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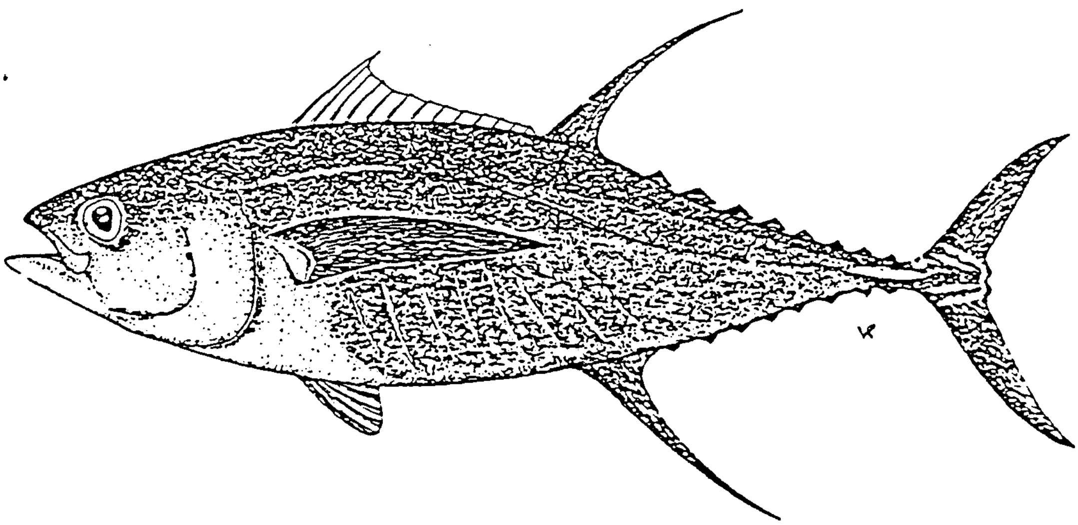
INDICES OF ABUNDANCE OF YELLOWFIN TUNA IN THE WESTERN PACIFIC DETERMINED FROM PURSE SEINE CATCH AND EFFORT DATA



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INTRODUCTION

The purse seine tuna fishery in the South Pacific Commission (SPC) statistical area (Figure 1) has undergone rapid expansion since the early 1980s, with estimated catches increasing from 51,389 mt in 1980 to 840,853 mt in 1991 (Lawson 1992a). Skipjack is the principal species taken by purse seining (666,068 mt, or 79 per cent, in 1991), however purse seine catches of yellowfin currently represent the largest component of yellowfin catches in the Western Pacific (174,785 mt, or 21 per cent, in 1991), as compared to catches by longline (38,799 mt), pole-and-line (2,470 mt) or artisanal catches in south-east Asia (150,481 mt) (Table 1). The principal purse seining nations have been Japan, Korea, Taiwan and the United States. Catches have also been taken in the Western Pacific by purse seiners from Australia, Federated States of Micronesia, Indonesia, Mexico, New Zealand, the Philippines, Solomon Islands and the former Soviet Union.

Indices of abundance have been constructed from the Western Pacific purse seine daily catch and effort data in the past. South Pacific Commission (1985) examined data from Japanese vessels for 1980—1985 using (1) various temporal and areal stratifications to estimate annual average catch rates from stratified means and (2) a general linear model to standardise catch rates for the effect of quarter, latitude, the absolute value of latitude, and longitude. The use of stratified means on data for Japanese purse seiners was expanded to include data for 1979—1986 by Polachek (1988). Medley (1990) analysed data for 1979—1986 from all fleets combined using a general linear model to assess the effects of time, area, vessel size and school type.

In the present study, a multivariate analysis of yellowfin catch rate using data covering the period 1979—1992 is used to construct indices of abundance. The variables examined in the linear model include school type, the presence of skipjack in the catch, geographic and temporal strata, vessel attributes and oceanographic parameters. The data are weighted to account for the effect of fishing effort being concentrated in areas of high catch rates.

METHODS

LOGBOOK DATA

The South Pacific Commission (SPC) holds daily catch and effort data for each of the purse seine fleets that have operated in the SPC region, though the data quality and coverage vary among the fleets. These logbook data have been provided by SPC member countries that have collected the data either from distant-water fishing nations under the terms of access agreements or from local fleets. The fleets of eleven fishing nations are covered by data held at SPC (Table 2).

Data for five smaller fleets, including Australia, Indonesia, Mexico, New Zealand, and the former Soviet Union, are limited in quantity. Data for these five fleets have not been included in the analysis in order to minimize problems associated with multiple sources of data, such as differences among the fleets in the years and areas fished, the fishing strategies and the quality of data.

Data for two of the fleets, though relatively extensive, are not appropriate for constructing indices of abundance for the SPC region as a whole due to the special conditions under which they operate. Catches by the fleets of the Philippines and Solomon Islands are based primarily on anchored fish aggregation devices (FADs) employed over limited areas in the waters of Papua New Guinea and

Solomon Islands. Data for these fleets are therefore not informative of yellowfin catch rates in the region as a whole.

Data covering the fleets of Korea and Taiwan have been excluded due to problems of under-reporting (see Lawson 1992b).

Only data for the Japanese and American fleets have therefore been included in the analysis. Coverage of the Japanese fleet averages 67 per cent annually (Lawson 1992b); most of the missing data cover activities on the high seas, in particular the area between the waters of Papua New Guinea (PNG) and the Federated States of Micronesia (FSM) (Figure 1). Coverage of the American fleet was poor until June 1988, when the multilateral treaty with Pacific island nations went into effect. Following June 1988, coverage of the American fleet has been nearly complete, including coverage of activities on the high seas.

Figure 2 shows annual yellowfin catches by the Japanese and American fleets during 1979—1992, determined from daily logbook data held at SPC. The data for the period 1979—1986 mostly cover the Japanese fleet operating to the west of 160°E and between 5°S and 10°N. Data for the Japanese fleet for the period 1987—1992 cover the same longitudes, i.e. to the west of 160°E, but the exclusion of the Japanese fleet from the waters of PNG in 1987 is reflected in decreased coverage between 5°S and the Equator. Data for the American fleet are limited until 1989, the first full year during which data were collected under the multilateral treaty. The area fished by the American fleet since 1989 has been different from the area fished by the Japanese fleet. While the Japanese fleet fished primarily in the waters of FSM, the American fleet fished in the waters of PNG during 1989, to the east of 160°E during 1990 and again in 1992, and both in the waters of PNG and to the east of 160°E in 1991.

Due to the limited coverage of the American fleet until 1989 and to the differences in the areas fished by the American and Japanese fleets during 1989—1992, it was decided to construct two separate indices, the first based on data for the Japanese fleet fishing to the west of 160°E during 1979—1992 and the second based on data for the American fleet fishing to the east of 160°E during 1990—1992. The two indices together thus cover the geographic range of the fishery, although data sufficient for constructing indices of abundance for the eastern area are available only after 1989.

The catches recorded on logbooks, which are usually measured by counting the number of brails taken from each set and multiplying by a constant which depends on the species composition and the average size of fish, have not been corrected with unloading data, which are measured with a scale. However, a comparison of logbook data to a large sample of unloadings indicates that total catches per trip estimated from logbooks for American vessels are unbiased on average (Lawson 1992b). Neither unloading data for Japanese vessels nor any other studies examining the quality of Japanese logboook data are available at SPC, therefore the quality of logbook data for the Japanese fleet is unknown.

Only sets from which the yellowfin catch was at least 3 mt were used in the analysis. A large proportion of sets resulted in catches of skipjack only. These sets were not included in the analysis because (1) they were considered to be relatively uninformative of yellowfin abundance and (2) their inclusion would have resulted in fitting a large number of zero yellowfin catch rates, which would have had the effect of improperly weighting the more informative sets from which yellowfin were caught. Sets from which the yellowfin catch was positive but less than 3 mt were not included because of the possiblility that the set was only partially successful.

Catch rate was defined as the catch (mt) of yellowfin per hour searched per set. While the time of the beginning of each set is recorded on logsheets provided to SPC, neither searching time between sets nor the time at the end of each set are recorded. Therefore hours searched were determined by assuming that searching began immediately following the beginning of the previous set and continued between 6:00 am and 6:00 pm daily. Handling time for the previous set is thus included in the searching time.

The allocation of all of the time between sets to searching time is not usually justified for sets on schools associated with floating objects. Sets on floating objects are most successful at dawn, therefore once floating objects are spotted, they are usually not set upon until the following morning. While waiting to make a set on a floating object, the vessels either search for other schools, associated or unassociated, or remain inactive. Further, it is not uncommon to make more than one set on the same floating object on successive days. Nevertheless, the absence of the information required to determine searching time with more precision precludes alternatives to using the daylight time between sets to define searching time.

The catch rates (mt per hour searched per set) were strongly skewed to the right, therefore a logarithmic transformation was applied. The transformed catch rates, $\ln(C / E)$, where C and E are the yellowfin catch (mt) and effort (hours searched) per set, respectively, were approximately normally distributed (Figure 3).

WEIGHTING

Weighting of the data is required if fishing effort is concentrated in areas of high abundance, since the indices of abundance will put less weight on data from areas of low abundance and will therefore overestimate the abundance of the population as a whole. Several measures indicate that the Western Pacific purse seine fleet has been concentrated.

Gulland (1956) proposed that the ratio of unstratified CPUE to CPUE averaged over area strata could be used as an index of concentration. The unstratified CPUE gives more weight to areas with more fishing effort, while the stratified CPUE gives equal weight to all areas, regardless of the amount of fishing effort. When concentration occurs due to vessels remaining in areas of high catch rates, the unstratified CPUE will be greater than the stratified CPUE, resulting in an index that is greater than 1.0.

Table 3 presents concentration indices determined by stratifying transformed catch rates by 1° x 1° square by month. All values are greater than 1.0, except for 1979 and 1988, indicating that concentration is a regular occurrence. The value of the index varies considerably, from no concentration (0.91 in 1979) to high concentration (1.57 in 1990). The lack of concentration in 1979 can be explained by low fishing effort at a time when fishing techniques for the Western Pacific were still developing. In 1988, yellowfin catch rates were much lower than average, which resulted in vessels concentrating on skipjack at the expense of yellowfin.

Table 4 indicates that average catch rates in time-area strata of low effort (1—2 days fished or searched per 1° x 1° square per month) have been lower than catch rates in other strata each year since 1979.

The implication of (1) a high degree of concentration and (2) low catch rates in areas of low effort is that the data to be used to construct indices of abundance must be analysed in some way such that equal weight is given to time-area strata of equal sizes. Punsley (1987) used the logarithm of catch rates (mt per hour searched per set) as replicates in a multivariate analysis and employed a weighting scheme such that each strata of 5° x 5° square by month received equal weight. He found that the weights which gave the minimum average bias in estimates of mean catch rate in year *k* relative to base year 0, using transformed data, $\ln(C_{ijk} / E_{ijk})$, was

$$W_{ijk} = \ln(E_{ijk} + 1) / \Sigma_i \ln(E_{ijk} + 1). \qquad (1)$$

where C_{ijk} and E_{ijk} are the catch (mt) and effort (hours searched) per set, respectively, from set *i* in strata *j* in year *k*. In the analysis below, catch rates for individual sets were weighted using (1) such that each 1° x 1° by month stratum received equal weight.

INDEPENDENT VARIABLES

School Type

Purse seine sets in the Western Pacific are made on free-swimming schools or on schools associated with floating objects, such as logs, drifting and anchored FADS and marine animals. Punsley (1987), in his study of Eastern Pacific yellowfin, used school type in defining a search classification that also accounted for the effect of skipjack in the catch and whether the school type was different from the previous school type. Medley (1990) used school type as a separate variable. Both studies found school type to be an important factor.

Yellowfin from unassociated schools accounts for 46 per cent of the total yellowfin caught by the Japanese and American fleets in the Western Pacific, while associated schools account for 54 per cent (Table 5). Catch rates differ considerably among associated and unassociated schools. Sets on unassociated schools are characterised by a lower rate of success than for associated schools (51 per cent compared to 92 per cent), but higher catch rates when they are successful (39.5 mt total per set and 8.8 mt yellowfin per set for unassociated schools, compared to 29.3 mt total per set and 7.0 mt yellowfin per set for associated schools). The average yellowfin catch for sets from which yellowfin were caught differs considerably between the two school types, 28.9 mt yellowfin per successful yellowfin set for unassociated schools, compared to 8.1 mt yellowfin per successful yellowfin set for associated schools.

The influence of school type differs between the areas/fleets (Table 5). Unassociated schools account for a much greater proportion of the yellowfin catch in the eastern/American area compared to the western/Japanese area (85 per cent compared to 29 per cent). While the average yellowfin catch per successful yellowfin set is greater for unassociated schools than for associated schools for both areas/fleets, the yellowfin catch per successful yellowfin set is much greater in the eastern/American area than in the western/Japanese area (40.4 mt per set for unassociated schools and 18.0 mt per set for associated schools in the eastern/American area compared to 22.9 mt per set for unassociated schools and 7.4 mt per set for associated schools in the western/Japanese area).

School type was included in this analysis as a classification variable with two values, indicating associated or unassociated schools.

Presence of skipjack

Table 6 shows that there are large differences in yellowfin catch rates in the Western Pacific depending on whether skipjack were also taken from the set. Table 6 also shows that the effect is greater for unassociated schools than for associated schools.

The presence of skipjack was included in the analysis as a classification variable with two values, indicating either a positive or zero catch of skipjack in the set.

Geographic strata

Medley (1990) analysed data covering all fleets in the Western Pacific during 1979—1986 and examined the effect of eleven 5° x 5° grids in his multivariate analysis. The grid effect was statistically significant, though small, with higher catch rates observed at lower latitudes.

Yellowfin catch rates from the current data set were mapped by various time-area stratifications, however, no clear pattern in the distribution of catch rates by geographic strata was observed. Nevertheless, geographic strata was included in the present analysis as a classification variable using 5° x 5° squares. The data were screened such that each 5° x 5° square was supported by at least 100 sets, which resulted in 23 squares being included in the analysis, compared to a total of 57 squares in the original data.

Temporal strata

Medley (1990) defined time strata as four periods of three months (March—May, June—August, September—November and December—February); the time effects, though statistically significant, were small.

Figure 4 presents average monthly yellowfin catch rate, separately for the western/Japanese area and the eastern/American area. Catch rates for the western/Japanese area appear to be independent of month, while for the eastern/American area the relationship is highly variable. The data for the eastern/American area indicates further that average monthly catch rate is variable for both school types, associated and unassociated. Temporal strata were included in the analysis as a classification variable consisting of twelve monthly periods.

Vessel Attributes

Medley (1989) examined data for all fleets combined in the Western Pacific and included gross registered tonnage (GRT) as a discrete variable of three classes (less than 400, 400 to 500, greater than 500). He noted that vessel size is confounded with vessel nationality; Japanese vessels usually fall into the 400—500 GRT class, while American and Korean vessels are usually greater than 500 GRT. It was found that GRT was significant; medium-sized vessels had the highest catch rates, while the largest vessels had the lowest. The effect of the 400—500 GRT class was to increase yellowfin catch per hour searched by 33 per cent relative to the under-400 GRT class, while the effect of the over-500 GRT class was a reduction of 7 per cent relative to the under-400 GRT class.

Figure 5 presents the number of vessels by GRT class for Japanese and American vessels. Most Japanese vessels are in the 0—100 to 500—600 GRT classes, while the American vessels are mostly in the 1000—1100 GRT class or greater. Figure 6 shows the relationship between yellowfin catch rates and GRT. Yellowfin catch rate appears to be positively correlated with GRT. However, the relationship is more pronounced for the larger, mostly American vessels, than for the smaller Japanese vessels. GRT was included in the present analysis as a classification variable with nine discrete classes of GRT, ranging from the 0—200 to the 1600—1800 GRT classes.

Gear technology for Western Pacific purse seiners has undergone considerable development since the early years of the fishery. Catching ability has been improved through adaptations in net size, hydraulics and vessel speed (Allen *et al* 1991). The Japanese are credited with developing larger nets required for conditions in the Western Pacific. New *Super Pacific Class* vessels entering the American fleet (and also the fleets of Korea and Taiwan) are rated at 17½ knots, compared to 15½ knots for older American vessels (Eastern Pacific vessels modified for use in the Western Pacific), while hydraulic power, which is related to pursing speed, has increased to 1000 hp for newer vessels, compared to 764 hp for older vessels. Unfortunately, however, information on gear technology (in particular vessel speed, hydraulic power, presence of bird radar, presence of helicopter) was lacking for most vessels and therefore could not be tested in the analysis.

Oceanographic parameters

The SURTROPAC group at the *Institut français de recherche scientifique pour le development en cooperation* (ORSTOM), Nouméa, New Caledonia, has compiled surface and XBT data covering the Western Pacific. Three parameters for the period 1979—1991 were examined: sea surface temperature (SST), the depth of the 14°C isotherm (D14) and the depth of the 21°C isotherm (D21).

The oceanographic data were originally stratified by 1° x 1° square by month. However, the number of sets covered by the oceanographic data was low. Therefore, the oceanographic data were averaged over strata of 5° x 5° by quarter. The averaged data are less detailed, but still should be useful in identifying interannual variations. However, even when the oceanographic data were averaged, only 50 per cent of all sets were covered (48 per cent of sets in the western/Japanese area and 62 per cent of sets in the eastern/American area).

Figure 7 presents yellowfin catch rates plotted against SST, D14 and D21, for the western/Japanese and eastern/American areas separately. The relationships between catch rate and both D14 and D21 in the western/Japanese area are increasing, though weak, while the relationship with SST is unclear. For the eastern/American area, the relationship with SST appears to be decreasing, while the relationships with D14 and D21 are unclear. In both the western/Japanese and eastern/American areas, the range of SST examined is small, from 28.5°C to 30.2°C.

The oceanographic parameters were included in the analysis as covariates after centering the data by subtracting the mean value and dividing by the standard deviation. Values of the oceanographic parameters for sets not covered by the data were assigned a value of zero, which corresponds to assigning the mean value. In addition to first degree polynomials, second and third degree poynomials were tested in order to detect nonlinear relationships.

MODEL SELECTION

The data were fitted using a stepwise multiple regression procedure. The initial model included only the year effect. During subsequent steps, each of the remaining independent variables (including school type, presence of skipjack, geographic strata, temporal strata, gross registered tonnage, oceanographic parameters in linear, quadratic or cubic formulations) were included in the model individually. The variable with the highest F value was then added to the model. The stepwise procedure was terminated when none of the variables tested resulted in an F value greater than 10. After all the independent variables had been tested and the stepwise procedure terminated, the interactions among all of the variables that had been included in the model were tested.

At each step, the possibility of backward steps, i.e. deleting variables whose partial F value dropped below 10 after the inclusion of a new variable, was left open. While the stepwise procedure thus potentially allowed for both forward and backward steps, no backward steps were actually required, since no partial F values dropped below 10 after the inclusion of a new variable.

Stepwise regressions usually proceed by accepting the variable at each step whose coefficients have the smallest probability of being equal to zero. The hypothesis that the coefficients for each variable are equal to zero is tested using the partial F value, i.e. the ratio of the mean square due to the variable to the residual mean square. In this case, however, the F test is almost certainly invalid due to the lack of independence among replicates. Independence in the present sense implies that the probability that the catch rate for an individual set will take a particular value is not related to the values of catch rates for any other sets. The demonstration of the concentration of fishing effort and of the difference in catch rates between areas of low effort and other areas, which is discussed above, is in clear contradiction to the assumption of independence among catch rates for individual sets.

The use of inferential statistics in data from experiments in which replicates are not statistically independent is termed *pseudoreplication* (Hulbert 1984). Green (1987) emphasized that a result of pseudoreplication is that the variance in error terms used in statistical tests is underestimated. During preliminary analyses, it was found that almost every variable tested had partial F values with probabilities of less than 10^{-5}, even in models with a large number of variables. This result, which is in contradiction to common sense, may indicate that the partial F values were overestimated due to an underestimated residual mean square.

In the present study, therefore, F statistics were not used in the strict statistical sense, i.e. with reference to the probability associated with the F value and its degrees of freedom, but only as a rough indicator of the level of importance of each of the variables. Furthermore, since the residual mean square was almost certainly underestimated, only variables with partial F statistics of at least 10, a relatively high value, were accepted into the model.

RESULTS

WESTERN/JAPANESE AREA

The variables accepted into the model for the western/Japanese area included year, school type, the presence of skipjack, geographic strata, sea surface temperature, sea surface temperature squared, and the interaction between school type and the presence of skipjack. The variables that were not accepted included temporal strata, gross registered tonnage and the depths of the 14°C and 21°C isotherms. Model coefficients are presented in Table 7. Partial F values for the final model are given in Table 8.

The amount of variation in the catch rates explained by the model amounted to 14.5 per cent, which is roughly similar to the amount explained in a similar model for eastern Pacific yellowfin (Punsley 1987). The most important variable was school type, followed by the presence of skipjack and year. The other variables, though accepted according to the criteria discussed above, had only a small effect on the amount of variation explained by the model.

A plot of the residuals against standard normal quantiles indicated that the residuals were almost normal (Figure 8). Histograms of the residuals plotted against year did not reveal lack of fit.

The indices of abundance were taken as the exponential of the coefficient for each year. The index for 1979 has the value of unity. Trends in the indices of abundance for 1979—1992 are shown in Figure 9. Trends in the nominal yellowfin catch per day fished are shown in Figure 10.

EASTERN/AMERICAN AREA

The variables accepted for the eastern/American area included year, school type, the presence of skipjack, the depth of the 21°C isotherm and the depth of the 21°C isotherm squared, and the interactions between year and school type and between school type and the presence of skipjack. The variables that were not accepted included geographic strata, temporal strata, gross registered tonnage, sea surface temperature and the depth of the 14°C isotherm. Model coefficients are presented in Table 9. Partial F values for the final model are given in Table 10.

The amount of variation in the catch rates explained by the model amounted to 21.5 per cent. The most important variable was school type, followed by the interaction between year and school type, the presence of skipjack, and year.

A plot of the residuals against standard normal quantiles indicated that the residuals were almost normal (Figure 11). Histograms of the residuals plotted against year did not reveal lack of fit.

Since the interaction between year and school type was important, it would be inappropriate to construct a single index of abundance for the eastern/American area. Therefore separate indices for each school type were constructed from the coefficients for year, school type and their interaction. Trends in the indices of abundance by school type for 1990—1992 are shown in Figure 12. Trends in the nominal yellowfin catch per day fished are shown in Figure 13.

DISCUSSION

WESTERN/JAPANESE AREA

The trend in the index of abundance (Figure 9) appears to be qualitatively different from the trend in catch per day fished (Figure 10) during the period 1979—1983, with the index showing a relatively consistent increasing trend, while the catch per day fished is variable. The index was not corrected for technological improvements nor the accumulation of experience that are known to have occurred during this period, therefore the increasing trend should be interpreted with caution.

During the period 1983—1992, the trends in the index and in catch per day fished are qualitatively similar, except for 1984—1985 and 1987—1988. Both trends are variable during 1983—1990 and show sharp increases during 1990—1992.

The large decline in yellowfin catch per day fished during 1988 (Figure 10) was associated with a drop in the proportion of the yellowfin catch from unassociated schools (13 per cent during 1988, compared to 32 per cent during 1979—1992). The decline in the proportion of yellowfin from unassociated schools was in turn associated with a drop in the proportion of successful yellowfin-only sets on unassociated schools (1 per cent of all sets in 1988, compared to 10 per cent during 1979—1992) and a decline in the catch per successful yellowfin set on unassociated schools (14.0 mt in 1988, compared to 22.9 mt during 1979—1992). The decline in the proportion of the catch from unassociated schools during 1988 may have been due to oceanographic events that occurred that year. In contrast, the index of abundance shows a slight increase from 1987 to 1988 (Figure 9). The difference is due to the fact that the index has been standardised on school type and has thus taken into account the effect of the decline in the proportion of the catch from unassociated schools during 1988.

EASTERN/AMERICAN AREA

The interaction between year and school type for the eastern/American area means that the effect of school type on catch rates differs among years. Therefore the effect of year and the effect of school type cannot be considered separately. In other words, the yellowfin fishery in this area ought be considered as consisting of two components, the fishery on associated schools and the fishery on unassociated schools. When the catch rates in the two components are standardised for the presence of skipjack and sea surface temperature, the result is the indices presented in Figure 12, which show, for associated schools, no change in 1991, relative to 1990, followed by an increase in 1992, and, for unassociated schools, a decline in 1991, followed by an increase in 1992. The trend in the catch per day fished more closely resembles the index for unassociated schools, which dominate the fishery in this area (Table 5).

The relationship between the indices for associated and unassociated schools, on the one hand, and the abundance of yellowfin, on the other, is unclear. While the possibility that the population consists of two separate components must be considered, other explanations as to why the effect of school type might differ among years should be entertained.

The number of associated schools in an area depends on the abundance of floating objects, while the number of unassociated schools depends on the number of free-swimming aggregations of prey species. If the average size of a tuna school is related to the absolute number of schools in an area, such that tuna schools tend to contain more fish when fewer schools are present, then the effect of school type on catch rates will vary with the number of floating objects or aggregations of prey. Annual differences in the effect of school type may therefore reflect annual differences in the number of floating objects or aggregations of prey, both of which are known to exhibit wide variations from year to year.

The importance of the interaction between year and school type may also be a statistical artifact due to only three years being included in the analysis. If the effect of school type in future years remains consistent, then the importance of the interaction, relative to other terms in the model, may diminish.

CONCLUSION

The indices of abundance for both the western/Japanese area during 1979—1992 and the eastern/American area during 1990—1992 do not exhibit the declines that might have been expected given the rapid increases in purse seine effort that have occurred. On the other hand, the present results are consistent with those from an analysis of data collected during an extensive tagging programme, conducted during 1990—1992, which indicate that fishing mortality on surface-caught yellowfin in the Western Pacific is relatively low (Hampton 1992).

The increasing trend in the index of abundance for the western/Japanese area during the early years of the fishery may be explained in part by technological advances and the accumulation of experience. However, no information is available at present that could be used to standardize catch rates for these variables. The indices could be improved with information for both the Japanese and American fleets on changes in technological attributes related to fishing power, such as vessel speed, winching power and fish-finding electronics.

The relationships between catch rate and sea surface temperature in the western/Japanese area, and catch rate and the depth of the 21°C isotherm in the eastern/American area, were included in the model, even though the coverage by the oceanographic data of the time-area strata fished was relatively poor. The indices of abundance could perhaps be improved by further interpolating the oceanographic data to obtain estimates of the oceanographic parameters for those time-area strata not covered by the data.

While the yellowfin catch rates have been standardised for several variables, the question remains as to the relationship between the indices and true population abundance. Clark and Mangel (1979), for example, have demonstrated that if the population is composed of a schooling component and a non-schooling or background component, and if the schooling component is limited in size, then catch rates may not be indicative of total population size. They showed that the population may decline while catch rates remain stable up until a very low population size is reached, after which catch rates decline dramatically. At present, evidence for the population structure just described is lacking. Nevertheless, the possibility that yellowfin populations are so structured, and, thereby, that catch rate and abundance are poorly correlated, cannot be dismissed.

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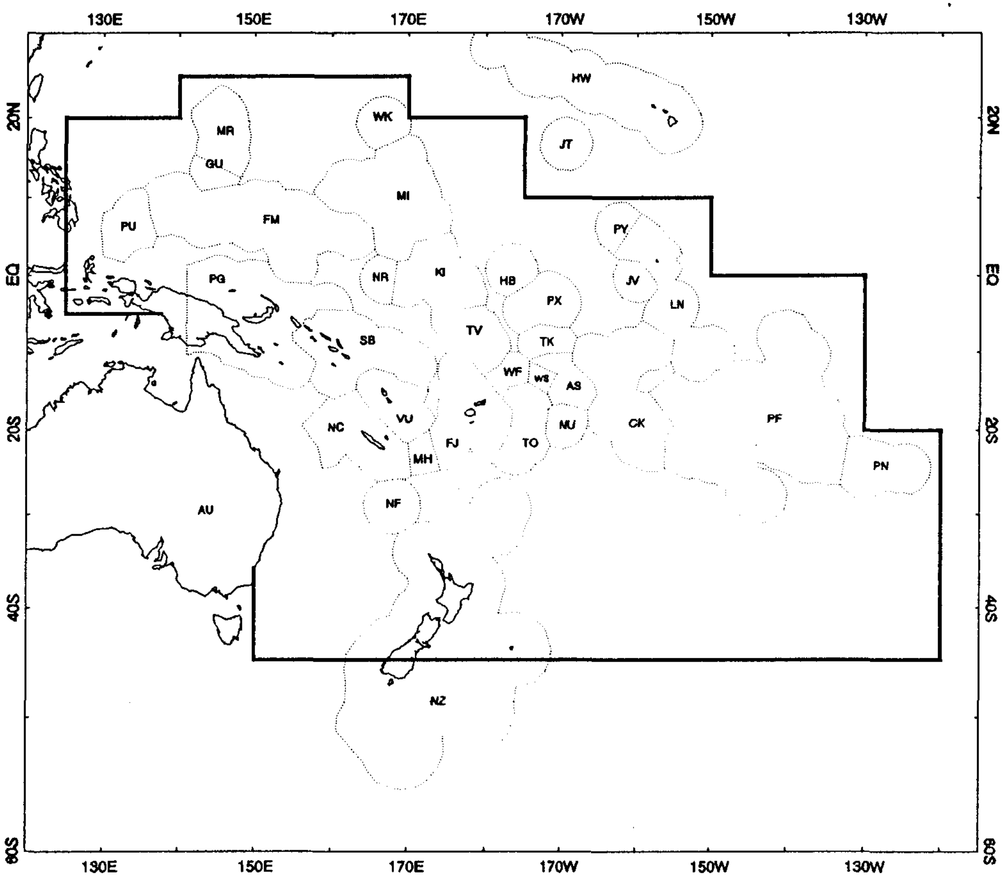
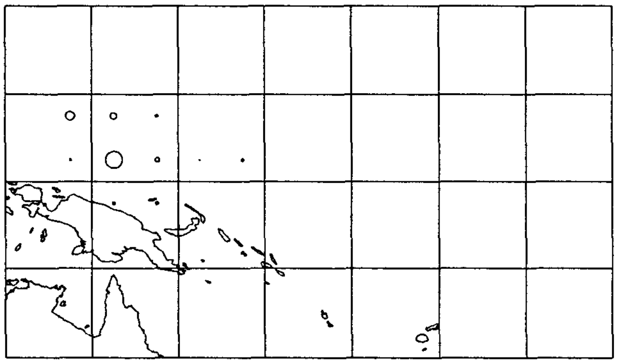


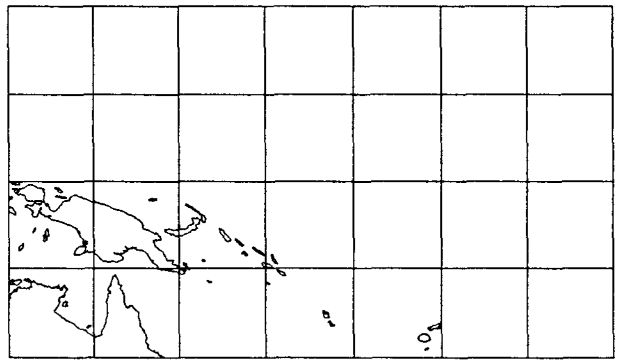
AS	American Samoa
AU	Australia
CK	Cook Islands
FJ	Fiji
FM	Federated States of Micronesia
GU	Guam
HB	Howland and Baker
HW	Hawaii
JT	Johnston
JV	Jarvis
KI	Kiribati
LN	Line Islands
MH	Matthew and Hunter
MI	Marshall Islands
MR	Northern Mariana Islands
NC	New Caledonia
NF	Norfolk
NR	Nauru
NU	Niue
NZ	New Zealand
PF	French Polynesia
PG	Papua New Guinea
PN	Pitcairn
PU	Palau
PX	Phoenix
PY	Palmyra
SB	Solomon Islands
TK	Tokelau
TO	Tonga
TV	Tuvalu
VU	Vanuatu
WF	Wallis and Futuna
WK	Wake
WS	Western Samoa

Figure 1. SPC statistical area

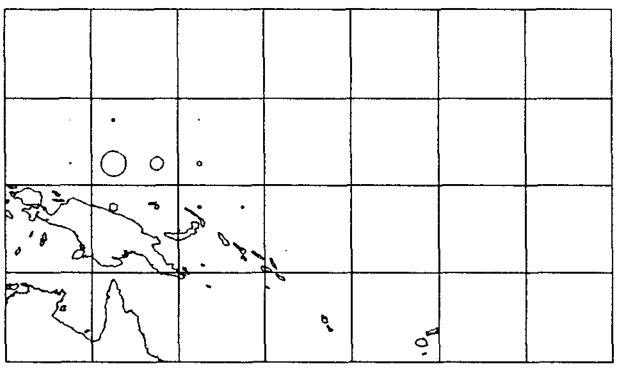
Figure 2. Distribution of yellowfin catches by Japanese and American purse seiners, 1979—1991, from daily logbook data held at SPC. Circles of 5° diameter represent catches of 7,000 mt or greater. Data for 1992 are incomplete.



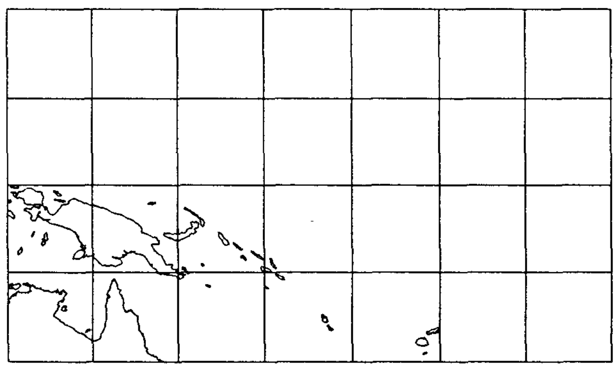
1979 • Japan



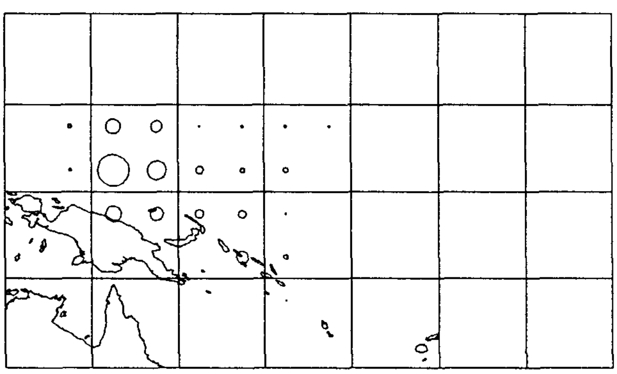
1979 • United States



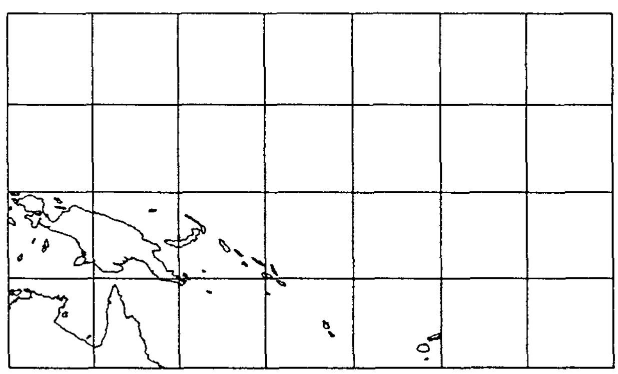
1980 • Japan



1980 • United States

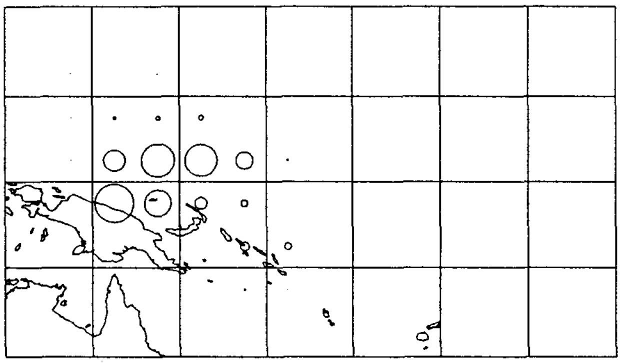


1981 • Japan

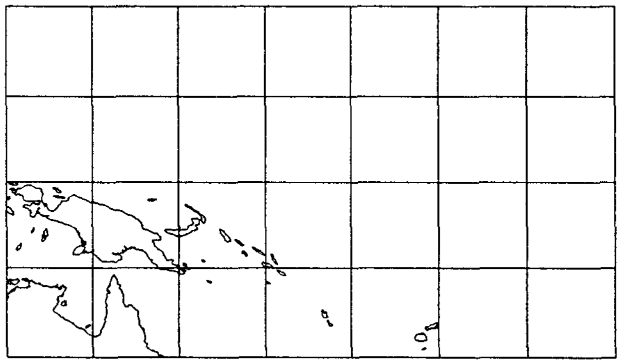


1981 • United States

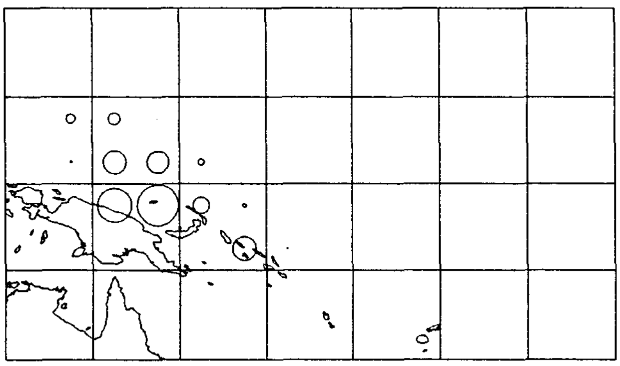
Figure 2 (continued)



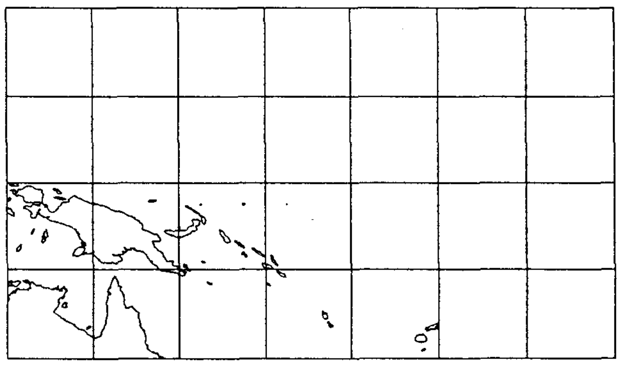
1982 • Japan



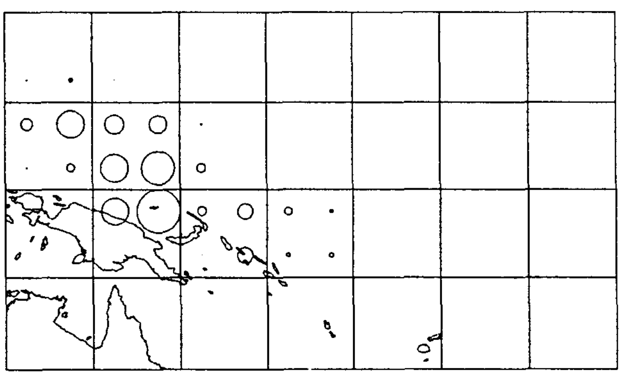
1982 • United States



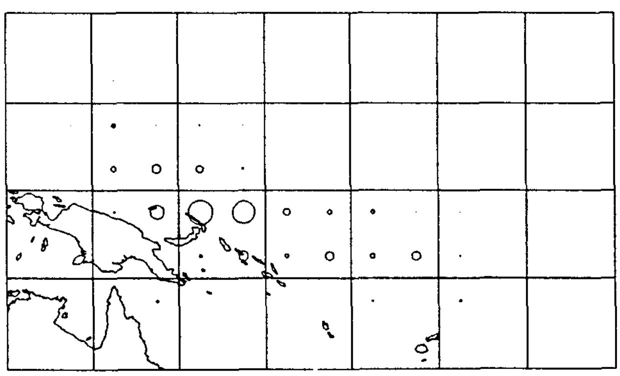
1983 • Japan



1983 • United States



1984 • Japan



1984 • United States

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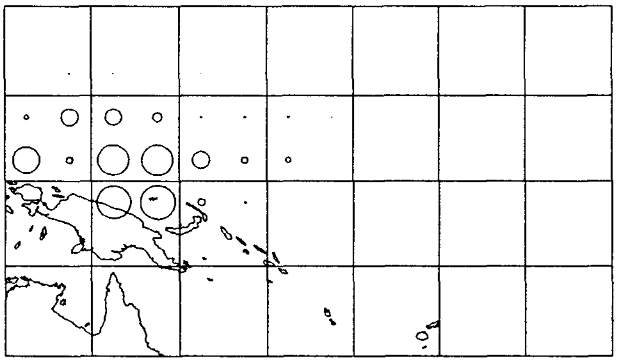
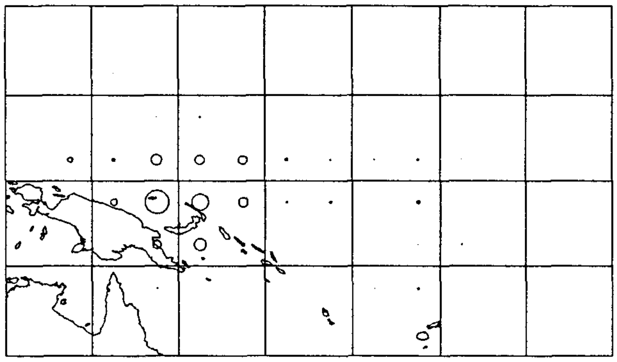
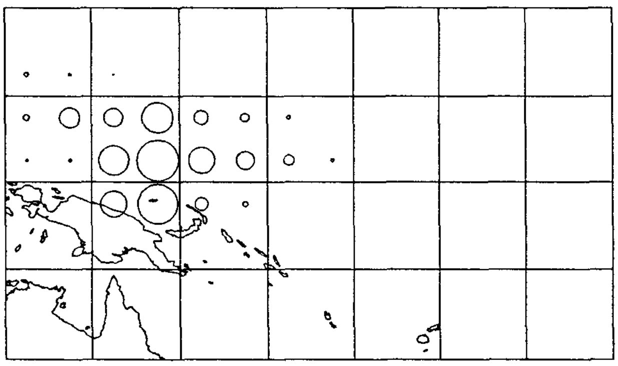


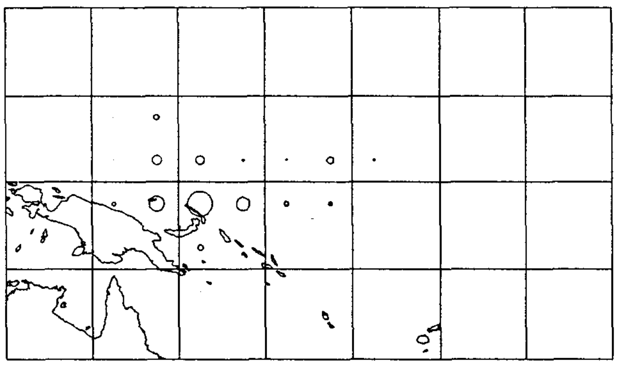
1985 • Japan



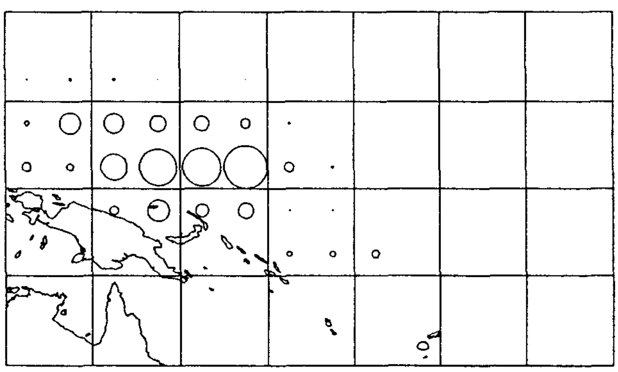
1985 • United States



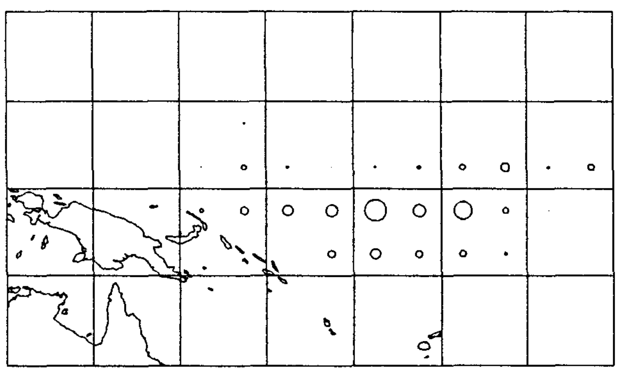
1986 • Japan



1986 • United States

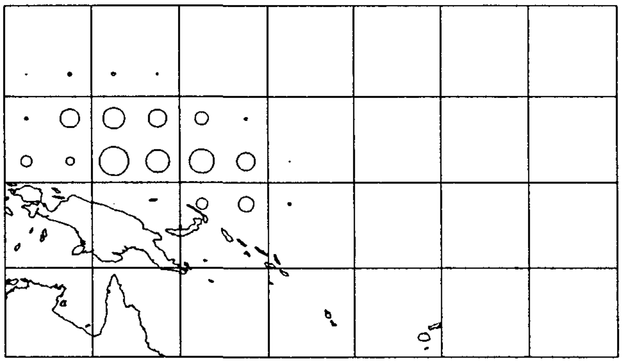


1987 • Japan

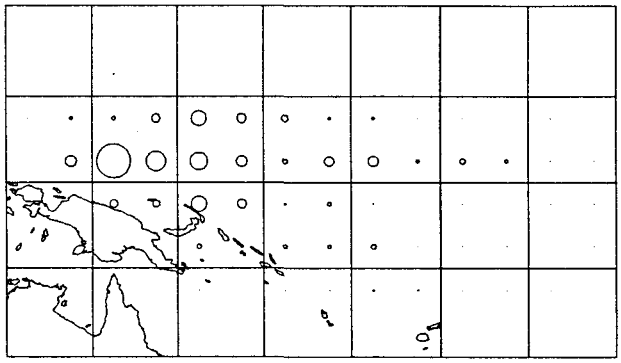


1987 • United States

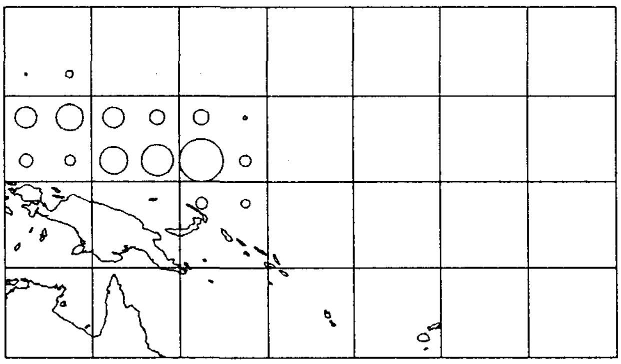
Figure 2 (continued)



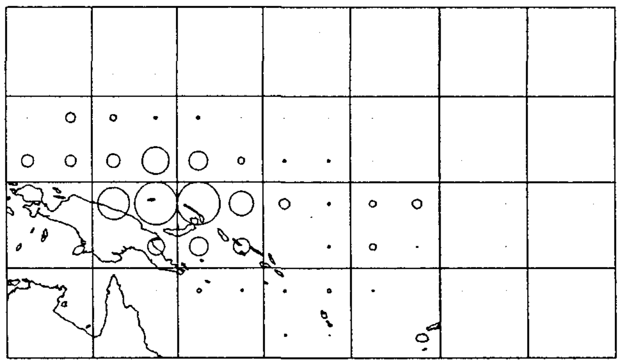
1988 • Japan



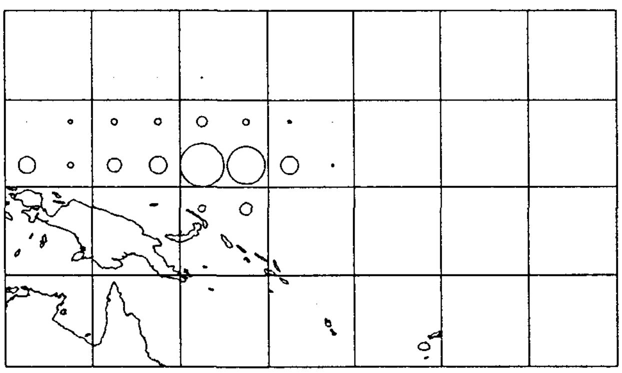
1988 • United States



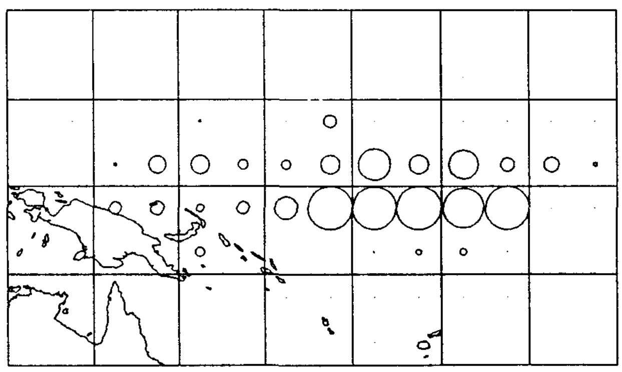
1989 • Japan



1989 • United States

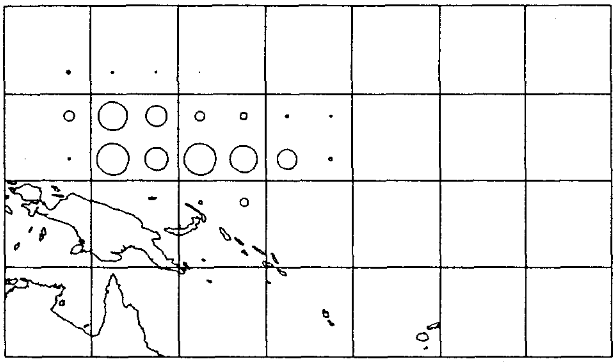


1990 • Japan

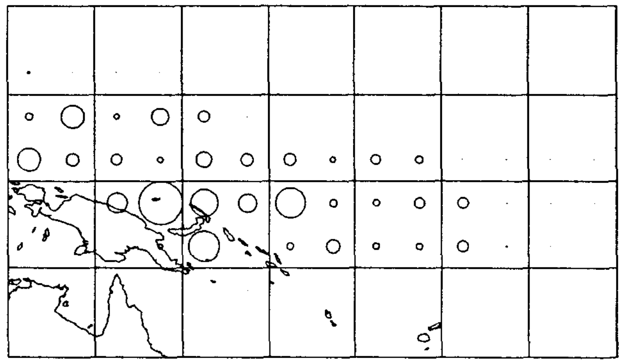


1990 • United States

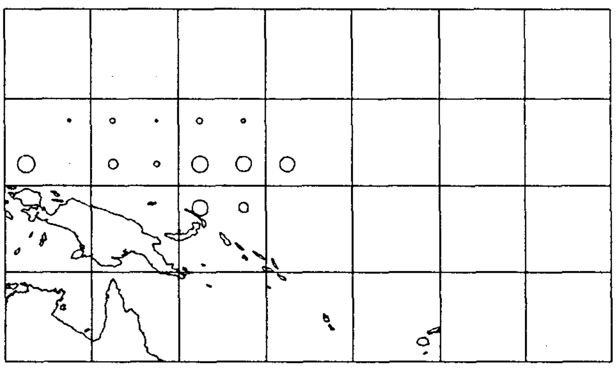
Figure 2 (continued)



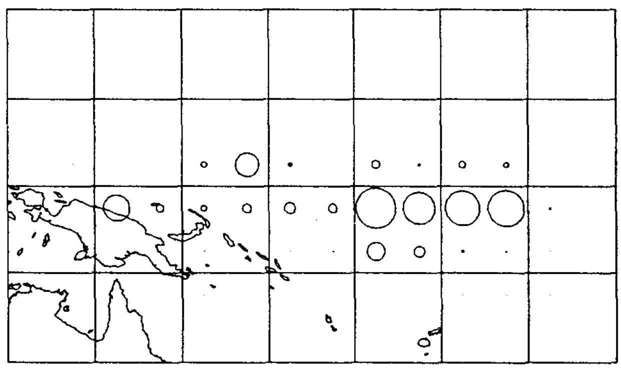
1991 • Japan



1991 • United States



1992 • Japan



1992 • United States

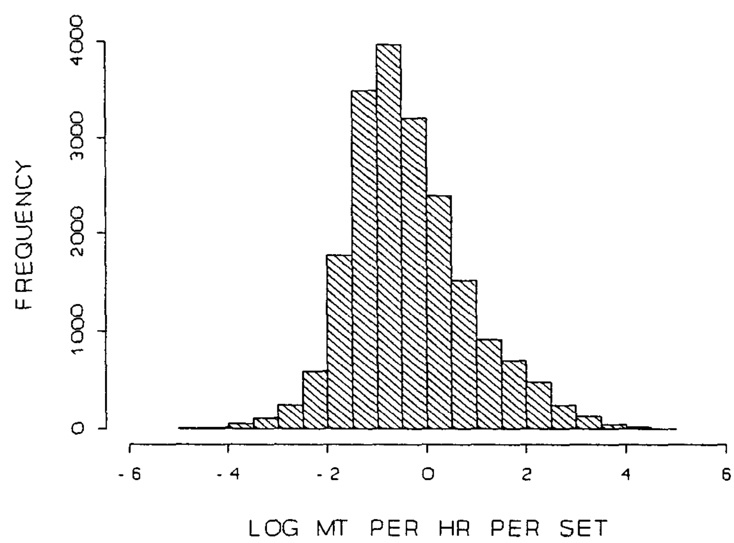


Figure 3. Frequency of transformed yellowfin catch rates

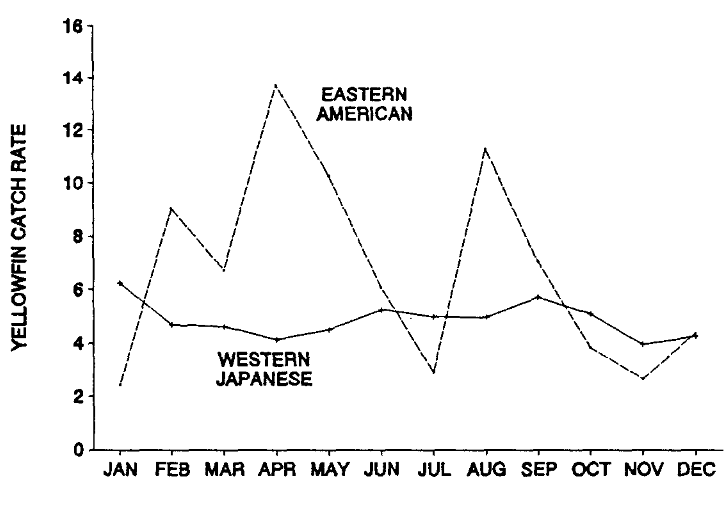
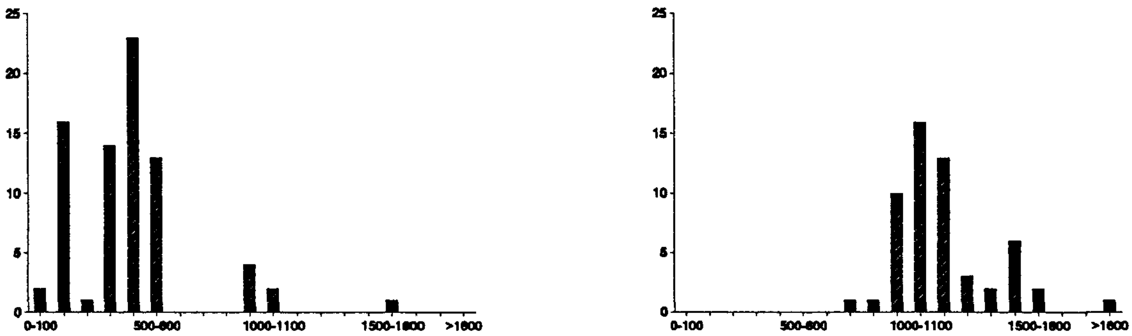


Figure 4. Yellowfin catch rate (mt per day) by month for the western/Japanese and eastern/American areas

Figure 5. Distribution of vessels in the Japanese and American purse seine fleets by gross registered tonnage



Japan

United States

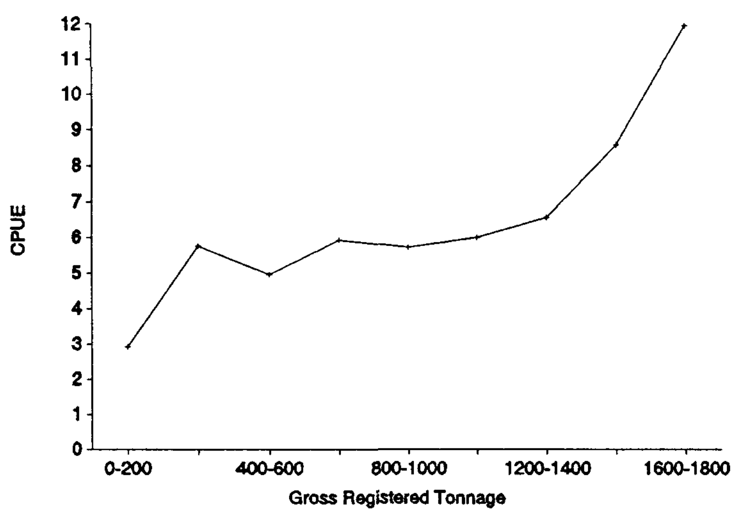
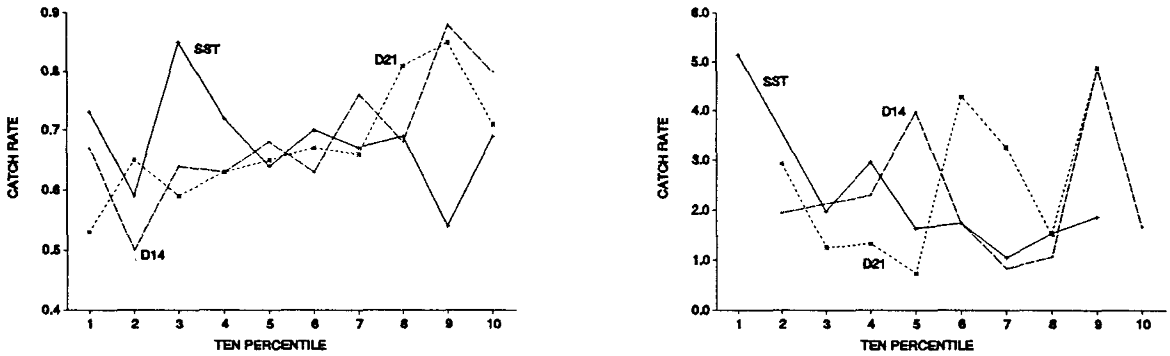


Figure 6. Yellowfin catch rate (mt per day) versus gross registered tonnage for Japanese and American purse seiners

Figure 7. **Relationship between yellowfin catch rate (mt per hour searched) and sea surface temperature (SST) and depths of the 21°C isotherm (D21) and the 14°C isotherm (D14). Catch rates are plotted against percentiles of the range calculated as two standard deviations above and below the mean. Catch rates for percentiles for which the total catch was less than 1,000 mt have been omitted.**



Western/Japanese Area **Eastern/American Area**

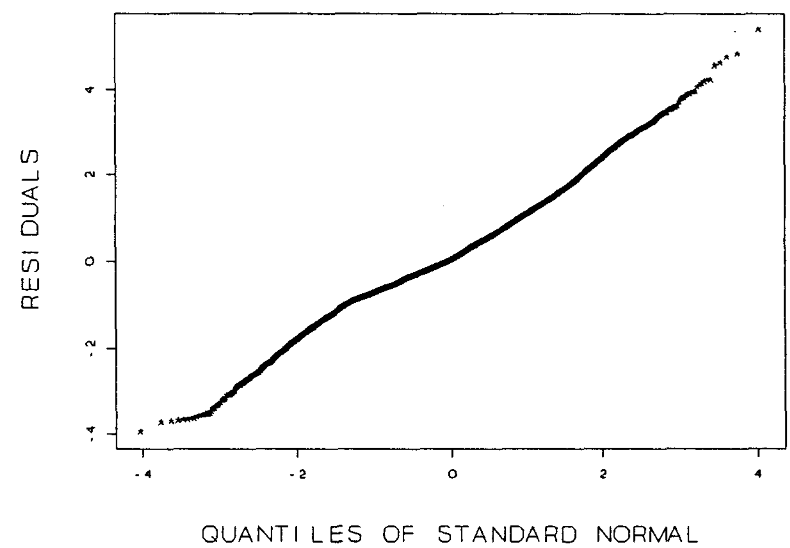


Figure 8. Residuals for the western/Japanese model versus quantiles of standard normal

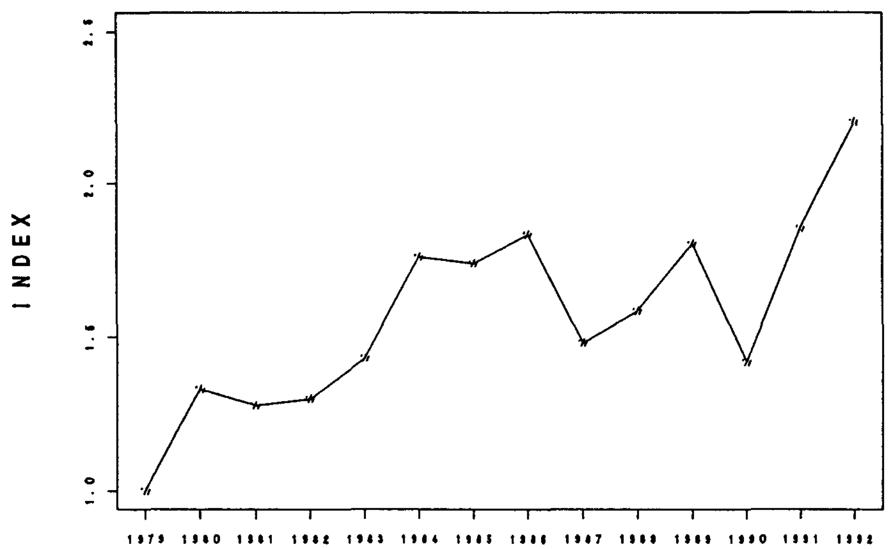


Figure 9. Indices of abundance for the western/Japanese area

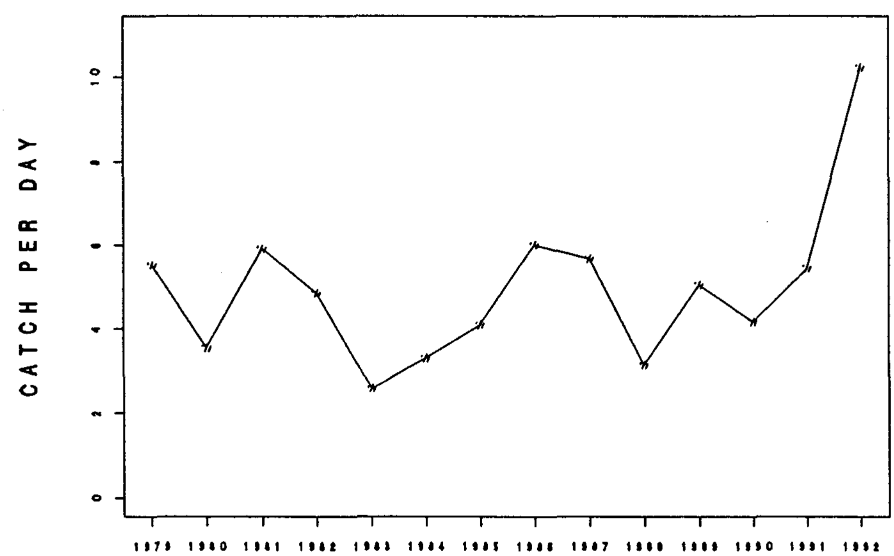


Figure 10. Yellowfin catch per day fished in the western/Japanese area

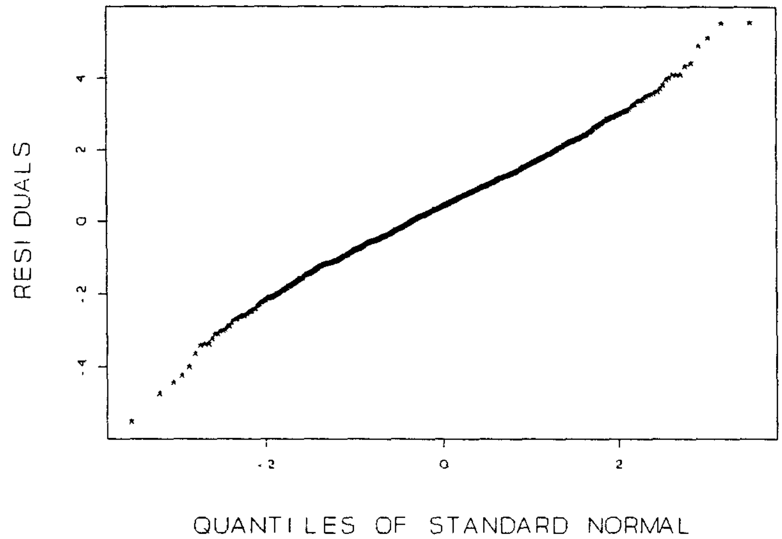


Figure 11. Residuals for the eastern/American model versus quantiles of standard normal

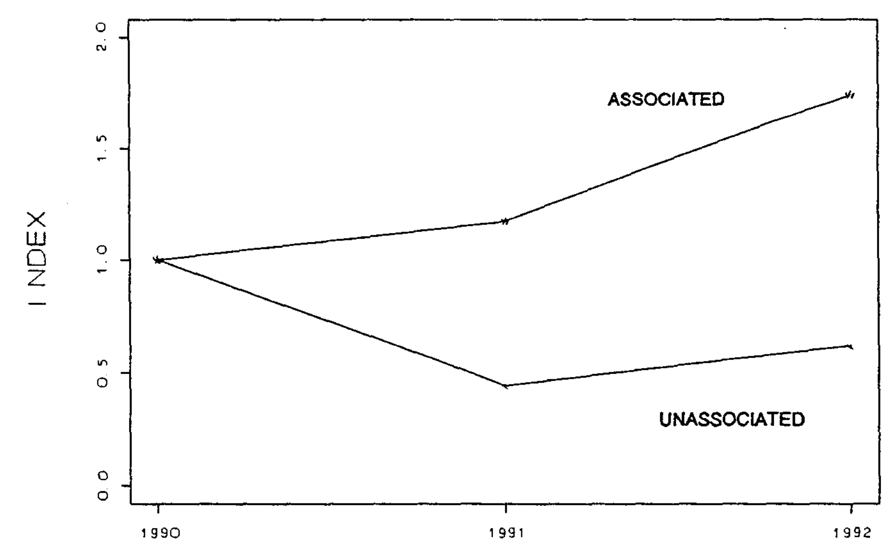


Figure 12. Indices of abundance for the eastern/American area

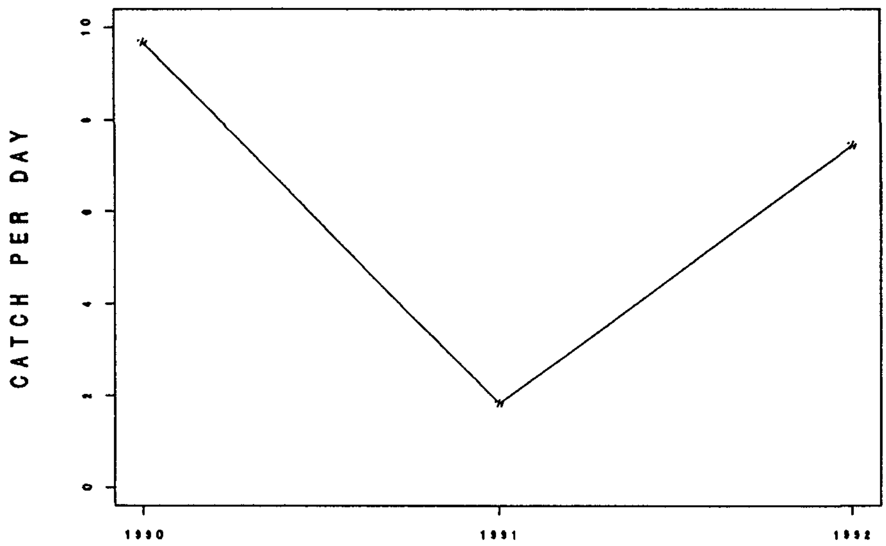


Figure 13. Yellowfin catch (mt) per day fished in the eastern/American area

Table 1. Catches of yellowfin by gear type

YEAR	LONGLINE	POLE-AND-LINE	PURSE SEINE	SE ASIA	TOTAL
1980	87,718	6,891	10,693	65,573	170,875
1981	61,397	10,393	42,055	78,065	191,910
1982	48,882	4,916	64,282	76,262	194,342
1983	49,762	3,580	81,411	82,236	216,989
1984	36,631	3,881	84,564	85,374	210,450
1985	40,279	7,261	76,785	93,880	218,205
1986	36,256	2,864	90,120	93,748	222,988
1987	36,394	4,838	146,660	84,246	272,138
1988	29,729	4,186	86,834	91,118	211,867
1989	33,160	3,456	147,120	108,568	292,304
1990	38,258	4,284	166,318	129,189	338,049
1991	38,799	2,470	174,785	150,481	366,535

Source: Lawson (1992a)

Table 2. Distribution of data (days fished or searched) by vessel nationality and year

YEAR	AU	ID	JP	KR	MX	NZ	PH	SB	SU	TW	US	TOTAL
1975	30	–	–	–	–	–	–	–	–	–	–	30
1976	7	–	–	–	–	–	–	–	–	–	–	7
1977	23	–	–	–	–	–	–	–	–	–	–	23
1978	62	–	–	–	–	–	–	–	–	–	–	62
1979	15	–	368	–	–	–	–	–	–	–	–	383
1980	15	–	1,063	5	–	–	–	–	–	–	–	1,083
1981	99	–	1,915	33	–	–	–	–	–	–	–	2,047
1982	55	–	4,423	177	–	–	118	–	–	–	–	4,773
1983	28	–	4,588	309	–	277	–	–	–	229	11	5,442
1984	4	–	5,480	621	167	226	276	179	–	524	624	8,101
1985	5	–	4,527	626	–	164	388	86	258	1,073	831	7,958
1986	1	134	4,698	477	–	183	211	177	1,000	1,114	567	8,562
1987	–	182	4,711	1,524	–	157	693	189	–	2,818	525	10,799
1988	29	244	4,895	1,732	–	166	817	231	–	3,717	4,215	16,046
1989	48	167	4,844	3,116	–	–	1,671	327	–	4,637	6,633	21,443
1990	427	23	4,152	2,355	–	–	1,811	328	–	6,950	6,410	22,456
1991	279	–	1,420	521	–	–	849	173	–	3,261	1,627	8,130

Key: AU Australia, ID Indonesia, JP Japan, KR Korea, MX Mexico, NZ New Zealand, PH Philippines, SB Solomon Islands, SU former Soviet Union, TW Taiwan, US United States

Table 3. Yellowfin catch rates (mt per day) and concentration indices for Japanese and American purse seiners, 1979—1991. CPUE was stratified by 1° x 1° square by month.

YEAR	POOLED	STRAT	INDEX
1979	5.16	5.70	0.91
1980	3.49	3.06	1.14
1981	4.95	4.15	1.19
1982	4.73	3.97	1.19
1983	4.05	3.49	1.16
1984	4.71	3.85	1.22
1985	4.79	4.02	1.19
1986	6.36	4.65	1.37
1987	6.62	5.00	1.32
1988	2.97	3.15	0.94
1989	4.76	4.29	1.11
1990	8.09	5.17	1.57
1991	3.05	3.03	1.01
1992	7.28	5.01	1.45

Table 4. Fishing effort (days fished or searched) and yellowfin catch rate (mt per day) for Japanese and American fleets for strata in which fishing effort was low (1—2 days fished per 1° x 1° square per month) compared to other areas. The t statistic compares the catch rate in strata of low effort to the catch rate in other areas. Significance of a one-tailed test at the 5 per cent level is marked by an asterisk. Data for 1992 are incomplete.

YEAR	TOTAL EFFORT	EFFORT IN LOW EFFORT STRATA	%	CPUE IN LOW EFFORT STRATA	CPUE IN OTHER STRATA	t	df
1979	411	88	21	3.52	4.41	0.83	111
1980	1,175	216	18	2.36	2.93	1.23	309
1981	1,959	458	23	2.92	5.14	5.18*	583
1982	4,707	420	9	2.45	4.26	5.41*	681
1983	5,144	380	7	2.09	3.68	4.77*	633
1984	6,701	500	7	2.86	3.77	2.22*	835
1985	5,510	539	10	2.52	4.00	4.52*	883
1986	5,489	616	11	2.96	5.16	6.12*	933
1987	5,385	634	12	3.51	5.21	4.65*	997
1988	5,900	554	9	2.52	3.05	1.84*	867
1989	5,969	656	11	3.47	4.19	1.81*	1,009
1990	12,079	1,556	13	1.55	5.08	10.90*	2,172
1991	11,219	1,334	12	1.75	3.36	5.69*	1,785
1992	4,864	770	16	2.89	5.82	4.88*	959

Table 5. Comparison of yellowfin (YFT) catch statistics for unassociated and associated schools in the western/Japanese area (west of 160°E) and the eastern/American area (east of 160°E). "Successful set" or "successful day" refers to sets or days on which fish of any species were caught. "Successful YFT set" refers to sets from which yellowfin were caught; other species may also be caught from "successful YFT sets."

	WHOLE REGION		WESTERN AREA		EASTERN AREA	
	UNASSOC	ASSOC	UNASSOC	ASSOC	UNASSOC	ASSOC
PROPORTION OF TOTAL CATCH (%)	46	54	29	71	85	15
PROPORTION OF YFT CATCH (%)	46	54	32	68	77	23
SETS PER DAY	1.42	1.05	1.29	1.05	1.57	1.01
SUCCESSFUL SETS (%)	51	92	51	92	51	93
SUCCESSFUL SETS, ONLY YFT (%)	9	6	10	6	8	13
TOTAL CATCH PER SUCCESSFUL SET (mt)	39.5	29.3	35.4	28.2	44.0	46.0
TOTAL CATCH PER SUCCESSFUL DAY (mt)	45.5	30.5	38.7	29.5	52.8	47.4
YFT CATCH PER SUCCESSFUL SET (mt)	8.8	7.0	8.8	6.5	8.7	15.5
YFT CATCH PER SUCCESSFUL DAY (mt)	10.6	7.3	10.1	6.7	11.2	16.5
YFT CATCH PER SUCCESSFUL YFT SET (mt)	28.9	8.1	22.9	7.4	40.4	18.0
YFT AVERAGE SIZE (kg)	26.0	8.5	28.0	8.4	23.9	9.5

Table 6. Average catches of yellowfin (mt) per successful yellowfin set, by school type (associated or unassociated) and the presence of skipjack, for the Japanese and American fleets. The number of sets is in parentheses.

PRESENCE OF SKIPJACK	UNASSOC SCHOOLS	ASSOC SCHOOLS
SKIPJACK CATCH > 0	18.8	7.7
	(1,637)	(21,718)
SKIPJACK CATCH = 0	35.8	11.6
	(2,405)	(1,931)

Table 7. Coefficients for the final model for the western/Japanese area

VARIABLE	VALUE	STD ERROR	T-VALUE	P
Intercept	-0.67100	0.092977	-7.2168	5.5378e-13
1980	0.28507	0.085301	3.3419	8.3375e-04
1981	0.24486	0.079724	3.0714	2.1338e-03
1982	0.26160	0.078861	3.3172	9.1116e-04
1983	0.35854	0.079951	4.4845	7.3532e-06
1984	0.56577	0.077330	7.3164	2.6557e-13
1985	0.55399	0.076717	7.2212	5.3602e-13
1986	0.60625	0.076450	7.9300	2.2204e-15
1987	0.39324	0.076477	5.1419	2.7484e-07
1988	0.46154	0.076944	5.9983	2.0322e-09
1989	0.59002	0.076584	7.7042	1.3767e-14
1990	0.34989	0.078718	4.4448	8.8494e-06
1991	0.61766	0.077785	7.9407	2.2204e-15
1992	0.79030	0.092947	8.5027	0.0000e+00
School type	1.11109	0.041880	26.5301	0.0000e+00
Skipjack	-0.27329	0.027622	-9.8939	0.0000e+00
0000N 13500E	-0.27260	0.081540	-3.3431	8.3005e-04
0000N 14000E	-0.31425	0.055485	-5.6638	1.5039e-08
0000N 14500E	-0.34673	0.055969	-6.1950	5.9554e-10
0000N 15000E	-0.28745	0.056017	-5.1315	2.9053e-07
0000N 15500E	-0.25036	0.058244	-4.2984	1.7297e-05
0500N 13000E	-0.38520	0.077199	-4.9897	6.1030e-07
0500N 13500E	-0.53998	0.058772	-9.1877	0.0000e+00
0500N 14000E	-0.34728	0.057734	-6.0153	1.8311e-09
0500N 14500E	-0.39694	0.059914	-6.6252	3.5671e-11
0500N 15000E	-0.42540	0.066044	-6.4411	1.2167e-10
0500N 15500E	-0.64908	0.084873	-7.6477	2.1538e-14
0500S 14000E	-0.26991	0.062086	-4.3474	1.3850e-05
0500S 14500E	-0.24870	0.060653	-4.1004	4.1427e-05
0500S 15000E	-0.27265	0.072083	-3.7824	1.5584e-04
0500S 15500E	-0.38293	0.072224	-5.3019	1.1595e-07
SST	-2.13736	1.097772	-1.9470	5.1551e-02
SST^2	-5.09074	0.989588	-5.1443	2.7138e-07
School:Skipjack	-0.23484	0.055599	-4.2239	2.4129e-05

Table 8. Partial F statistics for the final model for the western-Japanese area

VARIABLE	DF	SUM OF SQUARES	MEAN SQUARE	F
Year	13	137.5	10.6	37.4
School type	1	597.2	597.2	2111.2
Skipjack	1	56.8	56.8	200.8
Geo Strata	15	44.1	2.9	10.4
SST	2	8.2	4.1	14.4
School:Skj	1	5.0	5.0	17.8
Residuals	17727	5014.2	0.3	

Table 9. Coefficients for the final model for the eastern/American area

VARIABLE	VALUE	STD ERROR	T-VALUE	P
Intercept	-0.500245	0.106927	-4.67835	3.0941e-06
1991	0.157888	0.111013	1.42225	1.5512e-01
1992	0.556231	0.095043	5.85241	5.6852e-09
School type	1.856311	0.124352	14.92789	0.0000e+00
Skipjack	-0.021083	0.098847	-0.21329	8.3112e-01
D21	3.222712	1.653122	1.94947	5.1385e-02
$D21^2$	-3.615039	1.116547	-3.23770	1.2256e-03
1991:School	-0.972076	0.178087	-5.45843	5.4281e-08
1992:School	-1.035381	0.151830	-6.81937	1.2214e-11
School:Skj	-0.526035	0.149369	-3.52172	4.3878e-04

Table 10. Partial F statistics for the final model for the eastern/ American area

VARIABLE	DF	SUM OF SQUARES	MEAN SQUARE	F
Year	2	12.8	6.4	14.2
School type	1	160.1	160.1	355.1
Skipjack	1	12.7	12.7	28.1
D21	2	14.3	7.2	15.9
Year:Skj	2	31.4	15.7	34.8
School:Skj	1	5.6	5.6	12.4
Residuals	1917	846.3	0.4	