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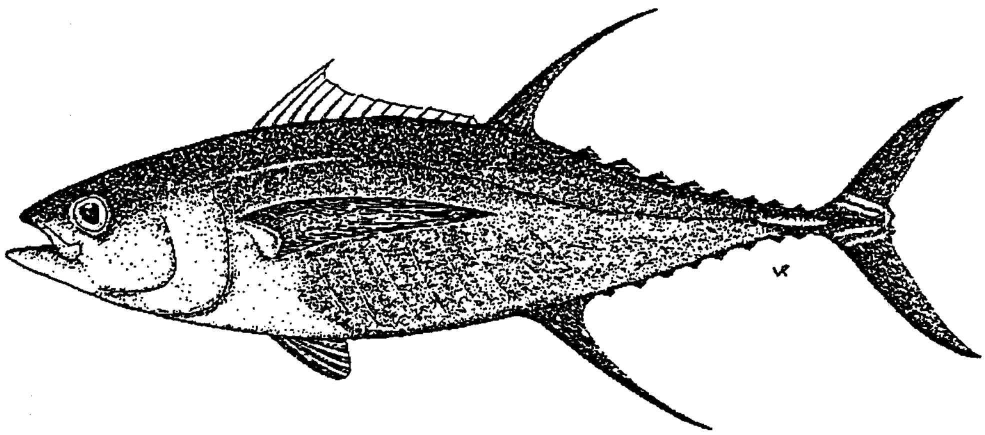
STATUS OF TUNA STOCKS IN THE SPC AREA: A SUMMARY REPORT FOR 1993



Tuna and Billfish Assessment Programme
South Pacific Commission
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STATUS OF TUNA STOCKS IN THE SOUTH PACIFIC COMMISSION AREA: A SUMMARY REPORT FOR 1993

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INTRODUCTION

The tuna fisheries in the South Pacific Commission (SPC) area (Figure 1) and adjacent areas have undergone significant expansion in the past decade. Total catches of the major commercial species – yellowfin, skipjack, bigeye and albacore – have increased from about 550,000 mt in 1980 to more than 1.4 million mt in 1991 (Figure 2). Much of this increase has resulted from development of the purse seine fleet, which has increased from 14 Japanese vessels at the start of 1980 to almost 200 vessels, from mainly Japan, United States, Korea, Taiwan and Philippines, in 1992.

There has been concern in some quarters regarding the ability of the tuna stocks to sustain such large catches. The SPC's Tuna and Billfish Assessment Programme (TBAP), which is charged with the responsibility of regional tuna stock assessment, has directed most of its efforts over the past decade to firstly developing a reliable database of tuna fisheries statistics, and secondly to estimating various parameters of the populations of the principal commercial species. Both of these activities are ongoing and are critical for the development of reliable stock assessments.

In this paper, we present a summary of the various analyses and other information that provide some indication of the status of stocks of each of the major tuna species. We begin by reviewing information on stock definition and follow with a brief review of fisheries indicators, primarily catch per unit effort (CPUE) time series. For yellowfin and skipjack, emphasis is given to recent work on tagging-based assessment, and, in the case of albacore, the preliminary results of an age-structured assessment model are described.

YELLOWFIN

Stock Definition

Yellowfin are fished throughout the Pacific by longliners, in the eastern Pacific and western Pacific by large purse seiners and in the Philippines and eastern Indonesia by pole-and-line, ring-net, handline and other small-scale methods. Longline CPUE for primarily adult yellowfin (>100 cm FL) shows no clear discontinuity in the Pacific, but tends to be higher in the western Pacific, gradually declining towards the east (Figure 3). Average size of longline-caught yellowfin increases from west to east (Suzuki et al. 1978). It is unclear to what extent these patterns reflect the yellowfin population itself, or rather, its vulnerability to longline gear. Certainly, the changing thermocline topography, generally deepening from east to west, would be expected to have some impact on longline CPUE.

The purse seine fisheries of the eastern and western Pacific do not overlap. The eastern Pacific fishery occurs off Baja California, Central and South America (about 30°N–20°S) but has a narrower westerly extension to about 145°W centred on 10°N (Figure 4). The western Pacific fishery is centred on the equator and extends to about 160°W. In both locations, both juvenile and adult yellowfin are captured. The discontinuous nature of these fisheries, and presumably of the abundance of surface schools, may be indicative of limited mixing between the eastern and western Pacific.

SPC tagging experiments in the western tropical Pacific have demonstrated extensive meridional movements between 120°E and 170°W (Figure 5). Several large-scale zonal movements of larger yellowfin have also been recorded, and more observed movements of this type might be expected as the tagged population ages. To date, no yellowfin tagged west of 170°W have been reported as recaptured in the eastern Pacific purse seine fishery, although several recoveries have been reported by longliners operating to the east of 150°W (Figure 5). No yellowfin tagged in the eastern Pacific fishery have been reported as recaptured west of 150°W (Suzuki et al. 1978).

The distribution of yellowfin larvae (Figure 6) and mature adults is considered to be consistent with at least eastern and western Pacific stocks, and possibly a central Pacific stock as well (Suzuki et al. 1978). While most of the evidence is inconclusive, a plausible hypothesis would be for separate eastern and western stocks with little inter-mixing as juveniles, but with possibly greater mixing through large-scale movement as adults (Lewis 1992). For stock assessment purposes, we will define the western stock to range from the Philippines and eastern Indonesia to 150°W. This eastern boundary is chosen on the basis that it is consistent with the available biological data on spawning and movements, and it neatly separates the eastern and western Pacific surface fisheries.

Catches

Western Pacific yellowfin catches doubled between 1980 and 1991, with much of the increase resulting from the expansion of purse seining (Figure 7). During the same period, increases also occurred in the Philippines and Indonesian domestic fisheries, but catches by the longline fleet have declined. Much of the increase in total catch has occurred since 1988. Prior to this time, total catches were stable for most of the 1980s at around 200,000 mt. In 1991 the total catch was approximately 370,000 mt, with a similar total expected to be declared for 1992.

Catch-Per-Unit-Effort

Nominal catch per day fished by purse seiners has fluctuated a great deal since the beginning of the fishery (Figure 8). In the early years of Japanese purse seining, CPUE tended to increase, presumably in response to gear enhancements and the acquisition of expertise. Since 1980, CPUE for both the Japanese and United States fleets (for which data quality and coverage are best) has varied greatly from year to year, but no declining trend has been in evidence.

The extent to which catch per day fished by purse seiners indicates variation in yellowfin abundance is not known. An analysis of purse seine CPUE, in which the effects of several factors shown to significantly affect yellowfin CPUE were removed using a general linear model (GLM), has recently been undertaken (Lawson 1993). For the model based on data for the Japanese fleet, school type, the presence of skipjack in sets, geographic strata, sea surface temperature, sea surface temperature squared and the interaction between school type and the presence of skipjack in sets were all accepted as significant factors in the model. Unfortunately, the effects of gear technology could not be tested because there was no data available. The resulting index of abundance suggested that the yellowfin population available to Japanese purse seiners has not declined during the last decade (Figure 9). In fact, an increasing trend, which might be due to technological advances and acquired expertise, is suggested (although most of the 95% confidence intervals overlap). These results need to be interpreted cautiously in view of the large amount of residual variation in the model (only 14.5% of the variance is explained by the model) and the likely effect of gear technology which could not be incorporated.

A long time series of yellowfin CPUE by Japanese longliners is also available (Figure 10). Three regions have been defined for the purpose of examining trends – 10°N–10°S, where most of the catch and the highest CPUEs are recorded, 10°N–40°N and 10°S–40°S. For the 10°N–10°S region, CPUE declined steadily from 1962 to 1975, possibly a fishing down process characteristic of most longline fisheries during their developing stages. CPUE increased sharply between 1975 and 1978. It is likely that this increase was the result of a series of strong year classes recruiting to the longline fishery, because the increase occurred over several years and higher than normal CPUEs were maintained for several years subsequent to 1978. Since 1978, CPUE has declined steadily, and in recent years has reached the low point of 1974–1975. CPUE in the northern region shows a similar pattern, although at much lower levels of CPUE. In the southern region, CPUE declined to 1976, increased to 1981, and has varied around this increased level since that time.

The post-1978 decline in CPUE in the main (tropical) fishing area has been interpreted in some quarters as an interaction effect associated with increasing catches in the purse seine fishery. We believe that the evidence for this is somewhat weak, because (i) a similar decline had previously occurred in the virtual absence of purse seining, (ii) the post-1978 decline was already well underway when the purse seine fleet began to expand in the early 1980s, and (iii) the current CPUEs are at about the same level as they were in 1974–1975. While some effect of increased purse seine catches on longline CPUE cannot be ruled out, a more plausible hypothesis is that the longline fishery itself was primarily responsible for fishing down a population that had been boosted by strong recruitment, in the same way that it had prior to 1975. A further complicating factor is that, since the early 1980s, many Japanese longliners have tended to target bigeye tuna by setting their lines deeper, and this may also have had a negative impact on CPUE.

The interpretation of the longline CPUE time series is therefore problematic. There are several possible factors – longline catches, purse seine catches and changes in targeting – that might have contributed to the post-1978 decline. A generalised linear model, which could test the significance of these and other factors and incorporate them into the model as appropriate, might be useful in resolving some of these problems.

Tagging

One of the major objectives of the Regional Tuna Tagging Project (RTTP) was to estimate the natural and fishing mortality rates and related population parameters of yellowfin from tag-recapture information. Between July 1989 and December 1992, the RTTP and associated in-country projects (including the Philippines Tuna Research Project) tagged and released 40,352 yellowfin throughout the major fishing grounds of the western tropical Pacific (Figure 11). As at 12 May 1993, there were 4,725 (11.7%) confirmed recaptures. A preliminary analysis of the data was reported to SCTB 5 (Hampton 1992); that analysis has now been updated to include yellowfin tagged prior to 1 August 1992 and associated recoveries with recapture dates prior to 1 October 1992. These cut-off dates were chosen to allow a reasonable time for recently recovered tags to be returned. An additional restriction on the data analysed was that only yellowfin with release lengths of at least 40 cm were included. This restriction was introduced to avoid complications associated with possibly higher natural and tagging-induced mortality of very small yellowfin. This final data set consisted of 24,318 releases and 2,341 associated recoveries.

The same basic methodology as reported in Hampton (1992) was used in this analysis. The main features of the model are:

- Natural (M) and fishing (F) mortality rates, assumed constant, can be estimated directly from the tagging data, which is stratified by month of release and month of recapture. Variable fishing mortality can be accommodated if monthly total catches are known. In this case, M and standing stock size (P) are the estimated parameters, and monthly fishing mortality rates can easily be computed.

- Other quantities that are useful for assessing the impact of fishing, the aggregate throughput (T) and the harvest ratio (H), can be calculated using standard theory. In addition, some indication of exploitation potential can be obtained, under the assumption of stable T and M, by calculating P, H, and F for different equilibrium catches.

- The estimated parameters and derived quantities represent average conditions across the area of the tagging experiment (approximately 10°N–10°S, 120°E–170°W). In reality, there may be areas of higher or lower natural and fishing mortality rates, stock densities, etc, but these features have not been incorporated into this model. What we are interested in here is an overall picture of the stock and its exploitation.

- The lack of spatial structure in the model means that an assumption of complete mixing of tagged and untagged yellowfin throughout the area of the study is necessary if the dynamics of the tagged fish are to be extrapolated to the stock as a whole. Movement rates of tagged fish suggest that four months is generally sufficient for this mixing process to take place. In the parameter estimation procedure, we have therefore excluded the recaptures of tagged fish made in the first four months after release from the likelihood function, but used these recaptures and the model parameters to calculate the number of tagged fish alive immediately after the mixing period.

- The valid use of a tag-recapture experiment to obtain information on fishing mortality is critically dependent on all sources of tag loss being accounted for. The loss rates that are not directly estimable from the model are the proportion of tags that are recaptured but not reported, the immediate and continuous tag-shedding rates, the immediate and continuous tagging-induced mortality rates, and the permanent emigration[1] rate. The reporting rate was estimated from the return rate of tags "seeded" (placed in dead fish) on board purse seiners during the course of the study. Tag-shedding rates were estimated from the returns of double-tagged tuna. We had no means of experimentally estimating tagging-induced mortality – we assumed an average immediate mortality associated with tagging of 0.05 and no continuous tagging-induced mortality. On the basis of observed movements of tagged yellowfin (Figure 5), permanent emigration of yellowfin from the area of the western Pacific fisheries is unlikely to be a significant source of tag loss. Similarly, the wide range of yellowfin sizes exploited by the fisheries would not suggest significant permanent loss of vulnerability associated with growth. Any losses due to these factors would be incorporated into the estimate of the natural mortality rate. The assumed or estimated values of each of these loss rates are shown in Table 1.

- We used bootstrap techniques (Buckland and Garthwaite 1991) to quantify the precision of the estimated parameters and related derived quantities. A stratified non-parametric bootstrap, in which pseudo-data sets of an identical structure to the real data were created by randomly sampling with replacement from the real data, was used to generate a multinomial sampling error. The true confidence intervals of parameters and derived quantities should include the effects of uncertainties in the various input parameters as well as those due to multinomial sampling error. In the case of the tag-shedding parameters, an independent parametric bootstrap, which simulated the binomial probability structure of the double-tagging experiment, was used to obtain 1,000 independent pseudo-estimates of the two tag-shedding rates. Similarly, 1,000 pseudo-estimates of the reporting rate and immediate tagging mortality rate were obtained by random sampling from beta distributions with means of 0.7 and 0.05, respectively, and coefficients of variation of 10% and 5%, respectively. These coefficients of variation, while somewhat arbitrary, were chosen to reflect the degree of uncertainty that we feel is appropriate for the point estimates. The 1,000 sets of pseudo-estimates (tag-shedding parameters, reporting rate and immediate tagging mortality) were used, in turn, as the input parameters for the analysis of the 1,000 sets bootstrapped tagging data. 1,000 pseudo-estimates of model parameters and derived quantities were so obtained, and the 2.5% and 97.5% quantiles of their distributions used to approximate the 95% confidence intervals.

Estimates and 95% confidence intervals of model parameters, derived quantities and input parameters are given in Table 1. The most useful estimate for inferring the current impact of fishing on the yellowfin stock is the harvest ratio, which is simply an estimate of the proportion of total mortality due to fishing (and also the proportion of the total throughput, removed by fishing). The current estimate of yellowfin harvest ratio is 0.16 (0.13–0.22). Although there are no general biological criteria to indicate a maximum acceptable harvest ratio, values less that 0.5 are normally associated with fisheries that can sustain increased exploitation. We would certainly not expect recruitment overfishing to occur in tuna fisheries at harvest ratios of less than 0.5. On this basis, we conclude that the current impact of the fisheries on the western Pacific yellowfin stock is at most moderate.

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[1] Here, we use the term emigration to include movement away from the area of the fishery or a loss of vulnerability to the fisheries associated with growth.

While this is useful information and is reassuring to fisheries management agencies in the region and countries involved in the fishery, it would also be informative to be able to predict the impact of increased catches on the stock. It is technically possible to extrapolate from the current situation, using the fitted model, if the estimated natural mortality rate and throughput are not affected by changes in exploitation. While such extrapolation may be useful, we must be careful not to extrapolate so far that we run the risk of violating these constant-rate assumptions. It is also necessary to remember that the predicted population responses are "average equilibrium responses" – in reality the population is affected by a range of seasonal, cyclical and random phenomena that our model cannot consider.

How far can we realistically extrapolate? The relationship between catch and fishing mortality in our model is such that, for very high levels of fishing mortality, the equilibrium catch approaches the throughput but can never exceed it (Figure 12). In reality, catches that approached this limit would quickly reduce the population to such an extent that the throughput could not be sustained because of recruitment failure. We therefore feel that it would be inadvisable to extrapolate beyond harvest ratios of 0.5. For harvest ratios <0.5, the standing stock would be more than half its unexploited level and the constant rate assumptions should not be grossly violated.

Projections of standing stock and harvest ratio, and their 95% confidence intervals, were made over the range of equilibrium catch levels corresponding to average harvest ratios of <0.5. As expected, the harvest ratio increases (Figure 13) and the standing stock decreases (Figure 14) with increasing equilibrium catch. The uncertainties in both quantities, as reflected by the 95% confidence intervals, increase with increasing catch.

There are many different criteria that could be applied to these relationships in order to nominate a "maximum safe" harvest. Two such criteria that are sometimes used in fisheries management are to (i) maintain a harvest ratio of no greater than 0.5 and (ii) maintain the standing stock at no less than half the level it would be in the absence of exploitation. To be at least 95% certain that these criteria would be met, we should choose catch levels in which not only the *average* harvest ratio or standing stock satisfies the relevant criterion, but also the *upper limit* (in the case of harvest ratio) or *lower limit* (in the case of standing stock) of the 95% confidence interval. These criteria should constitute fairly conservative definitions of "maximum safe" harvest. Using criterion (i), the maximum annual yellowfin catch would be about 800,000 mt (Figure 13). Criterion (ii) is slightly more conservative because of the larger confidence intervals on the standing stock estimates, and suggests a maximum catch of about 600,000 mt (Figure 14).

We should note that a decline in standing stock associated with increased catch would, if catchability remained constant, result in similar declines in CPUE, which may impact economic viability regardless of biological sustainability. However, compensatory increases in catchability might occur, e.g. through yellowfin schooling behaviour or increasing catching efficiency, which would tend to maintain CPUE at high levels. At present, there is no basis for predicting an exact, or even average, response of CPUE to changing standing stock levels.

Conclusions

Yellowfin occur throughout the tropical and sub-tropical waters of the Pacific Ocean, and there are no obvious barriers to movement. However, there is some evidence from fisheries, tagging and biological data that interchange between the eastern and western Pacific is limited. We have therefore defined western and eastern Pacific stocks separated at 150°W.

Yellowfin catches in the western Pacific have doubled in the past decade, with recent annual catches being of the order of 370,000 mt. Despite these increases, CPUE in the purse seine fishery, which is responsible for about half of the total catch, has not declined. Longline CPUE has shown a declining trend since the late 1970s, when CPUE was at an all time high, but the current level of CPUE is about the same as it was in the mid-1970s. The results of tagging experiments suggest that the impact of fishing on the yellowfin stock is currently mild. Using conservative criteria to define "maximum safe" catches, further increases in annual catch to 600,000–800,000 mt could be accommodated.

SKIPJACK

Stock Definition

Large industrial tuna fisheries for skipjack occur in the western Pacific from the Philippines and Indonesia to about 160°W and in the eastern Pacific from the coast of Baja California, Central and South America to about 145°W. In the western Pacific, most of the purse seine catch is taken between 10°N and 10°S and, as with yellowfin, there is no overlap with the eastern Pacific fishery (Figure 15). The pole-and-line fishery, primarily Japanese, is confined to the western Pacific but unlike the purse seine fishery, has a seasonal extension northwards to about 40°N (Figure 16).

Skipjack population structure in the Pacific Ocean has been investigated through tagging studies and studies of the geographical distribution of genetic and phenotypic characters. These studies have been reviewed most recently by Wild and Hampton (1991). Extensive tagging of skipjack in the western and central Pacific has indicated unrestricted meridional movement between 120°E and about 160°W, as well as seasonal movements into and out of higher latitudes (Figure 17). Tagging in the eastern Pacific has also demonstrated long-distance movements, with one instance of a skipjack tagged off Baja California being recaptured at approximately 160°E (IATTC 1984). Despite the large amount of tagging carried out in the western and central Pacific over the past 15 years, no recoveries of these fish have been recorded from the eastern Pacific purse seine fishery. Nevertheless, it is generally accepted that skipjack in the eastern Pacific originate from spawning that occurs in the central and/or western Pacific. This is largely based on the observation that little skipjack spawning occurs in the eastern Pacific (Figure 18). Gene frequency data for the esterase allele suggest a clinal population structure from 120°E to about 150°W (SPC 1981). There are no significant differences in gene frequencies between the central and eastern Pacific, which is in agreement with the hypothesis of a central Pacific origin of eastern Pacific skipjack.

If we accept the clinal population structure as indicated by the esterase data, we would conclude that skipjack is a Pacific-wide stock, but with gene flow restricted in an isolation-by-distance fashion. While this hypothesis appears reasonable, there are still some questions (such as whether such a cline could be maintained given the movement rates observed for tagged skipjack) that require further consideration. The development of a skipjack movement model based on tagging data will help to answer such questions.

In the meantime, we will consider skipjack in the western and central Pacific, i.e. west of 150°W, as a single stock for assessment purposes. While eastern Pacific skipjack may originate in the central Pacific, there is little evidence of significant exchange of adult fish between these areas. It is therefore unlikely that eastern Pacific skipjack contribute significantly to the reproductive potential of the overall population.

Catches

Catches of skipjack in the western and central Pacific have more than trebled since 1980, the 1991 catch approaching one million mt (Figure 19). As with yellowfin, most of this increase has been due to the expansion of purse seining in the western tropical Pacific. Catches in the Indonesian and Philippines domestic fisheries have also increased, but pole-and-line catches have declined as Japanese vessels have been retired from the fishery.

Catch-Per-Unit-Effort

Skipjack CPUE by Japanese purse seiners increased consistently throughout the 1970s, presumably as expertise and experience was acquired and cooperative searching among vessels developed. Since the late 1970s, CPUE has varied between 15 and 20 mt per day, although preliminary data suggest that the highest-ever CPUE was recorded in 1992 at 25 mt per day (Figure 20). Skipjack CPUE by United States purse seiners has increased consistently since the early 1980s, and its pattern of variability has closely resembled that of the Japanese fleet.

Skipjack CPUE by the Japanese pole-and-line fleet has tended to increase over the past decade (Figure 21). CPUE has generally been higher, but more variable, in the tropical fishing area than in the northern area. The increases in CPUE have coincided with substantial effort reduction in which the smaller, older and presumably less efficient vessels have been retired; the CPUE increases may therefore be due in some part to the changing fleet profile.

As with yellowfin, the interpretation of surface fishery skipjack CPUE is difficult without a good understanding of the relationship between CPUE and abundance. It is clear that technological advances in the location and capture of skipjack have occurred, and that these might have maintained CPUE at high levels even if the population had been declining. It is doubtful that a GLM approach would help to resolve this problem unless these technological advances could be quantified. The most we can say about the CPUE time series is that there is no evidence that the fisheries have impacted the skipjack population to the extent that their CPUE has been adversely affected.

Tagging

Most of our current knowledge of the dynamics of skipjack in the western and central Pacific has resulted from tagging experiments. SPC's Skipjack Survey and Assessment Programme (SSAP) undertook an extensive skipjack tagging experiment in the late 1970s and early 1980s, tagging approximately 140,000 skipjack. From the 6,000-plus returns, Kleiber et al. (1987) estimated that the fishery, catching approximately 230,000 mt of skipjack per year at the time, was having a minimal effect on the stock and producing a harvest ratio of only 0.037.

During the recent RTTP, 98,697 skipjack were tagged throughout most of the area currently subjected to fishing (Figure 22). As at 12 May 1993, 12,016 tagged skipjack had been recaptured and reported to SPC. The analysis described earlier for yellowfin has been applied to the skipjack data with identical restrictions on size at release and recapture date (resulting in 74,031 releases and 8,742 returns) and with a four-month mixing period assumed. The results of this analysis are summarised in Table 2. Skipjack, with its higher natural mortality rate and throughput, is more productive than yellowfin and capable of supporting higher catches. The harvest ratio has increased from 0.037 in the early 1980s to 0.15 (0.12–0.20) and suggests that, despite the large increases in catch over the past 10 years, the effect of fishing on the stock remains minimal. It is interesting to note that the recent estimate of the harvest ratio is exactly the harvest ratio that would have been predicted for the current catch using the SSAP parameter estimates. We therefore have two independent experiments carried out under very different fishery conditions giving us almost identical estimates of the stock dynamics.

We made projections of harvest ratio and standing stock for different levels of equilibrium catch, as was done for yellowfin, in order to determine approximate safe maximum catches. Under the criterion of harvest ratio <0.5 (with 95% certainty), the maximum skipjack catch would be about 2 million mt (Figure 23). Under the criterion of standing stock > half the estimated unexploited standing stock (with 95% certainty), the maximum catch would be about 1.5 million mt (Figure 24).

Conclusions

Skipjack are highly mobile and are capable of unrestricted movement throughout the Pacific Ocean. Most spawning seems to occur in the western Pacific, where most of the catch is also taken. Tagging results show substantial mixing of skipjack from Philippines and eastern Indonesia to at least 150°W, however movement, at least of adult skipjack, between the central and eastern Pacific appears more limited. We have therefore defined 150°W as the eastern limit of a western and central Pacific skipjack stock.

Despite a trebling of skipjack catches in the past decade, with recent annual catches being of the order of 1 million mt, CPUE by purse seiners and pole-and-liners remains high and has shown a tendency to increase since the early 1980s. Although there is little doubt that technological advances have contributed to the increased CPUE, there are no fishery indicators that would suggest that the stock is heavily exploited. The results of two major tagging experiments on skipjack, separated by an interval of approximately 10 years, provide consistent estimates of the stock dynamics. The recent experiment suggests that the impact of fishing remains modest, despite the increases in catch over the past decade. Conservative definitions of "maximum safe" harvest imply that annual average skipjack catches of the order of 1.5–2.0 million mt could be sustained.

BIGEYE

Stock Definition

Bigeye are caught throughout the Pacific by longliners and are a by-catch species in most surface fisheries. Longline CPUE for primarily adult bigeye (>100 cm FL) shows no discontinuity across the Pacific, although both CPUE (Figure 25) and average size of captured fish (Miyabe 1991a) tend to increase from west to east. As with yellowfin, changes in bigeye vulnerability to longline gear related to geographical differences in thermocline topography may be primarily responsible for these patterns.

Tagging programmes in the western tropical Pacific have tagged relatively few bigeye, and therefore the data on long-distance movement are sparse. Several movements of >1000 nmi have been observed (Figure 26), but there is little evidence of mixing throughout the Pacific.

Miyabe (1991a) lists several observations in support of a single Pacific-wide bigeye stock. These observations are based mainly on fisheries statistics and could just as easily be accommodated in a clinal or overlapping sub-population structure. The occurrence of bigeye larvae in the Pacific shows three concentrations, in the western, central and eastern Pacific (Figure 27), which would support a hypothesis of overlapping stocks. To date, there has been no population genetics work carried out on Pacific bigeye on a scale that could clarify stock structure. Similarly, the amount of bigeye tagging carried out to date has been insufficient to indicate the extent of movement throughout the life history. There is therefore little basis for concluding anything about bigeye stock structure in the Pacific at present. The different possibilities should be born in mind when reviewing catch statistics or conducting analyses for stock assessment.

Catches

Miyabe (1991a) gives estimates of total bigeye catch for the Pacific for 1955–1988. Since the mid-1970s, total catch has fluctuated between 100,000–150,000 mt per year, most of which is attributed to the longline fishery. These total catches may be under-estimates as the amount of bigeye caught is the surface fisheries of the Pacific is not known with any certainly. It is possible that around 10% of the declared yellowfin catch may in fact be bigeye, which would mean a current Pacific-wide bigeye catch in the surface fisheries of 50,000–60,000 mt.

Catch-Per-Unit-Effort

Bigeye CPUE by Japanese longliners for the entire Pacific and for areas east and west of 150°W is shown in Figure 28. While CPUE is substantially higher in the eastern Pacific, the pattern of variation is similar for both areas. This suggests that the factors affecting bigeye CPUE are common to both areas and are widespread. The trends for both areas and the whole Pacific appear stable since the mid-1960s.

In the mid-1970s, Japanese longliners began to target the more valuable bigeye by setting deeper, thus allowing lines to reach into the colder water (10°–15°C) favoured by bigeye (Hanamoto 1987). By the mid-1980s, most of the Japanese longliners fishing in the western and central Pacific had adopted this technique. This change in fishing behaviour may have affected CPUE. Miyabe (1991b) standardised the Pacific-wide bigeye CPUE time series for seasonal and spatial variation (using the Honma approach) and for variation in set configuration, which is related to fishing depth. Miyabe's result is not appreciably different to that shown in Figure 28, with CPUE declining until the mid-1960s, but remaining essentially stable since that time.

Stock Assessments

All of the published assessments for Pacific bigeye (reviewed by Miyabe 1991a) assume a Pacific-wide stock. Both production models and age-structured models have been used. For the production model analyses, maximum sustainable yields (MSY) of 100,000–160,000 have been obtained. As with most analyses of this type applied to tuna, the estimated MSY is approximately the same as the average catch in recent years. As Miyabe (1991a) shows (his Figure 17), a wide range of production curves (and corresponding MSYs) with different shape parameters provide equally good fits to the catch-effort data. As a result, MSYs from 130,000 mt per year upwards can be obtained with equal validity (or lack thereof).

Miyabe (1989) applied virtual population analysis to Pacific bigeye, assuming natural mortality rates of 0.4 and 0.6 per year. The analysis was tuned to the Japanese longline CPUE time series. For the analysis using M=0.4, there is no clear trend in population numbers at age, but the estimated fishing mortality rates are relatively high, about 0.3–0.6 per year for the fully recruited age classes. For the analysis using M=0.6, the fishing mortality rates are lower (0.2–0.4 per year), but the estimated numbers at age 1 show a declining trend. Miyabe (1989) considered these results to be preliminary, but concluded that the current level of catch was sustainable.

Tagging

During the RTTP, bigeye were often tagged incidentally to the main target species, yellowfin and skipjack. In total, 8,071 bigeye were tagged, a substantial proportion of which were large fish (>80 cm FL) released in the Coral Sea off north-eastern Australia (Figure 29). As at 12 May 1993, 703 of these had been recaptured and the tags reported to SPC. While these data are not yet amenable to the type of analysis undertaken for yellowfin and skipjack, some comparisons of tag return rates might be useful for indicating the degree of bigeye exploitation in the western Pacific surface fisheries.

If we exclude the releases off north-eastern Australia, which were of atypical size and not released in the vicinity of the major surface fisheries, the release and recovery details were as follows:

	Releases	Recoveries	Rate
Western tropical Pacific excluding the Philippines:	3,456	280	8.1%
Philippines domestic fishery	1,260	352	27.9%

The return rate of bigeye for the western tropical Pacific excluding Philippines was slightly less that those for yellowfin and skipjack in the same area. For releases in the Philippines, the bigeye return rate was similar to those for yellowfin and skipjack. If the processes that affect return rate (apart from exploitation rate) are similar for the three species and disregarding the effects of different natural mortality rates, it is reasonable to conclude that the exploitation rate of bigeye by the surface fisheries of the western Pacific is no higher than those of yellowfin and skipjack, which, on the basis of the analyses presented in this paper, are believed to be modest.

Conclusions

Bigeye occur throughout the tropical and sub-tropical Pacific, with no obvious barriers to movement. At present there are few data with which to test stock structure hypotheses; alternative structures should be considered, if possible, when analyses are being performed.

The stability of the longline CPUE time series and related abundance indices would suggest that the current levels of catch – up to 150,000 mt by longline and 60,000 mt by surface fisheries – are sustainable, although at least one of the age-structured analyses indicates that this represents moderate to high exploitation of age classes vulnerable to longline. The extent of surface fishery catch can only be roughly approximated, but tagging results would suggest that the current average exploitation rate of juvenile bigeye by the surface fisheries is no higher than those of yellowfin and skipjack (believed to be modest).

ALBACORE

Stock Definition

Albacore have a more temperate distribution than skipjack, yellowfin and bigeye, and are believed to constitute separate stocks in the North and South Pacific. Lewis (1990) provided a summary of the main evidence:

- A clear discontinuity in longline CPUE between 10°S and 10°N (Figure 30)
- Separate spawning areas in the North and South Pacific, centred around 20° of latitude
- A much stronger geographical segregation by size in the South Pacific
- No instances of trans-equatorial movement of tagged albacore recorded

Within the South Pacific, albacore are capable of extensive zonal and meridional movements, as evidenced by tagging data (Figure 31). Most albacore have been tagged in the surface fishery operating in the sub-tropical convergence zone (STCZ) at 35°–45°S, 140°–160°W. From this area, movement to the east, west and north has been observed. Exchange between the central Pacific and the Tasman Sea has also been demonstrated. While the capacity for trans-Pacific mixing is evident, there is considerable apparent zonal segregation of albacore by size. With spawning taking place primarily at 15°–30°S, juvenile albacore are first observed, probably as two-year-olds, around the coast of New Zealand and in the STCZ troll fishery (Figure 32). Adult albacore are caught primarily to the north of the STCZ and in the Tasman/Coral Seas by longline (Figure 33).

The available tagging and fisheries data suggest that albacore should be treated as a single stock in the South Pacific. This conclusion is supported by the results of a recent pilot study of albacore population structure in the Pacific by means of an electrophoretic analysis of blood proteins. Five South Pacific locations were sampled – Tasmania, New Zealand, New Caledonia, Fiji, and French Polynesia. None of the screened loci showed significant heterogeneity among the South Pacific locations, indicating gene flow at least sufficient to maintain genetic homogeneity.

Catches

Since the early 1960s, albacore catches in the South Pacific have generally ranged from 25,000 mt to 40,000 mt, with most of this catch being taken by longliners (Figure 34). During the 1980s, surface fisheries for juvenile albacore developed in the Tasman Sea and the STCZ. In 1989, the surface fisheries recorded a combined catch of more than 30,000 mt, and a record total annual catch of more than 50,000 mt resulted. With the phasing out of driftnetting, surface fishery catches, mainly by trolling, are currently less than 10,000 mt per year.

Catch-Per-Unit-Effort

The longline fleet fishing in the South Pacific consists mainly of Japanese, Korean and Taiwanese vessels. Of these, only the Taiwanese have consistently targeted albacore over a long period. The CPUE of this fleet is therefore generally used for examining trends in apparent abundance. Overall, CPUE has fluctuated between 2 and 4 albacore per 100 hooks since the early 1970s (Figure 35). There is some evidence of a downwards trend in CPUE since 1986 – the CPUEs for the last three years (1989–1991) are the lowest in the time series. CPUE varies by area, with the highest catch rates being recorded in the vicinity of the STCZ and the lowest in the equatorial area. The highest ever CPUEs in all areas were recorded in 1986, which may exaggerate the impression of recent CPUE decline to some extent.

It is interesting to note that the overall levels of albacore CPUE by Taiwanese longliners are substantially higher than those recorded for yellowfin and bigeye in tropical longline fisheries. This could imply a larger population of albacore vulnerable to longlining than for the tropical tunas, or simply greater vulnerability resulting from, for example, high-density vertical or horizontal concentrations of fish that the longliners can exploit. A proper analysis of albacore CPUE, incorporating spatial effects and targeting, would be very informative if the relevant data could be assembled.

CPUE in the troll fishery has been declining since the start of the fishery, but the time series is too short and the fishery too spatially concentrated to infer very much from this at present.

Age-Structured Models

The SPC is currently collaborating with Otter Research Ltd in the development of an age-structured model for albacore stock assessment. The model attempts to integrate the available size composition, catch and effort data to provide information on the stock and fishery dynamics. The basic concepts of the model, (unfortunately) dubbed SPARCLE (South Pacific Albacore Research Catch-at-Length Estimator), and preliminary results have been described by Fournier et al. (1993). The model consists of a set of parameters describing the age structure of the population, how the population is impacted by the fisheries and how these attributes would result in catches of certain sizes for each of the fisheries. The population age structure is modelled using standard population dynamics theory and is influenced by recruitment, natural mortality and fishing mortality. For each of the fisheries, fishing mortality is influenced by the amount of effort, catchability (which can vary over time) and selectivity (which can vary by age class). The size composition of the catch is then determined by growth characteristics and the assumption that the length at age is normally distributed about means that lie on a von Bertalanffy growth curve.

Preliminary fits of the model to albacore data have been carried out; an example of the time series trends in recruitment and population biomass estimated by the model is shown in Figure 37. In this example, relative biomass shows an increasing trend to 1980 and a decreasing trend since about 1985. However, the approximate 95% confidence intervals are wide, particularly in the second half of the time series, suggesting that the information in the data regarding total biomass are fairly weak and that the trends in the point estimates may not be significant. The estimates of recruitment are also bounded by wide confidence intervals, although there seems to be a strong signal in the data that recruitments in 1985 and 1990 were abnormally low. It is interesting to note that these low recruitments originated at about the same time as the *El Nino* events of 1982–83 and 1987. Fishing mortality rates of juvenile albacore estimated by the model are low relative to the assumed natural mortality rate, but are somewhat higher for adult albacore.

These results are preliminary, and more work on the model is planned. It is hoped that final results will be available in early 1994.

Somewhat as an aside, an interesting feature of the albacore data concerning sex ratio emerged during the consideration of natural mortality rate assumptions required for age-structured models. As has been observed with some other tunas, we have found that the proportion of female albacore in the longline catch declines sharply with size beyond about 96 cm FL (Figure 38). Almost no females >100 cm FL have been encountered during sampling operations in Noumea. This does not appear to be a growth effect, as no significant differences in growth of males and females have been found (Labelle et al. 1993). The most likely cause is that large females suffer higher natural mortality, possibly associated with spawning (although this is speculative) than similar-sized males. It will be important to account for this observation in stock assessment models, and suggests that an investigation of this phenomenon in the tropical tunas may also be warranted.

Tagging

During the summers of 1990–91 and 1991–92, approximately 10,000 albacore were tagged in the surface fisheries around New Zealand and in the central Pacific. As at 12 May, 33 tagged albacore had been recovered and reported to SPC. In contrast to the tropical tuna tagging programmes, all but 3 returns have been from longliners. This may indicate relatively low exploitation rates by the surface fishery at least, however it is impossible at this stage to make precise estimates with so few returns and with uncertainties regarding the magnitude of other tag loss, particularly non-reporting.

Conclusions

Fishery data and tag returns suggest that albacore in the North and South Pacific constitute separate stocks. These data, along with gene frequency data, further suggest that albacore throughout the South Pacific should be considered as a single stock.

Longline CPUE for South Pacific albacore is high relative to CPUE in tropical tuna longline fisheries. Overall, the longline CPUE time series has been fairly stable, although recent levels have been the lowest on record. The time series of troll–fishery CPUE is short but has generally been declining since the start of the fishery in the mid–1980s. It is not possible to say to what extent this reflects juvenile albacore abundance.

Assessments using age-structured models are at a early stage, but preliminary results suggest that surface fishery exploitation rates are low. This is also indicated by tagging results. It is possible that higher catches of juvenile albacore at least could be sustainable, although this is a tentative conclusion that requires confirmation.

SUMMARY

- *Yellowfin* catches in the western Pacific do not appear to be excessive, and further increases, possibly to around 600,000–800,000 mt per year on average, could be sustained. This conclusion is based primarily on the results of the RTTP, and confirmation using other stock assessment approaches would be desirable.

- *Skipjack* exploitation rates in the western Pacific remain low, and further increases in catch to around 1.5–2.0 million mt per year on average would appear to be biologically sustainable. This assessment is based on the results of the RTTP, which are strikingly consistent with those of the earlier SSAP.

- *Bigeye* stock assessment continues to be hampered by a lack of biological data and data on the extent and size composition of the catch by surface fisheries. The stability of the longline CPUE time series suggests that the current levels of catch, about 150,000–200,000 mt per year Pacific-wide, are sustainable.

- *Albacore* assessments are currently at an early stage, and the results of a three-year research programme are now being finalised. Preliminary results of tagging and an age-structured model suggest that increased catches of juvenile albacore could be sustained, however this requires confirmation.

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Table 1. Estimates and 95% confidence intervals of model parameters, derived quantities and input parameters for the western Pacific yellowfin tag attrition model.

	Mean	Lower 95% CI	Upper 95% CI
Model parameters			
Natural mortality rate (per month)	0.11	0.098	0.12
Standing stock (thousand mt)	1,431	1,032	1,837
Derived quantities			
Average fishing mortality rate (per month)	0.022	0.017	0.030
Harvest ratio	0.16	0.13	0.21
Throughput (thousand mt per month)	179	132	226
Input parameters			
Immediate tag-shedding rate	0.070	0.039	0.10
Continuous tag-shedding rate (per month)	0.0011	0.0000	0.0061
Reporting rate	0.70	0.55	0.83
Immediate tagging mortality	0.050	0.0014	0.18
Continuous tagging mortality (per month)	0	0	0

Table 2. Estimates and 95% confidence intervals of model parameters, derived quantities and input parameters for the western Pacific skipjack tag attrition model.

	Mean	Lower 95% CI	Upper 95% CI
Model parameters			
Natural mortality rate (per month)	0.14	0.13	0.15
Standing stock (thousand mt)	3,205	2,326	4,012
Derived quantities			
Average fishing mortality rate (per month)	0.024	0.019	0.032
Harvest ratio	0.15	0.12	0.20
Throughput (thousand mt per month)	487	354	612
Input parameters			
Immediate tag-shedding rate	0.033	0.0000	0.068
Continuous tag-shedding rate (per month)	0.0077	0.0000	0.017
Reporting rate	0.70	0.55	0.83
Immediate tagging mortality	0.050	0.0014	0.18
Continuous tagging mortality (per month)	0	0	0

Figure 1. The South Pacific Commission statistical area.

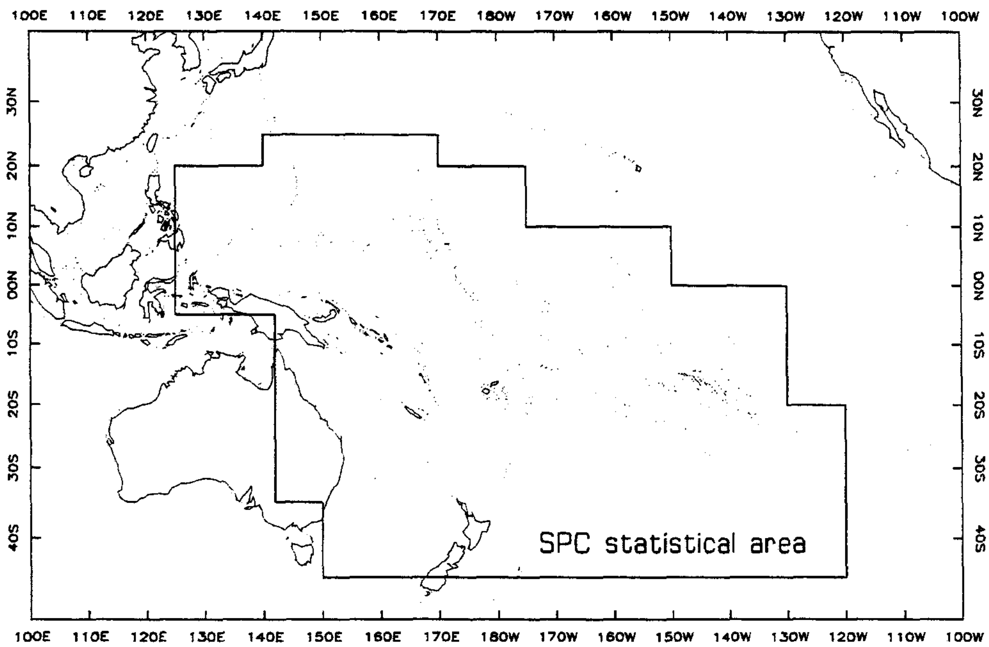


Figure 2. Total tuna catches, by fishery.

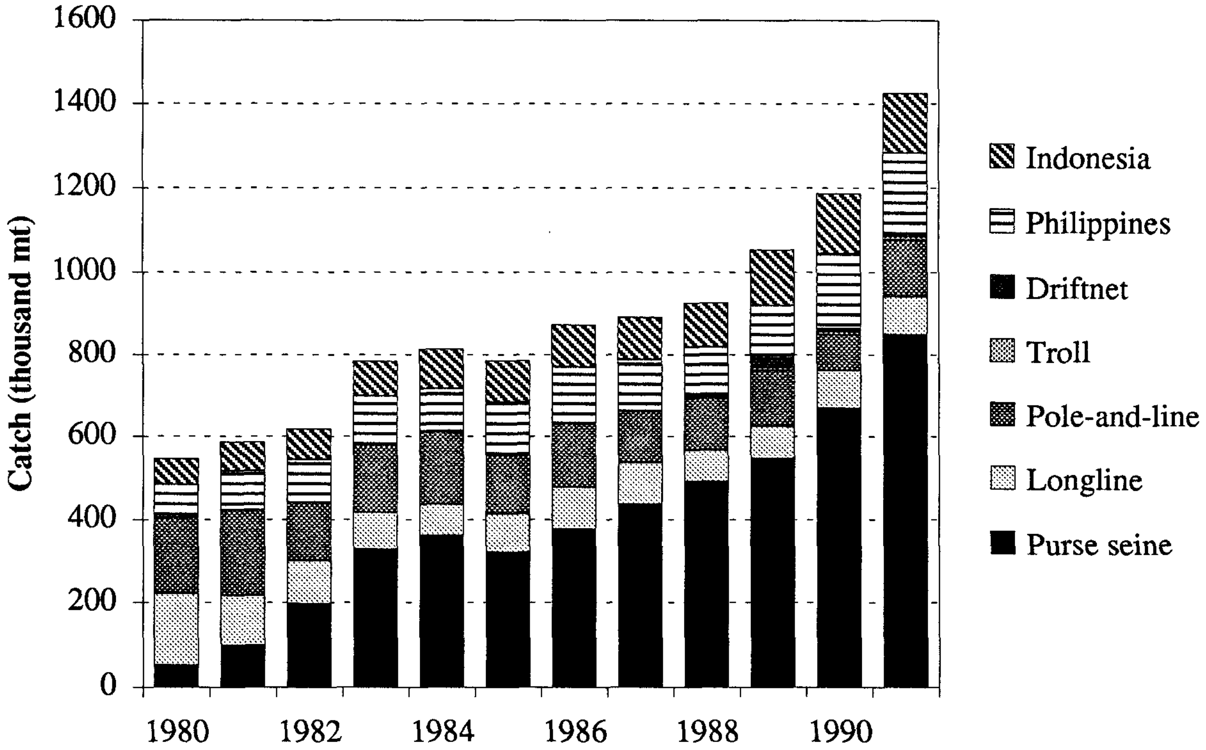


Figure 3. Geographical distribution of yellowfin CPUE by Japanese longliners in the Pacific Ocean 1981-1990.

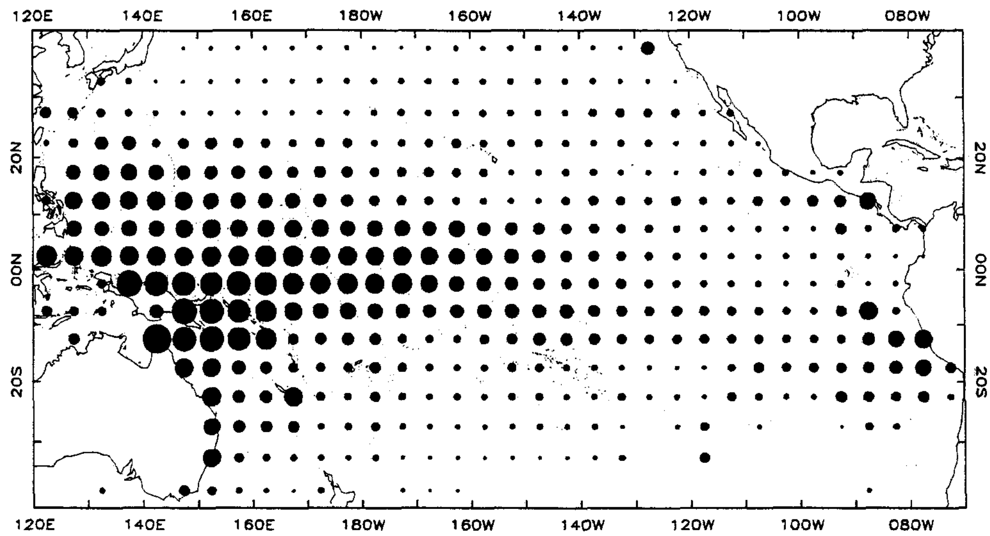


Figure 4. Geographical distribution of yellowfin catch by purse seiners in the Pacific Ocean 1981-1991.

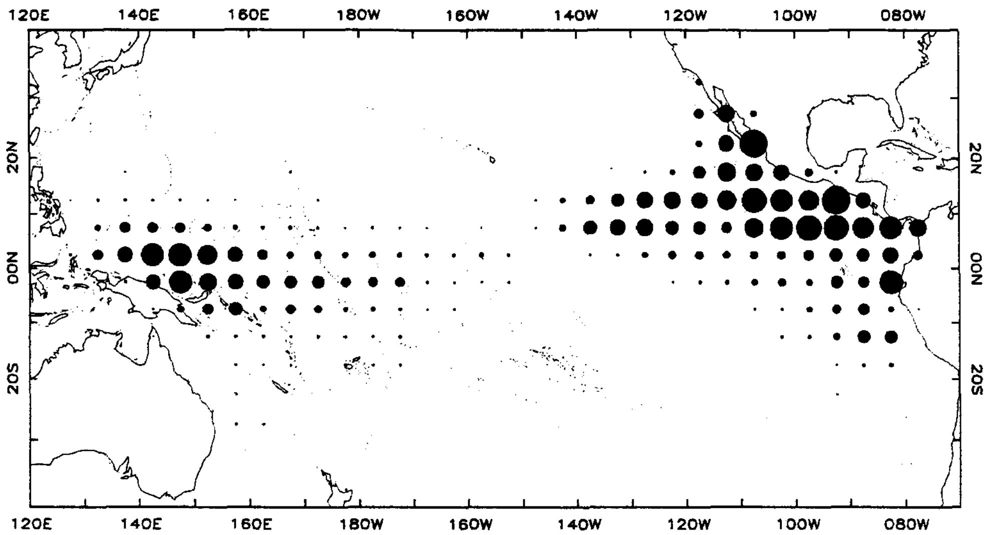


Figure 5. Movements of 1,000 nmi. or greater of yellowfin tagged during the Skipjack Survey and Assessment Programme and the Regional Tuna Tagging Project.

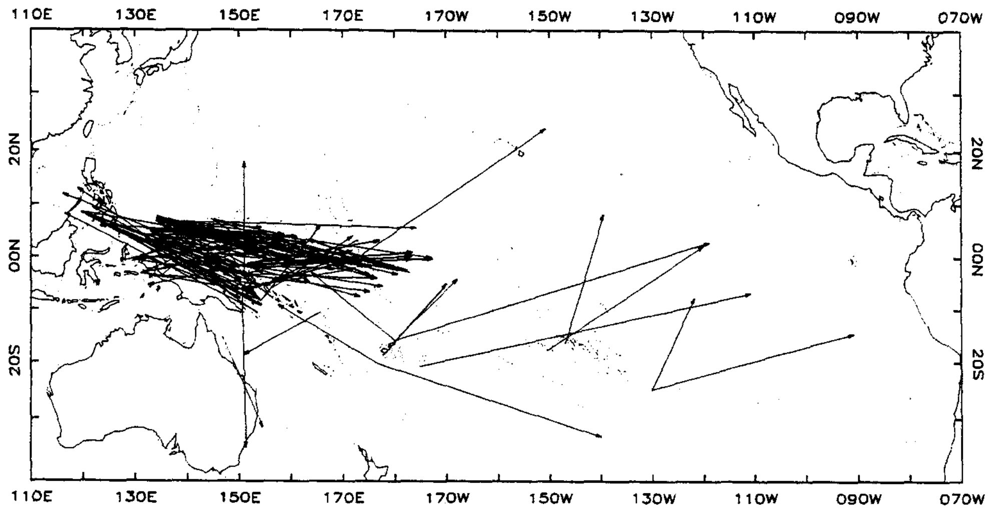


Figure 6. Schematic representation of yellowfin larval distribution in the Pacific Ocean. The diagonal hatching indicates areas of higher larval density. (Interpreted from Nishikawa et al. 1985).

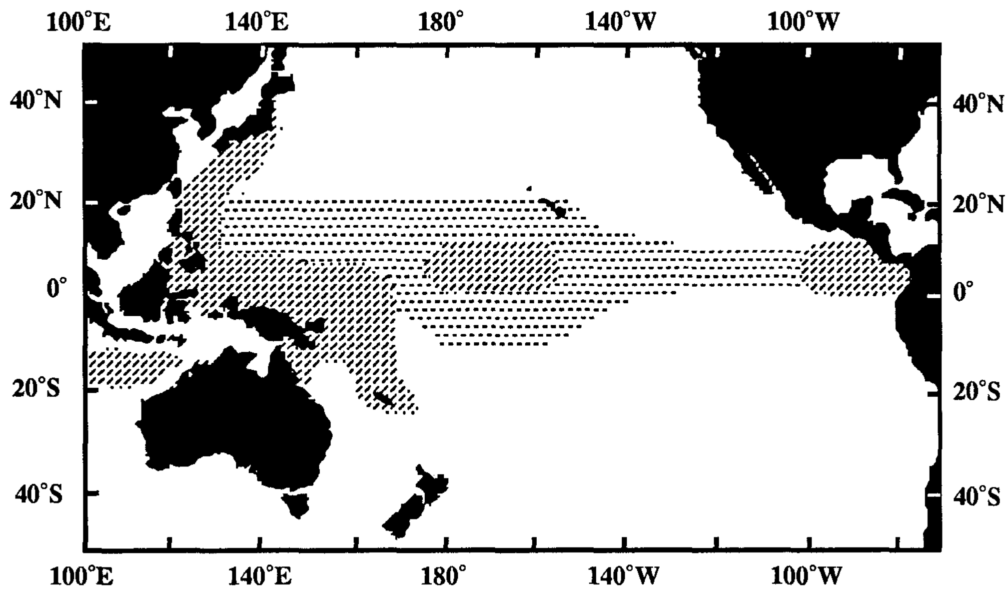


Figure 7. Yellowfin catches, by fishery.

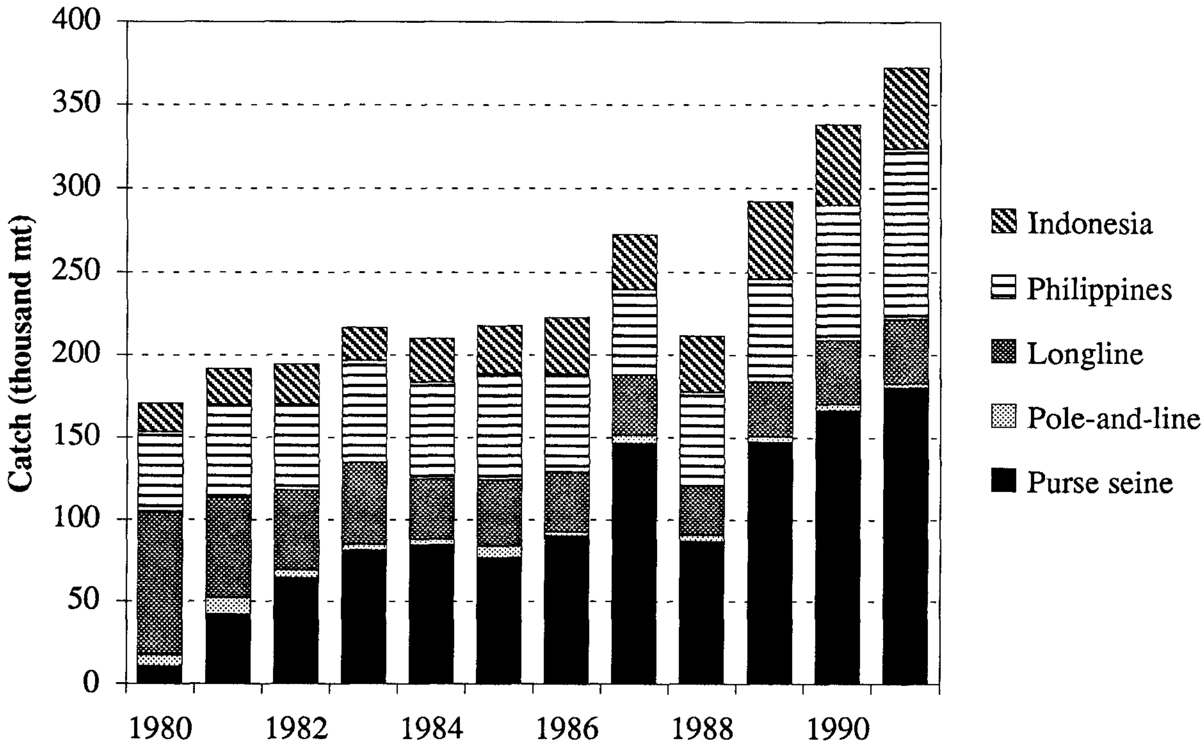


Figure 8. Yellowfin CPUE by purse seiners.

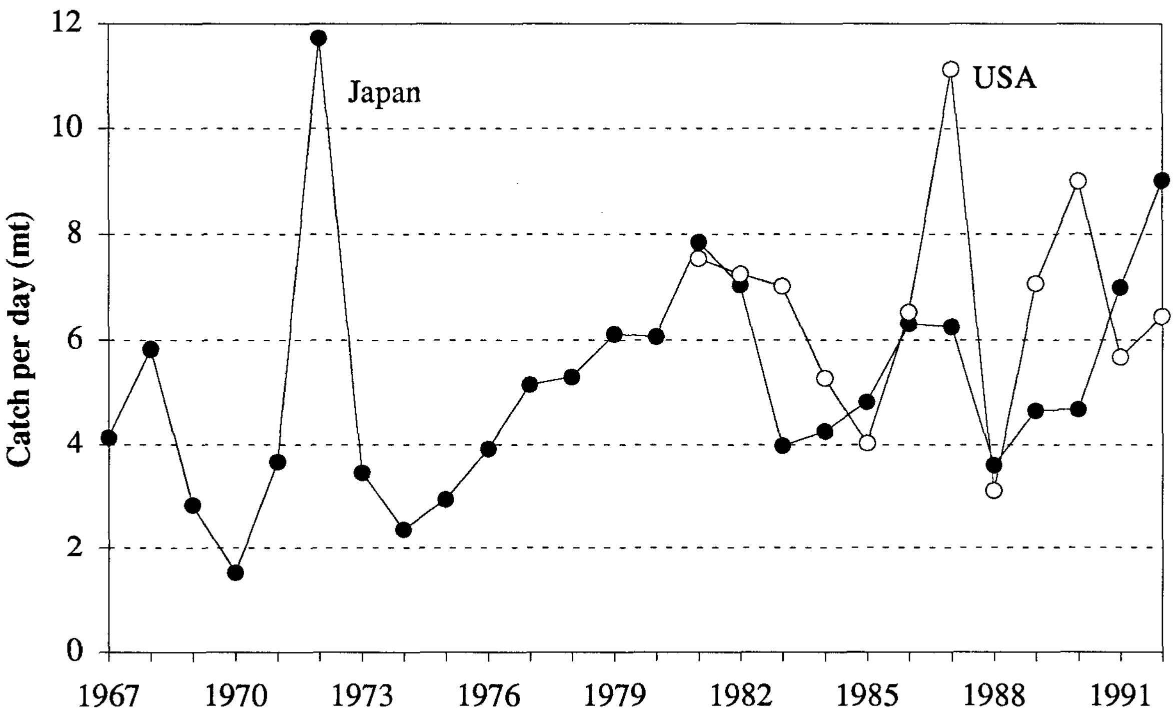


Figure 9. Yellowfin abundance index based on the Japanese purse seine fishery.

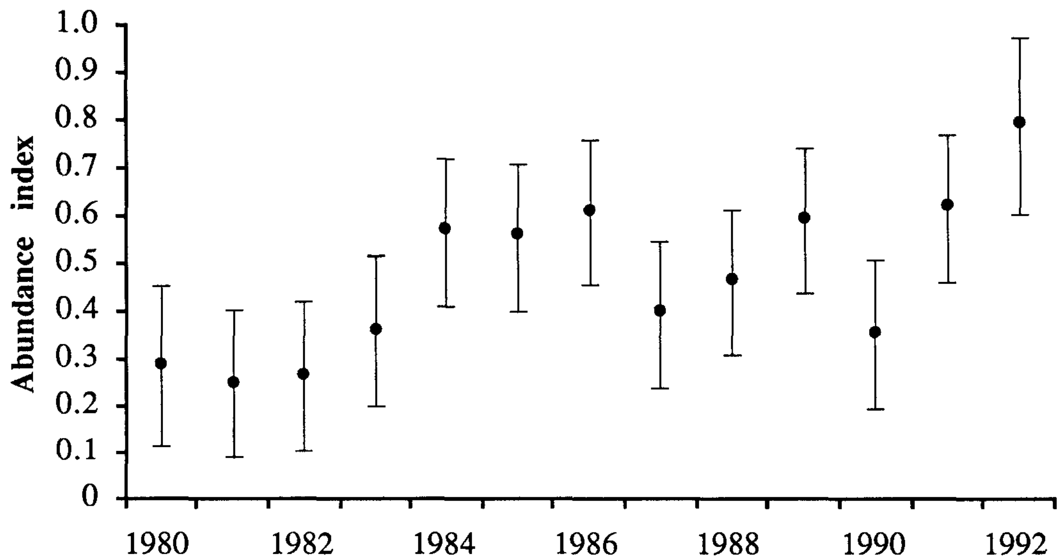


Figure 10. Yellowfin CPUE by Japanese longliners.

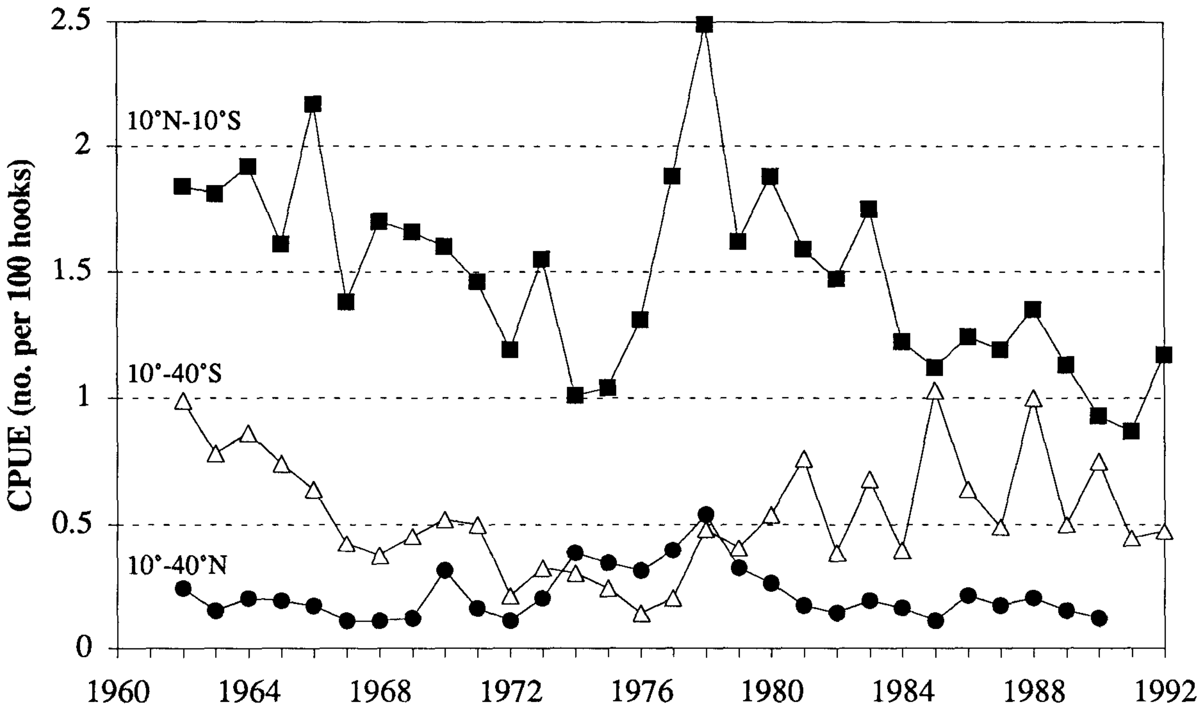


Figure 11. Geographical distribution of yellowfin releases by the Regional Tuna Tagging Project.

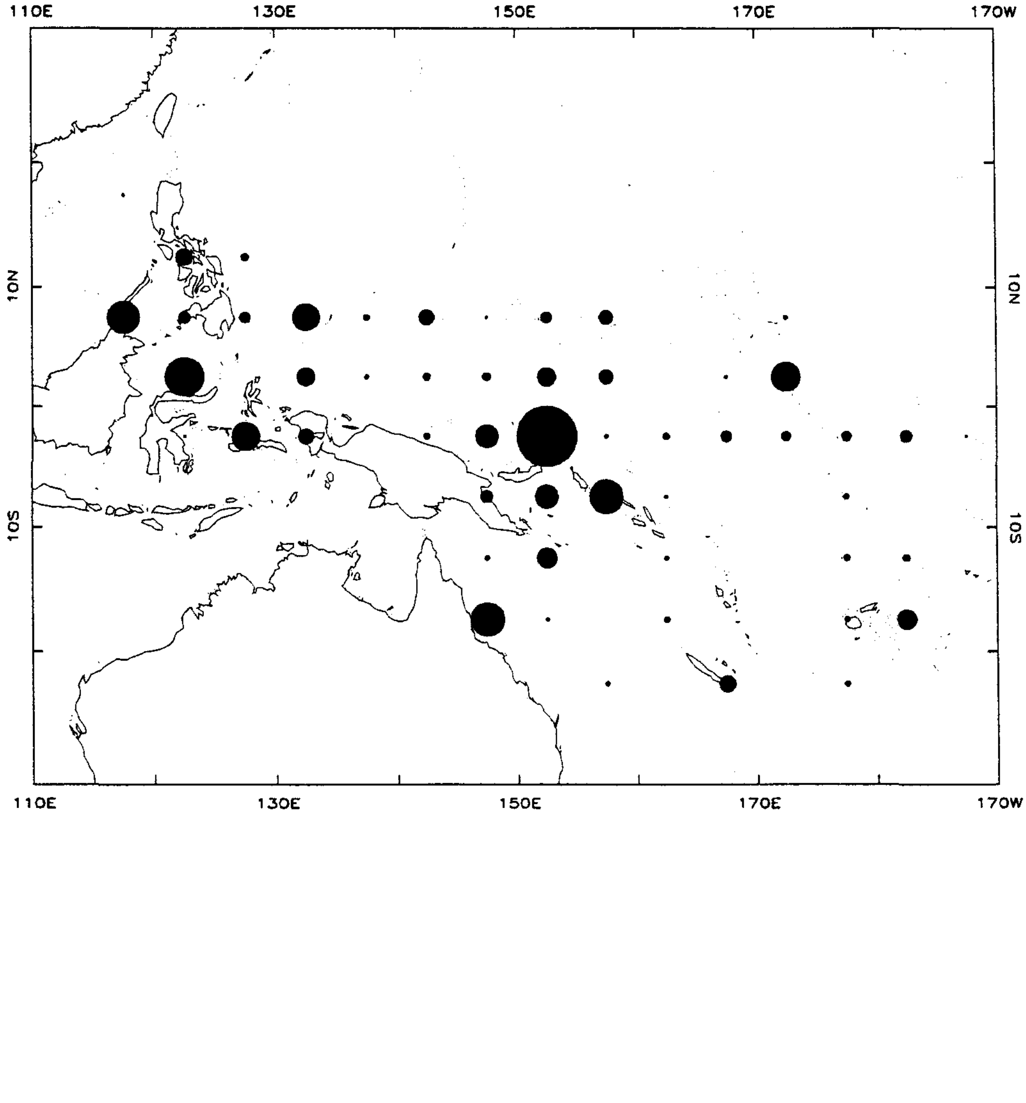


Figure 12. Relationship between yellowfin harvest ratio, fishing mortality rate and equilibrium annual catch, with assumptions of constant throughput and natural mortality rate.

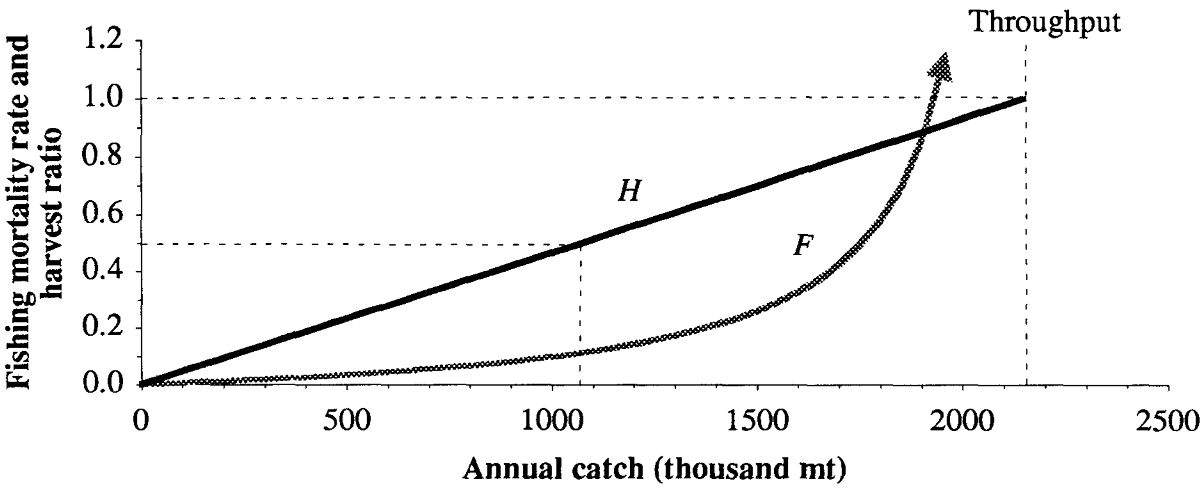


Figure 13. Predicted yellowfin harvest ratio as a function of annual catch. The bars represent 95% confidence intervals.

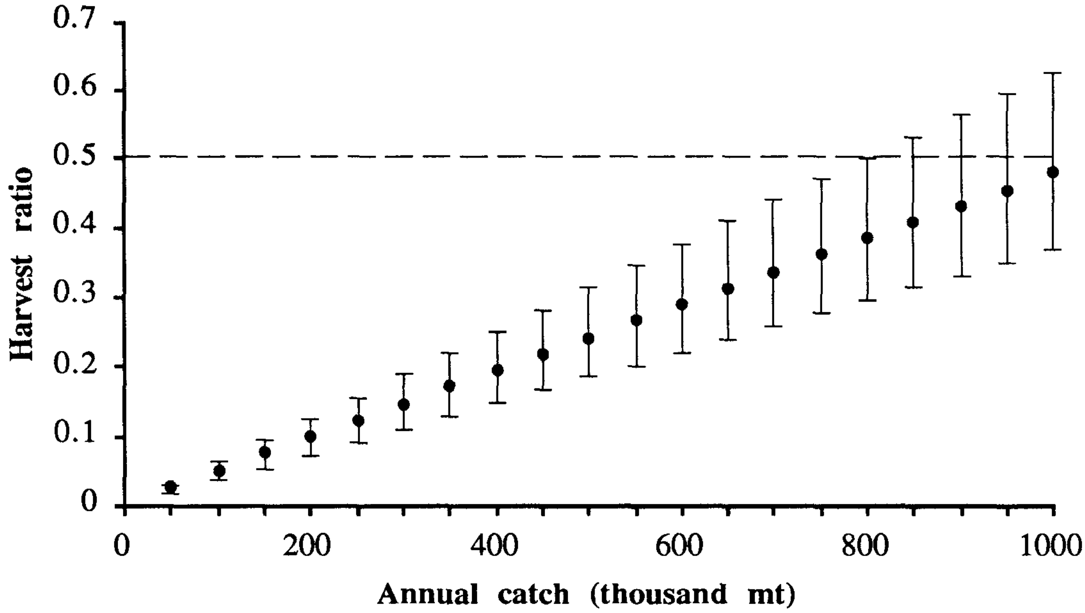


Figure 14. Predicted yellowfin standing stock as a function of annual catch. The bars represent 95% confidence intervals. The dashed line represents half the estimated unexploited standing stock.

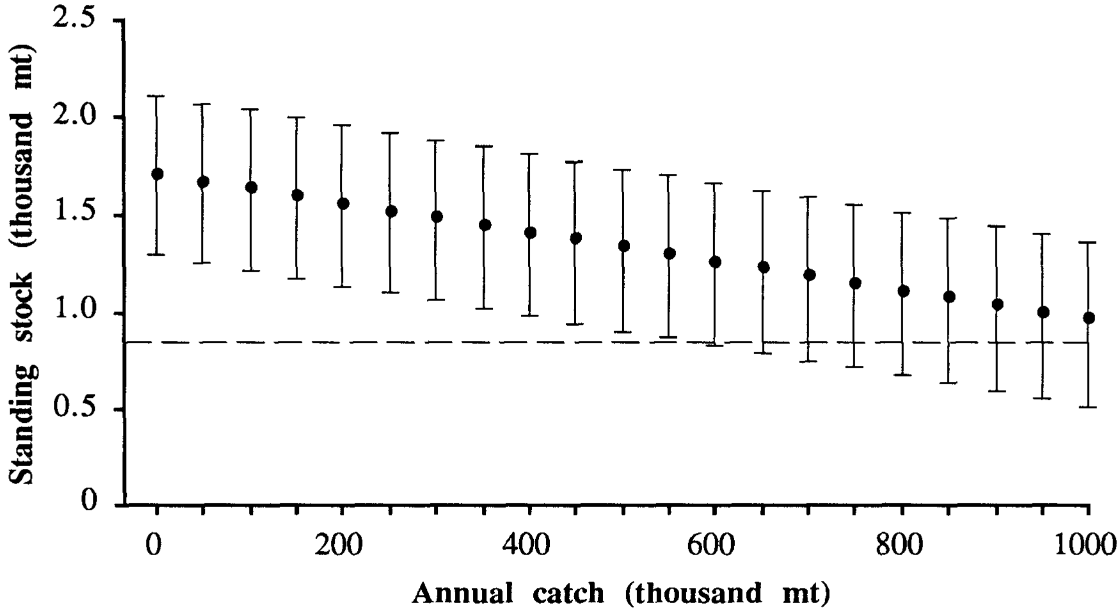
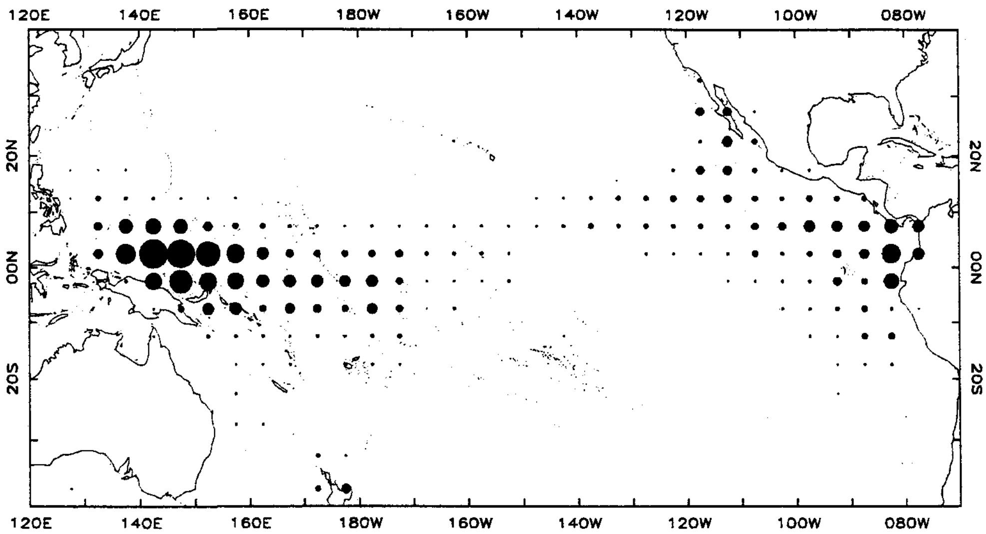


Figure 15. Geographical distribution of skipjack catch by purse seiners in the Pacific Ocean, 1981-1991.



Figrue 16. Geographical distribution of skipjack catch by pole-and-line vessels in the western Pacific Ocean, 1982-1991.

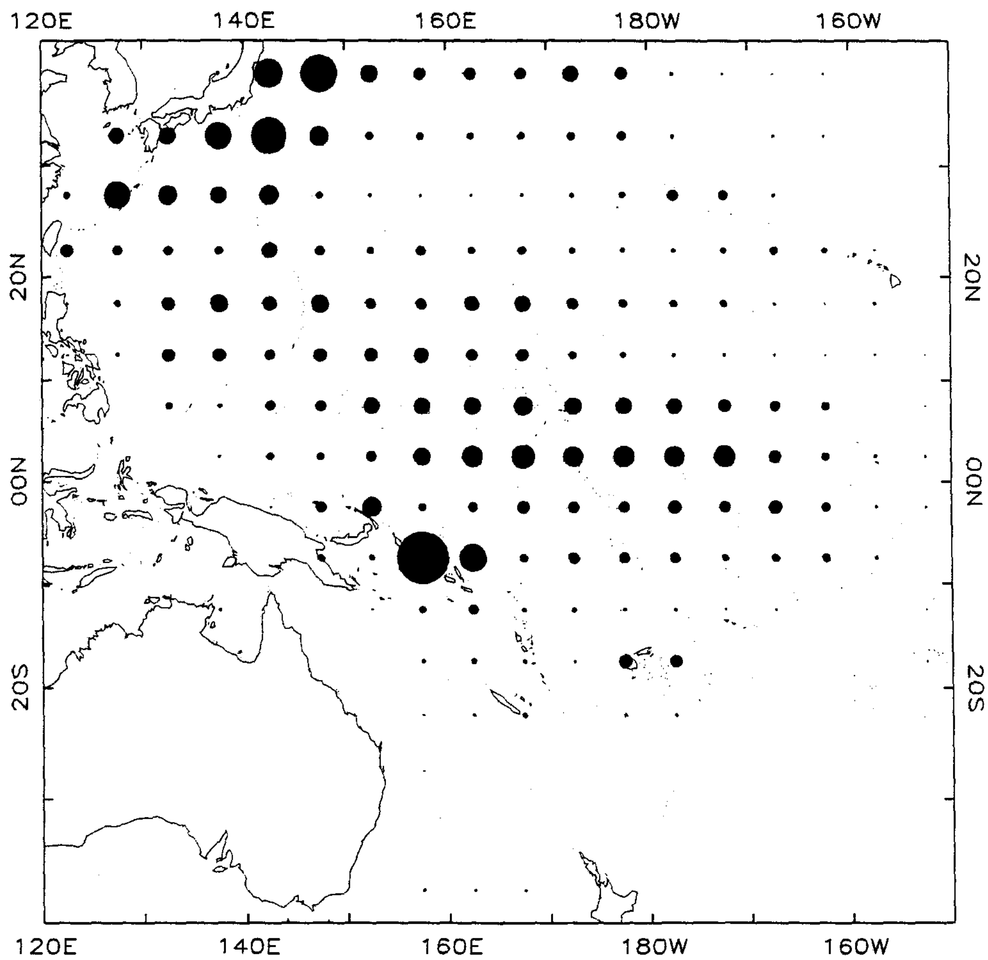


Figure 17. Movements of 1,000 nmi. or greater of skipjack tagged during the Skipjack Survey and Assessment Programme and the Regional Tuna Tagging Project.

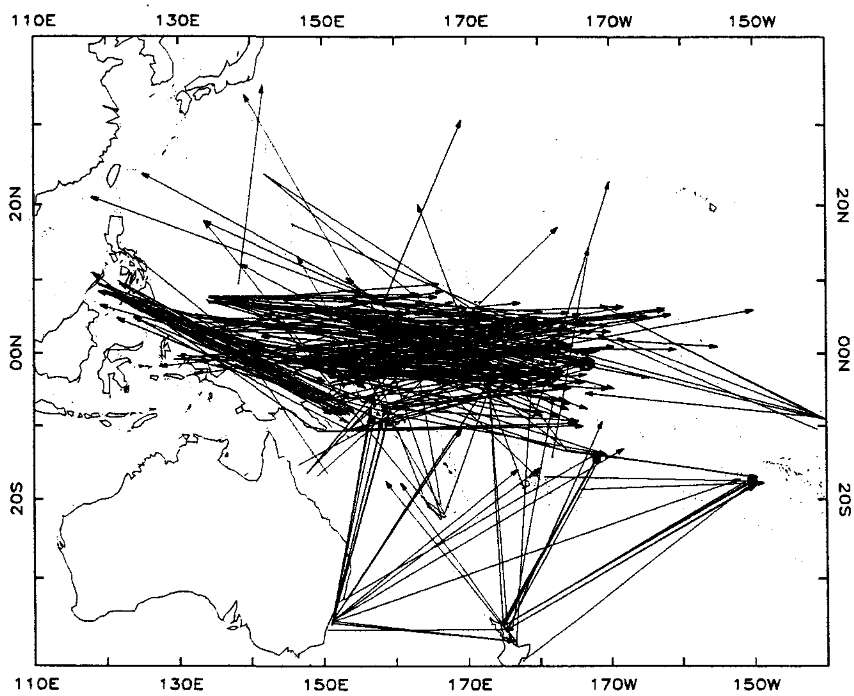


Figure 18. Schematic representation of skipjack larval distribution in the Pacific Ocean. The diagonal hatching indicates areas of higher larval density. (Interpreted from Nishikawa et al. 1985).

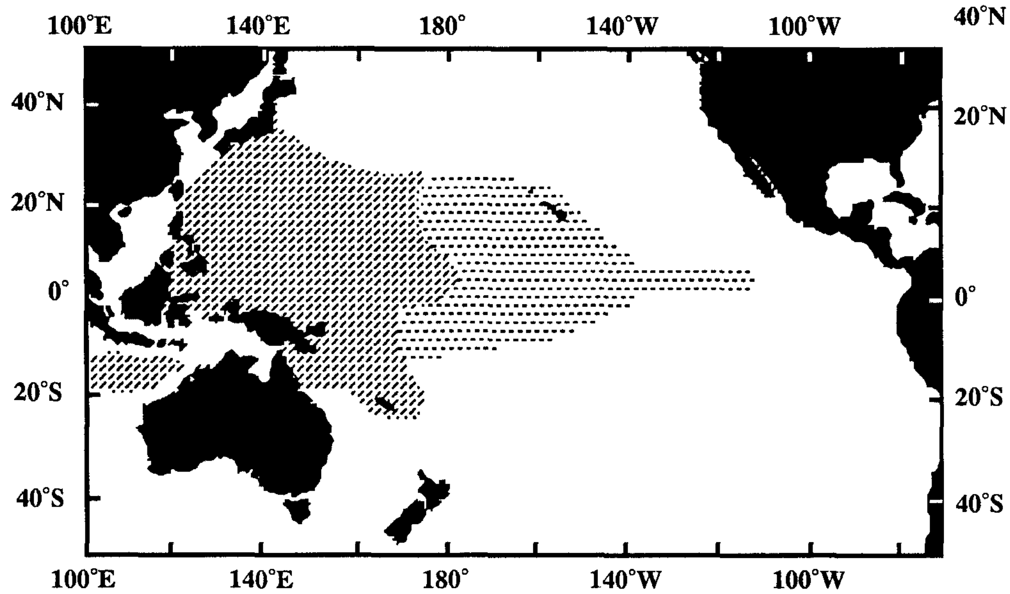


Figure 19. Skipjack catches, by fishery.

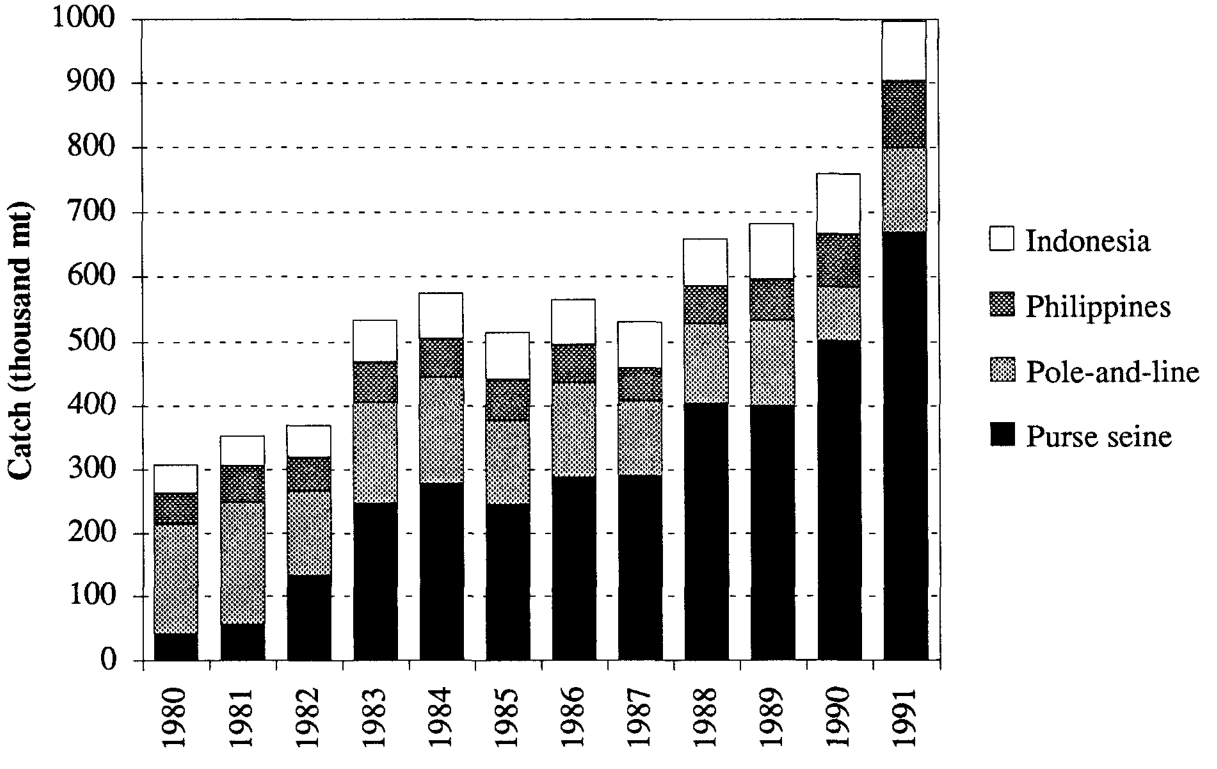


Figure 20. Skipjack CPUE by purse seiners.

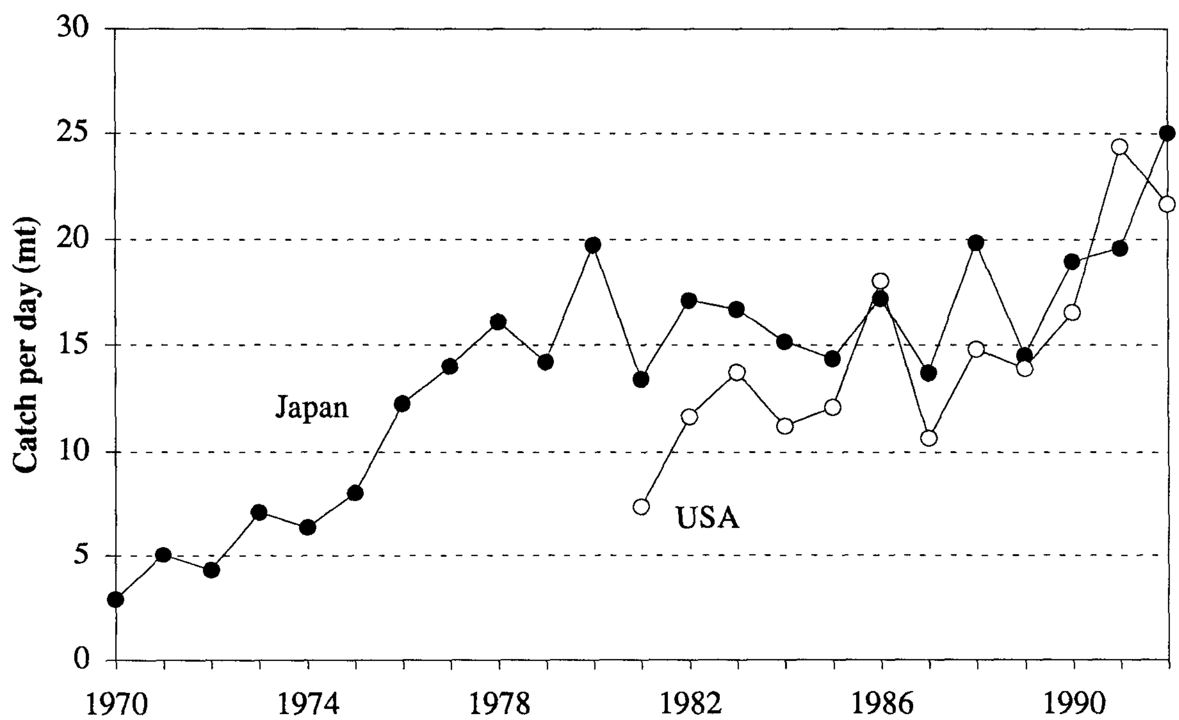


Figure 21. Skipjack CPUE by Japanese pole-and-liners.

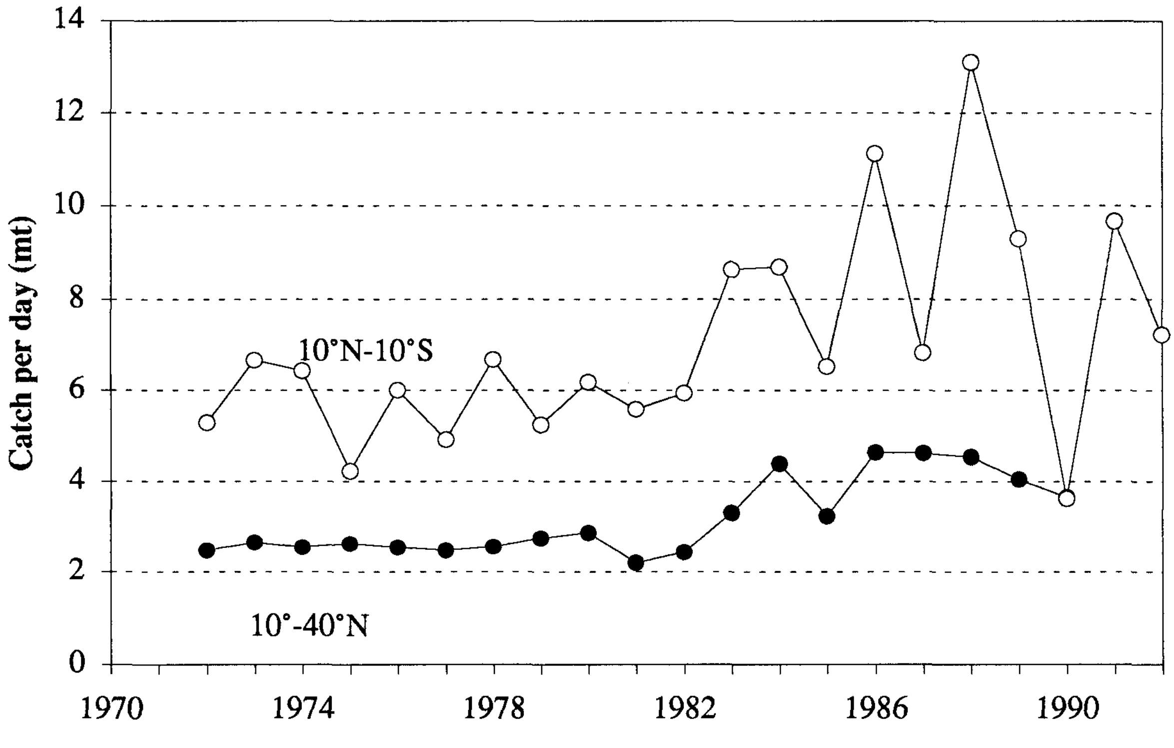


Figure 22. Geographical distribution of skipjack releases by the Regional Tuna Tagging Project.

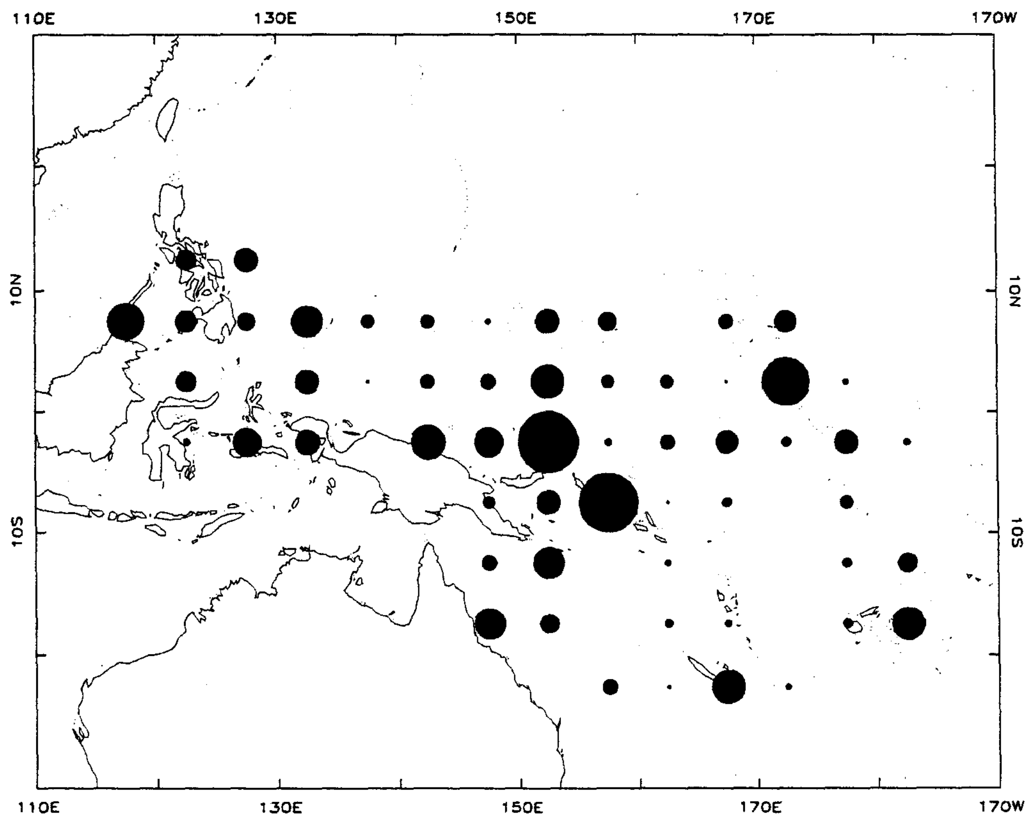


Figure 23. Predicted skipjack harvest ratio as a function of annual catch. The bars represent 95% confidence intervals.

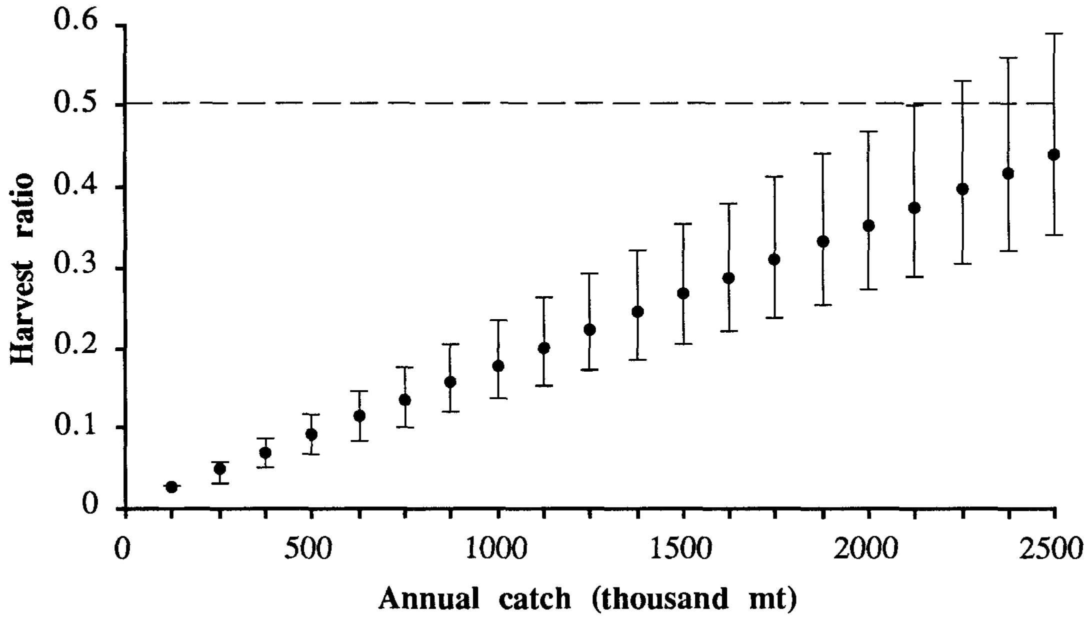


Figure 24. Predicted skipjack standing stock as a function of annual catch. The bars represent 95% confidence intervals. The dashed line represents half the estimated unexploited standing stock.

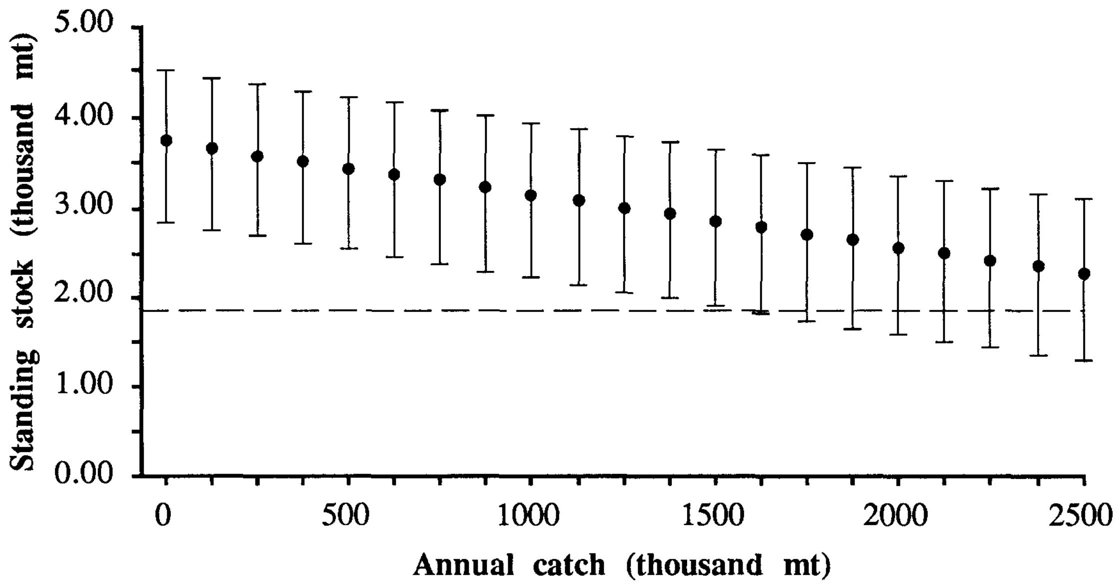


Figure 25. Geographical distribution of bigeye CPUE by Japanese longliners in the Pacific Ocean, 1981-1990.

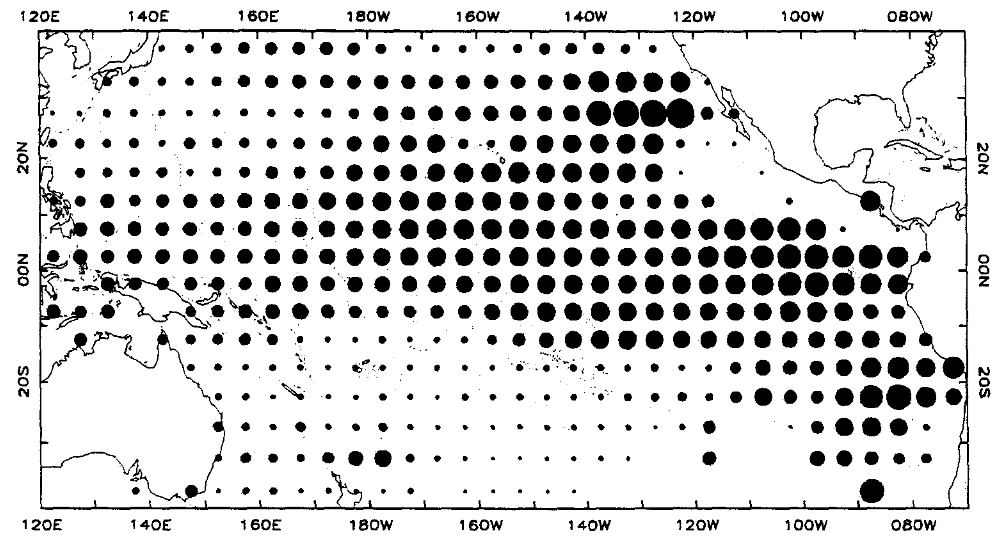


Figure 26. Movements of 1,000 nmi. or greater of bigeye tagged during the Australian East Coast Tuna Tagging Project and the Regional Tuna Tagging Project.

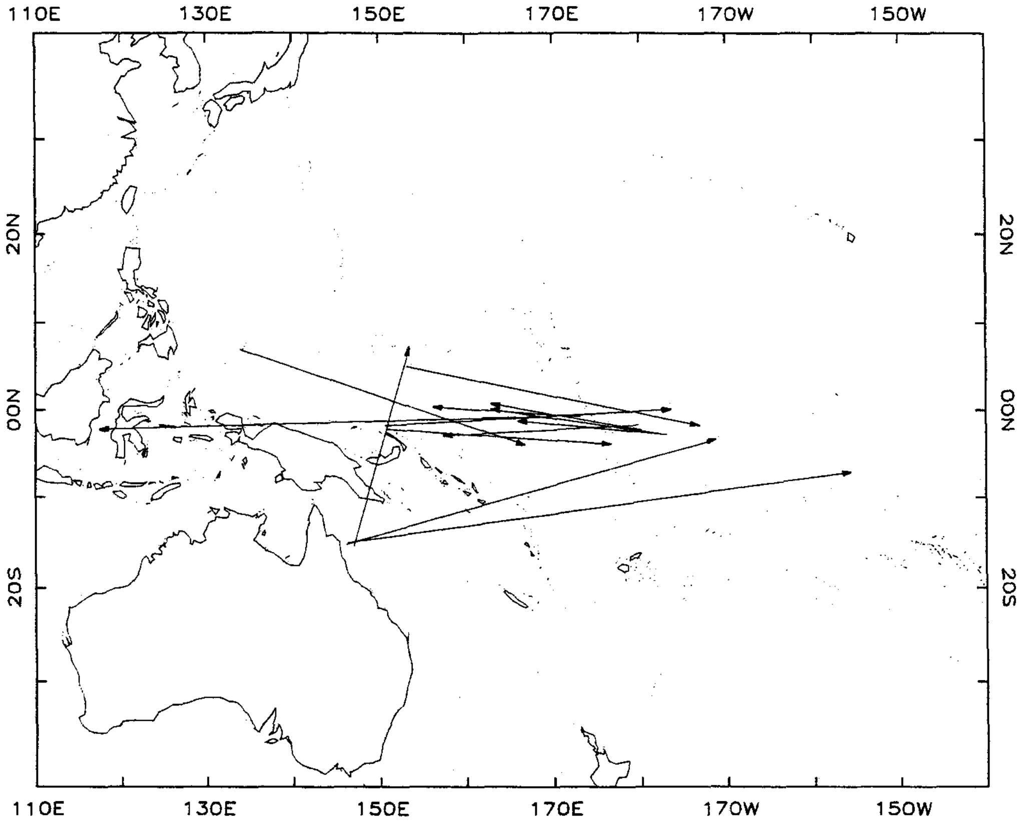


Figure 27. Schematic representation of bigeye larval distribution in the Pacific Ocean. (Interpreted from Nishikawa et al. 1985).

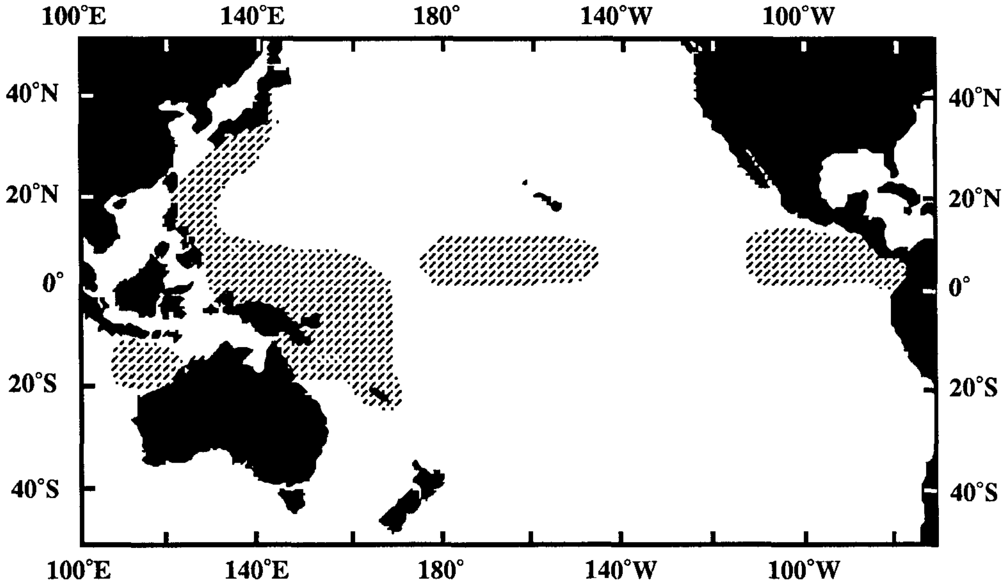


Figure 28. Bigeye CPUE by Japanese longliners in the entire Pacific Ocean (PO), in the Pacific Ocean west of 150°W (WPO) and in the Pacific Ocean east of 150°W (EPO).

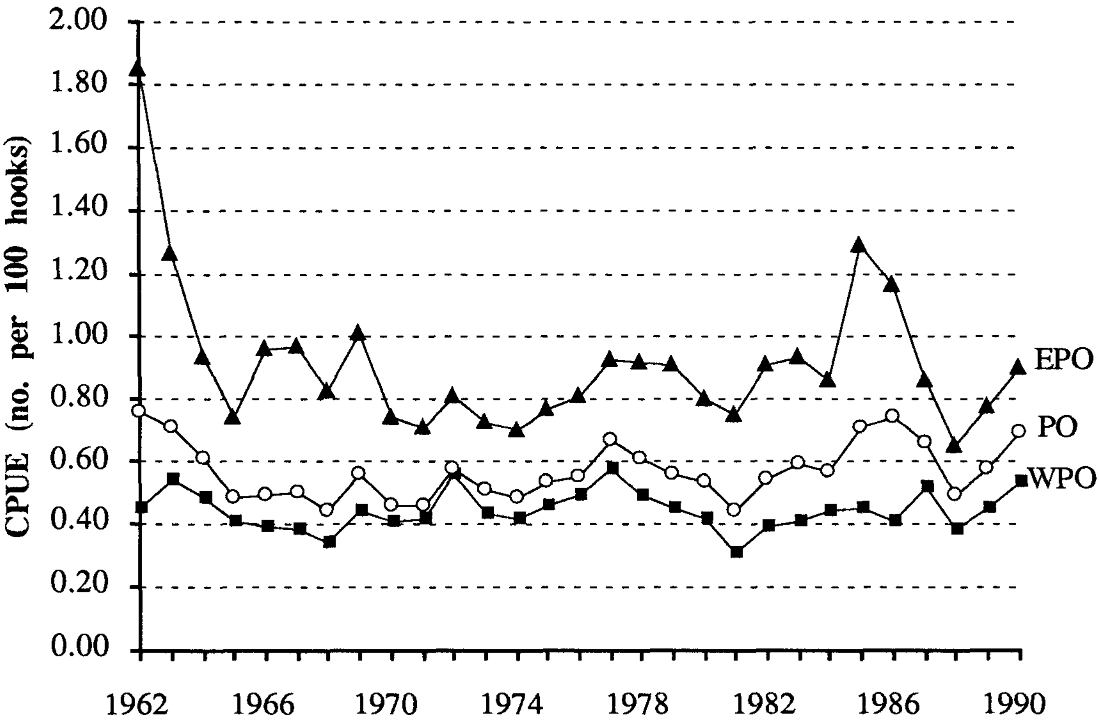


Figure 29. Geographical distribution of bigeye releases by the Regional Tuna Tagging Project.

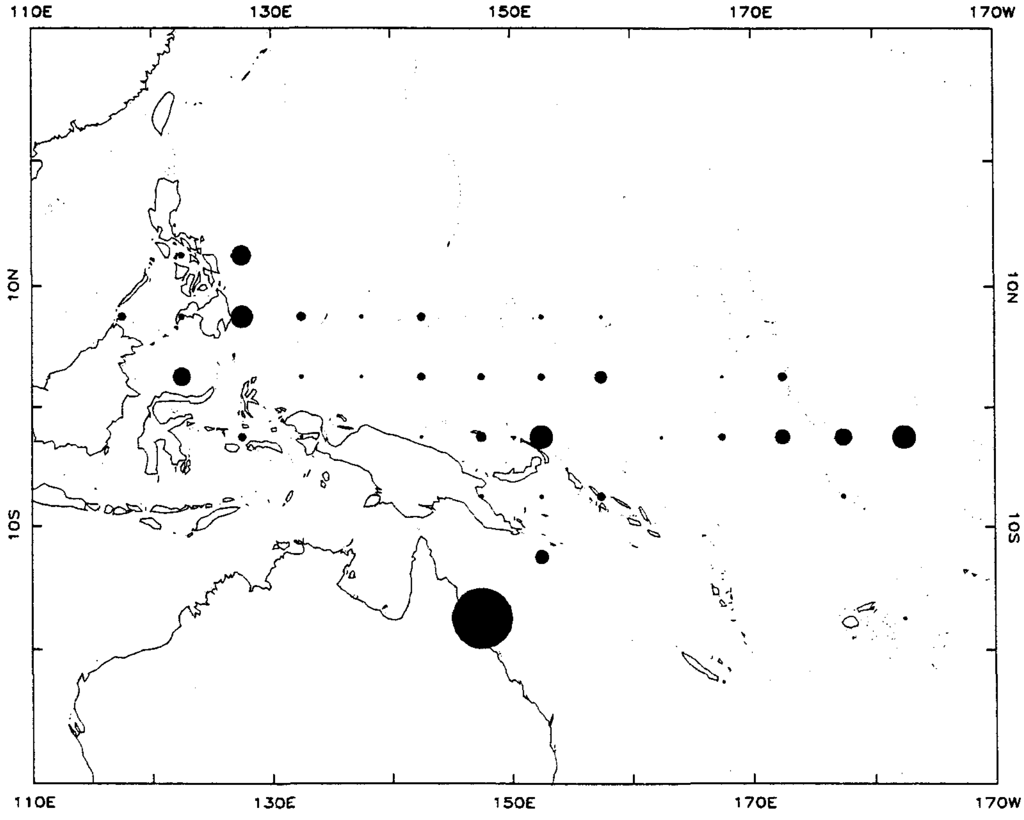


Figure 30. Albacore CPUE by longliners in the Pacific Ocean, 1981-1990.

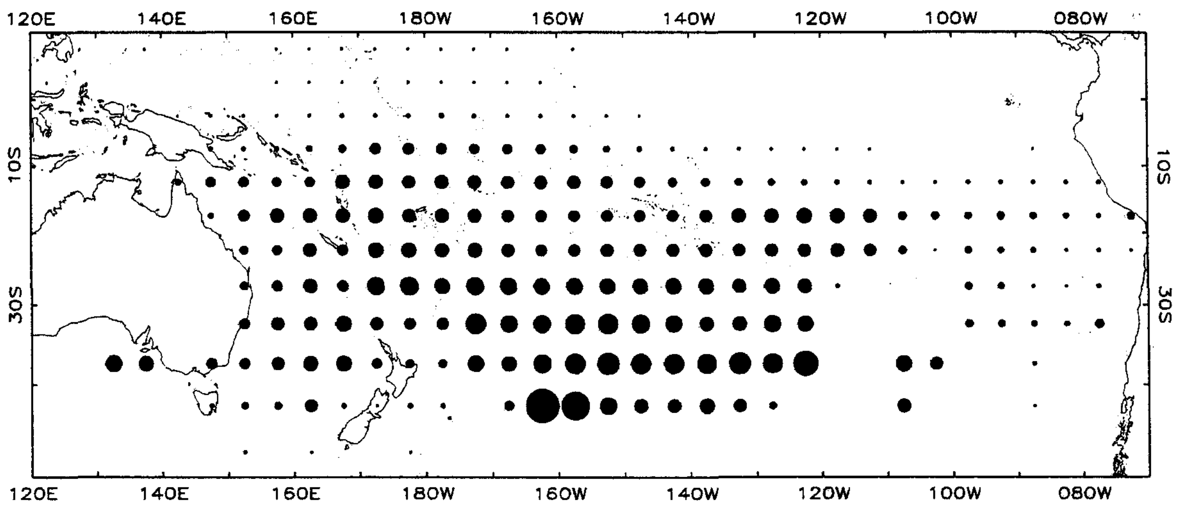


Figure 31. Movements of tagged albacore in the South Pacific.

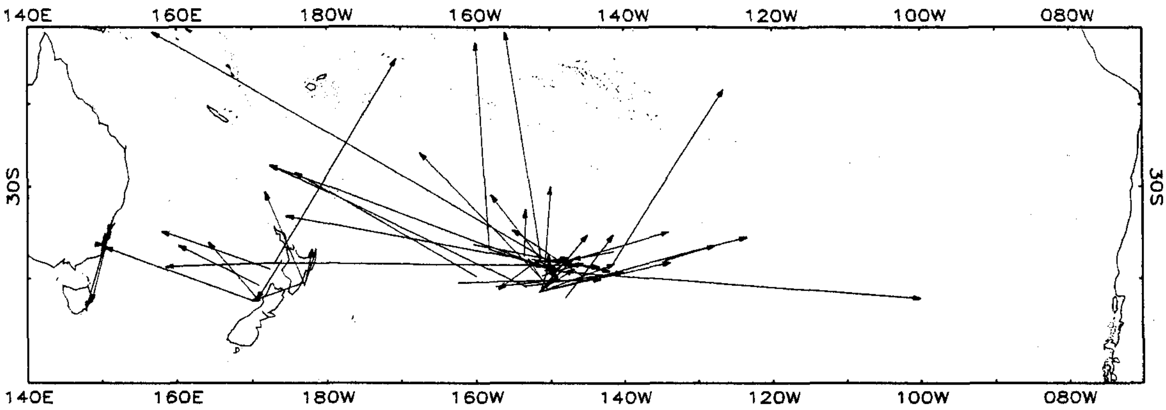


Figure 32. Geographical distribution of albacore catch by trollers in the South Pacific, 1990-91.

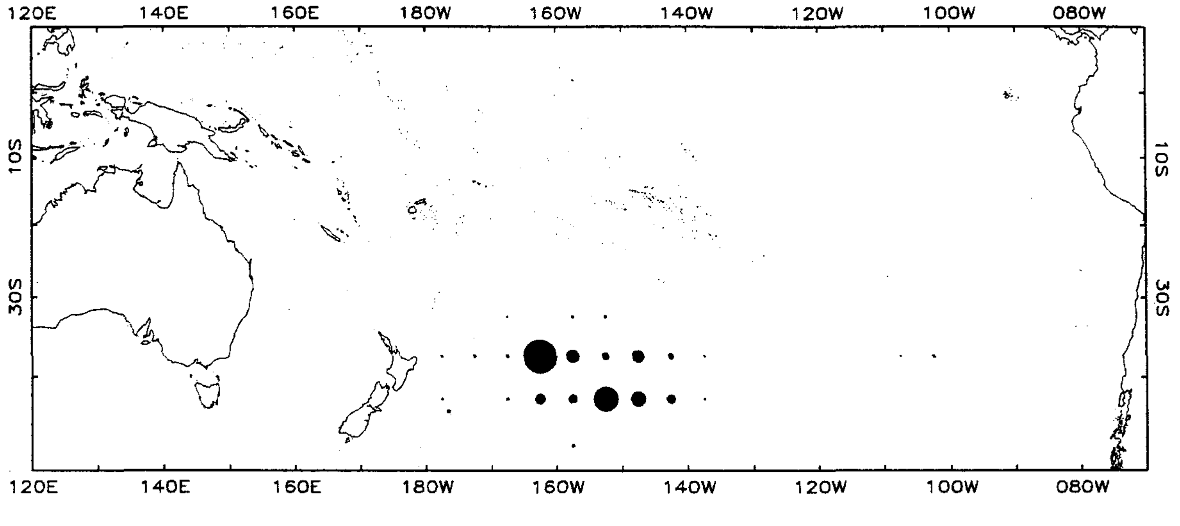


Figure 33. Geographical distribution of albacore catch by longliners in the South Pacific in 1990.

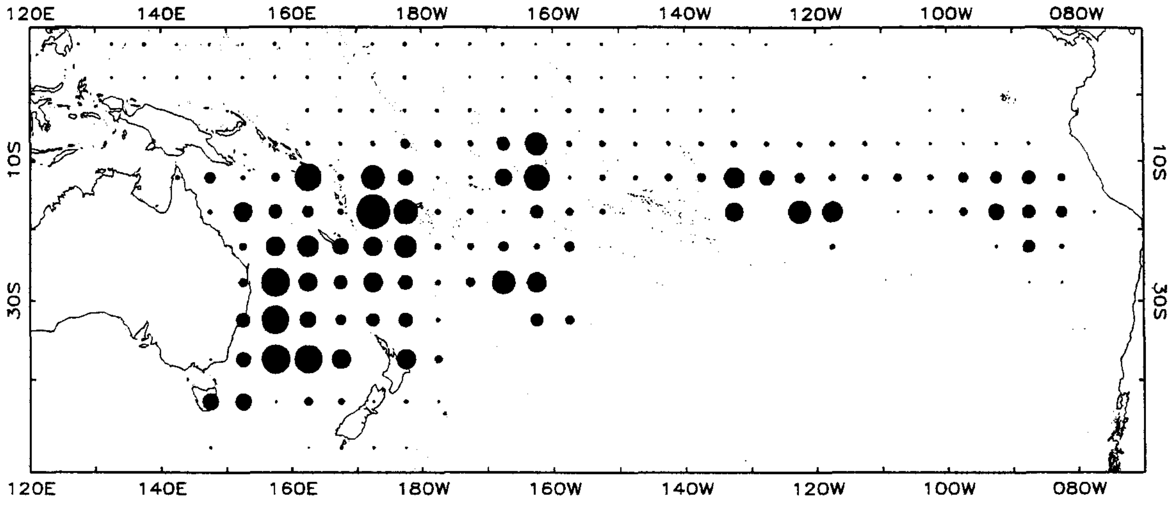


Figure 34. Albacore catches, by gear.

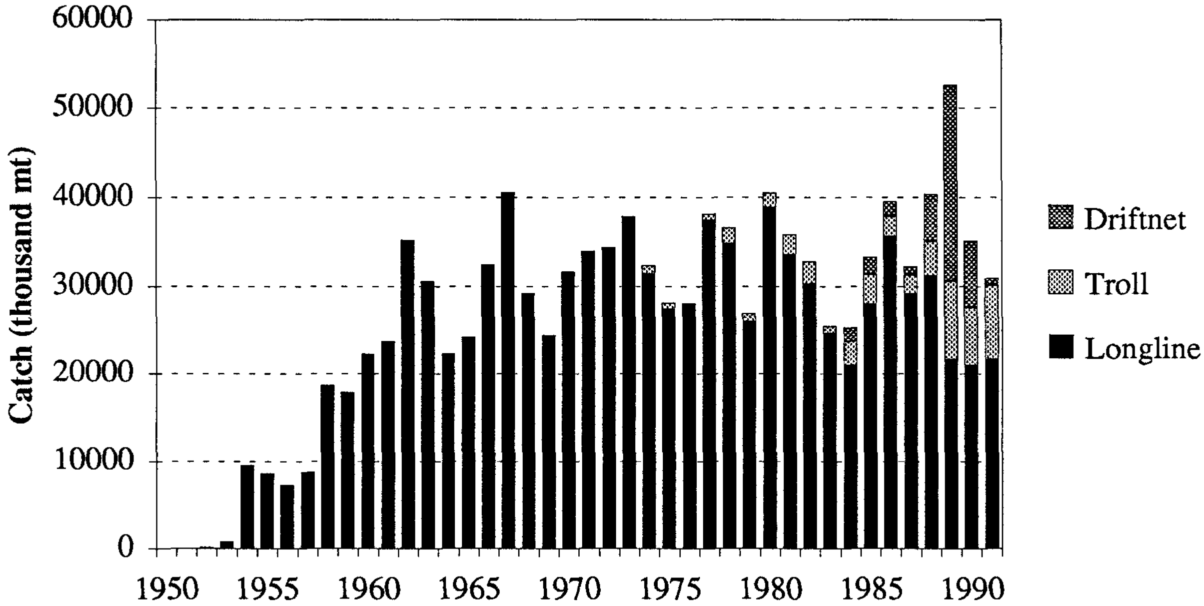


Figure 35. Albacore CPUE by Taiwanese longliners, by area.

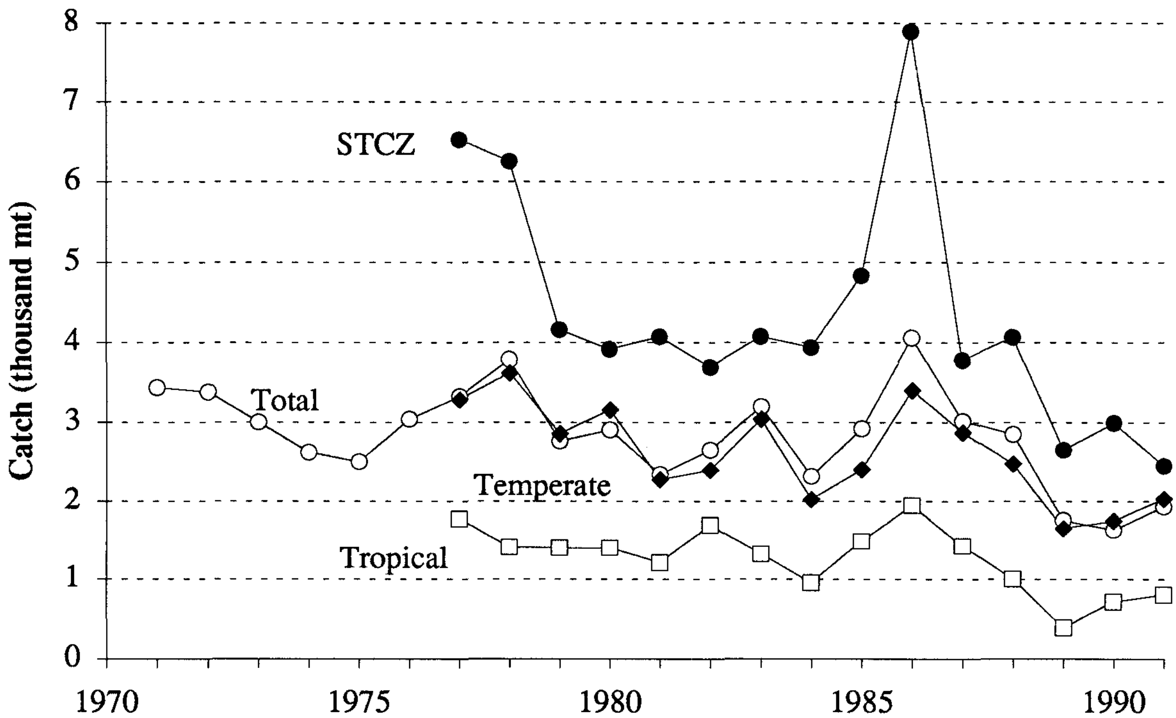


Figure 36. Albacore CPUE by USA trollers in the south Pacific.

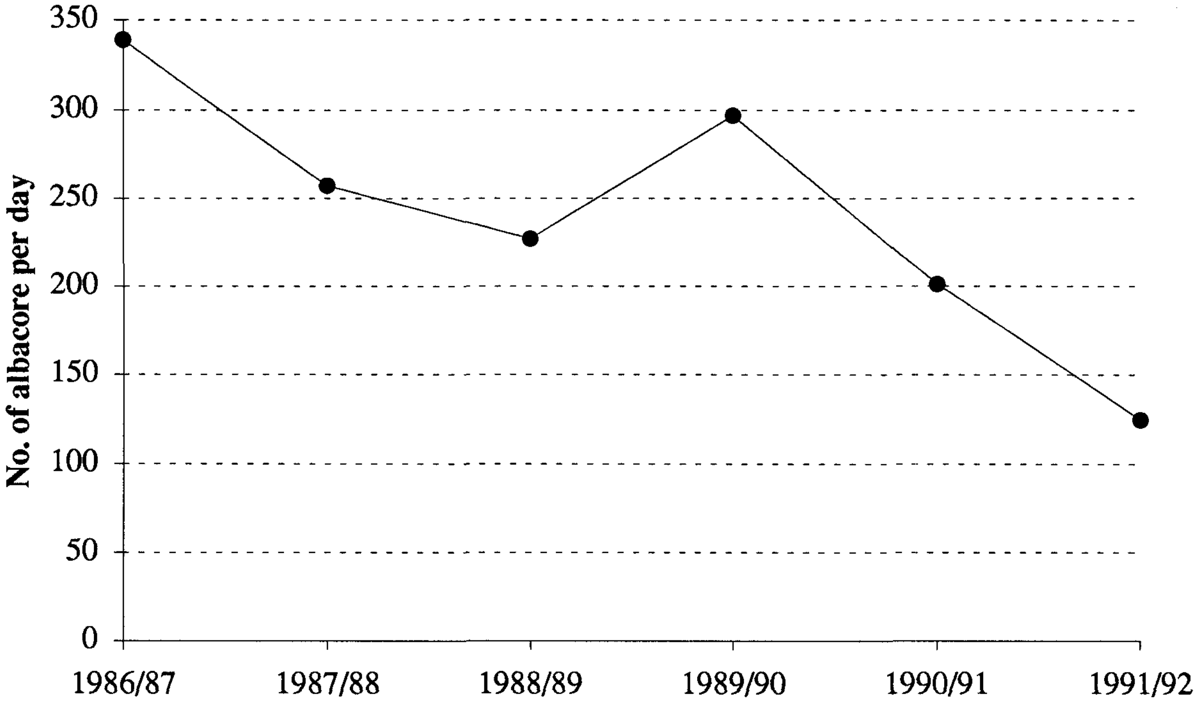


Figure 37. Estimated relative biomass (A) and recruitment (B) for South Pacific albacore.

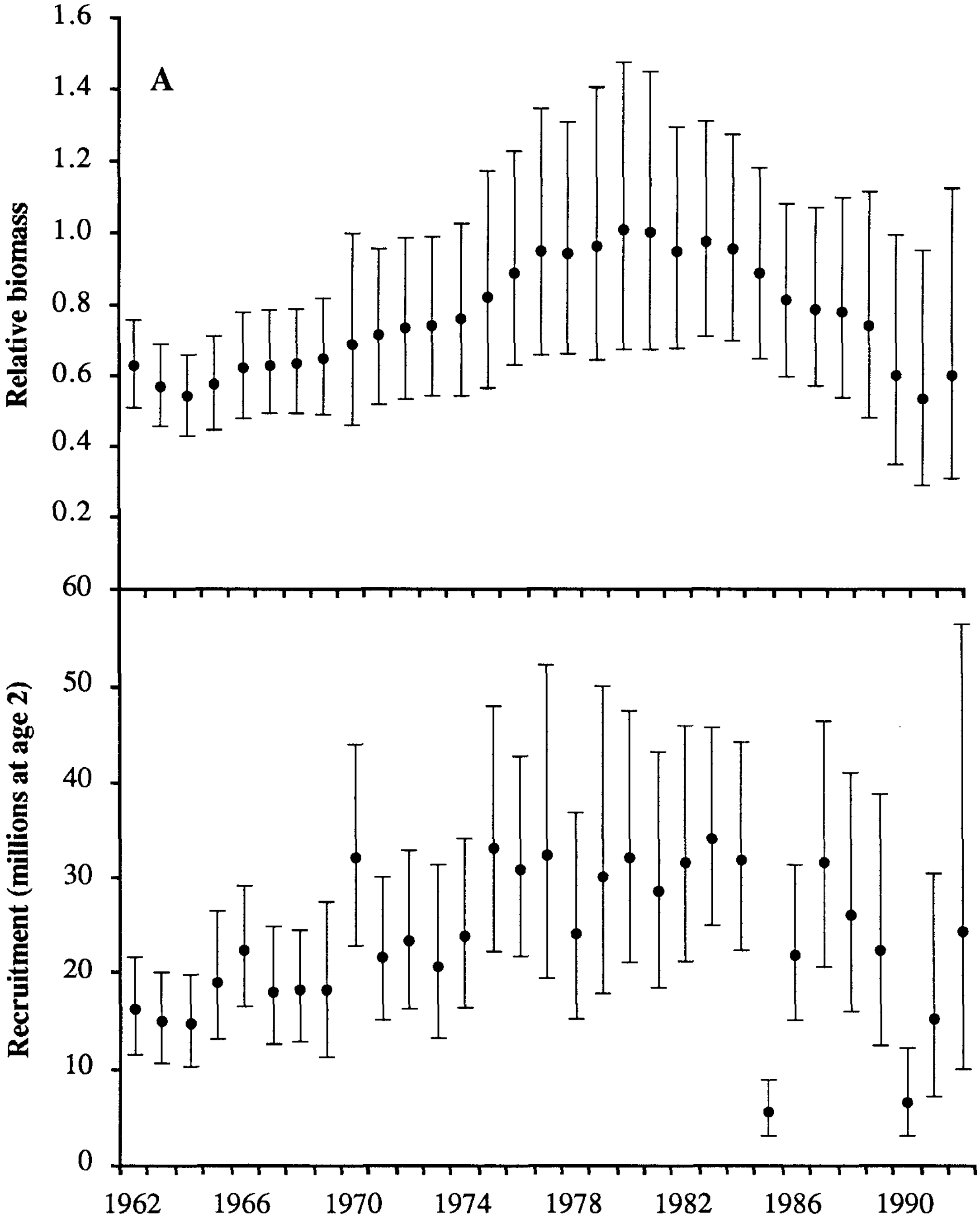


Figure 38. Proportion of females in samples of South Pacific albacore. The numbers indicate sample sizes for each length category.