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REVIEW OF PURSE SEINE CPUE

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INTRODUCTION

The purse seine tuna fishery in the Western Pacific (Figure 1) has undergone rapid expansion since the early 1980s, with catches increasing from 51,389 mt in 1980 to 840,853 mt in 1991 (South Pacific Commission 1992a). Skipjack is the principal species taken by purse seining (666,068 mt in 1991), however purse seine catches of yellowfin in 1991 (174,785 mt) were greater than 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, Indonesia, Mexico, New Zealand, the Philippines, Solomon Islands and the former Soviet Union.

The South Pacific Commission (SPC) has compiled daily catch and effort data for purse seiners since the inception of the Tuna and Billfish Assessment Programme in 1982. These 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 11 fishing nations are covered by data held at SPC, although the amount of data held varies considerably among the fleets and through time.

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) examined data for 1979—1986 from all fleets using a general linear model to examine the effects of time, area, vessel size and school type.

The factors included in these analyses, and some of those included in analyses of purse seine catch and effort for Eastern Pacific yellowfin (Punsley and Allen 1984, Anonymous 1984, Anonymous 1985, Punsley 1987), are examined below. The present work should be considered as an exploratory analysis to identify factors affecting the relationship between purse seine catch rate and yellowfin abundance. A more detailed analysis of catch rates and indices of abundance for Western Pacific yellowfin will be undertaken during the next reporting period. All purse seine logbook data held at SPC, including single seiners and group seiners, were examined for the period 1979—1991; data for 1991, however, are incomplete. For the present work, catch rate was defined as the catch per day fished or searched; future analyses will consider other possible definitions.

AREA FISHED AND SEASONALITY

Prior to examining the effect of fishing area and seasonality on yellowfin catch rates, the folowing three observations regarding the areal distribution of fishing effort are considered:

1. the area fished has expanded continuously since the inception of the fishery;

2. fishing effort has been highly concentrated; and

3. access agreements have resulted in the separation of fishing areas among fleets of different nationalities.

Expansion of the area fished

Figure 2 shows that the annual area fished increased considerably from 1979 to 1990. The area fished has been calculated using daily catch and effort logsheet data held at SPC. Coverage of fishing activities by the logsheet data is only about 50 per cent, however, coverage is roughly consistent through time (except for 1988), therefore the trend in area fished calculated from the logsheet data is representative. (In 1988, coverage of American purse seiners increased following the implementation of the *Treaty on fisheries between the governments of certain Pacific Island states and the government of the United States of America.*)

Figure 3 shows the distribution of fishing effort on an annual basis. In 1979, the fishery was located in an area north of Papua New Guinea. It then spread out progressively, particularly to the east. By 1985, the fishing grounds extended as far east as 160°W, near the Howland and Baker Islands and the Phoenix Islands. From 1986 to 1989, the area fished continued to increase. In 1990, a further increase in effort occurred in the eastern part of the fishing grounds, centred on the equator.

The expansion of the area fished, which appears to be still occurring, complicates the estimation of indices of abundance. While areas to the west have been fished continuously since 1979, areas to the east have only recently sustained significant fishing effort. Therefore, indices of abundance for early years will necessarily be less representative of the population currently vulnerable to fishing.

Concentration of fishing effort

A nonrandom distribution of fishing effort will affect the relationship between catch rates and abundance. If the fishery is concentrated in areas of high abundance, catch rates will overestimate the abundance of the population as a whole, since areas of low abundance will be under-represented. Several measures indicate that the Western Pacific purse seine fleet has been highly concentrated.

Examination of the logsheet data indicates that a large amount of the area fished each year accounts for only a small amount of fishing effort and that catch rates in areas where effort is low are usually less than in other areas. Table 2 shows that from 27 to 44 per cent of the area fished each year from 1979 to 1990 accounted for only one or two days fishing per 1° x 1° square. The average catch in areas of one or two days fished per 1° x 1° square were less than in other areas; for some years, the difference in catch rates between areas of low effort and other areas was considerable.

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 high catch rates, while the stratified CPUE gives equal weight to all areas, regardless of the catch rate. When concentration occurs, 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 catches by 1° x 1° square. Indices are presented for all species combined and for yellowfin separately. For all species combined, all values are greater than 1.0, indicating that concentration is a regular occurrence. The value of the index for all species combined varies considerably, from low concentration (1.03 in 1987) to high concentration (1.76 in 1986). When yellowfin is considered separately, concentration is still found to occur (except for 1987), though the magnitudes vary from those for all species combined.

Somewhat lower values of the concentration index were found by Polachek (1988), who stratified area into grids of 2½° latitude by 10° longitude and used data only for Japanese purse seiners. He also eliminated strata with less than five days of fishing effort. He concluded that "*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.*" However, his conclusion is somewhat misleading, in that, if area is examined on a finer scale, the strata he used included areas of low effort as well as concentrated effort. Nevertheless, Polachek's conclusion is disturbing in that it implies that there are too few data in areas with low effort and low catch rates for them to be accounted for in indices of abundance. If such is the case, indices of abundance will necessarily overestimate actual abundance.

Table 4 presents the total amount of annual fishing effort in areas of low effort (less than 1—2 days per 1° x 1° square) for Japanese vessels and for all vessels combined. For most years, the proportion of effort in areas of low effort is only slightly less for Japanese vessels than for all vessels combined, which suggests that, on average, Japanese vessels concentrate to only a slightly greater degree compared to all vessels combined. On the other hand, the absolute number of days fished in areas of low effort for all vessels combined are much greater than for Japanese vessels, at least following 1982, by which time other fleets had entered the fishery.

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 weighted in some way such that equal weight is given to fishing areas of equal sizes. Further, the size of the areas used must be small enough to allow the variation in catch rates to be observed. Punsley (1987) used the logarithm of the catch rate for individual sets as replicates in a multivariate linear analysis and employed a weighting scheme such that each 5° x 5° grid received equal weight. Anonymous (1985) used the average catch rate for each 2½° x 10° stratum as replicates, which gave equal weight to each stratum, but which masked the effect of concentration because the strata were large. Medley (1990) used the logarithms of the average catch rate in each 5° x 5° stratum as replicates, but each replicate was weighted by the number of observations in the stratum. This was done in order to give weight to strata in inverse proportion to the variance of the replicates, but also resulted in less weight being given to strata with fewer observations.

Access Agreements

Table 5 presents the breakdown of logsheet data by source and by vessel nationality. While a few fleets have operated in their home waters (Australia, New Zealand, Solomon Islands), all fleets except vessels from Solomon Islands have fished under access agreements with coastal states.

Table 5 shows that the fleets operating in each Exclusive Economic Zone (EEZ) have varied through time. During the early years, the fishery was dominated by Japanese vessels operating in the waters of the Federated States of Micronesia and Papua New Guinea. In 1987, the Japanese were excluded from the Papua New Guinea zone. Korean and Taiwanese vessels had fished in the waters of the Federated States of Micronesia and Papua New Guinea since the mid-1980s, but their access to the waters of the Federated States of Micronesia was terminated in early 1990. The American fleet has operated on a commercial basis in the Western Pacific since 1976, however coverage of the fleet's activities by logsheet data held at SPC was low until the implementation of the multilateral treaty in June 1988.

The inconsistency of access agreements has resulted in a non-uniform distribution of fishing effort among vessel nationalities. The fleets vary in their experience, vessel characteristics (vessel size, speed, hydraulic power, net size, carrying capacity, etc.), searching techniques (individually or in code groups, with or without helipcopters), fishing techniques (tendancy to target free-swimming schools versus schools associated with floating objects) and, therefore, in their catch rates. Incorporating the effect of fishing area in indices of abundance will thus be confounded by the effect of vessel nationality.

Polachek (1988) dealt with this problem by examining data only for Japanese purse seiners. However, the time period he examined, 1979—1986, was prior to the exclusion of Japanese vessels from the waters of Papua New Guinea and the expansion of the fishery to the east, where few data are available for Japanese vessels. For the period 1987—1990, data covering Japanese vessels are no longer representative of the areal distribution of the fishery as a whole.

The obvious approach for dealing with the problem is to include variables which account for differences in catch rates between vessel nationalities (vessel characteristics, school type, etc.) in a multivariate analysis. However, it is expected that, even so, not all of the differences would be accounted for, therefore it is expected that area effects would still be confounded to some degree.

Past techniques for analysing time and area effects

Punsley (1987) found that catch rates in the Eastern Pacific vary seasonally, and that the seasonal effects differ among areas. After exploratory analyses, he constructed six irregularly-shaped areas. Within areas, the number of "seasons" varied from two (eg, April—September and October—March) to four (eg, April—June, July—August, September—October and November—March). Thus the model contained 16 strata of time and area effects combined, rather than strata for time and area separately. While time-area effects were not as significant as other factors, they were included in the final model because the combined effect of time-area and the interaction between time-area and search classification was highly significant.

Polacheck (1988) examined data covering Japanese purse seiners in the Western Pacific and found much greater variation in catch rates latitudinally than longitudinally. He therefore defined geographic strata of 2½° latitude and 10° longitude in order to estimate annual catch rates from stratified means. However, the stratification by area ultimately had little effect. Polachek claimed that this was due to the lack of effort outside the areas of high concentration, but in the light of the examination of catch rates for areas of low effort per 1° x 1° square presented above, it may have been due to the size of the strata he examined. Polacheck (1988) also examined temporal stratifications by month and quarter and found that they also had little effect on estimates of annual catch rates, due to the even temporal distribution of fishing effort by Japanese purse seiners within a year.

South Pacific Commission (1985) tested the following variables to examine Japanese purse seine data in the Western Pacific using analysis of variance and as covariates in a multivariate linear model: quarter, latitude, the absolute value of latitude, and longitude. Each factor was significant when tested using analysis of variance. The best-fit linear model included terms for year, quarter, latitude and longitude. In contrast to Punsley (1987), who did not find significant interactions between year effects and other factors, Polacheck (1988) noted that fits of Japanese purse seine data to general linear models resulted in large interaction terms between year and area, and year and season, thus rendering the interpretation of the year effects problematic.

In contrast to Polacheck (1988), Medley (1990) analysed data covering all fleets in the Western Pacific. He included eleven 5° x 5° grids in his multivariate analysis and defined time strata as four periods of three months (March—May, June—August, September—November and December—February). The area effects were statistically significant, though small, with higher catch rates observed at lower latitudes; the time effects, though statistically significant, were also small. Further, similar to Punsley (1987) and in contrast to Polacheck (1988), Medley (1990) found that the interaction terms between year and other factors, though significant, were small.

South Pacific Commission (1990) used Japanese purse seine data to compare unadjusted annual catch rates to annual catch rates averaged over time-area strata for the period 1982—1988. The data were stratified into areas of 2° latitude by 5° longitude and either monthly or quarterly time periods. The adjusted catch rates showed trends similar to the unadjusted catch rates, though the variation in the adjusted catch rates was less than for the unadjusted catch rates. Catch rates on schools associated with floating objects showed little seasonality, while catch rates for unassociated schools was highly variable.

Yellowfin catch rate by time and area

Previous workers have found that area and seasonal effects on Western Pacific yellowfin, though statistically significant, have been relatively small. To examine these findings in the light of new data available, yellowfin catch per day fished was examined by various areal and temporal stratifications.

Figure 4 shows yellowfin catch rates by latitude. Catch rates appear to decline from south to north between 10°S and 10°N. The high catch rates at 8°S—10°S are largely due to the Solomon Islands fishery, where a high proportion of yellowfin are taken in association with anchored fish aggregating devices (FADs).

Figure 5 presents yellowfin catch rates by longitude. In the most western part of the fishery, around 130°E, catch rates are moderate. They tend to decline as one moves to the east, dropping to low levels around 140°E. Between 140°E and 160°E, catch rates tend to increase. The variable catch rates depicted to the east of 160°E are due in part to fewer years of data covering this area. Nevertheless, the average catch rate east of 160°E still appears to be higher than to the west of 160°E.

Figure 6 shows yellowfin catch rates by 5° x 5° square for 1979—1991 combined. Catch rates tend to decline at the high latitudes. To the west of 160°E, catch rates are rather homogeneous, except for moderately higher catch rates between 130°E and 135°E and around the Solomon Islands. To the east of 160°E, catch rates appear slightly less homogeneous, with more areas of higher and lower catch rates than to the west of 160°E.

Figure 7 depicts yellowfin catch rates by 1° x 1° square for 1979—1991 separately. From 1979 to 1983, effort is confined to the west of 160°E and catch rates within that area do not appear to exhibit any consistent patterns. Catch rates are generally moderate throughout the fishery; areas of continuously high or low catch rates are lacking. During the period 1984—1991, effort expanded to the east. The difference in the distribution of catch rates between the area to the west of 160°E and the area to the east is more evident than in Figure 6. In the western area, catch rates continue to be generally moderate, except for relatively high catch rates around Solomon Islands. In the eastern area, the distribution of catch rates is much less consistent, with areas of high and low catch rates changing from year to year.

Figure 8 presents yellowfin catch rates by 5° x 5° square for 1979—1991 separately. The same pattern of variable catch rates to the east of 160°E that was evident in Figure 7, for 1° x 1° squares, is noticeable in Figure 8, though less so.

Figure 9 presents yellowfin catch rates by month. From January to July, catch rates are stable. In August, the catch rate increases, peaking at a high level in September, then returning to the January—July level in October. In November—December, catch rates are lower than for the rest of the year.

Figure 10 shows yellowfin catch rates by month by 5° x 5° square for 1979—1991 combined. The high catch during August—October evident in Figure 9 appear to occur in the eastern region, between 170°E and 170°W.

Summary

Figures 4—10 indicate that the Western Pacific purse seine fishery exhibits certain consistencies in the temporal and areal distribution of yellowfin catch rates. Catch rates tend to decrease at high latitudes. They increase within certain longitudinal bands, i.e. 130°E—135°E and generally to the east of 160°E. Catch rates with the Solomon Islands EEZ tend to be higher than in surrounding waters. Catch rates in the eastern region increase during August—October. Catch rates are more variable among areas in the eastern region than in the western region. Areas of high and low catch rates in the eastern region vary from year to year.

Some of these patterns are probably due to factors other than time and area *per se*. High catch rates in the Solomon Islands purse seine fishery is due largely to the use of anchored FADs. High, though variable, catch rates in the eastern region are due to the higher proportion of unassociated schools fished in that area (see below).

SCHOOL TYPE

Purse seine sets in the Western Pacific are made on free-swimming schools or on schools associated with floating objects, including 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 39 per cent of the total yellowfin catch in the Western Pacific, while associated schools account for 61 per cent (Table 6). 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 (49 per cent compared to 92 per cent), but higher catch rates when they are successful (39.3 mt total per set and 11.9 mt yellowfin per set compared to 25.7 mt total per set and 6.1 mt yellowfin per set). The average size of fish taken from unassociated schools is greater than for those from associated schools (22.5 kg compared to 8.5 kg).

The influence of school type differs between the eastern and western regions (Table 6). Unassociated schools account for a much greater proportion of the yellowfin catch in the eastern region compared to the western region (74 per cent compared to 33 per cent).

Figure 11 shows the distribution of fishing effort by school type (associated or unassociated) and by area for 1980, 1985 and 1990. The western region is dominated by sets on associated schools, while in the eastern region, sets on unassociated schools are more frequent.

Figure 12 illustrates the relationship between average monthly yellowfin catch rate and school type. The catch rate for associated schools is relatively stable, while the catch rate for unassociated schools is seasonal, peaking in September.

Presence of skipjack in the school

Punsley (1987) found that yellowfin catch rates in the Eastern Pacific were usually lower from searches ending in sets in which skipjack were also caught. He therefore included the presence of skipjack in the set as a criterion in his search classification.

Table 7 shows that there are large differences in yellowfin catch rates in the Western Pacific depending on whether the yellowfin were caught in association with skipjack. For associated schools, the catch rate increases from 5.8 mt per set when skipjack are present to 11.0 mt per set when skipjack are absent. For unassociated schools, the effect is much greater. The catch rate increases from 5.1 mt per set when skipjack are present to 35.2 mt per set when skipjack are absent.

Summary

School type is an important factor in determining catch rates in the Western Pacific. Further, the differences in catch rates between the eastern and western regions discussed in the previous section would appear to be strongly related to differences in the relative proportions of unassociated and associated schools.

Catch rates for unassociated schools are seasonal, whereas those for associated schools are relatively constant.

Yellowfin catch rates are related to the presence of skipjack in the school, such that yellowfin catch per set is much greater when skipjack are absent.

VESSEL CHARACTERISTICS

Gross Registered Tonnage

Punsley (1987) found that in the Eastern Pacific, vessel speed, included as a covariate, was significant, while capacity, the presence of a helicopter on board, and net length and depth were insignificant. He also investigated the effect of individual skippers, in particular the effect of the interaction between skipper and set type. He added to the final model the mean residual for each skipper-set type combination as a covariate and found skipper effects measured in this way to be insignificant. It was noted that most of the effect of individual skippers is probably already accounted for in the Eastern Pacific data by time-area fished and vessel speed.

Medley (1989) 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.

The available information on vessel characteristics for Western Pacific purse seiners includes various attributes of vessel size (GRT, length, carrying capacity). Figure 13 presents the number of vessels by GRT class. Most vessels fall in the 0—200, 300—600 and 1000—1300 GRT ranges.

Figure 14 shows yellowfin catch rates by GRT. The relationship is not smooth, but there appears to be a tendancy for catch rates to increase with vessel size.

Improvements in Gear Technology

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 fleets of Korea, Taiwan and the United States 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 has increased to 1000 hp for newer vessels, compared to 764 hp for older vessels.

While some information on gear technology is available for some vessels, information on vessel speed and hydraulic power for most vessels is lacking. Nevertheless, a possible indicator of improvements in gear technology might be the time period during which a vessel entered the fishery. Vessels that have entered the fishery recently tend to be larger and faster than older vessels. Some vessels that entered the fishery during the early years may be less well-equipped with radar and hydraulics than vessels that have entered the fishery more recently.

Figure 15 shows the catch rate for all species combined by time period during which the vessels entered the fishery. When all vessels combined are considered, the average catch rate for vessels that have entered the fishery more recently is less than the catch rate for vessels that entered the fishery earlier. However, this is due to Japanese vessels dominating the fishery during the early years, followed by less efficient vessels entering the fishery beginning about 1983. When Japanese vessels are considered separately, the catch rate for vessels that entered the fishery more recently is greater than the catch rate for vessels that entered the fishery earlier, as expected.

Summary

Catch rates appear to increase with vessel size, however the relationship is not strong. The time period during which a vessel entered the fishery may be an indicator of gear technology, however, the effect on catch rate is confounded by vessel nationality.

VESSEL NATIONALITY

Previous authors have not examined vessel nationality explicitly. Punsley (1987) used data covering purse seiners in the Eastern Pacific from 1970 to 1985, which includes data primarily from American seiners, but which may include data for other fleets. Polacheck (1988) looked at data only for Japanese vessels. Medley (1990) used data covering vessels of all nationalities operating in the Western Pacific, but did not include vessel nationality as a factor in his model.

Several factors affecting catch rates in the Western Pacific are confounded with vessel nationality. The areas fished are similar for vessels of a particular nationality, due to access agreements (see above). Fishing technique, i.e. the proportion of yellowfin in the catch and the frequency of sets by school type, is also similar for vessels of a given fleet. Each fleet contains vessels of roughly the same size class, therefore the physical characteristics of the vessels (gross registered tonnage and capacity) will be consistent within fleets. Further, it should be noted that the availablity and quality of data varies considerably among vessel nationalities (South Pacific Commission 1992b).

Table 8 presents catch statistics by vessel nationality. The amount of data varies considerably, as do average catch rates, which range from 0.45 mt per day for New Zealand vessels to 9.33 mt per day for Solomon Islands vessels. For the major fleets, American vessels average 7.19 mt per day, Japanese vessels, 4.54 mt per day, Korean vessels, 3.10 mt per day, and Taiwanese vessels, 0.86 mt per day, according to logsheet data.

Area Fished

Table 5 presented a breakdown of data by vessel nationality for each of the 9 SPC member countries that have licensed purse seiners. It was noted above that the agreements have not always been continuous, with the result that the fleets have generally fished in different areas at different times. While most of the major fleets have changed the areas they have fished over time, it should be noted that Japanese vessels have fished in the waters of the Federated States of Micronesia continuously, from 1979 to 1991. Likewise, in the eastern region (east of 160°E), the most extensive data set is that for American vessels, which have provided data for all activities within the treaty area (Figure 1), including those on the high seas, since June 1988.

School Type

The proportion of yellowfin catches by school types varies among vessel nationalities. Table 8 shows that American vessels catch 70 per cent of yellowfin from unassociated schools, while Japanese vessels catch 74 per cent from associated schools. Taiwanese vessels take 92 per cent of yellowfin from associated schools. The Solomon Islands fleet, which has the highest average yellowfin catch rate, catches 99 per cent of yellowfin from associated schools. The Filipino fleet, which operates in the waters of Papua New Guinea (and, more recently, Solomon Islands, though no data are yet available), also catches 99 per cent of yellowfin from associated schools.

Vessel Characteristics

Figure 16 shows vessel size (GRT) by vessel nationality. For the major fleets, Japanese and Taiwanese vessels tend to be smaller than American and Korean vessels.

Availability of data

The distribution of the data by vessel nationality over time varies considerably (Table 9). For the period 1975—1979, only a small amount of data exists, for Australian and Japanese vessels. For 1980—1983, data for Japanese vessels are significant, but data for other fleets are negligible. For 1984—1987, data for the major fleets currently operating (Japan, Korea, Taiwan and the United States) are considerable, though data for Japan is still dominant. For 1988—1991, the amount of data for the major fleets and two of the smaller fleets (Philipines and Solomon Islands) increased due to increases in the number of vessels active and, for the American fleet, to the implementation of the multilateral treaty. For some fleets (Indonesia, Mexico, New Zealand and the former Soviet Union), data are available only over limited time periods.

Data Quality

In a recent study of the quality of logsheet data for Western Pacific purse seiners (South Pacific Commission 1992b), under-reporting was found to occur for Korean and Taiwanese vessels. Under-reporting by Taiwanese vessels in recent years may have been as much as 62—79 per cent, while for Korean vessels it was probably much lower, possibly 18—28 per cent. Under-reporting for Japanese vessels was found to be about 9 per cent. Under-reporting was found not to occur for American vessels.

Summary

Catch rates differ considerably among vessel nationalities. Most factors affecting yellowfin catch rates appear to be confounded with vessel nationality, such as area fished, school type and vessel characteristics. Data availability varies among the fleets. Considerable under-reporting by Korean and Taiwanese vessels is known to occur.

DISCUSSION

Several of the problems highlighted above seriously limit the utility of Western Pacific purse seine data for constructing indices of abundance. Perhaps the situation can best be summarised by saying that the Western Pacific purse seine fishery is composed of several fisheries, each with its own characteristics:

- Japanese vessels operate in the western region with a tendancy to target associated schools.

- The American fleet operates over the whole region, but more in the eastern region than the other fleets, targeting mostly unassociated schools.

- The Korean fleet operates mostly in the western region, but currently in areas separate from the Japanese fleet, targeting an even mix of associated and unassociated schools.

- The Taiwanese fleet operates in the same area as the Korean fleet, but targets associated schools almost exclusively.

- The Filipino and Solomon Islands fleets operate in small areas largely separate from the other fleets, fishing almost entirely off anchored FADs.

- The Australian and New Zealand fleets fish in areas at great distances from the other fleets.

The usual approach taken to construct indices of abundance in a fishery wherein one or more factors affecting catch rates are known to vary is to standardise on those factors. However, in order to standardise on a given factor, it is necessary that the confounding effect of other factors be minimized. For example, if one wishes to standardise catch rates for vessel size, yet each size class fishes in separate areas, standardisation is impossible because any difference between vessel size classes could also be attributed to the difference in area fished.

Multivariate linear analyses enable one to standardise over several factors simultaneously, while using all the information that may be available to separate the effects of the different factors. Nevertheless, if there is not enough information in the data to separate effects to begin with, the multivariate analysis will result in strongly correlated parameter estimates.

We have seen that area fished, school type, vessel size and the period during which vessels entered the fishery are all confounded with vessel nationality. School type is further confounded with area fished. The effect of seasonality is related to the effect of school type.

Perhaps the most important complicating factor is that the fishery has not remained constant through time, such that different fleets have operated at different times, and at different times in different areas. It is thereful possible that there will not be enough information in the data to separate the effects of the various factors affecting catch rates, without the parameter estimates being strongly correlated among themselves and with the year effects.

Nominal and stratified catch rates

While multivariate analyses should be carried out to evaluate the extent of the correlation of factors affecting catch rates, it would be of interest, in the interim, to examine nominal and stratified catch rates. Nominal catch rates determined from the data set as a whole are shown in Figure 17. Catch rates stratified by 1° x 1° square, and by 5° x 5° square by month, are shown in Figure 18. Neither nominal nor stratified catch rates show a consistent trend. Annual variation in all three plots is similar, except for 1987, for which nominal CPUE shows a decline, while both stratified CPUEs show an increase.

The nominal and stratified catch rates shown in Figures 17 and 18 are difficult to interpret in light of the confounding effects of the various factors discussed above. In an attempt to standardise as much as possible, prior to conducting a multivariate analysis, catch rates were determined from two subsets of the data which are consistent with regard to area fished, school type, vessel size and vessel nationality (Figure 19). The first subset includes data for Japanese vessels fishing in the waters of the Federated States of Micronesia (FSM) during 1979—1991, while the second subset includes data for American vessels fishing to the east of 165°E. Both sets of CPUE estimates are averages of CPUE stratified by 1° x 1° square, for all squares in which fishing effort occurred. (CPUE stratified by 5° x 5° square by month gives similar results.) The two areas are adjacent to each other and cover a large proportion of the total area fished.

The catch rates for Japanese vessels fishing in the FSM zone appear to be stable, particularly for recent years. Catch rates for American vessels fishing to the east of 165°E are similar to those for Japanese vessels in the FSM zone, except for 1987, when high catch rates were experienced in the eastern region, possibly due to the El Niño conditions prevalent that year.

Figures 17—19 should be interpreted with caution. Further analysis is required to refine the estimates of CPUE such that they can be used as indices of abundance. The information presented in the present document will be taken into account in formulating a multivariate analysis of yellowfin catch rates, which may possibly shed more light on trends in abundance. Hopefully other factors not examined in the present work, such as environmental variables (surface and subsurface temperature, current intensity, etc.), will also be examined.

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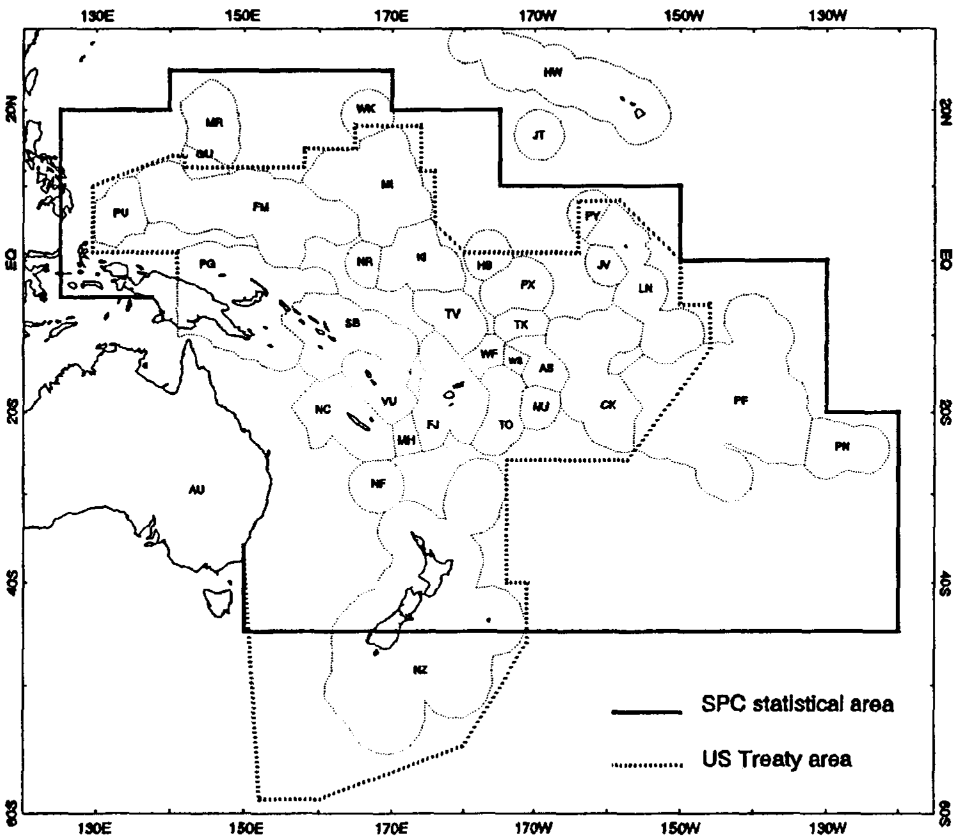


AS	American Samoa
AU	Australia
CK	Cook Islands
FJ	Fiji
FM	Federated States of Micronesia
GU	Guam
HB	Howland and Baker
HW	Hawaii
JT	Johnston
JV	Jarvis
KI	Kiribati
LN	Line Islands
MH	Matthew and Hunter
MI	Marshall Islands
MR	Northern Mariana Islands
NC	New Caledonia
NF	Norfolk
NR	Nauru
NU	Niue
NZ	New Zealand
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 1. La zone statistique de la CPS

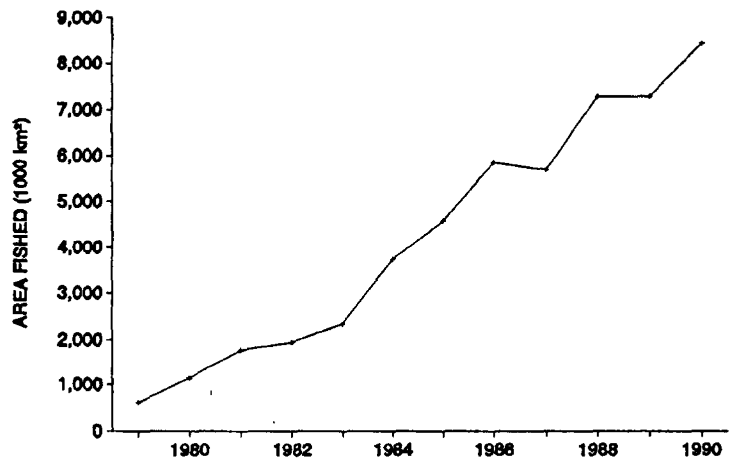
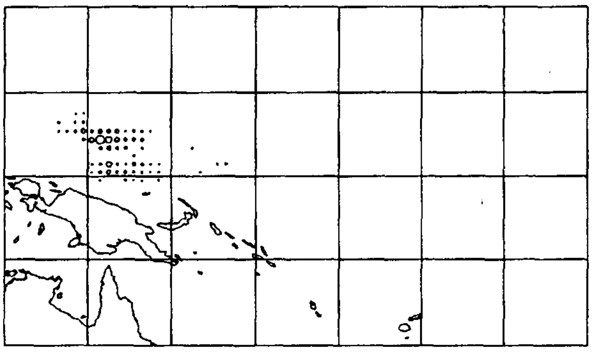


Figure 2. Area fished or searched in the Western Pacific purse seine fishery determined from logbook data held at SPC

Figure 3. Distribution of fishing effort, 1979—1991. Data for 1991 are incomplete.



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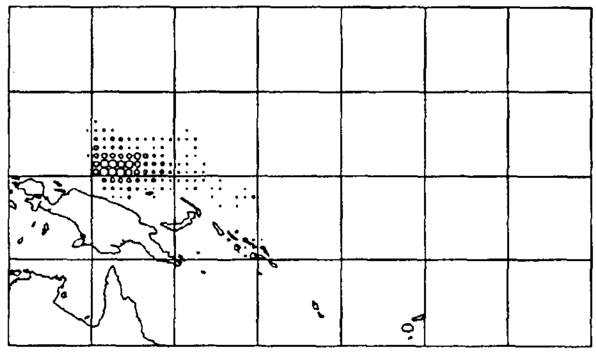

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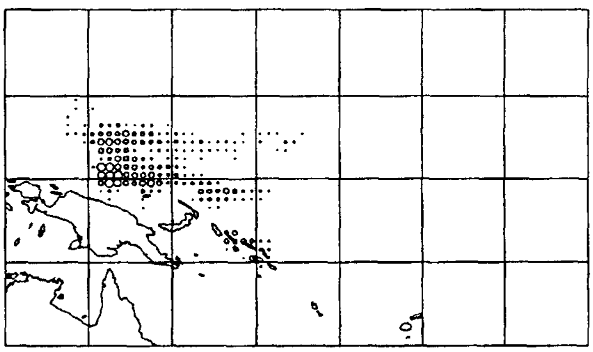

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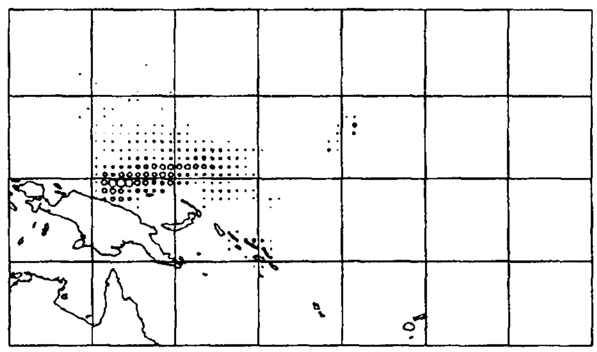

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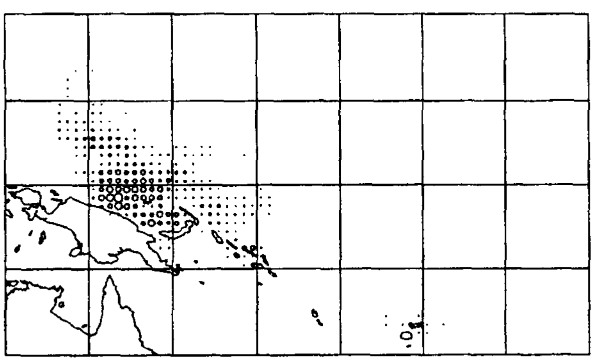
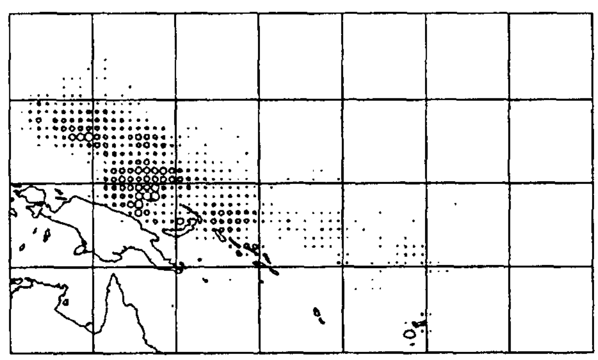


1983



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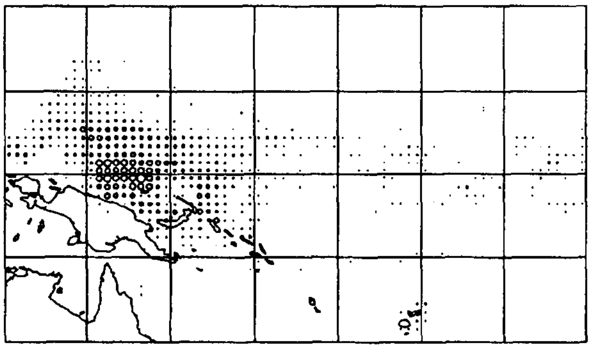

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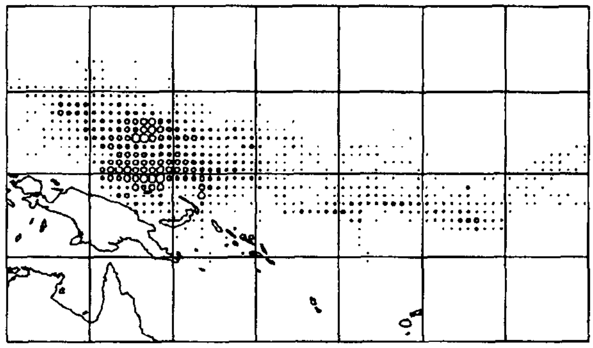

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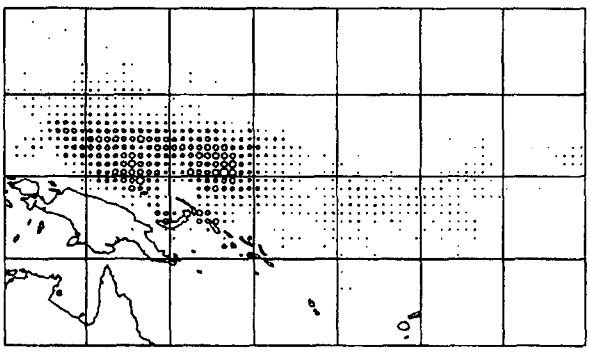

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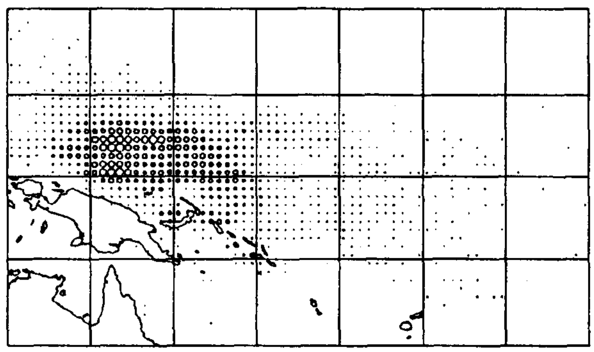

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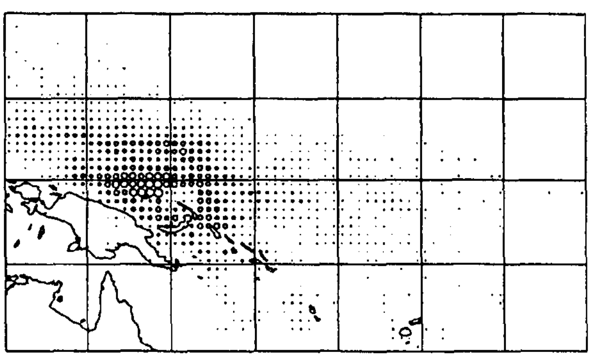

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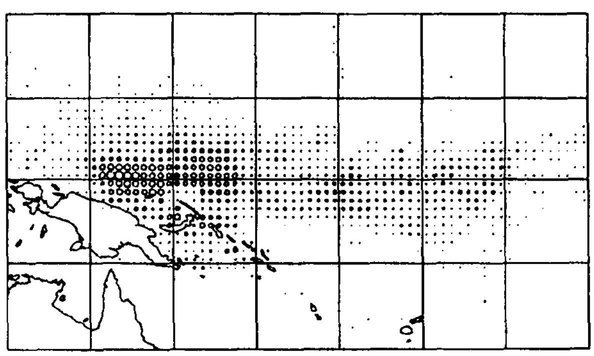

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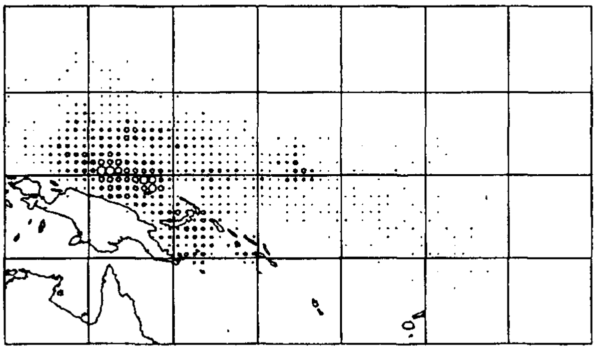

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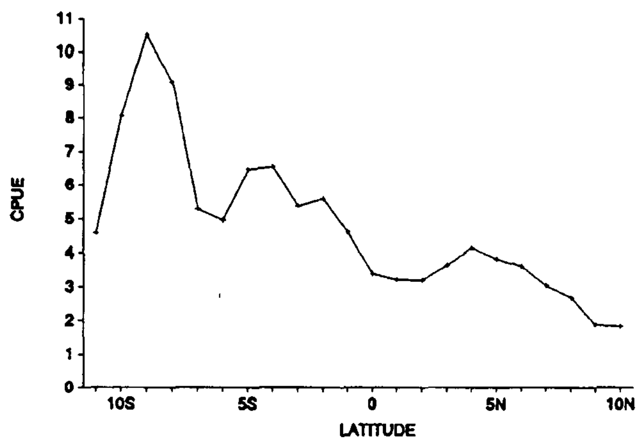


Figure 4. Catch rate (mt per day) by latitude, 1979—1991

Figure 5. Yellowfin catch rate (mt per day) by longitude, 1979—1991

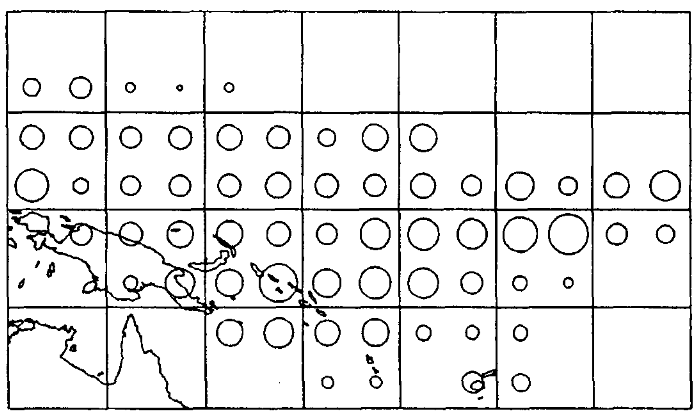
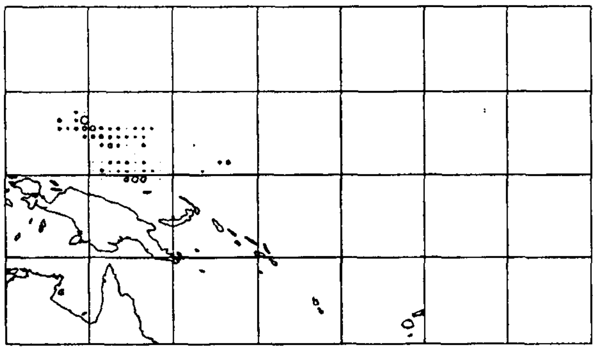


Figure 6. Yellowfin catch rate (mt per day) by 5° x 5° square, 1979—1991. Circles of 5° diameter represent 15 mt per day or more.

Figure 7. Yellowfin catch rate (mt per day) by 1° x 1° square. Circles of 1° diameter represent 25 mt per day or more. Data for 1991 are incomplete.



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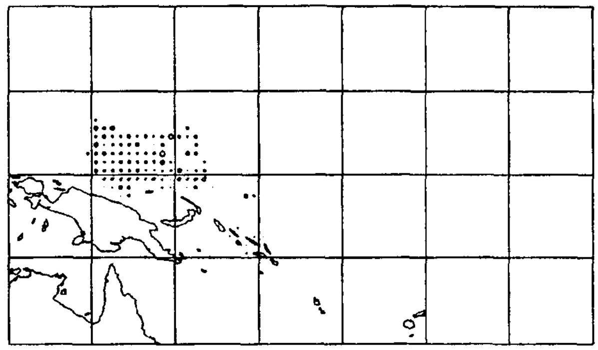

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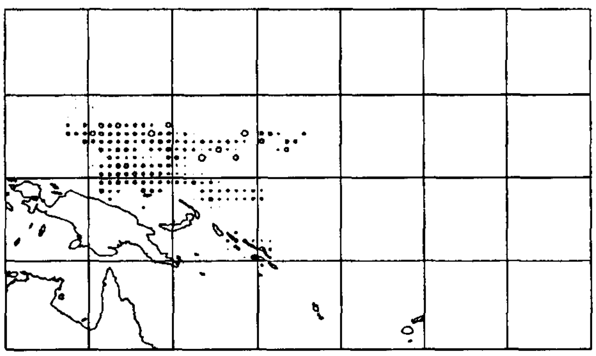

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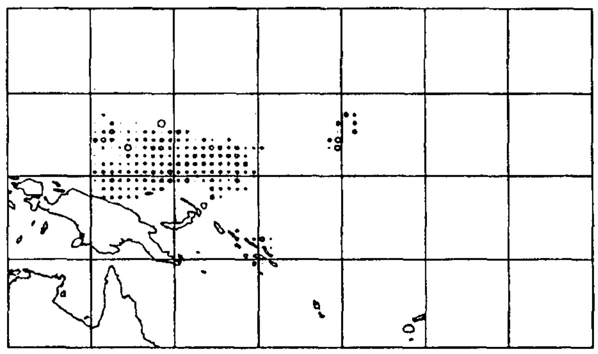

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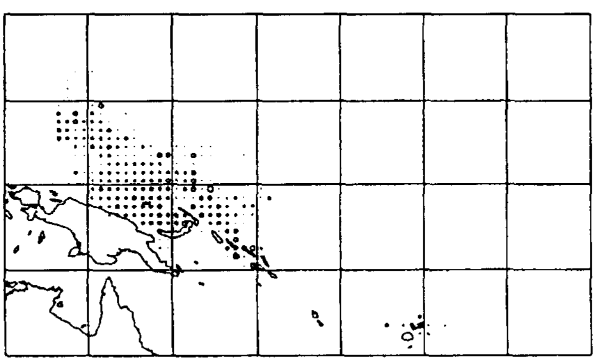

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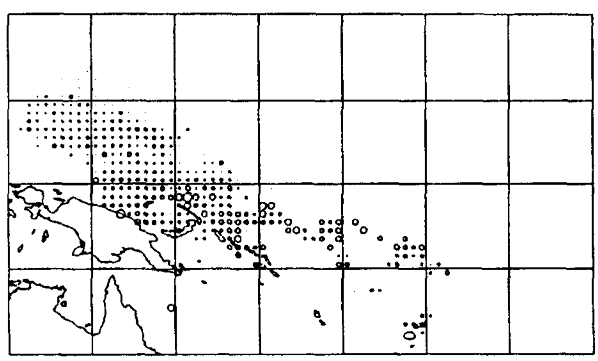

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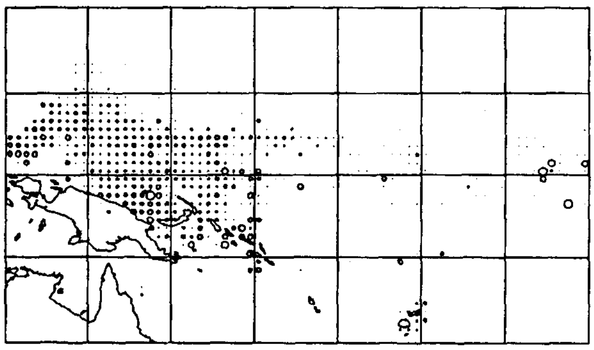

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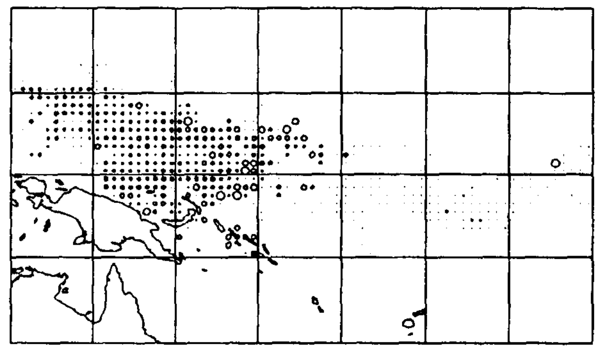

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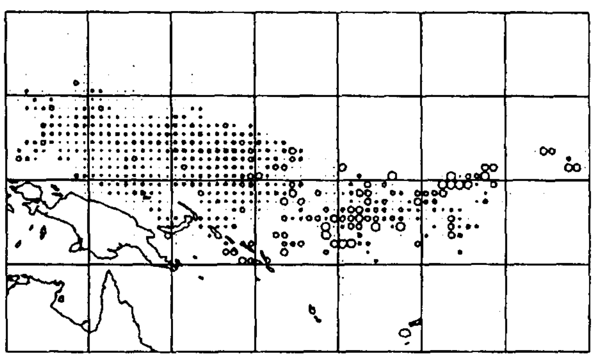

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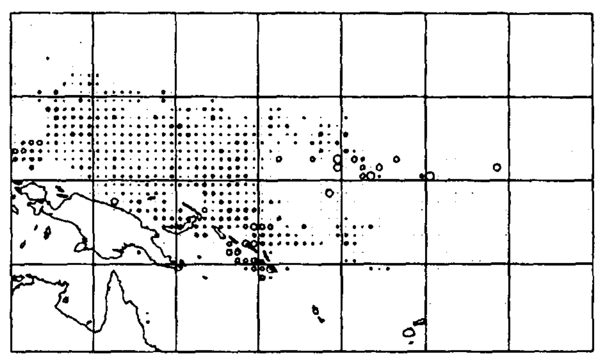

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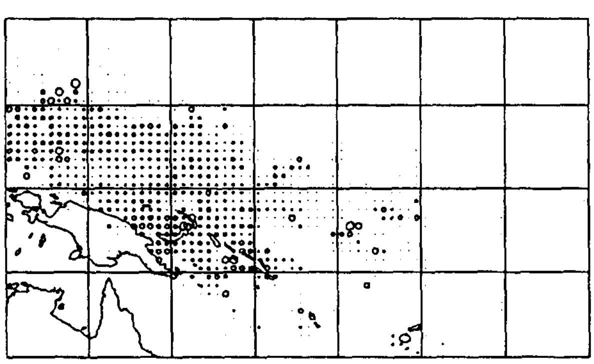

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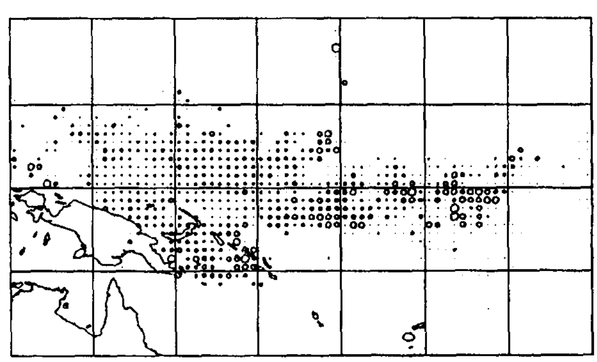

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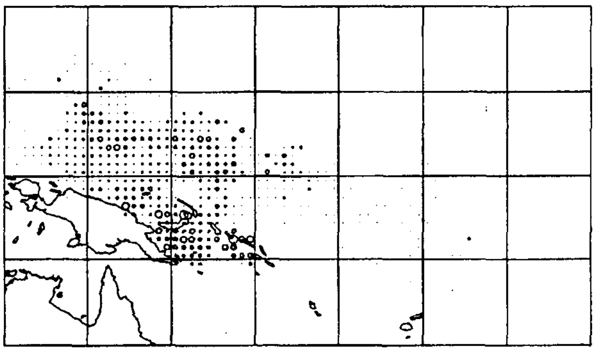
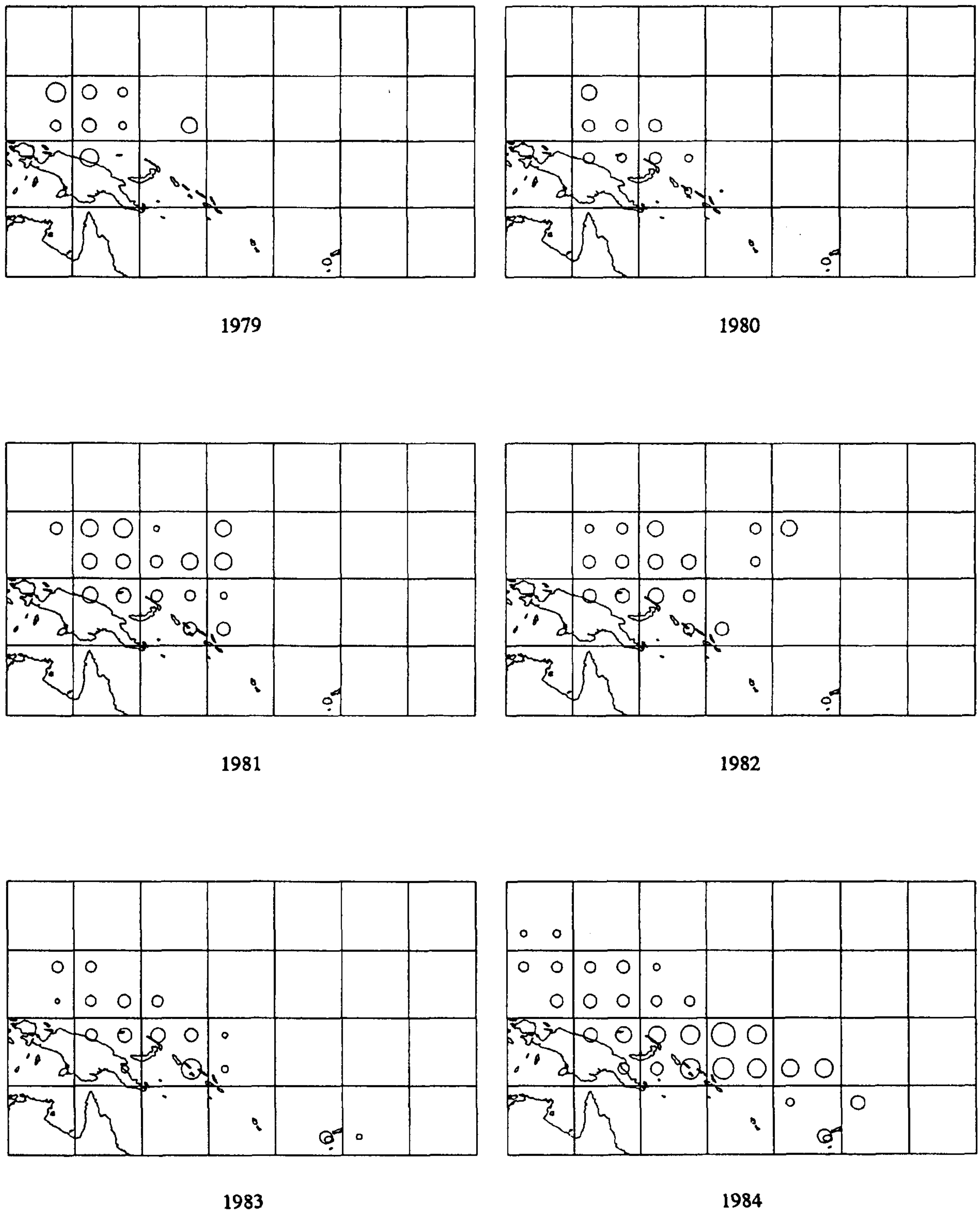


1991

Figure 8. Yellowfin catch rate (mt per day) by 5° x 5° square. Circles of 5° diameter represent 25 mt per day or more. Strata with less than 5 days fished have not been shown. Data for 1991 are incomplete.



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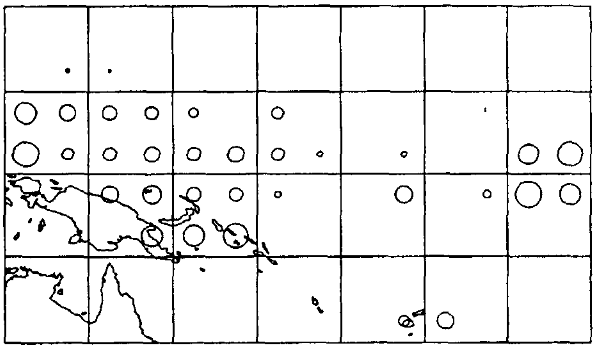

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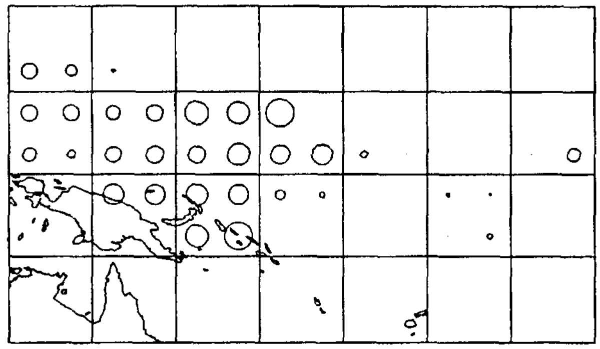

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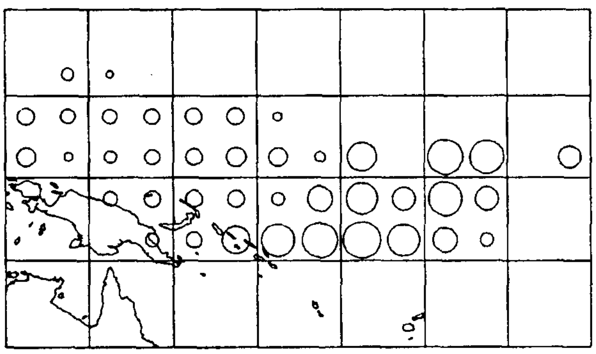

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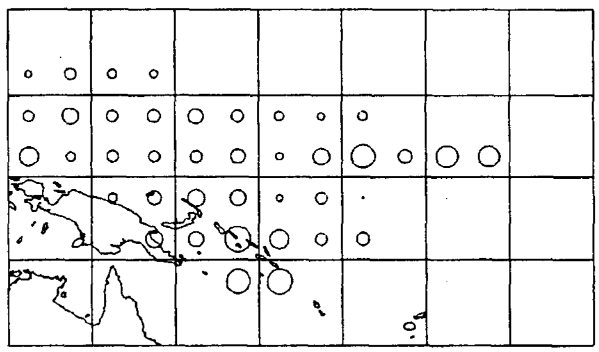

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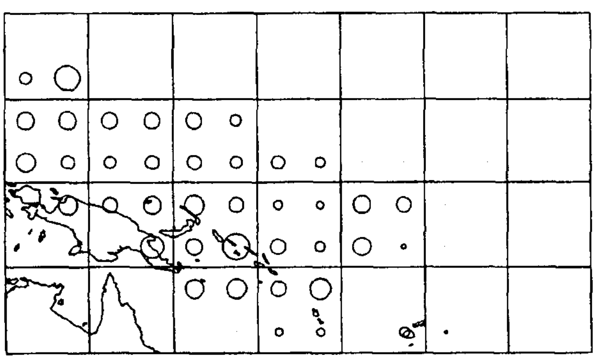

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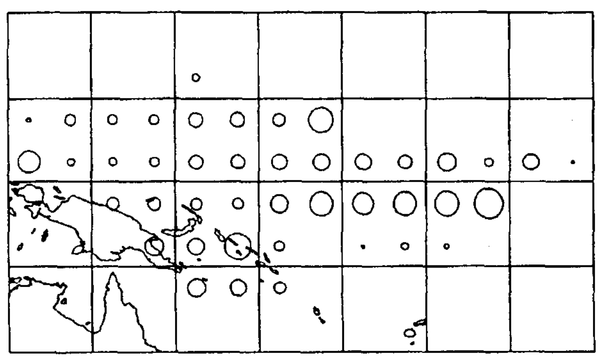

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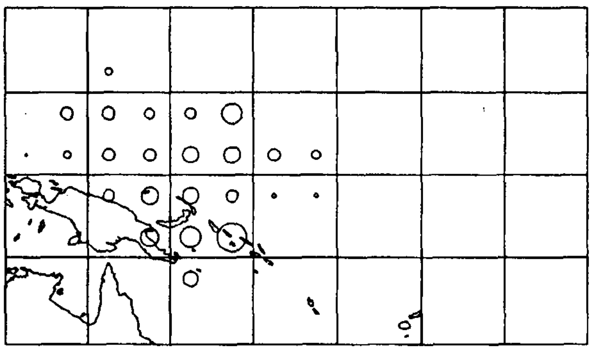

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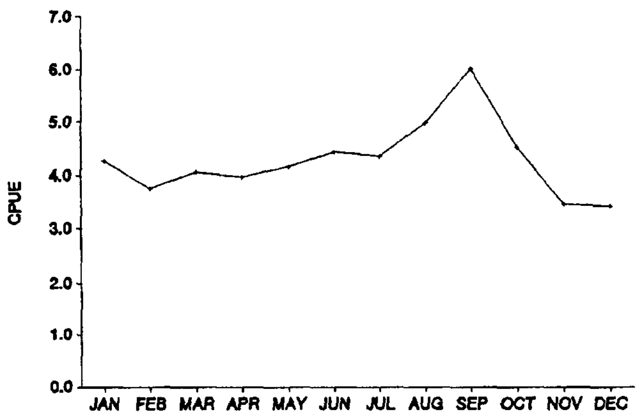
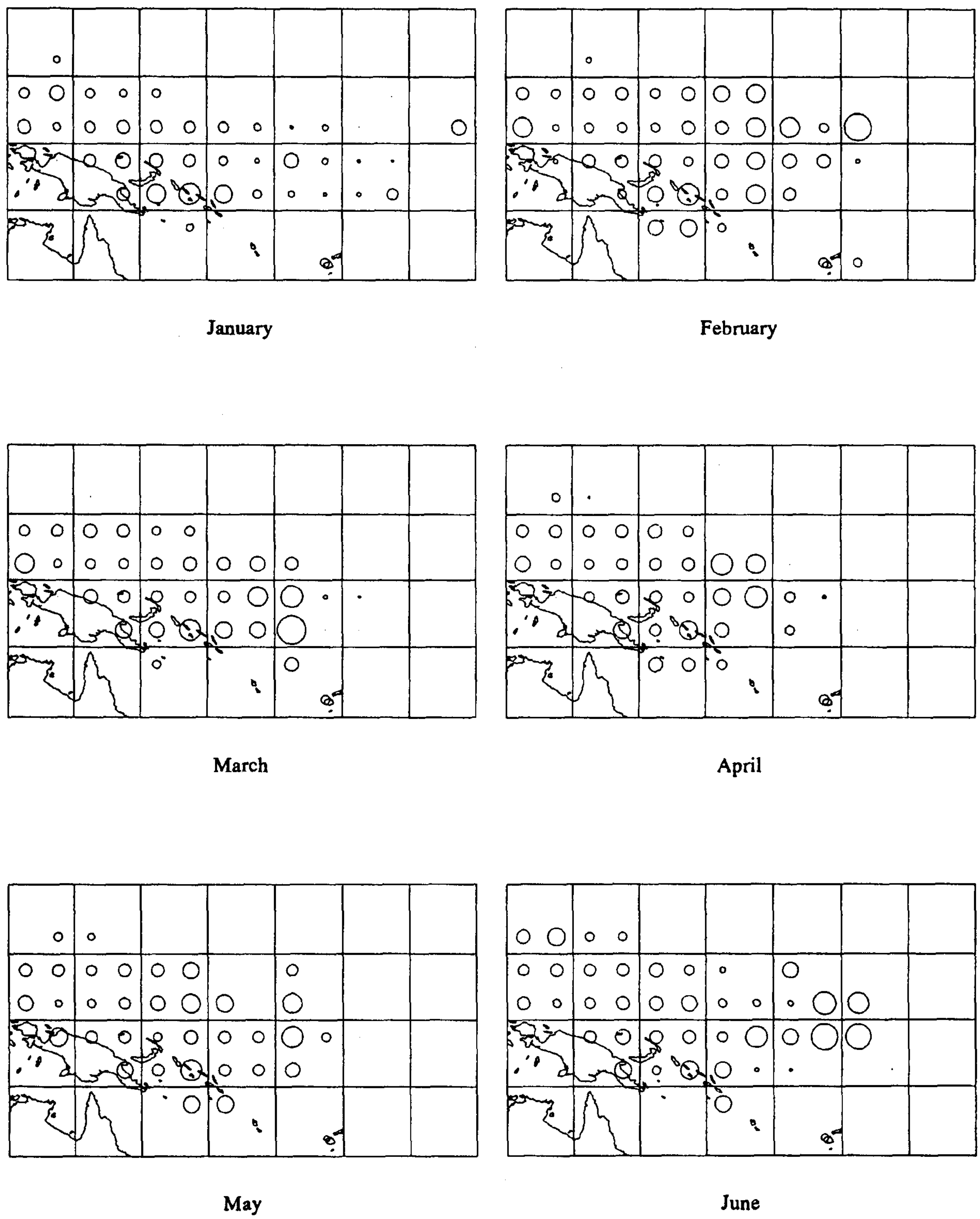


Figure 9. Yellowfin catch rate (mt per day) by month, 1979—1991

Figure 10. **Yellowfin catch rate (mt per day) by month, 1979—1991.** Circles of 5° diameter represent 25 mt per day or more. Strata with less than 5 days fished have not been shown.



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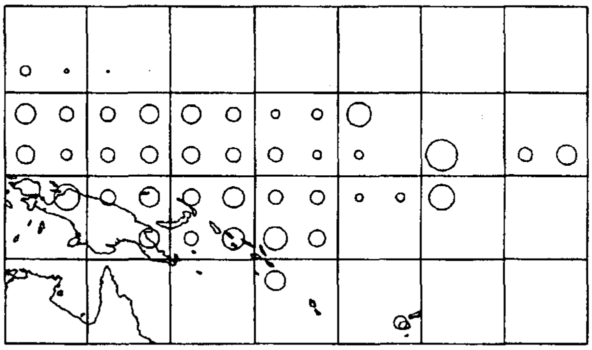

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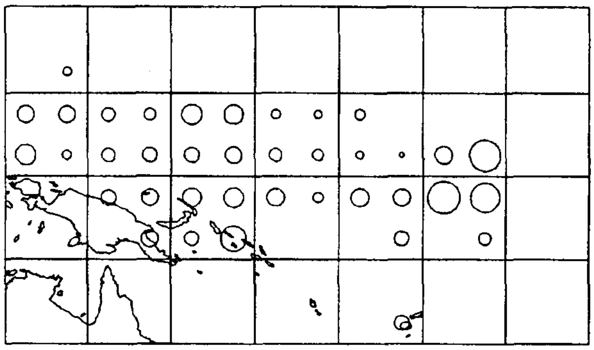

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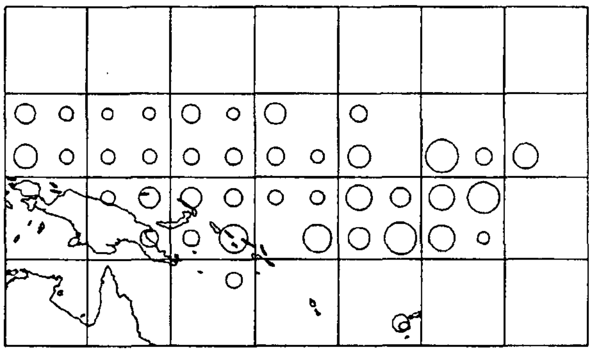

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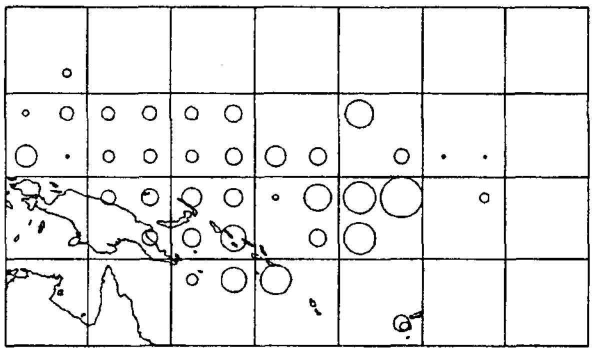

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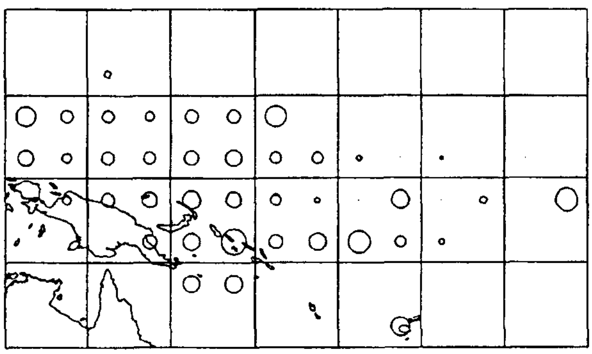
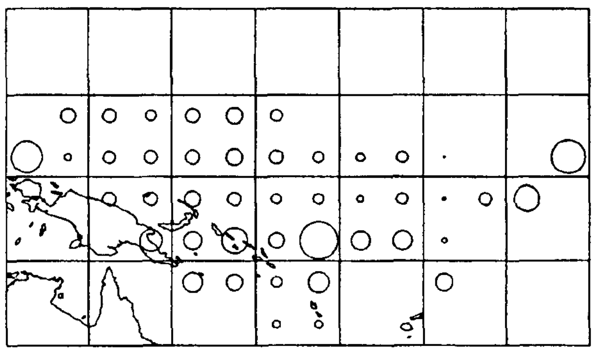
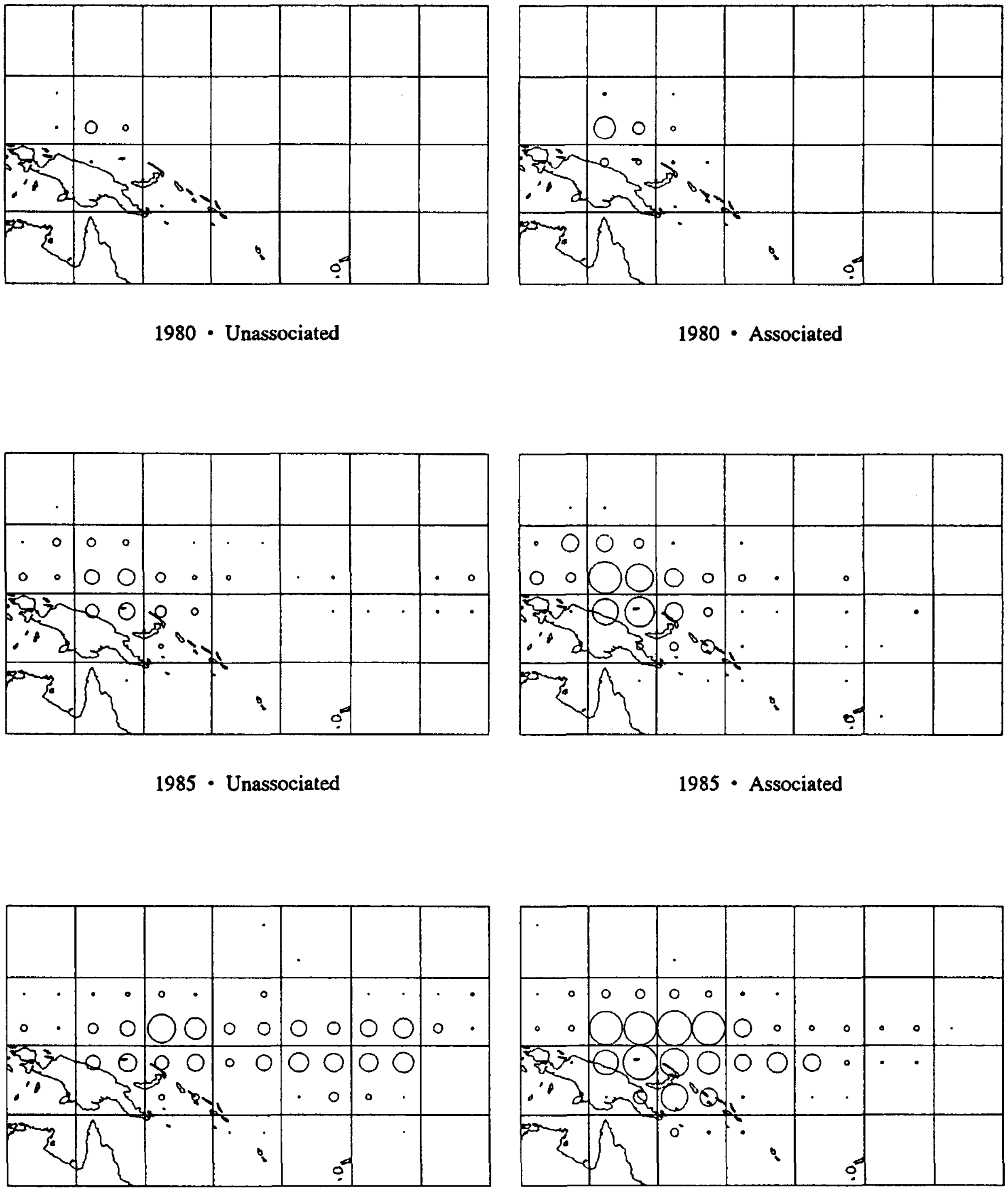


November



December

Figure 11. **Fishing effort (days on which a set was made) by school type (associated or unassociated).** Circles of 5° diameter represent 900 days or more.



1980 • Unassociated

1980 • Associated

1985 • Unassociated

1985 • Associated

1990 • Unassociated

1990 • Associated

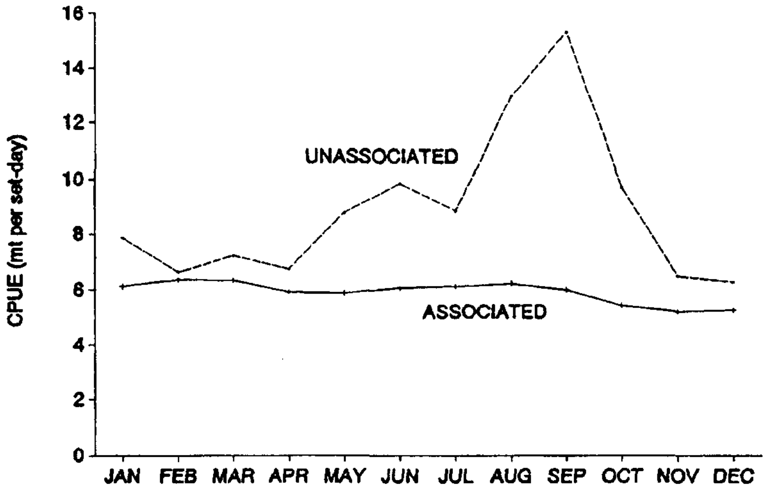


Figure 12. Yellowfin catch rate (mt per day on which a set was made) by month and school type for 1979—1991

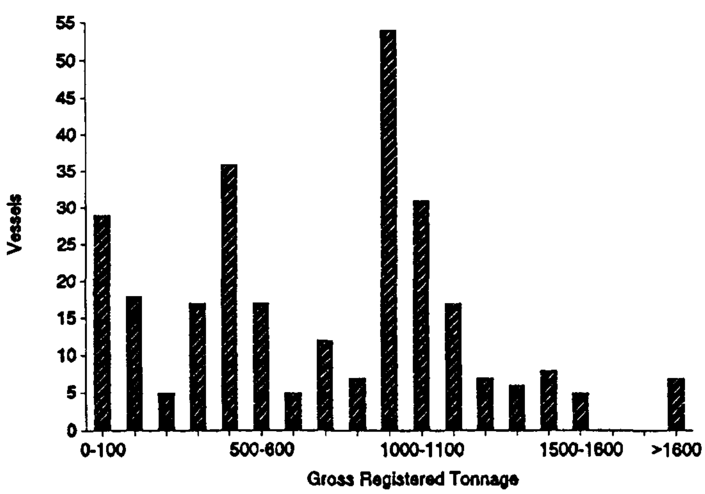


Figure 13. Number of purse seiners by gross registered tonnage

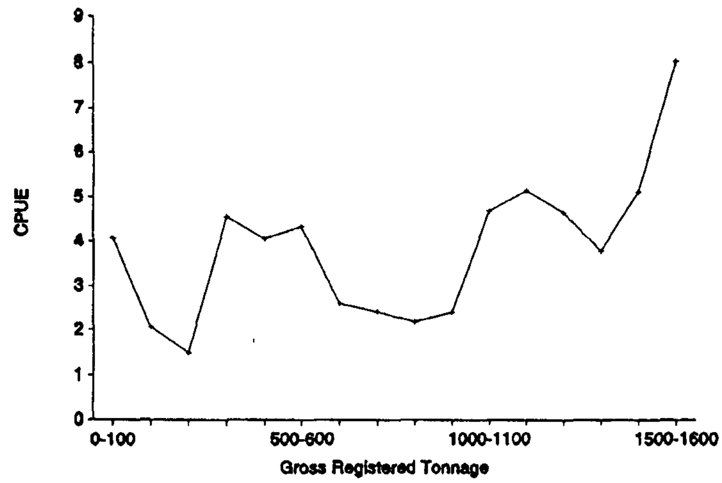


Figure 14. Yellowfin catch rates (mt per day) by gross registered tonnage

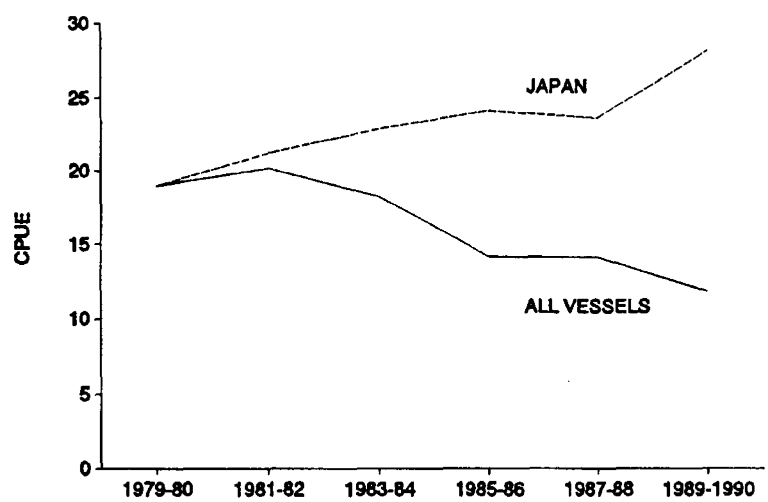
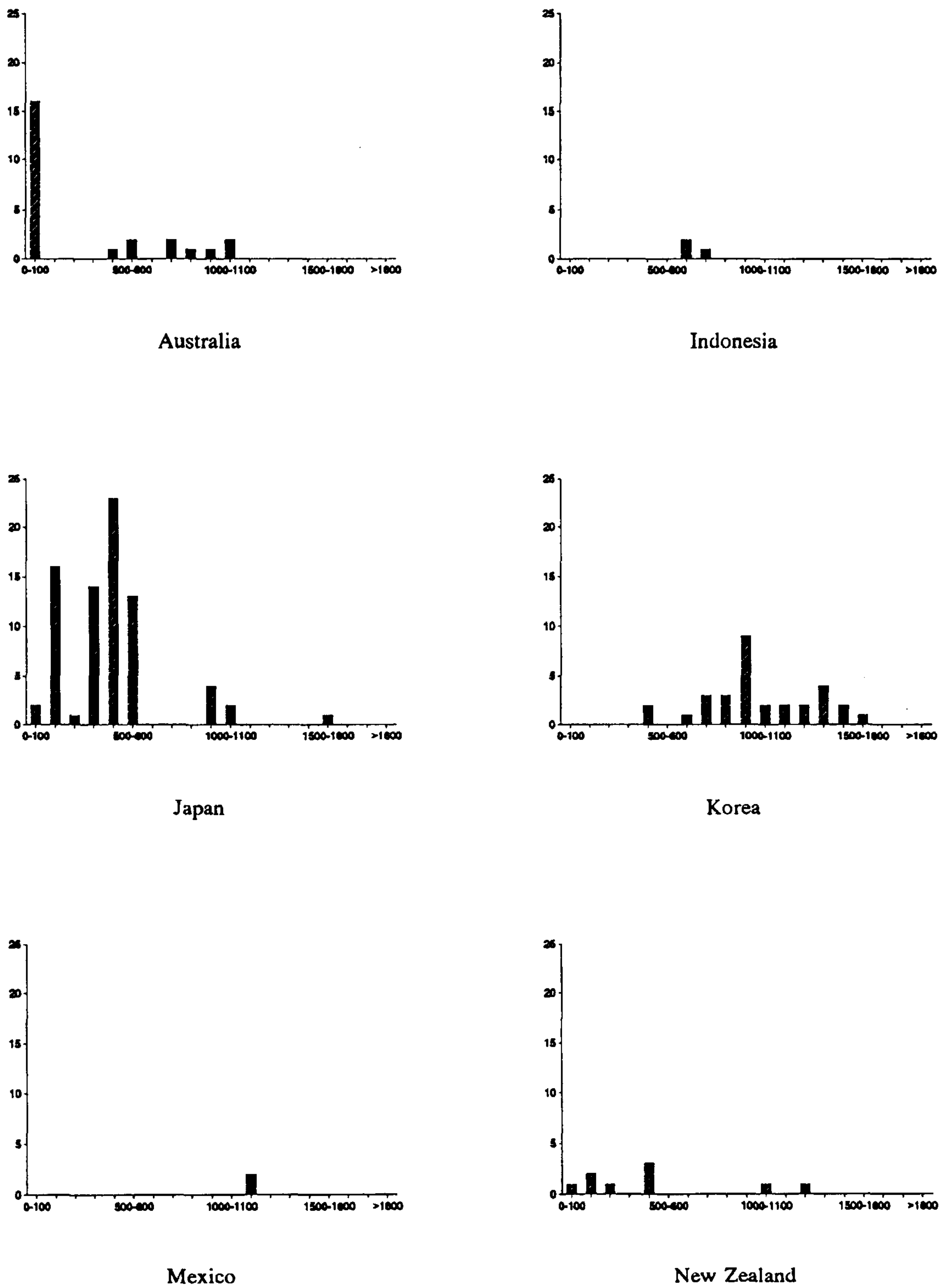


Figure 15. Catch rate (mt per day) for all species, by time period in which the vessel entered the fishery

Figure 16. Vessel size (GRT) by vessel nationality



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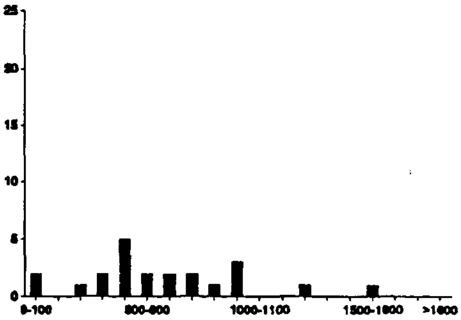
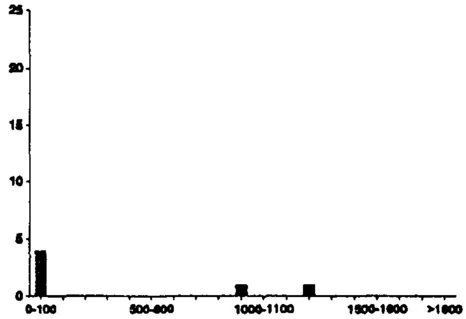
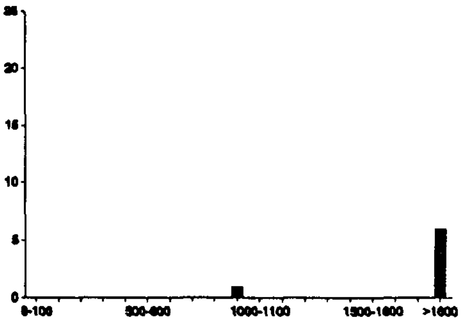


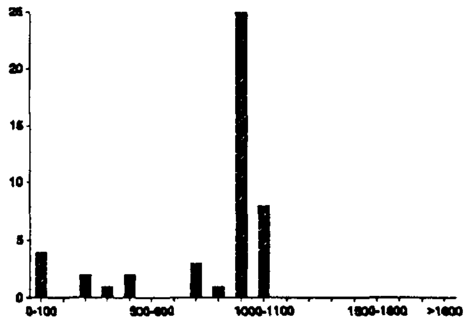
Philippines



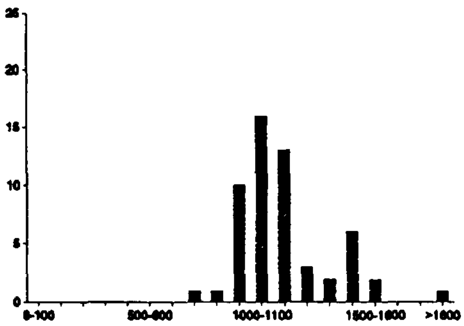
Solomon Islands



Soviet Union



Taiwan



United States

Figure 17. Nominal yellowfin CPUE (mt per day)

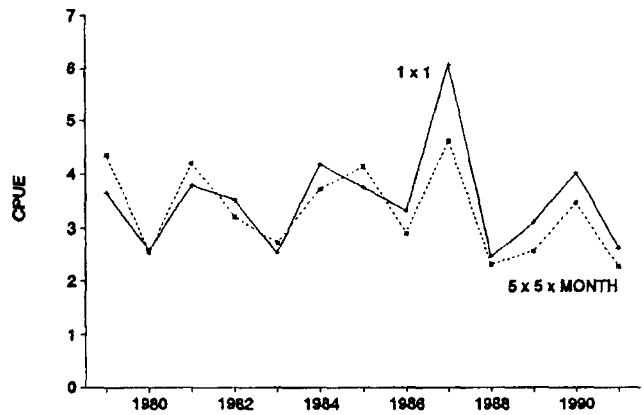


Figure 18. Yellowfin CPUE (mt per day) stratified by 1° x 1° square and by 5° x 5° square by month

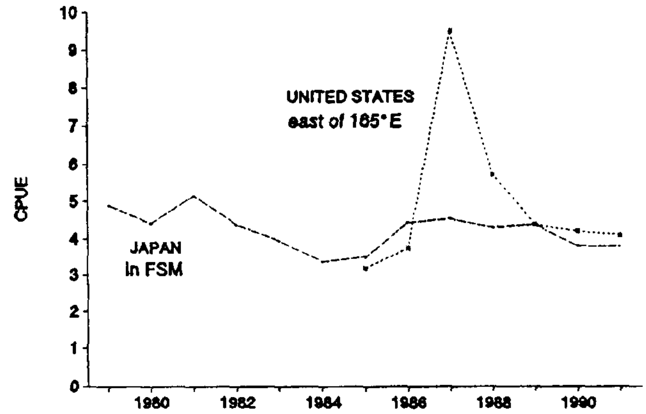


Figure 19. Yellowfin CPUE (mt per day) for Japanese vessels in the waters of FSM and American vessels east of 160°E, stratified by 1° x 1° square

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: South Pacific Commission (1992a)

Table 2. Area fished (1000 km^2) and catch rate (mt per day) for all species for areas in which fishing effort was low (1—2 days fished per 1° x 1° square per annum) compared to other areas. The t statistic compares the catch rate in areas 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.

YEAR	TOTAL AREA FISHED	AREA WITH LOW EFFORT	%	CPUE IN LOW EFFORT AREAS	CPUE IN OTHER AREAS	t	df
1979	608	249	41	13.54	15.23	0.47	64
1980	1,152	461	40	10.49	17.37	2.60*	123
1981	1,760	599	34	11.49	13.62	1.42	189
1982	1,945	525	27	7.50	13.06	3.41*	209
1983	2,350	765	32	11.71	15.80	2.00*	253
1984	3,732	1,189	32	9.34	15.75	4.40*	403
1985	4,580	1,834	40	10.08	15.43	3.12*	495
1986	5,843	2,415	41	3.66	14.00	9.34*	632
1987	5,686	1,954	34	12.84	15.51	1.79*	615
1988	7,281	3,189	44	5.48	14.09	8.19*	788
1989	7,281	2,940	40	4.38	13.50	9.78*	788
1990	8,442	2,617	31	6.35	14.34	7.75*	914

Table 3. **Catch rates (mt per day) and concentration indices for all species combined and for yellowfin.** Stratified CPUE was determined from 1° x 1° squares. Data for 1991 are incomplete.

YEAR	ALL SPECIES POOLED	ALL SPECIES STRAT	ALL SPECIES INDEX	YELLOWFIN POOLED	YELLOWFIN STRAT	YELLOWFIN INDEX
1979	16.34	15.50	1.05	4.56	3.63	1.26
1980	17.59	15.42	1.14	3.32	2.59	1.28
1981	16.14	13.57	1.19	4.63	3.78	1.23
1982	15.86	12.24	1.30	4.46	3.50	1.27
1983	19.23	16.34	1.18	3.75	2.54	1.47
1984	19.17	15.75	1.22	4.95	4.19	1.18
1985	17.19	15.56	1.10	4.34	3.74	1.16
1986	19.93	11.32	1.76	5.00	3.31	1.51
1987	16.11	15.70	1.03	4.79	6.07	0.79
1988	15.71	11.79	1.33	2.72	2.47	1.10
1989	15.72	11.05	1.42	4.62	3.10	1.49
1990	16.19	14.84	1.09	4.49	4.02	1.12
1991	16.37	12.96	1.26	4.17	2.63	1.58

Table 4. **Amount of fishing effort (days fished or searched) in areas of low fishing effort (1—2 days fished per 1° x 1° square) for Japanese vessels and all vessels combined**

YEAR	ALL VESSELS COMBINED TOTAL EFFORT	ALL VESSELS COMBINED EFFORT IN AREAS OF LOW EFFORT	ALL VESSELS COMBINED %	JAPANESE VESSELS TOTAL EFFORT	JAPANESE VESSELS EFFORT IN AREAS OF LOW EFFORT	JAPANESE VESSELS %
1979	426	36	8.5	411	29	7.1
1980	1,202	62	5.2	1,182	57	4.8
1981	2,169	93	4.3	2,010	87	4.3
1982	5,141	76	1.5	4,761	65	1.4
1983	6,181	114	1.8	5,151	81	1.6
1984	9,613	174	1.8	6,732	81	1.2
1985	9,224	248	2.7	5,559	91	1.6
1986	9,781	343	3.5	5,560	98	1.8
1987	12,108	284	2.3	5,504	131	2.4
1988	18,733	463	2.5	5,911	104	1.8
1989	25,260	404	1.6	5,973	76	1.3
1990	26,030	355	1.4	5,007	100	2.0

Table 5. Western Pacific purse seine catch and effort data (days fished or searched) by source and vessel nationality

SOURCE	VESSEL NATIONALITY	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AU	AU	15	15	99	55	28	4	5	1	–	3	26	59
FJ	NZ	–	–	–	–	71	56	83	–	–	–	–	–
FJ	PH	–	–	–	–	–	–	–	–	–	–	36	–
FM	AU	–	–	–	–	–	–	–	–	–	–	22	252
FM	ID	–	–	–	–	–	–	–	42	55	125	–	–
FM	JP	260	190	581	959	628	1,990	1,307	2,545	3,858	4,748	4,222	4,071
FM	KR	–	5	33	–	6	104	197	262	843	647	437	17
FM	MX	–	–	–	–	–	73	–	–	–	–	–	–
FM	PH	–	–	–	–	–	–	–	211	–	–	–	35
FM	TW	–	–	–	–	–	130	206	512	1,450	1,459	1,629	1,053
FM	US	–	–	–	–	–	–	–	34	79	73	–	–
KI	KR	–	–	–	–	–	–	–	–	26	–	–	–
KI	SU	–	–	–	–	–	–	258	1,000	–	–	–	–
KI	US	–	–	–	–	–	–	–	–	372	105	–	–
MI	JP	–	–	–	–	–	–	–	–	–	–	20	–
MI	PH	–	–	–	118	–	–	–	–	–	–	–	–
NZ	NZ	–	–	–	–	206	170	81	183	157	166	–	–
PG	AU	–	–	–	–	–	–	–	–	–	26	–	116
PG	ID	–	–	–	–	–	–	–	92	127	119	167	23
PG	JP	108	771	1,168	3,301	3,720	3,070	2,942	2,074	687	–	–	–
PG	KR	–	–	–	177	303	517	429	215	655	1,085	2,679	2,338
PG	MX	–	–	–	–	–	94	–	–	–	–	–	–
PG	PH	–	–	–	–	–	276	388	–	693	817	1,635	1,776
PG	TW	–	–	–	–	229	394	867	602	1,368	2,258	3,008	5,897
PG	US	–	–	–	–	11	624	831	533	74	120	–	–
PU	JP	–	–	–	–	–	372	278	79	141	147	602	81
SB	JP	–	102	166	163	240	48	–	–	25	–	–	–
SB	SB	–	–	–	–	–	179	86	177	189	231	327	328
TT	US	–	–	–	–	–	–	–	–	–	3,917	6,633	6,410

COUNTRY CODES

AU AUSTRALIA
FJ FIJI
FM FEDERATED STATES OF MICRONESIA
ID INDONESIA
JP JAPAN
KI KIRIBATI
KR KOREA
MI MARSHALL ISLANDS
MX MEXICO
NZ NEW ZEALAND
PG PAPUA NEW GUINEA
PH PHILIPPINES
PU PALAU
SB SOLOMON ISLANDS
SU SOVIET UNION
TW TAIWAN
US UNITED STATES

Note:

Data covering American purse seiners active throughout the Western Pacific have been collected by the South Pacific Forum Fisheries Agency since June 1988. These data are noted above by country code 'TT'.

Table 6. Comparison of catch statistics for unassociated and associated schools to the east and west of 160°E

	WHOLE REGION		WESTERN REGION		EASTERN REGION	
	UNASSOC	ASSOC	UNASSOC	ASSOC	UNASSOC	ASSOC
PROPORTION OF TOTAL CATCH (%)	33	67	28	72	65	35
PROPORTION OF YELLOWFIN CATCH (%)	39	61	33	67	74	26
SETS PER DAY	1.47	1.04	1.44	1.04	1.59	1.02
SUCCESSFUL SETS (%)	49	92	48	92	52	92
SUCCESSFUL SETS, ONLY YELLOWFIN (%)	11	6	10	6	14	9
TOTAL CATCH PER SUCCESSFUL SET (mt)	39.3	25.7	38.6	25.2	42.2	36.8
TOTAL CATCH PER SUCCESSFUL DAY (mt)	47.8	26.7	46.3	26.2	53.0	37.7
YELLOWFIN CATCH PER SUCCESSFUL SET (mt)	11.9	6.1	10.8	6.0	15.9	9.7
YELLOWFIN CATCH PER SUCCESSFUL DAY (mt)	14.8	6.3	13.4	6.1	19.8	9.5
YELLOWFIN AVERAGE SIZE (kg)	22.5	8.5	21.8	8.4	24.4	9.7

Table 7. Average catches of yellowfin (mt) per successful set, by school type (associated or unassociated) and the presence of skipjack. The number of sets is in parentheses.

PRESENCE OF SKIPJACK	UNASSOC SCHOOLS	ASSOC SCHOOLS
SKIPJACK CATCH > 0	5.1	5.8
	(11,960)	(43,389)
SKIPJACK CATCH = 0	35.2	11.0
	(3,501)	(3,262)

Table 8. Catch statistics for 1979—1991 by vessel nationality

FLAG	DAYS FISHED	ALL SPECIES CATCH	ALL SPECIES CPUE	YELLOWFIN CATCH	YELLOWFIN CPUE	SCHOOL TYPE % UNASS	SCHOOL TYPE % ASSOC
AU	1,127	19,460	17.27	1,521	1.35	26	74
ID	750	11,426	15.23	1,591	2.12	11	89
JP	47,084	990,775	21.04	213,570	4.54	26	74
KR	11,496	138,116	12.01	35,685	3.10	46	54
MX	167	3,191	19.11	1,169	7.00	2	98
NZ	1,173	26,709	22.77	526	0.45	–	100
PH	6,834	89,833	13.15	25,806	3.78	1	99
SB	1,690	50,425	29.84	15,766	9.33	1	99
SU	1,258	5,539	4.40	1,330	1.06	98	2
TW	24,323	136,741	5.62	20,805	0.86	8	92
US	21,443	491,733	22.93	154,081	7.19	70	30

FLAG CODES

AU AUSTRALIA
ID INDONESIA
JP JAPAN
KR KOREA
MX MEXICO
NZ NEW ZEALAND
PH PHILIPPINES
SB SOLOMON ISLANDS
SU SOVIET UNION
TW TAIWAN
US UNITED STATES

Table 9. 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