EXPLORATORY ANALYSES OF JAPANESE LONGLINE CATCH AND EFFORT DATA IN THE INDIAN OCEAN

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ABSTRACT

Document WPTT-01-13 presents a large number of analyses that summarize various aspects of the Japanese longline catch-and-effort data in the Indian Ocean since 1952. In particular, the analyses highlight the large spatial and temporal changes in the fishery over time and which need to be accounted for in stock assessments. The document shows that the fishery in the tropical regions of the Indian Ocean expanded rapidly throughout the 1950s and continued to expand spatially throughout the temperate regions until around 1970. There have also been large changes in the species composition of the total catch which indicate that significant changes in the spatial distribution of effort and targeting practices have occurred over time. Since 1970 fishing has occurred in around 150 five-degree squares each year, though the spatial distribution of the squares fished in any particular year can change significantly between years as does the spatial distribution of effort and catch rates. For most years, 95 percent of the bigeye catch is taken in around 50 five-degree squares (or about one-third of the total area fished). The document also highlights the fact that most five-degree squares have been fished infrequently over time. Furthermore, on a quarterly time-basis, the amount of effort deployed in five-degree squares is highly skewed, with most squares having little effort. For example, 21 percent of squares have less than 10,000 hooks (approx 3-4 sets). The extreme differences in the amount of effort within five-degree/quarter strata indicates that very large differences exist in the relative precision of catch rates and that for a large number of strata relative abundances are not well estimated. This problem is worse if one considers five-degree/month strata.

INTRODUCTION

In lieu of more integrated stock assessments, the calculation and interpretation of annual indices of stock availability based on the standardisation of catch and effort data remains an important focus of fisheries research within the Indian Ocean. A review of papers presented at past meetings of the IPTP and IOTC pertaining to such research has been given by Nishida (2001).

At the first meeting of the Working Party on Tropical Tunas, held in October 1999, Okamoto and Miyabe presented the results of work on standardising Japanese longline CPUE in the Indian Ocean fishery between 1952 and 1998 (Okamoto and Miyabe, 1999). Their results indicated that abundance levels of bigeye tuna in the tropical regions of the Indian Ocean (north of 20^{o}S) had declined over the period studied. Abundance in 1998 was estimated to be about 50 percent of 1977 level, and 36 percent of that in 1954. An unusual feature of the results, however, was a large jump in the annual index after 1976, the reasons for which remained unclear. Possible reasons included changes in fishing methods (possibility associated with the introduction of new gear technologies), the greater availability of bigeye tuna due to environmental shifts, or an unusually large recruitment event.

At the recent meeting of the Working Party on Methods (held April 2001), several papers were presented which investigated reasons for the large jump in bigeye CPUE after 1976. Okamoto, Miyabe and Inagake explored the likelihood of two hypotheses to explain this observation (Okamoto, et al, 2001). The first looked at whether there had been a concentration in fishing effort in regions of relatively high CPUE, while the second explored the possibility of an unusually large recruitment of bigeye tuna. However, the authors could not find any evidence to support either hypothesis. The introduction of deeper longlining was also ruled out as the principal factor leading to the sudden jump in CPUE in 1997, though large-scale changes in environmental conditions throughout the Indian Ocean could not be.

A review of factors included in models used to standardise CPUE data (Nishida and Shono, 2001) indicates that few, if any, models have included year interaction terms. However, such terms will be significant if there are large interannual shifts in the distribution of the resource and or area-specific changes in fishing practices over time. In order to help clarify the need for the inclusion or otherwise of such terms, and to investigate other factors which may have a bearing on the interpretation of CPUE patterns in the Indian Ocean this paper presents a rather detailed exploratory analysis of the Japanese longline catch and effort data.

TOTAL ANNUAL CATCH AND EFFORT

The annual effort and associated total catch (in number of fish) of the nine principal tuna and billfish species for Japanese longliners operating in the Indian Ocean since 1952 are shown in Figure 1. Total effort increased dramatically during the 1950s and 1960s, peaking at around 126 million hooks in 1967. Total catch first peaked at around 3.3 million fish in 1962, then peaked again at around 3.67 million fish in 1968. Since the late 1960s, total annual effort has oscillated significantly, with effort during the late 1970s and early 1990s being less than half the peak effort. However, effort levels in the early 1980s and mid-1990s were again similar to the peak level of 1967. The spatial distribution of effort (shown in Figure 2) shows the expansion of the fishery towards the southern Indian Ocean throughout the 1950s and 1960s, and the dramatic shift associated with the increased targeting of southern bluefin tuna below 35°S after the mid-1960s. Commensurate with the changes in effort, total catches has also varied significantly, though since 1972 the total annual catch has never exceeded 1.26 million fish (being less than 40 percent of the peak catch).

The annual total effort and total catch (again of the nine principal tuna and billfish species) within each quarter of the year (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec) is shown in Figures 3 and 4. The annual pattern in both effort and catch is seen to be similar across all quarters and indicates the year round nature of the fishery.

AREAS FISHED

Within the region of interest, (25°N-60°S, 20°E-145°E), and across all years, fishing operations have occurred within 247 five-by-five degree squares of latitude and longitude. The variation in the annual spatial coverage of the fishery is shown in Figure 5a. After a rapid expansion during the 1950s and 1960s, the fishery reached its maximal extent in any one year in 1967 when 220 five-degree squares were fished. During the 1970s the annual extent of fishery decreased to between 140-150 squares after which time it has remained relatively stable (though rising to around 160 squares during the 1990s).

Also shown in Figure 5a is the number of squares in each year which account for the top 95 percent of the total bigeye catch. This collection of squares, referred to as the core bigeye region, is seen to be about one-third of the total number of squares fished in any year.

The frequency and consistency with which different five-degree squares have been fished has been highly variable (Figure 6). Twenty-nine squares have been fished for either 45 or 46 of the 48 years between 1952 and 1999 while15 squares have been fished for only 1 or 2 of those years. Ninety-eight (40%) of the 247 squares have been fished less than half the 48 years, with only 52 squares (21%) being fished for more than 40 years.

The spatial coverage of the fishery has been greatest during the first half of the year with 237, 240, 217 and 221 five-degree squares fished within each of the four quarters respectively. Variations in the extent of the fishery each quarter are shown in Figure 5b. On a monthly basis, the number of squares that were fished at least once is shown in Figure 7 and indicates that the fishery has reached it maximal spatial extent during May and its least spatial extent during August. The consistency and frequency with which squares have been fished on a monthly basis is also highly variable. (Figure 8). However, on a monthly basis the frequency distributions tend to be highly skewed indicating that a large proportion of the squares have been fished relatively infrequently.

Figure 9 provides a geographic display of the five-degree squares in which there has been some fishing effort within each quarter. For each square, the size and shading of the circle represents the number of years in which fishing occurred in that square. Squares in which the circles are small and lightly shaded have been fished less than half (n<25) of the 48 years between 1952 and 1999. It is evident from this figure that there are regions that have been consistently fished, regions that have been intermittently fished and regions that that have been fished very infrequently. The consistently fished regions are clustered into three broad areas - the northern Indian Ocean (north of 15oS), off southern Africa and off south-western Australia. The last two of these regions also coincide with two of the main fishing grounds for southern bluefin tuna (Polacheck and Preece, 2001).

UTILISATION

The utlisation pattern (ie the pattern of years in which squares were fished) can provide insights into how the fishery operated. Figure 10 displays the history within each quarter of the total number of five-degree squares that had been first fished by the end of a given year and the number of squares that were never fished again after a given year. The spatial extent of the fishery each year is seen to have expanded in a generally linear manner throughout the 1950s and 1960s. However, by 1970 nearly all five-degree squares ever to be fished had been fished at least once. Indeed, on an annual basis only nine five-degree squares were fished for the first time after 1970. During the expansion phase nearly all squares continued to be fished, with only 8 squares fished before 1970 not being fished after this time. After 1970, the rate at which squares were not fished again is seen to have increased in a relatively linear manner, though there appears to have been an increase in this rate since the mid-1990s. Note, the jump in the last year is due to the fact that all squares where last fished in that year. In summary then, the period between 1952 and 1999 can be divided into two broad periods - a period of expansion between 1952 and 1970 followed by a period of consolidation between 1970 and 1999.

EFFORT CONCENTRATION

The amount of effort within five-degree square/quarter strata varies enormously (Figures 11a,b), from a minimum of less than 10,000 hooks to more than 9 million hooks (being equivalent to ~33 vessels setting 3000 hooks everyday for 3 months). The overall distribution of the number of hooks set within a square/quarter is highly skewed with most strata with any effort (72 percent) having less than 150,000 hooks deployed. Furthermore, of these strata, 30 percent (and 21 percent of all strata) have less than 10,000 hooks deployed. This extreme difference in the amount of effort within a five-degree/quarter strata indicates that very large differences exist in the relative precision in the average catch rates and that for a large number of strata relative abundances are not well estimated. This problem is worse if one considers five-degree/month strata.

Spatial squares that were less frequently fished also tend to have fewer number of hooks deployed in them when they were fished (Figure 12). However, even for squares that were fished in nearly every year (35-48 years), 17.5 percent of the quarters (and 27 percent of the months) in which they were fished had less than 10,000 hooks deployed.

VARIATIONS IN EFFORT DISTRIBUTIONS ACROSS YEARS

Tuna and billfish, together with the industrial longline fleets that caught them, are both highly mobile. Spatial shifts in the distribution of the tuna and billfish populations from one year to the next, possibly in response to large-scale oceanographic events, can lead to spatial shifts in the distribution of fishing effort. These shifts, in turn, influence the manner in which five-degree squares are fished, or sampled, from one year to the next. In order to ascertain some measure of the level at which fishing areas change between years, the percentage of squares fished in a given year which where also fished or not fished in the next year was calculated. The results are shown in Figure 13 and indicate that for most years between 60-80 percent of the squares that are fished in a given year are also fished during the next year. However, of interest is the fact that there are a number of years during the 1970s when this percentage is lower than usual. In particular, in 1977, only around 50 percent of the squares fished the previous year are fished, indicting that there was a significant change in the spatial pattern of fishing effort between these two years.

Changes in the spatial pattern of effort and bigeye catches are also seen in Figures 14a,b where values of the Pearson correlation coefficient relating the spatial distribution of these variables between adjacent years are displayed. The results indicate a smaller correlation between the annual distributions of bigeye catches during the 1970s than for other periods. In particular, the correlation of catch patterns between the fourth quarters of 1976 and 1977 is nearly zero, indicating a large shift in the spatial distribution of the catch. This shift can be clearly seen in Figures 15a,b.

Contingent with these changes in catch and effort distributions we can also investigate changes in the relationship between the distribution of effort in relation to bigeye catch rates. For this purpose, we plot the percentage of effort in the top percentage of squares fished each year ranked by bigeye CPUE. The results for each quarter are shown in Figures 16. Beginning around 1970, it is seen that a greater proportion of the annual effort was found in the squares with low bigeye CPUE. This change is largely due to effort shifting to the fishing grounds of southern bluefin tuna. However, there are a number of years, particularly during the 1970s, when the level of effort in squares having bigeye CPUE ranked between 20 and 60 percent is low. This can be seen by the closeness of the lines for these years. For these years and areas the level of sampling appears to be quite low.

SPECIES COMPOSITION

The total annual catch by quarter of each species is shown in Figure 17, while the catch of each species expressed as a percentage of the total quarterly catch is shown in Figure 18. As with the annual total, the total catch in each quarter shows a rapid increase during the 1950s during which yellowfin and albacore tuna where the dominant catch species. Catches peaked at over 1 million fish during each quarter on several occasions during the 1960s, with southern bluefin tuna accounting for a greater proportion of the catch. (Note, however, that the timing of the increase in SBT catches is seen to vary across quarters). There was a dramatic decrease in total catch during the late 1960s, with catches continuing to decline during the 1970s. By the mid-1070s, total catches were less than 200,000 fish (less than 20 percent of the peak catches) during all quarters. These changes no doubt reflect large-scale changes in the nature of the fishery and to some extent are seen in the species composition of the catches. For example, in the first and fourth quarters bigeye tuna accounted for a greater proportion of the total catch, whilst in the second and third quarters both bigeye and southern bluefin tuna become more dominant. After decreasing during the 1970s, total catches increased again during the first half of the 1980s then decreased again, reaching a low point around 1990. Catches have generally increased again during the 1990s. Catches of southern bluefin tuna decreased significantly during the 1990s, with yellowfin and bigeye making up a greater proportion of the total catch.

Marked latitudinal differences also exist in the composition of the catches. For example, the proportion of the total annual catch of bigeye, yellowfin, southern bluefin, albacore and swordfish that is bigeye within 10-degree latitudinal bands is shown in Figure 19. It can be seen that very little bigeye is caught below 40°S, while between 30-39°S the percentage of bigeye in the total annual catch has varied between 5-40 percent. Furthermore, this percentage displays an irregular increase from the late-1950s until the mid-1990s, after which time is has decreased sharply. Between 20-29°S, the percentage of bigeye in the total catch has also fluctuated significantly between years, but increased sharply to 40-60 percent during the 1990s. Between 20°S and 9°N, the percentage of bigeye in the catch shows a general increase over time, peaking at over 60 percent during the second half of the 1970s and remaining at over 50 percent since that time.

The changes observed in the total catch and the species composition of these catches since the fishery began in the early 1950s no doubt reflect major changes and shifts in the fishery during the past forty years. Some of these changes can be seen in changes in the spatial distribution of effort in the Indian Ocean over the last forty years (cf. Figure 2). Other changes, such as those associated with changes in targeting practices and other aspects of fishing strategies are, however, more difficult to ascertain. The increases observed above in the percentage of bigeye in the catch may be associated with increased targeting of this species, but other factors such as changes in retention practices (ie. albacore) may also be important. Since the mid-1970s, the practice of setting more hooks between the floats has been used to set the longline deeper so as to target deeper swimming tunas (especially bigeye). Details of the number of longline sets using the different gear configurations were given by Okomoto and Miyabe (1999) and the number of sets having different gear configurations is given in Figure 20. These authors grouped the different configurations into thee categories: 4-9 hooks-per-basket (hpb), 10-15 hpb and 16-21 hpb. The percentage of sets each year within each of these categories is shown in Figure 21a. The annual changes associated with a finer level of categorisation are shown in Figure 21b.

TEMPORAL TRENDS IN EFFORT AND BIGEYE CPUE WITHIN SQUARES

Figure 22 displays the number of five-degree squares fished each year and quarter stratified by the level of fishing effort. While the number of squares fished each year has varied by a factor of two, the proportion of squares in a year/quarter assigned different levels of effort has remained relatively constant, especially since the early 1970s. The one departure from this pattern is the observation that the while the number of squares fished in a year has varied, the number having more than 1 million hooks has remained fairly constant over time in all quarters. This pattern suggests that each quarter there is a relatively constant number of five-degree squares in which fishing effort is concentrated, with effort levels stratified over a fluctuating number of more marginal areas.

Figure 23 displays the number of five-degree squares fished each year and quarter stratified by the level of nominal bigeye CPUE. Only a few squares each quarter are seen to have a CPUE of 20 fish/1000 hooks or greater. Furthermore, the number of such squares is seen to have decreased over time. A similar trend is also seen for those squares with a CPUE of 10 or greater. The number of squares supporting a CPUE of 5 or greater has remained more stable over time, though to some extent this is off-setting the decrease in squares with higher CPUE. These changes would seem to imply that the number of areas supporting high catch rates of bigeye has decreased over time. However, as there is a relatively large degree of interannual variation in the number of such squares, other changes in the fishery, such as changes in targeting practices, may be contributing to the patterns observed in Figure 23. Finally, as the total number of squares fished each quarter has increased over the last twenty years, the number of squares having low levels of bigeye CPUE is also seen to have increased. It would appear then that the number of squares which can support high catch rates of bigeye tuna is somewhat limited (perhaps to a few core regions) and that expansion of the fishery to other regions of the Indian Ocean has not off-set the decrease in catch rates seen in these core regions.

RANKINGS OF SQUARES BY EFFORT AND BIGEYE CPUE

The relative ranking with respect to the amount of effort and bigeye catch rates was calculated for each five-degree square within a year and quarter. The results, shown in Figures 24 and 26 indicate that the mean rank for a square is not highly related to the number of years that it was fished either with respect to effort or CPUE. Although there is some tendency for squares that were fished more frequently to have a lower mean rank with respect to effort, there is, however, a very high variability in the ranking of a square among years both with respect to effort an catch rates. This is evident in Figures 25 and 27, where the maximum and minimum ranking for each square is plotted as a function of the number of years in which it was fished. As evident in these figures, in most cases where a square has been fished frequently, its rank can vary from having had the highest effort or CPUE to having had the lowest. Similarly, the ranks are highly variable among infrequently fished squares.

APPENDIX

A similar (but more selected) set of figures which summaries the results of the data analysis for the tropical regions of the Indian Ocean only is provided in the Appendix.

REFERENCES

NISHIDA, T. (2001) Review of "CPUE standardisation of the industrial longline tuna fisheries" and "Production model analyses" for yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) resources in the Indian Ocean. Working paper WPM-01-04 presented at the 1st meeting of the Working Party on Methods, held 23-27 April 2001, Sete, France.

OKAMOTO, H., N. MIYABE AND D. INAGAKE (2001) Interpretation of high catch rates of bigeye tuna in 1977 and 1978 observed in the Japanese longline fishery in the Indian Ocean. Working paper WPM-01-01 presented at the 1st meeting of the Working Party on Methods, held 23-27 April 2001, Sete, France.

OKAMOTO, H. AND N. MIYABE (1999) Standardised CPUE of bigeye caught by the Japanese longline fishery in the Indian Ocean, up to 1998. Working paper WPTT-99-06 presented at the 1st meeting of the Working Party on Tropical Tunas, held 1-4 September 1999, Victoria, Seychelles.

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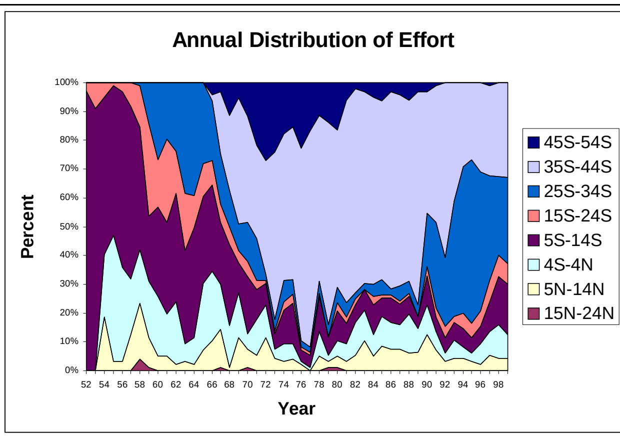


Figure 1: *Total annual catch and effort for Japanese longline vessels operating in the Indian Ocean. (Note: total catch is the combined catch of albacore, bigeye, southern bluefin and yellowfin tunas, black, blue and striped marlin, swordfish and sailfish.)*

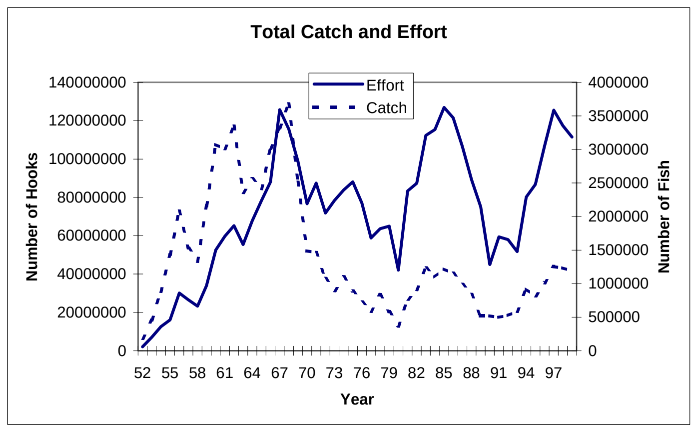


Figure 2: *Total annual Japanese longline effort of within each 10-degree strip of latitude.*

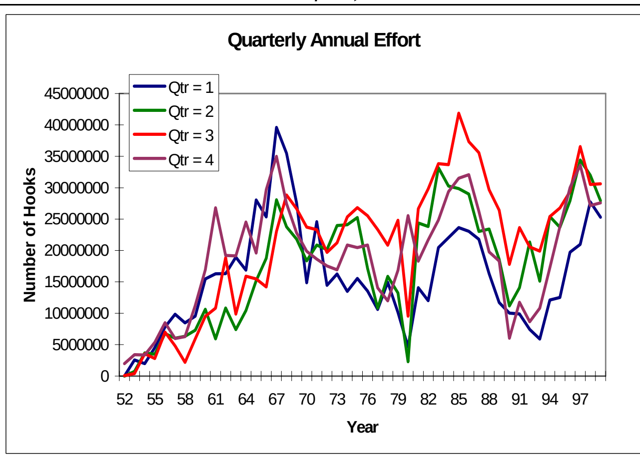


Figure 3: *Annual effort, by quarter, for Japanese longliners operating within the Indian Ocean. (Qtr 1 = Jan-Mar, Qtr 3 = Apr-Jun, Qtr 3 = Jul-Sep, Qtr 4 = Oct-Dec).*

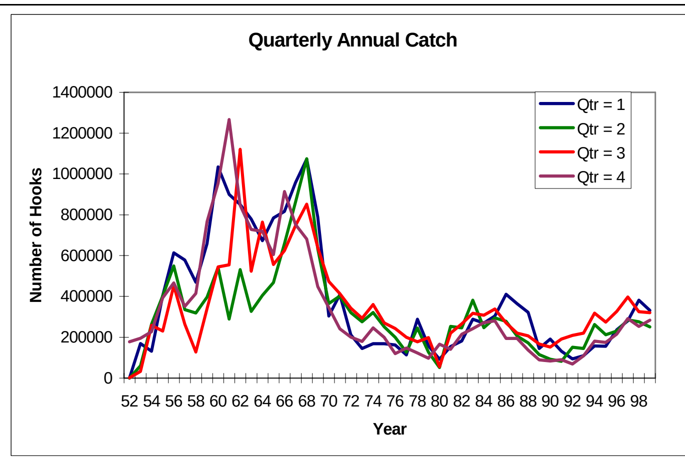
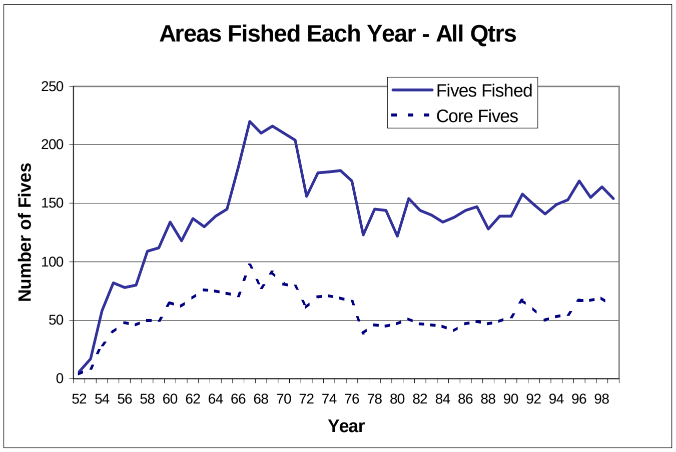


Figure 4: *Annual catch of tunas and billfish, by quarter, for Japanese longliners operating within the Indian Ocean.*



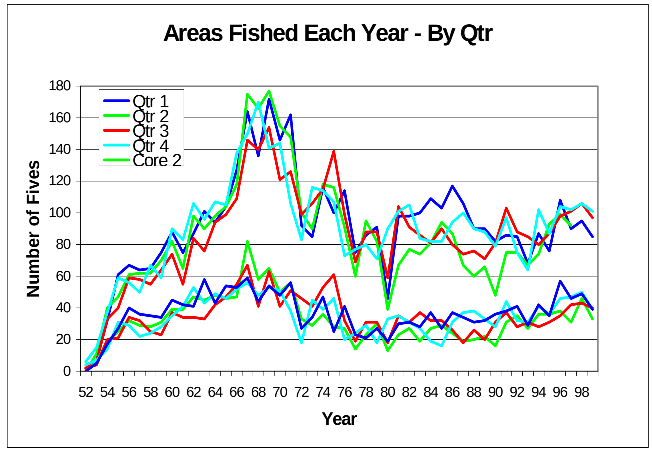
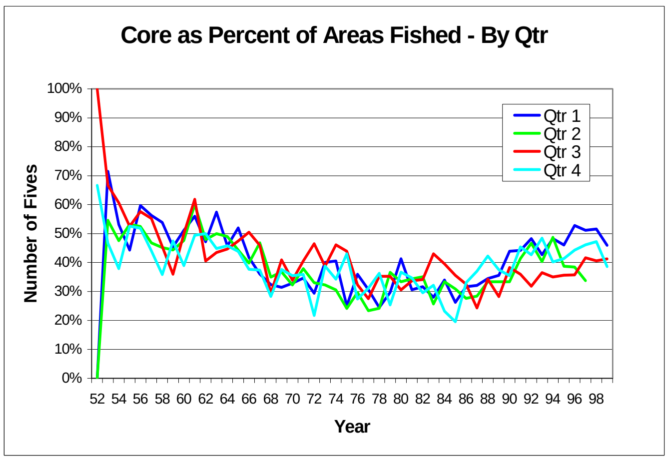


Figure 5a: *Total number of five-degree squares fished each year, together with number of squares comprising the core bigeye tuna fishery.*

Figure 5b*: Number of fives fished each quarter and within the core bigeye fishery***.**



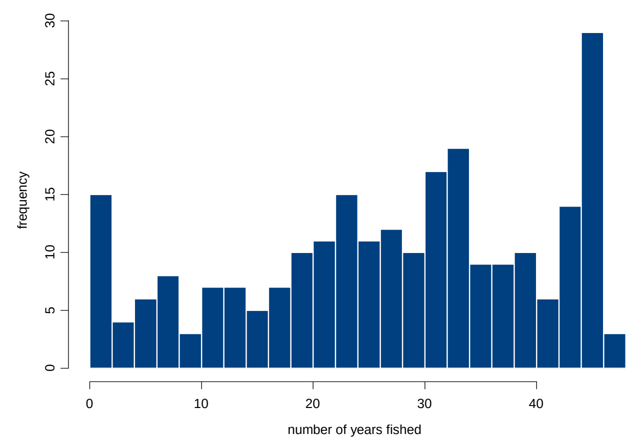


Figure 5c: *Spatial extent of the core biyeye fishery expressed as a percentage of the total spatial extent of the fishery each quarter.*

Figure 6: *The frequency distribution of the number of years that a five degree square has been fished between 1952 and 1999.*

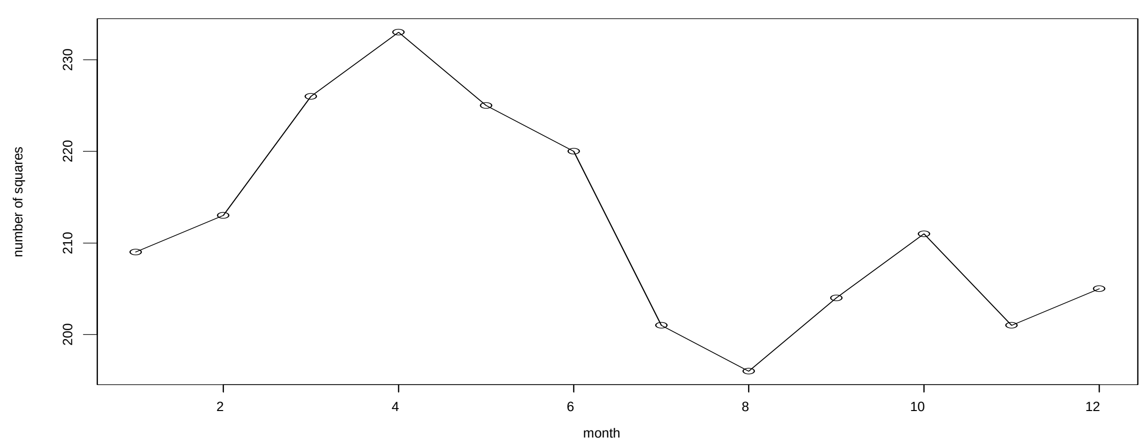


Figure 7: *The number of five-degree squares within each month that have been fished at least once between 1952 and 1999.*

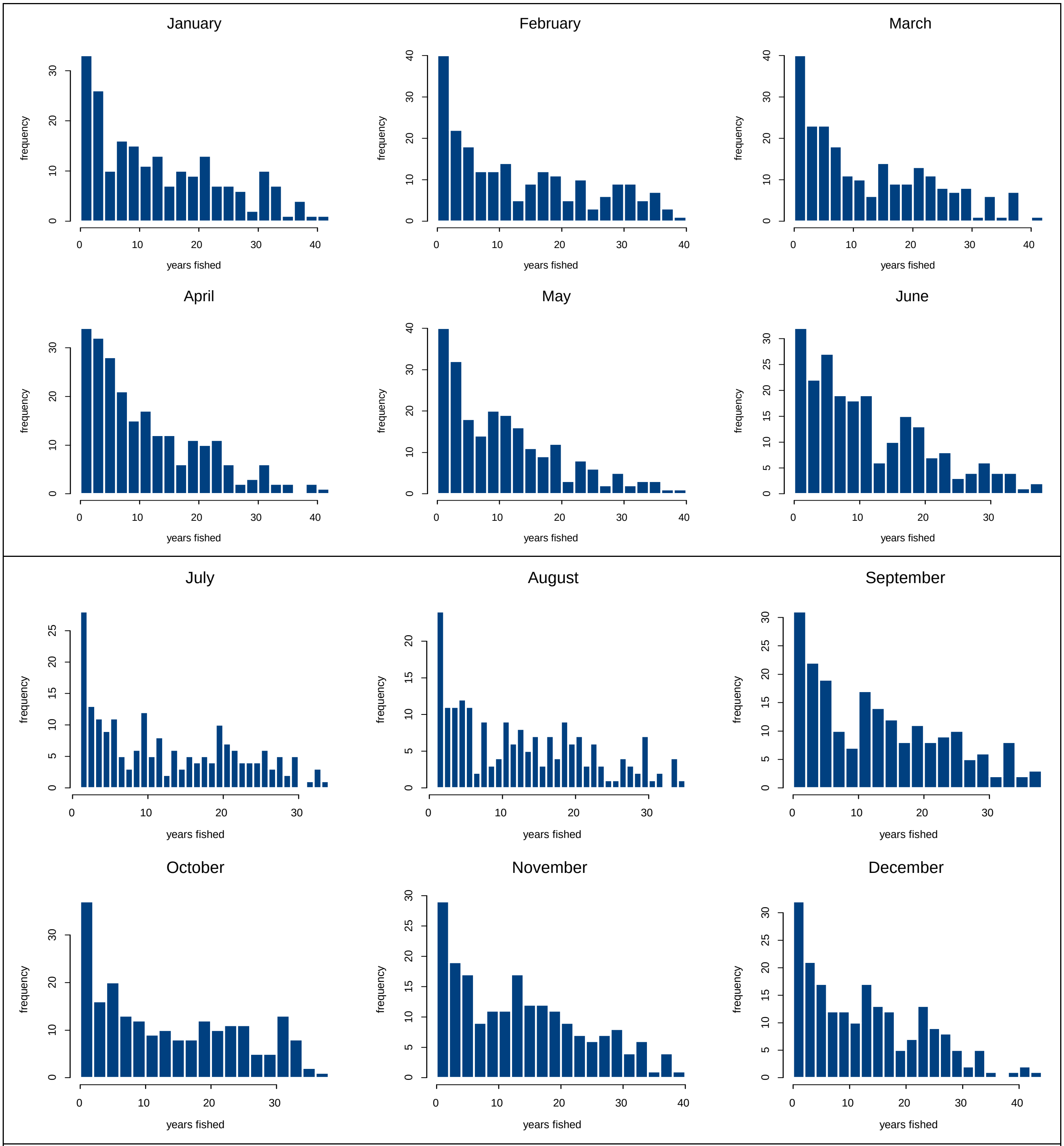


Figure 8. *Frequency distributions for each month of the number of years each five-degree square is fished.*

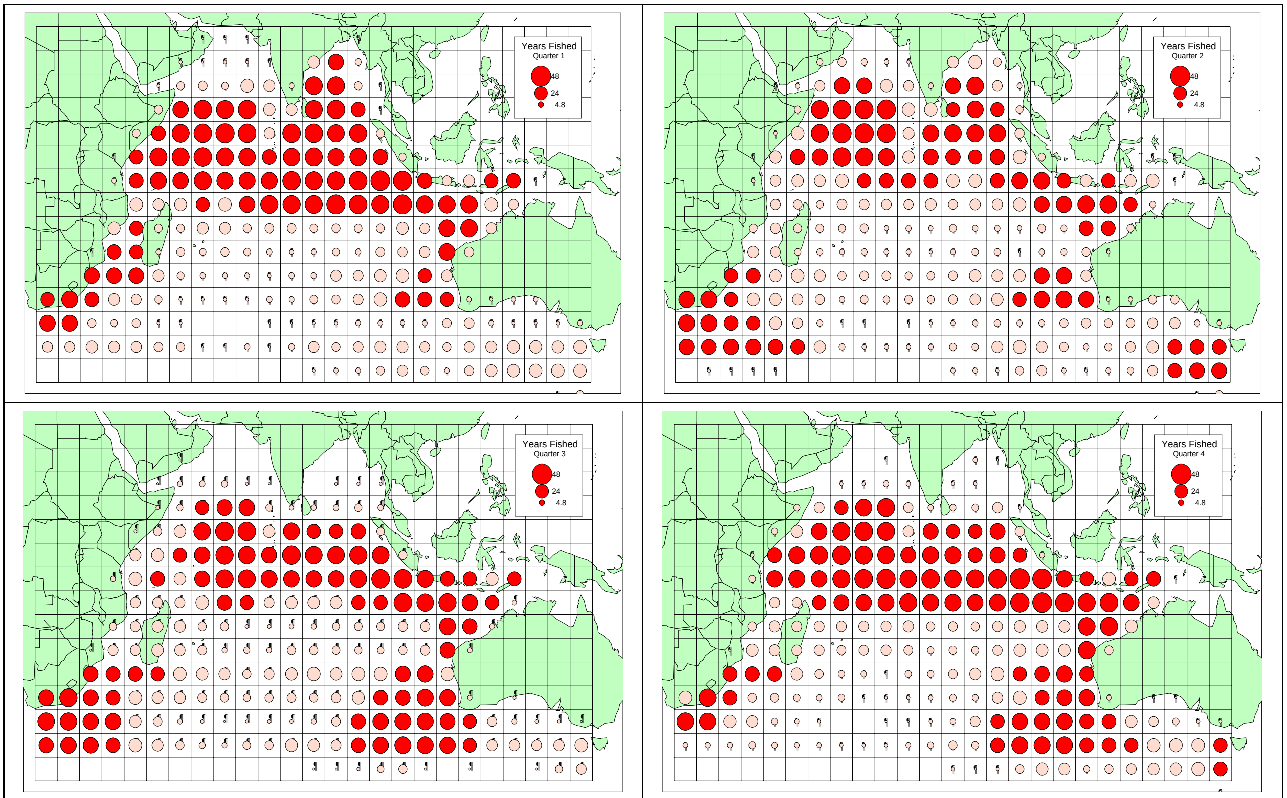


Figure 9: *Number of years fished for each five-degree square.*

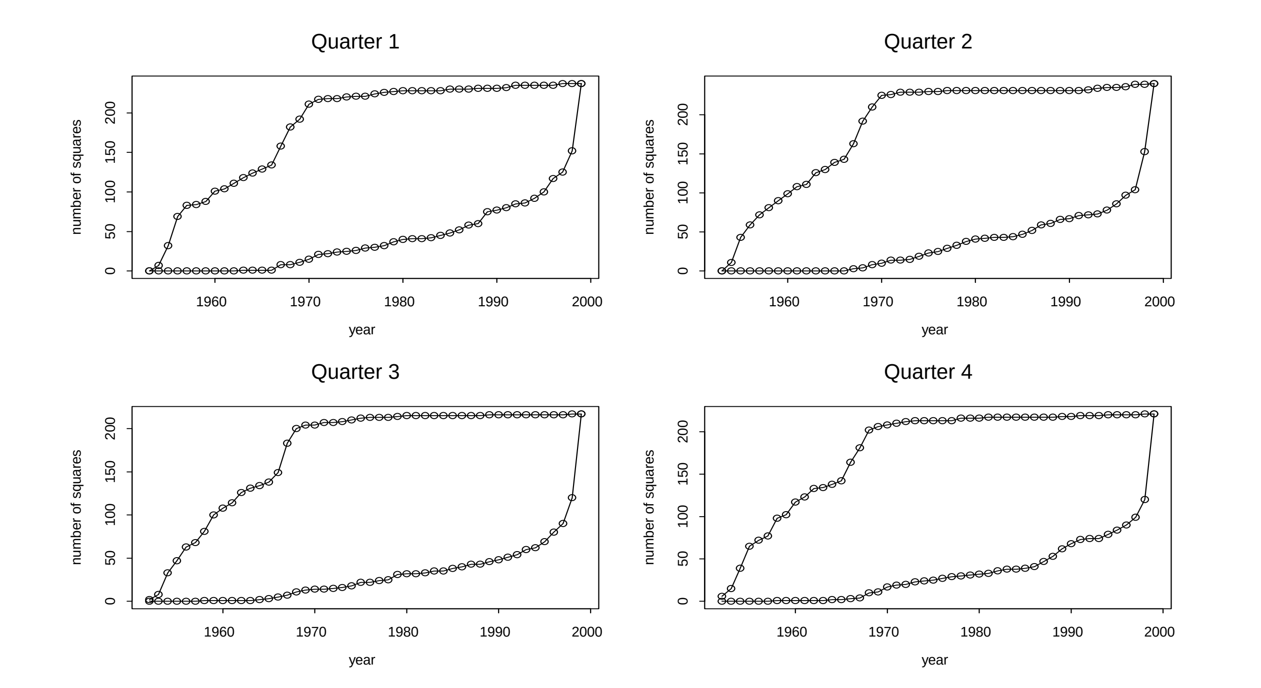


Figure 10: *The total number of 5-degree squares for each quarter that had been fished at least once prior to the end of a given year (upper line) and the total number of squares that were never fished after that given year (lower line).*

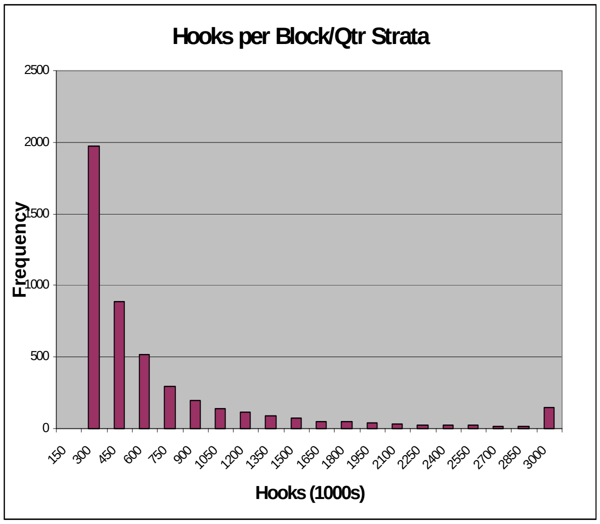


Figure 11a: *Histogram of the number of hooks within those five-degree/quarter strata where the number of hooks is greater than 150,000.*

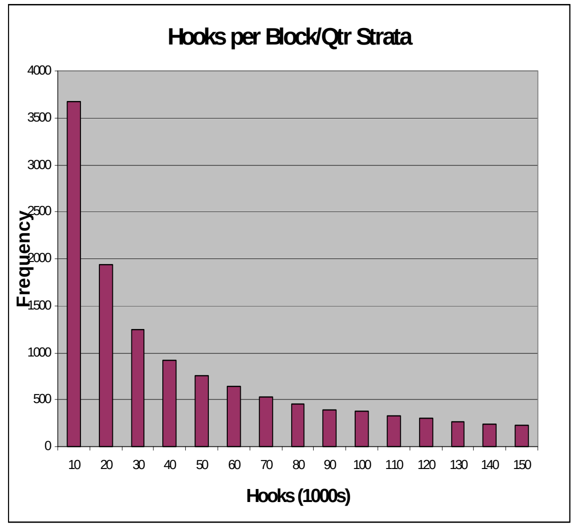


Figure 11b*: Histogram of the number of hooks within those five-degree/quarter strata where the total number of hooks is less than 150,000.*

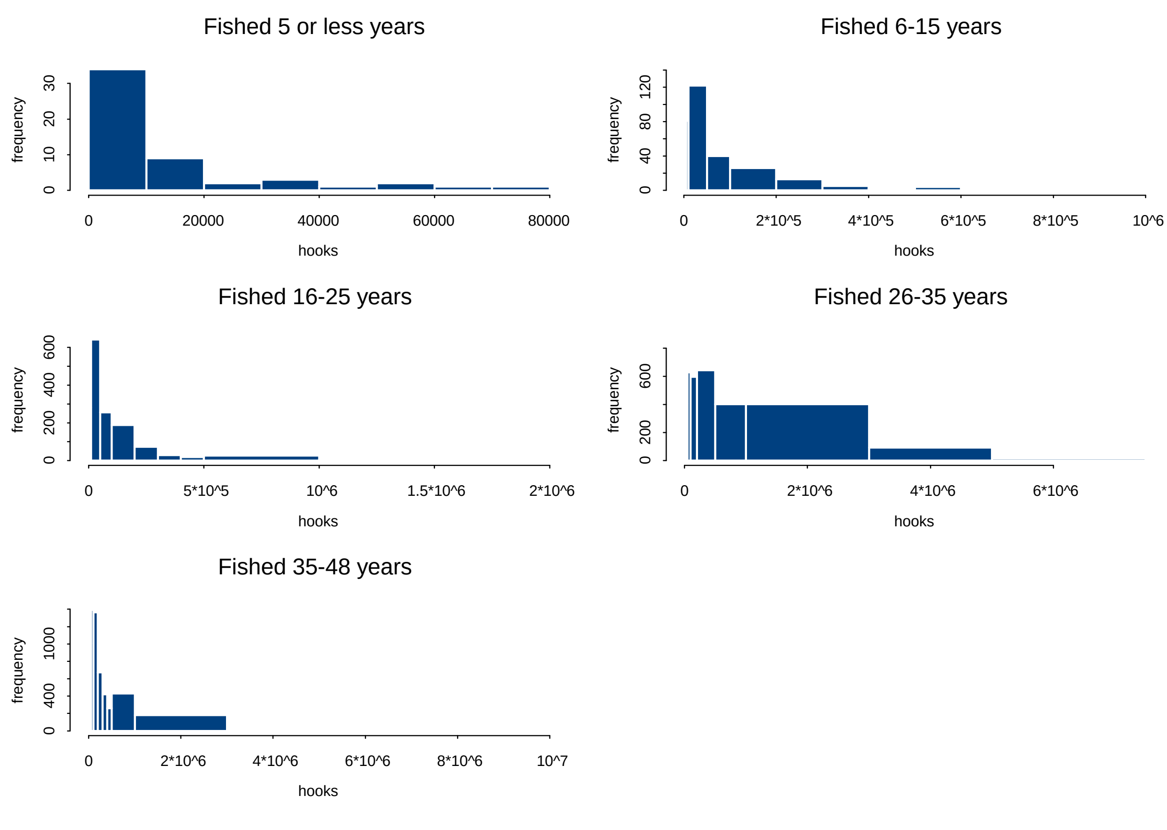


Figure 12: *Frequency distributions for the number of sets within a five-degree/quarter strata given that a strata was fished in a given quarter. The strata have been separated into the number of years in which they were fished. Data have been pooled across all years and regions.*

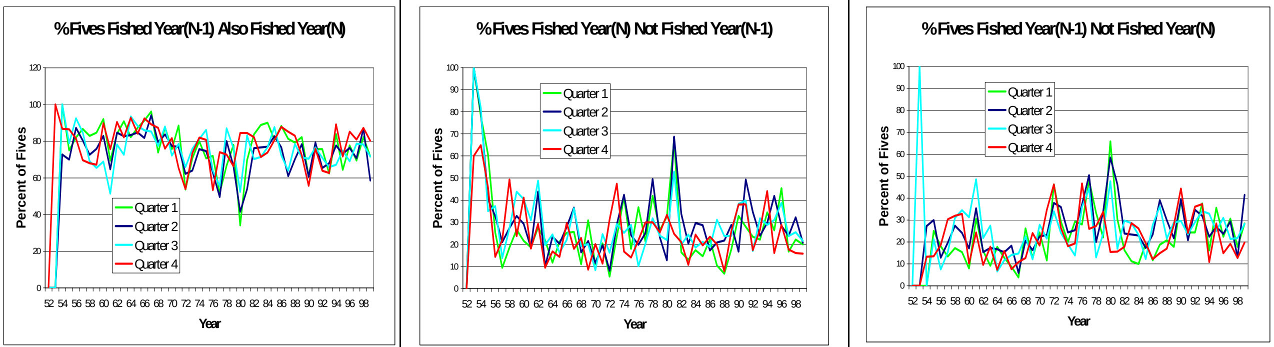


Figure 13: Relationships between the number of five-degree squares fished in adjacent years.

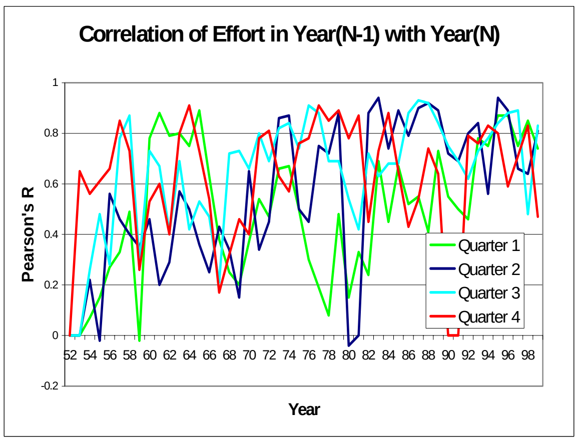


***Figure 14a**: Correlation between the spatial distribution of effort across five-degree squares in adjacent years.*

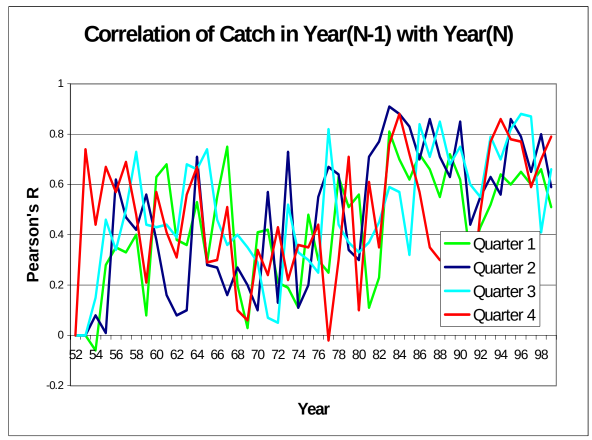


***Figure 14b**: Correlation between the spatial distribution of catch across five-degree squares in adjacent years.*

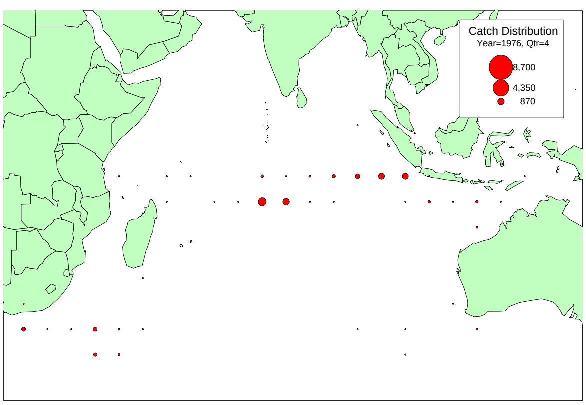


***Figure 15a**: Distribution of the bigeye catch in the fourth quarter of 1976.*

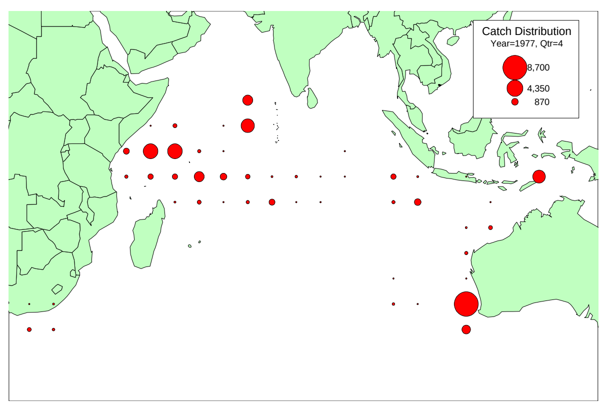


***Figure 15b**: Distribution of the bigeye catch in the fourth quarter of 1977.*

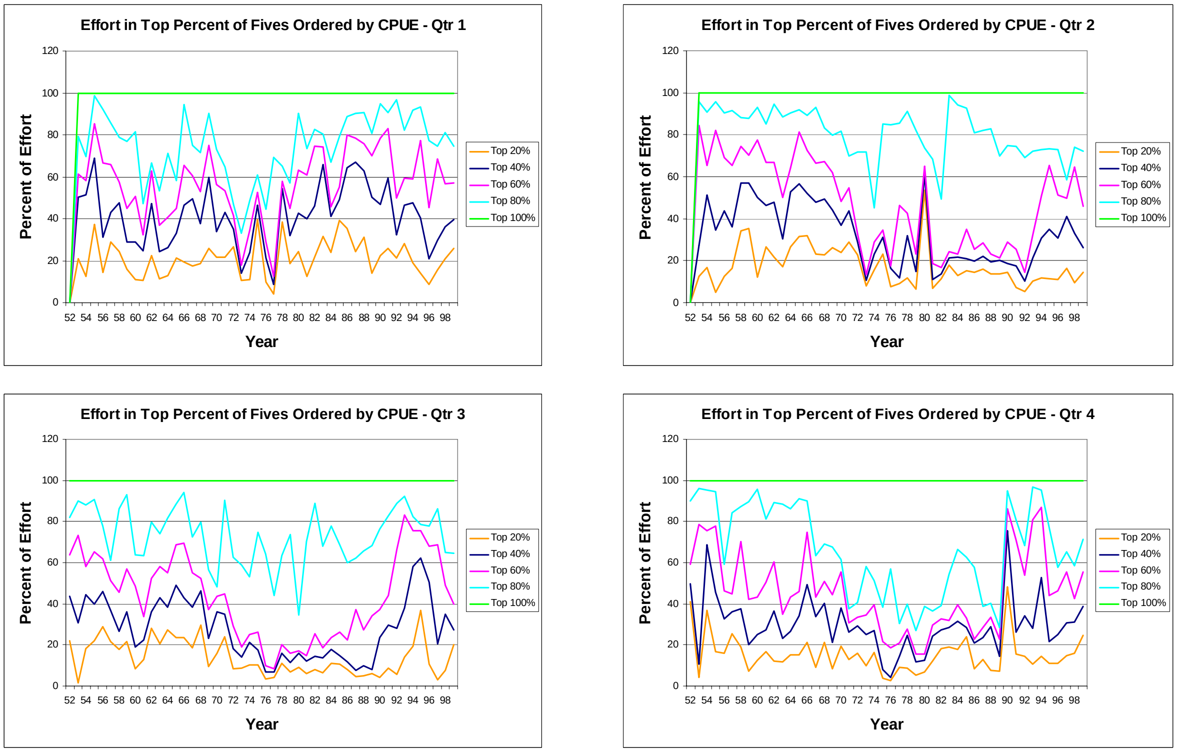


Figure 16: *Distribution of Japanese longline effort in squares ranked by bigeye CPUE.*

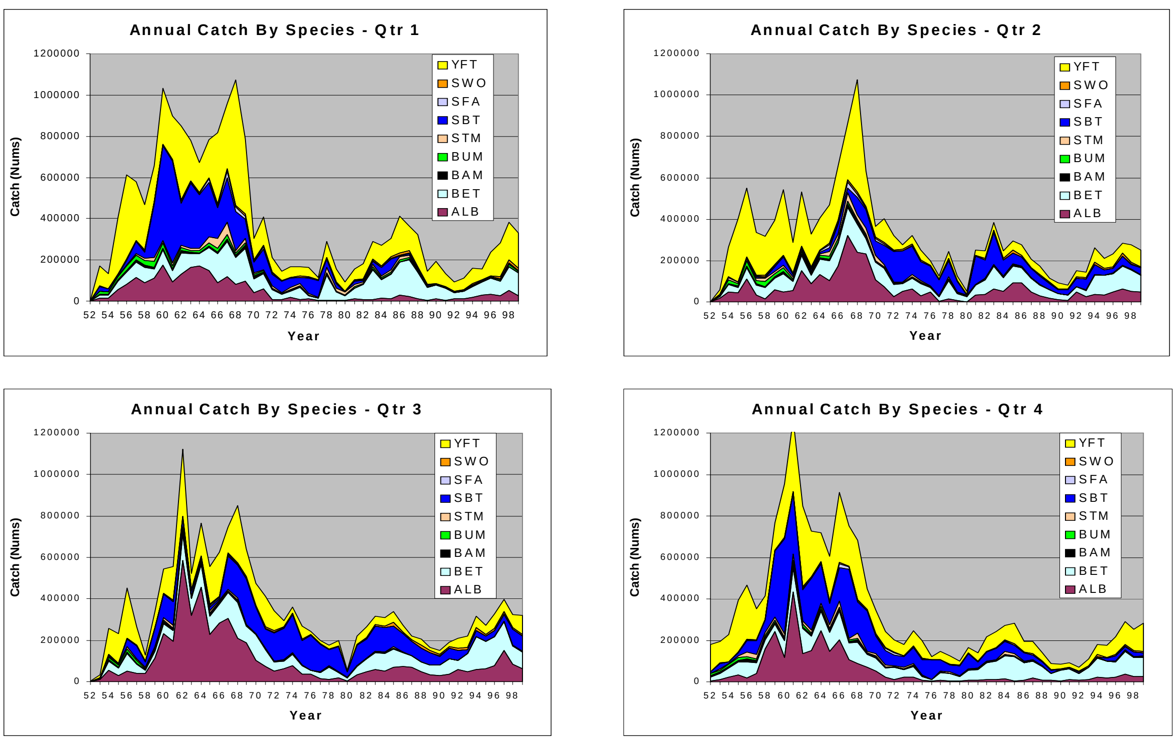


Figure 17: *Annual catch (in number of fish), by quarter, of tuna and billfish caught by Japanese longliners in the Indian Ocean.*

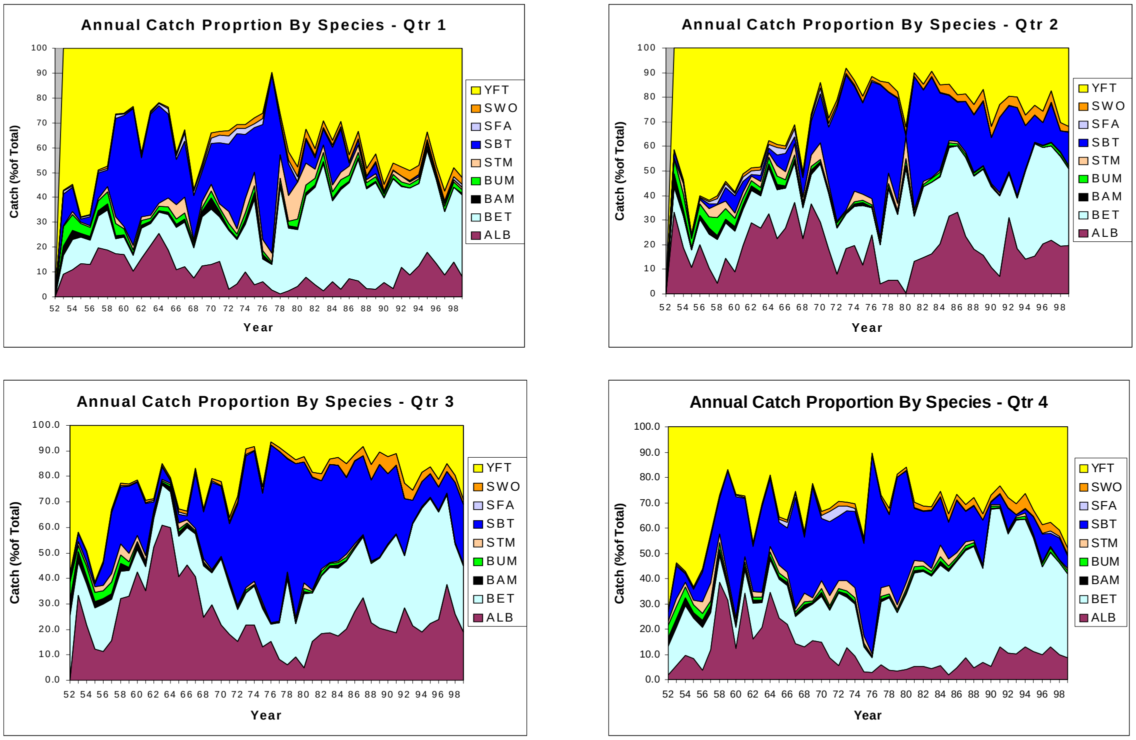


Figure 18: Quarterly catch of each species as a proportion of the total catch of tuna and billfish.

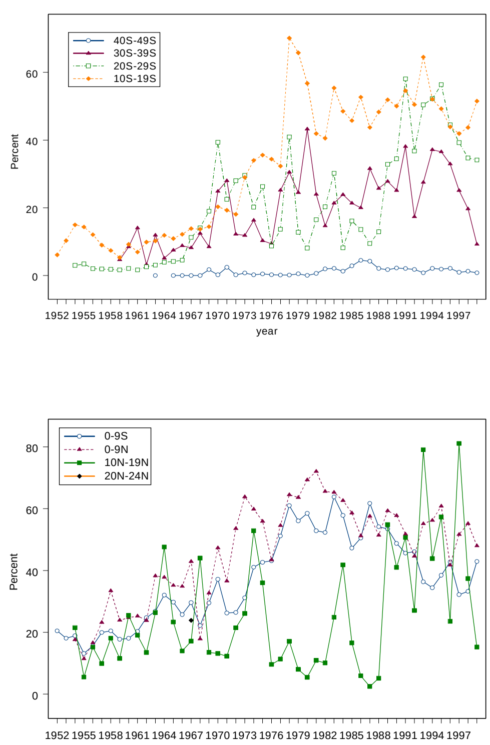


Figure 19: *The proportion of the total catch of BET, YFT, SBT, albacore and swordfish that was BET by 10-degree latitudinal bands*

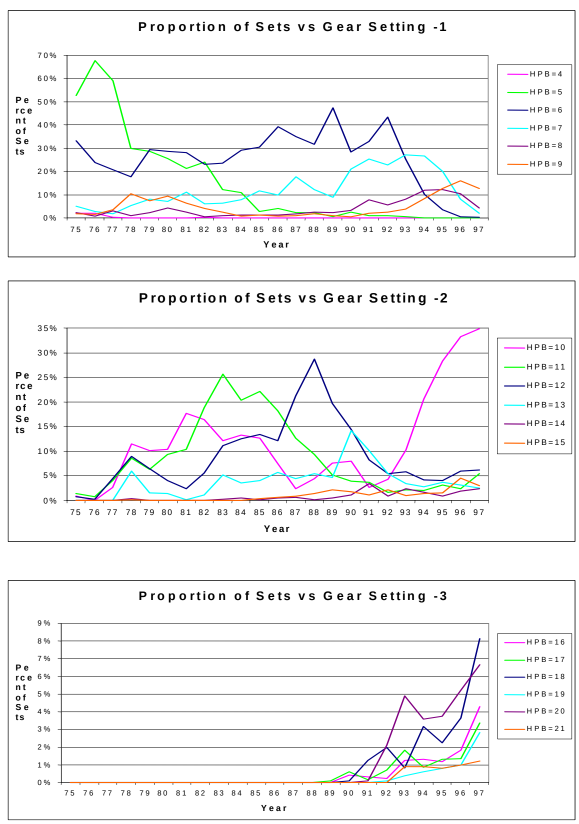


Figure 20*: Proportion of sets having different gear configurations each year.*

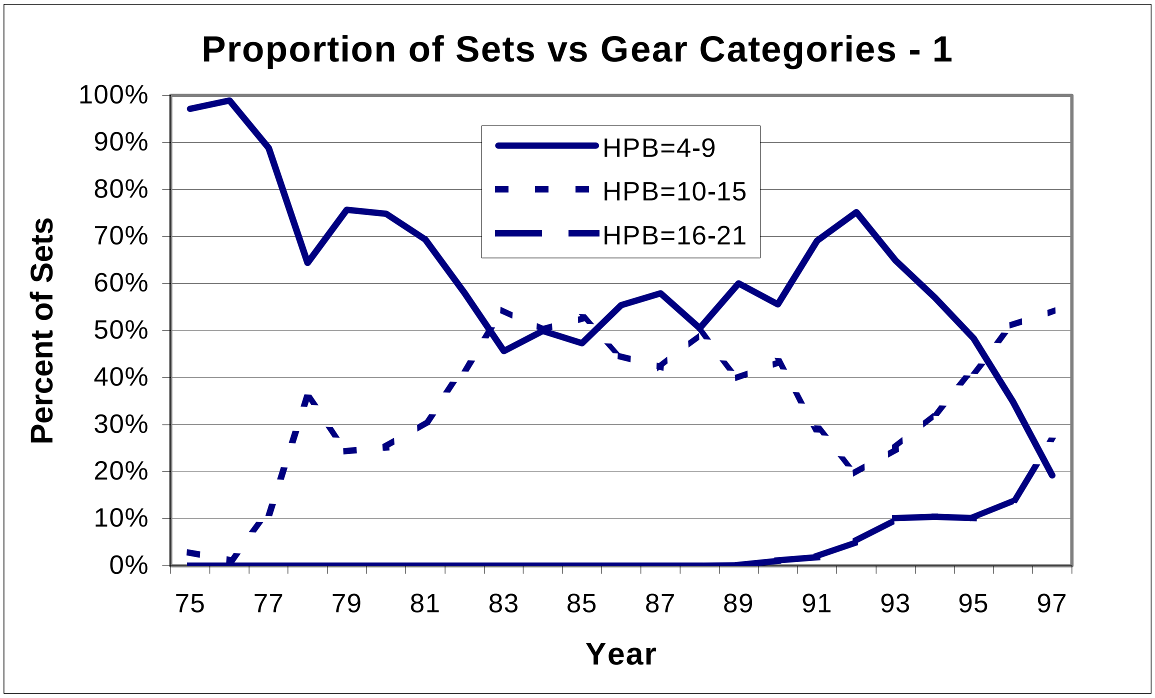


Figure 21a: *Proportion of sets within the three gear configuration categories specified by Okomoto and Miyabe (1999).*

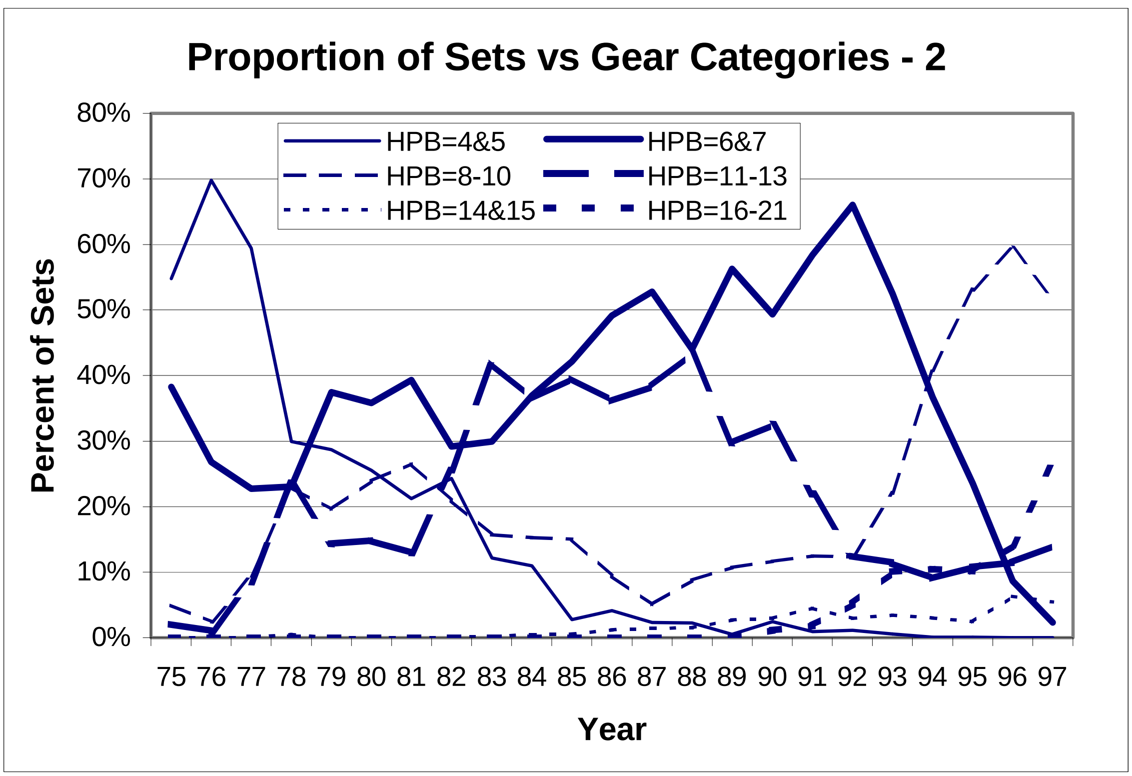


Figure 21b: *Proportion of sets within the six gear configuration categories.*

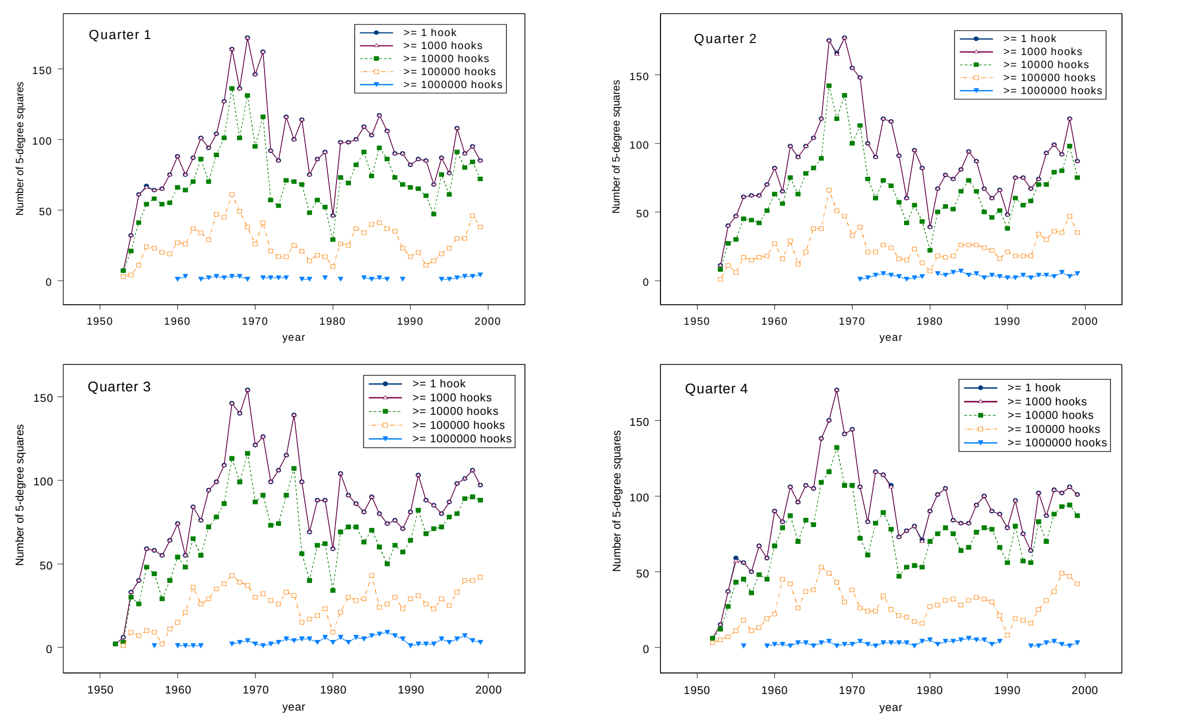


Figure 22: *The number of 5-degree squares by year and quarter stratified by levels of effort.*

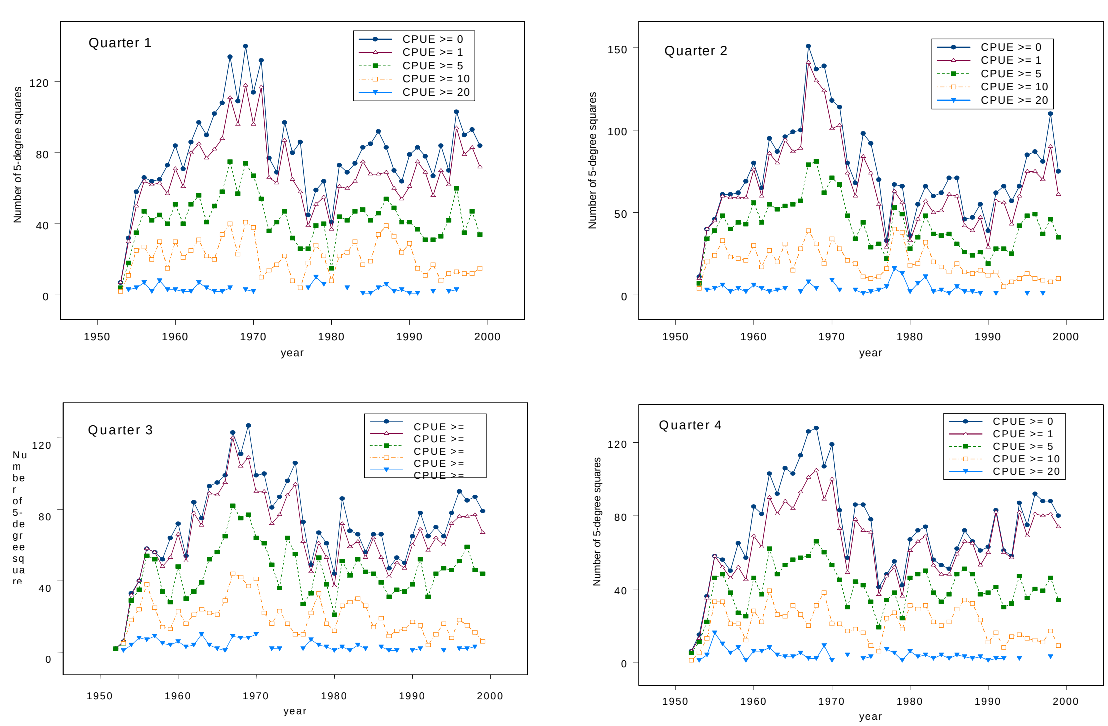


Figure 23: *The number of 5-degree squares by year and quarter stratified by levels of nominal bigeye CPUE.*

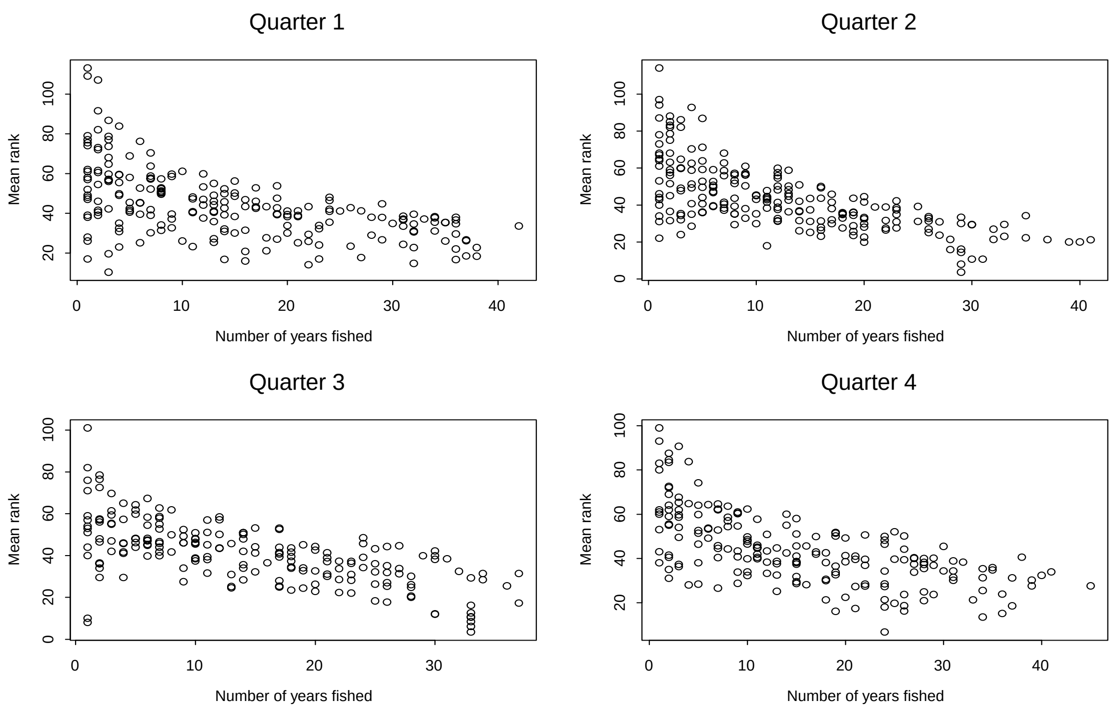


Figure 24: *The mean rank for the amount of effort within a year as a function of the number of years a square was fished within a quarter. A low rank of 1 indicates maximal effort. Note that because the number of squares fished within a quarter varies among years the highest rank value also varies among years.*

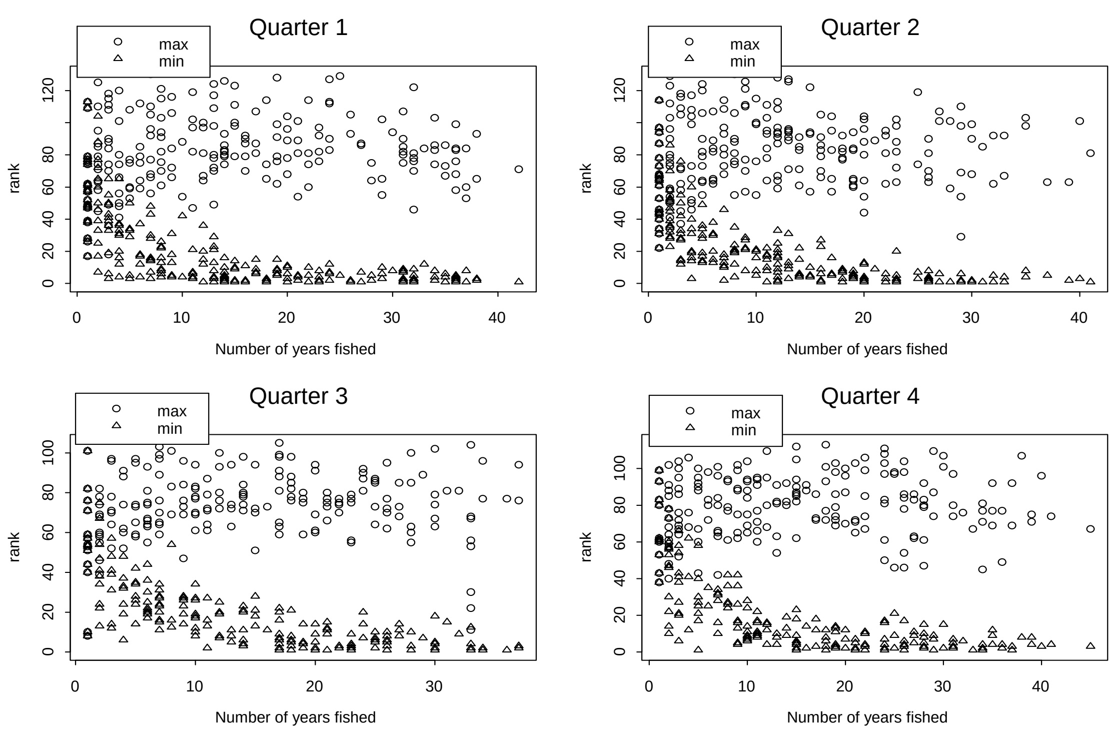


Figure 25: The minimum and maximum rank for the amount of effort within a year as a function of the number of years a square was fished within a quarter. A low rank of 1 indicates maximal effort. Note that because the number of squares fished within a quarter varies among years the highest rank value also varies among years

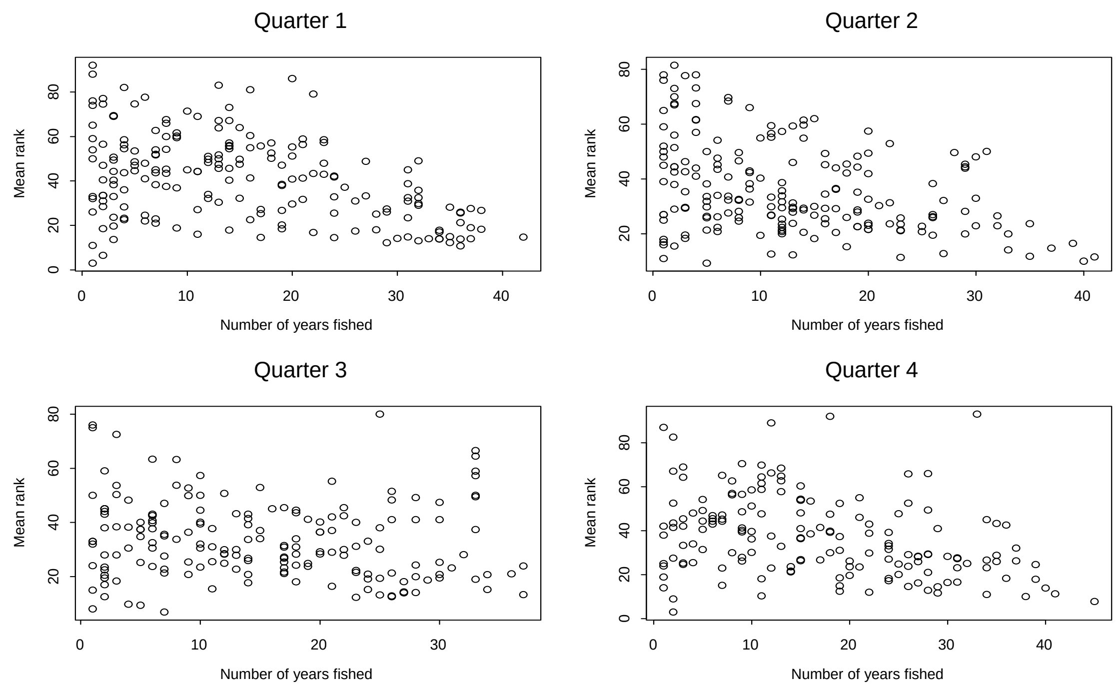


Figure 26: *The mean rank for the BET CPUE within a year as a function of the number of years a square was fished within a quarter. A low rank of 1 indicates maximal effort. Note that because the number of squares fished within a quarter varies among years the highest rank value also varies among years.*

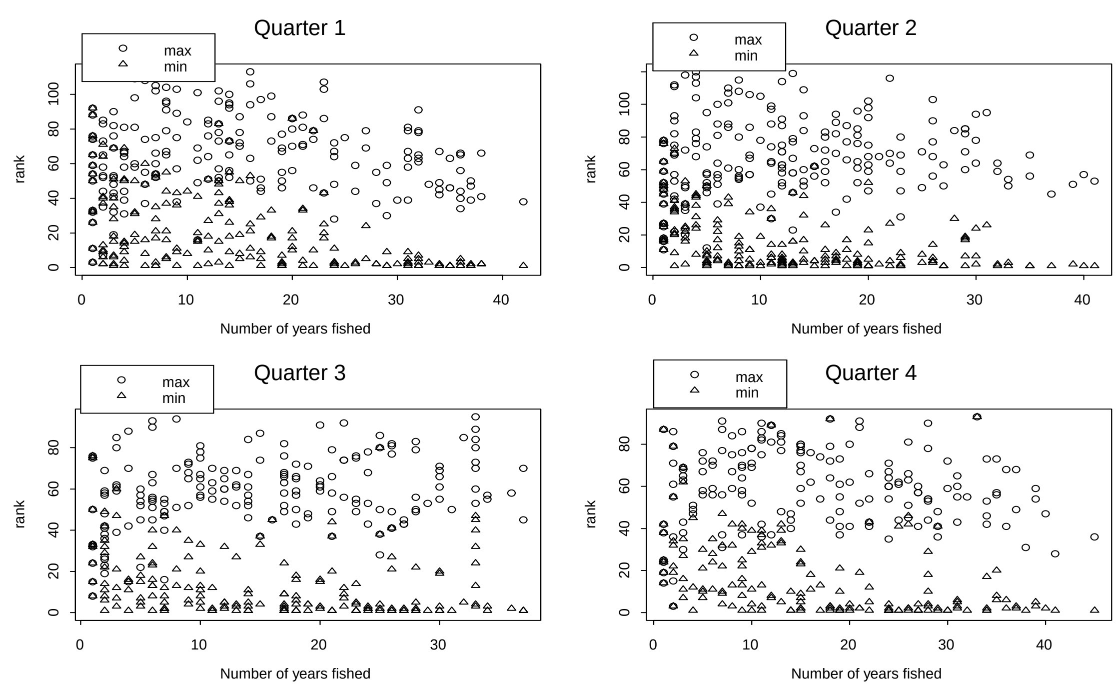


Figure 27: *The minimum and maximum rank for the BET CPUE within a year as a function of the number of years a square was fished within a quarter. A low rank of 1 indicates maximal effort. Note that because the number of squares fished within a quarter varies among years the highest rank value also varies among years.*