YELLOWFIN TUNA, *THUNNUS ALBACARES*, CATCH RATES IN THE WESTERN PACIFIC

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ABSTRACT

The surface fishery for yellowfin tuna, *Thunnus albacares*, in the western Pacific has increased dramatically since 1978. Catch and effort statistics from the Japanese purse seine and longline fisheries are examined in terms of changes in catch rates and the interaction between these two fisheries. In spite of a 10-fold increase in surface catches to around 100,000 metric tons per year, purse seine catch rates have remained relatively constant. Longline catch rates since 1980 have been declining, with the exception of high rates in 1983. Comparison of purse seine and longline catch rates within the same area and time period indicated no relation between them and suggests that the yellowfin tuna stocks are not homogeneous with respect to the two gears. In addition, observed changes in longline catch rates within areas of the western Pacific appear not to be related to the magnitude of the purse seine catches within these areas. The results provide no direct evidence for any interactions between the two gears, but whether purse seine catches are contributing to the possible, overall decline in longline catch rates remains an open question.

Purse seine catches of yellowfin tuna, *Thunnus albacares*, in the western Pacific have increased from 8,000 to 10,000 t (metric tons) in 1978 (Habib 1984[2]) to estimates of around 100,000 t in 1984. Prior to the advent of purse seining, the main vessels harvesting yellowfin tuna in this region were the Japanese, Korean, and Taiwanese longliners. Longliners still continue to harvest significant amounts of yellowfin tuna (an estimated 60,000 t in 1984). The effect of this 10-fold increase in purse seine catches since 1978, both on the overall stocks of yellowfin tuna in the western Pacific and the effect of the purse seine catches on the longline fisheries, is unknown, but the status of yellowfin tuna stocks is a critical question for a number of reasons. Yellowfin tuna represent the second largest fishery resource for the tropical western Pacific area. Yet, there is no adequate assessment of the magnitude of the harvestable catch for the region, while yellowfin tuna stocks in other regions appear vulnerable to overexploitation by purse seiners (IATTC 1979, 1980, 1981, 1982; Fonteneau and Diouf 1983; Au 1983). In addition, about two-thirds of the yellowfin tuna longline catch is targeted for the Japanese sashimi market and, as such, has an economic value exceeding that of the purse seine-caught fish. Longliners harvest older and larger fish than purse seiners (Cole 1980). In the present paper, the most recent data available on the catch and effort for yellowfin tuna are examined for information on the current yellowfin tuna stocks and on the interaction between longline and purse seine fisheries.

METHODS

Data

The data available for examining catch rates come from records of daily catch and effort supplied by vessels to individual island states in the western Pacific as part of access arrangements which allow vessels to fish within the 200-mile EEZ's (Exclusive Economic Zone) of these states. These catch records have been subsequently transmitted to the Tuna and Billfish Assessment Programme of the South Pacific Commission (SPC), and have formed the core of the regional statistical data base. Data are only supplied as a requirement of access for fishing within EEZ's. While some vessels include activity in international waters in their reports, the available data are relatively incomplete for these waters. Also, for some states in past years, adequate data reporting was not included in the access agreements. In addition, prior to 1984 almost no data are available from United States and some other eastern Pacific purse seiners.

Because of incompleteness and limitations in the

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[2]Habib, G. 1984. An overview of the purpose seine tuna fishery in the central/western Pacific and development opportunities for island states. Workshop on National Fishing Operations, Tarawa, Kiribati, 28 May–4 June 1984.

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available data, the analyses in this present paper are based on catch rates for Japanese vessels. These data form the most extensive and complete set of data currently available to the SPC. Records of daily fishing activity go back as far as the second half of 1978 for the longline fishery and 1979 for the purse seine fishery. However, these earliest data are not complete and need to be interpreted with caution.

The stock or subpopulation structure and their geographic limits for yellowfin tuna in the Pacific are unknown despite considerable tagging and genetic research (Cole 1980). However, a single stock spanning the entire Pacific is considered unlikely. For the present paper, the geographic boundaries used for the western Pacific are from long. 130°E to 180°E and from lat. 10°S to 15°N. For the Japanese purse seine fishery, this area encompasses virtually all of the reported catch and effort data. For the Japanese longline fishery, this represents an area in which the fishery has been relatively consistent and its reporting fairly complete.

Catch Rates

Catch rates or catch per unit effort are calculated below as a measure of relative abundance. An extensive literature exists on the use of catch rates as abundance indices (Gulland 1956a; Beverton and Holt 1957; Paloheimo and Dickie 1964; Allen and Punsley 1984). However, the question of the relation between catch rates and abundance for these yellowfin tuna fisheries needs further research (see Discussion).

For longlining, the effort measure used here is the number of hooks set (in thousands). Catch is reported as the number of fish caught. For purse seining, the effort measure used is the number of days in which vessels made a set or were actively searching for schools of tuna. The catch is recorded in metric tons. In the earliest purse seine data, there may be an underestimation of effort, as it is not clear whether days in which vessels were searching for fish, but did not catch any, were accurately reported.

The average catch rates and their variances within any statistical stratum were calculated as the weighted mean of the observed catch rates for all cruises within the stratum. Thus, an individual cruise's catch rate within a stratum constitutes the primary sampling unit or replicate in the analyses below. The weights used were equal to a vessel's fishing effort. For the estimates of the mean catch rate, this is equivalent to the sum of the total catch divided by the sum of the total effort within a stratum.

Various temporal and areal stratifications of the data have been considered. Monthly, quarterly, and annual stratifications are examined. When the data were stratified by area, geographic strata were defined as rectangular areas of 2.5° of latitude and 10° of longitude. These strata were chosen because preliminary analyses indicated that there was much greater variation both in effort and catch rates latitudinally than longitudinally. If smaller areas are selected, there tends to be too little data in many of the strata for meaningful analysis.

There are two statistical reasons for stratifying data: 1) to eliminate biases due to unequal distribution of sampling effort in strata with different means, and 2) to reduce the variance associated with the estimate of the mean. The first reason is a primary concern in calculating catch rates from fisheries data since the distribution of fishing effort both spatially and temporally is likely to be related to catch rates (i.e., fishermen probably concentrate on when and where the fishing is best).

In order to estimate an average catch rate for time periods and areas of interest, the estimates of the catch rates in the various strata need to be combined. For stratified data, an estimate of the average catch rate across strata is the weighted mean of the average catch rate within each stratum, where the weights are proportional to the magnitude of a stratum (Snedecor and Cochran 1967). The geographical and temporal stratifications presented below were considered to be equal in area and time. (This is not strictly true both because of land masses and differences in the length of a degree of longitude at different latitudes. For two of the geographical strata, the amount of land area of Papua New Guinea is large and these two strata should probably be given smaller weight in any extensions or refinements to the estimates presented below.) When all strata are of equal magnitude, the average catch rate across strata is the simple average of the within-strata estimates. Similarly, in this situation, an estimate of the variance is the average of the variance estimates for each stratum (Snedecor and Cochran 1967).

Because catch and effort statistics are not derived from a well-designed and controlled sampling experiment, there is not an a priori single best estimate for the average catch rate covering large areas and time periods. Thus, when considering estimates of the annual average catch rates, a set of different estimates based on various areal and temporal stratifications are presented. Comparison of the estimates for different stratifications of the data may indicate possible sources of bias and can provide some indication of the robustness of any temporal trends suggested by any single set of estimates.

Another approach for dealing with possible biases due to unequal distribution of fishing effort is to calculate standardized catch rates using a general linear model (Gulland 1956b; Robson 1966; Allen and Punsly 1984). The advantage of this approach is that well-developed, standard statistical procedures can be employed to test for significant differences in catch rates over time where the effect of other factors on catch rates have been taken into account. Disadvantages of this approach include: 1) the data may be nonnormal even when transformed, 2) effects may not be simply additive (or multiplicative if a logarithmic transformation is used), and 3) the design matrix is almost always unbalanced and incomplete.

Extensive attempts were made to fit a general linear model to the catch rate data presented here. While the model was successful in greatly reducing the total sums of squares (e.g., an R^2 as high as 0.80), in all cases, the models included significant and large interaction effects between year and area, and between year and season. Such interactions are an indication of changes in availability and distribution between years and are not surprising given the large El Niño of 1983. When large interaction terms exist in a model, particularly when it is unbalanced and incomplete, direct interpretation of the main effects (in this case year) is problematical. An alternative to estimating the main effects in this situation is to develop μ_{ij}-models (Searle 1971) to compare directly the average effect between those combination of cells which are of interest. Conceptually this approach is similar to the stratified means approach developed above, but the calculation of the variance for the stratified means makes no assumption about the equality of the variance between cells. Because of the similarity of these two approaches and the problems with traditional general linear model estimates for unbalanced and incomplete data, the results of the general linear model have not been included in the present paper.

Interactions

The relationship between the longline and purse seine fisheries is considered in detail from two different approaches. In the first, catch rates of purse seiners and longliners operating in the same area during the same time period are compared. In this case a strong positive relationship would suggest that yellowfin tuna are a homogeneous stock with respect to the two fisheries. For this analysis, it is important that relatively fine scale temporal and area strata be used in order that differences in abundance between areas and time do not mask any relationship. Comparison of quarterly longline and purse seine catch rates are made for each individual 2.5° × 10° rectangular area in which there were at least five quarters with a reasonable amount of effort by both gears (i.e., 5 days of purse seine effort and 20,000 longline hooks).

The second approach involves the comparison of changes in longline catch rates in different areas to the purse seine catches that have occurred within these areas. This approach is a direct test of whether any reduction in longline catch rates can be detected as a result of the large catches by purse seiners. A fundamental assumption of this approach is that the stocks of yellowfin tuna within the areas being compared are largely spatially distinct or mixing only slowly. If the stock being fished is a homogeneous mixture, then no purse seine-induced differences between areas would occur.

For this second approach the percentage change in the average 1984–85 longline catch rate, relative to the average 1979–81 catch rate, are calculated for each of the 2.5° × 10° rectangular areas. The average catch rates within an area for the periods 1979–81 and 1984–85 were calculated as the simple average of the quarterly rates for an area. The percentage changes between these two periods are then examined in relation to past purse seine catches that have occurred in these areas. These two time periods were chosen for this comparison in order to see whether there has been differential and consistent long-term changes in abundances, and if so, whether these changes can be related to the distribution of purse seine catches.

It should be noted that these two approaches are meant to test for specific, possible localized interactions (either temporal or spatial). They are not meant as an exhaustive examination of the interactions between these two gears, but as feasible analyses given the short time series and limits of the current data.

RESULTS

Purse Seine Catch and Effort

Effort by Japanese purse seiners increased steadily through the first half of 1982 to around 450 days per month (Fig. 1A). Since 1982, levels of effort have remained relatively steady and have fluctuated

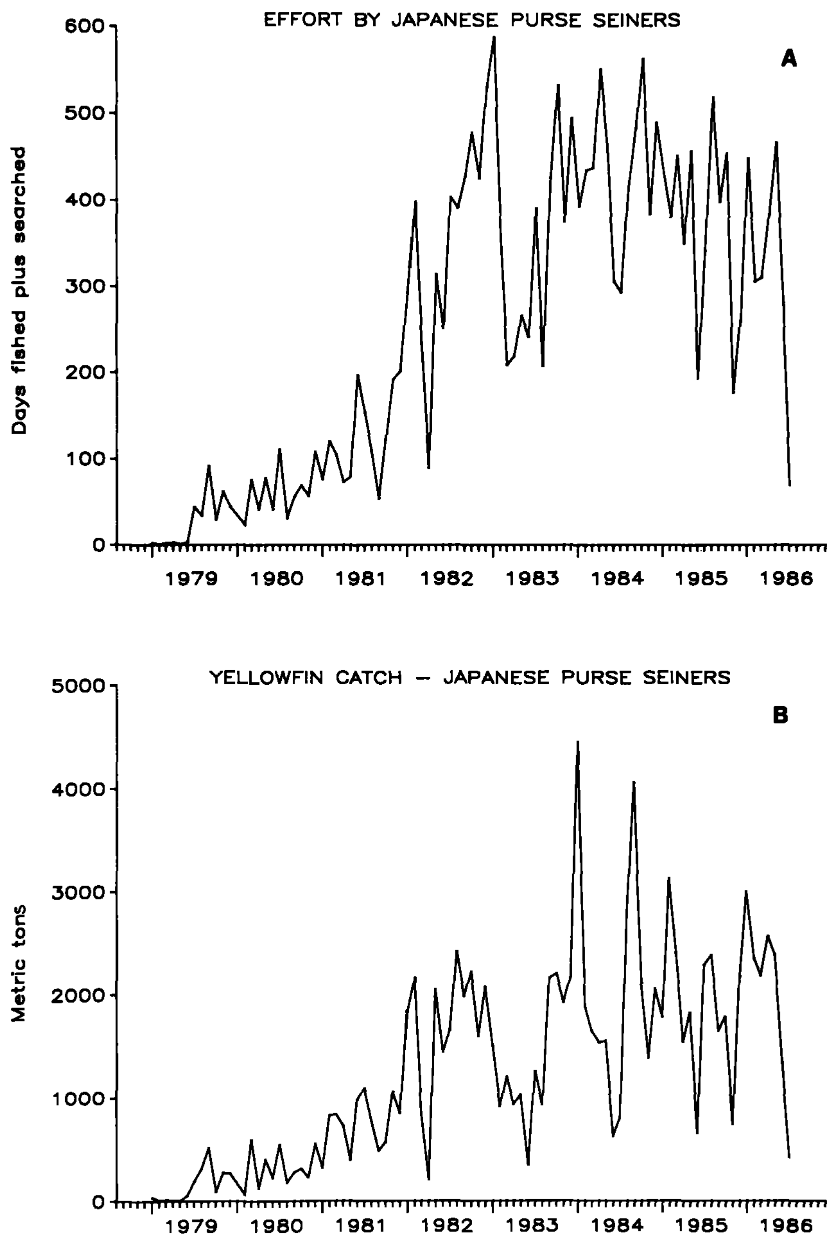

FIGURE 1.—Monthly catch of yellowfin tuna and effort statistics for Japanese purse seiners in the western Pacific based on data currently reported to the South Pacific Commission.

around this level. (Note that the apparent drop in effort for 1986 is an artifact due to time lags in receiving catch reports.)

The total catch of yellowfin by Japanese purse seiners roughly parallels the temporal distribution of effort (Fig. 1A, B). Overall, the corresponding catch rates have remained fairly constant with the lowest rates observed in 1983 (Fig. 2).

Table 1 presents a range of estimates of the annual catch rates for the various areal and temporal stratifications of the data. There are no consistent differences among the different stratifications

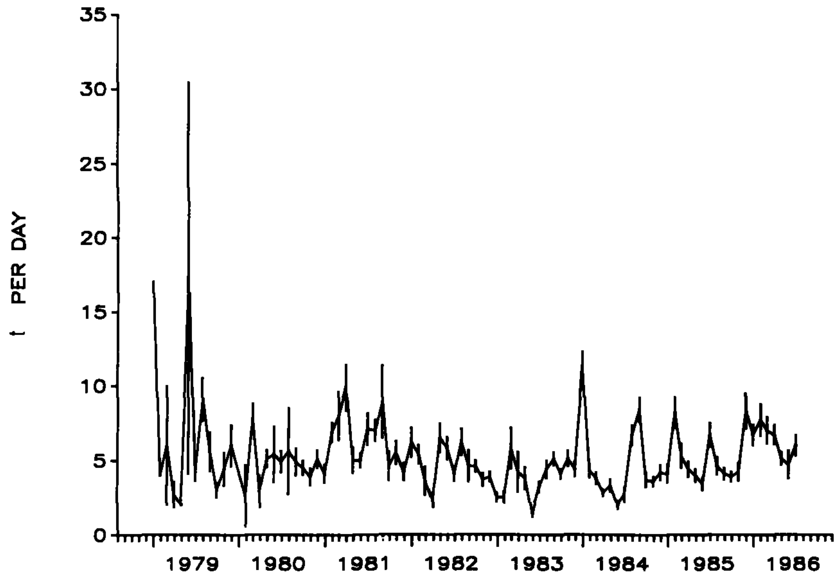

FIGURE 2.—Estimates of the monthly catch rates of yellowfin tuna for Japanese purse seiners (metric tons per day of effort) in the western Pacific. Error bars represent the estimates of one standard error.

TABLE 1.—Comparison of annual estimates of the overall average catch rate of yellowfin tuna (metric tons per day) by Japanese purse seiners in the western Pacific based on various areal and temporal stratifications of the data. Values in parentheses are estimates of standard error and *n* is the number of strata contained within each estimate. Stratum with less than five days of effort are not included.

Year	No areal or temporal stratification	Stratified by month	Stratified by quarter	Stratified by area	Stratified by quarter and area
1979	5.50 (0.59) *n* = 1	5.39 (0.46) *n* = 6	7.35 (1.59) *n* = 4	5.26 (0.53) *n* = 6	5.48 (0.85) *n* = 9
1980	5.02 (0.31) *n* = 1	4.80 (0.42) *n* = 11	5.21 (0.38) *n* = 4	5.18 (1.45) *n* = 7	4.66 (0.30) *n* = 13
1981	5.98 (0.32) *n* = 1	6.35 (0.38) *n* = 12	6.18 (0.32) *n* = 4	4.15 (0.39) *n* = 15	5.34 (0.51) *n* = 29
1982	4.82 (0.23) *n* = 1	4.74 (0.22) *n* = 12	4.97 (0.23) *n* = 4	4.69 (0.60) *n* = 11	4.91 (0.34) *n* = 24
1983	3.83 (0.20) *n* = 1	3.89 (0.21) *n* = 12	3.74 (0.20) *n* = 4	3.24 (0.29) *n* = 14	3.48 (0.27) *n* = 25
1984	4.77 (0.23) *n* = 1	4.75 (0.16) *n* = 12	4.85 (0.20) *n* = 4	3.70 (0.20) *n* = 13	3.39 (0.17) *n* = 36
1985	5.04 (0.25) *n* = 1	5.09 (0.20) *n* = 12	5.00 (0.22) *n* = 4	4.61 (0.24) *n* = 18	5.36 (0.26) *n* = 41
1986	6.26 (0.32) *n* = 1	6.26 (0.30) *n* = 7	6.19 (0.32) *n* = 3	4.84 (0.29) *n* = 15	5.26 (0.27) *n* = 21

within a year. The larger differences that do exist tend to include stratification by area. If a normal distribution is assumed, the only significant differences at a 0.05 probability level among the stratifications within a year (i.e., 1981, 1984, and 1986) would be in stratifications which include area.

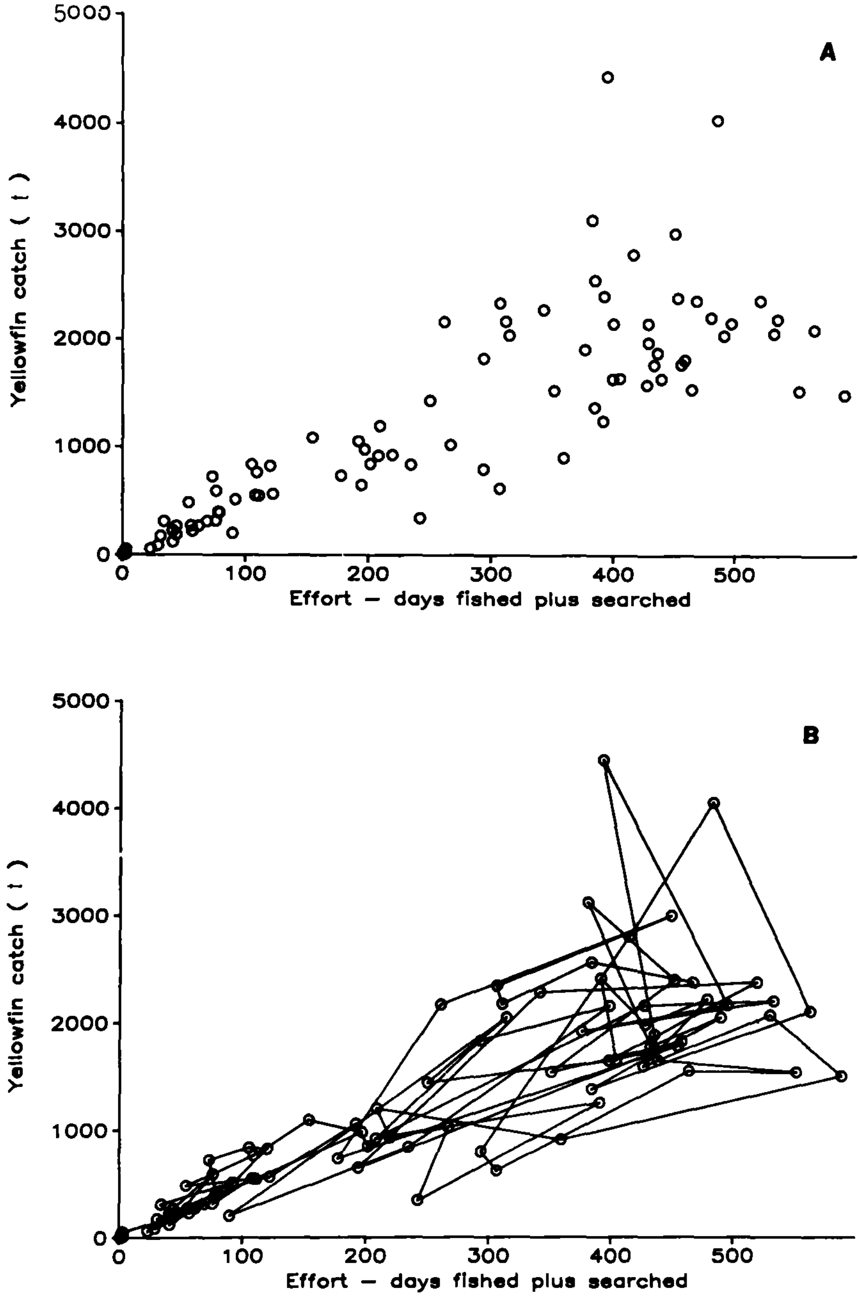

FIGURE 3.—The relationship between monthly yellowfin tuna catch and effort by Japanese purse seiners. The points have been connected in the temporal sequence in which they occur.

However, for estimates stratified by both area and season, only the 1984 estimate would be significantly different from any of the other stratified means within a given year. A lack of consistent differences among the various stratifications within years does not mean that siginificant area and seasonal differences may not exist, but only that whatever effects may exist tend to balance in the present data.

Among the various annual estimates in Table 1, the estimates for 1983 tend to be the lowest (perhaps reflecting the large El Niño of that year), while those for 1979 and 1986 tend to be the highest. While the length of the time series is short, there is no indication within any of the stratifications of an overall temporal trend in the annual estimates.

Relationship Between Purse Seine Catch and Effort

A production plot of total monthly catch versus total monthly effort suggests that monthly catch rates can be highly variable and that months with the highest effort tend to have lower catch rates (Fig. 3). Thus, the catch rates in the 6 months in which the total effort exceeded 500 days of effort are all below the overall mean catch rate (Fig. 4)

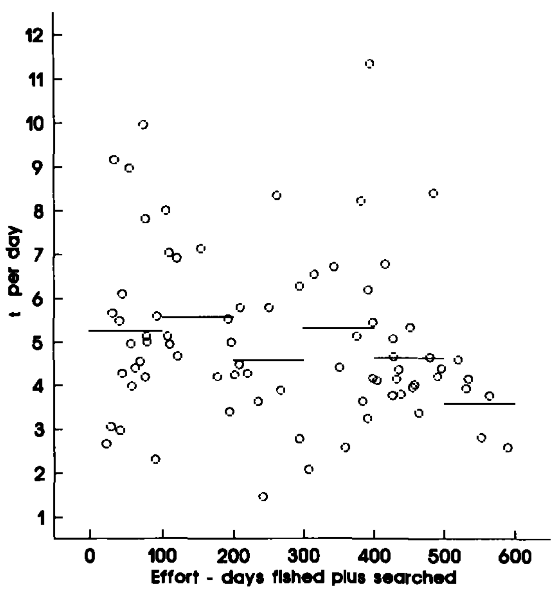

FIGURE 4.—The relationship between monthly catch rates (metric tons per day) and fishing effort of yellowfin tuna by Japanese purse seiners. The horizontal lines represent the mean catch rate for each 100 day range of effort.

and the average of the catch rate for these 6 months is 38% below the mean catch rate for all 77 months. However, the results in Figure 3 should not be interpreted in terms of a general catch curve because the changes in catch rates associated with change in effort appear to be too large to be a reflection of the overall population dynamics (see Discussion). These lower catch rates at higher effort levels are not as apparent when a quarterly stratification of the data is considered (Fig. 5), and there is no evidence for these lower rates with an annual stratification (Fig. 6). Caution is warranted in interpreting any of these figures as general catch curves since they are not based on total catch and effort statistics for the yellowfin tuna surface fisheries (most significantly, the lack of information from the United States and other eastern Pacific vessels). Also, note that for all of the catch curves, statistics from 1986 are not included because of current incompleteness of currently available data.

Longline Catch and Effort

Effort by Japanese longliners has been relatively constant, but with some decline in recent years. However, a large amount of monthly variation occurred, with a suggestion of seasonal periods of reduced effort during the second half of the year (Fig. 7A). Catches also exhibit a large amount of monthly variation, but suggest a declining trend since 1982 (Fig. 7B). As with the purse seine statistics, the drop in catch and effort in 1986 is due to the time lag in receiving catch reports. There has been a general decline in the average hooking rate since 1979–80, except for 1983 (Fig. 8).

Comparison of estimates of the average annual catch rates of yellowfin tuna for various combinations of temporal and area stratification shows a consistent temporal pattern (Table 2) which is similar to the pattern shown by the monthly rates in Figure 8. The annual estimates of the average catch rate tend to be highest in 1983, and the lowest estimates occur either in 1985 or 1986. The high catch rates in 1983 might be related to a change in vulnerability as a result of the large El Niño which occurred during this year. The 1985–86 estimates are about 33% below the 1979–80 levels. Whether overall the catch rates in this short time series indicate a general decline depends critically upon the interpretation given to 1983 catch rates (see Discussion).

Similar to the purse seine estimates, there is no consistent pattern among the stratified annual

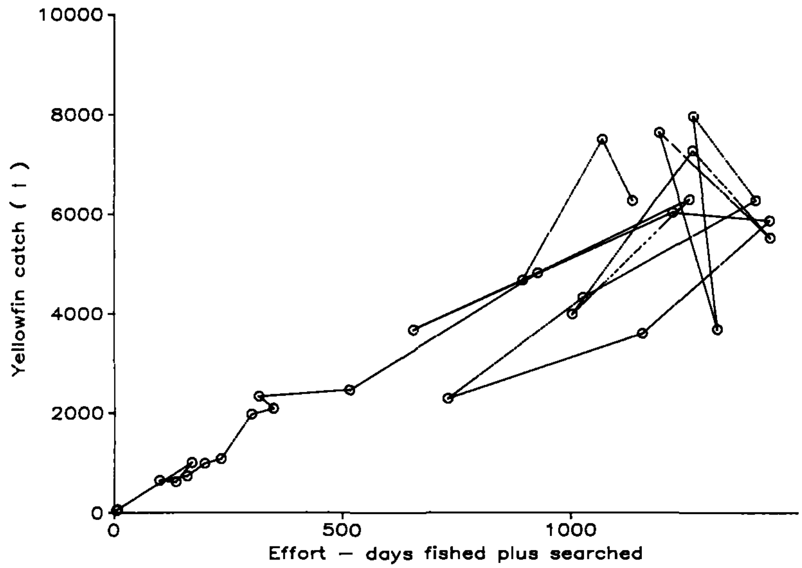

FIGURE 5.—The relationship between Japanese yellowfin tuna catch and purse seine effort based on quarterly statistics. The points have been connected in their temporal sequence.

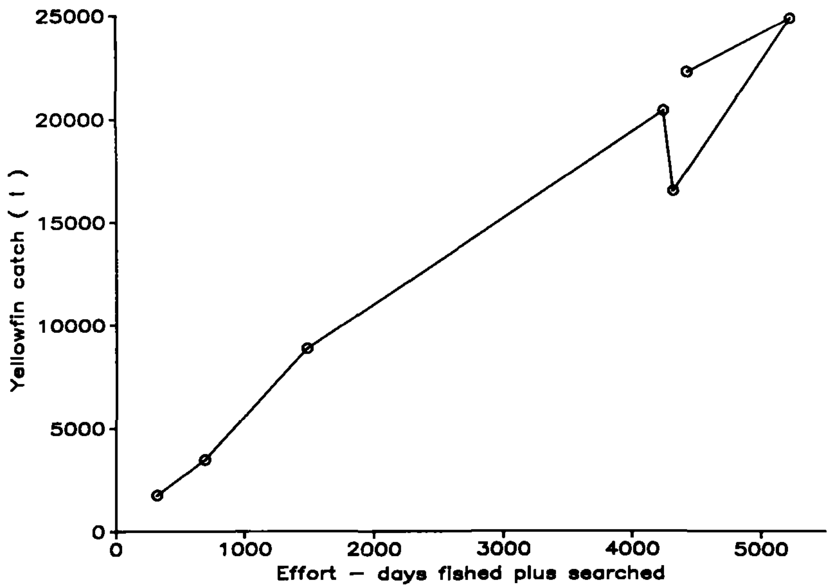

FIGURE 6.—The relationship between Japanese yellowfin tuna catch and purse seine effort based on annual statistics. The points have been connected in their temporal sequence.

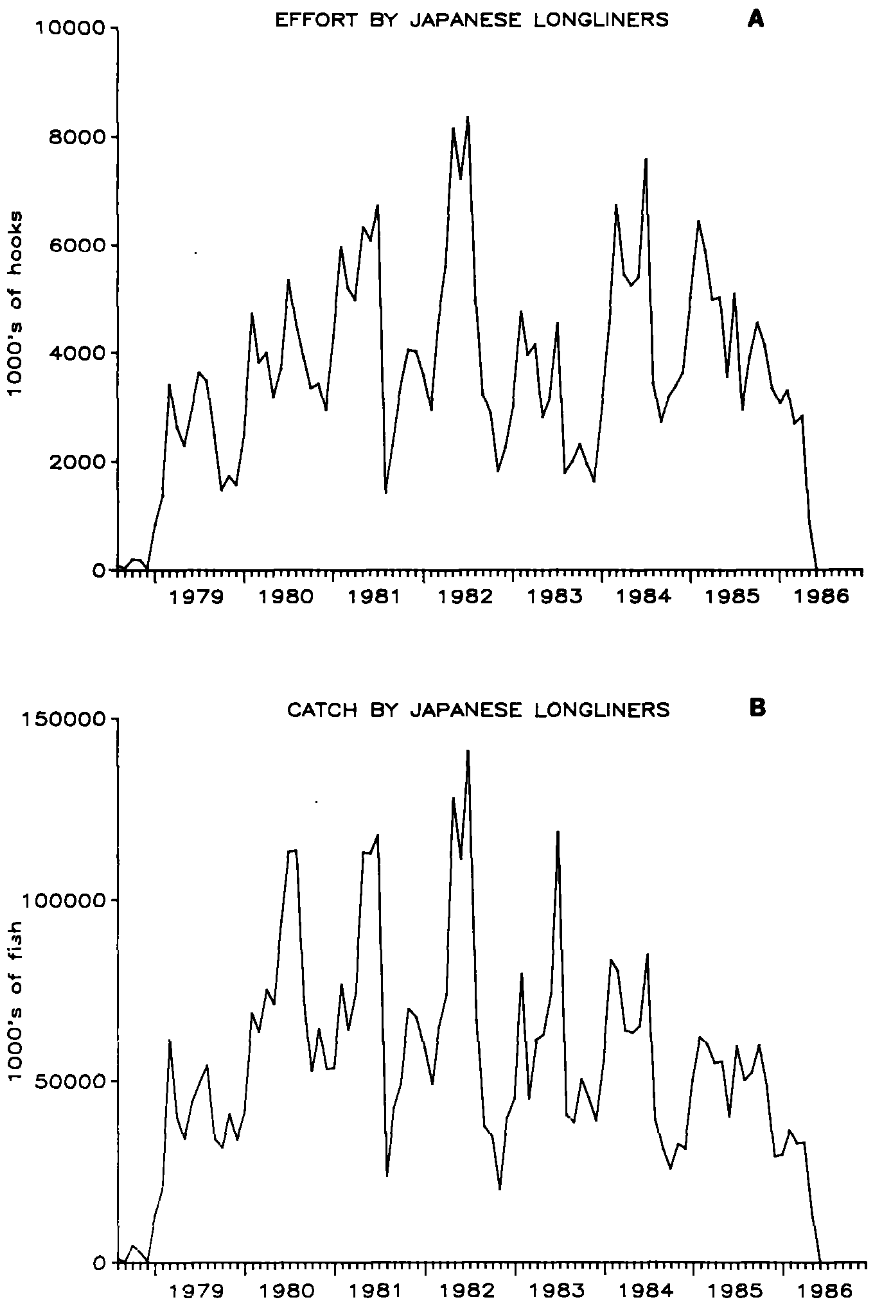

FIGURE 7.—Monthly catch of yellowfin tuna and effort statistics for Japanese longliners in the western Pacific based on data currently reported to the South Pacific Commission.

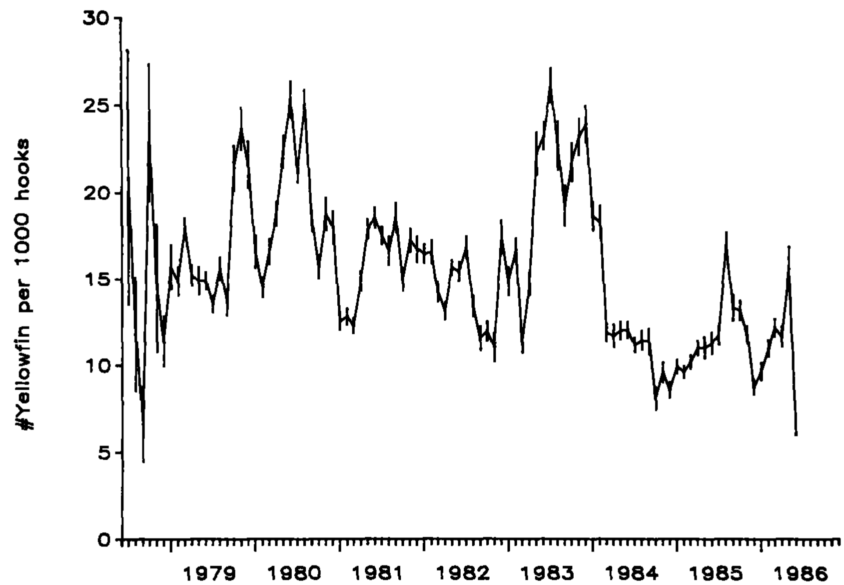

FIGURE 8.—Estimates of the monthly catch rates for Japanese longliners (number of yellowfin tuna per 1,000 hooks) in the western Pacific. Error bars represent estimates of one standard error.

TABLE 2.—Comparison of annual estimates of the overall average catch rate of yellowfin tuna (number/1,000 hooks) by Japanese longliners in the western Pacific based on various areal and temporal stratifications of the data. Values in parentheses are estimates of standard error and n is the number of strata contained within each estimate. Stratum in which less than 20,000 hooks a set were not included.

Year	No areal or temporal stratification	Stratified by month	Stratified by quarter	Stratified by area	Stratified by quarter and area
1978	16.47	13.53	14.06	17.30	17.65
	(2.10)	(1.36)	(1.79)	(1.45)	(1.32)
	n = 1	n = 5	n = 2	n = 10	n = 11
1979	16.43	16.90	17.17	18.16	16.66
	(0.27)	(0.27)	(0.27)	(0.41)	(0.25)
	n = 1	n = 12	n = 4	n = 38	n = 106
1980	19.42	19.25	19.23	18.35	18.40
	(0.29)	(0.23)	(0.27)	(0.43)	(0.29)
	n = 1	n = 12	n = 4	n = 45	n = 145
1981	15.79	15.88	15.95	13.96	13.60
	(0.22)	(0.18)	(0.20)	(0.18)	(0.17)
	n = 1	n = 12	n = 4	n = 42	n = 146
1982	14.81	14.48	14.67	12.50	12.60
	(0.23)	(0.19)	(0.22)	(0.15)	(0.15)
	n = 1	n = 12	n = 4	n = 41	n = 143
1983	19.38	19.99	20.10	17.42	18.54
	(0.35)	(0.29)	(0.32)	(0.28)	(0.36)
	n = 1	n = 12	n = 4	n = 43	n = 120
1984	12.09	12.06	11.84	12.58	12.40
	(0.23)	(0.18)	(0.20)	(0.28)	(0.17)
	n = 1	n = 12	n = 4	n = 44	n = 149
1985	11.35	11.54	11.51	11.08	11.12
	(0.19)	(0.16)	(0.18)	(0.17)	(0.15)
	n = 1	n = 12	n = 4	n = 41	n = 146
1986	11.41	11.99	11.73	10.71	10.88
	(0.33)	(0.34)	(0.34)	(0.30)	(0.27)
	n = 1	n = 5	n = 2	n = 37	n = 58

estimates within years. If a normal distribution is assumed, most of the differences among the different stratifications within a year would not be significant at the 0.05 probability level. As with the purse seine data, the lack of differences in the annual estimates should not be interpreted to mean that area and temporal effects do not exist.

Fine-Scale Relationship Between Purse Seine and Longline Catch Rates

Comparison of catch rates by longliners and purse seiners in the same area and during the same time period suggests that there is little relationship between them (Fig. 9). Thus, for all the rectangular areas in which there were at least five quarters with a reasonable amount of effort by both gear types, the correlation coefficient between the catch rates for the two gear types ranges from −0.37 to 0.89 (Table 3). When the variances associated with the individual catch rates are taken into account (e.g., Figure 9), there is nothing to suggest that these correlation coefficients are not zero.

TABLE 3.—Estimates of the correlation coefficients for the quarterly yellowfin tuna catch rates between Japanese longliners and purse seiners within rectangular areas of 2.5° of latitude by 10° of longitude.

Coordinate southwest corner of the area	Correlation coefficient	Number of quarters
7.5°N, 140°E	0.62	10
7.5°N, 130°E	0.89	5
5.0°N, 140°E	0.53	20
5.0°N, 130°E	0.12	13
2.5°N, 150°E	0.00	9
2.5°N, 140°E	−0.07	24
2.5°N, 130°E	−0.11	8
0.0°N, 150°E	−0.09	12
0.0°N, 140°E	0.10	25
2.5°S, 150°E	−0.37	14
2.5°S, 140°E	−0.25	22
5.0°S, 140°E	0.34	11

Changes in Longline Catch Within Areas Relative to Purse Seine Catches

A comparison of the percentage change in the 1984–85 yellowfin tuna hooking rate from the 1979–81 rate within an area suggests that the observed changes are not related to the magnitude of the purse seine catches (Fig. 10). In Figure 10, the percentage changes are compared with the purse seine yellowfin tuna catch from 1979 to 1983 in order to allow for a time lag due to the differential size or capture in the two gears. Similar results are obtained if different time frames are used for the purse seine catches. The spatial distribution of these percentage changes suggests that the largest decline in longline catch rates has occurred in the western and northern borders of the area fished by longliners (Fig. 11). This area overlaps, but tends to be outside of the areas of major Japanese purse seine catches (Fig. 12).

DISCUSSION

Effect of Different Stratifications

For both the longline and purse seine fisheries for yellowfin tuna, the different stratifications yielded relatively consistent patterns for the annual changes in catch rates. For the purse seine rates, the fact that different temporal stratifications had little effect on the overall annual averages is not surprising given the relatively equal temporal distribution of effort within a year (i.e., any seasonal differences in catch rates will be given approximately even weight in the pooled estimates).

Stratifications by area could have been expected to have a large effect on the annual purse seine catch rates given the highly clustered distribution of effort during any given month (Fig. 13; unpubl. results). The ratio of an unstratified catch rate estimate to a stratified estimate has been defined as a concentration index by Gulland (1955). A value near 1 for this ratio is usually interpreted to mean that fishermen are not concentrating their fishing effort in area and time strata where fish are most abundant. Values for this index based on the values in Table 1 range from 0.82 to 1.39. While there is some tendency for the annual estimates of catch rates which include stratification by area to be less than the unstratified estimates, the lack of any large and significant differences is due to the fact that there is almost no effort outside of these areas of high concentration. Thus, the data even when stratified, adds little information on catch rates outside the specific areas being fished at any given time.

For the longline results, the value of Gulland's concentration index ranges from 0.9 to 1.18 when calculated from the values in Table 2. In this case the lack of any large differences between the stratified and unstratified estimates in Table 2 is not due to effort being concentrated in only a few strata, but may be related to the multispecies aspect of the

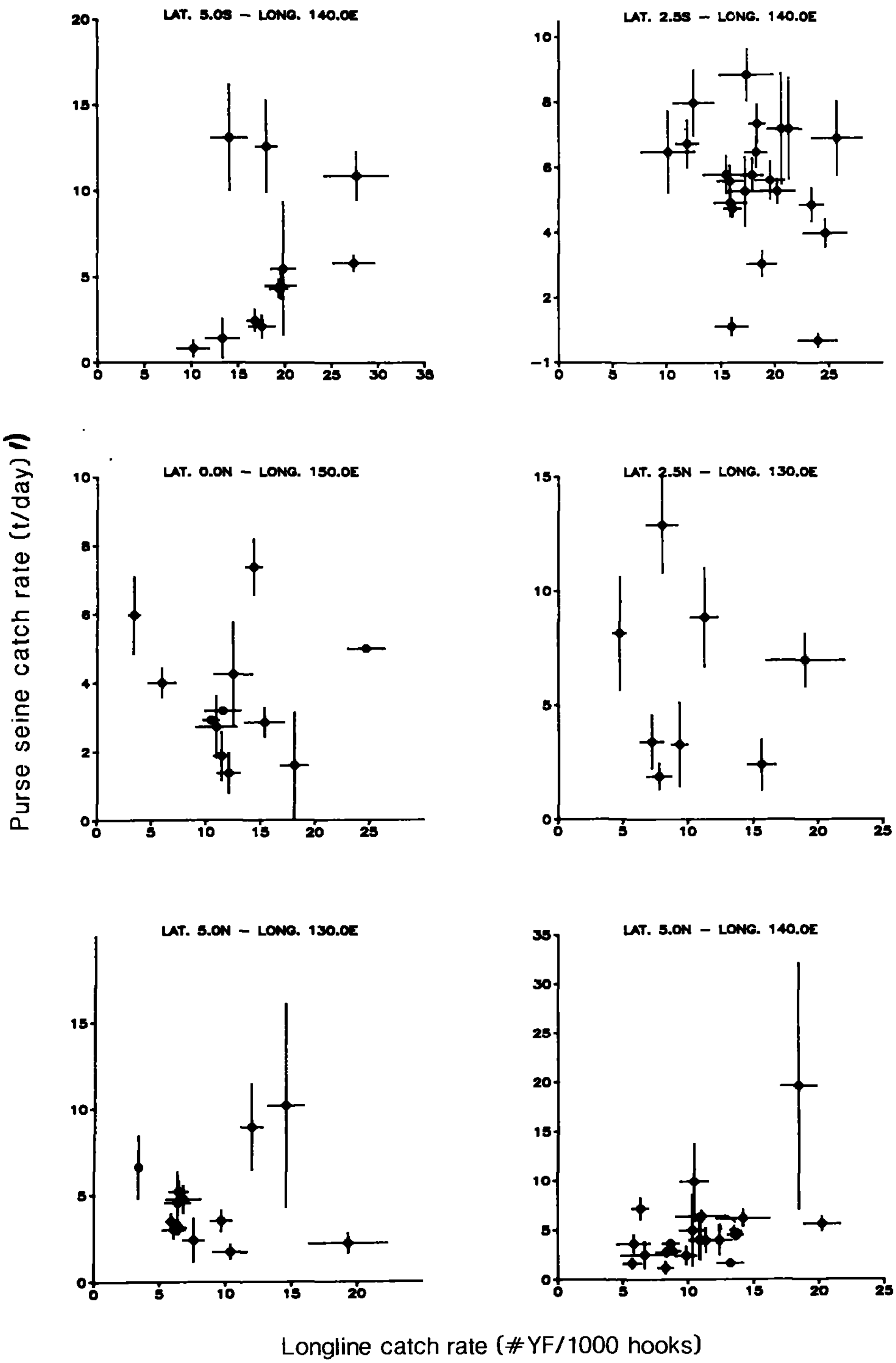

FIGURE 9.—The relationship between quarterly yellowfin tuna catch rates by Japanese longliners and purse seiners within rectangular

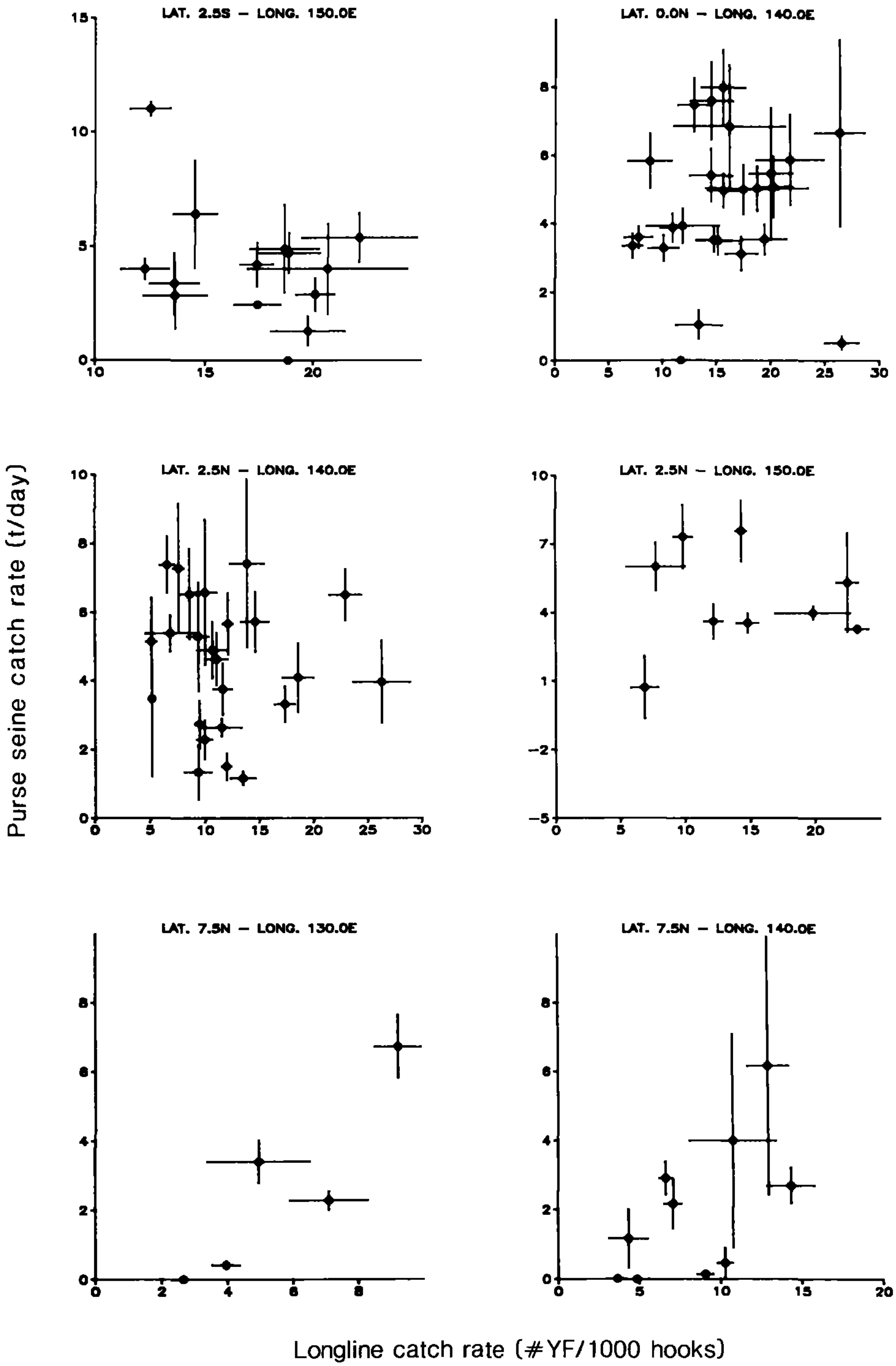

FIGURE 9.—*Continued*—areas of 2.5° of latitude and 10° of longitude. Error bars represent estimates of one standard error.

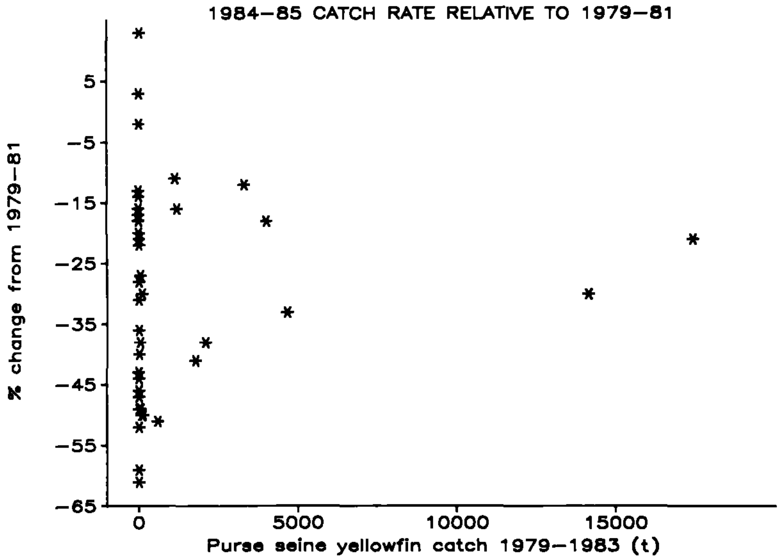

FIGURE 10.—The relationship between yellowfin tuna catches by Japanese purse seiners and the percentage change in yellowfin longline catch rates for rectangular areas of 2.5° of latitude by 10° of longitude in the western Pacific.

longline fishery. Thus, concentration indices for the combined catch of the major tuna species are generally greater than the value for any individual species (unpubl. results).

Purse Seine

The results of this paper suggest that there is no evidence that the western Pacific yellowfin tuna surface stocks vulnerable to purse seining have declined. Catch rates have remained relatively constant despite a 10-fold increase in catches since 1978. However, some cautions are warranted in interpreting the catch rates from this fishery in terms of indices of abundances. There are a number of factors specific to this fishery which are likely to result in nonlinear relation or lack of relation between changes in catch rates and changes in the size of the population. These could result in catch rates remaining high despite significant changes in abundances. Many of these have been discussed previously in connection with catch rates for schooling populations and for purse seine gear (e.g., Neyman 1949; Paloheimo and Dickie 1964; Quinn 1980; Mangel 1982; Gulland 1983). Probably the most important factor for the Japanese purse seine fishery is that a high proportion of the catch comes from early morning sets on naturally occurring flotsam (called logs by the fishermen) or manmade, free-floating fish aggregating devices (referred to as payao's in recognition of their Philippine origin). Generally, Japanese purse seiners tend to make a single early morning set on a log or payao located the previous day. Often vessels will return to the same log or payao over a period of several weeks (Gillett 1986; Farman 1987). Thus, purse seine catch rates will be a function both of the density and detection rate for logs and more importantly the renewal rate of fishable tuna schools under a log. Little is known about any of these processes, but they are not likely to be a simple linear function of yellowfin tuna densities.

Other factors which also might cause a nonlinear relation between catch rates and population density are the nonrandom distribution of searching effort and the sharing of fishing information among vessels. The fact that the concentration indices of Gulland discussed above are generally low does not indicate that the nonrandom distribution of searching effort (e.g., Figure 12) is not a major concern. Purse seine effort during any given month occurs only in a small portion of the range for surface yellowfin tuna. Thus, even when stratified by area, it is not possible to determine whether the catch rates are representative of overall abundance.

The catch curves based on monthly and quarterly statistics (Figs. 3, 5) might be interpreted as contradicting the above conclusions that there is no

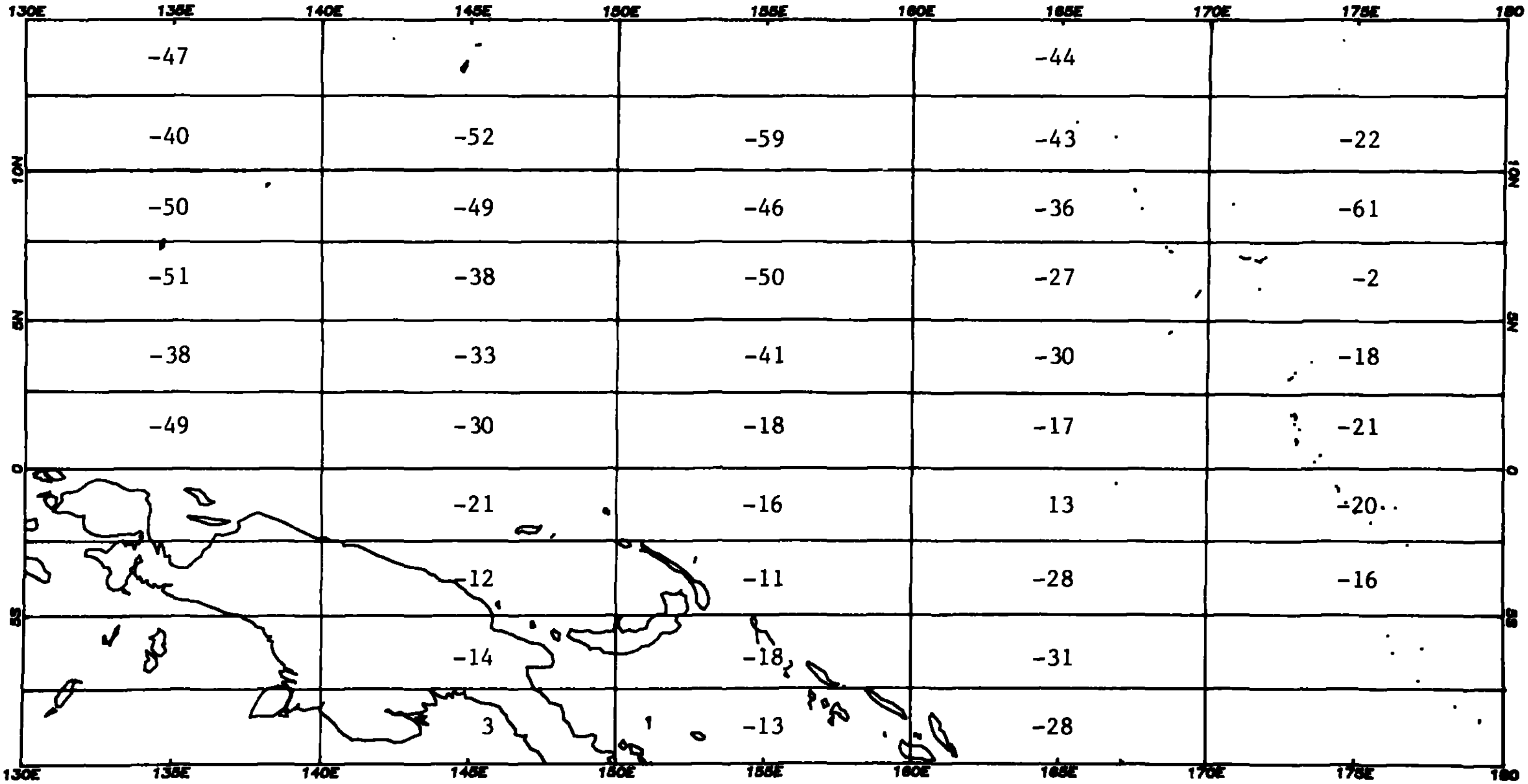

FIGURE 11.—The percentage change in the yellowfin tuna catch rate by Japanese longliners for 1984–85 relative to 1979–81 by rectangular areas.

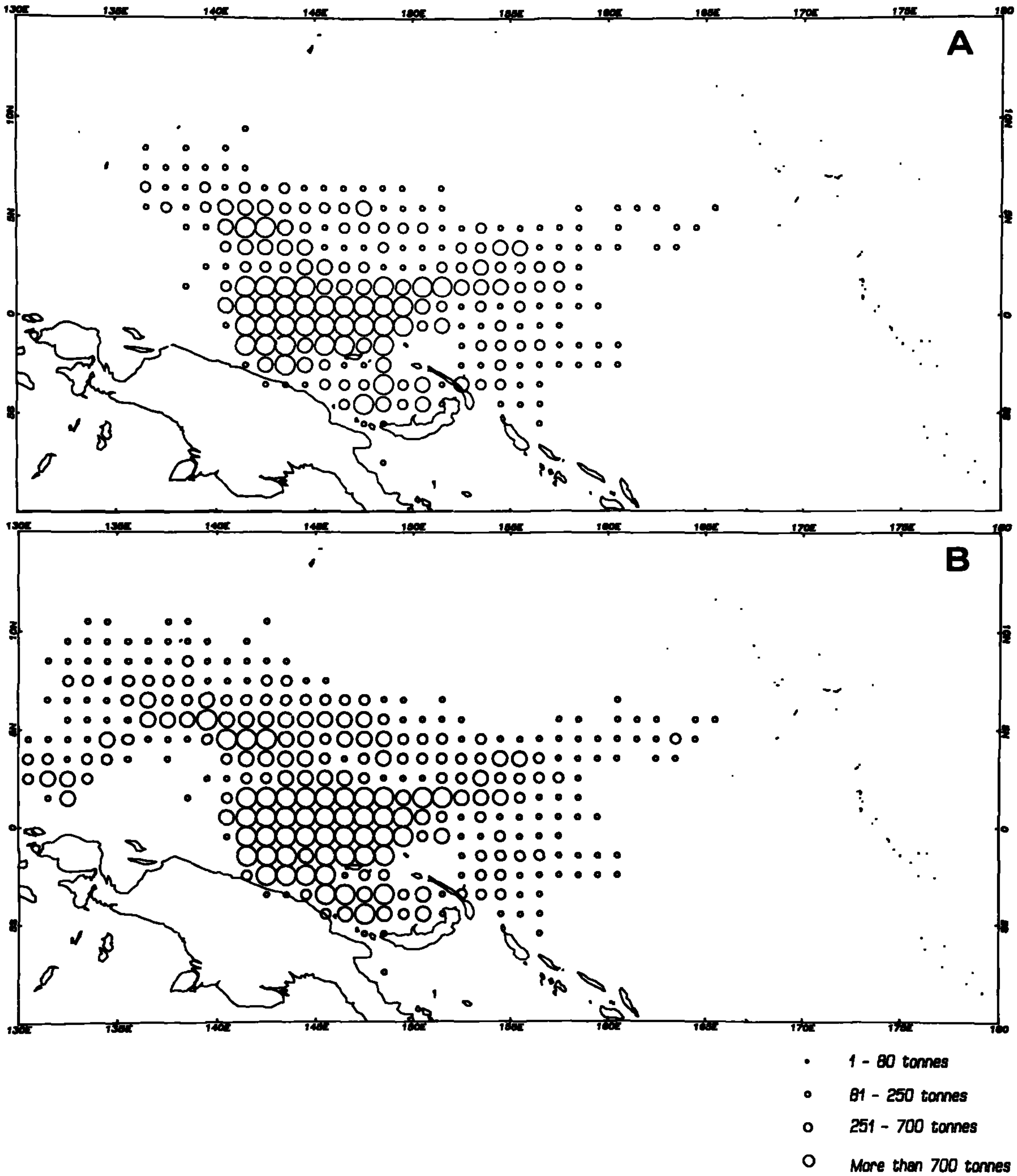

FIGURE 12.—The distribution of Japanese yellowfin tuna purse seine catches by one degree square: A) 1979 to 1983; B) 1979 to 1985.

evidence that surface yellowfin tuna stocks have declined. However, the time sequence of changes in catches in relation to changes in effort are not those that would be expected if these catch curves were a reflection of the overall population dynamics. Thus, when the temporal sequence of changes in catch and effort are considered by connecting the points in Figure 3, the resulting pattern suggests that during a time interval of one month, a large change in effort results in correspondingly large changes in the catch rates. If these changes in catch rates reflected changes in the overall yellowfin tuna abundance, it would mean that catches of 3,000–5,000 t represented a very significant proportion of the total yellowfin tuna stock and that a very rapid recovery of the yellowfin tuna stocks (i.e., during the course of a month) can occur with reductions in effort. Neither of these conclusions seem reasonable. Also, the fact that there is no evidence that catch rates are lower at the highest effort levels so far experienced when the data are combined into annual statistics, further suggests that the catch curves based on monthly and quarterly statistics do not reflect the overall population dynamics.

The apparent reduction in catch rates at the highest effort levels based on the monthly or quarterly stratification is an interesting phenomenon warranting further investigation. The reduction in catch rates at these highest effort levels does not appear to be the result of increased handling time at higher effort levels. The number of sets per day has remained relatively constant and unrelated to the total number of days fished. Two possible explanations for the decline in monthly catch rates with higher effort are localized depletions and interactions with skipjack tuna catches. In this regard, it is interesting to note that monthly or quarterly catch curves for skipjack tuna, *Katsuwonus pelamis*, from this same fishery do not show this apparent decline in catch rates at highest effort. The lack of decline in the catch rate for skipjack tuna is another indication that the decline observed for yellowfin tuna is not due to handling time.

Longline

Longline catch rates in 1984 and 1985 are substantially lower than those in 1979. Whether this decrease represents a general long-term decline is not possible to determine without a longer time series of data. Interpretation of the temporal trend depends partially upon whether the observed rates in 1983 are attributable to the large El Niño of 1983 or whether they are a measure of the random variability in the fishing process. The magnitude of the increase observed in 1983 is much larger than might be expected given the observed variability both between and within months (the latter is indicated by the error bars in Figure 8). While it is tempting and even reasonable to attribute the high rates in 1983 as an El Niño effect, the length of the current time series and available information on the effects of El Niño on yellowfin tuna are insufficient to objectively resolve whether the high 1983 rates are the results of El Niño.

Caution in interpreting longline catch rates as directly reflecting changes in population abundances is also warranted. While the operational procedures in tuna longlining would appear not to be very susceptible to inducing a nonlinear relationship between abundance and catch rates (i.e., handling time is not a major factor and the length of a single longline insures that effort can not be highly concentrated in space). However, concerns have been raised about potential hook competition at higher densities (Rothschild 1967; Au 1985). More importantly, longliners target different depths depending upon local conditions, market factors and the relative abundance of different species. In addition, the fact that surface catches in the Atlantic were able to greatly exceed previous catches of large yellowfin tuna by longliners despite the fact that longline catch rates had declined steeply suggests that the relationship between availability to the different gears versus overall abundance is not simple (Fonteneau 1981).

In order to gain a broader temporal perspective to compare the current catch rates, longline hooking rates from 1962 to 1980 for the same area considered in this paper are plotted in Figure 14 based on published data by the Fisheries Agency of Japan (1962–80). Longline hooking rates were generally declining through the mid-1970s and then appear to have entered a period of recovery. Because of the commencement of the purse seine fishery in 1980, interpretation of the overall long-term temporal trend is confounded and depends upon whether the apparent increase in the 1970s was a true recovery or a reflection of the variability that can be expected in this fishery.

Interaction

The results presented in this paper suggest that the relation between longline and purse seine fisheries is complex. The above discussion indicates that the current data is insufficient to determine whether a general decline is occurring in longline catch rates.

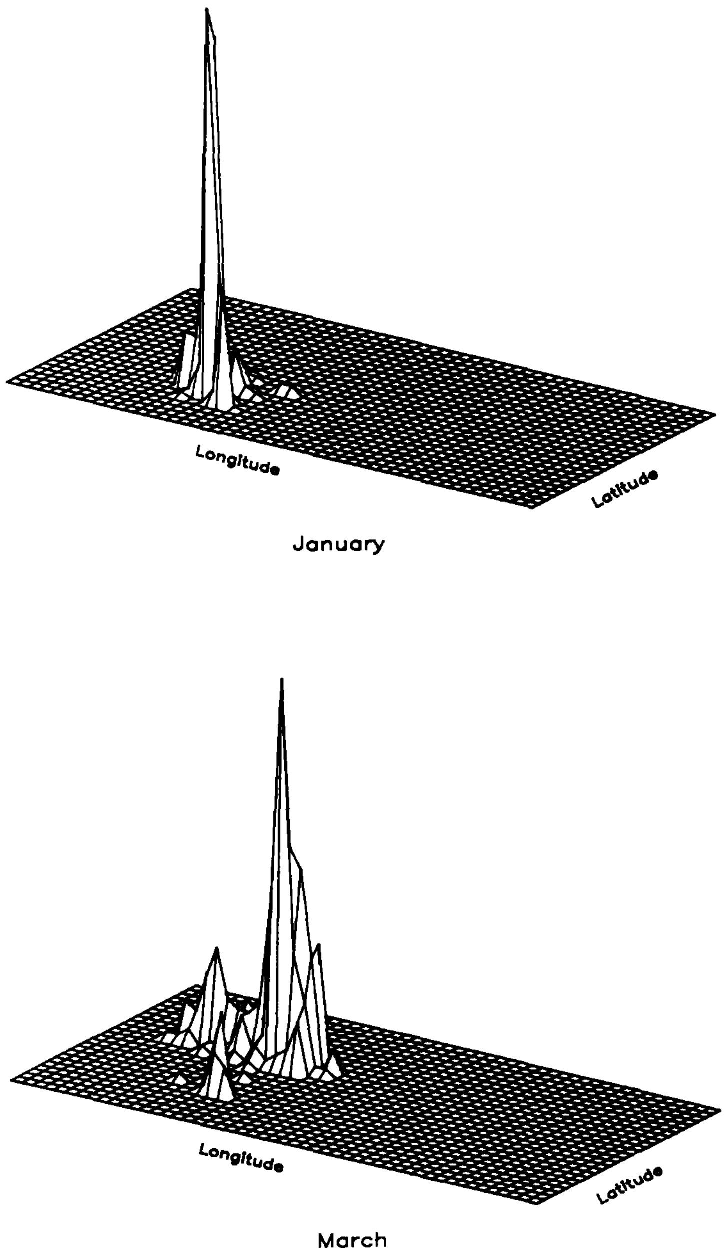

FIGURE 13.—Examples of monthly prospective block drawings showing the distribution of fishing effort by one degree square for Japanese purse seiners. The

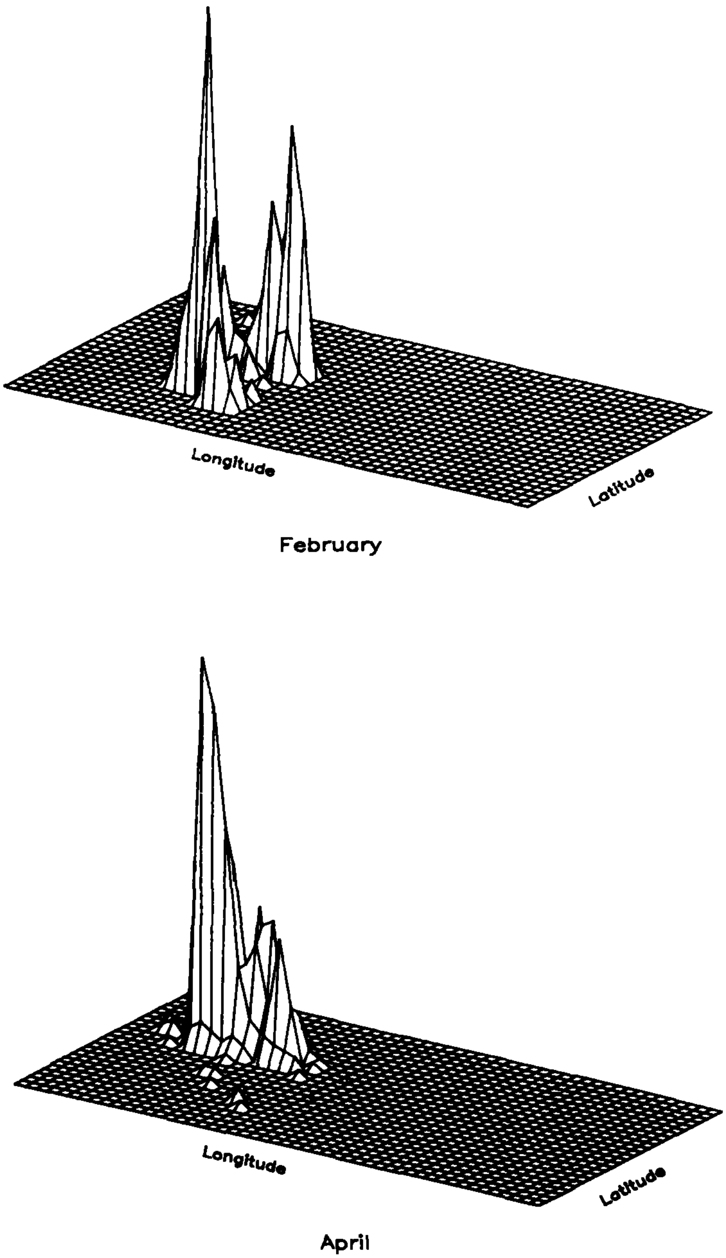

FIGURE 13.—*Continued.*—figures presented are for the first four months of 1984. The boundaries of the area are from lat. 10°S to 15°N and long. 130°E to 180°E.

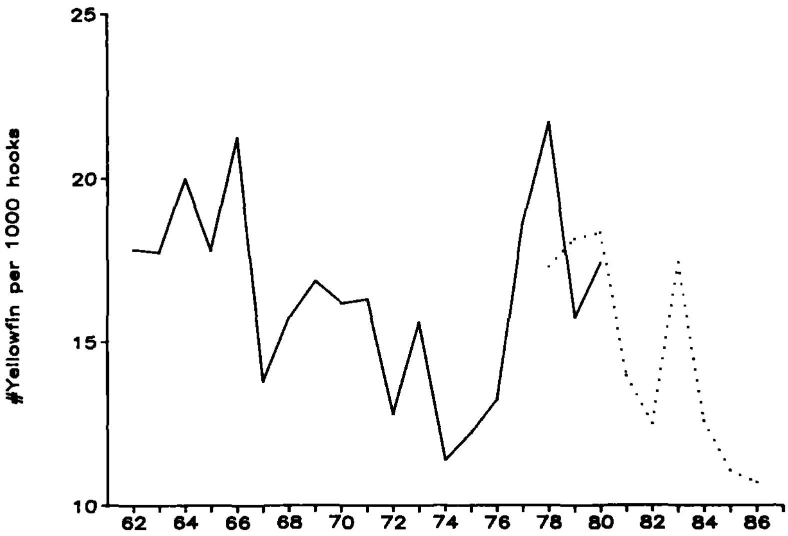

FIGURE 14.—Estimates of annual catch rates for Japanese longliners (number of yellowfin tuna per 1,000 hooks) in the western Pacific. The solid line represents stratified estimates based on five degree square areas from published data by the Fisheries Agency of Japan (1962–80). The dotted line represents the estimates stratified by area from Table 5 based on data held by the Tuna and Billfish Assessment Programme of the South Pacific Commission.

Even if a general decline is occurring, it would not be possible to evaluate whether the purse seine catch is a likely cause of the decline without either more detailed information on the age structure of the catches or a much longer time series of data.

Based on the comparison of catch rates within the same area and time period, yellowfin tuna do not appear to be a homogeneous stock with respect to purse seining and longlining. The lack of any relationship at a fine spatial and temporal scale could be due to

1. factors affecting vulnerability to surface gear are unrelated to factors affecting vulnerability to longline gear, or
2. those portions of the yellowfin tuna population being exploited by the purse seine fishery (i.e., primarily 2–3 year old fish) have a spatial-temporal distribution which does not coincide with that for the older and larger yellowfin tuna being harvested by longliners.

In reality, probability both of these factors, plus random elements in the fishing process are contributing to the apparent lack of any relationship.

The fact that the observed changes in longline catch rates within areas appear not to be related to the purse seine catches taken from that area may be due to any number of factors. Some possible hypotheses include

1. The level of exploitation by purse seiners within any of the areas considered has been insufficient to affect a significant decline in longline catch rates.
2. Given the difference in the size and age of the fish exploited by the two fisheries, a time lag would be expected before any effect could be observed and the presently available time series may be too short to detect the effects.
3. There is a large amount of movement of yellowfin tuna so that the yellowfin being harvested by longliners are not merely the escapement from the purse seine fishery within that area.
4. There are two independent stocks or substocks of yellowfin tuna—a deep and a surface one—each of which is primarily vulnerable to only one gear type.
5. The available purse seine catch statistics are incomplete and areas in which the greatest decline in longline catch rates have occurred may in fact be areas where large, unreported purse seine catches have occurred.
6. The main areas in which the largest decline in longline catch rates have occurred border the EEZ's of the Philippines and Indonesia. The

Philippine surface tuna fishery has increased dramatically and there is a suggestion that overfishing has occurred there (Floyd and Pauly 1984).

It is not possible with existing knowledge to distinguish between these hypotheses while available data suggest that all of the above may be contributing to the observed results. Thus, for example, very limited tagging data from the western Pacific suggest that the yellowfin tuna stocks may be very large and that yellowfin tuna caught by longliners in the Pacific can travel long distances from their initial place of capture. Ten yellowfin tuna tagged by the SPC were recaptured by longliner and traveled an average distance of 1,280 miles from their point of release (unpubl. data). Tag experiments from the Atlantic yielded no returns by longliners which suggests that yellowfin tuna cannot be considered as a single homogeneous stock in that ocean with respect to the different gears (Fonteneau 1981). Yet, the fact that surface tagged fish have been recaptured by longliners in the Pacific means that they are not totally distinct. A better understanding of the interactions between longline and purse seine fisheries is dependent upon both a more complete set of catch and effort statistics and a longer time series of data, plus biological information from other sources. The present low longline catch rate and the importance of longline fisheries in the South Pacific make this a question of immediate concern.

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