Exploring possible causes of historical discontinuities in Japanese longline CPUE

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Executive Summary

The Indian Ocean Tuna Commission's 7th Working Party on Methods (IOTC-2016-WPM07-R) noted concern about a step change in the Japanese CPUE in the late 1970s, which affects the joint indices and therefore the assessments. The WPM recommended work to improve the understanding of the fishery, including the factors that created the discontinuity in the bigeye (and to a lesser extent yellowfin) CPUE 1976-80, and the associated size data.

We explored the characteristics of the 1977 discontinuity, and found that it occurred in all datasets examined, which included Japanese data for all oceans, and Taiwanese and Korean data for the Indian Ocean. It occurred for both bigeye and yellowfin to differing degrees, and in multiple regions in each ocean. We also analysed Japanese size data, and found no contemporary changes in that dataset. We discuss some possible explanations, and suggest that changes to the population or catchability (oceanography, introduction of deep setting) are unlikely. Explanations associated with catch reporting appear more plausible, partly due to elimination of alternatives, but we have not identified any evidence of such effects. We suggest some options for further exploring the issue.

Introduction

Integrated stock assessments are very dependent on understanding the fisheries that provide the data. Two of the primary datasets in tropical tuna assessments are the catch and effort data used to generate indices of abundance, and the associated size frequency data. The Indian Ocean Tuna Commission's 7th Working Party on Methods (IOTC-2016-WPM07-R) noted concern about a step change in the Japanese CPUE in the late 1970s, which affects the joint indices (Hoyle et al. 2016) and therefore the assessments. The IOTC-WPM recommended work to improve the understanding of the fishery, including the factors that created the discontinuity in the bigeye (and to a lesser extent yellowfin) CPUE 1976-80, and the associated size data.

The step change in bigeye CPUE in the 1976-80 period has attracted the attention of researchers for many years (Campbell *et al.* 2001; Okamoto *et al.* 2001). The increases are not only remarkable for occurring at similar times in multiple regions and oceans, they are outliers within individual series (Wibawa *et al.* 2017).

Possible causes include changes in abundance in fished areas due to high recruitment or oceanographic changes that cause fish to move into heavily fished areas; increased catchability due to changed fishing practices or oceanographic changes; or changes in data management such as logbook or data entry policy that affected bigeye reporting. In this paper we explore possible changes in fishing practices and data reporting practices in the period from 1970 to 1980, by examining CPUE and size data. We standardize the size data to look for patterns that may otherwise be hidden by changes in the distribution of effort through time. We also compare Indian Ocean

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CPUE indices with indices from other oceans, and explore changes in fishing variables such as hooks between floats.

Data description and analysis methods

Size data (Table 1) were imported into R (R Core Team 2016) and prepared by allocating to location and time strata. The data were used as provided, with no additional range checking or cleaning. Due to changes in rounding practices through time (Hoyle *et al.* 2017), we generated adjusted bins that represented the midpoint of each bin, which depended on the binning interval and the rounding direction by year.

Size data were provided for multiple species but here we focus on bigeye and yellowfin. For 1952-1964 only yellowfin data were provided, and were measured in very large numbers (Figure 1). Other species were measured during this period but are held in a different database which was not provided.

Samples were obtained from commercial vessels and from training and research vessels (Figure 2), with training and research vessels combined in one category. Prior to 1965 all samples came from commercial vessels, but training and research vessel sampling began in 1965 and soon dominated the dataset. During the 1976-78 period of the CPUE discontinuity 80-90% of samples came from training and research vessels, so these size data will not necessarily be informative about sizes caught in the commercial fisheries.

To investigate changes in the 1976-80 period, we examined Japanese CPUE indices for bigeye and yellowfin in the Indian Ocean calculated in 2016 and including vessel effects from 1979, without hooks between floats, and both with and without including clusters (based on species composition) in the standardization model (Hoyle *et al.* 2016).

We examined possible association of catch rate changes with operational changes, based on available information about fishing practices.

We obtained Japanese CPUE indices for bigeye in the Atlantic (Matsumoto & Satoh 2015) and yellowfin in the Atlantic (Satoh & Matsumoto 2017) from the latest working papers presented to the relevant RFMOs. The Atlantic indices were standardized to account for year-quarter, continuous variables for latitude and longitude, hooks between floats, SST, and mainline and branchline material, including interactions and polynomial terms for some variables.

We obtained the most recent CPUE indices for bigeye and yellowfin in the Western and Central Pacific Ocean (WCPO) (McKechnie *et al.* 2017) from the authors. The WCPO indices included terms for 5° grid cell and species-composition cluster. The WCPO indices contain data from multiple fleets, but Japanese data provide the majority of the records before 1980, except in regions 4, 5, and particularly region 6 (McKechnie *et al.* 2015). We also examined earlier indices which are based only on Japanese data (Hoyle & Okamoto 2011). We also searched the literature for information about indices from other fleets.

We compared the observed patterns in indices for all oceans, particularly during the year 1977, which was marked in most plots.

To explore potential changes in selectivity we standardized the size data by fitting generalized linear model by species, spatial resolution, and data type (lengths and weights), with normally distributed errors. The model took the following form: $size \sim yq + grid + \epsilon$, where *size* was the adjusted bin value, *yq* was a combined year-quarter effect, and *grid* was the spatial cell given the resolution of the data. Both variables were fitted as categorical variables. For plotting, mean sizes were predicted for each year-quarter or the grid, with the corresponding variable fixed at the level of the grid cell or year-quarter with the most records.

Results

In the tropical Indian Ocean regions, which are regions 1 and 2 for bigeye tuna and regions 2 and 5 for yellowfin, there was a spike of higher CPUE in the year 1977 (Figures 3 and 4). The bigeye tuna indices maintained the higher catch rates long term, to the extent that in both tropical regions the standardized catch rates remained on average above the level observed 1970-76 until at least 1995. Yellowfin CPUE did not maintain the higher rate, and returned to the previous average within a few years.

In the temperate region 3 there was no apparent spike for bigeye, though effort was only high enough to estimate an index in the last quarter of 1977. Region 4 bigeye showed what may be a spike, though the indices were very variable. In the temperate yellowfin regions 3 and 4 there appeared to be spikes of higher catch rates in 1977 and 1978, before a return to the previous average.

For tropical bigeye, including 'cluster' in the standardization model reduced the sizes of the spikes and the differences in relative catch rate between before and after 1977, on both tropical regions. For yellowfin there was a smaller effect in the opposite direction, mainly in the western tropical region 2, which slightly increased the spikes and increased the relative CPUE after 1977 when cluster was included.

The effect of the cluster variable was consistent with the fact that clusters dominated by bigeye (cluster 3 in R1 and cluster 1 in R2) were much more prevalent after 1976 (Figure 5). It is also notable that median hooks between floats were higher in the bigeye cluster than in the other clusters.

Indices for bigeye tuna in the main Japanese fishery region of the Atlantic Ocean (Figure 10) showed a similar discontinuity with a sharp increase in 1977 (Figure 11). In contrast, Japanese yellowfin indices estimated for the west and east regions of the Atlantic (Figure 12) show no spike in 1977 (Figure 13). However, CPUE is highly variable in this analysis, which has a latitudinal range covering 100 degrees of latitude, and includes fleets with very divergent targets. The eastern indices appear particularly affected by southern bluefin tuna targeting in the 1970s. Any catch rate signal in these Atlantic yellowfin indices is likely to be swamped by other sources of variability.

The Western and Central Pacific Ocean (WCPO) indices were developed for the 2017 regional structure (Figure 14). For bigeye (Figure 15) there were clear spikes in 1977 in regions 1, 2, 3, 7 and 8, and suggestions of increased mean CPUE close to 1977 in regions 4, 5 and 6. For yellowfin (Figure 16) there are clear spikes in 1977 or 1978 in regions 3, 7, and 8, and suggestions of increased mean CPUE close to 1977 in regions 1, 2, 4, 5, and 6.

The WCPO indices developed in 2011, based only on Japanese data, showed clearer discontinuities than the 2017 joint WCPO indices. Spikes or increases were apparent in all regions for bigeye, except region 6 where there was insufficient data, either in 1977 or shortly thereafter in the case of region 5 which had no indices in 1977 (Figure 17). Yellowfin indices showed spikes or increases in regions 3, 4, and 5 (Figure 18). Regions 1 and 2 showed no clear change. Region 6 had insufficient data.

Hsu & Liu (2000) standardized aggregated Korean data for the period 1975-1992, and found increased catch rates in 1977-78. We analysed an aggregated Korean dataset held by IOTC, and also analysed Taiwanese data. Operational Taiwanese data for 1977 have been lost so are not included in the dataset used for joint standardization (Hoyle *et al.* 2015). Indices for both bigeye and yellowfin tuna showed higher catch rates in most regions during 1977, for both the Korean (Figures 6 and 7) and Taiwanese fleets (Figures 8 and 9).

We examined the Japanese size data for signs of contemporaneous changes that might indicate changes in targeting, data management, the population, or oceanography. Yellowfin and bigeye size data were standardized separately for each measurement unit, and year-quarter means plotted. For yellowfin, the 1 x 1 length data covered the period from 1967-2016, the 1 x 1 weight data covered 1986-1996, the 5 x 10 length data covered 1952-1968, and the 5 x 10 weight data covered 1953 and 1956-1991. The size datasets were dominated by research and training vessel data during the 1970-1980 period (Figure 2).

For yellowfin, the 5 x 10 weight indices were sparse between 1970 and 1985 due to low sample sizes, but showed no sign of a selectivity change during the 1970-1980 period (Figure 19). In the 1 x 1 length indices were variable with no clear trend until the early 1980s (Figure 20). Variability reduced in the mid-1980s. Mean sizes did appear to increase from about 1992, but this coincided with reduced sample sizes and wider confidence intervals.

The 1 x 1 bigeye data coverage was similar to yellowfin but started in 1965. Size indices from the 5 x 10 weight dataset were relatively stable until the early 1970s (Figure 21), but subsequently very variable with the low sample sizes until the early 1980s. The mean weight then became more stable, possibly declining slightly over the decade to 1990. In the 1 x 1 length data, temporal indices showed no obvious changes until the mid-1980s but then declined until about 1990, increased until the mid-1990s, declined until 2000 and then became very variable and uncertain as sample sizes declined (Figure 22).

Discussion

Numerous explanations for the Indian Ocean discontinuities have been proposed, tested, and largely rejected. Okamoto *et al.* (2001) considered the hypotheses of increased effort concentration in the areas with highest catch rates, and very high bigeye recruitment in 1977-78, but found no evidence to support them. They reported that effort distribution did not change substantially, and they found no major changes in size distribution that would accompany a large recruitment spike.

Furthermore, we have found that CPUE indices for the Indian, Atlantic and Western Pacific oceans show spikes or other discontinuities in 1977 in most cases. In the Pacific the discontinuities were more apparent in the indices based purely on Japanese data than in indices where several datasets were combined. In the Indian Ocean the discontinuities were observed in Taiwanese and Korean as well as Japanese indices. The main exception to the widespread discontinuities was the Japanese yellowfin CPUE time series from the Atlantic, but this time series may be unrepresentative since it includes data from a much broader latitude range than other analyses and appeared to be affected by effort targeted at other species.

Given the widespread nature of this discontinuity in catch rates, it is very important to find an explanation. CPUE is one of the most important and influential inputs to stock assessments, so this discontinuity, if unrepresentative of abundance, will bias all stock assessments for bigeye and yellowfin tunas that start before 1977. Knowing why the discontinuities occurred may allow us to repair them, or to develop a strategy to work around them.

We suggest that the widespread occurrence of such large discontinuities is highly unlikely to be due to simultaneous changes in both bigeye and yellowfin populations, in most regions of all tropical and temperate oceans. It is similarly unlikely to be due to oceanographic conditions. Short-term spikes in CPUE occur due to process error (e.g. catchability changes) and observation error, but such variability occurs randomly in time and relatively independently among regions and oceans. These explanations are not consistent with almost simultaneous discontinuities in multiple regions of every ocean.

A somewhat more plausible explanation for the discontinuities is changes in fishing behaviour or technology. Although we might expect behaviour change to spread progressively through a fleet, with gradual change in mean CPUE, a behaviour change that produces much higher catch rates may spread quite rapidly. Such a change in fishing behaviour (and potentially also technology) occurred close to 1977 with the introduction of deeper setting in the Indian Ocean. The average Japanese hooks between floats (HBF) increased substantially at around that time (Figure 23). There was also very low Japanese Indian Ocean effort in 1977 (Figure 24), which may have made it easier for behaviour change to spread rapidly. High fuel costs due to the 1970s oil crisis reduced the size of the Japanese fleet in the Indian Ocean.

On the other hand, the WCPO also saw Japanese catch rates spike in 1977, but higher HBF had already been introduced by 1976 and potentially earlier, although full data are unavailable (Figure 25). Also, effort in the WCPO was by no means low, but high and increasing (Figure 26). Okamoto *et al.* (2001) indicate that deep longlining was introduced at different times in each ocean, 1977-1981 in the Indian Ocean, 1979-1983 in the Atlantic, and 1974-1978 in the Pacific. Moreover, while catch rates for bigeye generally increase with deep setting, yellowfin catch rates generally decrease, and we have seen increases in both bigeye and yellowfin catch rates. This seems to indicate that deep setting did not cause the discontinuity in catch rates.

Our analyses of the size data show no evidence of change in the size composition of the Indian Ocean catches of yellowfin or bigeye in 1977, which does not support the idea of a targeting a previously unfished component of the stock. However, size samples at the time came largely from the research and training vessels, which may not have changed their fishing behaviour at the same time as the commercial vessels.

It is also interesting to note the very large recent spike in bigeye catch rates in the north-western tropical Indian Ocean (Figure 27), which may have some similarities to the 1976-78 peak. It is believed to have occurred when vessels returned to the area that had been unfished for several years due to piracy. The peak was quite short-lived, and may be more consistent with a change in catchability than local abundance. It would be very interesting and potentially informative to study the catch rates, fish sizes, and vessel behaviour in detail.

A further possible explanation is bias in reporting behaviour by vessels, or in the treatment of logbooks by vessel owners. For example, Indian Ocean bigeye catches were misreported in Taiwanese logbooks during 2002-4 due to transfer of catch from the Atlantic ('fish laundering') (ICCAT 2005; IOTC 2005). Management changes can provide incentives for vessels to misreport catches. For example, the prospect of quotas can incentivise vessels to inflate their catches so as establish a catch history. We are not aware if any such management changes were considered a possibility in the late 1970s, but it may be useful to explore the possibility. There were major changes in international fisheries jurisdiction and management at the time, with Japan introducing its own 200-mile EEZ in 1977.

Another potentially plausible explanation for the catch rate discontinuities is a change in reporting or data handling by data managers at the Japanese Fisheries Agency. Such a change would likely affect, within a narrow time window, data from all regions and oceans, with some time differences due to delays in providing logbooks from more distant regions. Japan introduced its exclusive economic 200-mile zone in 1977, which would have been a major event for the fisheries administration. Such events can cause a cascade of changes to procedures. However, this would not explain the contemporary changes in Taiwanese and Korean catch rates.

Data management changes that can affect catch estimates include:

- Change in the approach to reporting or data entry of catches of small fish or discards. If small fish were included the catch after not previously being included, this would increase reported catch rates. We would need to account for the observation that bigeye tuna catch rates spiked more than yellowfin, and remained high in the tropical Indian Ocean but not elsewhere.
- Change in the approach to species identification for small fish, which can be difficult to identify as yellowfin or bigeye. We would need to account for the observation that both yellowfin and bigeye tuna CPUE increased in 1977. Also, species ID occurs on the vessel, so such a change is unlikely to occur simultaneously in all regions.
- Change in logbooks or catch reporting methods. However, logbooks may take several years to spread through the fishery.
- Change in the data entry procedures.

An earlier version of this paper suggested taking a random sample of the original paper logbooks from 1975-76 and another sample from 1977-78, re-entering the logbooks into a database using current data entry protocols, and comparing each sample with the matching records in the existing database. This work has now been done (Matsumoto & Satoh 2017), and found no change in the treatment of the datasets between before and after 1977.

We suggest the following as further work:

- Compare the species compositions of the catches before and after 1977, using cluster analysis and investigating data from all oceans and all fleets.
- Explore available data from all oceans and all fleets that show catch rate spikes in 1976-78. Examine vessel behaviour, set by set catch rates, and all available size data from commercial vessels.
- Research the history of the Japanese Fisheries Agency, and of the Japanese longline fleet, to identify changes that may have occurred in 1977.
- Research the history of management discussions by FAO and others, to identify any periods when management changes may have been considered and could have affected reporting.

In conclusion, we have explored the characteristics of the 1977 discontinuity, and found that it occurred in all datasets examined, which included Japanese data for all oceans, and Taiwanese and Korean data for the Indian Ocean. It occurred for both bigeye and yellowfin to differing degrees, and in multiple regions in each ocean. We also analysed Japanese size data, and found no contemporary changes in that dataset. We discuss some possible explanations, and suggest that changes to the population or catchability (oceanography, deep setting) are unlikely. Explanations associated with catch reporting appear most plausible, largely due to elimination of alternatives, but we have not identified any causes. We suggest some approaches for further exploring the issue.

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Tables

Table 1: Fields available in the size dataset, variable descriptions, and the meaning of each code.

Variable	Description	Codes	Meaning
Species		1 2 3 4 5 6 7 8 9 10 11 12	bluefin tuna southern bluefin tuna albacore bigeye yellowfin swordfish striped marlin blue marlin black marlin sailfish shortbill spearfish skipjack
level	Spatial resolution in degrees of latitude x longitude	1 2 3 4	10 x 20 5 x 10 5 x 5 1 x 1
latitudec	Latitude type	1 2	N S
longitudec	Longitude type	1 2	E W
fleet	Set type	1 2	Longline Longline (night setting)
vesselc	Type of vessel	1 >2	Commercial vessel Training and research vessel
M_unit	Measurement unit	1 2 3 4 5 6 7 8	kg 1 cm 1 kg 2 kg 5 kg 1 cm 2 cm 5 cm
place	Sampling location	1 2 3 4 5 6 7 8 9 10 11 12 13	On board by fishermen Port sampling Kagoshima Port sampling Katsuura Port sampling Yaizu Port sampling Shimizu Port sampling Tokyo Port sampling Shiogama Port sampling Kesennuma SBT monitor ship Port sampling Sakai-minato Port sampling Kamaishi Port sampling Misakai On board observer
sex		0 1 2	unknown female male

Figures

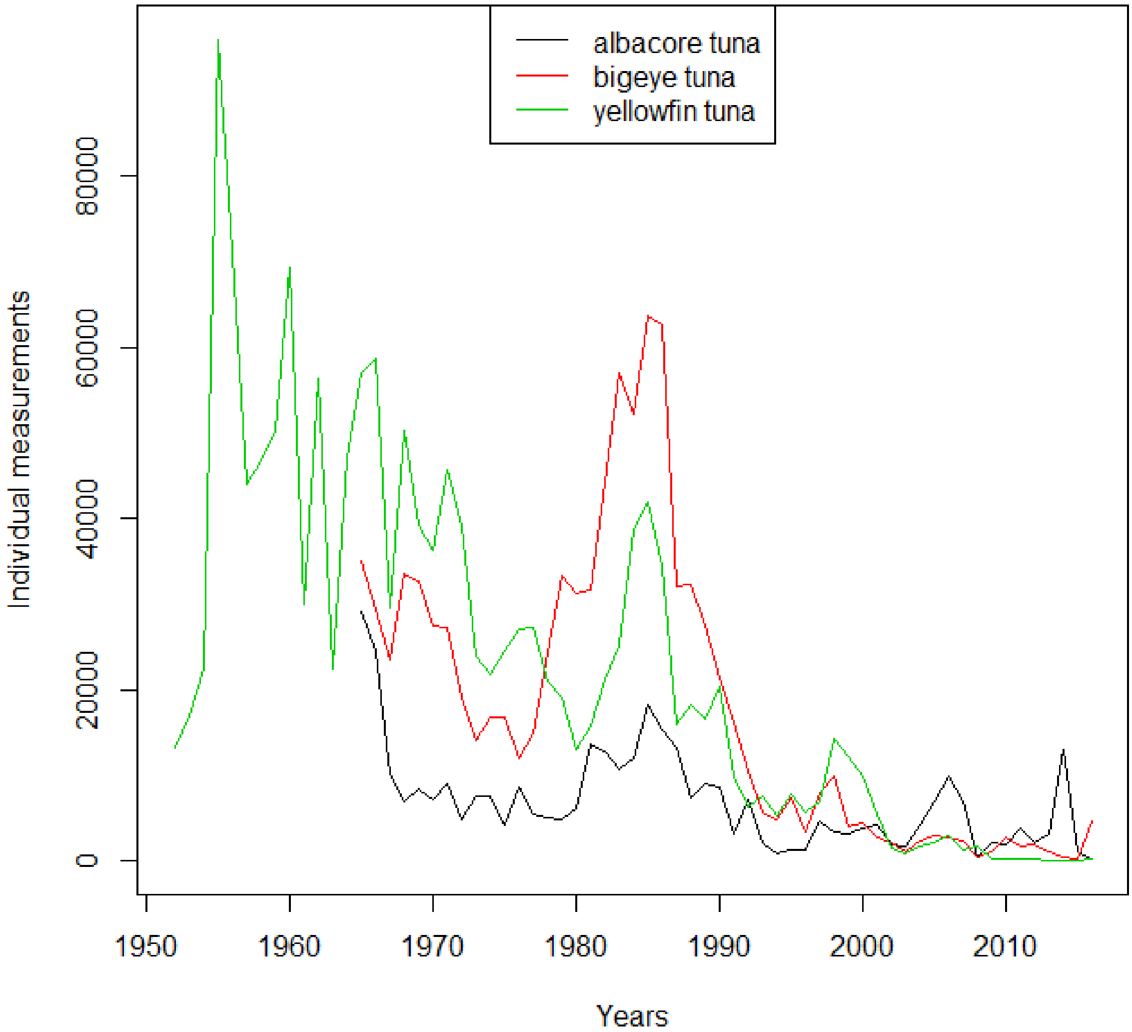


Figure 1: Number of fish measured and weighed by species and year.

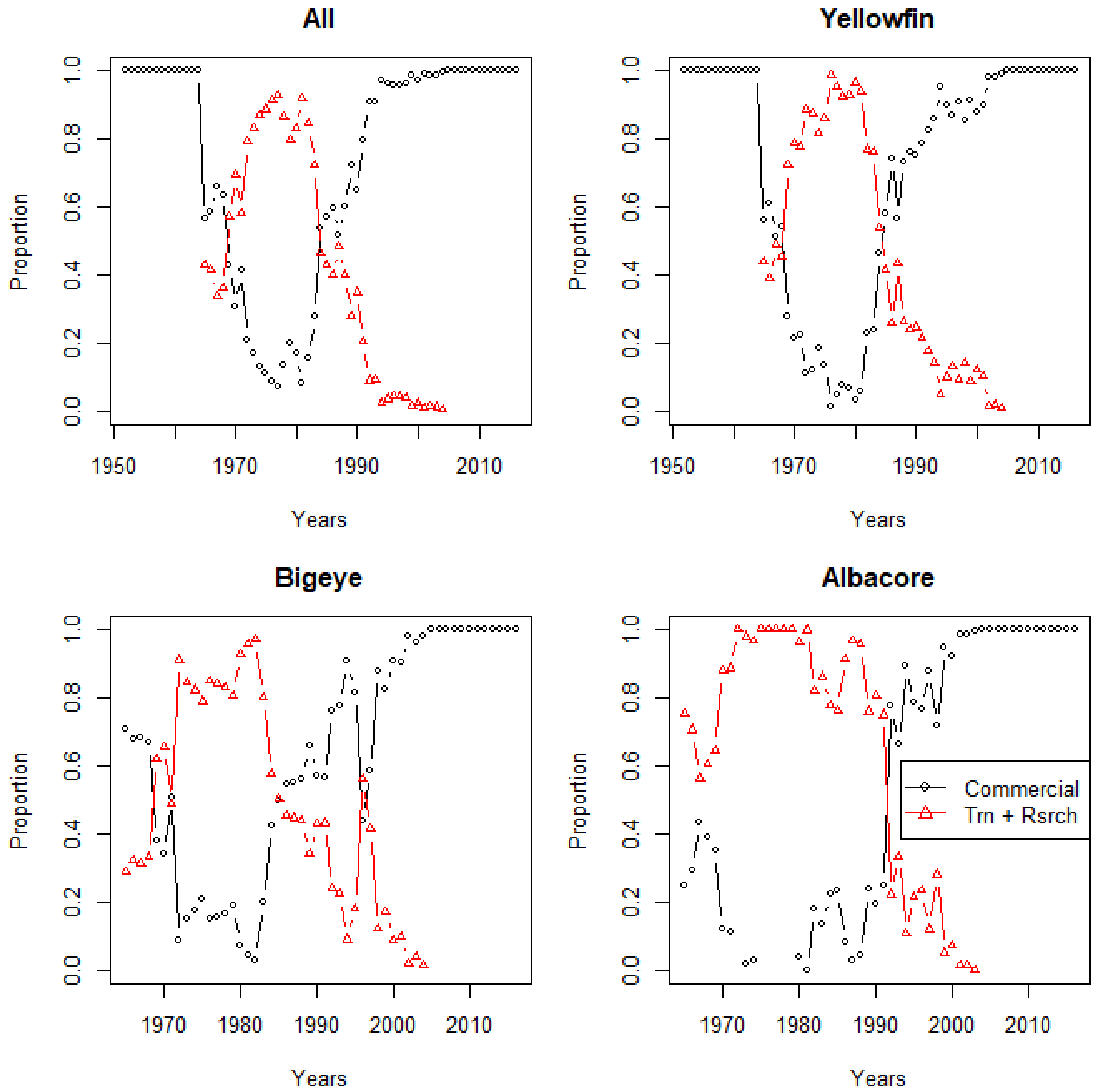


Figure 2: Proportions of measurements by type of vessel and year, for all species combined and separately for bigeye, yellowfin, and albacore.

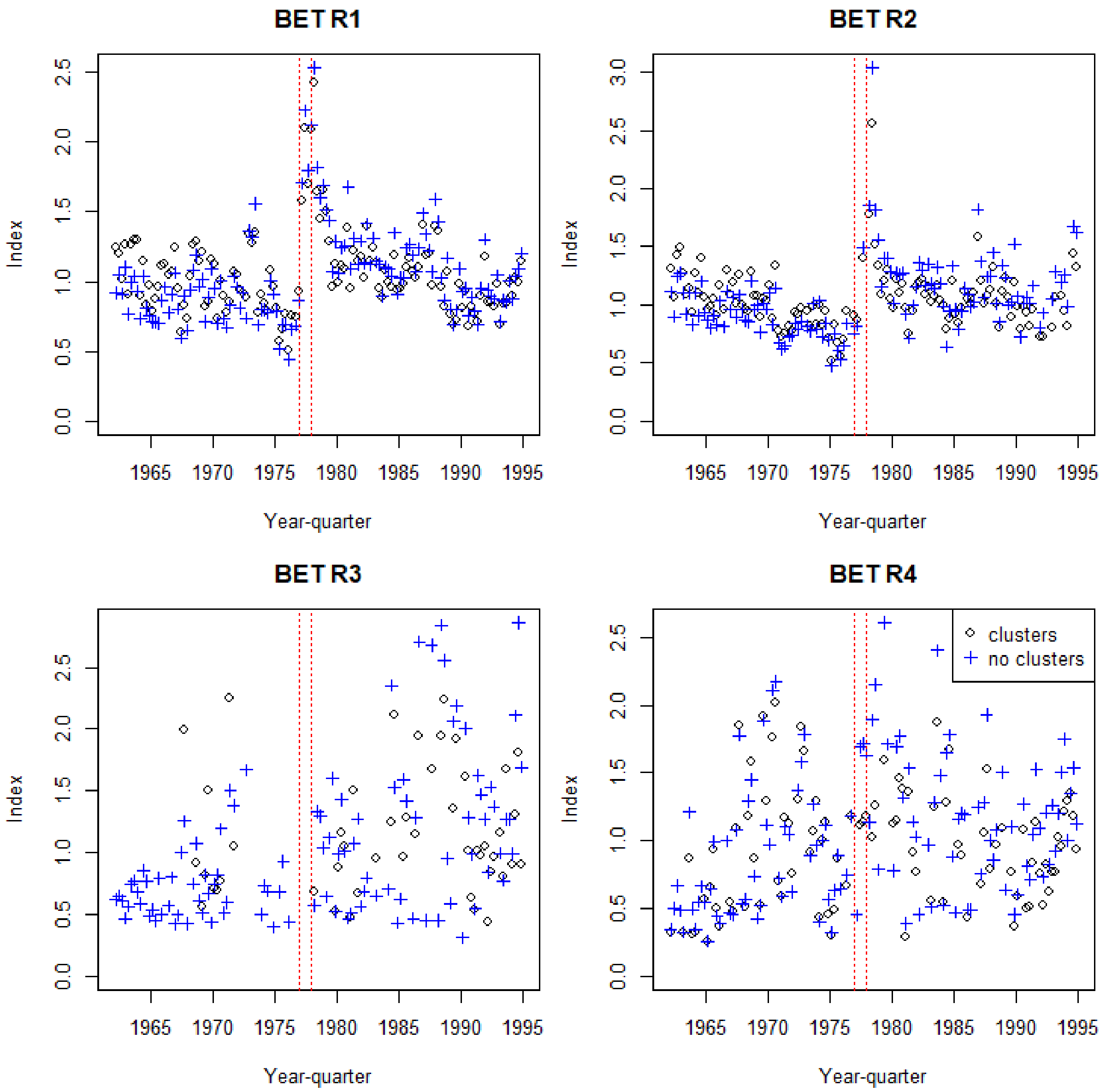


Figure 3: Bigeye standardized CPUE indices by Indian Ocean region (Hoyle et al 2016) from standardization models both with and without cluster as a covariate. The red lines mark the starts of the years 1977 and 1978.

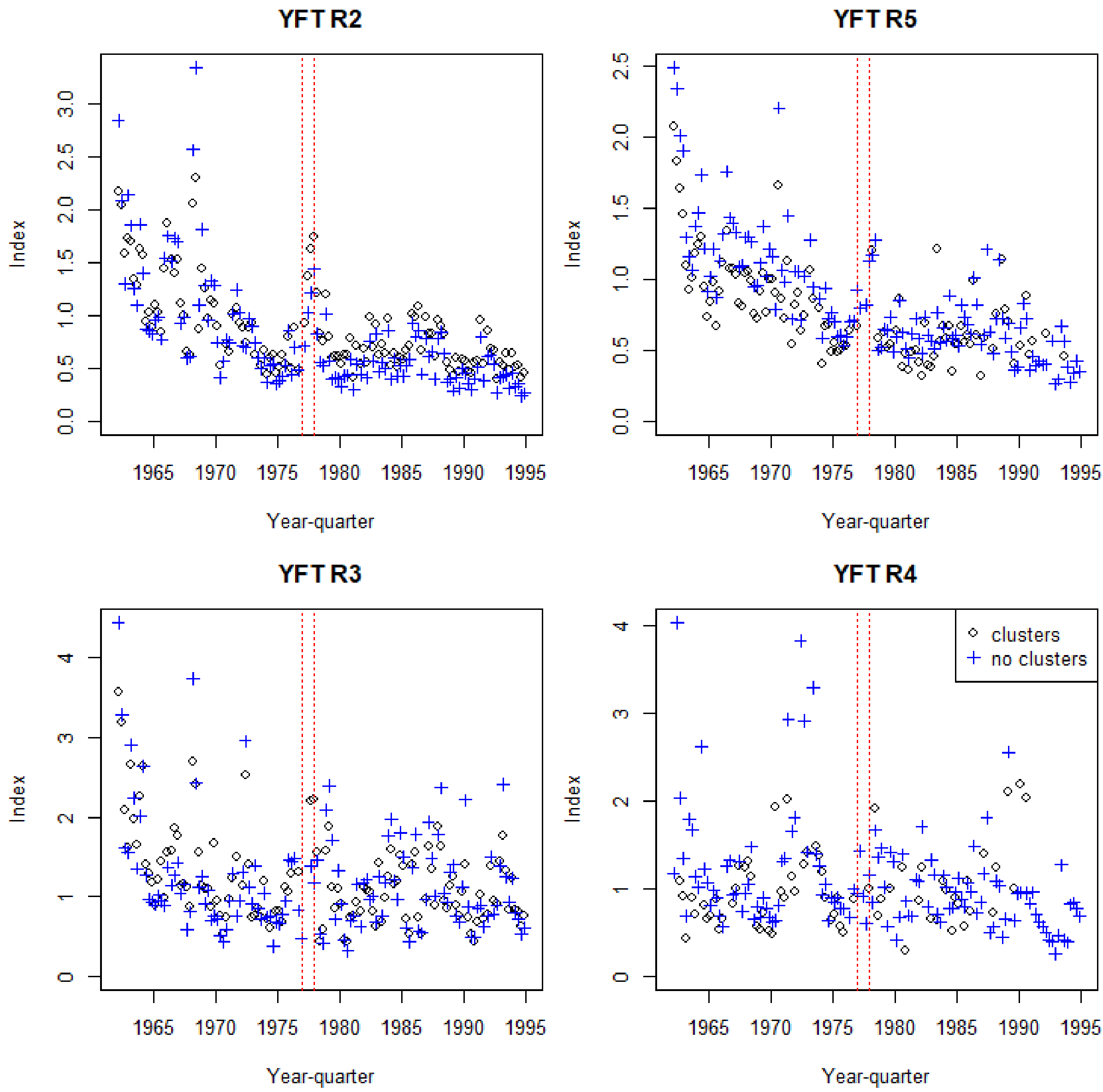
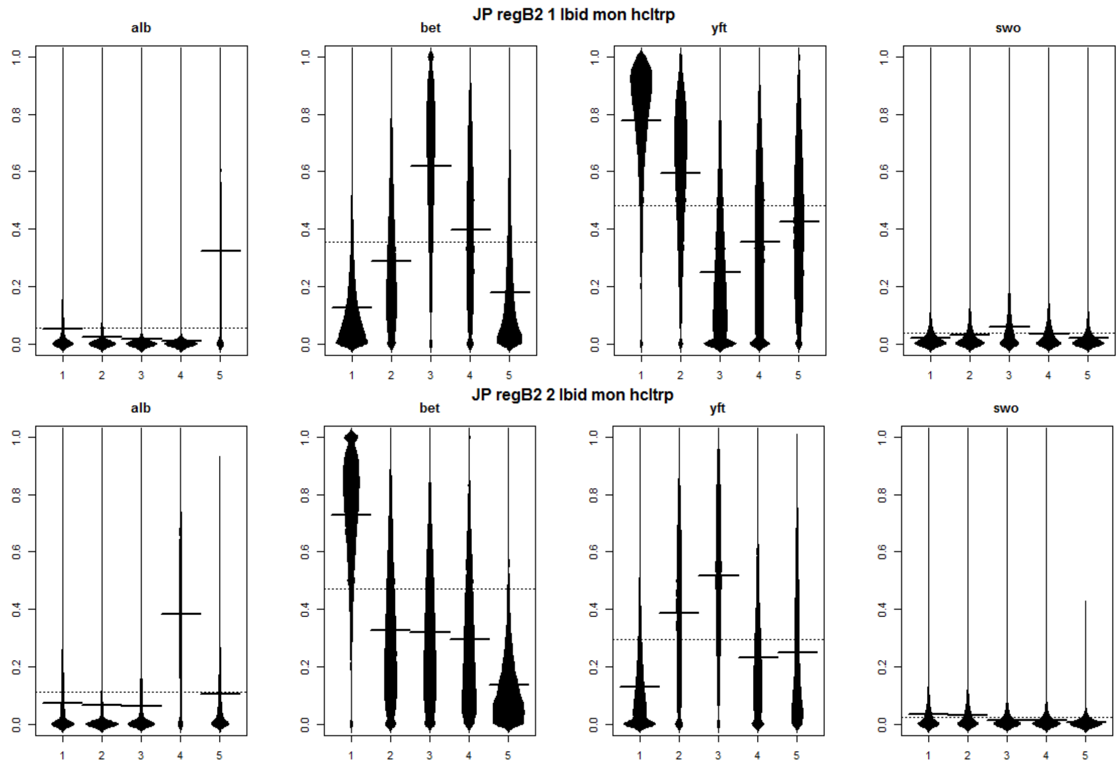
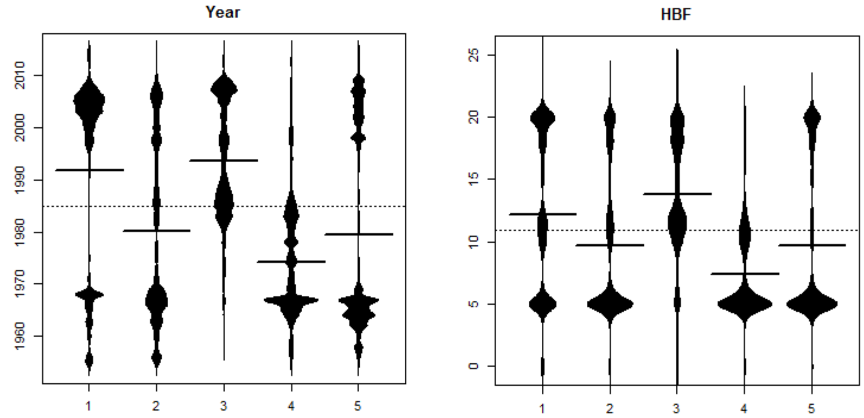


Figure 4: Yellowfin standardized CPUE indices by Indian Ocean region (Hoyle et al 2016) from standardization models both with and without cluster as a covariate. The red lines mark the starts of the years 1977 and 1978.



Bigeye R1



Bigeye R2

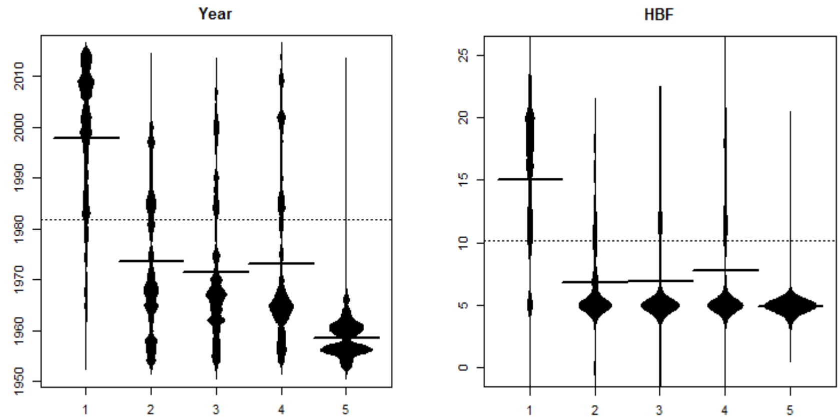


Figure 5: Figures from Indian Ocean bigeye tropical regions 1 and 2 showing clusters, their species composition (rows 1 and 2), distributions through time (rows 3 and 4, lower left), and across HBF (lower right)

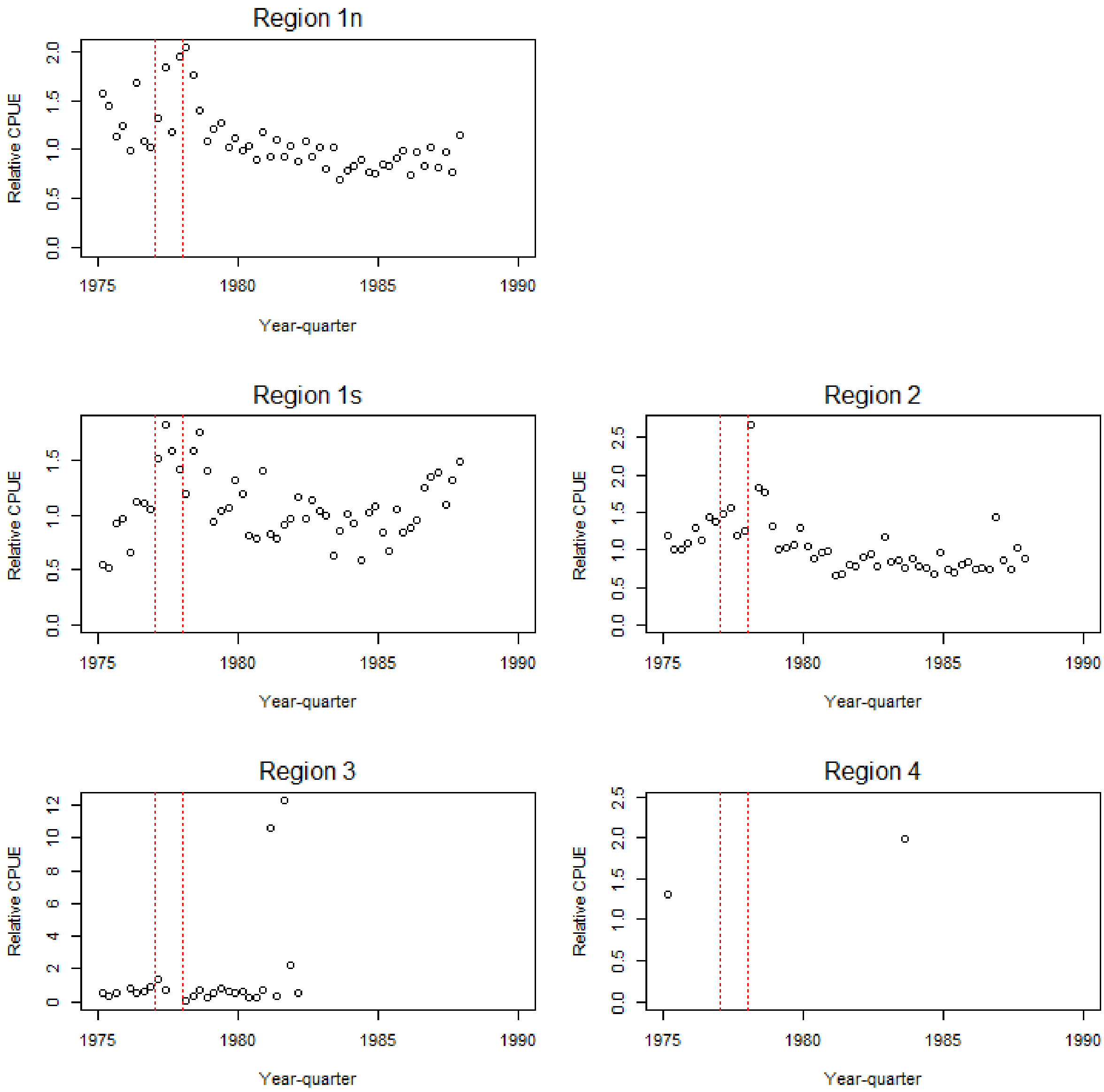


Figure 6: Bigeye CPUE by the Korean fleet based on standardization of aggregated data held by IOTC.

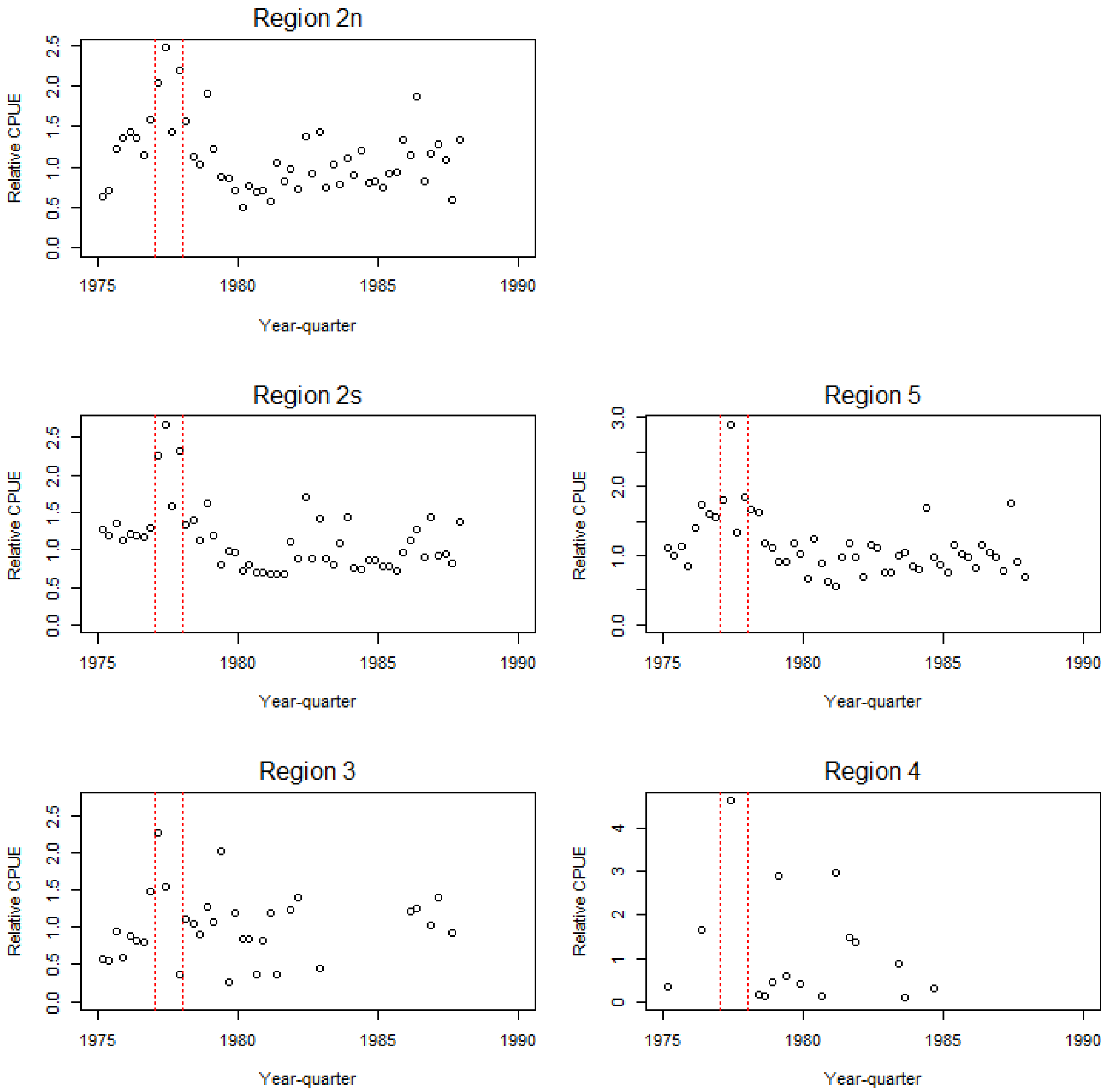


Figure 7: Yellowfin CPUE by the Korean fleet based on standardization of aggregated data held by IOTC.

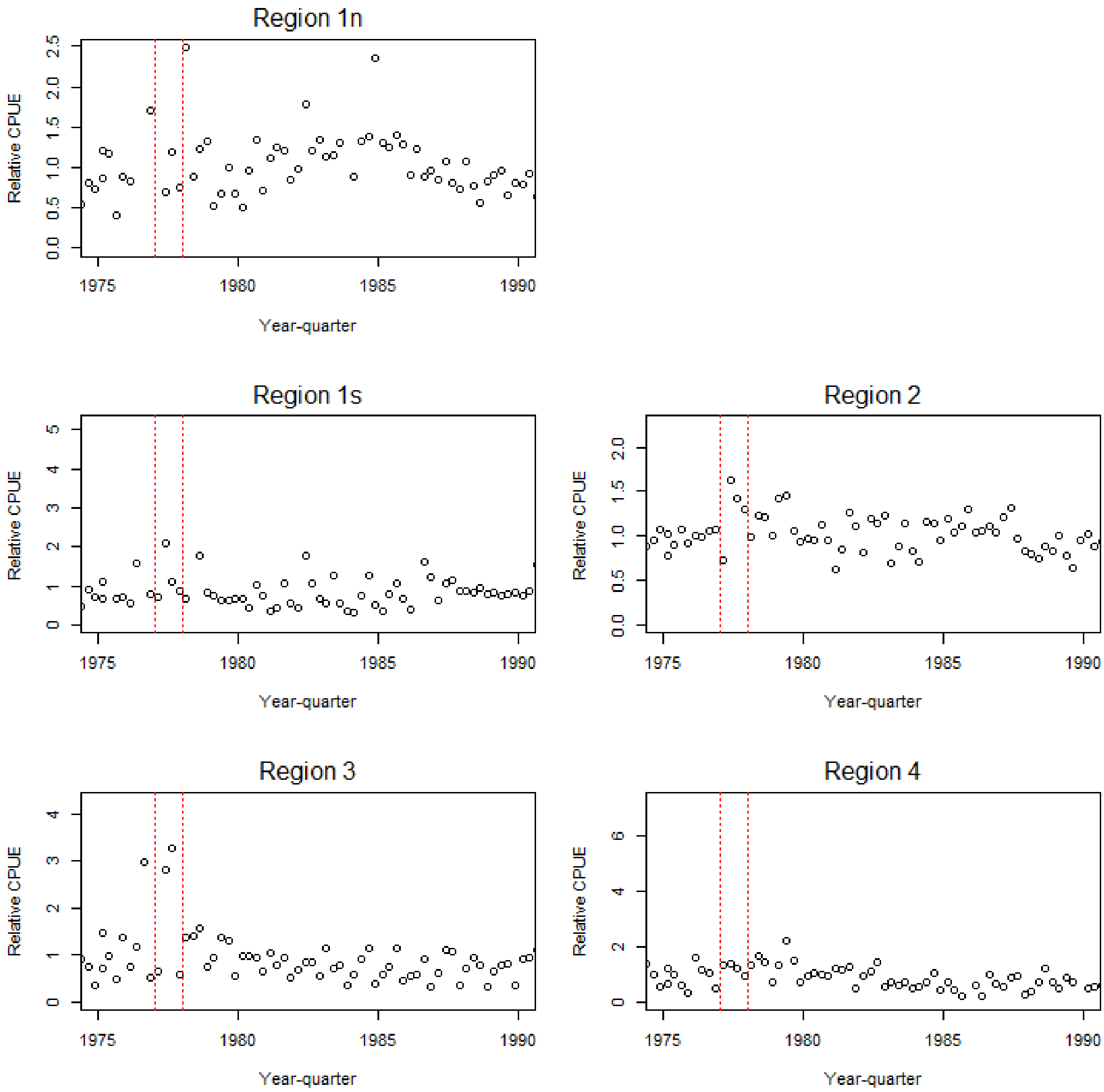


Figure 8: Bigeye CPUE by the Taiwanese fleet based on standardization of aggregated data held by IOTC.

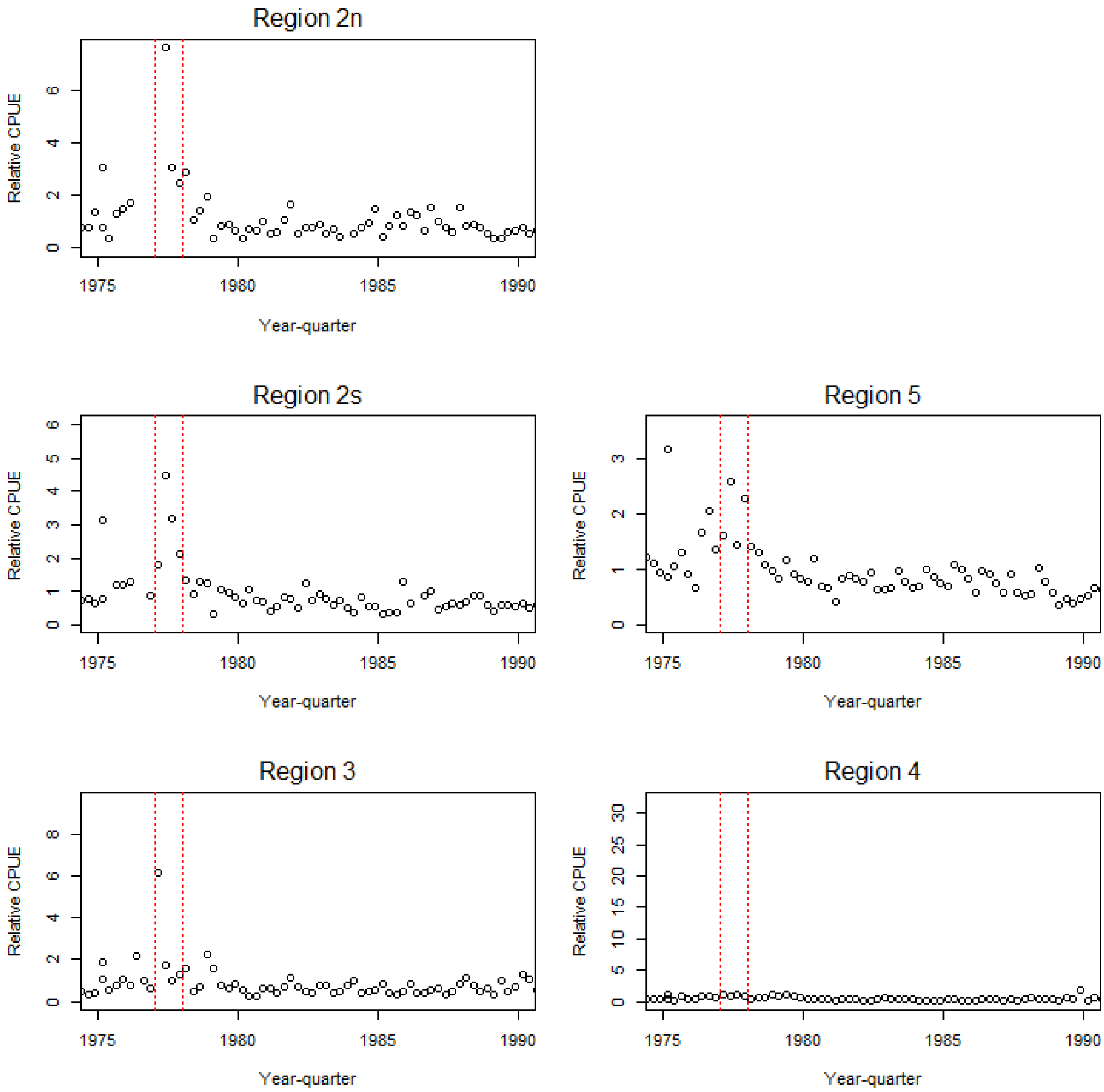


Figure 9: Yellowfin CPUE by the Taiwanese fleet based on standardization of aggregated data held by IOTC

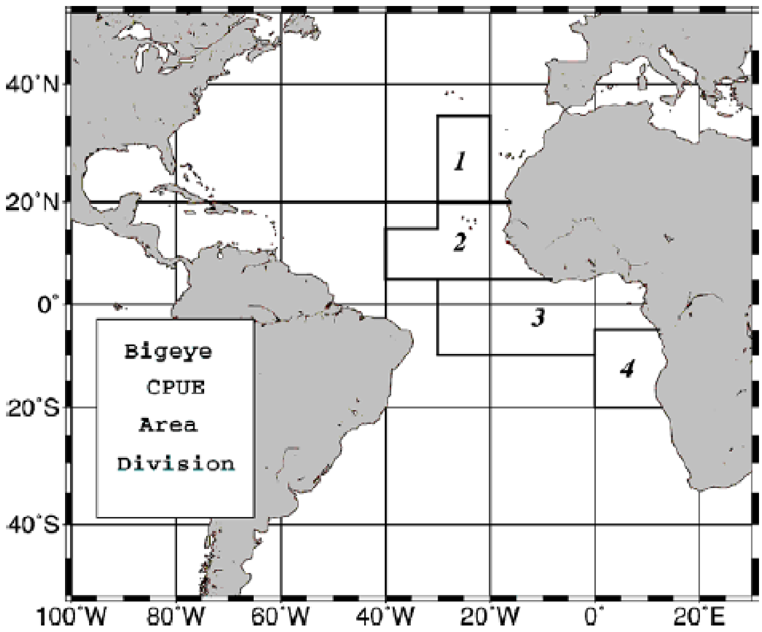


Figure 10: Areas 1 to 4 represent the main Atlantic bigeye fishing area for Japanese longliners, and are included in the standardization model (from Matsumoto and Satoh 2015).

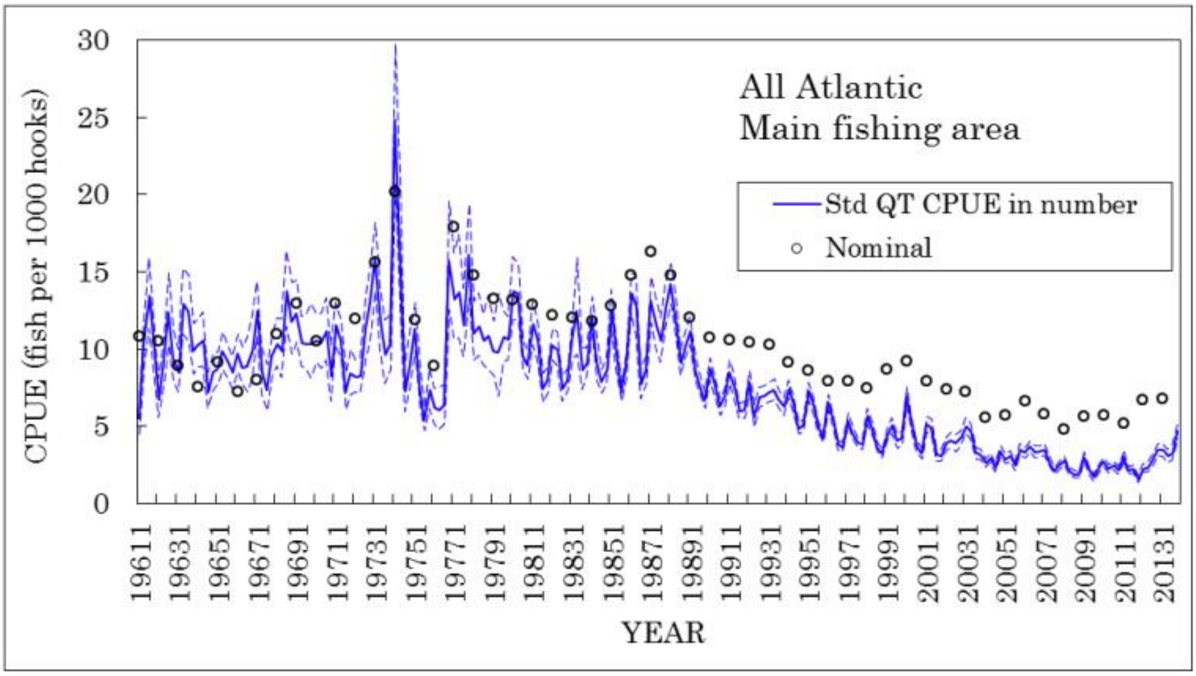


Figure 11: Standardized quarterly CPUE indices for bigeye tuna in the main Atlantic fishing ground (from Matsumoto and Satoh 2015).

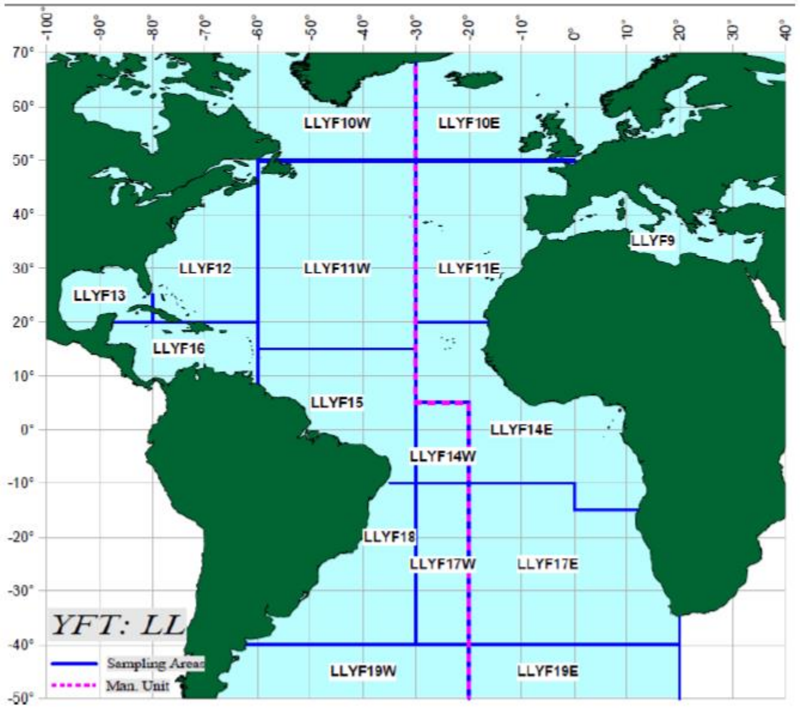


Figure 12: Area definition for the west and east regions used in the Atlantic yellowfin CPUE standardization (from Satoh & Matsumoto 2017).

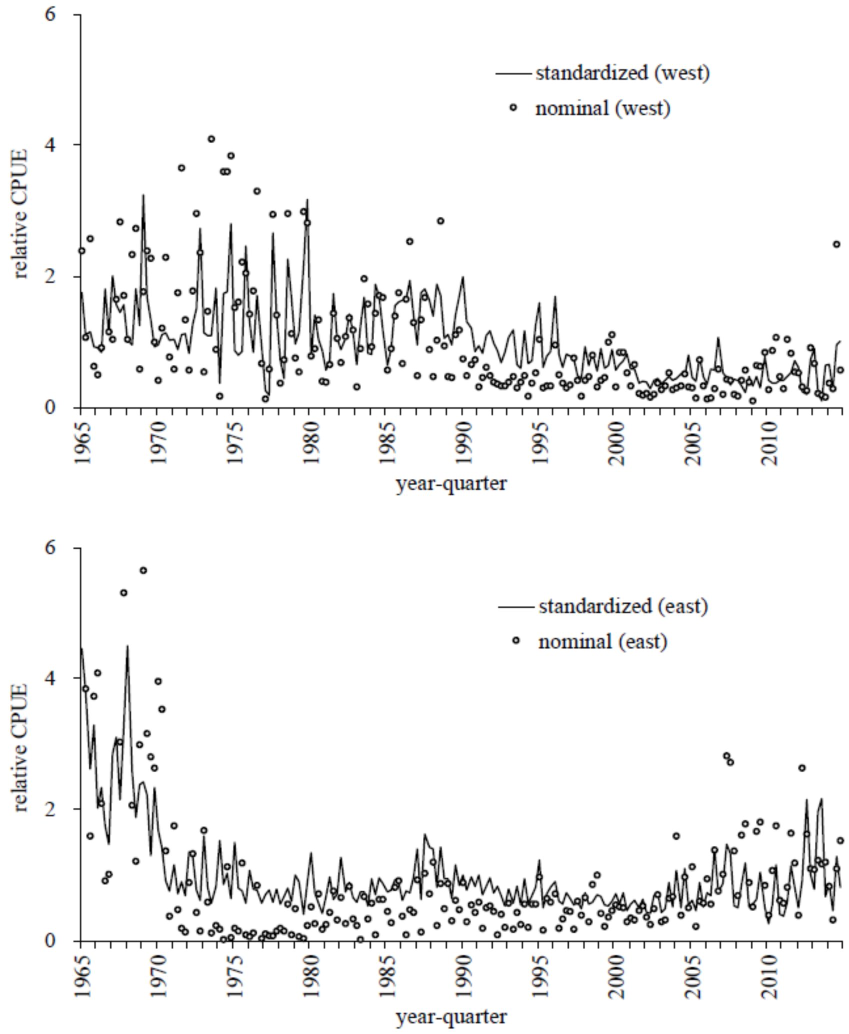


Figure 13: Atlantic yellowfin CPUE indices for the west (above) and east (below) regions (from Satoh & Matsumoto 2017).

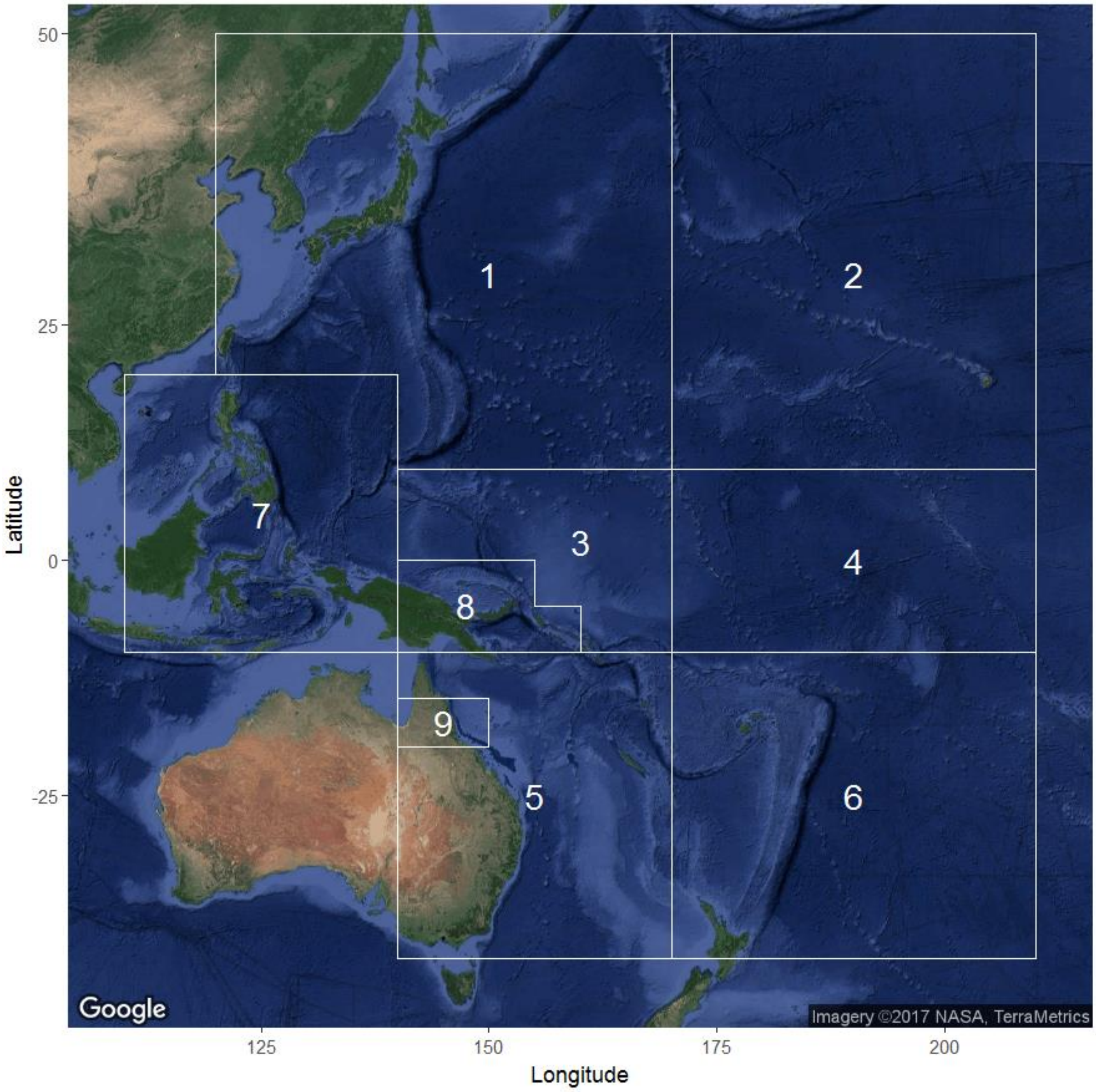


Figure 14:WCPO regional structure for the 2017 bigeye and yellowfin CPUE indices.

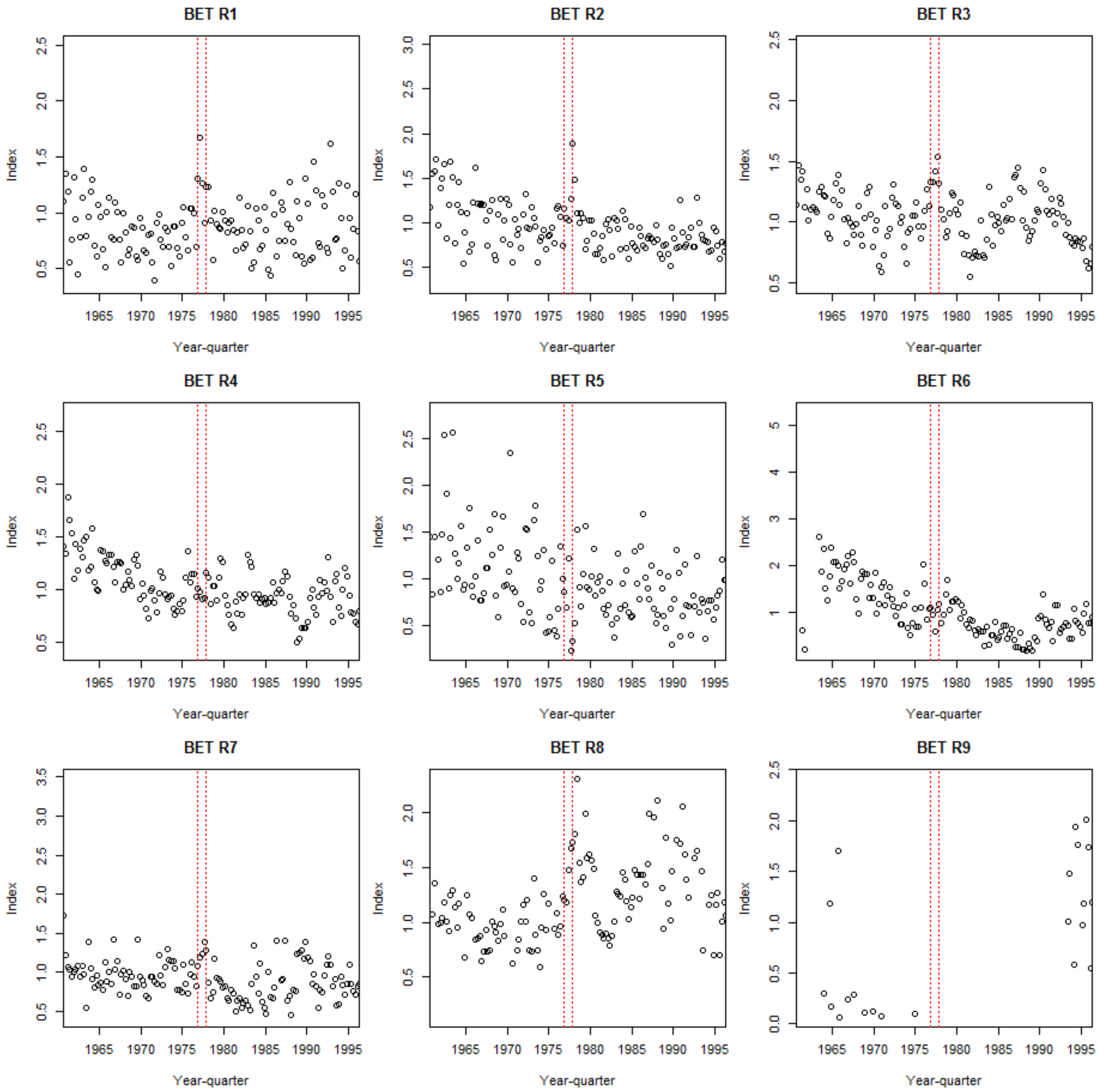


Figure 15: Bigeye standardized CPUE indices by WCPO region (McKechnie et al 2017). The red lines mark the starts of the years 1977 and 1978.

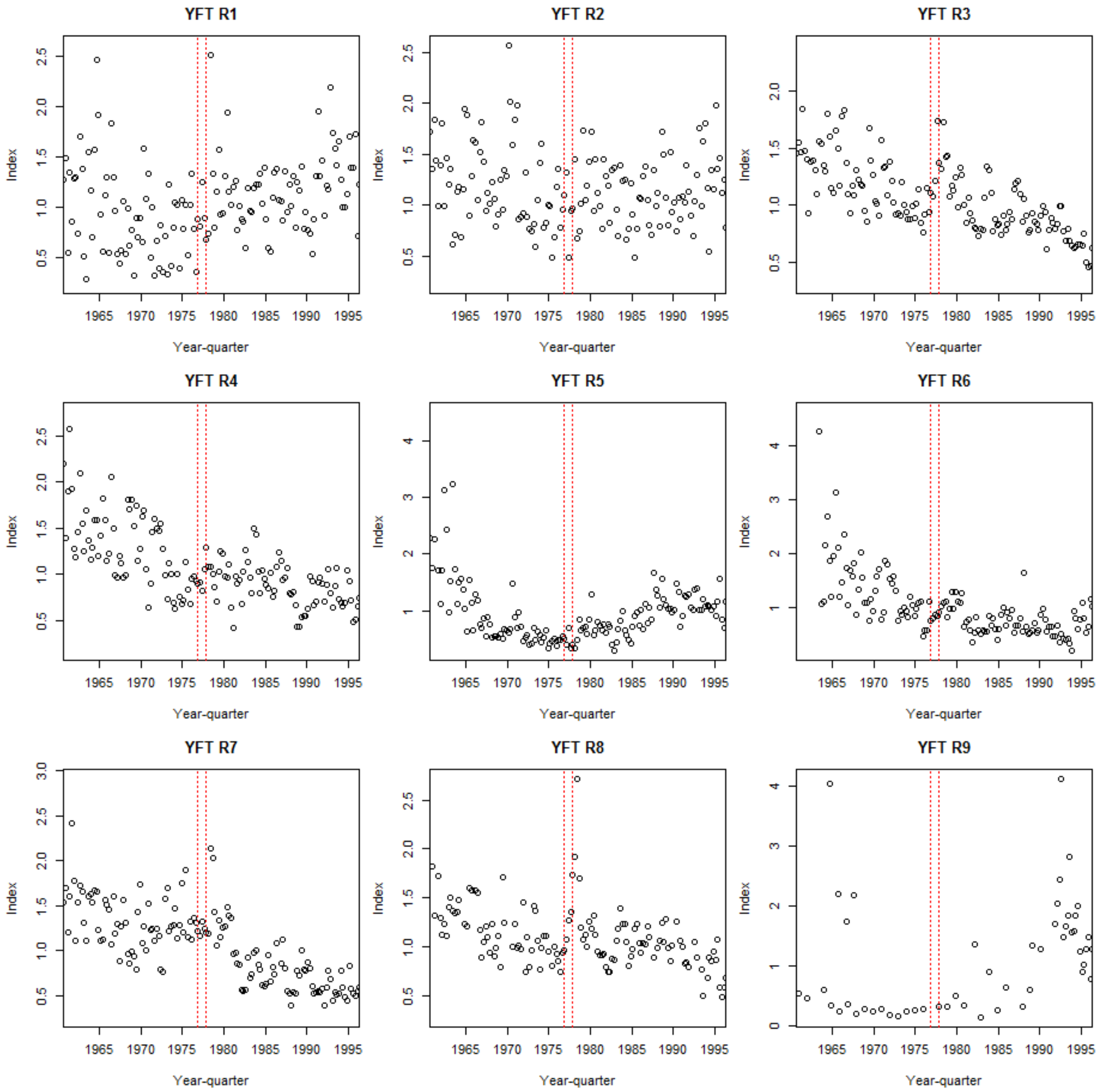


Figure 16: Yellowfin standardized CPUE indices by WCPO region (McKechnie et al 2017). The red lines mark the starts of the years 1977 and 1978.

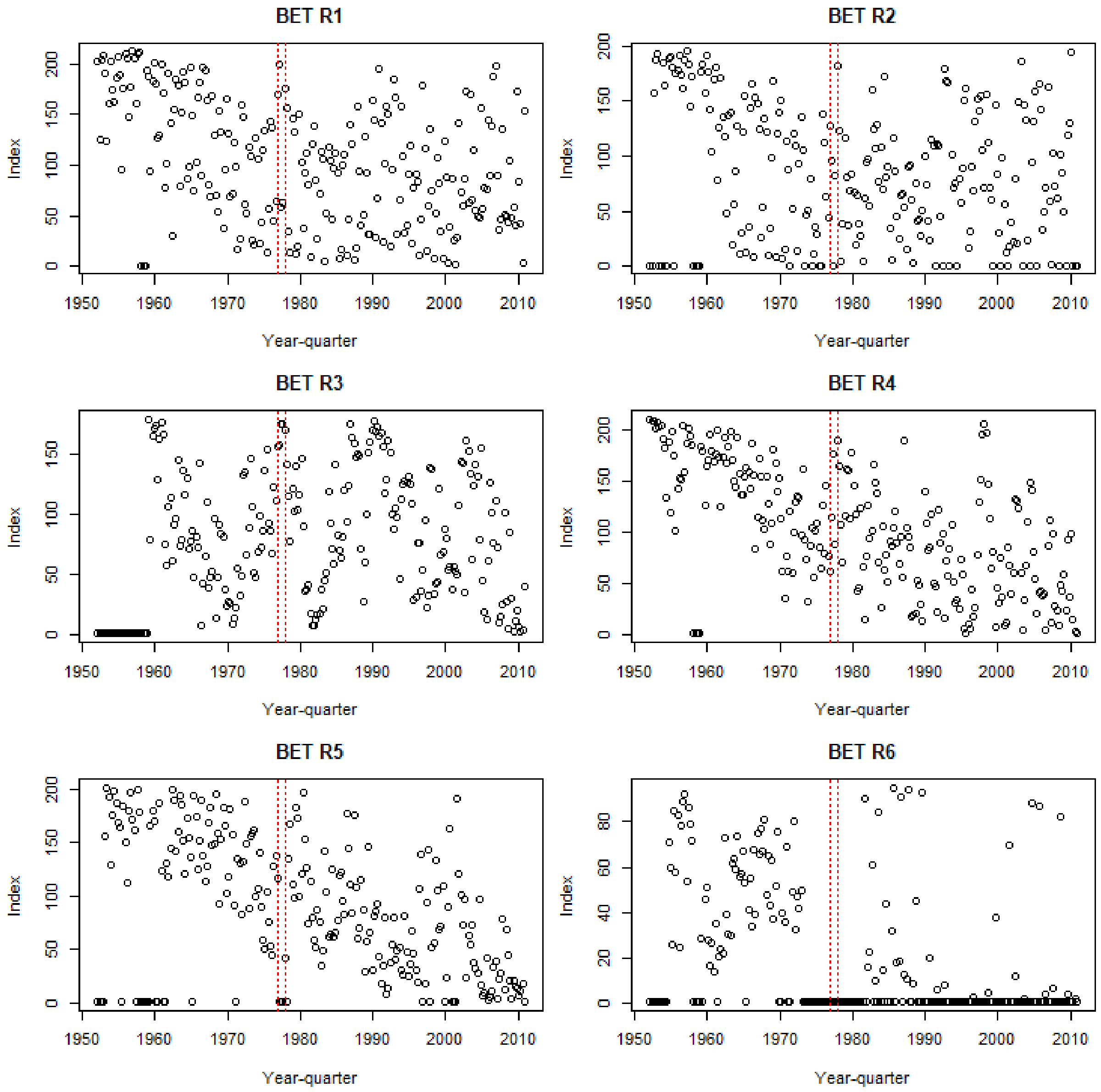


Figure 17: Bigeye standardized CPUE indices by WCPO region using Japanese data only (Hoyle and Okamoto 2011). The red lines mark the starts of the years 1977 and 1978.

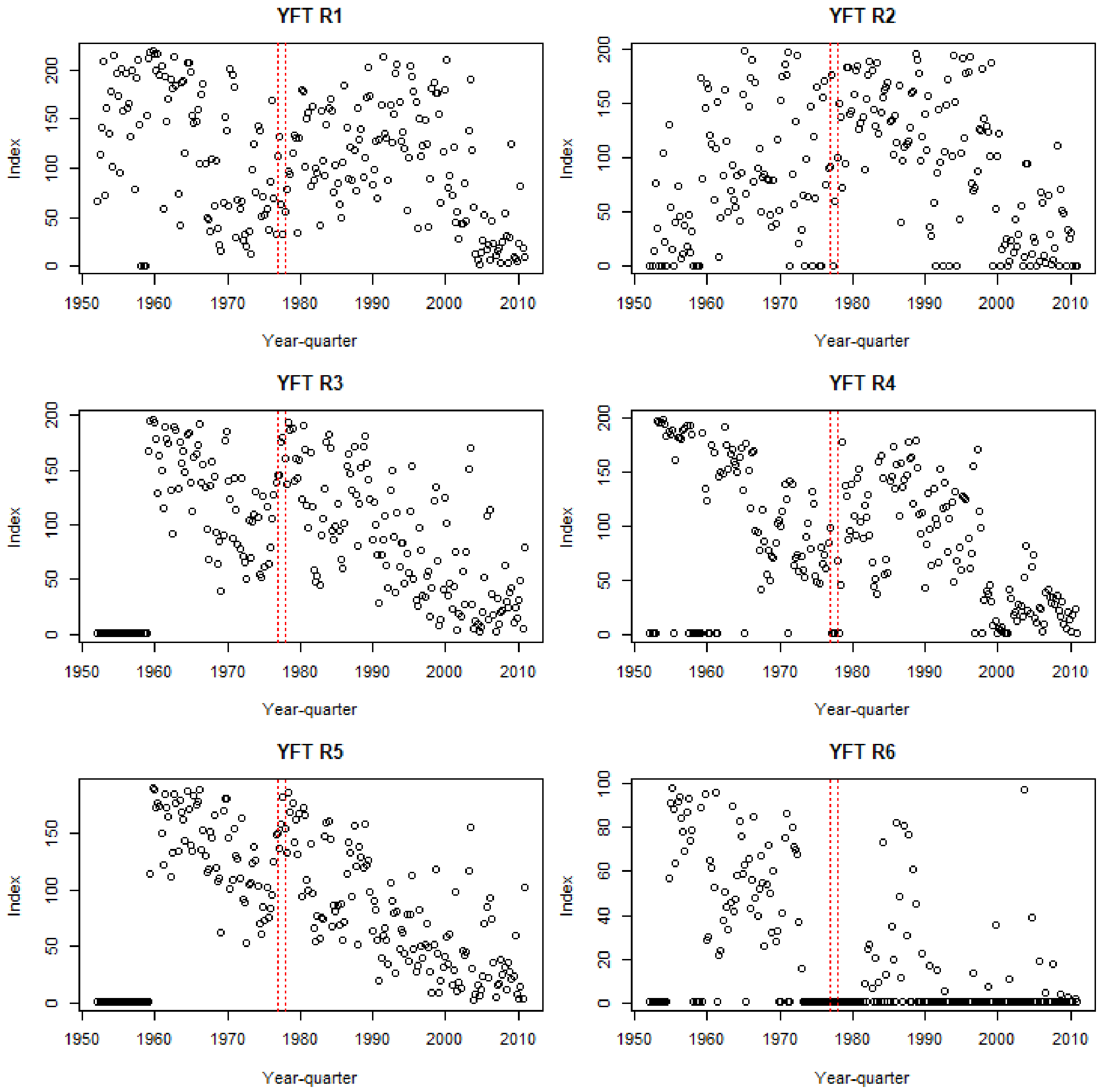


Figure 18: Yellowfin standardized CPUE indices by WCPO region using Japanese data only (Hoyle and Okamoto 2011). The red lines mark the starts of the years 1977 and 1978.

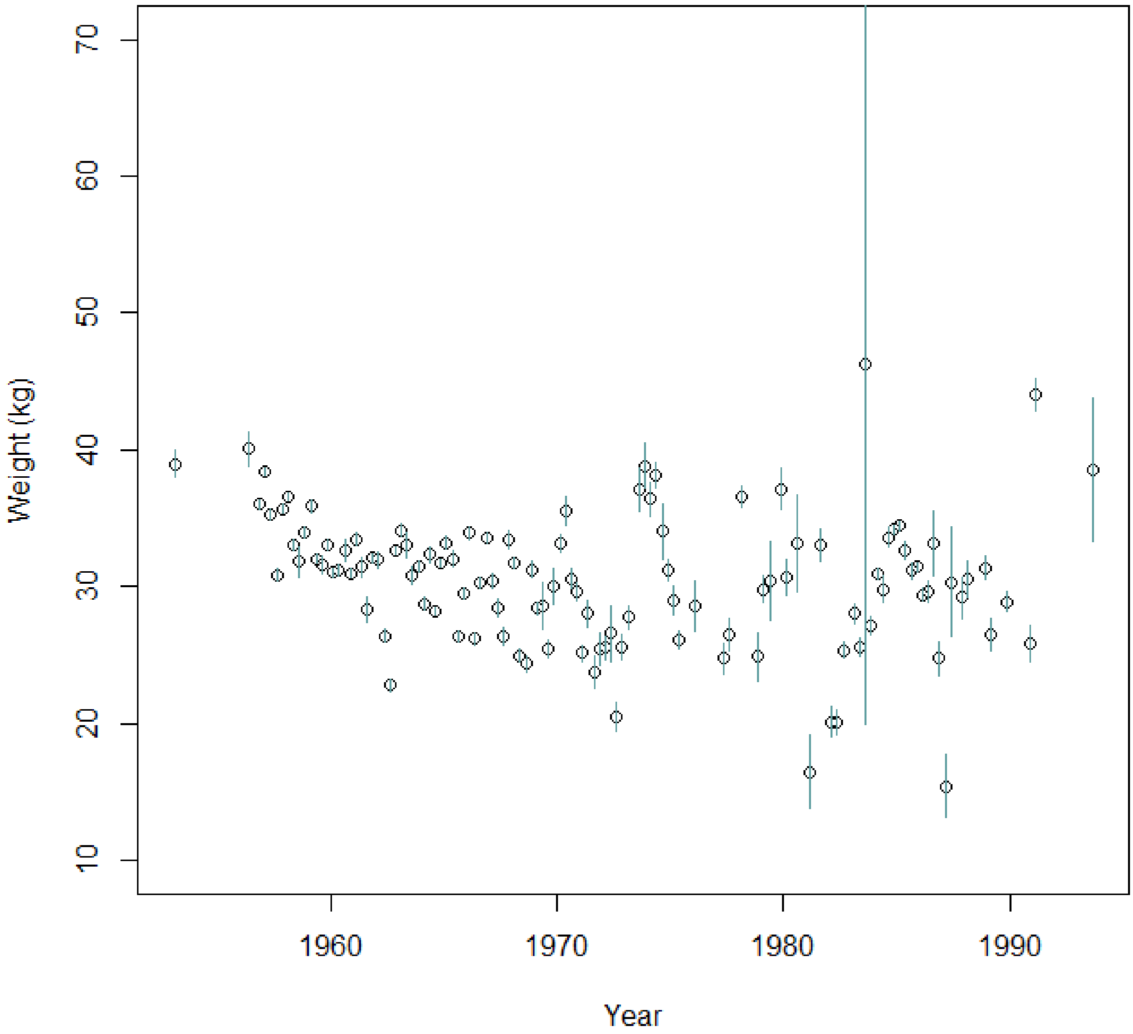


Figure 19: Yellowfin predicted quarterly mean weights from a model fitted to Japanese Indian Ocean 5 x 10 weight data.

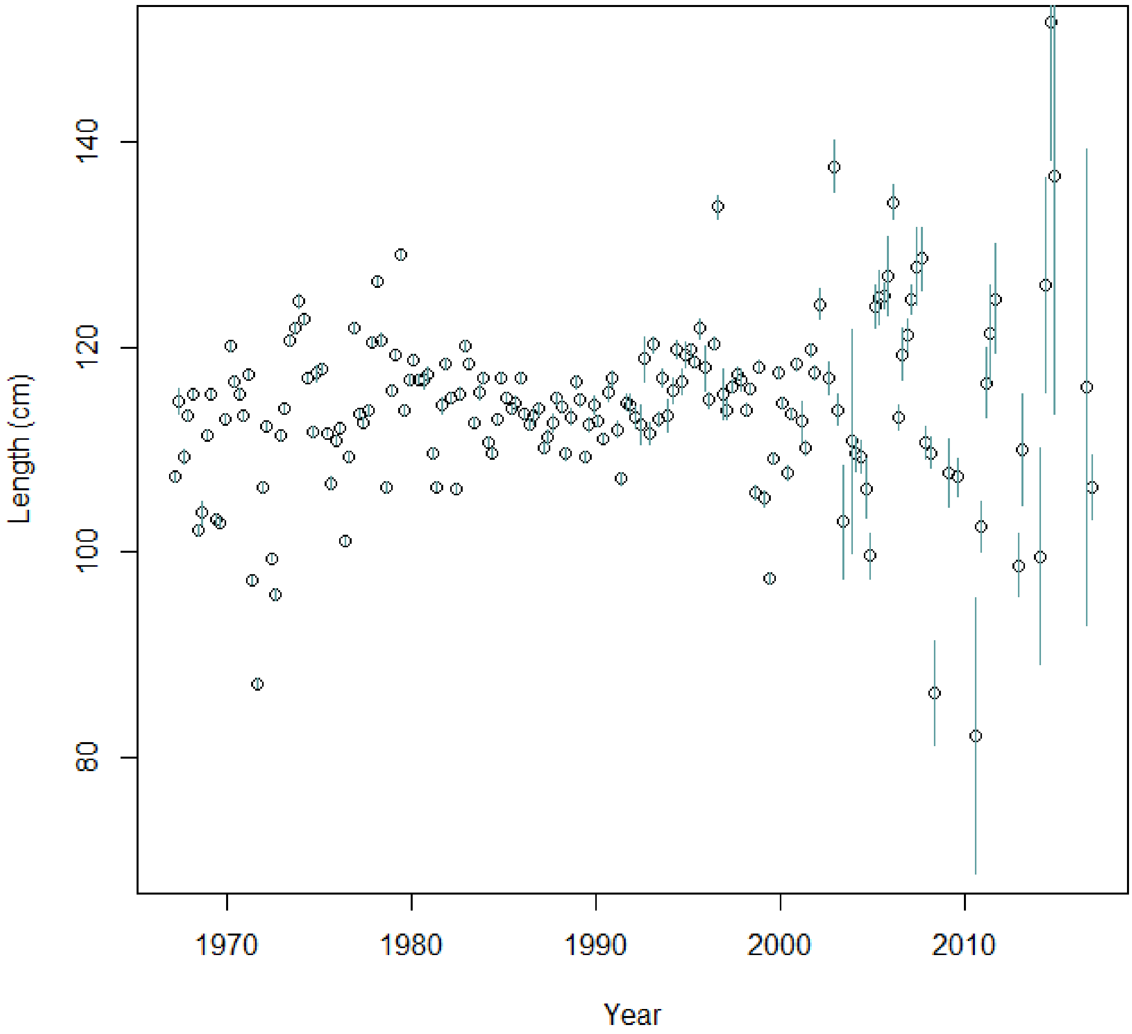


Figure 20: Yellowfin predicted quarterly mean lengths from a model fitted to Japanese Indian Ocean 1 x 1 length data.

Figure 21: Bigeye predicted quarterly mean weights from a model fitted to Japanese Indian Ocean 5 x 10 weight data.

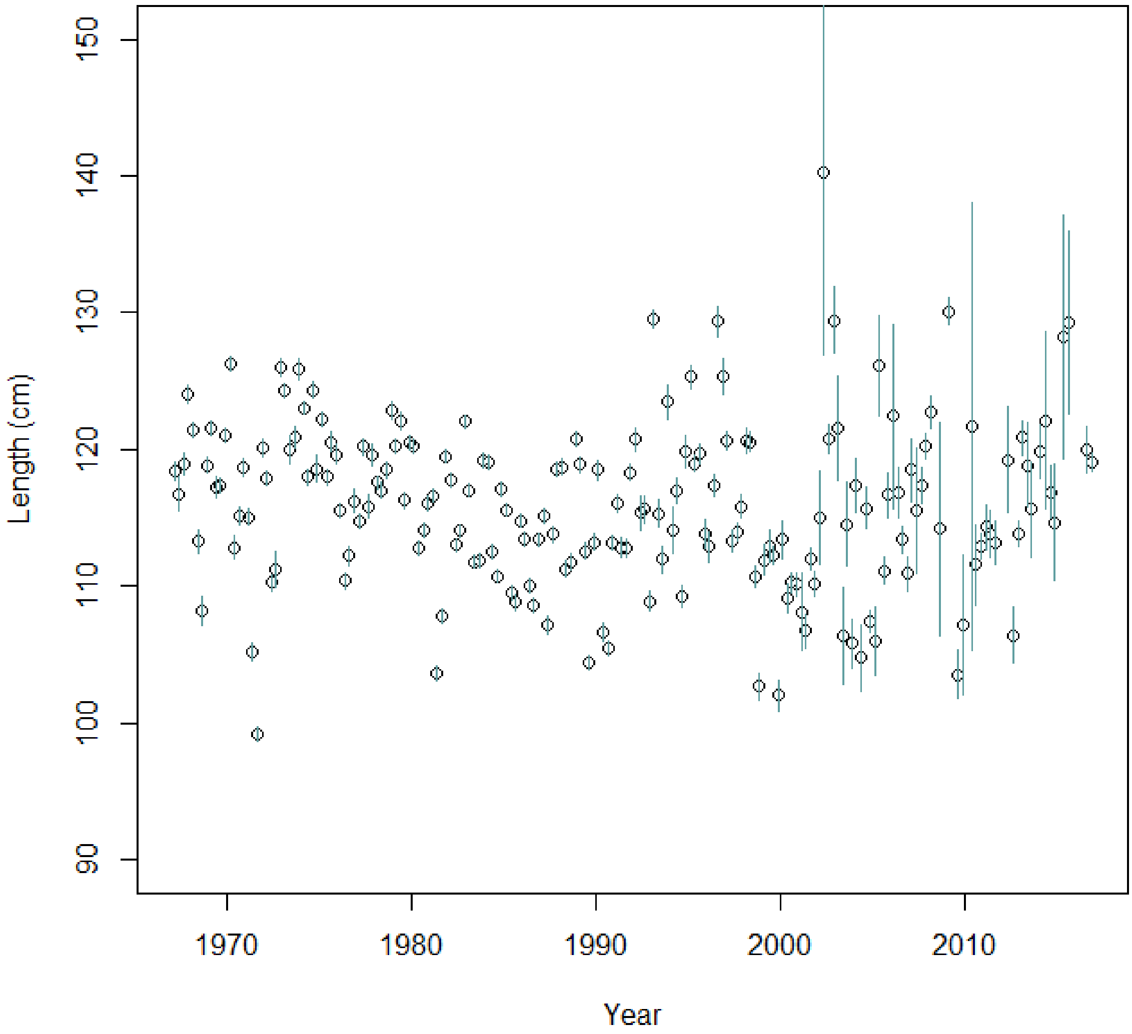


Figure 22: Bigeye predicted quarterly mean lengths from a model fitted to Japanese Indian Ocean 1 x 1 length data.

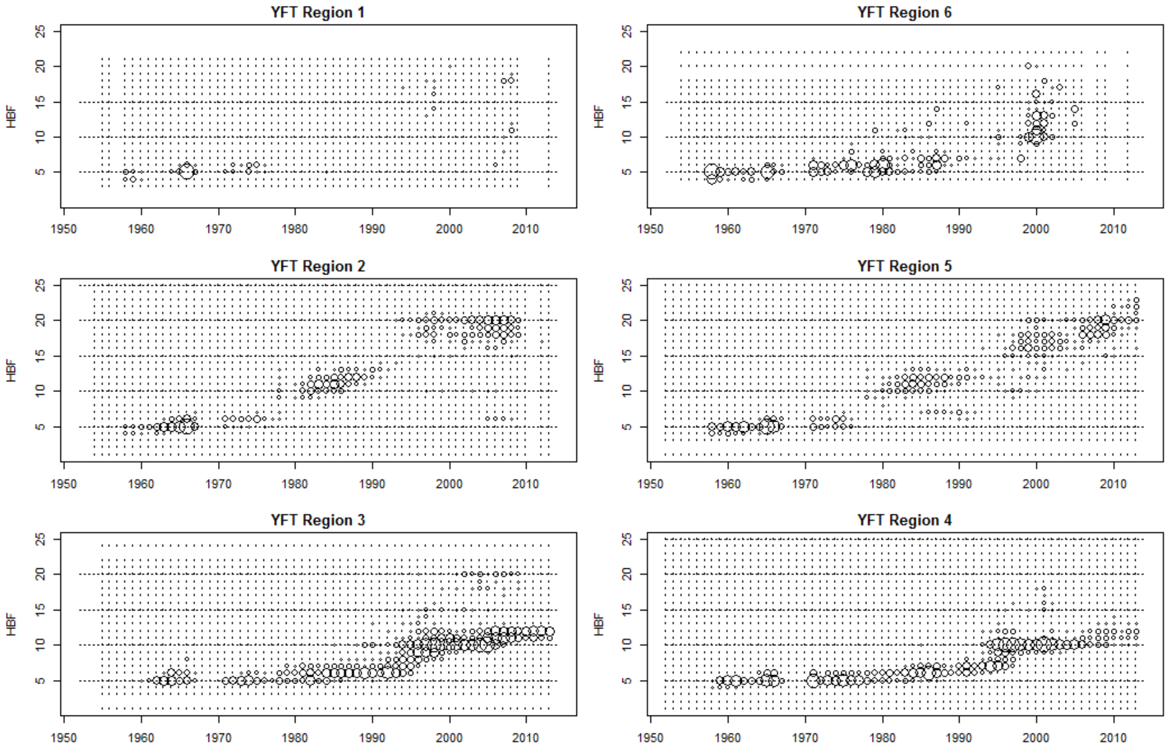


Figure 23: Japanese HBF by year and region in the Indian Ocean. Circle area is proportional to effort in hooks. Figure from Hoyle & Okamoto (2015). The term 'YFT' refers to the YFT region configuration in use at that time.

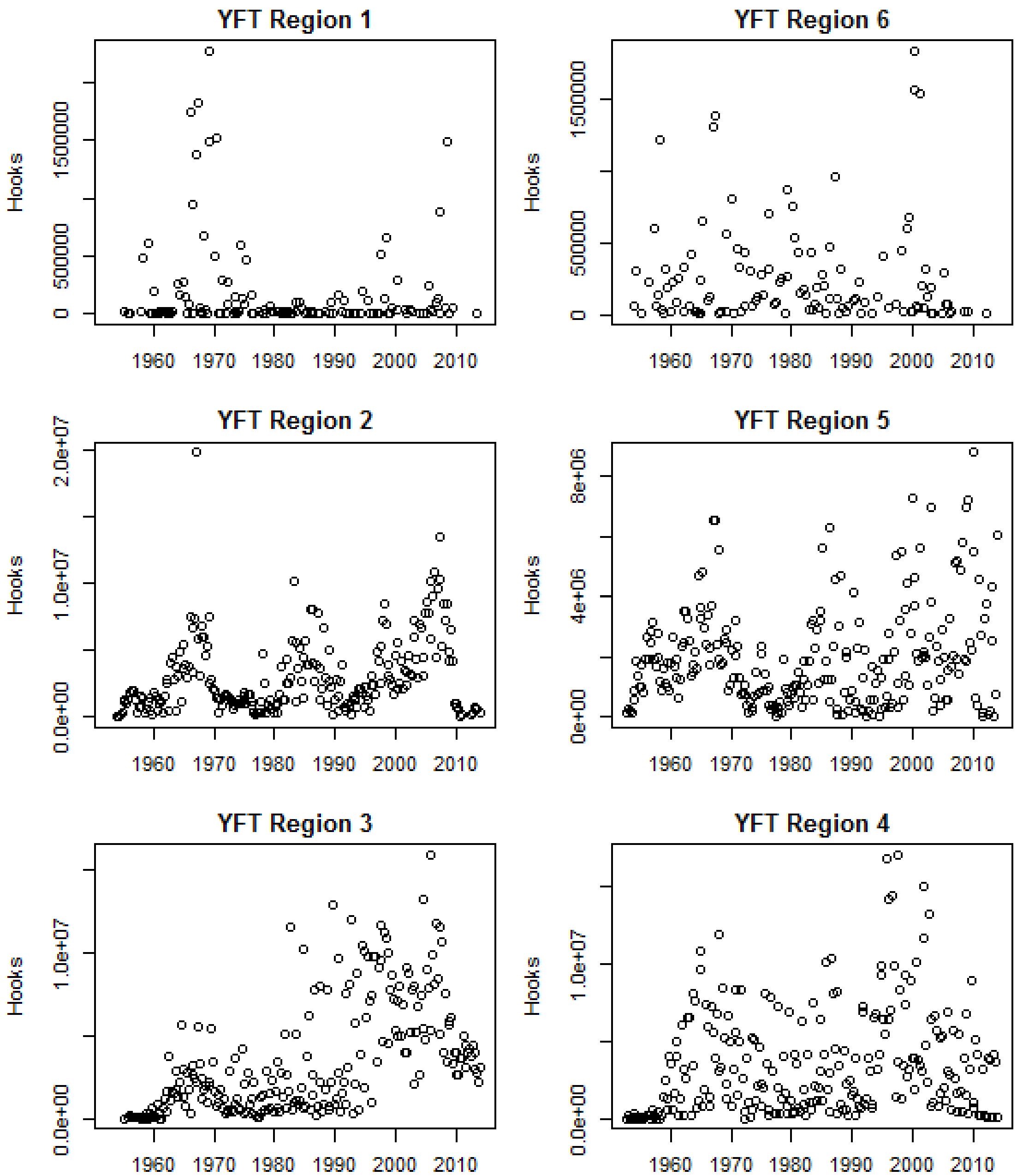


Figure 24: Hooks per year-quarter by yellowfin region for the Japanese fleet in the Indian Ocean. Figure from Hoyle & Okamoto (2015). The term 'YFT' refers to the YFT region configuration in use at that time.

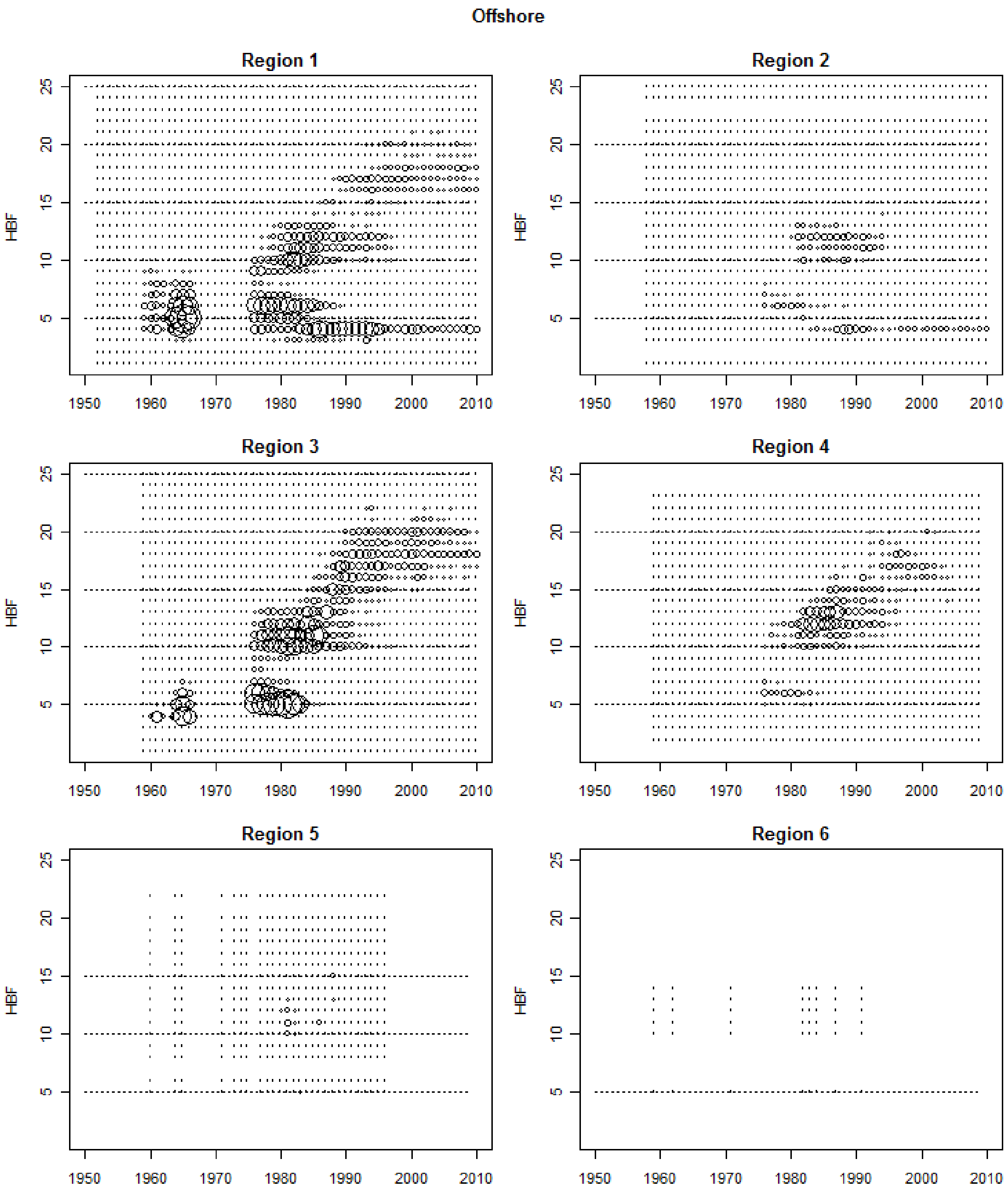


Figure 25: HBF by region by year for Japanese offshore vessels in the WCPO. Circle area is proportional to the number of sets. Figure from Hoyle & Okamoto (2011). HBF available from 1958 to 1966 and 1976 to present.

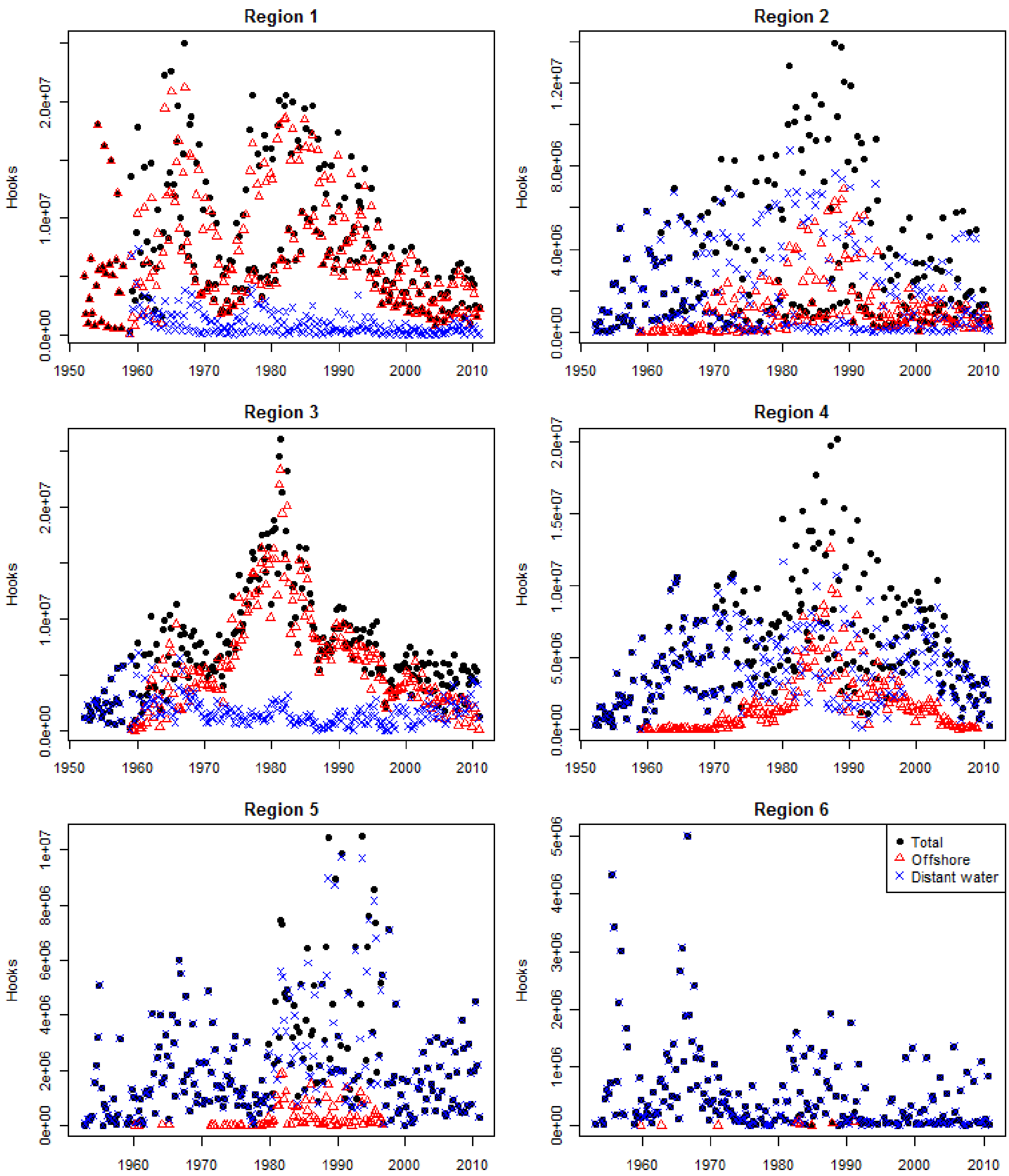


Figure 26: WCPO Effort by region, fleet, and year-quarter by the Japanese longline fleet, both distant water and offshore, as recorded in the operational dataset. Figure from Hoyle & Okamoto (2011).

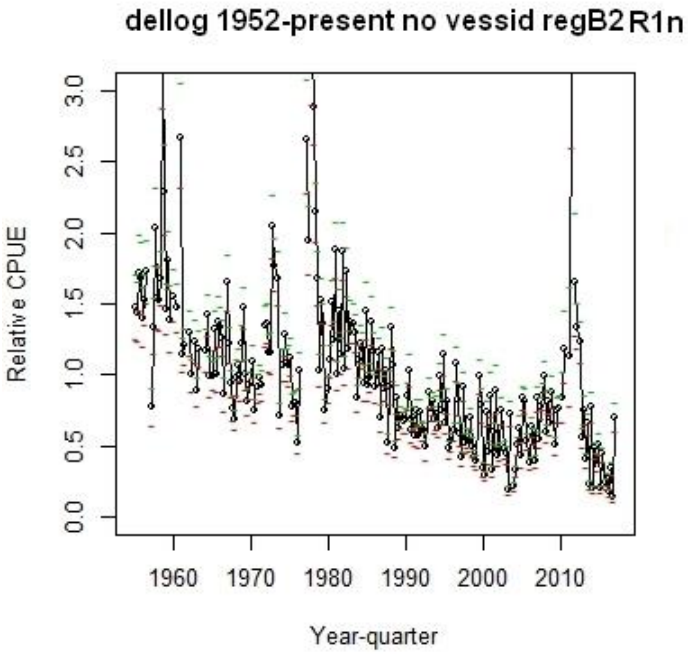


Figure 27: Bigeye standardized joint CPUE indices for the north-western tropical Indian Ocean region R1n, as estimated in 2017.