W.P. 6

SKIPJACK IN THE EASTERN PACIFIC

by

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Skipjack tuna are highly migratory (traveling thousands of miles in their lifetime) and very responsive to their physical surroundings. Unfortunately neither of these factors are compatible with the standard population assessment techniques such as Production Model or Yield per Recruit analysis, unless prior adjustments are made to the underlying models. With a highly migratory species moving through a fishery, unless one has some measure of immigration or emigration, one simply cannot perform a meaningful Murphy analysis, the cornerstone of any age-structure analysis. And unless one knows the dynamics of availability of the underlying population to the fishery one cannot subject a time series of catch and effort statistics to a Production Model analysis.

Our basic knowledge of the skipjack tuna that are exploited in the eastern tropical Pacific is as follows:

1) The skipjack caught in the eastern Pacific surface fishery originate from spawning in areas to the west of where they are caught (presumably between 180° and 130°W).

2) They migrate into the area of the fishery (predominantly along the coasts of Baja California and of Central and South America) first appearing at approximately 40 cm total length (probably about one year of age).

3) They remain in the fishery from one to two years at which time they migrate back to the west.

4) Since 1950 the annual catch of skipjack tuna in the eastern Pacific surface fishery has fluctuated from 37 to 134 thousand tons, and exhibits large scale variability from year to year. Figure 1 gives the 1° areas of the eastern Pacific where skipjack was captured in 1975.

Many critical factors concerning the skipjack of the eastern Pacific surface fishery are not understood. For example it is not known whether the fluctuations in year-class strength in the catch reflect corresponding fluctuations in real year-class abundance or perhaps changes in migratory behavior and hence year-class availability. Also it is not known whether the fish exploited in the area south of 15°N have any relationship to those exploited north of this latitude. (Both segments of the fishery exhibit semesterality in their sizo compositions, however tagging indicated virtually no exchange). What we do have, at present, is simply a statistically significant relationship between environmental conditions in the apparent spawning area and total cohort catch in the eastern Pacific.

Research on the structure and dynamics of the eastern Pacific skipjack fishery has been undertaken by IATTC since its inception. A summary of the most recent work follows.

SIZE DISTRIBUTION OF SKIPJACK

With the exception of 1974, the proportion of larger and older fish in the catches of skipjack in the eastern Pacific Ocean has been greater during the 1971-1976 period than in earlier years. It is possible that this is due to larger skipjack being found in the new areas exploited in the westward expansion of the fishing effort in the CYRA in the zone between 5°N and 15°N, where much of the yellowfin is now taken. To examine this possibility mean weights of skipjack captured by purse-seiners by quarter in 22 selected 5° areas where most of the skipjack is taken were calculated for the two periods 1965-1970 and 1971-1975 (Figure 2a,b). The skipjack fishing area was divided into three main regions - northern, central and southern - as shown by the heavy lines in the figure. The area east of 85°W and north of 5°N was not included in the central area because it appeared to have smaller mean weights like those south of 5°N. The upper number in each 5° area indicates the mean value of the average weight in each quarter where length-frequency samples were taken and the lower number indicates the number of quarters; five-degree areas with mean weights $\geq$ 4 kg. are shown by hatching. It is evident that the number of hatched areas in the northern region has remained the same in both periods, while those in the central and southern regions have increased from 3 to 11. The average of the area values by region (using areas with more than one quarter sampled) is as follows:

	1965-1970	1971-1975
Northern region	3.4 kg.	3.3 kg.
Central region	3.5 kg.	4.3 kg.
Southern region	3.2 kg.	4.0 kg.

Both central and southern regions show an increase of 0.8 kg. during the later period as compared to the earlier one. Examination of Figure 2 reveals that in these regions 12 of the 5° areas compared showed an increase in mean weight in the 1971-1975 period while only 2 showed a decrease. This indicates that the increase in the proportion of larger fish in recent years is not related to the westward expansion of the fishery, but is fairly consistent throughout the entire fishery south of 15°N.

In Figure 3 are shown mean length-frequency distributions for the two periods and three regions obtained by combining data from 5° areas from skipjack taken by purse-seiners. In the northern region the distributions are similar except for the second quarter where there is a slight shift to larger fish in the later period. In the central region there is no change in the second quarter, a slight increase in the percent of larger fish in the first and fourth quarters and a marked increase in the third quarter. In the southern region, however, the changes in the size distributions are quite remarkable: for the 1965-1970 period the curves are characterized by one dominant peaked mode in all quarters, and quarters 1 and 3 show a small secondary mode as well; for the 1971-1975 period the curves are flattened with a greater proportion of larger fish in the first three quarters, and also a tendency for a greater proportion of smaller fish as well, particularly in the fourth quarter. This spreading of size distributions is also seen to a lesser degree in the last two quarters in the central region. It appears that more older fish are entering the fishing areas south of 15°N, or that more fish, having entered as younger fish, are remaining longer and growing into older fish and delaying their migration back to the spawning areas of the central Pacific.

Preliminary data for the first two quarters of 1976 (Figure 4) show that this distribution is being maintained with an estimated catch of 50,000 tons of age 2 + fish for all areas.

More than half of the yellowfin captured in the CYRA have been between 50 cm and 80 cm in length. For the 1971-75 period the increase in the proportion of older skipjack captured south of 15°N was for fish between 50 cm and 70 cm in length. Skipjack and yellowfin of similar size eat much of the same food species available in an area, and may be presumed to be in competition for food when the supply is limited. The logged catches of yellowfin of all ages captured south of 15°N in the CYRA has risen since the early 1960's as shown by the following mean values:

1961-1965	46,400 tons
1966-1970	64,600 "
1971-1975	108,800 "

While a good proportion of this tonnage was taken from areas where skipjack is not abundant, at least half of the yellowfin captured in skipjack areas were of sizes that could compete with skipjack for food. Perhaps the larger skipjack have replaced some of the smaller yellowfin removed by fishing, because of the increased supply of food available. Further investigations are planned to test this possibility.

SKIPJACK GROWTH

An asymptotic growth curve, where growth decreases with increasing age, has traditionally been used to express the relationship between age and length of fish. Examination of quarterly modal progressions for both yellowfin and skipjack in the eastern Pacific suggests that the growth is linear for fish within the range of modal sizes captured by the fishery. For skipjack the modes that can be conservatively interpreted to show growth range from 37 to 73 cm, and for yellowfin from 42 to 154 cm. For skipjack, 23 modal progressions showed similar slopes, with an average growth of 4.35 cm per quarter or 1.45 cm per month.

COHORT ANALYSIS FOR SKIPJACK

The identification of A and B semestral groups in the size distributions of skipjack has always been subjective and questionable, and the calculations of cohort catches are dependent upon the assumptions made for those identifications. The previous method of cohort analysis consisted of tentatively identifying the dominant group in each quarter north and south of 15°N and analyzing as such, i.e. using different separation lengths to separate age-1+ fish from age-2+ fish according to whether the dominant group was believed to consist of group-A or group-B fish. (Separation lengths for group-A fish were 57, 61, 66 and 70 cm. for quarters 1 to 4 respectively; those for group-B fish were 7 cm. less). Reexamination of the data has led to the conclusion that large errors could be made in the calculations of the relative numbers and tonnage of younger and older fish if the dominant groups were misidentified. A modified method of cohort analysis has more recently been used which would avoid the problem of misidentification. The same quarterly separation lengths were assigned for all fish regardless of which group appeared to be dominant: These lengths were midway between those previously used for each group. This method is more conservative than the previous one, and is free of subjective bias, as no decision need be made concerning the identification of groups. There necessarily will be errors in calculating cohort catches for quarters where one group predominates when using separation lengths that are an average of those formerly used for each of the groups. However, the more serious errors made by using separation lengths for one or the other group when, in fact, the group has been misidentified, are avoided. Thus far the problems presented by the likelihood of there being two groups of skipjack are insoluble in terms of cohort analysis, but this method (method 4) appears to be the best of poor alternatives. Because a higher proportion of very young fish, apparently of age 0+, were caught in 1975, 3 year-classes were separated using method 4 as follows:

Quarter	Age (year)	Separation length (cm)	Age (year)	Separation length (cm)	Age (year)
1	0+	36	1+	53	2+
2	"	40	"	57	"
3	"	45	"	62	"
4	"	49	"	66	"

The difference between separation lengths for age 0+ and 1+, and separation lengths for age 1+ and age 2+ is 17 cm, representing a year's growth based on the use of the linear growth equation. Previous methods have assumed that the number of age 0+ skipjack was neglibible, and they were included in the estimates of age 1+ fish. In Figure 5 it is evident that the proportion of age 0+ fish has increased in 1975 and is no longer negligible, the total catch being 10,000 tons. Cohort catches are calculated by adding the catches of the previous year's age 0+ fish and the following year's age 2+ fish to those of the age 1+ fish.

SKIPJACK AND THE SOUTHERN OSCILLATION

Sea-surface temperature (SST) data in the southern spawning area, assumed to lie somewhere between 0°and 30°S and 130°W and 180°, are insufficient to obtain reliable indices of SST to be correlated with indices of skipjack abundance in the eastern Pacific at a later time. The Southern Oscillation (S.O.) index is the mean pressure difference between Easter Island and Darwin, Australia. The S.O. index and SST along the equator between 130°W and 180° are indicative of oceanographic conditions in the southern spawning area. The strength of the southeasterly trade winds is directly related to the S.O. index, and SST in the southern spawning area is dependent in part upon the tradewind strength through mixing, and SST along the equator is dependent in part upon tradewind strength through divergence and upwelling. The S.O. index is believed to be a better indicator of SST in the southern spawning area than is temperature along the equator. The effects of the Southern Oscillation are believed to extend northward into the northern spawning area as well.

In past years tentative predictions of total annual catches of all ages of skipjack have been made on the basis of SST and the S.O. index in order to test the apparent relationship. Predictions of total catches of all ages for 1974 and 1975 have failed, and no further such predictions will be made. Predictions for cohort catches are being made instead, as they are thought to be more representative of the population size of year-classes which are apparently correlated with environmental conditions in the spawning areas and possibly with conditions affecting migrations in and out of the fishery.

In correlating skipjack cohort abundance with the 6-month S.O. index there is a lag period of about 2 years between the index and the year of recruitment (i.e., S.O. index April-September 1972 is paired with 1974 cohort catch). Sea-surface temperatures along the equator in the central Pacific appear to lag behind the S.O. index so that peak spawning in the southern spawning area is believed to occur about 1 1/2 y-ars before the middle months of the cohort year.

SKIPJACK COHORT PREDICTIONS

The effects of cohort analysis by this modified method on the apparent relationship between the Southern Oscillation index and cohort catches at a later time is negligible; the regression line for the cohort years 1961-1974 remains essentially the same by all methods.

Preliminary data for the first semester of 1976 indicate that over half of the catch of skipjack by weight is composed of older age-2+ fish, as shown below:

	Logged catch			Estimated total catch
Quarter	Age 0+	Age 1+	Age 2+	Age 2+
	(thousands of short tons)			
1	0.0	14.8	26.7	29.1
2	0.1	19.1	11.4	20.5
Semester	0.1	33.9	38.1	49.6

Total catches of age-2+ fish were estimated from ratios of logged catch of all ages to total catch of all ages (from the weekly "Estimated Tuna Catch and Fleet Information" reports). About 50,000 tons of older fish belonging to the 1975 cohort has already been captured in 1976. This brings the 1975 cohort catch to 116,000 tons which is a minimal estimate for the final value, as additional older fish are expected to be taken during the remainder of the year. The prediction for the 1975 cohort, based on a high S.O. index, was for a low catch (best estimate 60,000 tons) and it is apparent that it has failed completely, the actual cohort catch being the fourth largest since 1955, when length frequency samples were first available. For the 1961-1974 cohort years the correlation coefficient (r) was -0.80 ($P < 0.001$) for cohort catches and the S.O. index; including the 1975 cohort data reduces the coefficient to -0.69 ($P < 0.01$), meaning that only 48% of the variation in cohort catch can now be attributed to the Southern Oscillation and associated oceanic conditions (see Figure 5).

RATE OF DEPLETION OF SKIPJACK COHORTS

The estimated numbers of skipjack captured by quarter for all areas east of 150°W from the 1955 to the 1974 cohorts are plotted in Figure 7. Numbers in the figure indicate cohorts by year of recruitment. The circled points indicate the latest quarter where significant recruitment was assumed to have occurred (these were selected subjectively by examination of the curves and are the quarters after which the catches decline rapidly). The heavy lines connect points used to calculate the rate of depletion, Z_A. The portion of the catch curve showing a relatively steady downward trend with time represents a combination of natural mortality (M), fishing mortality (F), and emigration (E), designated as the rate of depletion (Z).

All but four of the 1955-69 cohorts show a sudden increase in numbers in quarters 6, 7 or 8 but usually in quarter 7 (third quarter of the second year). This may represent a group of older fish entering or re-entering the fishery. A normal catch curve was plotted from the median numbers of fish in the 1955-69 cohorts by quarter east of 150°W and is shown in Figure 8 (because of extreme high values in some quarters the median was regarded as a better measure of central tendency than the mean). Vertical lines indicate range, bars indicate 95% confidence limits and heavy lines connect points used to calculate the rate of depletion, Z_A. A rapid depletion is seen between quarters 4 and 6, but from quarter 6 to quarter 7 the value remains constant, suggesting that a small influx of older fish occurs at this time. The depletion rate from quarter 7 to 8 appears to be about the same as that from quarter 4 to 6, but little confidence can be placed in the median value for the eighth quarter because of the wide confidence limits.

With the exception of the 1973 cohort, the 1970-74 cohorts show catch curves differing markedly from those of the 1955-69 cohorts. In the 1970's a large number of older fish appears to have entered the fishery in quarters 4 to 6 (Fig. 7). The reasons for these apparent changes in the catch curves are not understood.

Attempts were made to calculate the rate of depletion for each cohort by linear regression of the logarithms of the numbers captured and the quarter. The points on the catch curves used were selected according to the following criteria: 1) a minimum of four consecutive points was required, beginning with the circled point (Fig. 7); values increasing with time in the later quarters (6, 7 and 8) were excluded as they were assumed to represent an influx of older fish, and subsequent values were also excluded; values of less than 10,000 fish (indicated by horizontal lines in Figure 7) were excluded as unreliable. The points used in the regressions are shown connected by heavy lines in Figure 7. A total of 11 cohorts out of 20 showed data which fulfilled the criteria. The instantaneous rate of depletion on an annual basis, Z_A, ranged from 3.60 to 5.60 with one outlier of 8.00 for the 1962 cohort. Exluding this value, the variance among the remaining values of Z_A was low and the values normally distributed. The mean value for the 10 cohorts used was 4.62 (with 95% confidence limits of 4.19 and 5.05). This means that for every 1000 fish captured from a cohort when initial recruitment is complete only 10 will be captured a year later, providing a second wave of older fish has not reentered the fishery.

The rate of depletion calculated from the median values for the 1955-69 cohorts for quarters 4, 5 and 6 is 6.40 (Fig. 4), meaning that only two fish will be captured a year later for every 1000 at full recruitment. This method, and the first method based on analysis of individual cohorts, both show high depletion rates but the estimate of $Z_A = 4.62$ from the first method is regarded as the better one.

In the IATTC bimonthly report for January-February 1976, the rate of depletion for tagged fish (fishing and natural mortality, shedding of the tags, mortality due to carrying tags, and emigration) minus fishing mortality was found to agree approximately with a previous estimate (IATTC Bulletin, 13(1)) of 0.23 for the monthly instantaneous rate, or 2.59 for the annual instantaneous rate (X_A). This Bulletin also uses a value of 0.14 for the monthly instantaneous rate of natural mortality, or 1.68 for the annual rate (M_A). If we assume, for simplicity, that the effects of tags are negligable the estimates of the parameters of which the rate of depletion (Z_A) is composed are as follows:

$$
\begin{array}{rl}
 & F_A = 2.01 \\
X_A = 2.59 \left\{ \begin{array}{l} M_A = 1.68 \\ E_A = 0.91 \end{array} \right. & \\
\hline
 & Z_A = 4.60
\end{array}
$$

These estimates suggest that fishing mortality (F_A) has the greatest effect and emigration (E_A) the least effect on the rate of depletion. Little confidence, however, can be placed in any of these estimates because of the many assumptions involved and the great variation among the results of tagging. To the present investigator it is more likely that emigration rate should be greater than fishing mortality, than the reverse. Further investigations are planned to examine these rates by fishing areas north and south of 15°N.

ESTIMATES OF CATCH-PER-UNIT-OF-EFFORT FOR SKIPJACK

The problem of estimating effort on a species in a multi-species fishery is a difficult one. Logged catch and effort data from the purse-seine fishery of the eastern Pacific for yellowfin and skipjack from 1961 to 1975 has been re-examined in an attempt to obtain meaningful estimates of effort and catch-per-unit-of-effort (CPUE) for skipjack. Only data from 22 five-degree areas designated as skipjack areas were used (see Figure 2).

This already eliminates some of the effort on yellowfin in areas where little skipjack is usually captured. Data from seiners in each of the 22 areas were examined by quarter, and only those area-quarter strata having ≥ 100 day's fishing standardized to class-3 seiner, and having ≥ 200 tons of skipjack captured by seiners were used. These values were arbitrarily set. The objective was to eliminate, as much as possible, effort assumed to be mainly for yellowfin, while retaining as much of the skipjack catch as possible. Annual CPUE values were calculated by dividing the sum of the retained catch by the sum of the retained effort in the area-quarter strata used.

The percent of logged effort and catch retained relative to total logged effort and catch in the CYRA is shown in columns A and B of the following table. The mean effort retained was 55% while the mean catch retained was 89%, so 45% of the effort, assumed to be mostly on yellowfin, has been removed while losing only 11% of the skipjack catch. However, the percent of logged effort retained increased to 70% in 1974 and to 71% in 1975. This may be related to the increase in the sum of the surface areas of the five-degree areas in the strata selected for these years (column D in the table). The fleet was more dispersed geographically and in time within the 22 skipjack areas in 1974 and 1975, as well as exerting more effort (column E of the table; Figure 10, center panel). Possibly more effort on yellowfin has been included in these years relative to earlier

Estimates of annual catch per unit of effort (CPUE) for skipjack. Annual CPUE values computed from 22 selected 5°-areas, using logged seiner data from area-quarter strata with ≥ 100 standardized class-3 day's fishing (SDF) and with ≥ 200 tons of skipjack captured.

Column	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
					All 22 areas			Areas North of 15°N			Areas 5°N to 15°N			Areas south of 5°N		
Year	Percent of logged effort retained	Percent of logged catch retained	Percent of retained catch from area 2-05-080	Sum of 5° areas fished by quarter	Effort 1000's SDF	Catch 1000's tons	CPUE tons/SDF	Effort 1000's SDF	Catch 1000's tons	CPUE tons/SDF	Effort 1000's SDF	Catch 1000's tons	CPUE tons/SDF	Effort 1000's SDF	Catch 1000's tons	CPUE tons/SDF
1961	42	95	49	9.4	7.8	31.9	4.1	1.4	2.8	2.1	5.0	13.4	2.7	1.4	15.6	11.0
62	61	95	54	13.3	11.6	48.9	4.2	2.2	3.8	1.7	4.3	13.6	3.2	5.1	31.6	[illegible]
63	56	87	52	14.8	9.6	59.3	6.1	2.2	8.1	3.7	2.2	8.1	3.7	5.3	43.1	8.1
64	40	90	61	12.5	6.5	33.8	5.2	2.2	6.1	2.7	1.5	5.4	3.6	2.7	22.4	8.2
65	[illegible]	87	77	13.7	10.6	48.3	4.6	3.0	5.8	2.0	1.8	2.5	1.4	5.9	40.0	6.8
66	50	92	89	9.1	8.3	40.3	4.9	0.8	1.3	1.6	1.1	2.5	2.2	6.3	36.5	5.8
67	64	96	48	13.3	9.4	93.8	10.0	4.7	33.6	7.1	0.5	0.3	0.5	4.2	59.9	14.4
68	64	94	19	16.5	9.9	51.7	5.2	1.1	4.8	4.2	4.8	20.8	4.3	3.9	26.1	6.7
69	43	75	62	14.0	7.8	28.4	3.6	4.5	4.6	1.0	1.0	2.3	2.3	3.5	19.6	5.6
70	50	86	28	[illegible]	8.9	28.2	3.2	6.3	18.5	2.9	0.7	1.8	2.4	1.8	7.9	4.3
71	64	94	45	18.8	13.6	80.6	5.9	3.7	13.5	3.6	4.3	28.5	6.6	5.6	38.6	6.9
72	45	84	33	14.3	8.6	16.6	1.9	1.5	3.1	2.1	3.1	3.4	1.1	4.1	10.2	2.5
73	51	87	16	15.8	12.3	24.9	2.0	1.3	0.5	0.4	6.9	10.2	1.5	4.1	14.3	3.5
74	70	90	9	23.8	19.9	62.5	3.1	1.9	2.6	1.4	13.2	44.7	3.4	4.8	15.3	3.2
75	71	91	46	32.7	21.4	85.7	4.0	4.8	7.8	1.6	7.9	20.3	2.6	8.7	57.7	6.6
Mean	55	89	46				4.5			2.5			2.8			6.7

Note: Values in columns E to P were rounded after dividing catch by effort, so division of rounded values will result in small differences in some values of CPUE.

years, which would explain the increased amount of effort retained. If this is, in fact, the case, then the CPUE values for skipjack for these past two years are too low relative to the other years.

Out of the 22 five-degree areas examined an average of 46% of the annual retained catch came from the Gulf of Guayaquil area (2-05-080) with extreme values ranging from a low of 9% in 1974 to a high of 89% in 1966 (column C of the table). So the skipjack fishery may be regarded as composed of two fisheries: a highly concentrated one in a very small area (the eastern portion of area 2-05-080); and a diffuse one in the remaining 21 areas. The westward expansion of effort on yellowfin between 5°N and 15°N brought increased catches of skipjack as well from these areas and the effort has increased considerably in 1973, 1974 and 1975 (column K of the table). The area north of 15°N traditionally has been investigated separately from that south of 15°N because of a gap in the skipjack distribution off central Mexico where high temperatures and/or associated oceanic properties are thought to be unfavorable for skipjack. The 22 five-degree areas were therefore divided into three regions: north of 15°N; 5°N to 15°N; and south of 5°N. For the southern region, in most years, most of the catch came from the Gulf of Guayaquil area. The data for these three regions are given in columns H to P of the table and the CPUE values are shown in Figure 9. The CPUE values in the southern region were much higher then in the other regions from 1961 to 1970; from 1971 on the differences are less; in fact, in 1974 the CPUE in the central region exceeded that in the southern region. The southern region shows a marked downward trend in CPUE which is statistically significant (Figure 9, lower panel). However, the 1975 CPUE in the southern region is double that of the previous three years, so perhaps the trend is reversing itself. A similar, but even greater decline is seen from 1961 on, in the catch per-capacity-ton of the Ecuadorian fleet of small baitboats.

There appears to be a slight downward trend in CPUE in the northern region but it is not statistically significant. There is no trend in the central region.

RELATIVE COHORT CPUE OF SKIPJACK

The cohort catch (catch from a year-class) of skipjack east of 150°W has been significantly correlated with the Southern Oscillation (S.O. index). No correction for changes in effort had been made, mainly because of the problem of allocating effort in a two-species fishery, and partly because effort in the skipjack areas was not believed to have increased, as no trend in annual catches was apparent. The large increase in effort in the skipjack areas in 1974 and 1975 (Figure 10, center panel) now requires that the cohort catch be corrected for effort in order to serve as a measure of year-class abundance.

The total estimated numbers of fish captured east of 150°W in each age group (0+, 1+, and 2+ years of age) was divided by the retained logged effort in the skipjack areas (see preceding section) for the years of capture, and the three values added to obtain relative cohort CPUE (in thousands of fish per day's fishing standardized to class-3 seiners). The term relative is used because the total catch is divided by a portion of the unknown total effort on skipjack. The retained logged effort used is assumed to be well correlated with the unknown total effort on skipjack, so that if the assumption is valid, the values obtained are measures of relative apparent abundance, even though the true CPUE values would be lower could they be calculated. For simplicity it was assumed that all the catch was taken by seiners; when in fact, a minor proportion, varying annually, was taken by baitboats during the period studied.

Total cohort catch, effort on skipjack, and relative cohort CPUE are shown in Figure 10. The trend line for relative cohort CPUE (lower panel) was drawn by eye through the 4-year running means. There is a marked drop in the later years, with the 1971-75 period having values lower than any of the previous ten years, the means dropping from 2.8 to 1.2 thousand fish per day - a decrease of 57%. The decrease is somewhat less when the CPUE is calculated with tonnage rather than numbers of fish, because of the increased proportion of larger and older fish captured in recent years, but numbers are a better indicator of year-class abundance than is weight. Cohort catch in tons was formerly used for predictive purposes. The downward trend is thought not to be related to increased effort as the CPUE began to drop before the effort increased (Figure 10, center panel). The effort value for 1976 was assumed to be the same as in 1975 for the purpose of estimating CPUE of age 2+ fish of the 1975 cohort captured in 1976, so that the value of the relative cohort CPUE for 1975 is a preliminary estimate.

The downward trend in apparent abundance is thought to be a natural fluctuation caused by unknown changes in oceanic conditions, either in the spawning areas of the central Pacific, in the migration routes, or in the fishing areas, particularly south of 5°N and in the Gulf of Guayaquil area as suggested by Figure 9. There has been no corresponding trend in the S.O. index, or in the sea-surface temperature in the spawning areas. The effect of the S.O. index appears to be superimposed on the trend. The linear relationship of the percent deviation of the CPUE from the trend with the S.O. index was tested and proved significant with a correlation coefficient of -0.61 ($P<0.02$). The coefficient for cohort numbers uncorrected for effort and the S.O. index was -0.68 ($P<0.01$) so the effect of correcting for effort by this method has reduced confidence in the apparent relationship between skipjack abundance and the S.O. index. The relative cohort CPUE, in spite of the weaknesses of many of the assumptions required in this method of estimating relative effort on skipjack, is probably still a better measure of year-class abundance than is the uncorrected cohort catch because of the large increase in effort beginning in 1974.

STUDIES ON SKIPJACK MIGRATION (by Forrest R. Miller)

A study was begun to investigate the possible relationship between the apparent abundance of skipjack in the eastern Pacific and periodic changes in the location and strength of the North Equatorial Counter Current (NECC).

Seasonal variations in the structure and strength of the NECC are also correlated with the Southern Oscillation (S.O.) through air-sea interaction processes. It has been hypothesized that skipjack may migrate eastward in or near the NECC in a passive or active manner and in numbers depending on the physical and biological conditions in the ocean area encountered. For example, in some seasons upwelling along the equator and in the NECC and the availability of tuna forage between the equator and 10°N may be greater than in other seasons, depending on the changes in large-scale ocean and atmospheric circulations. The area considered to have a suitable environment for skipjack outside the CYRA lies between 120°W and 150°W from about 3°N to 15°N. Since 1960 the largest annual logged catches of skipjack outside the CYRA have been made between the equator and 10°N during the summer months (June-August) (See IATTC Annual Report for 1975). Oceanographic cruises crossing the NECC between 120°W and 150°W have found a zooplankton peak in the surface convergence zone which lies between the equator and the center of the NECC. Periodic fluctuations in the strength of the NECC and/or the Equatorial Undercurrent (Cromwell Current) are associated with changes in the S.O. These fluctuations in the NECC may influence in some way the migratory paths of the skipjack into the eastern Pacific.

The long-term positions and strength of the NECC for June, July and August along 120°W, 140°W and 160°W from the equator to 12°N have been calculated. Mean temperature and salinity profiles, taken from historical files of hydrocast data, were used to calculate dynamic heights of density (temperature-salinity) surfaces at 2° latitude intervals. From these calculations the monthly mean strength (or transport rate) of the NECC has been calculated. The temperature and salinity (T-S) relationships obtained for the monthly mean NECC calculations of speed and transport from the ocean surface to a depth of 500 meters will provide the long-term mean (climatology) reference for comparing calculations of the strength of the NECC between 120°W and 140°W for specific months and years that skipjack were being captured in the eastern Pacific. At this time work is progressing to determine the monthly and/or seasonal (summer) variations in the strength of the NECC during June to September 1971. One of the largest catches of skipjack on record occurred in 1971, and in 1972 one of the lowest catches occurred. Various factors related to the strength and locations of the NECC in the summer of 1971 will be compared to the long-term mean NECC strength. In addition, the strength of the NECC in 1972 will be calculated and compared to the long-term mean and the 1971 strengths and locations of the NECC to determine if there exist any relationships between the two contrasting skipjack years of 1971 and 1972. Adjustments in time and space variations in the NECC for each period studied will be considered also.

FIGURE CAPTIONS

Figure 1. Areas of skipjack capture in 1975.

Figure 2. Average values of mean quarterly weights of skipjack captured by purse seiners by 5°areas for two periods. The hatched areas indicate values $\geq$ 4.0 kg.

FIGURE 3. Length-frequency distributions of skipjack captured by purse seiners for two periods and three regions of the CYRA.

FIGURA 4. Length-frequency distributions of skipjack captured by baitboats and purse seiners in the first semester of 1976 (preliminary data), north and south of 15°N.

FIGURE 5. Percent of age 2+ skipjack (by weight) and catches by age captured east of 150°W.

FIGURE 6. Plots of cohort catch of skipjack and the southern oscillation index. Cohort value for 1975 is preliminary.

FIGURE 7. Estimated number of skipjack captured by quarter from 1955-1974 cohorts.

FIGURE 8. Median estimated numbers of skipjack captured by quarter from 1955-69 cohorts.

FIGURE 9. Catch-per-unit-of-effort of skipjack by seiners from 1961 to 1975 in 22 five-degree skipjack areas by regions; and catch-per-capacity-ton of skipjack by the Ecuadorian fleet of small baitboats from 1957 to 1975.

FIGURE 10. Total cohort catch of skipjack east of 150°W in the eastern Pacific (upper panel); retained logged seiner effort from area-quarter strata in 22 5-degree skipjack areas, having $\geq$ 100 days fishing standardized to class-3 vessels, and having $\geq$ 200 tons of skipjack (center panel); and relative cohort catch-per-unit-of-effort (CPUE) of skipjack (lower panel) from 1961 to 1975.

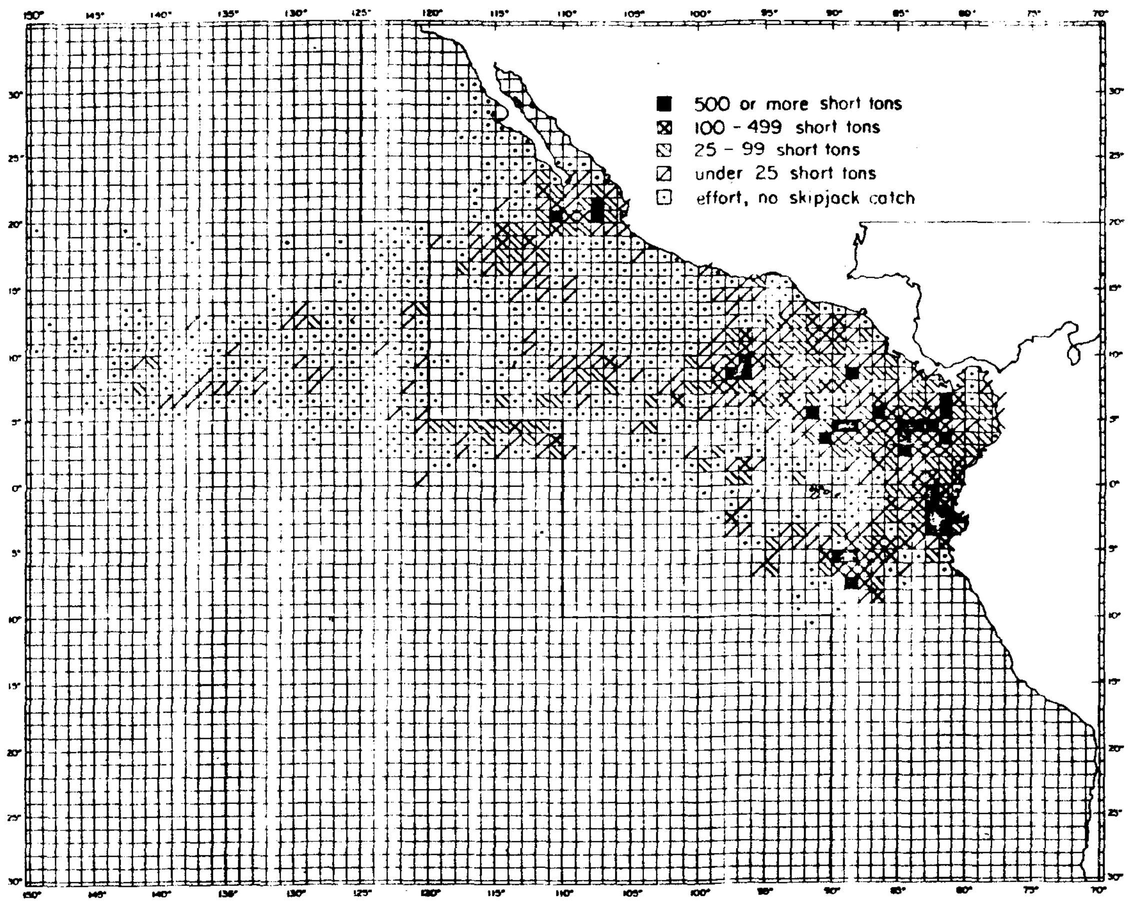
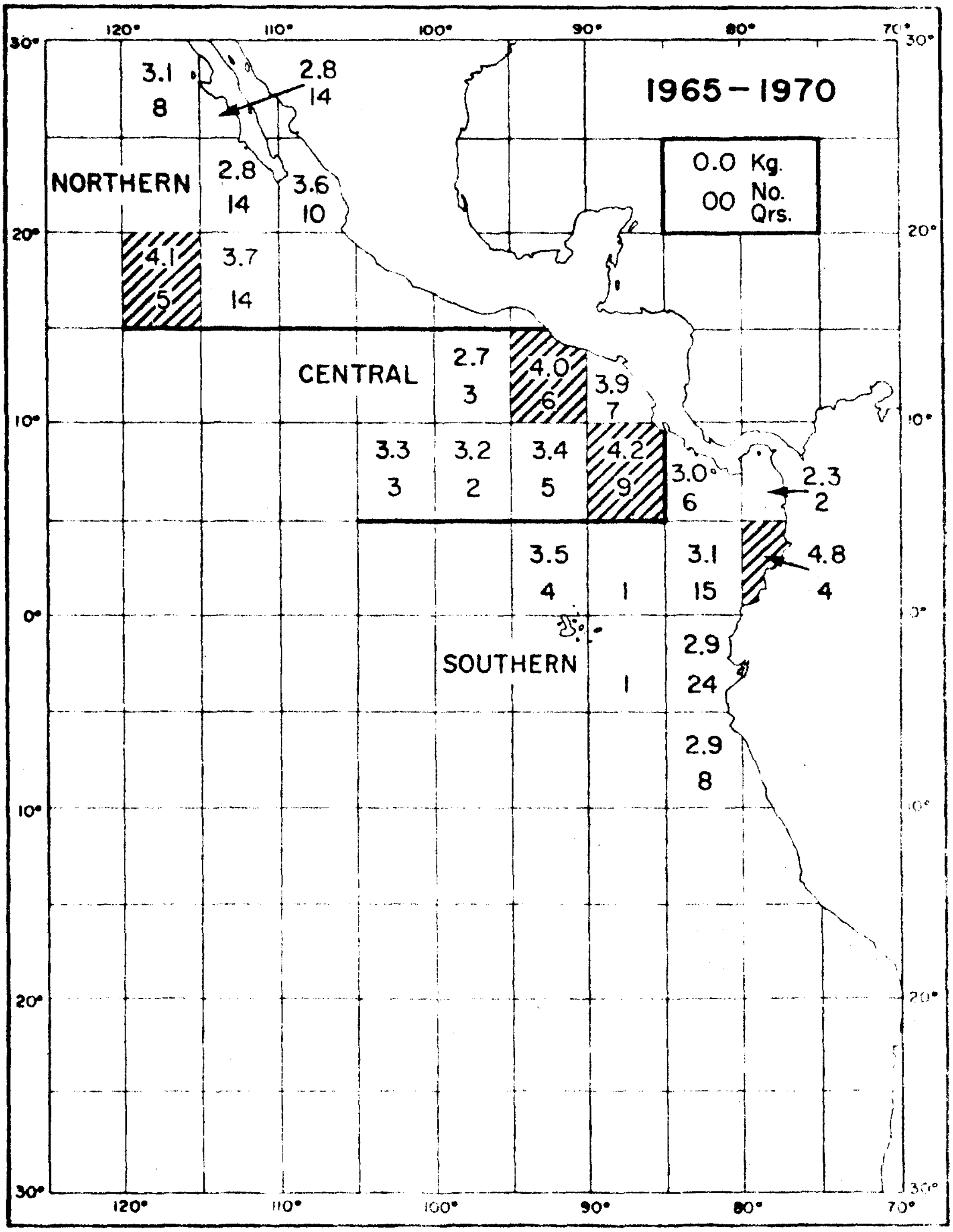

500 or more short tons
100 - 499 short tons
25 - 99 short tons
under 25 short tons
effort, no skipjack catch

Figure 1



1965 – 1970
0.0 Kg.
00 No. Qrs.
NORTHERN
CENTRAL
SOUTHERN
3.1
8
2.8
14
2.8
14
3.6
10
4.1
5
3.7
14
2.7
3
4.0
6
3.9
7
3.3
3
3.2
2
3.4
5
4.2
9
3.0
6
2.3
2
3.5
4
1
3.1
15
4.8
4
2.9
24
1
2.9
8
30°
20°
10°
0°
10°
20°
30°
120°
110°
100°
90°
80°
70°

Figure 2a

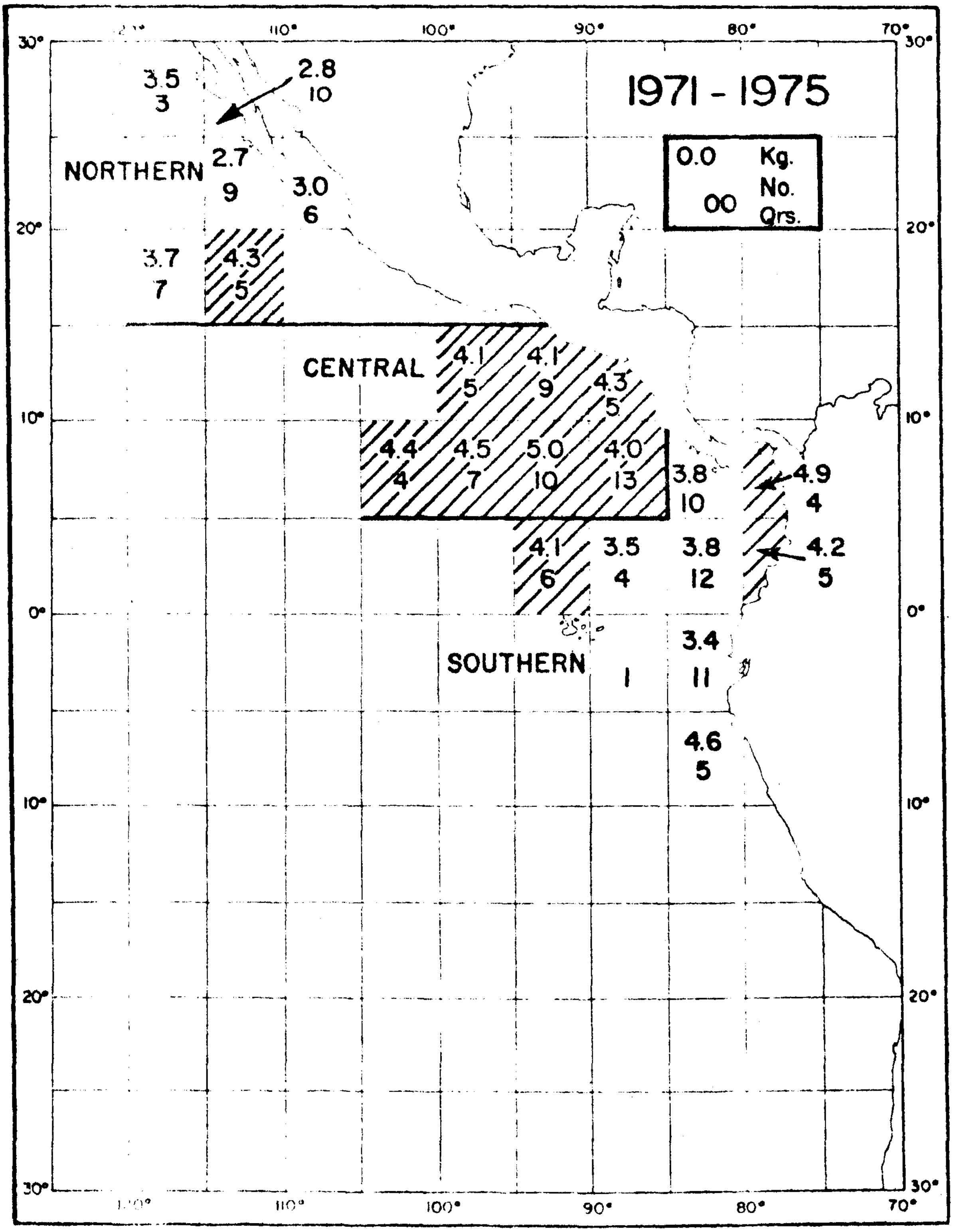

1971 - 1975
0.0 Kg.
00 No. Qrs.
NORTHERN
CENTRAL
SOUTHERN
3.5
3
2.8
10
2.7
9
3.0
6
3.7
7
4.3
5
4.1
5
4.1
9
4.3
5
4.4
4
4.5
7
5.0
10
4.0
13
3.8
10
4.9
4
4.1
6
3.5
4
3.8
12
4.2
5
3.4
11
1
4.6
5
110°
100°
90°
80°
70°
30°
20°
10°
0°

Figure 2b

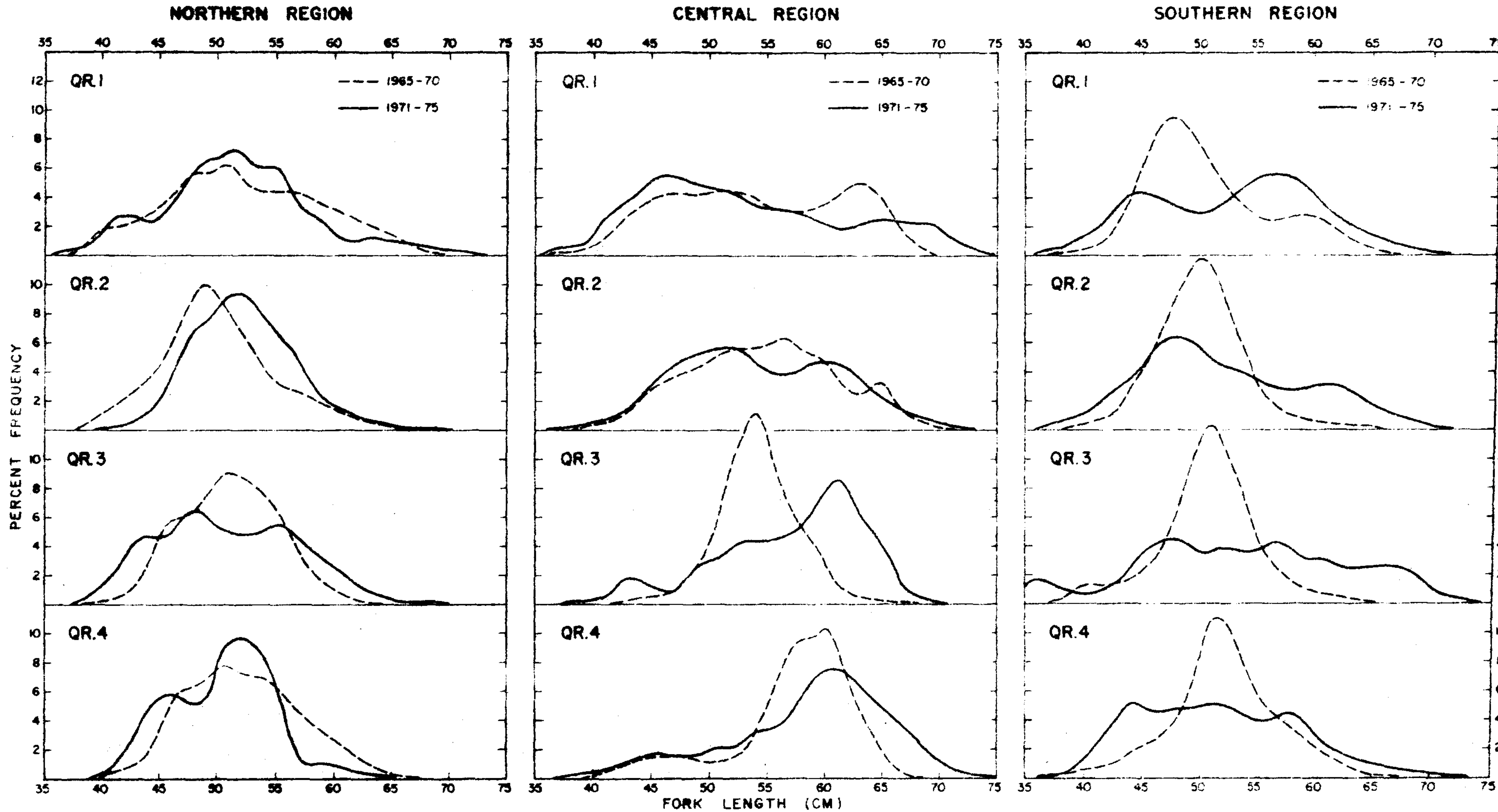

NORTHERN REGION
CENTRAL REGION
SOUTHERN REGION
QR.1
QR.2
QR.3
QR.4
1965-70
1971-75
PERCENT FREQUENCY
FORK LENGTH (CM)

Figure 3

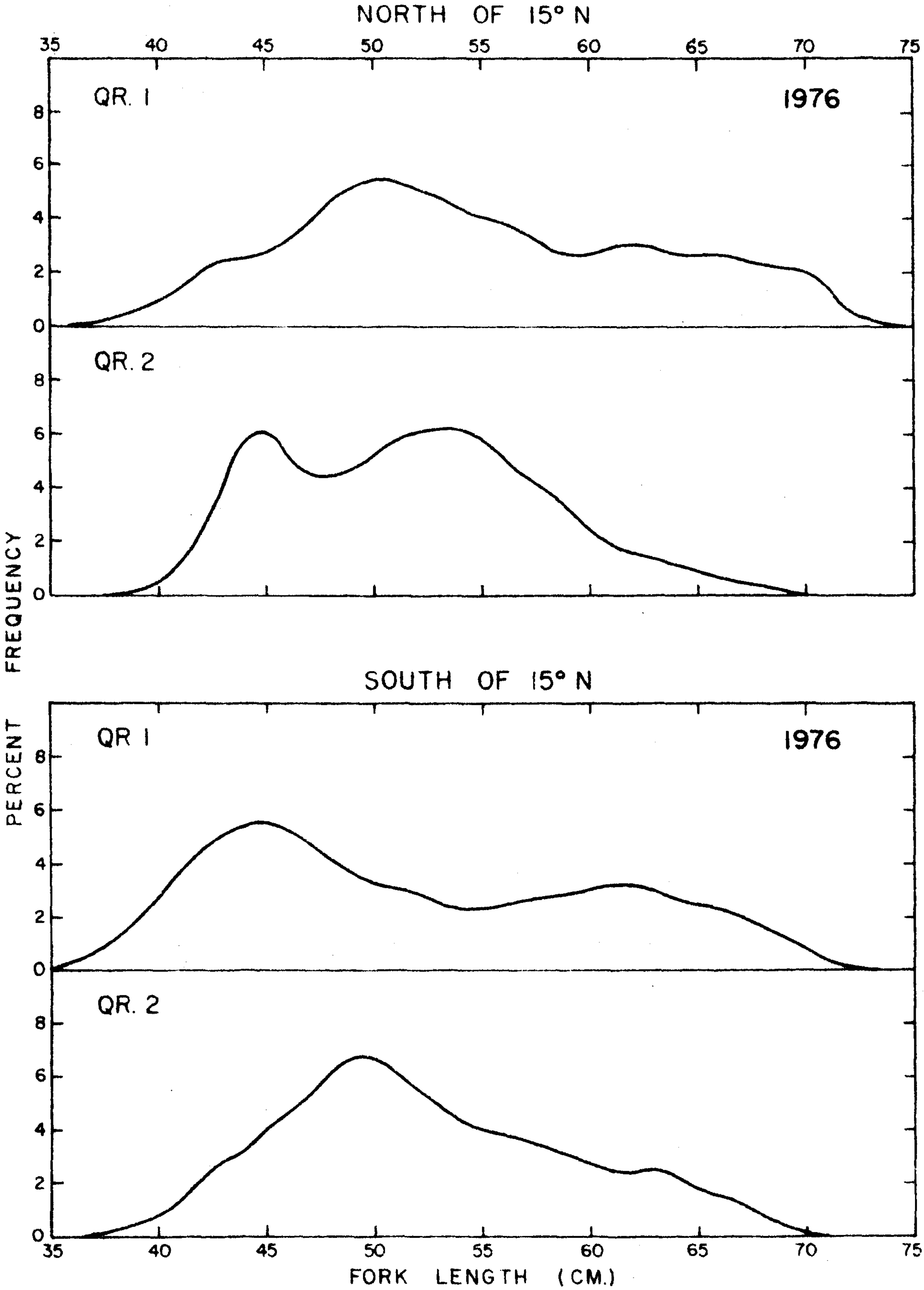

NORTH OF 15° N
QR. 1
1976
QR. 2
FREQUENCY
PERCENT
SOUTH OF 15° N
QR 1
1976
QR. 2
35 40 45 50 55 60 65 70 75
0 2 4 6 8
FORK LENGTH (CM.)

Figure 4

AGES ASSIGNED ACCORDING TO METHOD 4

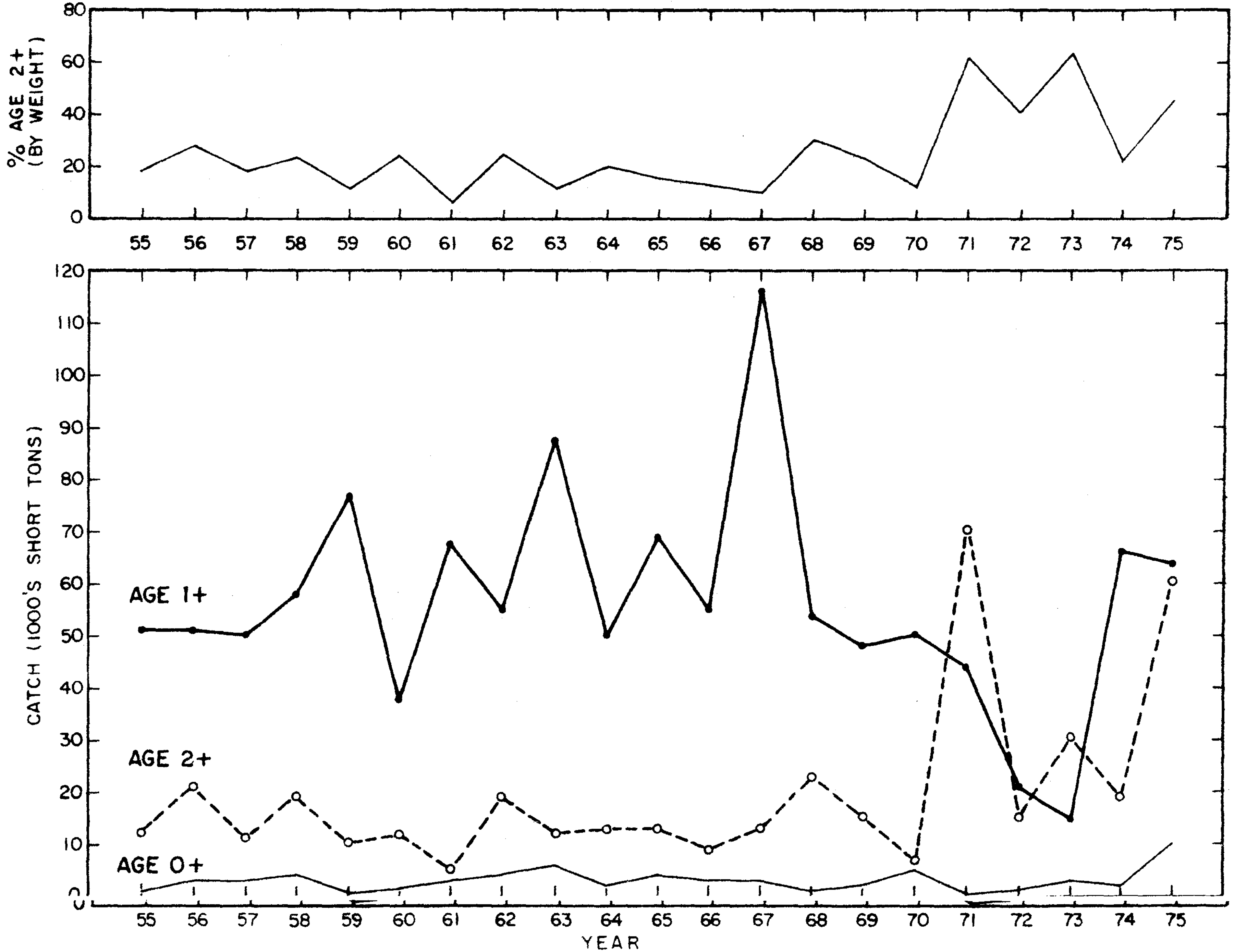


Figure 5

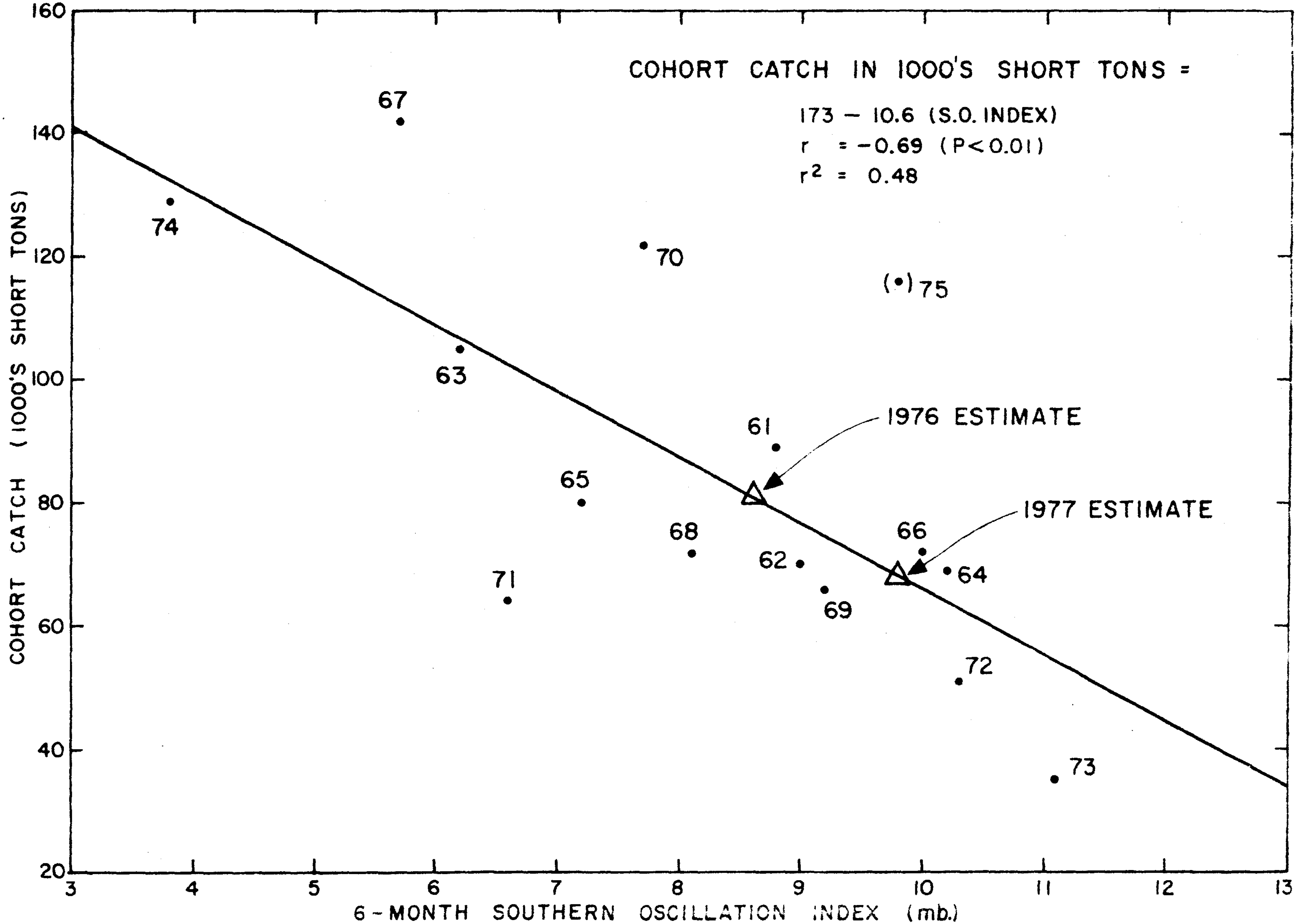

COHORT CATCH IN 1000'S SHORT TONS =
173 − 10.6 (S.O. INDEX)
r = −0.69 (P<0.01)
r2 = 0.48
1976 ESTIMATE
1977 ESTIMATE
67
74
70
(•) 75
63
61
65
68
62
66
64
71
69
72
73
160
140
120
100
80
60
40
20
3
4
5
6
7
8
9
10
11
12
13
COHORT CATCH (1000'S SHORT TONS)
6-MONTH SOUTHERN OSCILLATION INDEX (mb.)

Figure 6

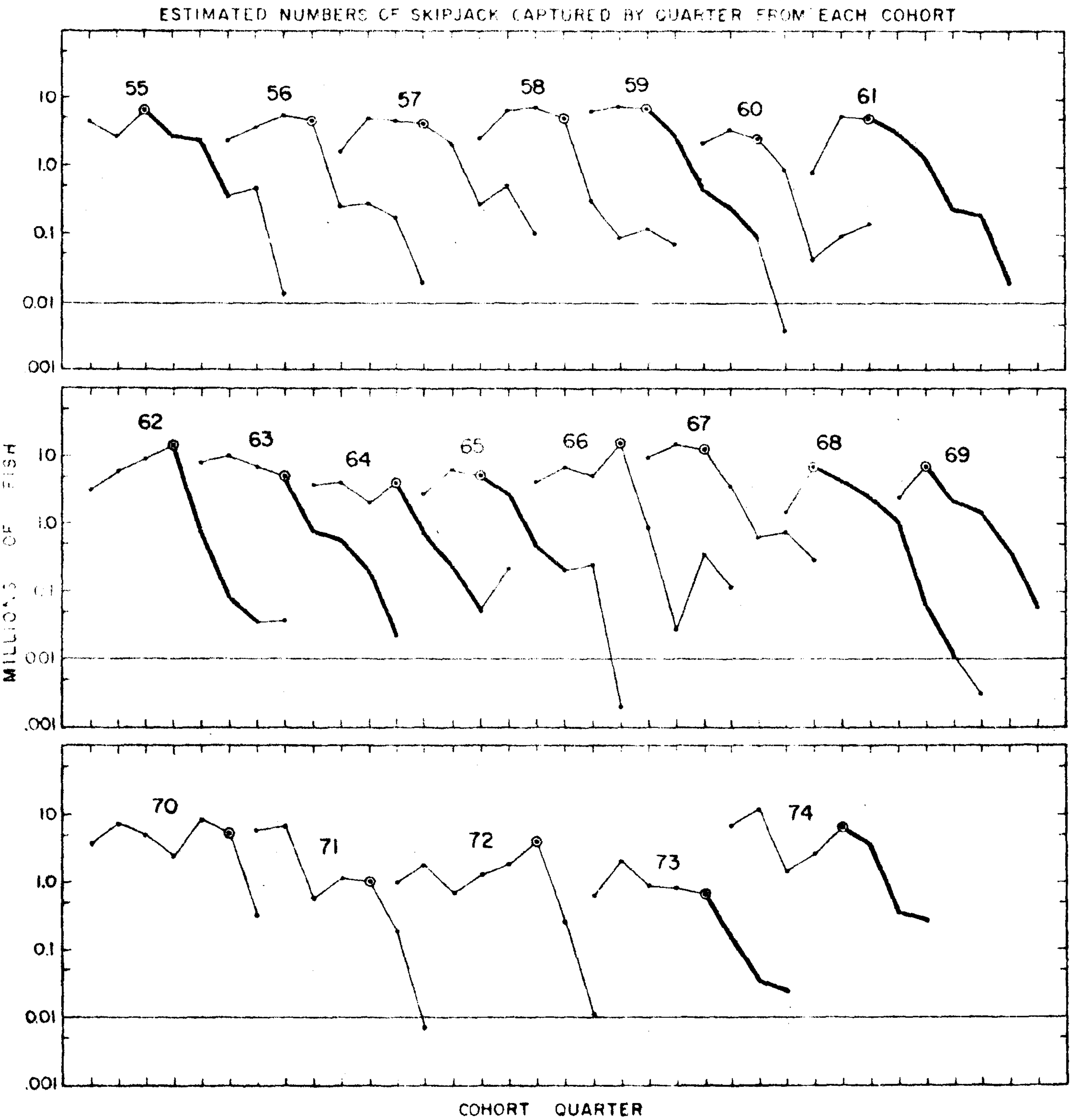

ESTIMATED NUMBERS OF SKIPJACK CAPTURED BY QUARTER FROM EACH COHORT
MILLIONS OF FISH
10
1.0
0.1
0.01
.001
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
COHORT QUARTER

Figure 7

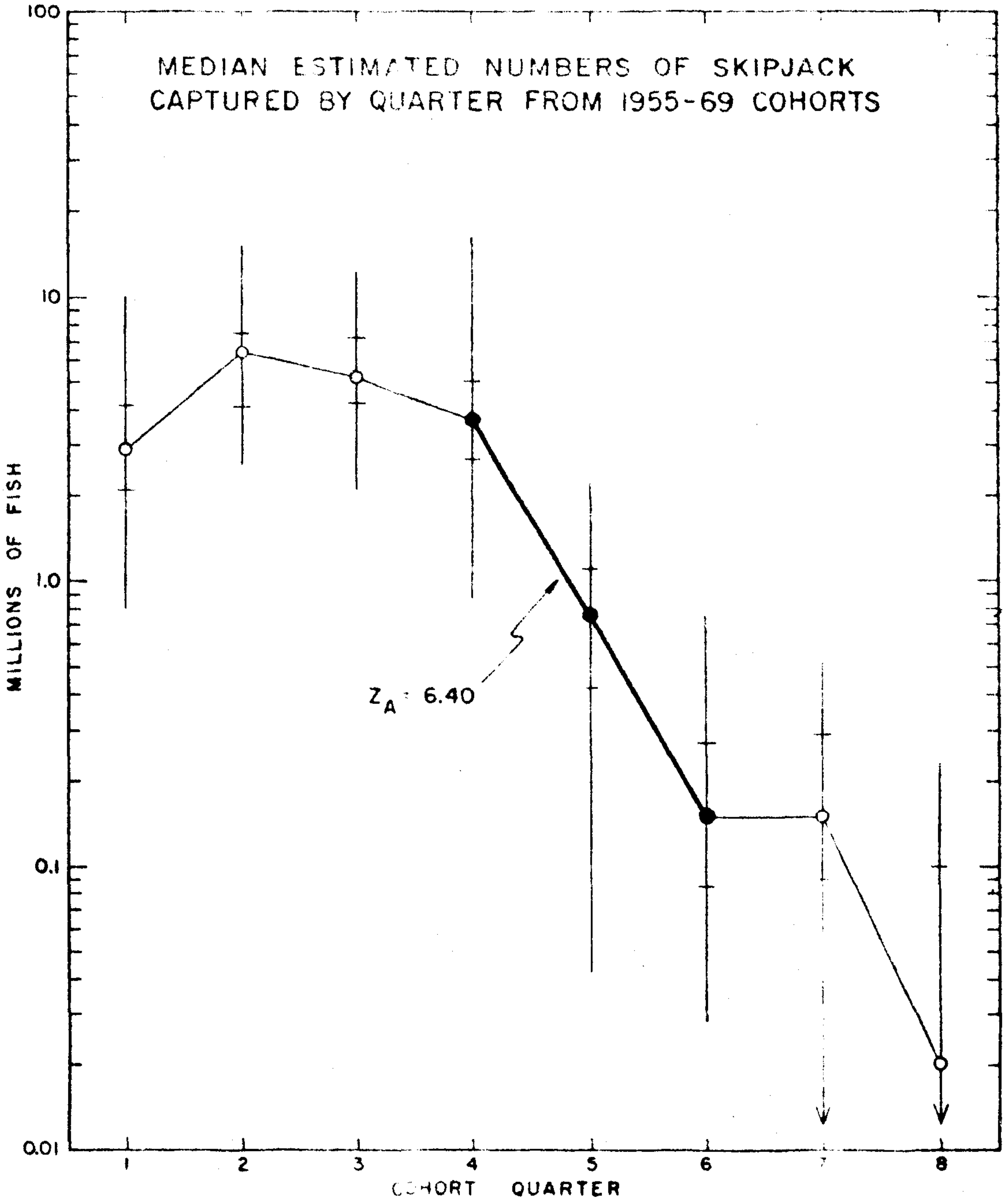

MEDIAN ESTIMATED NUMBERS OF SKIPJACK
CAPTURED BY QUARTER FROM 1955-69 COHORTS
100
10
1.0
0.1
0.01
MILLIONS OF FISH
Z_A = 6.40
1
2
3
4
5
6
7
8
COHORT QUARTER

Figure 8

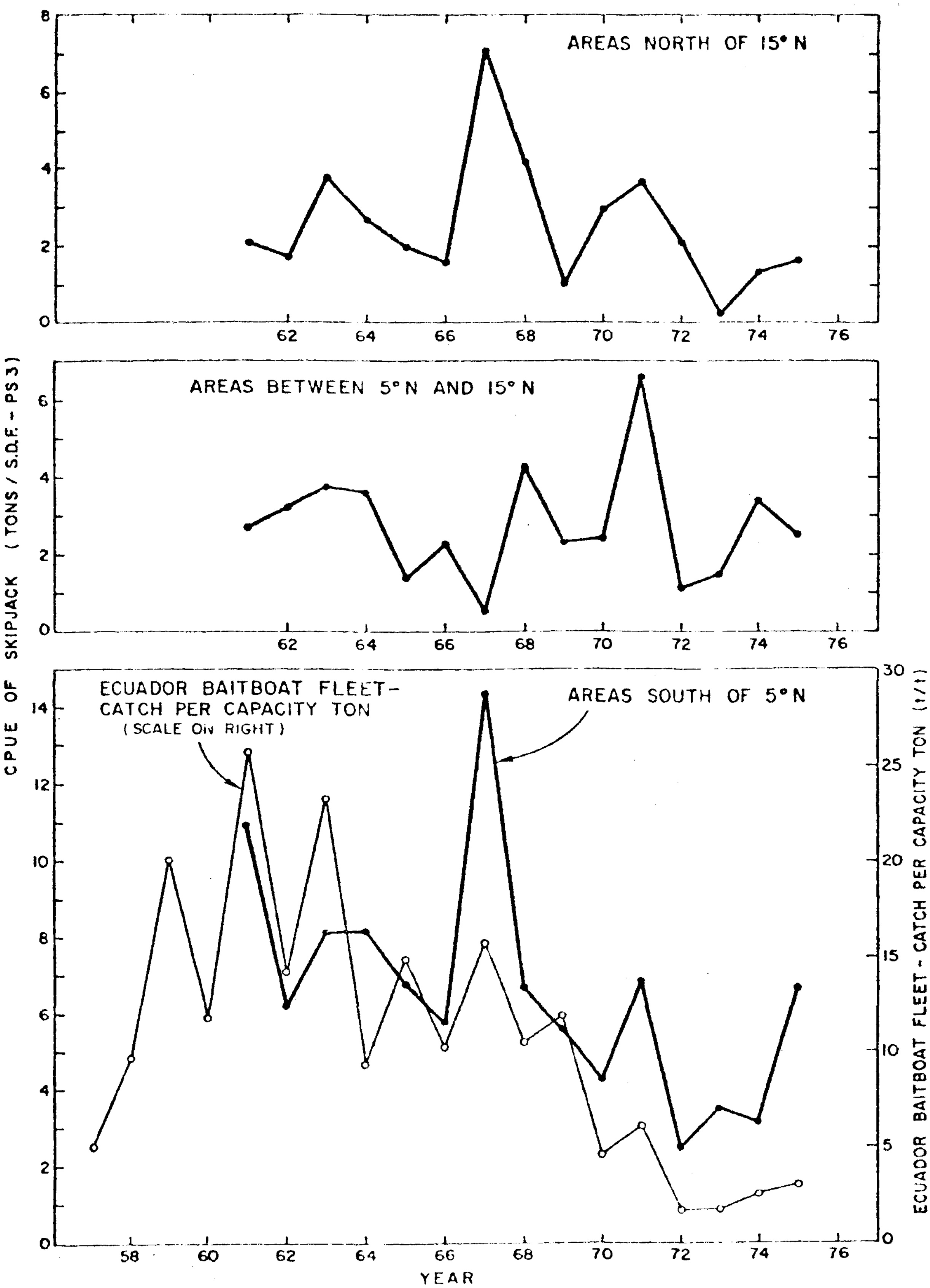

AREAS NORTH OF 15° N
AREAS BETWEEN 5° N AND 15° N
ECUADOR BAITBOAT FLEET-
CATCH PER CAPACITY TON
(SCALE ON RIGHT)
AREAS SOUTH OF 5° N
CPUE OF SKIPJACK (TONS / S.D.F. - PS 3)
ECUADOR BAITBOAT FLEET - CATCH PER CAPACITY TON (t/t)
YEAR

Figure 9

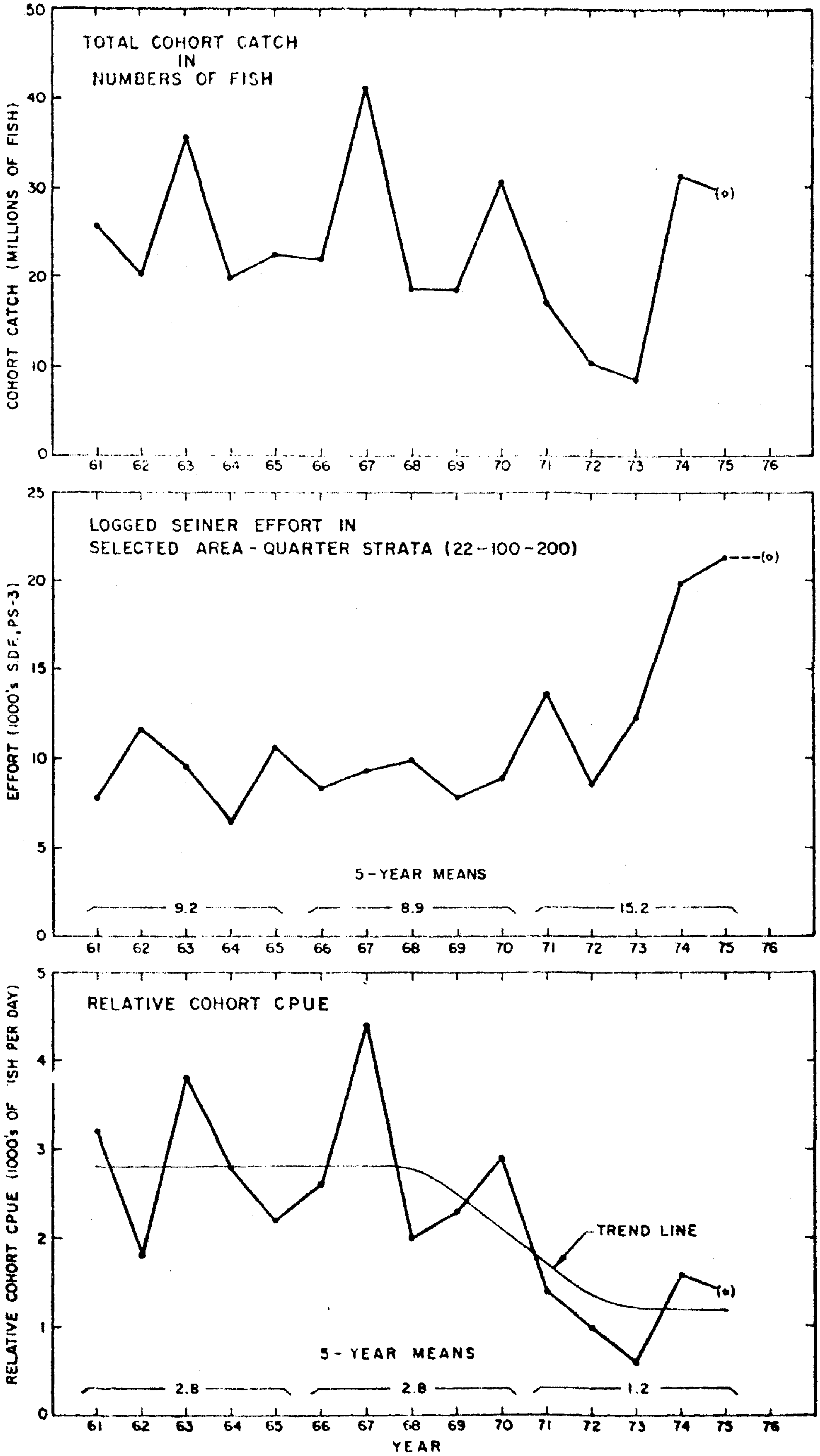

TOTAL COHORT CATCH IN NUMBERS OF FISH
COHORT CATCH (MILLIONS OF FISH)
LOGGED SEINER EFFORT IN SELECTED AREA - QUARTER STRATA (22-100-200)
EFFORT (1000's S.D.F., PS-3)
5-YEAR MEANS
9.2
8.9
15.2
RELATIVE COHORT CPUE
RELATIVE COHORT CPUE (1000's OF FISH PER DAY)
TREND LINE
5-YEAR MEANS
2.8
2.8
1.2
YEAR

Figure 10