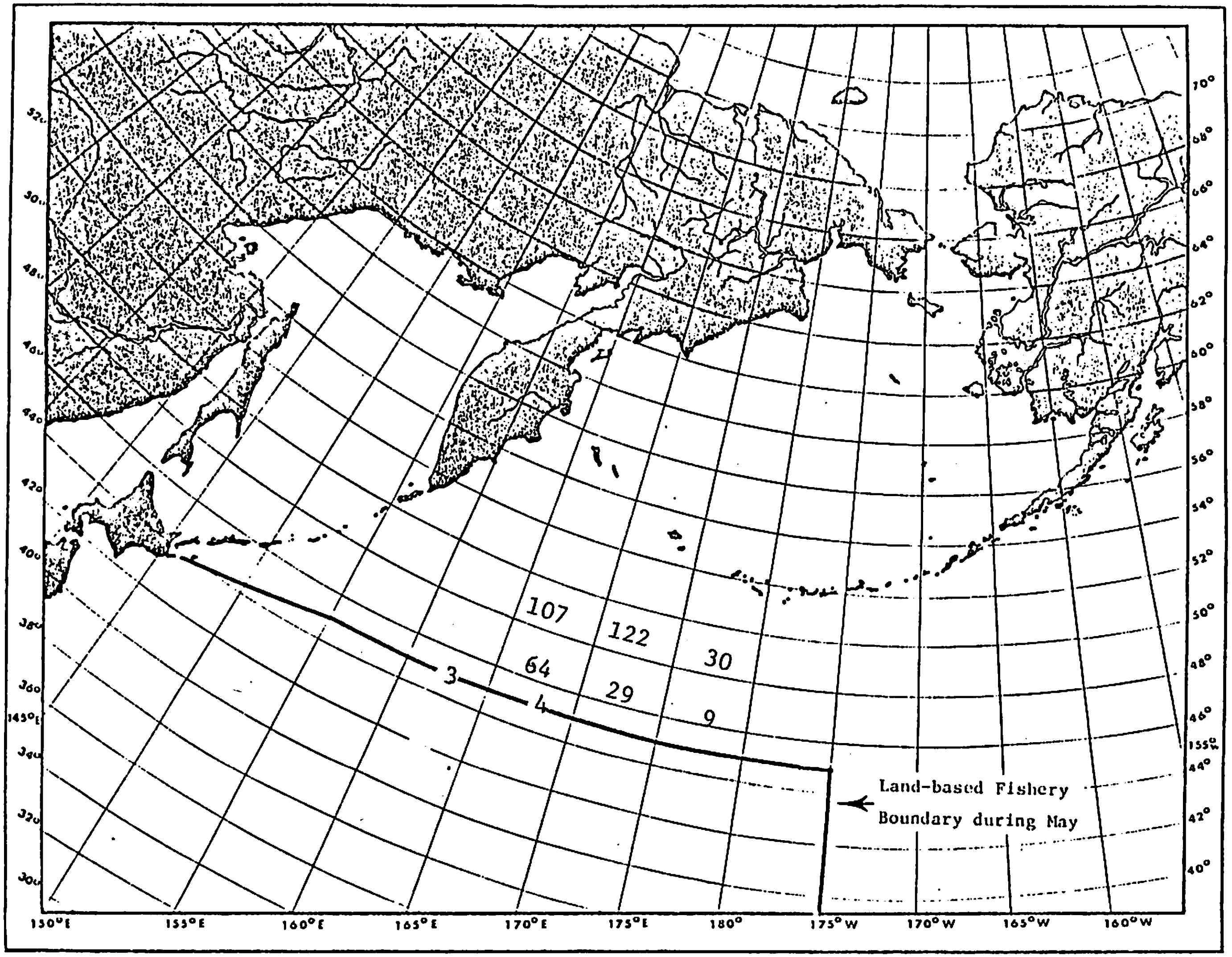

Figure 13. The number of available scales from age 2.3 mature sockeye salmon by INPFC statistical area for the period May 21 - May 31, 1975.

Summary

Previous studies by Anas & Murai (1969) and Cook and Lord (1978) have provided a sound theoretical framework, which we have expanded upon to develop methods for identifying the origins of sockeye salmon intercepted by the Japanese land-based fishery. Implementation and testing of the method has been limited by availability and flow of samples, training of technicians and inefficient data collection procedures. Of these problems availability and flow of samples is still troublesome. We are addressing these problems.

Results of implementing the method will be completed by September 30, 1978. This first year's work is directed at mature fish intercepted by the Japanese in 1975. Results of this study will provide a basis from which recommendation for future work will be made.

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