Long term trends in yellowfin tuna abundance in the South-West Pacific

by

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1. Introduction

Catch-per-unit-effort (CPUE) has long been used to determine the availability of fish and to analyse trends in stock status. For highly mobile species like tunas and billfish, standardised research surveys to determine stock status and fishery-independent estimates are often difficult and costly to implement. Until the development of more detailed assessment models is completed, the assessment of the status of the tuna resources found off the east coast of Australia and elsewhere is likely to continue to rely on the analysis of catch and effort data provided by fishers.

In this paper the trends in yellowfin tuna resources caught within two separate regions within the south-west Pacific are presented. These trends are based on the aggregated monthly 1-degree catch and effort data (stratified by hooks-per-basket) pertaining to the Japanese longline fleet fishing within the region [0,39]°S and [140,169]°E. This region is shown in Figure 1. The National Research Institute of far Seas Fisheries in Japan kindly provided this data, covering the years 1971 to 1995, for the purposes of this study.

Note: This paper presents some results included in the report "Status of the yellowfin tuna resource off eastern Australia: a preliminary study" which is nearing completion.

2. Spatial-Temporal Coverage of Fishing Effort in the south-west Pacific

Analysis of catch and effort data for determination of annual indices of stock abundance is often compromised by spatial and temporal changes in both the spatial distributions of the stock and the fishing effort. For example, if the fishing effort contracts over time to areas of high and/or reliable catch rates (perhaps with the introduction of quotas) then the spatial extent of the stock will remain inherently ill-determined. This problem is one of the major sources of uncertainty in the current assessment of the southern bluefin tuna stock (Campbell, 1998).

A summary of the spatial and temporal distribution of the fishing effort by the Japanese longline fleet within the region [0,39]°S and [140,169]°E is given in Table 1. In this table the number of years between 1971 and 1995 that the Japanese longline fleet has fished within each 5x5-degree block during each quarter is given. The results indicate that only 15 (9.6%) of the 156 quarter/block cells have been fished every year. For those cells fished in 23 years or more the coverage of quarter/blocks increases to 36 (23%).

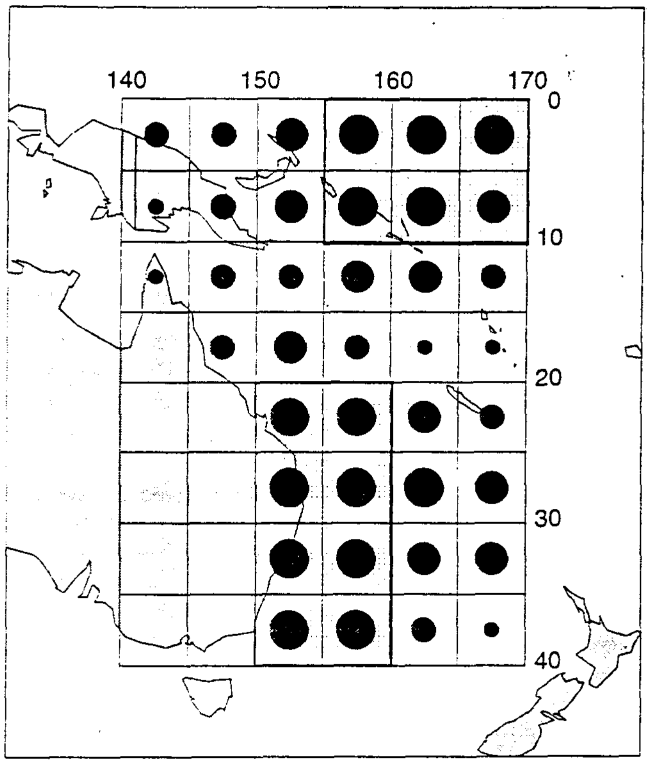
Given the variability in the spatial and temporal coverage of fishing effort within the entire region, any analysis of catch rates to obtain annual indices of stock abundance will be the subject of much uncertainty. Nevertheless, by restricting the analysis to smaller spatial-temporal regions it is possible to achieve a high level of data coverage. For example, within the region off the east coast of Australia between 20-39°S and 150-159°E and during the third quarter (July-September) all but two of the eight 5-degree blocks have been fished every year between 1971 and 1995. The two blocks not fished every year are missing data for only one year each. Another region of consistent data coverage is in the equatorial south Pacific between [0-10]°S and [155,170]°E, again during the third quarter. These two regions are indicated by the shading in Table 1 and the temporal coverage of effort for the entire region during the third quarter is shown in Figure 1.

2. Indices of Annual Resource Abundance

Annual indices of abundance of the tuna resources within each of the two regions identified above were calculated using the NRIFSF catch and effort data. Two sets of indices are presented. Each of the methods is briefly described.

Figure 1. Spatial and temporal distribution of Japanese longline fishing effort during the third quarter (July-September). The number of years each 5-degree block was fished over the 25-year period between 1971 and 1995 is indicated by the size of the dot. Note the size of the dot is not proportional to the number of years. Instead

● = 23 to 25 years, ● = 17 to 22 years, ● = 11 to 16 years, • = 0 to 10 years



i) Simple-Sum Indices:

Annual abundance indices were calculated by summing the catch rates within each 1-degree square. These indices are based on the assumption that the catch rate is a proxy for abundance in each 1-degree square and that the total abundance is given by summing over all areas, which is this case are of equal size. However, a degree of uncertainty arises when some of the one-degree squares in the fishery are not fished, ie when there are no observations on which to base an estimate of the average catch rates in those squares. In this instance, we can make three simple assumptions: (Note, in each model below the spatial extent of the fishery in each 5-degree block is equal to the maximal number of 1-degree squares fished in any year.)

- The squares in the fishery are fished at random. In this case we would expect that the average of the catch rates in the squares which are not fished would be similar to the average of the catch rates in the squares which are fished. In the following the protocol is adopted in which the catch rates in the one-degree squares not fished in any 5-degree block are assumed equal to the average of the catch rates of the one-degree squares which are fished in that block. When an entire 5-degree block is not fished in any given year, the catch rate in each 1-degree square for that block is set to be equal to the average catch rate in the 5-degree blocks which are fished. The index based on this assumption is called the B-avg index.
- Within each 5-degree block for a given year, the fishing effort is assumed to preferentially target the one-degree squares with the highest catch rates. Catch rates in the one-degree squares not fished are based on the tail of the distribution of catch rates in one-degree squares within a block which are fished, averaged over all years and all 5-degree blocks

Table 1. For each of the given 5x5-degree blocks and for each quarter of the year the number of years between 1971 and 1995 that the Japanese longline fleet has fished within each spatial-temporal region is shown. Blank cells indicate cells on land. The shaded cells indicate the two sub-regions for which temporal trends in catch rates were determined.

a) January-March

	Longitude					
Latitude	140-145	145-149	150-154	155-159	160-164	165-169
0-4	16	18	19	19	25	24
5-9	1	14	18	23	22	18
10-14	5	17	19	23	19	9
15-19		15	21	17	8	3
20-24			21	24	14	11
25-29			21	25	20	21
30-34			16	24	23	24
35-39			9	21	18	17

b) April-June

	Longitude					
Latitude	140-145	145-149	150-154	155-159	160-164	165-169
0-4	13	15	17	20	25	25
5-9	0	14	16	22	19	16
10-14	0	10	15	20	19	9
15-19		3	11	9	9	3
20-24			15	16	8	8
25-29			24	23	12	15
30-34			24	25	22	22
35-39			25	25	22	12

c) July-September

	Longitude					
Latitude	140-145	145-149	150-154	155-159	160-164	165-169
0-4	15	16	18	23	24	23
5-9	3	16	17	25	23	20
10-14	4	13	16	22	19	11
15-19		13	20	14	6	3
20-24			25	24	22	11
25-29			25	25	24	22
30-34			25	25	19	22
35-39			24	25	12	3

d) October-December

	Longitude					
Latitude	140-145	145-149	150-154	155-159	160-164	165-169
0-4	15	17	20	21	23	22
5-9	3	17	16	23	23	19
10-14	7	20	15	21	20	10
15-19		22	20	19	12	2
20-24			19	23	19	8
25-29			19	25	22	17
30-34			11	12	10	7
35-39			9	6	3	0

(see Campbell, 1998 for further details). The index is called the B-ratio index.

- The squares not fished contain no fish. In this case the catch rate is zero in all squares not fished. The resulting index based on this assumption is called the B-min index.

Whilst it is very unlikely that there will be no fish in the squares which are not fished, making the third assumption an extreme of what may be possible, the B-min index is useful in that it sets a lower bound on the resource index. Furthermore, it is unlikely that fishers have sufficient knowledge about the spatial distribution of the resource in order to target their effort at only the high catch rate squares within each block. However, in calculating the B-ratio index it is also assumed that the spatial extent of the stock remains constant (ie. all one degree squares contain fish) each year. Given the large-scale movement of fish on an interannual basis in response to large oceanographic events such as the El Nino/Southern Oscillation this may not necessarily be correct. Furthermore, as a resource is depleted there may be a disproportional depletion of the resource in marginal habitat areas in comparison to core habitat areas. On the other hand, the B-avg index will in most instances overestimate abundance levels due to the fact that fishers do possess knowledge and have access to information which assists them find areas considered favorable to the targeted species. We assume therefore that the true index of resource abundance lies between the B-avg and B-min indices and possibly closer to the B-ratio index.

Note: two figures are shown for the simple sum indices in the following results. The first figure shows the absolute values of the indices. Differences between the indices highlight differences due to the three sets of assumptions made above. In the second figure, all indices are standardised so that the mean index over the 25-year period is one. This allows greater comparison of trends over time and also allows comparison with the nominal catch rates which are adjusted in a similar manner and shown on the same figure.

ii) General Linear Models

Whilst the above simple-sum indices allow one to standardise for changes in the fine-scale (ie one-degree) spatial distribution of effort and the target resource, it does not account for other factors which may influence the expected catch rates in the fishery. For this purpose the General Linear Model has been widely adopted. Based on the data available we fit the following model to the Japanese catch and effort data:

$$E[\log(CPUE_{ijkab})] = \text{Intercept} + \text{Year}_i + \text{Block}_j + (\text{Year.Block})_{ij} + \text{HPB}_k + \text{SOI}_a + \text{SST}_{ab}$$

where Year_i is the effect of the i-th year
Block_j is the effect of the j-th 5-degree block fished.
HPB_k is the effect of the k-th hooks-per-basket gear configuration
SOI_a is the effect of the Southern Oscillation Index in the a-th month
SST_{ab} is the effect of the Sea-Surface Temperature in the a-th month and b-th one degree square.

The standardising effects of Year, Block and HPB are fitted as factors while the effects of SOI and SST are fitted as covariates. Both these covariates were normalised and included a quadratic term. The transformed variable z=log(CPUE) is assumed to have a Normal distribution. Due to the unavailability of all data sets over the entire 25-year period since 1971 (HPB is only available since 1976 and SST since 1982) two sub-models were fitted to the data separately. These were:

1971-95: $E[\log(CPUE_{ija})] = \text{Intercept} + \text{Year}_i + \text{Block}_j + (\text{Year.Block})_{ij} + \text{SOI}_a$

1982-95: Full model shown above.

For a more detailed description of the calculation of indices of the abundance using the above GLM approach the reader is referred to Campbell et al, (1995).

2A. Central eastern AFZ – third quarter.

Because of the small catch of yellowfin tuna south of 35°S (this region being predominantly a southern bluefin tuna fishery) the analysis is confined to the six 5x5-degree blocks between [20-34]°S and [150,159]°E. The plots given in Figure 2 provide a summary of the aggregate fishery statistics for this region. The number of hooks deployed each year shows a large degree of variation over the 25-year period. From an annual effort level of around 1.5 million hooks in the early 1970s the number of hooks deployed in this region each year shows a steady increase during the 1980s, peaking at around 7 million hooks in 1989, after which time the annual effort decreased to around 3 million hooks in 1995. The average number of hooks deployed each year in each decade was 1.48 million during the 1970s, 4.37 million during the 1980s and 4.01 million during the 1990s. The spatial extent of the fishery, as measured by the number of one-degree squares fished each year, varied considerably in the 1970s (average of 62 squares) before stabilizing at around 82 squares during the 1990s decreasing slightly to an average of 78 squares in the 1990s. Some of these changes will be due to management imposed exclusion zones.

The number of yellowfin, bigeye and southern bluefin tuna caught, as shown in Figure 2b, mimics the changes in effort over the years. Yellowfin tuna dominates the catch each year while the catch of southern bluefin tuna is a relatively small component of the total catch in most years. If yellowfin tuna is the principal target species in this region then the indices of annual abundance hopefully correlate well with the actual availability of this resource. While the trend in the catch of bigeye closely follows the catch trend in yellowfin tuna, the interannual variation is much smaller. This may indicate that the availability of bigeye does not undergo interannual variations as large as that found in the yellowfin tuna resource.

The nominal catch-per-unit-effort for each of the three species is shown in Figure 2c. The large catch rates in 1977 and 1978 for yellowfin tuna coincide with years of very little effort. Excluding these two years the nominal catch rate remained relatively stable between 1971 and 1988 (average of 6.56 fish per 1000 hooks). After 1989, the nominal catch rate decreased then remained relatively stable over the next 6 years (average of 4.95) before increasing again in 1995. For bigeye, the catch rates were quite variable during the 1970s but have remained quite stable since 1980. Indeed, the average catch rates in the 1980s and 1990s are the same (1.43 fish per 1000 hooks).

The standardised indices of abundance for the yellowfin tuna in this region are shown in Figure 3. Note, these indices are based on the region between [154,159]°S in order to overcome temporal biases due to the exclusion of the fleet from inshore zones in the latter years. All indices indicate a fluctuating pattern of yellowfin tuna resource levels in this region over the 25-year period. There is, however, no indication of a long-term decline in resource levels. For both sets of indices abundance levels of yellowfin tuna in the early 1980s appears to have been low while between 1985 and 1988 abundance levels appear to have been above the long term average. Abundance levels in 1994 were the lowest for ten years. Finally, the level of inter-annual variation is quite high. For example, 1994 was a year of low abundance while 1995 was a year of high abundance, being 2.4 times that of the previous year.

It is interesting to speculate on the relationship between abundance levels of yellowfin tuna in the eastern AFZ and the cycle of ENSO events. The incidence of low abundance levels in the early 1980s and 1994 coincide with prevailing El Nino events at these times. While a simple correlation between the SOI index and the above abundance indices is not strong, the relationship between abundance levels of tunas and billfish off eastern Australia with large-scale changes in the oceanography in the Western/Central Pacific warrants further investigation.

Figure 2. Plots of a) annual effort (number of hooks) and spatial coverage (number of one-degree squares fished), b) annual catch and c) annual nominal catch-per-effort for Japanese longliners operating in the central eastern AFZ region bounded by [20-39]°S and [150,159]°E during the third quarter of each year.

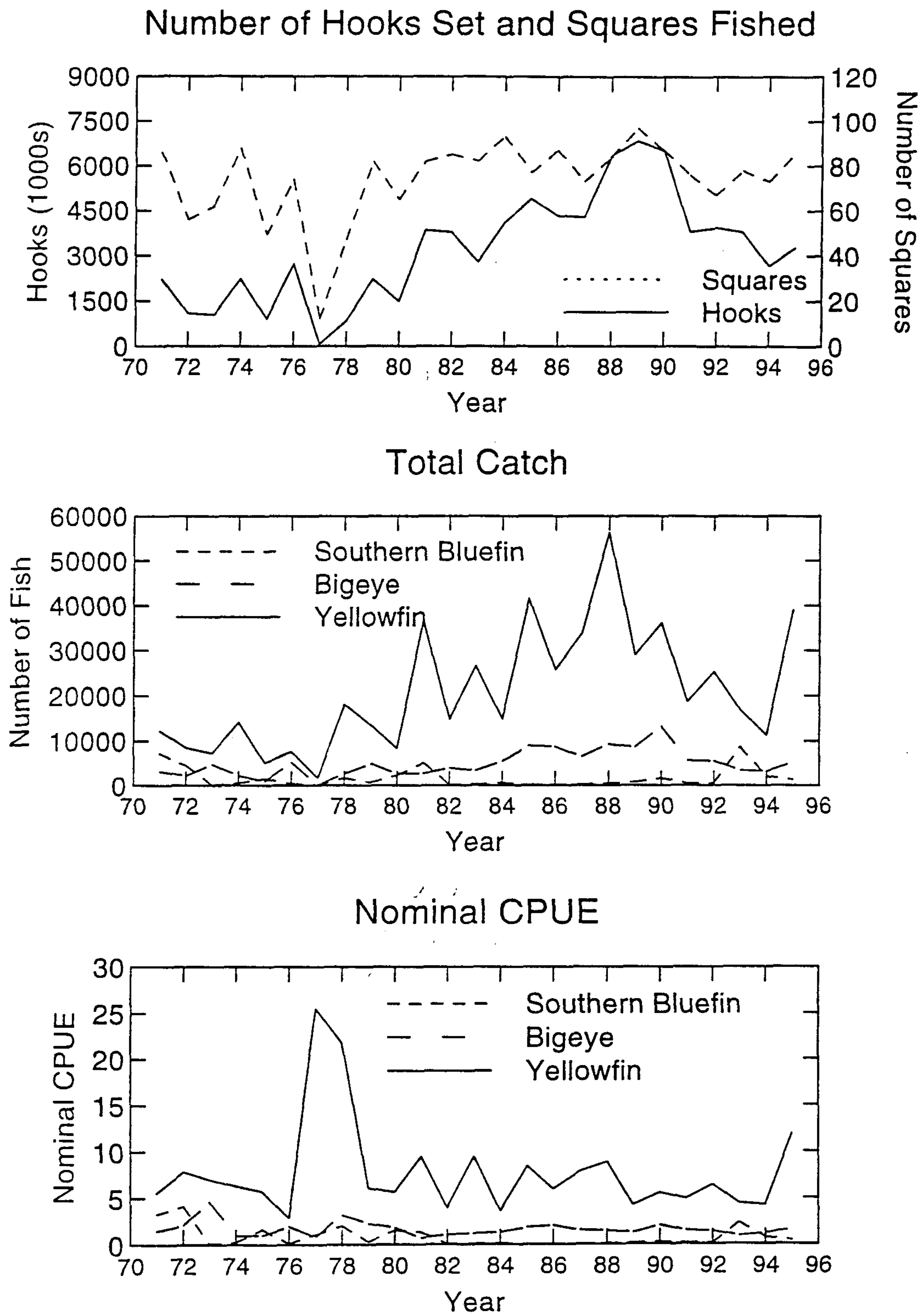
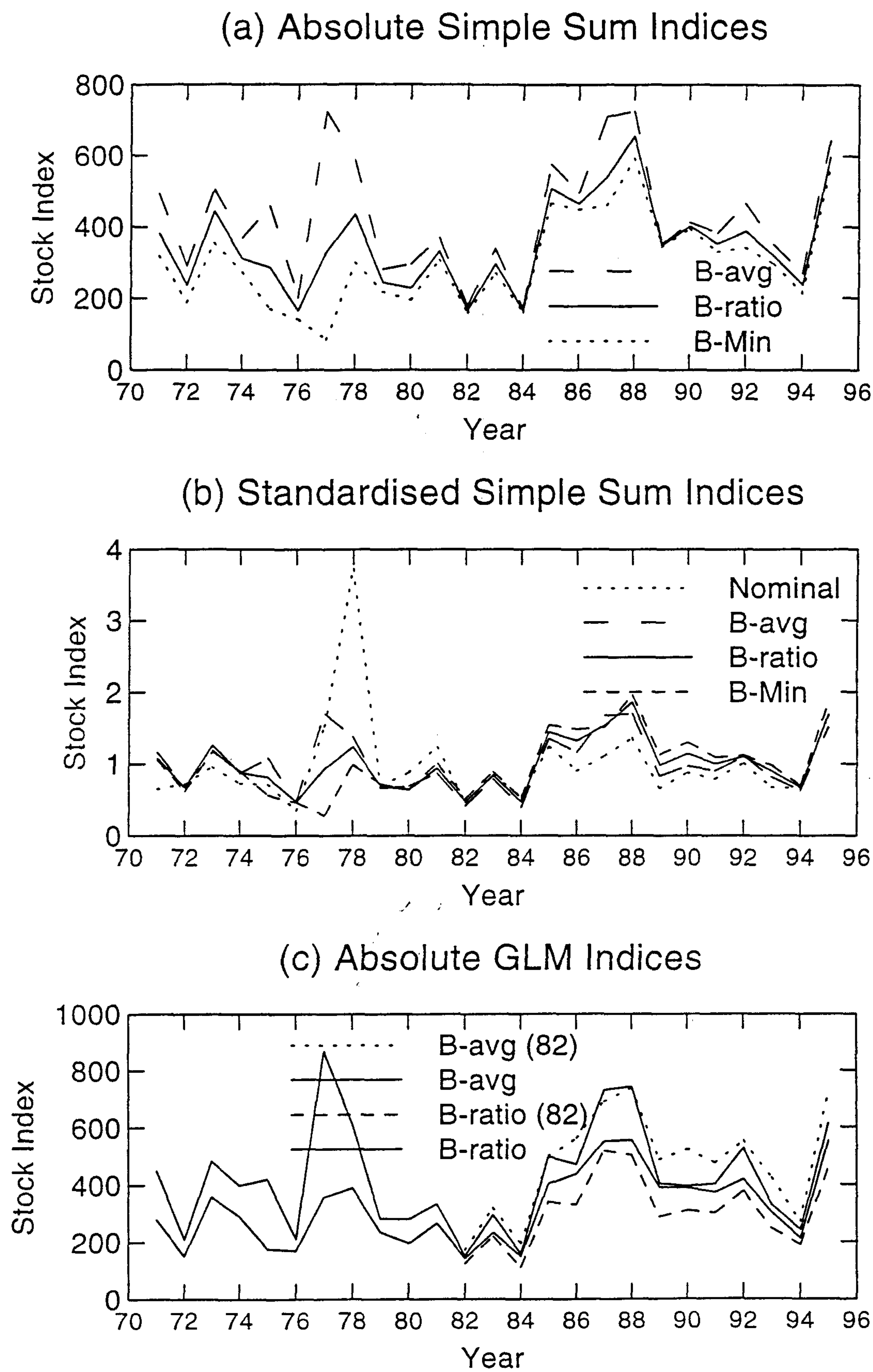


Figure 3. Annual indices of resource abundance for yellowfin tuna within the central eastern AFZ during the third quarter (July-September) since 1971.



2B. Equatorial Pacific – third quarter

This region consists of the six 5x5-degree blocks between [0-9]°S and [155,169]°E and includes the Solomon Islands and the water to the east. The plots given in Figure 4 provide a summary of the aggregate fishery statistics for this region. Fishing effort by Japanese longliners has varied considerably over the 25-year period. From an annual effort level of around 1.0 million hooks in the early 1970s the number of hooks deployed each year increase to around 3 million in 1980 after which time effort has ranged between 1 and 4 million hooks. Since 1992 effort has fluctuated widely each year, being 18,000 in 1992 and 4.2 million in 1993. The spatial extent of the fishery was relatively stable in the 1970s (average of 80 squares) but after the mid-1980s the fishery contracted to only 47 squares in 1992 (and only 5 in 1993). Although the effort was widespread in 1993 (108 squares), like the number of hooks it has fluctuated widely since 1992 and through the 1990s has averaged only 49 squares. The reason for this decline remains unclear.

In line with the changes in effort, the number of yellowfin tuna caught each year has also fluctuated considerably (Figure 4b). Being a tropical region no southern bluefin are caught and instead the number of billfish caught (comprising black, blue and striped marlin, swordfish and sailfish) is shown instead. Bigeye tuna comprises a considerable proportion of the catch while the proportion of billfish in the catch is small. The ratio of bigeye to yellowfin tuna in the annual catches has varied from 0.363 in the 1970s, 0.272 in the 1980s to 0.395 in the 1990s. Whether these differences are due to changes in targeting practices or due to changes in the availability of the respective species, or both, remains unclear.

Nominal catch rates for yellowfin show marked interannual variation between 1971 and the mid-1980s, though the average remained relatively constant at around 21 fish per 1000 hooks (Figure 4c). Between 1971-78 the mean annual catch rate was 21.3 and between 1979 and 1985 it was 21.9. These catch rates are considerably higher than that obtained in the central eastern AFZ. After 1986 the catch rates of yellowfin tuna declined with the average for the period 1986-90 being 16.3 and for the period 1991-95 being 13.8. However, during the last decade the interannual variation in nominal catch rates has been considerably smaller than that observed before 1985.

The standardised indices of resource abundance are shown in Figure 5. Although there is a degree of separation between the three indices in Figure 5a, all three indices display a similar pattern over the 25-year period (Figure 5b). The overall decline from the late 1970s to 1995 shown by the simple sum indices is slightly greater than that indicated by the nominal catch rate. Furthermore, between 1971 and 1985 the abundance levels display large inter-annual variation and any overall decline is small. After 1985 the abundance levels have remained historically low with smaller interannual variation. The GLM indices also indicate a relatively constant resource level after 1985 with the B-ratio and B-avg indices in 1995 being similar to those in 1987. However, unlike the simple sum indices, the GLM B-avg index appears to show some overall decline between 1971 and 1985. The reasons for the abrupt decline in abundance levels after 1985 remain unclear but may be due to an interaction with the large-scale purse-seine operations which began during the 1980s or a change in availability due to long-term shifts in environmental conditions.

The GLM indices that include standardisation of hooks-per-basket and the sea-surface temperature (called the second set) vary to some extent from those that do not (the first set). The decline after 1986 is not as abrupt as shown in the first set and the overall decline to the mid-1990s is smaller. Indeed, a simple regression analysis indicates that while the decline since 1982 is significant for the first set of indices it is not for the second set. Hence, while a decline in the resource abundance since the early 1980s is still apparent in the second set of indices, the inclusion of at least one of the other standardization factors in the model appears to have reduced the size of this decline.

Figure 4. Plots of a) annual effort (number of hooks) and spatial coverage (number of one-degree squares fished), b) annual catch and c) annual nominal catch-per-effort for Japanese longliners operating in the equatorial Pacific region bounded by [0-9]°S and [155,169]°E during the third quarter of each year

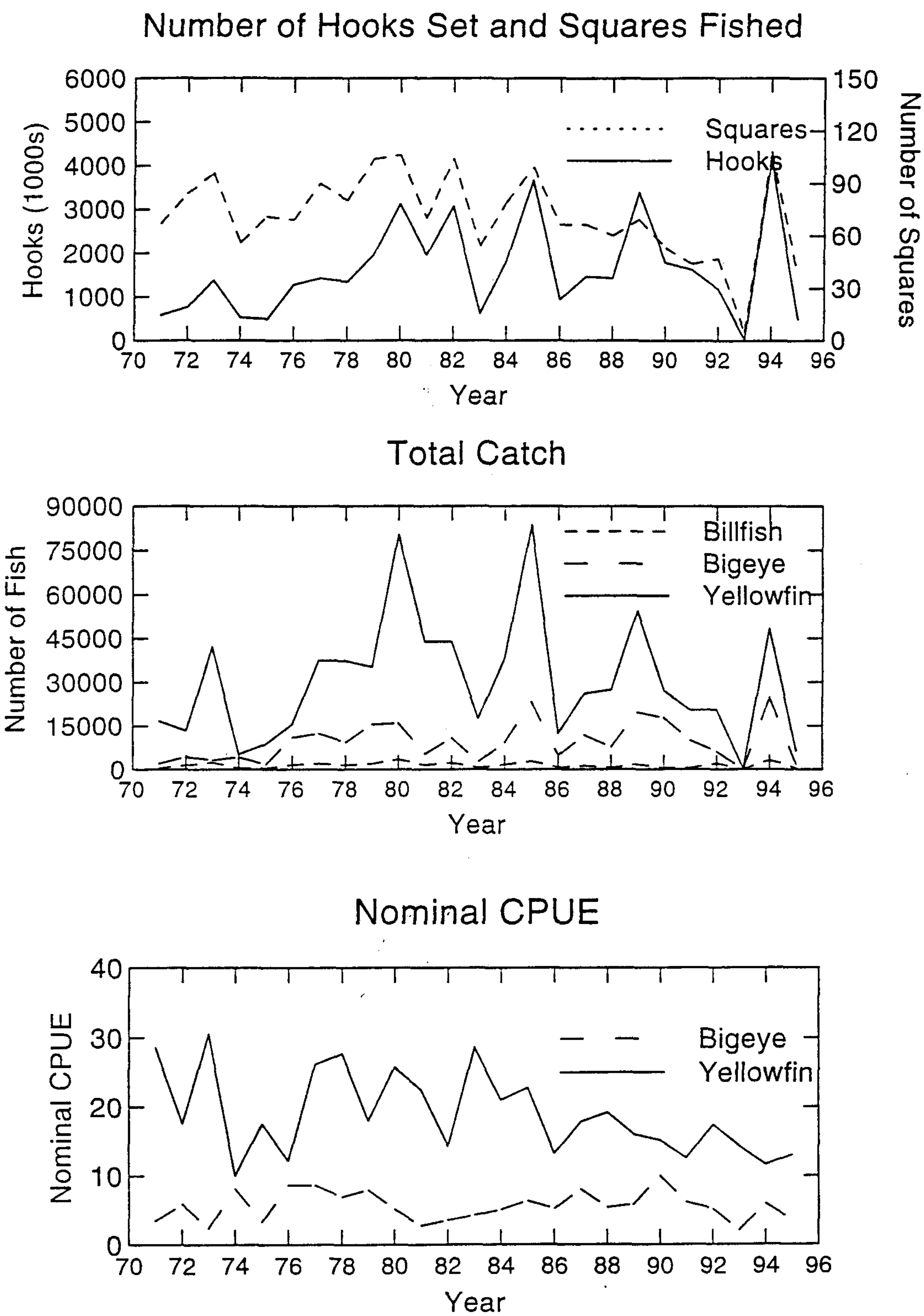
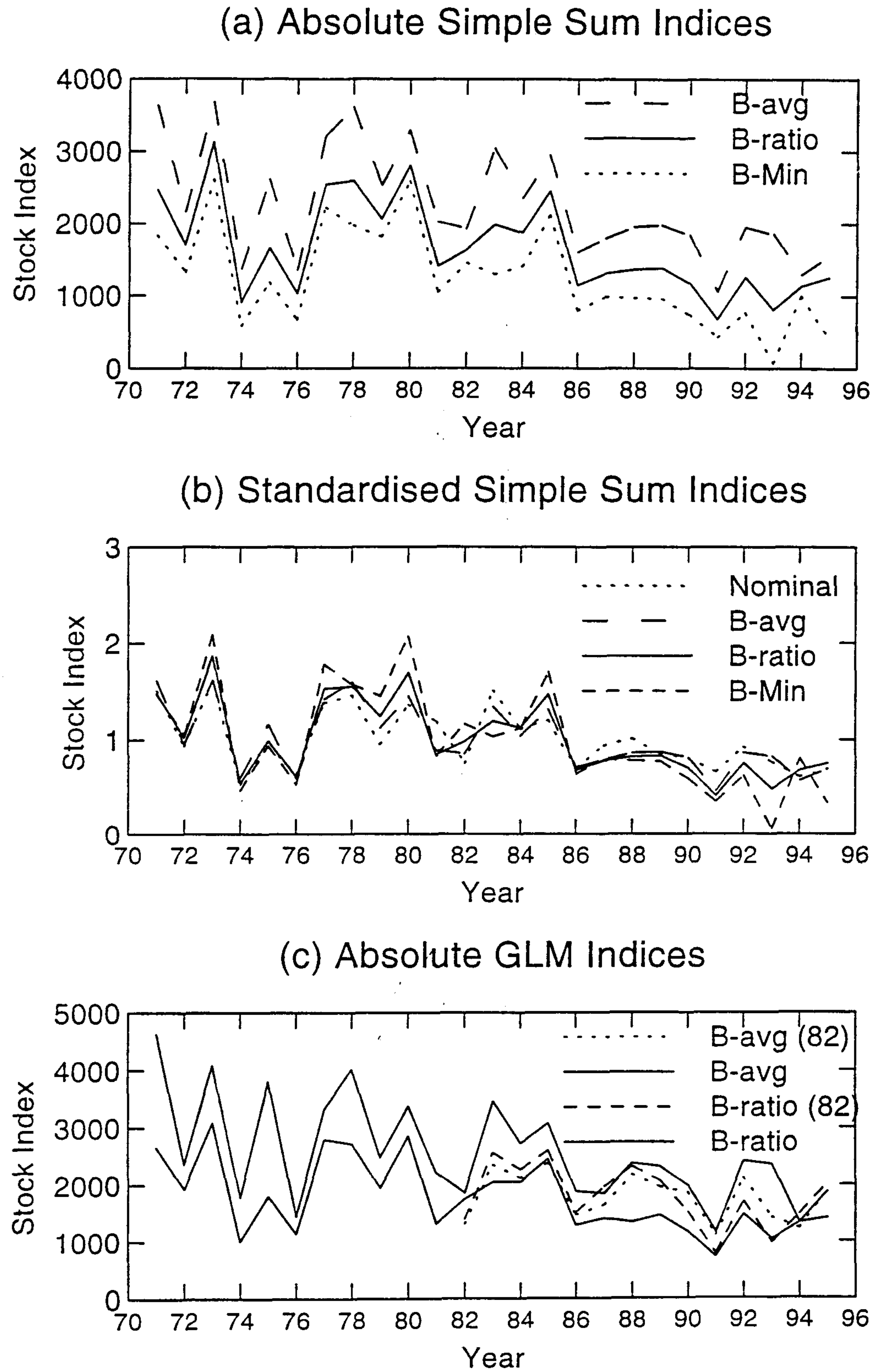


Figure 5. Annual indices of resource abundance for yellowfin tuna within the equatorial Pacific during the third quarter (July-September) since 1971.



3. Targeting Practices

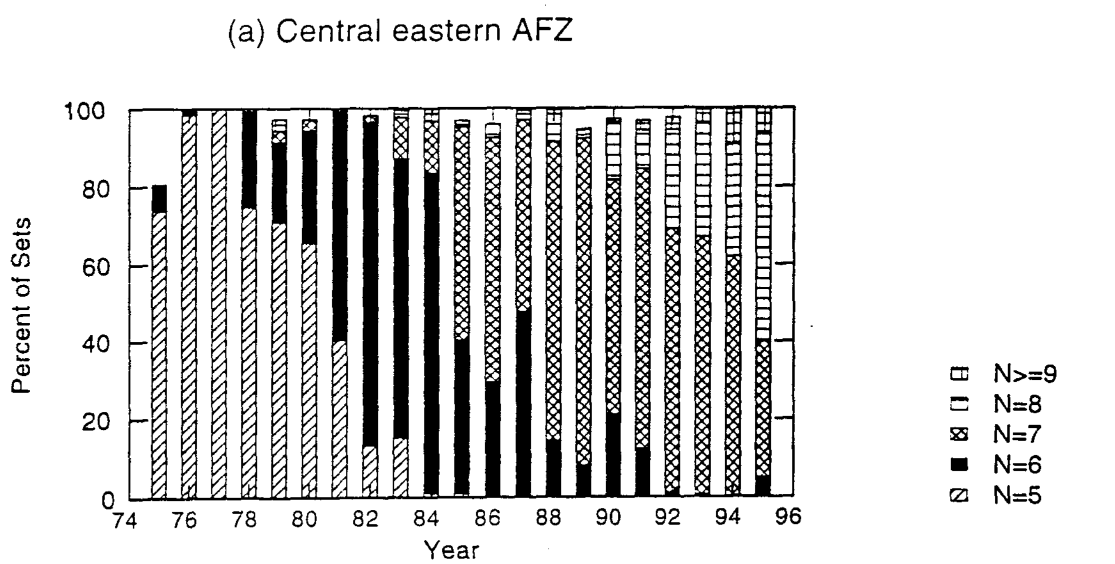
A number of assumptions underlie the preceding analyses and attempts to draw conclusions from the results will depend on the validity of these assumptions. Central to these assumptions is the relationship between changes in catch rates and the changes in the abundance of the target species. It is well known that many factors can affect catch rates apart from changes in abundance. These factors include technical changes in the fishery (eg. changes in gear efficiency), economic (eg. changes in the target species) and biological (eg. shifts in availability). While it is not the intention here to debate the merits or otherwise of present catch rate analyses, the above analyses attempt to account for some of these factors.

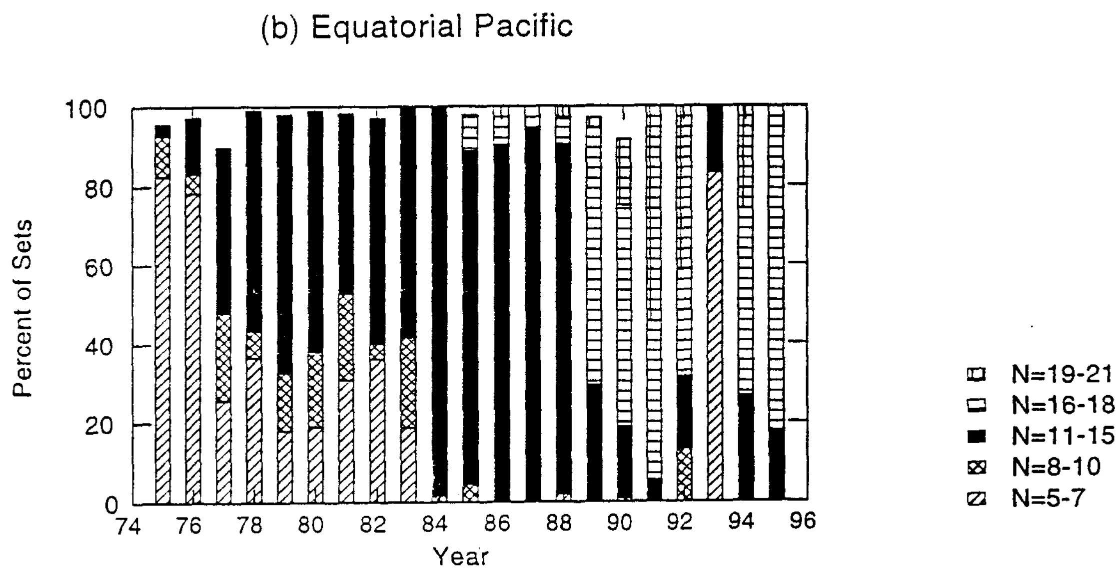
The issue of changes in targeting practices is an important consideration for the interpretation of the above results as it is likely to have a large influence on catch rates for individual species. Like other regions of the tropical and sub-tropical western Pacific, the Japanese longline fishery within the eastern AFZ is principally a multi-species fishery targeting yellowfin and bigeye tunas and at times broadbill swordfish and striped marlin. Ideally, the analysis of catch rates should be based on the effort targeted at a specific species. Without being able to clearly identify the targeted effort, as is the situation in here, one usually needs to make some assumptions concerning the fishing practices of the fleet. A simple assumption one can make is that the targeting practices have not changed over time. That is, the percentage of the total effort targeted at each of the species has remained unchanged over time. If this approximates the true situation, then the possibly of temporal bias in the resulting indices of abundance may be minimised even though the total effort in the fishery is used in the analyses. Note: An attempt to identify the effort targeted at yellowfin using a cluster analysis is included in the full report.

Unfortunately, the underlying fishing strategies adopted by the Japanese fleet operating in the eastern AFZ or the equatorial Pacific remain unknown. Instead, changes in the annual distributions of the gear configurations (number of hooks deployed per basket) across individual sets for the Japanese longline fleets where analysed. These distributions are shown in Figure 6. In both regions there has been a shift towards setting more hooks per baskets, though the nature of these shifts varies between region. Within the central eastern AFZ a major shift away from setting mainly 5 hooks-per-basket to setting 6 then 7 hooks-per-basket took place between 1980 and 1985. Since then 7 hooks per basket has remained the dominant setting but the use of 8 or more hooks has increased (especially in the third quarter where 8 hooks was dominant in 1995). On the other hand, the shifts in the number of hooks-per-basket used by the Japanese longline fleet within the equatorial Pacific are more pronounced. While approximately 80 percent of the sets deployed 5-7 hooks-per-basket in 1975, by 1977 around 50 percent of sets deployed 11-15 hooks-per-basket. The distribution of gear configurations remained relatively steady between 1977 and 1983 but during 1984 there was another change with nearly all sets deploying 11-15 hooks-per-basket. This configuration remained dominant between 1984 and 1988 after which time there has been increased use of gear configurations with 16 or more hooks per basket.

Reasons for the above shifts remain unclear. However, the shift after 1975 within the equatorial Pacific to using 11-15 hooks-per-basket is likely to be the result of the increased targeting of bigeye tunas (Suzuki et al, 1977). This may also explain the changes observed within the central AFZ after the mid-1970s. Indeed, observers report the use of 8-9 hooks-per-basket when targeting bigeye tuna. The increasing use of monofilament main lines by Japanese longliners has also lead to an increase in the use of more hooks-per-basket as these lines are more buoyant than the older Kuralon type rope mainlines. The use of monofilament longlines, however, has been mostly restricted to what in Japan are known as offshore longliners. These vessels fish almost exclusively the waters north of 14°S whilst distant water longliners have generally only operated south of this latitude except in recent years. The introduction of monofilament longlines began in the late 1970s but was mainly confined to

Figure 6. Percentage of sets deployed by Japanese longliners each year with each gear configuration (number of hooks-per-basket) in various spatial-temporal regions. Note the small gap at the top of the column for some years is due to sets where the gear configuration is not specified.





small-sized vessels that carry ice. Larger-sized vessels, which have a deep freezer, have in the main continued to use the traditional gear (N. Miyabe, pers comm).

4. Changes in Size Distributions

Due to a lack of information on the age distributions of the catches, changes in the age structure of the yellowfin tuna resources within the two regions were not included as part of the proceeding analyses. However, changes in the age structure or length distributions of the fish caught can be used as indictors of stock status. For example, a long-term decrease in the size of the fish caught may indicate a depletion of adult fish and the increased likelihood of recruitment failure. Indeed, Kamimura and Homna (1962) noted that there appeared to have been a decrease in the size of yellowfin tuna landed in the western Pacific over the duration of the fishery in this region. However, it remained uncertain whether or not this decrease was a reflection of changes in the size composition of the stock itself.

In the following sections we compare size information collected and published over a number of years within the two regions considered previously. Four types of size data were available for these analyses:

1. Individual length and weight measurements taken and recorded by domestic fishers and recorded on the Australian logbook.
2. Individual length and weight measurements taken and recorded by Australian observers on Japanese longliners fishing within the AFZ.
3. Length and weight measurements collected from Japanese longliners and collated by the National Research Institute of Far Seas Fisheries in Shimzu, Japan. Dr N. Miyabe has kindly provided a copy of part of this data – size data for yellowfin tuna south of the equator between 140-179°E and for the years 1970-95. The data is aggregated by month and in spatial blocks of size 10° of latitude and 20° of longitude. The data incorporates weight data that has been converted to length using a weight-to-length relationship, possibly Morita (1970). The proportion such data in the total remains unknown.
4. Length histograms published in the literature.

4A. Central Eastern AFZ

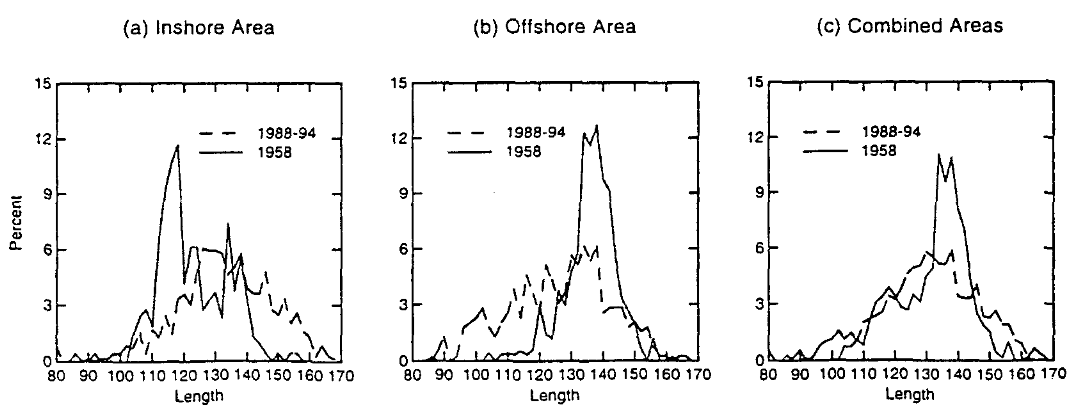
We consider the region bounded by 20-29°S and 140-159°E. This region includes the eastern AFZ from Bowen in Queensland down to Coff's Harbour in NSW. Detailed size composition data for the catches taken in this region before 1970 were not available for analysis and so it is difficult to ascertain the possible changes in length distributions of the yellowfin tuna caught in this region over the entire period of the fishery. However, a small amount of information on the size-distribution of yellowfin tuna caught in this region was published in the paper by Kamimura and Honma (1962). This data is based on the catches taken by a single Japanese longliner during August 1958. The published data was associated with the following two areas:

- Area A: [24-26°S, 153-155°E], n=215 fish from 9 operations
- Area B: [20-23°S, 158-160°E], n=524 fish from 15 operations

Kamimura and Honma presented this data to support the more general observation that small or younger yellowfin tuna are more likely to be caught in waters near land. Because of this inference, in the following we call Area A the inshore area and Area B the offshore area. The size distributions for these two areas are shown in Figure 7. The absence of smaller fish within the offshore area is clearly seen.

For comparative purposes, size-distributions of fish measured by observers on board Japanese longliners between 1988 and 1996 at similar times of the year and in similar areas are also shown. In particular the samples were collected from the following regions and months:

Figure 7. Size-distributions associated with fish caught off eastern Australia.



- Inshore: [24-26°S, 154-155°E] – July to September, n=693 fish
- Offshore: [20-26°S, 158-160°E] – August & September, n=391 fish Note that this area is extended to the south of Area B due to a lack of samples in the smaller region.

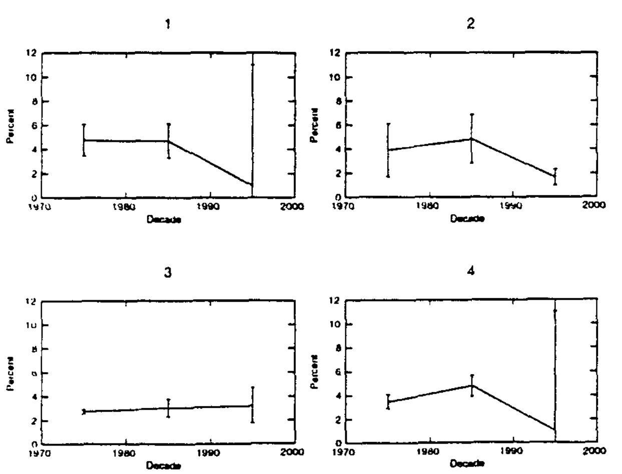
While there are some misgivings with the representative nature of the samples used here, especially using data from only a single vessel in a single month in 1958, the distributions nevertheless display a similar range of both small and large fish. The data for 1958 is susceptible to distortions due to the sampling from single episodic events and is likely to explain the spiky nature of the results. It is interesting to note, however, that the data collected by observers indicates similar size compositions in the two areas, with the occurrence of large fish inshore and small fish offshore being greater than that observed in 1958 and used by Kamimura and Honma for supporting their conjecture.

Finally, in Figure 7c the data from the two areas has been combined (weighted by sample sizes). The distributions for the two periods are seen to be quite similar, though there is a more defined modal structure in the earlier sample. This is likely to be due to be fact that this earlier sample is from a single month. There is also a greater proportion of fish around 135cm in the earlier sample. Whether or not this difference is due to changes over time in the size-composition of yellowfin available within these areas, or is an artifact of the single vessel and monthly sample from 1958 is not known.

After 1970 we make use of the size data provided by the NRIFSF. In particular, we analyzed the data pertaining to the 10x20-degree block bounded by 20-29°S and 140-159°E. As this data is aggregated on a much larger scale than the data presented on the previous page it will not be possible to ascertain fine scale changes within this region if any exist.

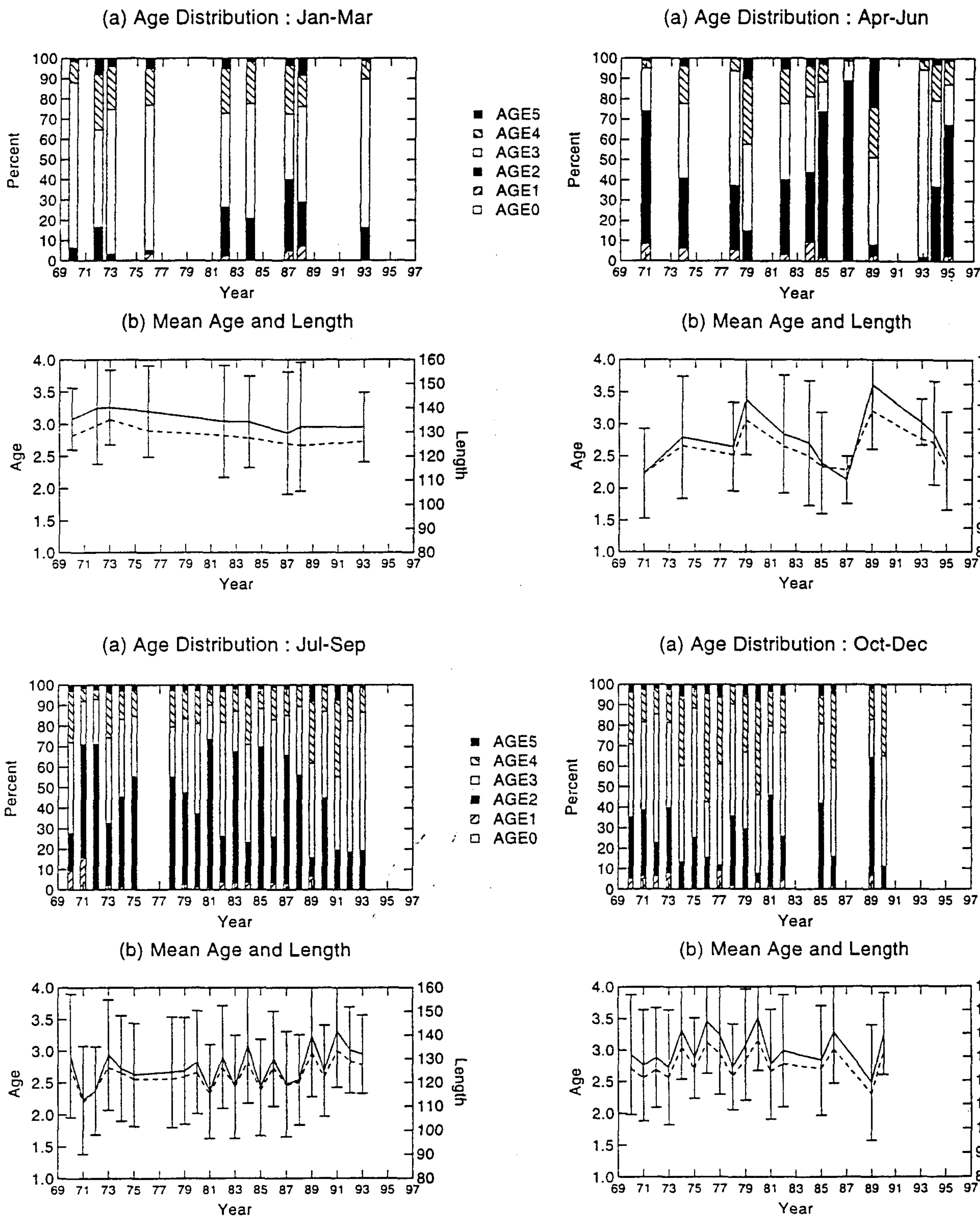
For each year and quarter the data was used to ascertain the age structure of the associated catch. The results of this analysis are shown in Figure 8. Note that only those year/quarter strata having a sample of more the 90 fish are shown. Sample sizes varied from between 95 and 8,200 fish with a mean of 1,381. For each quarter there is a high degree of variability in the percentage of fish of each age class, though some of this variability will be due to sampling errors. However, there appears to be no trend over time and this fact translates into the lack on a trend in the averages shown in the lower graphs for each quarter. Indeed, fitting a simple linear regression to the results indicated no significant trend (at the 5 percent level) over time for any age class in any quarter. The second quarter displays the highest degree of variation on the mean age while the first quarter has the lowest.

Figure 9. Percentage of age 5+ yellowfin sampled by year and quarter.



There have been some anecdotal comments made by fishers that the instance of large yellowfin tuna in recent years has declined from a decade or two earlier. In order to investigate this possibility, the percentage of fish of age 5+ in the samples for each year were averaged for each decade and quarter. The results, together with the standard errors on these means, are shown in Figure 9. Again the sample were limited to those containing more than 90 fish. The large standard errors in the first and fourth quarters in the 1990s indicate that only a single year of data was available.

Figure 8. Annual plots of (a) age distributions and (b) mean age (solid line) and length (broken line) for fish sampled within the region 20-29°S and 140-159°E. Standard deviations are shown for the distribution of ages. Years with missing bars or error lines denote years with when less than 90 fish were sampled.



The results indicate no significance difference between the percentage of 5+ fish in the samples between the 1970s and the 1980s. However, the results for the 1990s are more ambiguous. While the samples for the third quarter (July-September) indicate no change from the two previous decades, all the other quarters indicate a decrease. However, for these quarters the decrease is not statistically significant. Larger sample sizes will be needed to help resolve this issue.

4B. Equatorial South Pacific

We repeat the above analysis for the region for a region just south of the equator. Yabuta and Yukinawa (1959) provide modal composition data collected in the early 1950s for a number of areas within the region [0-9°S, 155-170°E]. This data for the months June-August is summarised in Table 2a. As the sample sizes are not known, the simple average of the percentages for each modal length in the samples is given in Table 2b. Note that due to the differences in mid-point lengths for the modes at 106 and 124cm, the data Jun-Aug, 19953 was re-distributed to realign the sample with modes at 115cm and 128cm. From the NRIFSF size data, modal distributions for the months June-August were also calculated for the three periods [1970,75], [1980-85] and [1990-95]. Again the length samples where partitioned into the modes in Table 2b using the mid-point lengths. Furthermore, due to different spatial aggregation of the NRIFSF data the region [0-9°S, 160-179°E] was used.

A comparison of the distributions for the 4 periods is shown in Figure 10. Three features can be noted for the results for the winter months (June-August). First, there was a greater percentage of larger fish in the samples collected in the early 1950s. Second, while the percentage of fish in the 127cm mode is relatively similar over the total period, there appears to the sequential decrease in the mean size over the same period. For example, the mode with the highest percentage of fish was 128cm in 1952/53, decreasing to the 115cm mode between 1970-75, to the 95cm mode between 19880-85 and to the 78cm in 1990-95. Third, a high percentage of the fish sampled in the 1990s are small, being in the 78cm mode, and the percentage of fish in the higher length modes is correspondingly smaller.

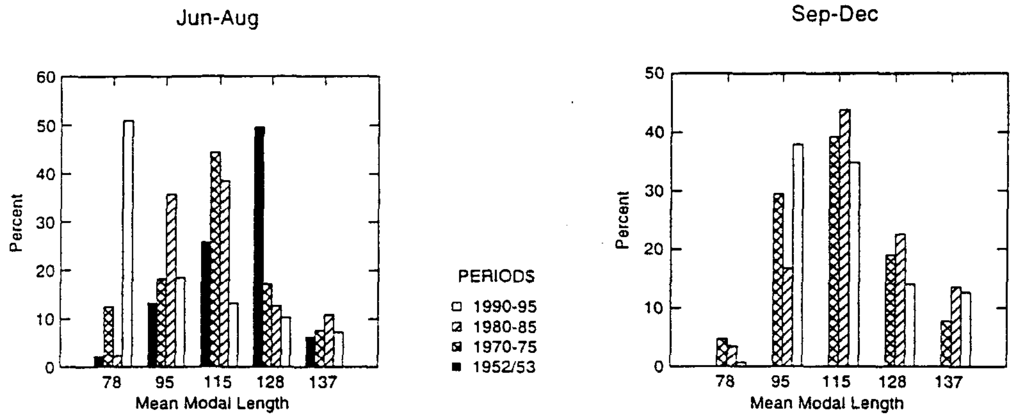
Table 2a. Modal mid-point lengths and the percentage within each mode for yellowfin sampled in the south equatorial region. (data from Yabuta and Yukinawa, 1959).

Period	Region	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Sample
Jun-Aug 1952	2-6°S 155-165°E	79cm 2.6%	95cm 25.9%	114cm 22.5%	128cm 38.5%	137cm 3.9%	N/a
Jun-Aug 1952	6-10°S 155-165°E	77cm 4.0%	95cm 6.0%	115cm 24.9%	128cm 60.4%	150cm ? 2.8%	N/a
Jun-Aug 1953	6-10°S 155-165°E		95cm 7.6%	106cm 30.0%	124cm 49.8%	137cm 11.8%	N/a
		78cm 0.8%	*95cm 18.51%*	*115cm 23.1%*	*128cm 45.8%*	*137cm 11.8%*	

Table 2b. Summary of data in Table 2a plus modal distributions for yellowfin tuna caught in the south equatorial regions during the indicated periods since 1970 (data source NRIFSF).

	Region	78cm	95cm	115m	128cm	137cm	Sample
Jun-Aug 1952-53	2-10°S 155-165°E	2.5	16.8%	23.5%	48.2%	6.2%	97.2%
Jun-Aug 1970-75	0-9°S 160-179°E	12.5	18.2	44.4	17.2	7.6	2,700
Jun-Aug 1980-85	0-9°S 160-179°E	2.3	35.7	38.5	12.7	10.8	18,759
Jun-Aug 1990-95	0-9°S 160-179°E	50.9	18.4	13.2	10.3	7.2	1,635

Figure 10. Modal composition of yellowfin tuna length samples collected in the south equatorial region [0,9]°S, [155,179]°E at different times since 1952.



These results would indicate a sequential decrease in the mean size of fish in the catch in the decades since the 1950s. However, it remains uncertain whether these results are indicative of actual changes within the yellowfin tuna population or are artifacts of changes in the sampling practices over this period. For example the large percentage of fish in the 78cm mode in the 1990s may be influenced by large recruitment events. The dissimilarity of the regions between and after 1970 may also influence the results. Furthermore, a similar comparison of the modal distributions for the months September-December, given in Table 2c and Figure 10b, indicate a less consistent pattern over time in the percentage of fish sampled within each modal length. For example, the average modal size of fish sampled increases between the early 1970s and the early 1980s. However, the fish sampled during the period 1990-95 are still, on average, the smallest. The large mode observed at 78cm in the winter months in the period 1990-95 is now seen at the 95cm mode and is likely to reflect the fast growth of these fish over these lengths.

Table 2c. Modal mid-point lengths and the percentage within each mode for fish sampled in the south equatorial region during September-December (data source NRIFSF).

Period	Region	78cm	95cm	115m	128cm	137cm	Sample
Sep-Dec 1970-75	0-9°S 160-179°E	4.7	29.4	39.2	18.9	7.7	22,113
Sep-Dec 1980-85	0-9°S 160-179°E	3.5	16.7	43.8	22.5	13.6	14,301
Sep-Dec 1990-95	0-9°S 160-179°E	0.7	37.9	34.8	14.0	12.6	904

4C. South-Western Pacific Region

For this analysis we make sole use of the data provided by the NRIFSF. As detailed above, this data consists of histograms of the number of fish measured by length (with a length interval of 2cm) and is aggregated by year and month within spatial blocks of size 10° of latitude and 20° of longitude. In order to handle the large number of years, we further aggregated the data across the five-year periods 1970-74, 1975-79, 1980-84, 1985-89 and 1990-95 and considered the changes between these periods. The data was also aggregated by quarter of the year. As we are interested in changes in the distribution of lengths within a region, we use the average length of fish within each spatial/temporal region as a proxy for these distributions.

The results for each region and quarter are shown in Figure 11. The periods with no bar indicate those periods where no fish were sampled, while the periods where the bar is clear are those where the total sample is less than 90 fish. While a visual inspection of the results

Figure 11. Average length of yellowfin tuna caught in each 10-20° block by quarter where:

1. [0-9°S, 140-159°E]
2. [0-9°S, 160-179°E]
3. [10-19°S, 140-159°E]
4. [10-19°S, 160-179°E]
5. [20-29°S, 140-159°E]
6. [20-29°S, 160-179°E]
7. [30-39°S, 140-159°E]
8. [30-39°S, 160-179°E]

January-March　　　　　　April-June

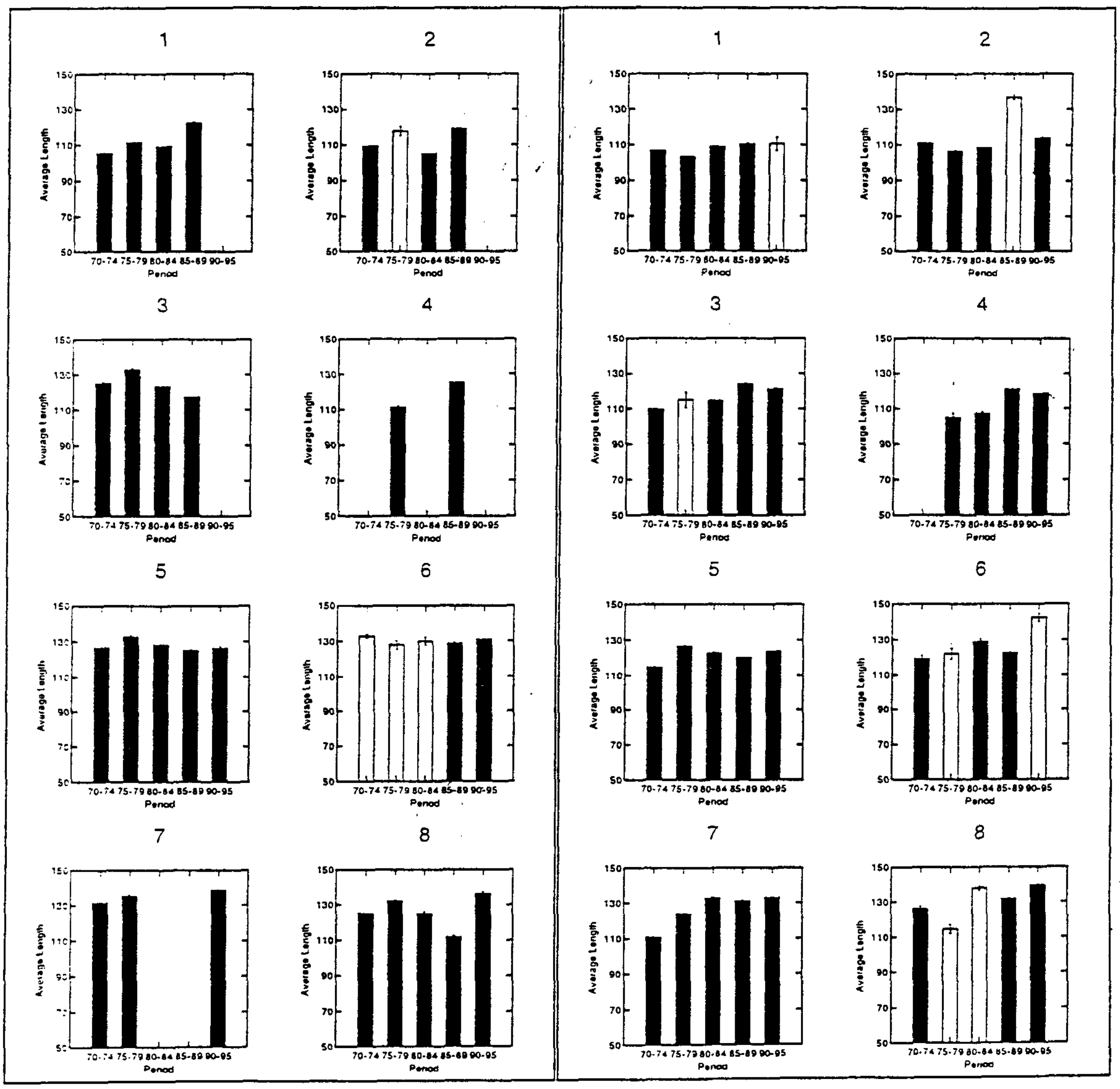
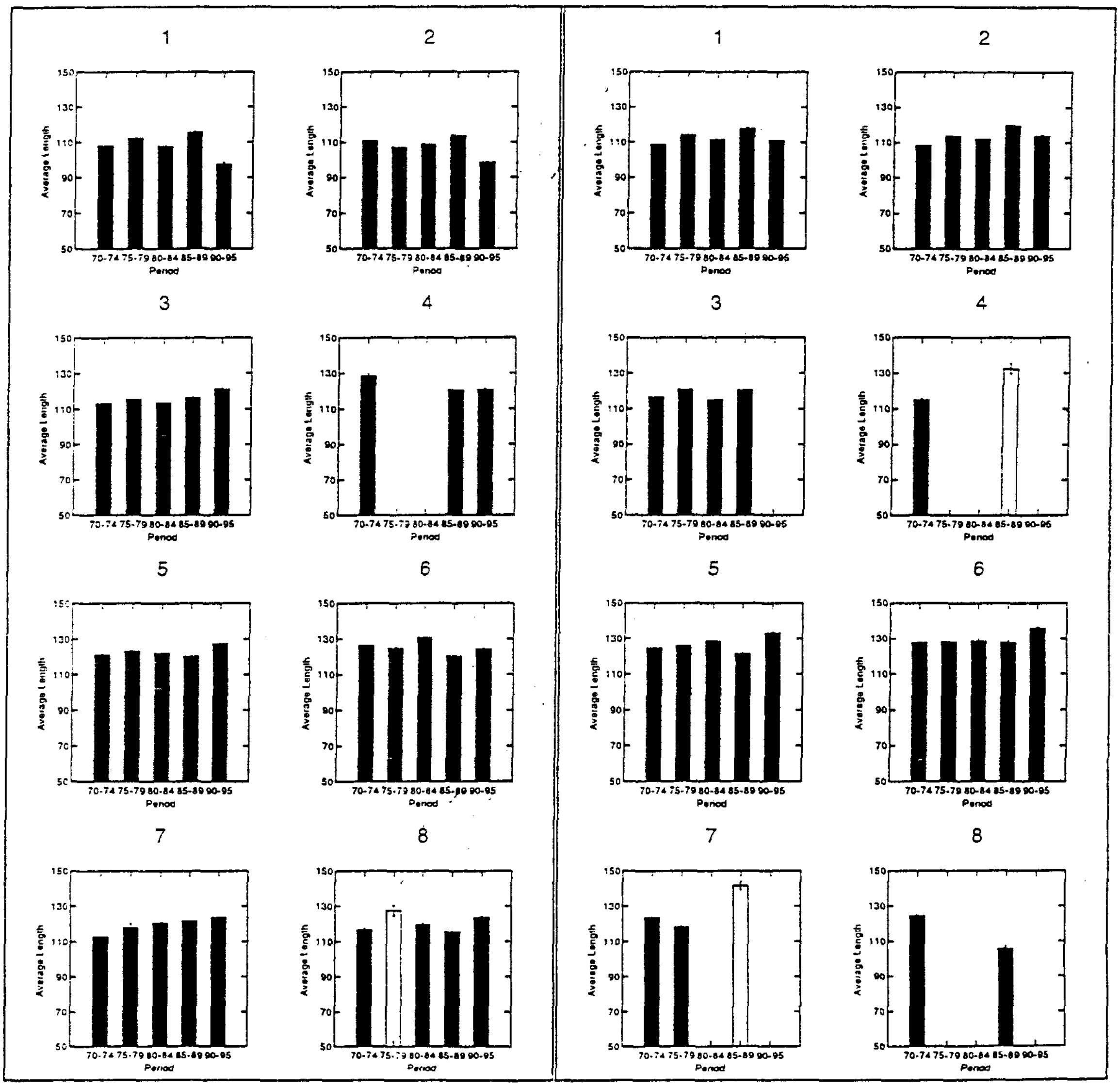


Figure 11 (cont'd). Average length of yellowfin tuna sampled in each 10-20° block by quarter where:

1. [0-9°S, 140-159°E]
2. [0-9°S, 160-179°E]
3. [10-19°S, 140-159°E]
4. [10-19°S, 160-179°E]
5. [20-29°S, 140-159°E]
6. [20-29°S, 160-179°E]
7. [30-39°S, 140-159°E]
8. [30-39°S, 160-179°E]

July-September | October-December



for each 10x20° block indicates some changes in the average size of fish between 5-year periods, there does not appear to be any consistent sequential change over the whole region. However, during the period 1990-95 there appears to have been a decrease in the average size of fish in the equatorial regions (blocks 1 and 2), while during the same period the average size appears to have increased in the more southern regions.

Overall, the results presented in Figure 11 show no consistent long-term changes in the size of fish caught by Japanese longliners in the SW-Pacific. However, this analysis, together with all the previous analyses presented, assumes that the fish sampled within each spatial-temporal period used are i) representative of the fish caught and ii) representative of the yellowfin resource itself. While the first of these assumptions can be checked, the second of these assumptions is more difficult to validate.

5. Spatial Distributions within the SW-Pacific

Superimposed on the annual changes in abundance levels and size structure of the yellowfin tuna population(s) in the SW-Pacific may be longer term changes in the spatial distributions of these resources in this region. An increasing population may extend its area of distribution, whereas a decreasing population may shrink to the main centres of its distribution. For example, a decrease in the spatial range of the southern bluefin tuna stock is thought to explain the collapse of the southern bluefin tuna fishery off southern NSW in the early 1980s. With the rebuilding of the juvenile stocks in the 1990s, and a concomitant expansion of the its spatial distribution, the fishery off southern NSW has again developed.

In order to investigate the possibility of changes in the spatial distribution of the yellowfin tuna resource within the SW-Pacific, we consider further the possibility of disproportional shifts in resource abundance within the region shown in Figure 1 eg. [0,39]°S and [140,169]°E. However, in order to understand the basis of the analysis to be presented we first consider the following hypothetical example.

Consider the distribution of catch rates shown in Figure 12. Consider also the distribution of catch rates in two subsequent years (not shown). In the second year all catch rates decline in a

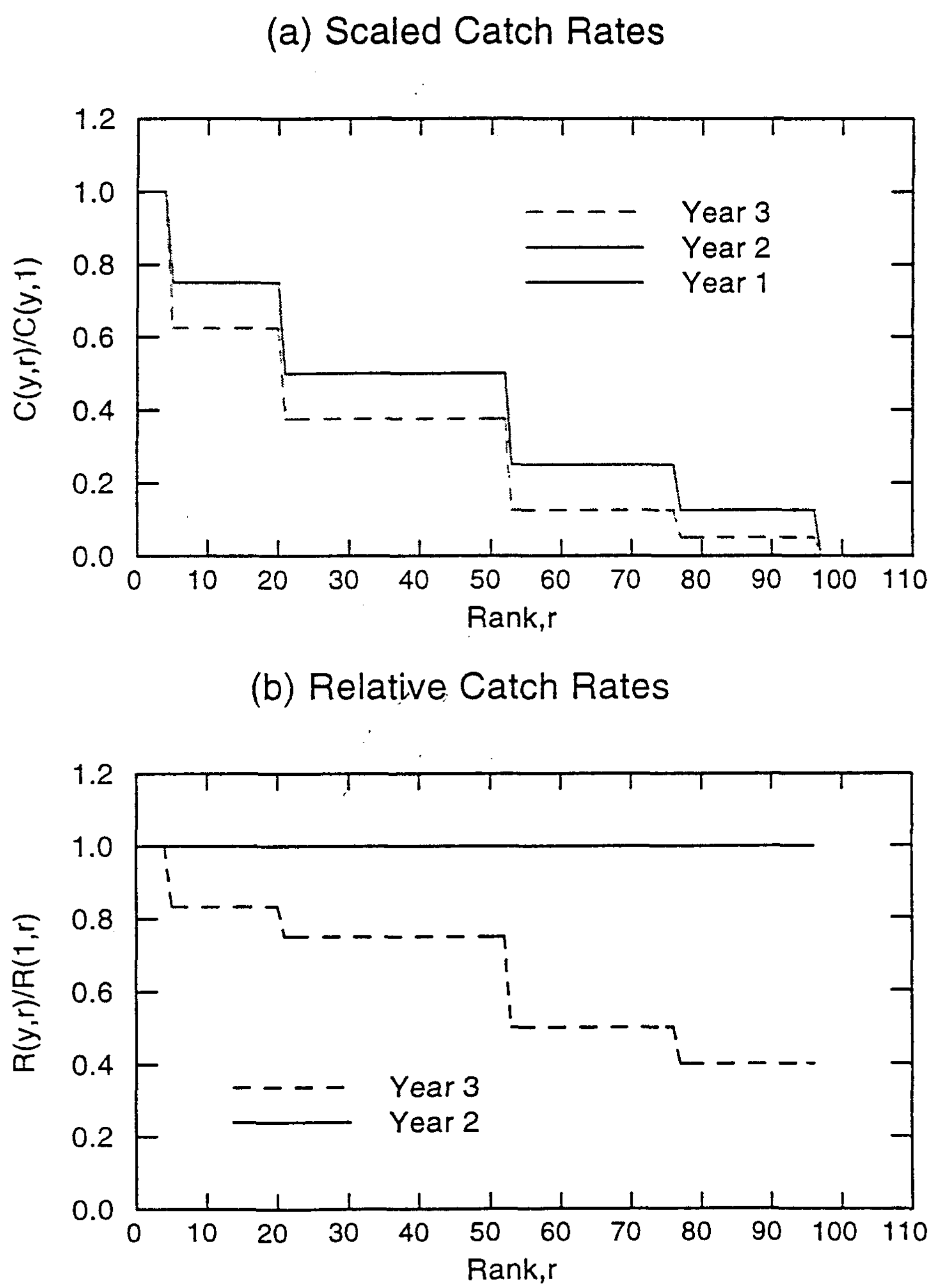
Figure 12. Hypothetical spatial distribution of catch rates used in the worked example discussed in the text.

				5	5	5	5	0			
			0	10	10	10	10	0			
		0	10	20	20	20	20	10	0		
	0	10	20	20	20	20	20	20	10	0	
5	10	20	20	30	30	30	30	20	20	10	5
5	10	20	30	30	40	40	30	30	20	10	5
5	10	20	30	30	40	40	30	30	20	10	5
5	10	20	20	30	30	30	30	20	20	10	5
0	0	10	20	20	20	20	20	20	10	0	0
		0	10	20	20	20	20	10	0		
			0	10	10	10	10	0			
				5	5	5	5	0			

Table 3. Ranked and scaled catch rates by year for the worked example described in the main text.

Rank	Catch Rates			Scaled Catch Rates			Ratio R(y,r)/R(1,r)	
r	C(1,r)	C(2,r)	C(3,r)	R(1,r)	R(2,r)	R(3,r)	Z(2,r)	Z(3,r)
1-4	40	20	20	1.00	1.00	1.00	1.00	1.00
5-20	30	15	12.5	0.75	0.75	0.625	1.00	0.83
21-52	20	10	7.5	0.50	0.50	0.575	1.00	0.75
53-76	10	5	2.5	0.25	0.25	0.125	1.00	0.50
77-96	5	2.5	1	0.125	0.125	0.05	1.00	0.40
97-108	00	0	0	0	0	0	-	-

Figure 13. Plots of annual scaled and relative catch rates versus rank for the worked example described in the main text.



spatially homogeneous manner so that in all squares they are half the value in the first year. In the third year the catch rates continue to decline but in a spatially inhomogeneous manner such that the proportional decline in the squares with a low catch rates is greater than that in the squares with high catch rates. In order to compare the distributions within each year we rank the catch rates within each square for each year. The resulting distributions, C(y,r) where r is the rank in the y-th year, are given in Table 3 where for brevity we have grouped similar ranked catch rates. In order to compare the shape of these distributions across year, each catch rate is divided by the highest catch rate for that year. The resulting distributions, R(y,r) = C(y,r)/C(y,1), are also given in Table 3 and plotted in Figure 13a. The distributions of R(y,r) are seen to be the same for the first two years while the distribution for the third year displays a greater decline with rank.

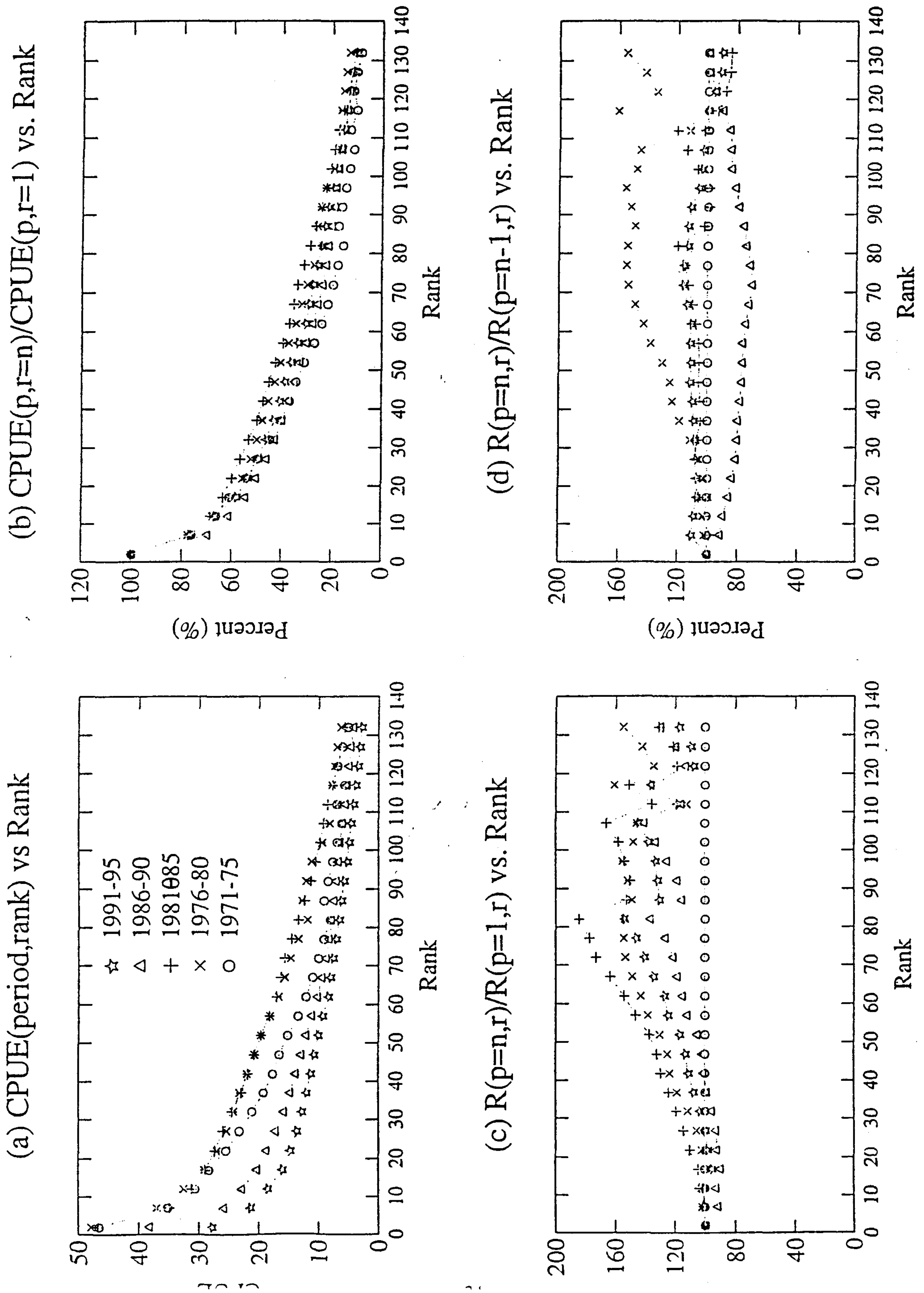
A more direct comparison of these distributions is provided by scaling the scaled catch rates in any year by the similar ranked value in the first year, ie Z(y,r) = R(y,r)/R(1,r). Again the results are given in Table 3 and displayed in Figure 13b. The resulting distributions indicate that where the change in catch rates is proportionally similar, the resulting distribution has a stationary value. On the other hand, where the change in catch rates is disproportionate the resulting distribution is non-stationary. In both situations the functional value of the distribution gives the ratio of the change in the r-th ranked square to the change in the highest ranked square. For example, the catch rate of the highest ranked square in the third year is half that of the highest ranked square in the first year, whilst the catch rate of the 90-th ranked square in the third year is only a fifth of that in the first year. Hence, the ratio of these two values is 0.5/0.2=0.4 which corresponds to the value of Z(y,r) for that rank. (Note, a more detailed discussion of this approach in analyzing changes in the spatial distributions within a fishery and its application to the southern bluefin tuna fishery is given in Campbell and Tuck, 1996.)

The above example illustrates a method for analysis of catch and effort data that allows investigation of the nature of the changes in the spatial distribution of catch rates (and hopefully the underlying resource itself) between years. For the yellowfin tuna resource within the south-west Pacific we use the one-degree square data provided by the NRIFSF. The spatial unit considered is the one-degree square and in order to filter out observations based on few samples, only those squares with three or more sets were used in the analysis. Furthermore, after the catch rates were ranked in any year, the mean catch rate in descending groups of five was calculated and only these ranked means were used in the subsequent analysis. This was done in order to help smooth out the data so that the ratio with the highest ranked square in each year was based on observations from a group of squares, not one alone. Finally, the results for each year were averaged over five yearly intervals (1970-75, 1976-80, 1981-85, 1986-90, 1991-1995) in order present average results for each period and to minimise the number of yearly comparisons.

The results of the analyses using the nominal catch rates in quarter 3 are shown in Figure 14. The following four distributions are shown:

a) Five yearly means of the ranked nominal 1x1 catch rates. These values correspond to C(y,r) in the example above where y now corresponds to the y-th five year period and r is the rank of the group of five similarly ranked one-degree squares.
b) Five yearly means of ranked nominal 1x1 catch rates expressed as a percentage of the highest ranked catch rate in that period, ie C(p,r)/C(p,1) = 100*R(p,r).
c) Relative change of similarly ranked groups of squares in the p-th period to the first period, expressed as a percentage, ie 100*R(p,r)/R(1,r) = 100*Z(p,r).
d) Relative change of similarly ranked groups of squares in the p-th period to the previous period, expressed as a percentage, ie 100*R(p,r)/R(p-1,r).

Figure 14. Details of the changes in the spatial distribution of the yellowfin tuna resources found within the SW-Pacific since 1971.



Note: the number of one-degree squares with more than three sets each year is different, varying between 85 and 248 (mean=166). The above results are based on the catch rates in the squares ranked between 1-135 in each year.

In Figure 14a the distribution of catch rates in the top 135 squares is shown. For the first three five-yearly periods the top catch rates were similar (around 47 fish per 1000 hooks), but there has been a decline in this rate over the last two periods. Between 1976 and 1985 the catch rates in most squares exceeded those in the preceding five year period, but again there is an overall decline in catch rates during the last two periods. Whilst the shapes of the distributions have remained similar over all periods (cf. Figure 14b), the period 1975-1985 had the flattest distribution while the first period had the most pronounced. These changes are shown more dramatically in Figure 14c.

After 1975 the proportional changes in catch rates has not been the same across the spatial range of the data. Indeed, for each of the periods after 1975 the catch rates in squares with a rank greater than 20 are seen to be higher than if the relative changes in the catch rates in the highest ranked squares had been spatially homogeneous across the entire distribution. However, two different factors explain these similar results. During the period 1976-1985 there was negligible change in the catch rates in the highest ranked squares, so for those squares where $Z(p,r)>100$ percent there was an absolute increase in catch rates. For the last two periods, however, there were significant declines in the catch rates in the highest ranked squares. Thus for those squares where $Z(p,r)>100$ percent the relative decline in catch rate is not as great as the decline in the highest ranked squares. Figure 14d shows that the changes that have been the most spatially inhomogeneous have taken place in the two periods 1976-80 and 1986-90. During the period 1976-80 catch rates in the highest ranked squares remained similar to those in the previous five-year period but the catch rates in the squares with a rank greater than about 20 increased. On the other hand, during the period 1986-90 there was an overall decline in catch rates with the relative decrease being greater away from the squares with the highest catch rates.

In summary, these results indicate that there have been a number of changes in the spatial distribution of the yellowfin tuna resource since 1971. Apart from the areas with the highest catch rates, there was a general increase in abundance in the period 1975-80 which persisted through the period 1981-85. During the period 1986-90 there was a decrease in abundance across the entire spatial range of the fishery (though greatest in the areas of highest catch rates) to levels below that on the early 1970s. This decline has persisted throughout the first half of the 1990s. There is no evidence, however, that the spatial range of the yellowfin tuna resource has decreased over the entire 25-year period. It is interesting to speculate whether or not the decreases seen in the late 1980s were due to the large catches taken by the purse-seine fleets which began operating in the Western/Central Pacific throughout the 1980s. On the other hand, other reasons may include responses in recruitment/availability to natural cycles in environmental conditions. Finally, the above results are preliminary and depend on a relationship between nominal catch rates and resource abundance. The analysis should ideally be repeated using standardised catch rates so that effects due to factors other than resource abundance can be eliminated from the analysis.

6. Future Work

The analyses presented in this paper make us of the data pertaining to the Japanese longline fleet which is held by the National Research Institute of Far Seas Fisheries (NRIFSF) in Shimizu, Japan. The analyses are also limited to the region in the SW-Pacific. However, in a collaborative project between the author and Dr Naozumi Miyabe of the NRIFSF to be undertaken later this year these analyses will be extended to encompass the whole Western/Central Pacific region. It is also intended to undertake a similar set of analyses on the data pertaining to bigeye tuna. The results of this work will be reported to the SCTB in 1999.

Although the results presented here indicate that there has been no long term decline in the yellowfin tuna resources in the eastern AFZ, many uncertainties remain in our knowledge about the yellowing tuna resources found in this region. Much of this uncertainty relates to the stock structure and movement dynamics of these resources, although there are also uncertainties in the biology of the species itself. Until the extent and nature of the tuna fisheries are better defined and the issue of stock structure is resolved the management of the tuna fisheries off eastern Australia will remain problematic.

While bigeye tuna and broadbill swordfish have become major target species for the domestic Australian longline fishery in recent years (Ward, 1998), yellowfin tuna remains the dominant catch species in the eastern AFZ and a high research priority. As such, over the next three years CSIRO is undertaking to construct an operational model of the yellowfin tuna resources in the SW-Pacific region. The construction of the basic underlying operational model will be guided by our current knowledge regards the population dynamics of yellowfin tuna in this region and will incorporate the results of ongoing and future analyses. However, where there is uncertainty, the model will allow for the incorporation of a range of possible hypotheses. The model will then be used to evaluate the implications to managers of the Eastern Tuna and Billfish Fishery of the range of possible hypotheses regarding the stock structure and movement dynamics of the yellowfin populations(s) in this region (Campbell et al, 1998).

Central to the range of hypotheses to be incorporated into the model are those concerning the spatial structure of the yellowfin resources within the region, especially the relationships between the tuna found in the eastern AFZ and those in the western and central Pacific. These hypotheses include the possibilities that i) these populations are separate, ii) that there is a separate Australian spawning site that provides most recruits to the eastern AFZ, and that there is occasional influxes of tuna from the greater western Pacific that join the Australian breeding group, iii) that there is a separate Australian spawning site that provides most recruits to the eastern AFZ, and that there is occasional influxes of tuna from the greater western Pacific that pass through the eastern AFZ but do not join the Australian breeding group, iv) the Western/Central Pacific consists of one stock with either slow or fast movement dynamics. Completion of another CSIRO project into the origin of yellowfin recruits to the eastern AFZ (Gunn, 1997) will help discriminate between these competing hypotheses. Analysis of the results of the Regional Tuna Tagging Program, together with those from the recreational tagging of yellowfin tuna in the AFZ, should also assist in refining possible movement hypotheses.

The movement dynamics of tuna in relation to large-scale oceanographic features also remains uncertain. Central to this issue is the effect of inter-annual variations in the strength of large–scale oceanographic features on the relation between the resources found off eastern Australia and those in the Western/Central Pacific. For example, it is hypothesized that the movement of tropical water from the western pacific into the eastern AFZ may be linked with ENSO oscillations, and that recruitment, particularly under hypothesis (iv) above, would be low in El Nino years and high in La Nina year. Indeed, in line with this hypothesis, there was a large recruitment of 2-year-old yellowfin tuna into the eastern AFZ during the La Nina year of 1996. The ongoing collection of size information of the fish caught by domestic longliners operating within the eastern AFZ will assist in the understanding of such events. On a smaller scale the movement dynamics of yellowfin tuna in relation to the East Australia Current, which is thought to be the principle vector for transport of tuna along the east coast of Australia, also needs to be better understood. To this end CSIRO is presently undertaking a study to assess the relationship between sea-surface temperatures and ocean productivity (using the SeaWifs satellite) and the distribution of tunas caught off the east coast of Australia (Anon, 1997).

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