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AN ANALYSIS OF THE DISTRIBUTION OF FISHING EFFORT AND CATCH PER UNIT EFFORT IN THE JAPANESE LANDBASED DRIFTNET FISHERY, 1978-1984

by

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INTRODUCTION

Although the Japanese landbased drift gill-net fishery (LBDN) has existed in some form since the 1930's, the offshore portion of this fishery is relatively new. This part of the fishery began in 1952 and quickly turned the LBDN fishery into one of the world's largest salmon fisheries, reaching peak effort levels during the early 1970's. Before 1978, the fishery operated west of 175°W and south of 46°N (also, south of 48°N between 160°E and 170°E). However, when the INPFC treaty was renegotiated, the eastern boundary of the fishery was moved to 175°E to reduce interceptions of North American salmon. Although there are no indications that North American pink and chum salmon occur in the present LBDN areas, growing evidence that North American sockeye, coho, and chinook salmon and steelhead trout inhabit parts of the LBDN area has recently led some U.S. interest groups to suggest that the eastern boundary be moved further west. The Japanese have resisted this change because it may require a large reduction in their high-seas catch of Asian origin salmon; viz., chum and pink salmon. The following analyses address the dynamics of salmon caught in the LBDN area and the distribution of effort by the LBDN fishery, in an attempt to better understand factors that influence the distribution of fishing effort and consequences of any effort redistribution.

METHODS

Catch per unit effort (CPUE) and fishing effort data were stratified by 10-day period, year, and INPFC 2° x 5° statistical area. The fishing season begins May 1; thus, period one represents May 1-10. The LBDN fishing area includes 22 INPFC statistical 2° x 5° areas, and because some analyses required aggregations of data into general catagories, we combined statistical areas into three relatively distinct strata. INPFC 2° x 5° areas west of 155°E comprise the first stratum (area X), and the final two strata are constructed by separating INPFC areas 2° x 5° east of 155°E by latitude 42°N (INPFC areas east of 155°E and north of 42°N are denoted as area Y, whereas INPFC areas east of 155°E and south of 42°N are called area Z, Figure 1).

Examinations of the temporal use of fishing grounds and cluster analysis of INPFC 2° x 5° statistical areas provided the basis for these stratifications. We randomly selected the year 1978 to provide data for our cluster analysis and applied a clustering algorithm to 2° x 5° statistical areas in each of the seven fishing periods. Catch rates for all five species of salmon provided the multivariate data needed to calculate areal similarity.

We examined variability in catch rates with respect to the three factors, year, fishing period, and area by analysis of variance (ANOVA) methods. The ANOVA helps identify the underlying structure of catch rates, and it is a useful tool which reveals insight into the relationship between catch rates and these factors. Often a particular analysis may be improved by removing excessive levels of stratification. The ANOVA reveals the consequences incurred by these aggregations; aggregations occurring over factors which strongly interact with other factors require special attention.

Because little fishing effort was expended by the LBDN in 2° x 5° statistical areas east of 155°E and south of 42°N, and catch rates in this area are somewhat heterogeneous, we removed these data from the ANOVA. Interactions between factors were evident by preliminary inspection, and this required further refinements of the data. Periods one and two were combined, periods five and six were combined, and periods seven and eight eliminated from the ANOVA. This refinement eliminated empty cells in the design matrix of ANOVA, a requirement necessary to examine interactions. One further step was necessary for our analysis. Histograms of CPUE data, within each stratum, indicated rightward skewness in the distribution of catch rates. Furthermore, the mean and variance of catch rates were positively correlated. Therefore, log transformations of catch rates were used in the ANOVA. Because of unequal cell sizes in the ANOVA (unbalanced design), we used the method of weighted squares of means (BMDP2V) to test our hypotheses.

The value of catch in each stratum is examined by applying prices for Japanese high seas gill-net caught salmon landed at the port of Hanasaki, Hokkaido on July 6, 1981 to the recorded catch weight. Average prices (in dollars) are as follows: 1) sockeye--3.80; 2) chum--2.50; 3) pink--1.11; 4) coho--2.77; and 5) chinook--3.51. The price structure is applied to catch weights for individual INPFC 2° x 5° statistical area, fishing period, and year strata. Many assumptions are implicit in this decision. For example, we know that the size of fish affects its price; thus, we assume that the distribution of fish sizes are similar between areas and fishing periods. To some extent, this assumption is unrealistic; however, the effect of its violation is unclear and we haven't chosen to examine it. Other assumptions bring similar difficulties; however, our approach seems reasonable for an initial analysis. Because our data are limited to the year 1981, we likewise limit this analysis to 1981 catch data.

RESULTS

Stratification of Statistical Areas

A simple examination of fishing patterns reveals that the temporal usage of many statistical areas are similar (Table 1) and these patterns can be stratified into three relatively homogeneous areas.

Results of the cluster analysis further support these classifications. Two definite groupings of 2° x 5° statistical areas are identified through the analysis: the areas west of 155°E and the areas north of 44°N and east of 155°E (hereafter called area X and area Y, respectively). Statistical areas east of 155°E and south of 44°N (denoted as area Z) appear unrelated to any group or each other.

Summary Statistics of Effort and CPUE Data

Since 1978, there has been a slight decline in the number of tans fished each year (Table 2a and 2b). Most of this decline has occurred in the area north of 42°N and east of 155°E. There has been a significant increase in effort below 42°N and east of 155°E; however, this increase is still much less than the overall effort decrease. The sum of these changes suggest that since the early 1980's there has been a southwesterly movement to the mean latitude and longitude of fishing effort.

Catch rates of sockeye and coho salmon, stratified by 2° x 5° statistical area, are virtually zero west of 155°E (Table 3). Since these data include all years and fishing periods, the persistence of these null catches is notable. The data show inverse longitudinal clines in catch rates of pink, sockeye, chinook, and coho salmon. Clines in catch rates of pink and sockeye salmon are inversely related, whereas sockeye and coho catch rates demonstrate similar longitudinal trends. Both chum and chinook salmon CPUE rates appear unrelated to geographical area. Interpretation of these trends is difficult because the data are averaged over year and fishing period. Subsequent analyses showed that catch rates vary by year and fishing period for most species; thus, catch rates for a particular area may depend upon the time of year the area is fished and the distribution of effort in particular years.

Catch rates also depend upon fishing period (Table 4). Sockeye salmon are predominately caught during May. Catch rates then decline during June, and by July, few sockeye are harvested. Pink, coho, and, to some degree, chinook salmon exhibit catch rate trends opposite to that of sockeye; catch rates increase as the season progresses. These results are similar to catch rates stratified by INPFC 2° x 5° statistical area. Pink and sockeye salmon catch rates are inversely related; however, now chinook, coho, and pink rates correlate positively. Note that catch rates of sockeye and pink salmon, averaged over year and area, change 14 fold and catch rates of coho 45 fold from the beginning of May through the first period of July, a period of 70 days.

Catch patterns are further illuminated by stratifying catch rates for each fishing period into three groups of areas, called X, Y, and Z, in which catch rates are relatively homogeneous (Table 5). If we accept the assumption that the interaction of catch rates between areas and years is minimal, then the following catch patterns are apparent in the fishery:

Sockeye salmon. Incidence of sockeye salmon primarily occurs east of 155°E; CPUE rates west of 155°E are small and variable. The declining trend in catch rates through successive fishing periods, as shown in Table 3, also occurs in all areas. Catch rates in area Z are one-half those in area Y, which suggests that catch rates of sockeye salmon are also a function of latitude.

Chum Salmon. It is difficult to discern any temporal or spacial trend in the incidence of chum salmon. CPUE rates appear greatest during the second to fourth fishing period for all three areas (X, Y, and Z);

however, this peak is slight. The important point is that catch rates of chum salmon are similar in all fishing periods and geographical areas; time-area restrictions should not impact, on the average, the catch rates of chum salmon.

Pink Salmon. The potential catch of pink salmon is much greater in area X, the area west of 155°E. The most unproductive area is Z, whereas area Y is moderately productive. These data clearly show that any strategy which increases fishing effort west of 155°E will result in greater catches of pink salmon.

Coho Salmon. CPUE rates of coho are greatest in area Z, the southeastern portion of the landbased fishing area. Thus, any strategy which moves the fleet to this area results in increased catch rates for coho salmon. However, the lowest catch rates are west of 155°E, and this reduction is significant.

Chinook Salmon. CPUE rates of chinook salmon, like that of chum salmon, are also rather uniform in time and area. There is a general trend, however, toward higher catch rates as the season progresses.

We can now summarize the effect of different time-area strategies on catches. The strategy of eliminating area Y will redirect effort to areas with catch rates that are as follows: 1) greatly lower for sockeye; 2) equal for chum; 3) greater and lower for pink; 4) both greater and lower for coho; and 5) equal for chinook.

The strategy of eliminating all areas east of 155°E will redirect effort to areas with catch rates that are as follows: 1) greatly lower for sockeye; 2) equal for chum; 3) greatly higher for pink; 4) greatly lower for coho; and 5) equal for chinook.

Analysis of Variation in CPUE

Results of the ANOVA are summarized in Table 6. Although the method of weighted squares of means furnishes unbiased estimates of main effects in the presence of interaction, the interpretation of these effects is difficult. Thus, the presence of significant three-way interaction between the year, area, and fishing period factors impairs additional insight into causes of variation in catch rates of both chinook and chum salmon. Note that all main effects and two-way interactions are significant for chinook salmon. Thus, catch rates for chinook salmon are inherently difficult to model and thus inherently difficult to predict.

Three-way interactions for sockeye, pink, and coho salmon are, however, nonsignificant, which allows us to further examine catch rate variability for these species. The ANOVA indicates that the declining trend in catch rates of sockeye salmon throughout the fishing season is constant over time; i.e., the interaction between the factors, year and fishing period, is nonsignificant. However, areal differences in catch rate do vary by year, and the slope of the trend in rates by fishing period varies by area. (Note that these results merely corroborate conclusions obtainable by inspection of Table 5.)

The lack of significant two-way interactions in the pink salmon ANOVA suggests that 1) temporal trends in catch rates vary little by year; 2) differences in catch rate between areas vary little by fishing period; and 3) areal differences in catch rate also vary little from year to year. Examinations of main effects reveal that catch rates adjusted for area and fishing period are constant between years. Main effects for the area and fishing period factors are each highly significant.

Differences in areal catch rates for coho salmon vary little by year; however, the other two-way interactions are significant. Recall that catch rates are lowest in area X, intermediate in area Z, and highest in area Y. The ANOVA results suggest that these differences persist over time.

Analysis of the Value of Catches

We expect to see a positive correlation between effort and value of catch under the assumption that the fleet desires to fish in areas which will maximize the value of its catch. Our results shed little light on the validity of this assumption. In some fishing periods, a positive correlation is apparent, whereas in other periods, no relationship or an inverse correlation appears (Figure 2). The value of catches is much more variable in the western portion of the LBDN area (Table 7); the catch value ranges from very high to very low. However, catch value in the eastern LBDN areas is quite similar between areas. Furthermore, the chance of fishing east of 160°E in a 2° x 5° statistical area in which catch value is low, is remote.

If we compare the contribution of individual salmon species to the value of catches in area X versus area Y, several striking features emerge (Figure 3). Catches in the western portion of the LBDN area are exclusively comprised of chum and pink salmon. Catches in the eastern portion may include significant portions of four salmon species, chum, pink, coho, and sockeye salmon. Perhaps the increased number of salmon species contributing to catches east of 155°E causes the reduced variation in catch value between 2° x 5° statistical areas.

Interpretations of figure 3 require careful examination. Consider fishing period three. Although it appears that catch rates of chum salmon are highest in the LBDN area east of 155°E, the converse is in fact true. Catch rates are highest in the western portion. The percentage contribution of chum salmon to catch value is small because the value of catch is quite large--much larger than the catch value for the eastern portion of the LBDN area. Thus, comparisons of percentages must include an assessment of the "size of the pie". This latter information is found in table 7.

Catch rates of chum salmon in the eastern portion of the LBDN area were constant throughout the fishing season in 1981. Catch rates of chum salmon westward were initially quite large, then declined to low values by fishing period five (Figure 3). Recall that chum salmon catch rates appeared somewhat homogeneous with respect to fishing period and fishing area (Table 5). That perspective rested on the assumption that interaction between years and areas was minimal. The ANOVA suggested otherwise. Thus, the foregoing analysis points out that although catch rates of chum salmon, stratified by fishing period and fishing area, and averaged over years, appear homogeneous, actual rates for individual years may prove differently.

DISCUSSION

The basic question we attempted to address is "What motivates the distribution of effort in the Japanese LBDN salmon fishery?" A plausible hypothesis is that fishing effort is distributed to maximize the value of catch. The preceding analyses give some support to this hypothesis. By constructing a crude measure for the value of catch, we found that this value measure, at times, positively correlated with the amount of fishing effort during some fishing periods. We also found that fishermen tended to fish in areas in which variability in the value of catch was small. In other words, fishermen may choose to fish in areas that minimize the risk of poor catches--a strategy commonly called risk aversion. We caution the reader that this analysis and perhaps any analysis of catch value is fraught with difficulties. We recommend a more thorough analysis of catch value before significant weight is given to this portion of the analysis.

Our results do suggest that if the LBDN fishery desires to maximize the catch of pink and chum salmon of Asian origin, the redistribution of fishing effort westward should not reduce its ability to do so. Catch rates of pink and chum salmon are usually greatest west of 155°E.

However, the desire to harvest sockeye and coho salmon requires fishing effort directed at areas east of 155°E. Recall from Table 3 the absence of sockeye and coho west of 155°E, even when data are aggregated over all fishing periods and 7 years. Stock composition estimates for the months of May and June, and for fishing areas east of 160°E, suggest that about 89% of the sockeye catch is of Asian origin (Meyer and Harris 1983). There are no published estimates of coho catches of Asian origin by the LBDN fishery. The results of tagging and scale analyses are inconsistent; however, there are indications that the majority of age 2.1 fish, the predominant age group in the LBDN area, are of Asian origin.

Briefly, the problem is this: The Japanese LBDN fishery, to harvest Asian origin sockeye and coho salmon, must fish in areas that North American sockeye and coho inhabit. Furthermore, it appears that the harvest of these species may be required for the fleet to maximize the value of the catch or minimize the risk of poor catches, even though CPUE estimates for the most abundant salmon species, chum and pink, are greatest west of 155°E.

Note carefully that although effort redistribution to the west will greatly increase the density of effort for those western statistical areas; some areas in years past have supported an even greater intensity of fishing effort. For example, in May 1975, 1,316,104 tans of gill net were recorded in INPFC statistical area 6544E. Average fishing effort for the month of May in the entire LBDN fishing area since 1978 is less than 1.3 million tans. Conceivably then, the entire LBDN fishery could be confined to one 2° x 5° statistical area and still not equal this historical level of fishing effort. Thus, the issue is not over-intensifying fishing effort in a geographical area but the ability to harvest Asian origin fish and to achieve maximum value for the catch.

Potential resolution to these problems requires increased or better information in two areas of research. An indepth study of the economics of catch by the LBDN fleet and the relationship of the value of catch to 2° x 5° statistical area and fishing period is one such area of needed research. Economic information supplemented with better stock composition estimates could then provide the necessary ingredients for fully understanding the dynamics of this fishery and its impact on North American salmon.

REFERENCES

Meyer, Walter G. and Colin K. Harris. 1983. Interceptions of North American and Bristol Bay sockeye salmon by the Japanese landbased driftnet fishery, 1972-1981. 58 pp. (Document submitted to 1983 annual meeting of the International North Pacific Fisheries Commission, November 1983, Anchorage, U.S.A.) University of Washington, Fisheries Research Institute, FRI-UW-8316. Seattle.

Table 1. Number of years fishing effort was recorded in each INPFC 2°x5° area for the first 8 fishing periods.

INPFC 2°x5° Area	Fishing Period May 1 1	2	3	June 1 4	5	6	July 1 7	8
4038								
4040			5	5	1	1		1
4042		1	6	6	1	4	2	
4538		1		2	1			
4540	1	4	6	7	6	4	4	1
4542	3	3	6	7	6	4	3	
5038				1				
5040			6	5	3			
5042		1	6	6	5	3	5	
5538								
5540			3	6	3	1		
5542	2	4	7	7	7	7	7	3
6038								
6040	1	1	5	6	4	2	1	
6042	6	7	7	7	7	7	7	4
6538								
6540	1	2	5	3	2	3		
6542	6	7	7	7	7	7	7	4
7038								
7040		1	2	2	4	3		
7042	6	7	7	7	7	7	7	3
7044	6	7	7	7	7	2	1	1

Table 2a. Mean latitude and longitude of fishing effort. Note that latitude and longitude were recorded respectively in 2 and 5 degree increments.

Year	Latitude North	Longitude East
1978	43.6145	166.6935
1979	43.4545	166.8412
1980	43.4633	168.3070
1981	43.5224	168.4619
1982	43.2744	166.5234
1983	43.0490	164.8615
1984	42.9227	163.5887

Table 2b. Number of tans fished per year stratified into the three groupings of statistical areas.

Year	Area X	Area Y	Area Z	Total
1978	385,589	2,971,335	15,700	3,372,624
1979	394,669	2,819,661	4,160	3,218,490
1980	253,126	2,882,265	660	3,136,051
1981	275,860	2,949,380	3,795	3,229,035
1982	259,089	2,670,077	23,473	2,952,639
1983	304,854	2,652,547	145,985	3,103,306
1984	308,970	2,277,839	236,895	2,823,704

Table 3. Average CPUE of salmon in Japan's landbased drift gillnet fishery summarized by 2°x5° statistical area.

INPFC 2°x5° Area	CPUE				
	Sockeye	Chum	Pink	Coho	Chinook
4040	0.0000	0.5419	17.5551	0.0000	0.0563
4042	0.0000	0.7997	7.2053	0.0000	0.0808
4538	0.0000	0.6215	13.1747	0.0000	0.0370
4540	0.0000	0.7770	11.5848	0.0166	0.0683
4542	0.0000	0.8254	9.1716	0.0000	0.0658
5038	0.0000	0.7591	12.4848	0.0000	0.0000
5040	0.0954	1.2652	2.5162	0.0221	0.0426
5042	0.1139	0.9267	4.5169	0.4190	0.0888
5540	0.0246	1.0455	2.8679	0.2949	0.0607
5542	0.1543	0.9499	8.6284	0.2625	0.0705
6040	0.0932	0.8582	3.9603	0.3506	0.0650
6042	0.2345	0.9291	8.4297	0.2473	0.0424
6540	0.1341	0.7557	1.9728	0.7789	0.0768
6542	0.2916	0.8657	3.1373	0.3822	0.0455
7040	0.0832	0.4916	1.6418	1.1337	0.0743
7042	0.2398	0.7225	2.2828	0.7601	0.0694
7044	0.4018	0.9490	1.2887	0.3493	0.0489
Average:	0.1616	0.8547	5.8509	0.3288	0.0613

Table 4. Average CPUE summarized by fishing period. N is the number of 2°x5° statistical areas fished in each fishing period.

Fishing Period	CPUE Sockeye	Chum	Pink	Coho	Chinook	N
1.	0.4447	0.8898	1.5764	0.0213	0.0279	32)
2.	0.3756	0.9249	4.4765	0.0319	0.0384	46)
3.	0.2204	1.0274	3.9324	0.1013	0.0593	85)
4.	0.0950	0.8433	5.2868	0.2487	0.0690	91)
5.	0.0868	0.8864	5.0714	0.4168	0.0726	71)
6.	0.0750	0.7287	6.9349	0.6240	0.0655	55)
7.	0.0359	0.6572	8.6160	0.7096	0.0638	44)
8.	0.0300	0.5828	22.8199	0.9690	0.0888	17)
Average	0.1616	0.8547	5.8509	0.3288	0.0613	441)

Table 5. Average CPUE summarized by fishing period and stratified by three general groupings of statistical areas (see Figure 1 for description of groupings).

Fishing	Sockeye			Chum			Pink			Coho			Chinook					
Period	Area X	Area Z	Area Y	Area X	Area Z	Area Y	Area X	Area Z	Area Y	Area X	Area Z	Area Y	Area X	Area Z	Area Y	N_x	N_z	N_y
1.	0.0000	0.2048	0.5316	0.6708	0.6588	0.9413	8.3103	1.5030	0.5460	0.0000	0.3125	0.0022	0.0365	0.0600	0.0240	4)	2)	26)
2.	0.0497	0.3518	0.4805	0.9750	0.9769	0.9027	4.6086	1.1483	4.8513	0.0000	0.1289	0.0297	0.0676	0.0284	0.0305	10)	4)	32)
3.	0.0801	0.1539	0.3892	0.9914	1.1972	0.9907	5.8893	3.8297	2.0196	0.0079	0.3407	0.0920	0.0672	0.0789	0.0429	35)	15)	35)
4.	0.0096	0.0506	0.2118	0.8529	0.5410	0.9795	7.1459	3.5316	4.0677	0.0124	0.7172	0.2843	0.0671	0.0950	0.0585	39)	17)	35)
5.	0.0271	0.0226	0.1498	0.7482	0.8989	0.9726	8.1685	2.4043	4.0268	0.0260	0.6338	0.5930	0.0782	0.0597	0.0737	23)	13)	35)
6.	0.0000	0.0052	0.1360	0.7072	0.5040	0.8076	9.0696	1.1886	7.5203	0.2561	1.1319	0.6678	0.0788	0.0447	0.0645	16)	9)	30)
7.	0.0002	0.0000	0.0543	0.7443	0.1424	0.6329	13.5443	0.7212	6.5090	0.4497	0.0455	0.8580	0.0641	0.0000	0.0658	14)	1)	29)
8.	0.0000	--	0.0340	0.4039	--	0.6067	89.6042	--	13.9153	0.0000	--	1.0982	0.0051	--	0.0999	2)	0)	15)

Table 6. Probabilities from the ANOVA of log transformed catch rates of salmon. The factors are: 1) year (1978-1984); 2) Area (X and Y); and period (1 + 2, 3, 4, 5 + 6). Separate ANOVA's were conducted for each salmon species.

Source of Variation	DF	Sockeye	Chum	Pink	Coho	Chinook
Main Effects						
Year	6	0.00	0.00	0.64	0.00	0.00
Area	1	0.00	0.00	0.00	0.00	0.02
Period	3	0.00	0.00	0.00	0.00	0.00
2-Way Interactions						
Year x Area	6	0.03	0.00	0.17	0.27	0.00
Year x Period	18	0.45	0.00	0.10	0.04	0.00
Area x Period	3	0.00	0.44	0.77	0.00	0.03
3-Way Interactions						
Year x Area x Period	18	0.37	0.01	0.89	0.27	0.00

Table 7. Geographical comparison of the value of salmon catches by fishing period for the Japanese LBDN in 1981. Units are dollars/tan with standard deviations in parenthesis.

	Average Value of Catches	
Fishing Period	2°x5° statistical areas west of 155°E	2°x5° statistical areas east of 155°E
1	12.8[1] (0.0)	4.8 (1.1)
2	4.7 (3.3)	4.8 (0.7)
3	13.1 (21.1)	4.9 (1.8)
4	9.0 (9.7)	5.8 (2.4)
5	11.2 (15.0)	9.6 (1.8)
6	8.7[1] (0.0)	9.0 (2.4)

[1]Catches were recorded in only one 2°x5° statistical area.

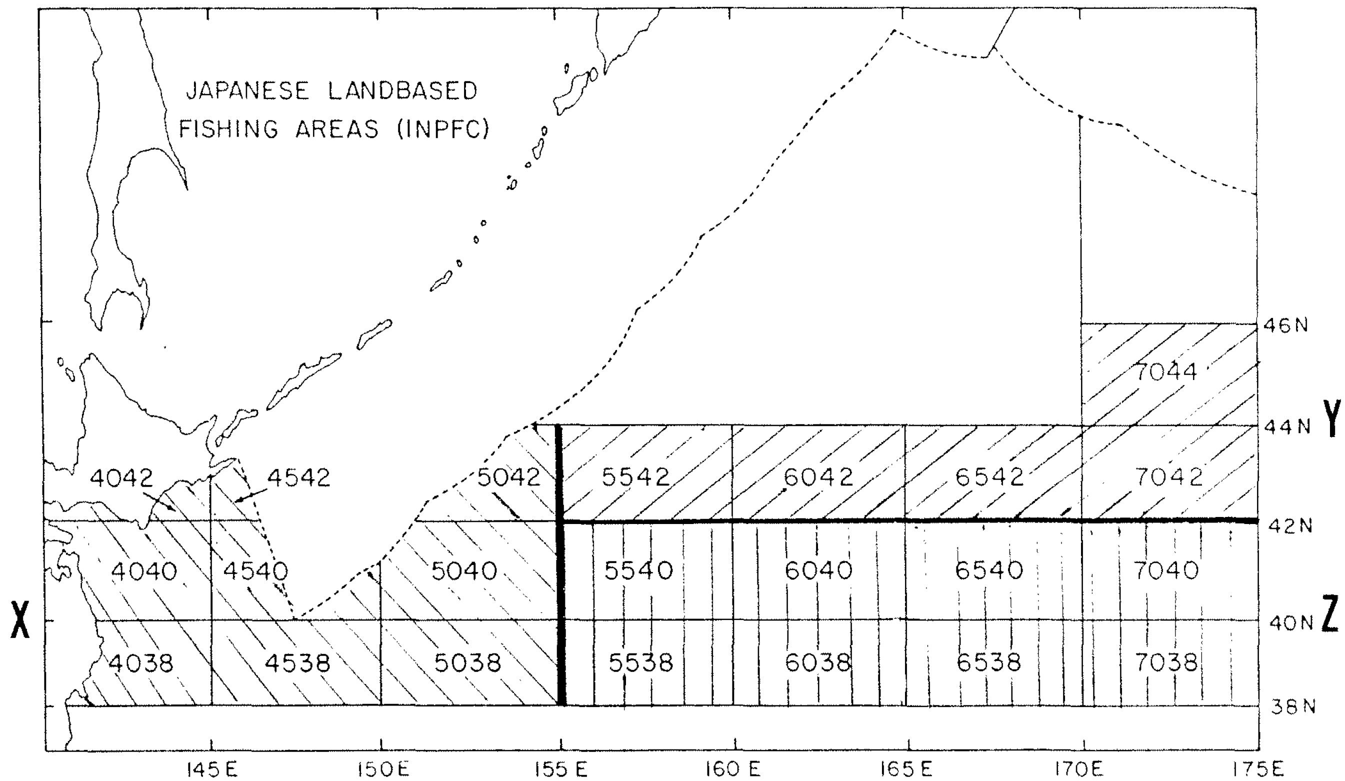


Figure 1. INPFC 2° X 5° statistical areas fished by the Japanese landbased driftnet salmon fishery since 1978. The statistical areas are also categorized into three broad groupings; areas X, Y, and Z.

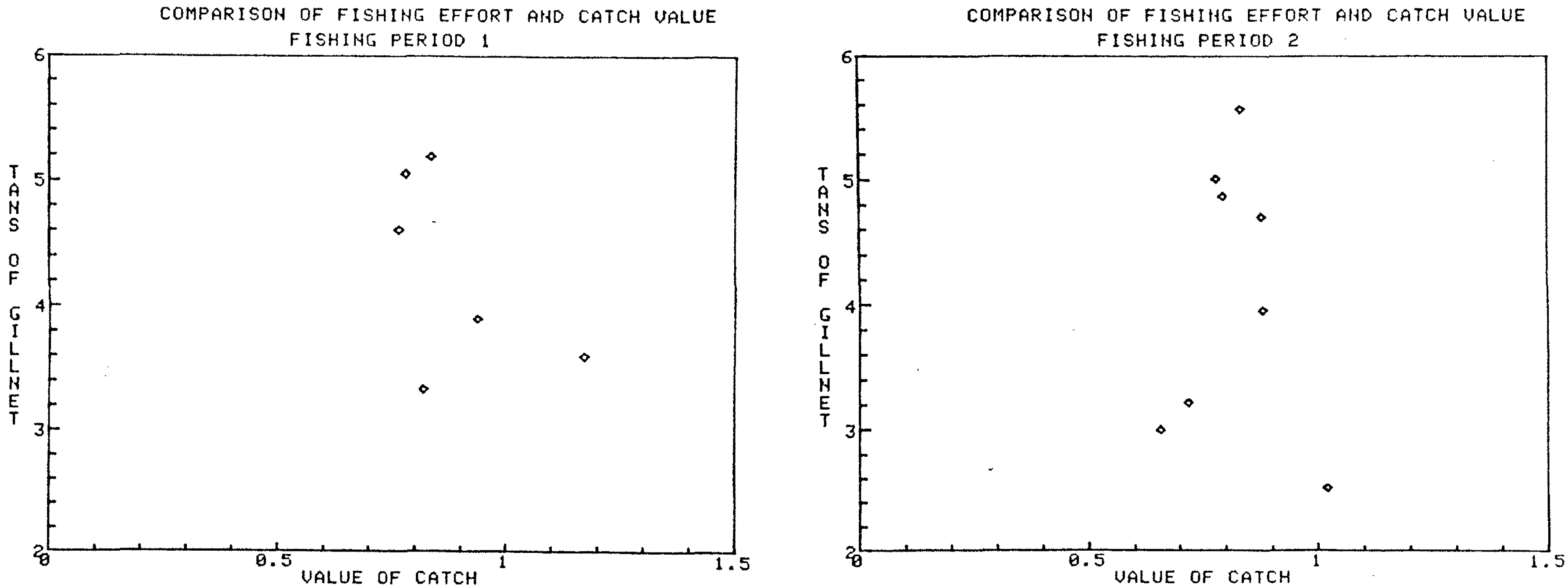


Figure 2. Bivariate relationship between the amount of fishing effort and estimated catch value for a given fishing period in 1981. Data points represent data from 2° X 5° statistical areas. Logtransformations have been applied to both variables.

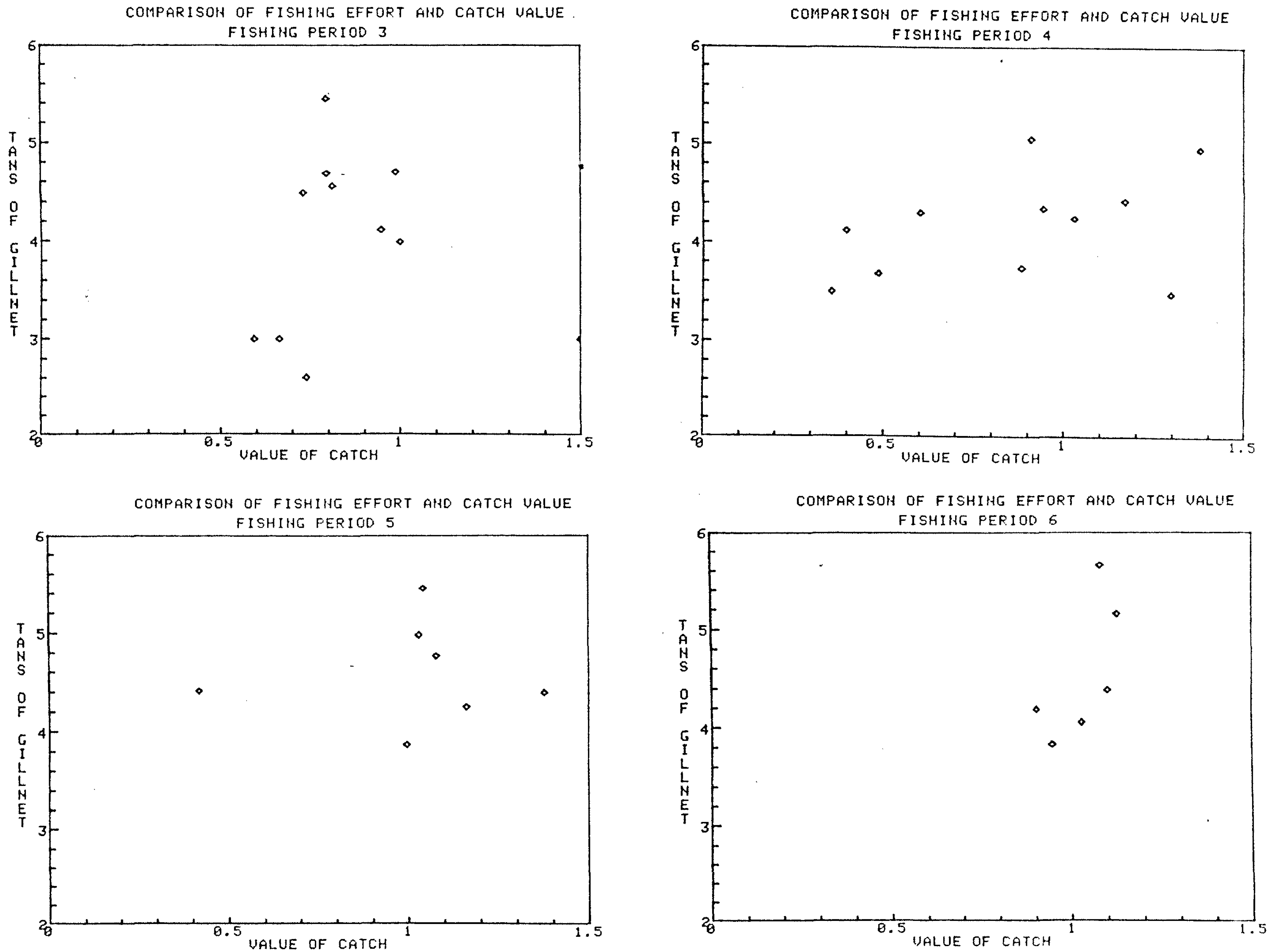
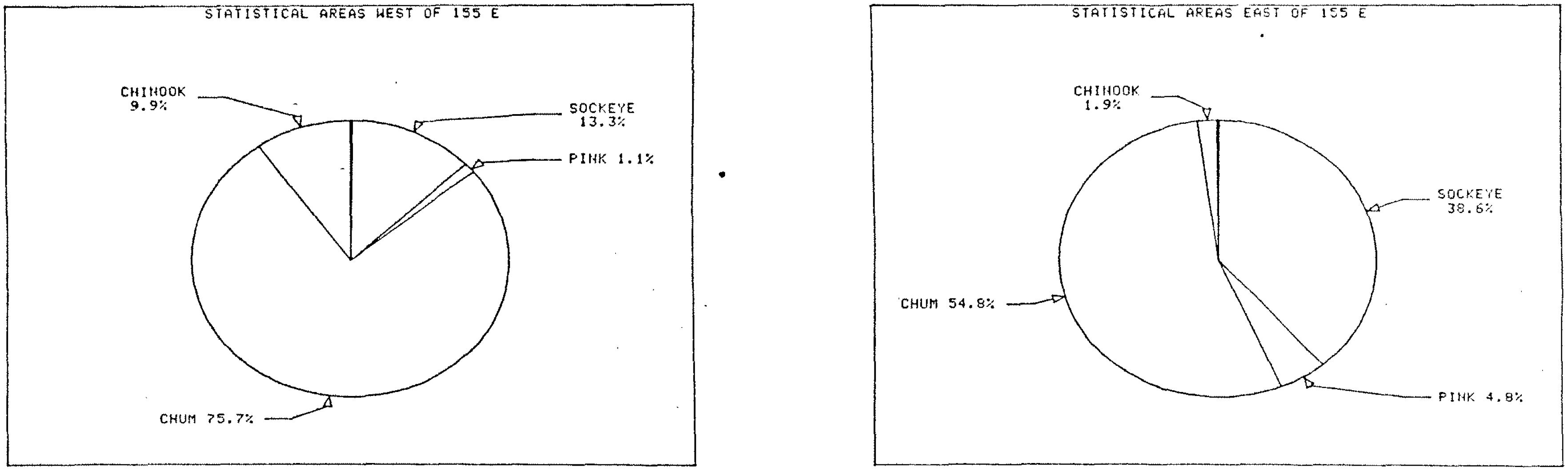


Figure 2. Continued.

FISHING PERIOD 2



FISHING PERIOD 3

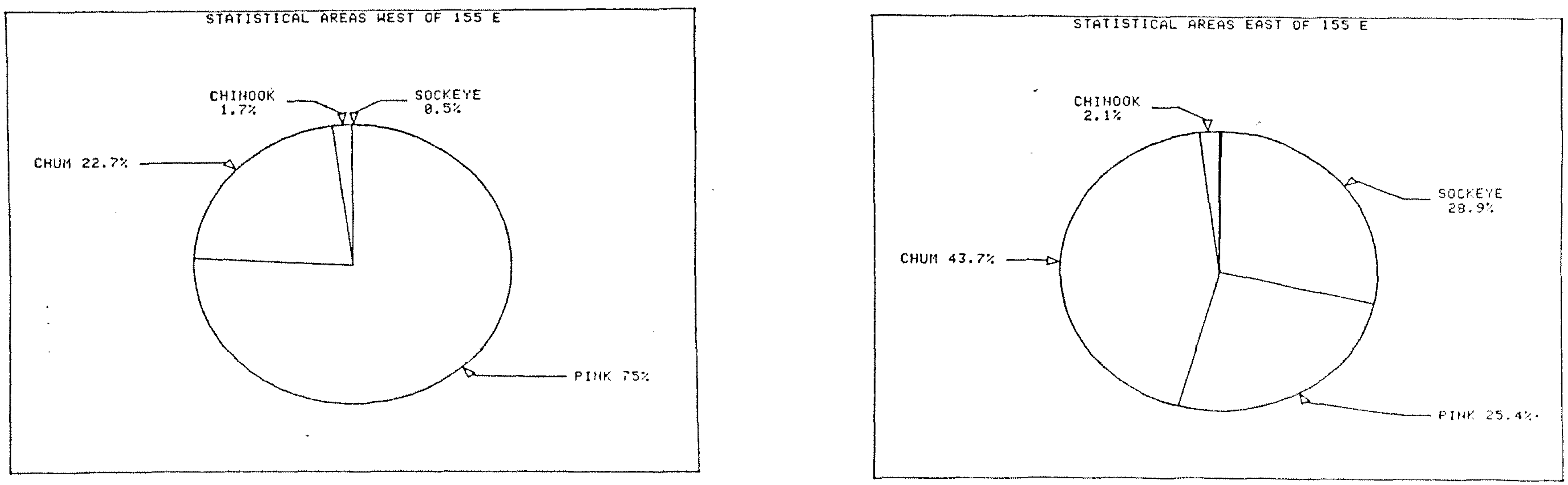
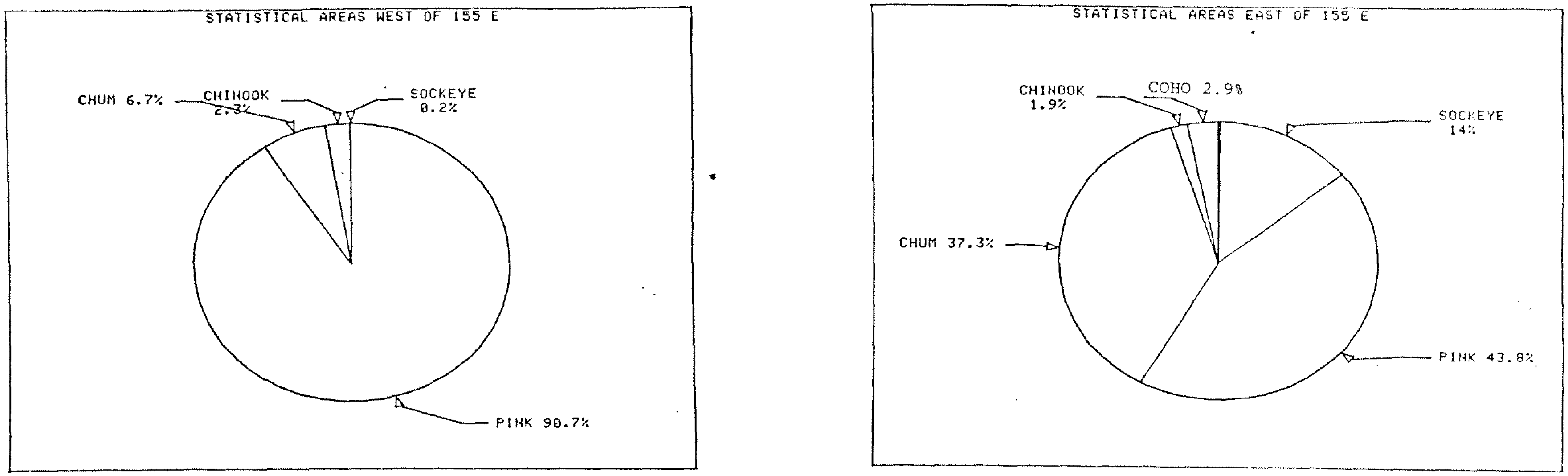


Figure 3. Comparisons of the contribution of individual salmon species to the value of catches for INPFC 2° X 5° statistical areas west and east of 155 E.

FISHING PERIOD 4



FISHING PERIOD 5

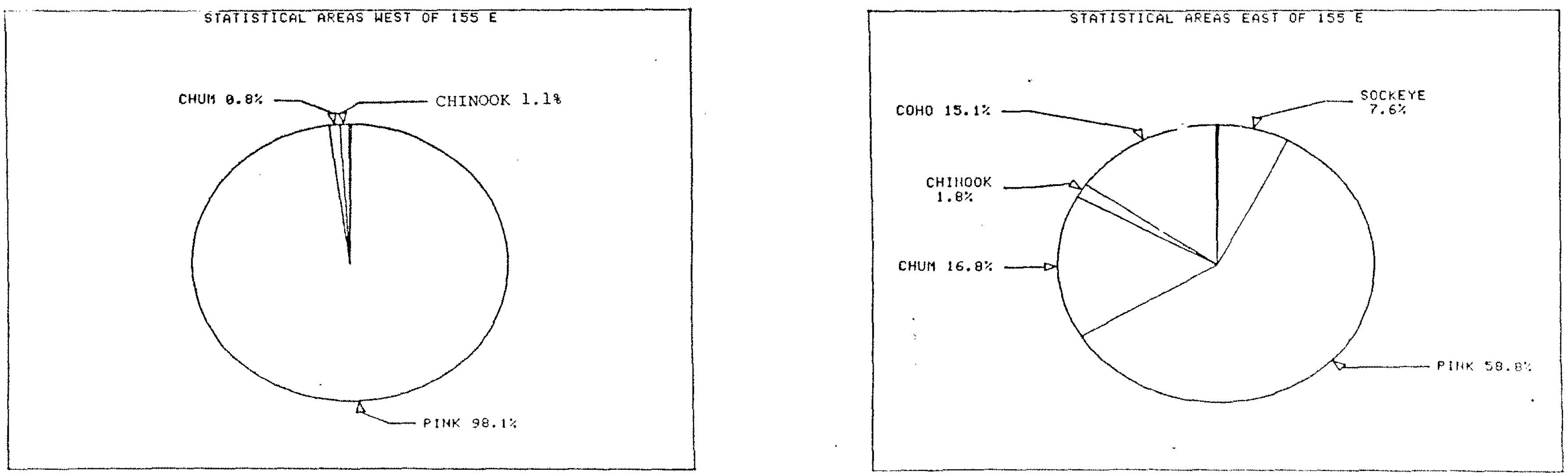


Figure 3. Continued.