SCIENTIFIC COMMITTEE

NINTH REGULAR SESSION

Pohnpei, Federated States of Micronesia

6-14 August 2013

Target changes in the tropical WCPO Japanese longline fishery, and their effects on species composition

WCPFC-SC9-2013/SA-IP-04

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Executive Summary

This paper represents part of the response to the independent review of the 2011 bigeye tuna (BET) stock assessment, specifically the examination of changes in targeting within the Japanese longline fishery operating to the tropical western and central Pacific Ocean (WCPO). This work was undertaken at the National Institute for Far Seas Fisheries (NIFSF) in Shimizu Japan over a two week period in September 2012, using Japanese-held operational catch and effort data.

The interest in targeting changes in the longline fishery is because 1) longline CPUE is the primary abundance index in the bigeye assessment, and 2) there is a stark difference in the trends in CPUE for bigeye and yellowfin tuna (YFT) through time. Changing targeting behaviour (towards bigeye and away from yellowfin) is one explanation proposed for this difference. Changing relative abundance is another.

The analyses described in this paper are divided into four parts: 1) a description of spatial temporal patterns in CPUE and catch composition of the longline fishery – the patterns we hope to explain; 2) temporal changes in fishing patterns, in particular the characteristics of the fishing gear used; 3) a series of investigations using regression trees, cluster analyses, and generalized linear models to try and relate the patterns in (1) to either changes in abundance or targeting; and 4) an analysis of how individual vessels react to catch on a set, in terms of where they set next.

The key findings under the four areas of investigation are as follows:

- **Patterns in CPUE and catch composition:**
    - Bigeye CPUE has remained relatively stable since 1960 in the equatorial WCPO, in contrast with yellowfin CPUE which has declined significantly over the same period; and
    - There are strong spatial temporal patterns in catch composition with yellowfin declining in both time and space as a proportion of both YFT+BET and YFT+ALB
- **Fishing strategies:**
    - Effort in the fishery has decreased considerably since a peak in the early 1980s, and the areas and seasons (quarters) fished have also declined over this period. Most of the decline has occurred to the south of the main tropical fishery, but effort has also declined in the equatorial region.

  - There have been large changes in the fishery through time such as an increase in the number of hooks set per day and the number of hooks between floats. Interpreting the latter is complicated by changes in line materials.
  - While a variety of important data have been collected from the Japanese fleet since 1950, a number of potentially important variables are not available (e.g. time of set and soak time) and other fields have been collected inconsistently (e.g. hooks between floats (HBF) and bait type). This complicates the analysis.
- **Investigation of changes in targeting**
  - Cluster analysis identified groups of trips with either higher bigeye or higher yellowfin catch rates. The proportion of sets in the bigeye cluster increased through time, particularly in region 4, but the clusters may be driven by abundance rather than vessel behaviour.
  - Changes in species composition were more strongly associated with year and location than with individual vessels or the available operational factors.
- **Response of individual vessels to catch rates of BET, YFT and BET+YFT**
  - Analyses of vessel behaviour showed that long movements were more likely after catches of fewer fish. Movements were more affected by low bigeye catches than they were by low yellowfin catches, but were most affected by the combined catch of BET+YFT;
  - Importantly, there was no evidence that the preference for moving after low catches of bigeye had increased through time

Introduction

This paper represents part of the response to the independent review of the 2011 bigeye tuna (BET) stock assessment, specifically the examination of changes in targeting within the Japanese longline fishery operating to the tropical western and central Pacific Ocean (WCPO). This work was primarily undertaken in at the Far Seas Fisheries laboratory in Shimizu Japan over a two week period in September 2012 using Japanese-held operational catch and effort data.

Bigeye CPUE has remained relatively stable since 1960 in the equatorial WCPO (Hoyle and Okamoto 2011), in contrast with yellowfin CPUE which has declined significantly over the same period (Figure 1). These observations could be explained by either a decline in the relative abundance of yellowfin, or a decline in its relative catchability. Such a decline in relative catchability could occur if vessels are progressively targeting bigeye more than yellowfin; in other words, target change in the equatorial WCPO away from yellowfin and towards bigeye may have artificially stabilised bigeye CPUE.

The main objective of CPUE analysis for stock assessment is to obtain an index of abundance. Change in the species targeted affects these indices by producing abundance-independent changes in the CPUE of individual species. Target change has its practical effect via catchability change, which reduces the value of the CPUE index as an index of abundance. Standardizing approaches (e.g. GLM) are intended to correct for such changes but depend on the inclusion of variables that are correlated with the targeting activity.

We examine targeting in the tropical WCPO Japanese longline fishery at three levels: 1) the motivating factors that drive the use of particular fishing strategies; 2) the strategies that fishermen use to target particular species; and 3) the resulting species compositions and catch rates.

Understanding the factors that drive targeting can help to identify the changes that occur. Targeting describes intentions, which are motivated by the skills and experience of the fishermen, administrative restrictions, the costs of different fishing methods, and the catch rates and prices of the target species. Information about these factors through time can help identify and understand target changes. However, we have no data that describes intentions; only proxies for what may represent changes in target.

In a practical sense targeting behaviour is defined in terms of fishing strategies and technology. These include the fishing location, season, and the moon phase. The setting strategy includes factors such as the number of light sticks, the time of the set, depth of set, the bait type, the hook type, the number of hooks between floats (HBF), the number of hooks, and the direction of set relative to oceanographic features.

Patterns in CPUE and catch composition

It is well known that the longline catch composition and CPUE vary across the Pacific, with higher proportions of bigeye in the east and yellowfin in the west. Long term spatial variation in catch rates is accounted for in CPUE standardization models that fit CPUE as a function of cell (5° square) + time. Stock assessments use these long term patterns to infer relative abundances in space, via area scaling analyses (Langley et al., 2005; Hoyle & Langley, 2007). However, the finer details of these patterns have not been described or mapped, and nor have the changes that have occurred through time due to variation in abundance and in fishing patterns.

Fishing strategies

One of the most significant changes to occur in tuna longline fisheries was a change in targeting practices in all oceans by the Japanese longline fleet during the 1960's and 1970's. Economic factors and the introduction of super-cold freezers led to distant water longliners targeting fish to supply the higher value sashimi market rather than canneries (Sakagawa et al., 1987). This led to more targeting of bigeye, with its higher value for sashimi, and a progression towards deeper sets (Suzuki et al., 1977; Ward & Hindmarsh, 2007).

Many other changes in fishing technology have occurred though time including the introduction of electronic devices, new and improved gear materials, and faster vessels that can deploy more hooks (Ward & Hindmarsh, 2007). However, the relationships of many of these changes with targeting practices are unclear.

Investigating changes in targeting

Accounting for targeting requires analyses at multiple levels, with spatial factors, vessel effects, and operational effects at the set level all coming into play.

Operational-level data can be effective for identifying targeting at the set level. We have previously differentiated effort targeting tuna and other species from effort targeting swordfish, based on the use of squid bait before 1980 (bait type available 1952-1993) and low HBF after 1980 (HBF available after 1975) (Hoyle & Okamoto, 2011). However, data on fishing behaviour during specific operations are often limited with too few operational variables reported to discriminate between targeting methods.

Analyses at the individual vessel level can account for targeting to the extent that vessels are consistent in their behaviour through time. Individual vessels' catch rates may reflect both their targeting behaviour and their ability to catch individual species, which are affected by both the vessel characteristics and the preferences and abilities of skipper, fishing master, and crew. Vessel-level effects contribute substantially to catch rate variation among sets, and long term changes in average vessel effects result from both increases in fishing power and changes in targeting through time (Hoyle & Okamoto, 2011). It is possible for individual vessels to change their fishing strategies and HBF, but target change often occurs at the fleet level, with individual vessels maintaining consistent behaviour but changes in the proportions of vessels with each strategy. Targeting changes by the Japanese longline fleet have been observed particularly in subtropical areas, and also in the north of region 3 (Hoyle et al., 2010). However, analyses of Japanese effort before 1975 are less informative because it is rarely possible to identify individual vessels and trips. It has therefore been difficult to standardize for the effects of the target change towards bigeye during the 1960's and 70's.

The aim of targeting is to maximise the catch of one or more species, so it follows that target change should result in a change of the species mix. We can sometimes identify changes in fishing strategy from their effects on the relative catch rates of different species. Including the catch rates or proportions of other species in the analysis can, however, introduce bias, and should usually be avoided (Hoyle, 2009).

Cluster analysis can be used to separate fishing activity according to the proportions of each species in the catch (He et al., 1997), and we can then analyse the separate clusters with confidence that each cluster has consistent targeting behaviour. Cluster analyses of operational data from longline fishing by multiple flags in the south Pacific have identified clusters targeting different species, and differentiated between targeting of yellowfin, albacore, and mixed species (Bigelow & Hoyle, 2012).

Changes in vessel behaviour

Another approach for investigating fishing strategies is to examine vessel behaviour. An innovative approach used by Langley (2007) was to compare the distances that vessels moved between sets after catch rates of different species. When a vessel uses its catch rates to inform its search, longer movements were more likely after low catch rates of the target species. This approach was applied to VMS data and reported without statistical analysis, but can be extended to other data types and implemented in a statistical modelling framework.

This paper discusses work carried out at the NRIFSF laboratory in Shimizu, Japan, in September 2012. The aim of the study was to investigate targeting and to develop a more realistic index of abundance that takes target into account.

Methods

Data

Catch and effort data came from the operational Japanese longline dataset from 1952 to 2011 held by NRIFSF. For details of data preparation, see Hoyle *et al.* (2010) and Hoyle and Okamoto (2011).

Patterns in CPUE and catch composition

We mapped patterns of species composition and CPUE in order to provide an overview and to generate hypotheses. The species composition maps showed average compositions in the catch by decade and 1 degree square, based on the partial proportions: $\frac{yellowfin}{bigeye+yellowfin}$ and $\frac{albacore}{albacore+yellowfin}$. We mapped yellowfin-bigeye composition for both the whole WCPO and the equatorial WCPO, and albacore-yellowfin composition for the equatorial WCPO. CPUE and catch by species were also mapped and the more significant results are discussed, but are not presented due to the space requirements.

Fishing strategies

We investigated changes in operational characteristics through time, to the extent possible given data availability, by plotting patterns by time and location. Available fields were vessel tonnage GRT (1963-66, 1976-2011), fishing category (offshore or distant water, 1958-2011), reported target (1994-2011), mainline material and branchline material (1994-2011), bait type (1952-1993), hooks between floats (1958-1966 with 35 – 95% coverage, and 1976-2011), and hooks per set (1952-2011). Individual vessels could be identified from their callsigns from 1979-2011, with close to 90% coverage from 1984. Although Japanese vessel names were available 1958-66 and 1976-2011, transcription problems and spelling inconsistencies made them difficult to use.

Investigation of changes in targeting

We analyzed the catch and effort data in order to investigate potential changes in targeting through time. Analysis methods included regression trees, cluster analysis, and generalized linear modelling.

Regression trees

Regression trees, useful for exploring data, are more flexible and efficient than generalized linear and additive models for examining multiple possible relationships, including nonlinearity and interactions. We fitted regression trees (R package 'rpart') to data from the core equatorial area between 5S and 10N. This area was chosen to exclude any possible albacore targeting and to focus on differentiating any possible bigeye or yellowfin targeting behaviour. The proportion bigeye in the catch BET/(BET+YFT) was the response variable, and we offered the model the variables latitude, longitude, year, fishing category (OS or DW), albacore CPUE, swordfish CPUE, hooks, and hbf. Analyses for 1976-1993 included bait, and analyses for 1994-2011 included branchline and mainline materials.

Cluster analysis

Cluster analysis can be used to identify groups of data with discrete characteristics. Species composition is often very variable among sets, so we applied clustering at the trip level, which averages across sets to give a more consistent picture of the species being captured.

We ran cluster analyses in R (package 'cluster') based on the proportions of albacore, yellowfin and bigeye tuna caught in each trip. These analyses were initially applied to the whole of region 3, and subsequently to the core equatorial area between 5S and 10N in regions 3 and 4. Swordfish was included in exploratory analyses, but later excluded due to the low proportions in core equatorial areas. Due to random variation in species availability per set, clustering at the set level will assign some sets to the wrong target method. In addition, analysis by set was computationally prohibitive. Clustering was therefore conducted by trip. Trips that caught no tuna were uninformative and therefore removed from the cluster analysis. Clustering was applied to the time series from 1990 and 2011.

Two approaches were used to estimate the appropriate number of cluster groups. First, the *k*-means method (Hartigan & Wong, 1979) was applied with values of k from 1 to 15, and the within-groups sum of squares plotted against k. Secondly, a Ward hierarchical clustering or agglomerative approach (hclust, (Maechler et al., 2013) was applied by region to both the full region 3 and 4 data, and the core equatorial data for regions 3 and 4, to produce dendrograms that suggested the number of clusters represented in the data. The equatorial analyses resulted in two clusters, one with more yellowfin and the other with more bigeye catch. The proportion of effort in the yellowfin cluster was plotted against a) year and b) on a map at 1 degree resolution, by 5 year period.

Generalized linear modelling

If bigeye distribution changes substantially at spatial resolutions finer than 5 degree squares, and vessels' ability to target bigeye at these finer resolutions has improved through time, then such changes need to be taken into account in CPUE standardizations. Generalized linear modelling of bigeye CPUE was carried out with spatial effects modelled at finer resolutions of 1 degree squares and 2 degree squares rather than the standard approach of 5 degree squares. Changes in the resulting indices were investigated by taking the ratios of the resulting normalized time series. The average trends of the ratios were calculated, to check for changes in bigeye targeting at finer spatial scales.

In order to examine more closely the contributions of targeting to changes in species composition through time, we standardized the data on species composition per set with models similar to those used in developing CPUE indices (Hoyle & Okamoto, 2011). We fitted the following model, assuming that species composition was binomially distributed. The spatial resolution in this case was 3 degree squares, so as to provide as much spatial resolution as possible while remaining computationally feasible. Data in the core equatorial area were included, in this case from 5S to 13N, and we ran separate models for regions 3 and 4 of the BET/YFT assessment.

$$glm\left(\frac{BET}{BET+YFT} \sim yrqtr + vessel + latlong + poly(HBF,6)\right)$$

Year, vessel, and HBF effects were represented on xy plots. Spatial effects were represented by colours and mapped. Vessel effects were also displayed by plotting each vessel effect during each time step when the vessel reported effort, estimating for each time step the mean of the vessel effects across all sets, and then plotting a line through the means.

Vessel behaviour in response to catch rates

Following Langley (2007) we modelled vessel behaviour by examining the distances moved by vessels after catches of different sizes. Set locations were reported at the 1 degree square level, which is approximately 111 km of both latitude and longitude at the equator. For each set we calculated the distance in degrees to the next set by the same vessel.

We modelled the probability of moving more than one degree using generalized linear model with a binomial distribution, with covariates that included the year-qtr and 5 degree square (as factors), and the bigeye and the yellowfin catches in numbers.

$$glm((mv > 1) \sim yearqtr + latlong + ns(bet, df = 4) + ns(yft, df = 4), family = "binomial")$$

We ran a second model that replaced the species-specific catches per set with the catches of bigeye plus yellowfin.

$$glm((mv > 1) \sim yearqtr + latlong + ns(bet + yft, df = 4), family = "binomial")$$

Both models were run by decade, for the decades starting in 1980, 1990, 2000, and 2010, to investigate possible changes in the behaviour of vessels in response to catch rates of bigeye and yellowfin tuna.

In a second analysis we modelled the year-specific probabilities of moving more than one degree, permitting those probabilities to vary among years, and predicted the ratio of movement probabilities after zero catch vs the mean catch. We then fitted smoothing splines to the relative movement probabilities to investigate possible changes through time.

$$glm((mv > 1) \sim ll + yearqtr * bet + yearqtr * yft, family = "binomial")$$

$$glm((mv > 1) \sim ll + yearqtr * (bet + yft), family = "binomial")$$

Results

Patterns in CPUE and catch composition

Maps of the species composition by decade showed strong spatial and temporal variation. For the proportion of bigeye in the catch of bigeye + yellowfin, bigeye dominated initially (1950-59) in the east and further north, with a strong latitudinal band and a sharp transition between bigeye and yellowfin at 5N (Figure 2, Figure 3). This transition zone progressively spread out in each decade from the 1950s, with more overlap between the species, and had largely disappeared by the 1990s. In the 1980s bigeye began to increase as a proportion of the catch in the western equatorial Pacific, and by the 2000s formed quite a high proportion of the catch there.

If yellowfin abundance has genuinely declined relative to bigeye, rather than target switching to bigeye, then we expect a decline relative to albacore as well as to bigeye. The proportion of albacore in YFT+ALB has increased since the 1950s north of 10N (Figure 4, note that YFT is red in this figure), with the fishery expanding south into areas where yellowfin was once caught as much as or more than albacore. Albacore appears to now dominate the longline catch north of 10N and west of 200E. In the south there may be a trend towards yellowfin in the 70s and 80s, then back to albacore later. Albacore and yellowfin fishing involve different targeting practices, so some of these trends may explained by target change. North Pacific albacore has increased in abundance since 1975 (ISC Albacore Working Group, 2011), and targeting by the Japanese fleet of both north and south Pacific albacore declined in the 1970's (Suzuki et al., 1977; Hampton et al., 2005).

Fishing patterns

We investigated changing fishing patterns in the available fields reported target (1994-2011), mainline material and branchline material (1994-2011), bait type (1952-1993), hooks between floats (1958-1966 with 35 – 95% coverage, and 1976-2011), and hooks per set (1952-2011). Individual vessels could be identified from their callsigns from 1979-2011, with close to 90% coverage from 1984. Fishing category (offshore or distant water, 1958-2011) and tonnage (1958-66, 1976-2011) were also available but are accounted for in the standardization.

The reported target is uninformative about target change, being dominated by tuna in both regions 3 and 4 for the whole time series, with very little temporal variation.

Before 1970 bait type was almost always reported as pacific saury, but at that time vessels began to report other species, and by 1980 saury was rarely reported (Figure 5). This indicates that either other fish species became popular, or that pacific saury was used with other fish species and/or squid. The other species would have included mackerel, pilchards, and squid. In the last few years of data squid bait suddenly begins to be reported at much higher levels for the distant water fleet, in up to 40% of sets in region 4.

During the late 1950s and early 1960s vessels mostly set 4-6 hooks between floats (Figure 6). By 1976 when reporting restarted, HBF ranged between 5 and 13 HBF, with two modes at 5-6 and 10-13. In the region 3 offshore fishery HBF starting in the early 1980s, the smaller size mode at 5-6 disappeared and the 10-13 range had by 1990 been largely replaced by HBF between 15 and 20. The region 3 pattern was very similar for distant water longliners. Similar changes through time occurred in region 4, although the takeover by 15-20 HBF occurred about 5 years later than in region 3.

Hooks per set for region 3 offshore vessels averaged approximately 1200-1400 until about 1967, increasing to 1700-1900 between 1972 and 1982 (Figure 7). There were further increases to average in the low 2000s hooks per set from about 1990. Distant water vessels had relatively stable hooks per set averaging in the 1700-1900 range but began to increase in the early 1980s, averaging 2500-3000 until about 2005, when they increased again to over 3000 hooks per set. In region 4 the trends through time for distant water and offshore vessels were similar to one another, apart from a period with low sample sizes for OS prior to 1968. This region also saw an increase in the average hooks per set from about 1900 to 2200-2500, starting in about 1980. Hooks per set stabilized until 2005 and then increased again.

The spatial distribution of effort included most 5 degree squares of region 3 until the 1980s, then began to decline until by the mid-2000s only 2/3 of squares were fished (Figure 8). In region 4 there was less decline, with a reduction in the 1980s followed by a recovery starting in 1990. Both regions, however, saw increasing effort concentration as measured by the Gini coefficient, from a low point in the 1960s and 70s. This suggests that effort has increasingly been targeted at preferred areas. Gulland's indices of concentration show that for the entire period 1950-2011, effort in region 3 has been concentrated in areas of above average catch rates for both bigeye and yellowfin tunas. There may be a trend towards areas with higher yellowfin catch rates in recent years, but with little change for bigeye tuna. In contrast, Gulland's index in region 4 is greater than 1 for bigeye but less than 1 for yellowfin, apart from a decade starting in the early 1990s. This is consistent with targeting of bigeye tuna in region 4. However this pattern may be affected by the fast-moving currents near the equator in region 4 where yellowfin are more abundant, which can make it difficult to set longlines.

Investigation of changes in targeting

Regression trees were run for the core equatorial area, for the periods 1979-1993 and 1993-2011. In both cases the spatial variables latitude and longitude and the temporal variable year were the main variables selected. Spatial and temporal variables are already accounted for in the standardization (Hoyle & Okamoto, 2011), and in a related paper (McKechnie et al 2013), and were not investigated further. No operational variables were statistically significant.

K-means cluster analyses for regions 3 and 4 showed substantial reductions in sums of squares for up to 3 groups and small further reduction with more groups. Ward clustering of these data produced 3 well-separated clusters in region 3, and 2 main clusters in region 4. Clustering data from the core equatorial areas produced two clearly- separated groups in both regions. Examining the proportions of effort in each cluster by year suggested a decline in the proportion of effort in the yellowfin tuna cluster (Figure 9). This is consistent with the decline in yellowfin CPUE through time. However, the clusters appear to be reasonably well separated spatially, and yellowfin clusters have moved into areas occupied by bigeye clusters (Figure 10) as yellowfin catch rates have declined. The clusters appear likely to represent fishing trips in areas where catch rates of one species or another are higher, rather than fishing techniques that target a particular species. Spatial effects are taken into account in the CPUE standardization where they are consistent through time, and time-area interactions are being considered in a related paper McKechnie et al 2013.

Generalized linear modelling of bigeye CPUE was carried out with spatial effects modelled at finer resolutions of 1 degree squares and 2 degree squares rather than the standard approach of 5 degree squares, taking changes in effort concentration into account by weighting as recommended by Punsly (1987; Hoyle & Okamoto, 2011). There were small differences in the resulting indices, but the population trends from 1990 to 2011 were not significantly different in either the 1 degree (-0.11% ± 0.17, Figure 11) or 2 degree (-0.054% ± 0.14) analysis.

Species composition was then standardized in order to estimate the contributions of different factors to the observed changes through time. Region 3 results are shown in Figure 12, and region 4 results in Figure 13. In region 3 the year effects showed very strong changes with far more bigeye caught in recent years. Region 4 year effects were also strong but mostly occurred during an apparent transition in the early 2000s. Spatial effects showed the usual pattern of higher bigeye catch rates to the north and east. Vessel effects in both regions did not show the anticipated pattern of an increasing trend through time towards vessels with higher bigeye catch rates, but instead showed a slight trend towards vessels with higher yellowfin catch rates, particularly since about 1995. The HBF effects were quite small compared to other effects in the model, apart from a poorly determined estimate for the largest HBF in region 4. HBF effects were larger when the data were restricted to the 1990-2011 period.

Vessel behaviour in response to catch rates

Analyses of vessel behaviour showed that long movements were more likely after catches of fewer fish (Figure 14). Movement probabilities tended to be more affected by low bigeye catches than they were by low yellowfin catches, and this difference was apparent in each of the four decades, with no clear evidence of change through time. However, the catch of both species combined was a better indicator of the likelihood of large movements than was either species by itself. Similarly, when examined by year-qtr there was evidence that movement was more likely after low catches of bigeye than yellowfin, but no evidence that the preference had increased through time (Figure 15).

Discussion

There have been large changes in the relative catch rates of yellowfin and bigeye tuna in the equatorial WCPO, particularly in region 3 since 1980, and in region 4 since the mid 1990s. We investigated possible causes, with a particular focus on target change as a possible cause, and drew the following conclusions. Target change from albacore to bigeye and yellowfin targeting before 1975 is well documented and associated with deeper sets (Suzuki et al., 1977; Sakagawa et al., 1987), and the data show that hooks per basket increased between 1966 and 1975. However, the information included in the available operational data for this period are limited, and we did not find other signatures of target change. Better data were available for the period after 1975, but analyses of species composition and vessel behaviour did not provide evidence for major target change during this time. Cluster analyses suggested more effort with higher bigeye catch rate, but this pattern may be explained by relative abundance rather than targeting. Greater use of squid bait may have increased the ratio of bigeye to yellowfin (Ward, 2008), but we could not examine this possibility with the available data.

Maps of species composition through time showed large scale changes, with the distributions of albacore and bigeye relative to yellowfin expanding. The albacore increase is thought to be affected by increasing albacore abundance (ISC Albacore Working Group, 2011). Bigeye dominated initially (1950-59) in the east and north of the equatorial latitudes, with albacore most prevalent further north, while yellowfin was most commonly caught in the south and west. The transition in species composition between bigeye and yellowfin areas was quite sharply defined. The transition zones progressively spread out in each decade from the 1950s, with increasing species overlap. This change may reflect increasing overlap between the species, and/or it may reflect increasing diversity of fishing strategies so that one species is caught in an area previously dominated by the other, with different set depth or bait type.

Changes during the 1960s and early 1970s associated with the introduction of super-cold freezers, and increasing fuel costs in the 1970s, motivated greater targeting of bigeye for the sashimi market, rather than albacore and yellowfin which were mainly used as material for canning or sausages (Suzuki et al., 1977; Sakagawa et al., 1987). Such changes in targeting are supported by operational data showing that some vessels started using more than 7 hooks between floats between 1966 and 1975. In equatorial areas higher HBF increases catchability for bigeye and reduces it for yellowfin (Hoyle & Okamoto, 2011). If individual vessel information and HBF information can be retrieved from old records, we would be able to identify the target change towards bigeye in this period more clearly. Clustering at the trip level requires vessel identity information. Cluster analysis at the set level may be applied in future, if the computational difficulties of working with very large datasets can be resolved.

There have been ongoing changes in the operational characteristics of fishing, including more hooks per set, more hooks between floats, and the introduction of monofilament mainlines and branchlines. In particular, greater use of squid bait may have increased bigeye catchability relative to yellowfin in equatorial areas since 1990. Although bait data are available 1952-93, there is little clear information for equatorial areas because the indeterminate ‘other’ category largely replaces Pacific saury in the 1970s and 80s. The greatest interest is in the sudden increase in reporting of squid bait from about 1990. Squid bait has been anecdotally reported as the most popular bait for Japanese longliners since the 1970s, though varying between the fleet categories and through time as prices have changed (Ward & Hindmarsh, 2007). Squid bait has been found to reduce yellowfin and possibly increase bigeye catch rates in analyses of Australian observer data (Ward & Hindmarsh, 2007; Ward, 2007; Ward, 2008). Future work should estimate how bait type affects bigeye and yellowfin catch rates in equatorial areas. In addition, we may be able to explore the prevalence of squid and other bait types by accessing the records of long line bait sellers.

To try to discriminate between abundance trends and target change, we standardized species composition data for the period 1976-2011. Species composition appeared to be strongly associated with year and spatial effects, while vessel effects were comparatively weak. Year-space interactions, which were not investigated, may also have occurred given changes observed in Figure 3. These spatio-temporal changes may be explained by relative abundances changing through time, or target change occurring on existing vessels, not associated with vessel replacement. Operational characteristics such as hooks between floats and line type also had relatively small effects. However, the line type data were of variable quality, and potentially important factors such as bait type were not available in the operational data.

Target changes are often motivated by economic factors such as changes in the relative prices or catch rates of different species, or the costs of fishing. We investigated the first of these issues by examining published price data but found little evidence of market changes that would have motivated more targeting of bigeye. Tuna prices are affected by multiple factors, with quality particularly important, which makes relative prices across species difficult to compare directly. Data from multiple sources can nevertheless be used to examine general trends. Monthly averages show that bigeye tuna has attracted higher prices per kg than yellowfin tuna since at least the mid 1970's, but with little change in the relative prices until the mid 1990's (Figure 16) (Bose & McIlgorm, 1996). Data for the period 1985 to 2008 suggest moderate decline in the prices of some bigeye categories, with more stability for yellowfin apart from 2003-6 (Figure 17) (Miyake et al., 2010).

Changes in targeting are likely to affect the behaviour of vessels, and we investigated vessel movement distances after catches of different sizes. The bigeye catch appeared to be more important than yellowfin catch in providing motivation to either set again in a similar location, or move further away. However, the total catch was considerably more important again, and there was no apparent change in the relative effects of the species through time. However, factors other than recent catch may have become more influential through time, given that many vessels now obtain information from remote sensing (Ward & Hindmarsh, 2007). This information may permit vessels to use fine-scale differences in habitat preference of target species.

The analyses presented in this paper do not give us reason to reject the current indices of catch per unit effort in equatorial areas since 1975 as indicators of bigeye and yellowfin abundance, on the basis of target change. However, the study raises several issues that should be followed up if possible. The well-known target change before 1975 (Suzuki et al., 1977; Sakagawa et al., 1987) is unlikely to be fully accounted for assuming HBF of 5 for sets with unknown HBF before 1975. This issue may be dealt with via cluster analysis on set-by-set data; such analyses should be a high priority. Bait type may also be a significant factor to be followed up for understanding target change.

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Tables

Table 1

YEAR	No. of operations	Operation date	Lat & Long	Vessel name JP	Call sign	License	Tonnage	Fishing category	Target	line materials	Bait Type	HBF	Hooks/ set	start trip
1952	19411	100%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%
1953	25066	100%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%
1954	45271	100%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%
1955	50020	100%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%
1956	45463	100%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%
1957	46415	100%	100%	1%	0%	0%	1%	1%	0%	0%	100%	1%	100%	1%
1958	60632	100%	100%	100%	0%	1%	97%	100%	0%	0%	93%	64%	99%	92%
1959	78060	100%	100%	100%	0%	0%	89%	100%	0%	0%	100%	63%	100%	87%
1960	94256	100%	100%	100%	0%	0%	89%	89%	0%	0%	100%	51%	100%	92%
1961	98040	100%	100%	100%	0%	0%	89%	100%	0%	0%	100%	54%	100%	93%
1962	126222	100%	100%	100%	0%	2%	91%	100%	0%	0%	100%	35%	100%	94%
1963	150687	100%	100%	100%	0%	89%	99%	100%	0%	0%	100%	43%	100%	100%
1964	197685	100%	100%	100%	0%	99%	100%	100%	0%	0%	100%	55%	100%	100%
1965	195759	100%	100%	100%	0%	100%	100%	100%	0%	0%	100%	93%	100%	100%
1966	111039	100%	100%	100%	0%	100%	100%	100%	0%	0%	100%	95%	100%	100%
1967	io9926	100%	100%	4%	0%	4%	4%	100%	0%	0%	100%	4%	100%	4%
1968	76642	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1969	66697	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1970	77475	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1971	17919	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1972	16328	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1973	14626	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1974	17232	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1975	15824	100%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	100%	0%
1976	96285	100%	100%	100%	0%	100%	100%	100%	0%	0%	100%	96%	100%	0%
1977	89833	100%	100%	100%	0%	100%	100%	100%	0%	0%	100%	97%	100%	0%
1978	84973	100%	100%	100%	5%	100%	100%	100%	0%	0%	100%	99%	100%	0%
1979	109227	100%	100%	100%	60%	100%	100%	100%	0%	0%	100%	84%	100%	100%
1980	120363	100%	100%	100%	67%	100%	100%	100%	0%	0%	100%	89%	100%	100%
1981	129136	100%	100%	100%	71%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1982	111031	100%	100%	100%	78%	100%	100%	100%	0%	0%	100%	97%	100%	100%
1983	90917	100%	100%	100%	83%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1984	98314	100%	100%	100%	87%	100%	100%	100%	0%	0%	100%	99%	100%	100%
1985	91281	100%	100%	100%	89%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1986	79633	100%	100%	100%	89%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1987	73167	100%	100%	100%	93%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1988	83292	100%	100%	100%	94%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1989	77509	100%	100%	100%	95%	100%	100%	100%	0%	0%	100%	96%	100%	100%
1990	70802	100%	100%	100%	96%	100%	100%	100%	0%	0%	100%	95%	100%	100%
1991	63759	100%	100%	100%	97%	100%	100%	100%	0%	0%	100%	95%	100%	100%
1992	56602	100%	100%	100%	99%	100%	100%	100%	0%	0%	100%	94%	100%	100%
1993	61980	100%	100%	100%	100%	100%	100%	100%	0%	0%	100%	98%	100%	100%
1994	56577	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	94%	100%	100%
1995	53858	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	90%	100%	100%
1996	47091	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	85%	100%	100%
1997	42438	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	85%	100%	100%
1998	45603	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	87%	100%	100%
1999	44130	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	89%	100%	100%
2000	44679	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	86%	100%	100%
2001	42981	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	88%	100%	100%
2002	41953	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	89%	100%	100%
2003	39247	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	88%	100%	100%
2004	36259	100%	100%	100%	99%	100%	100%	100%	100%	100%	0%	87%	100%	100%
2005	30095	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	89%	100%	100%
2006	27973	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	92%	100%	100%
2007	29208	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	92%	100%	100%
2008	25326	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	93%	100%	100%
2009	21839	100%	100%	100%	98%	100%	100%	100%	100%	100%	0%	95%	100%	100%
2010	25662	100%	100%	100%	96%	100%	100%	100%	100%	100%	0%	96%	100%	100%
2011	22356	100%	100%	100%	95%	100%	100%	100%	100%	100%	0%	97%	100%	100%

Figures

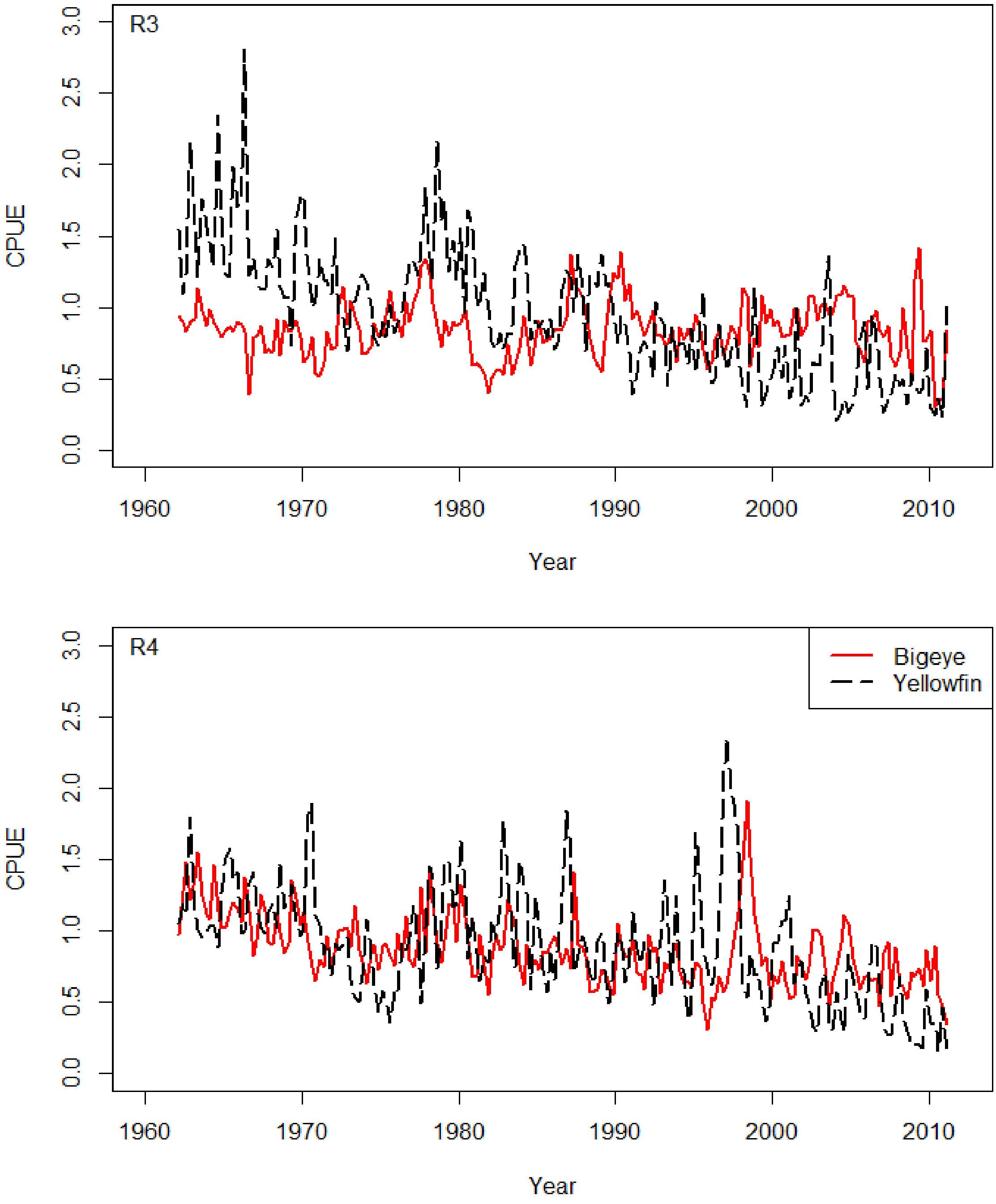

Figure 1: Standardized indices of bigeye and yellowfin CPUE in the WCPO, from the 2011 stock assessments.

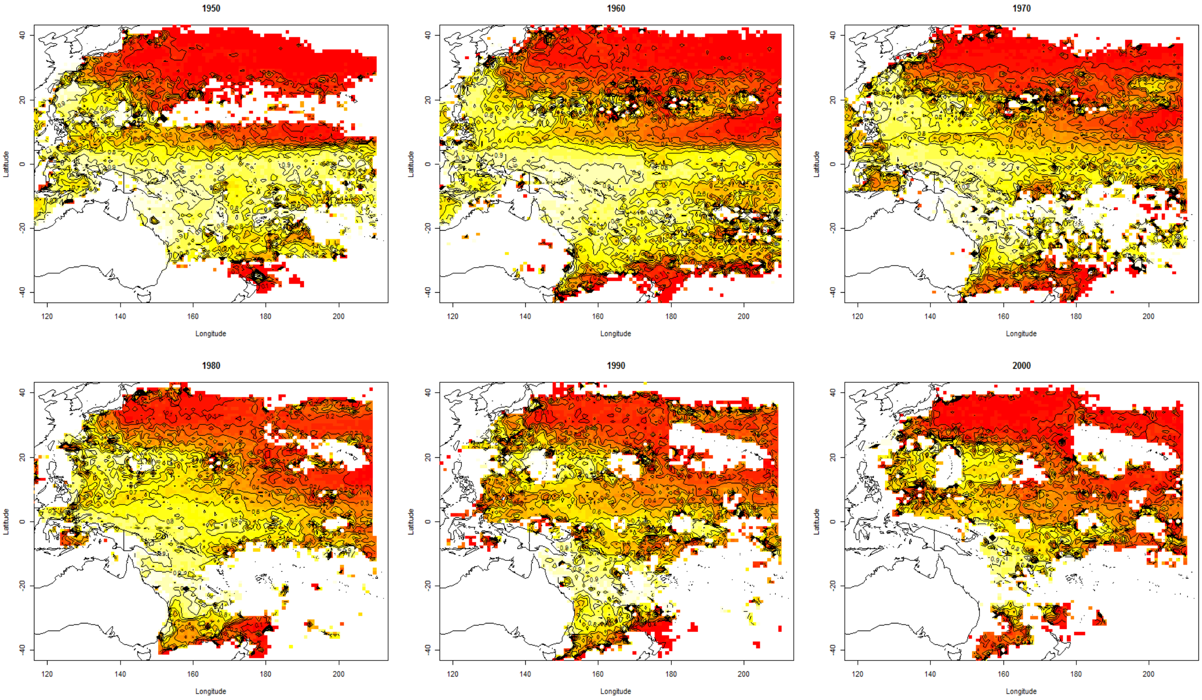

Figure 2: The average proportions of yellowfin (yellow) and bigeye (red) in the JPLL catch of bigeye + yellowfin by decade, for the whole of the WCPO, mapped at 1 degree resolution. The more yellow, the higher the proportion of yellowfin.

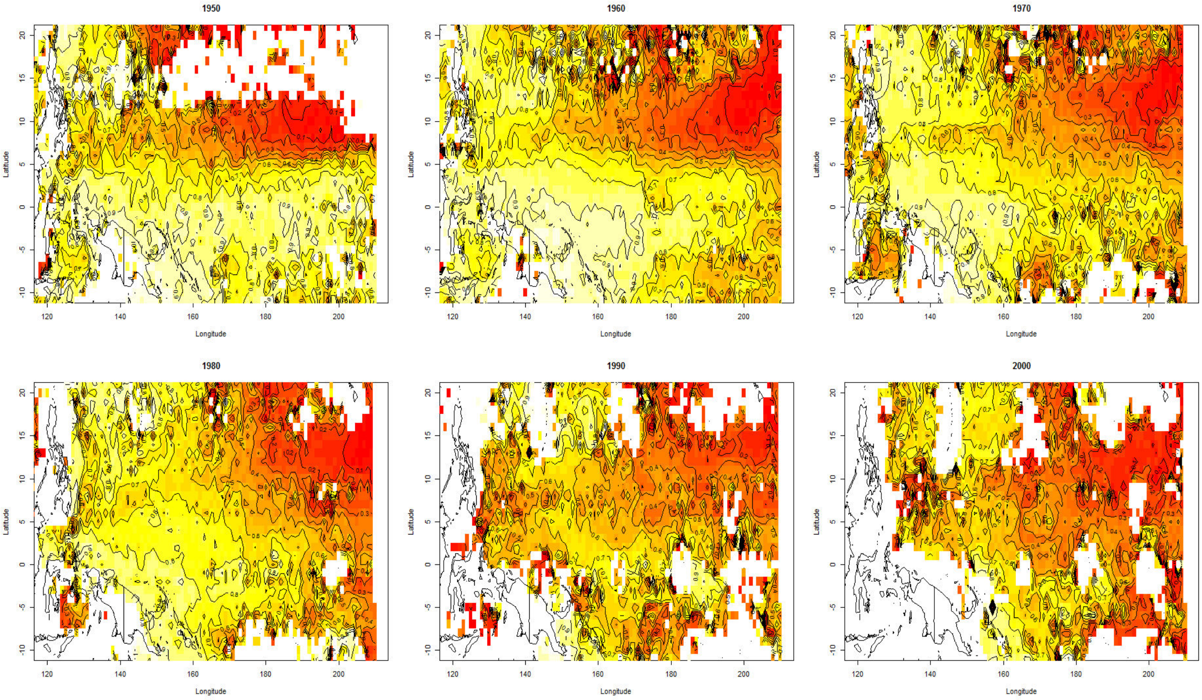

Figure 3: The average proportions of yellowfin (yellow) and bigeye (red) in the JPLL catch of bigeye + yellowfin by decade for the equatorial WCPO between 10S and 20N, mapped at 1 degree resolution. The more yellow, the higher the proportion of yellowfin.

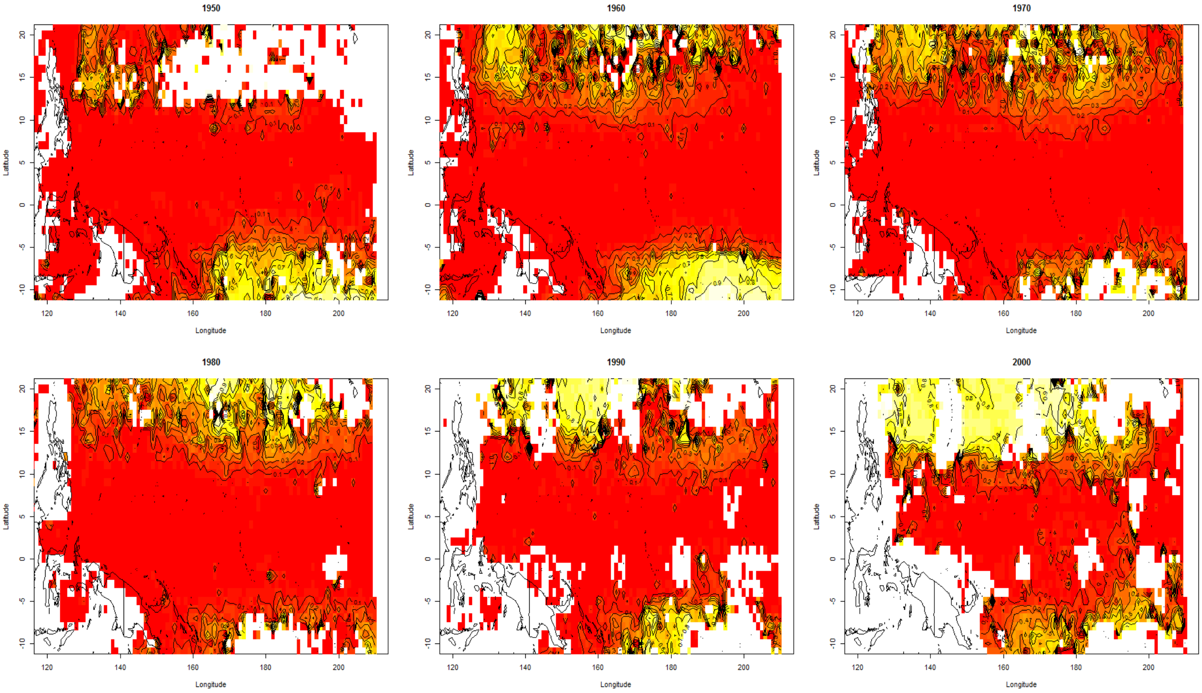

Figure 4: The average proportions of albacore (yellow) and yellowfin (red) in the JPLL catch of yellowfin + albacore by decade for the equatorial WCPO between 10S and 20N, mapped at 1 degree resolution. The more red, the higher the proportion of yellowfin.

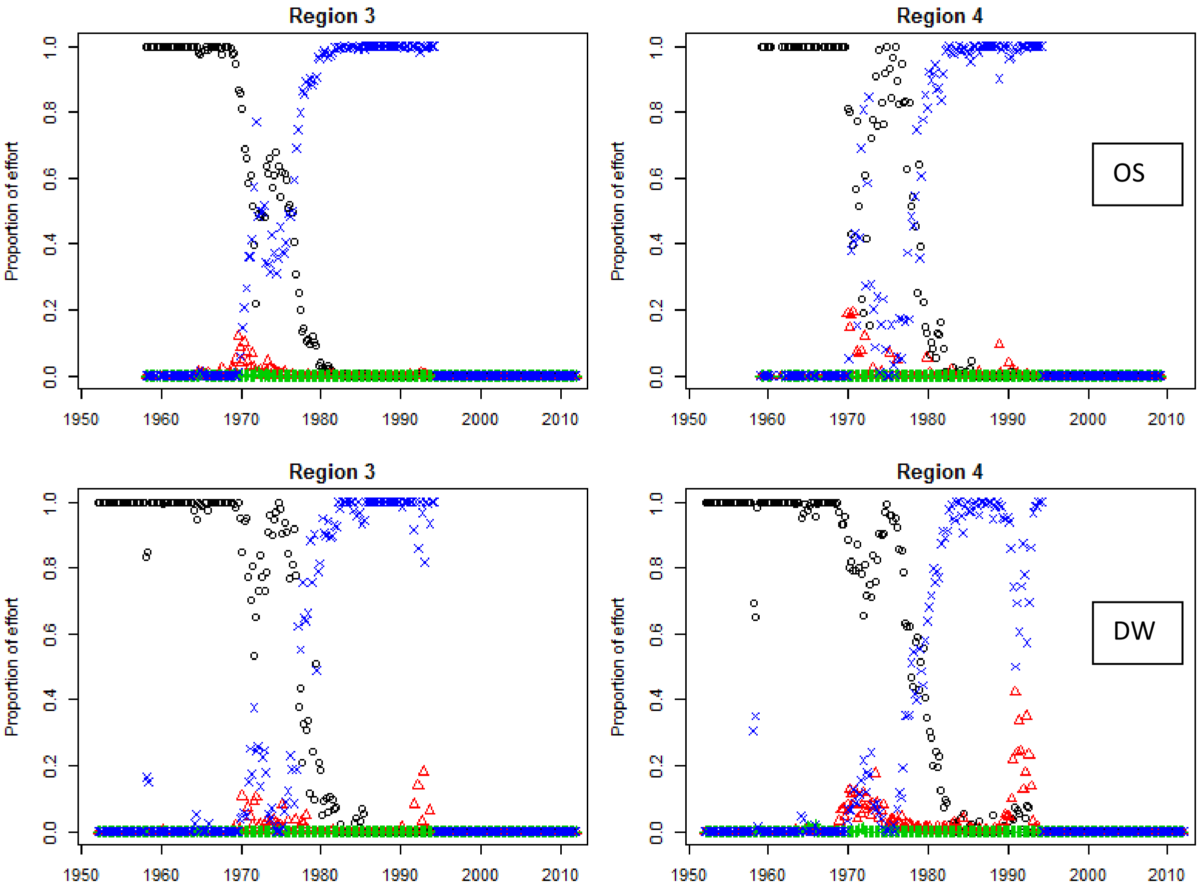

Figure 5: Bait use in the equatorial WCPO Japanese longline fleet, for offshore (top) and distant water (bottom) vessels. Pacific saury (black circles), squid (red triangles), live bait (green pluses), and other bait (blue crosses).

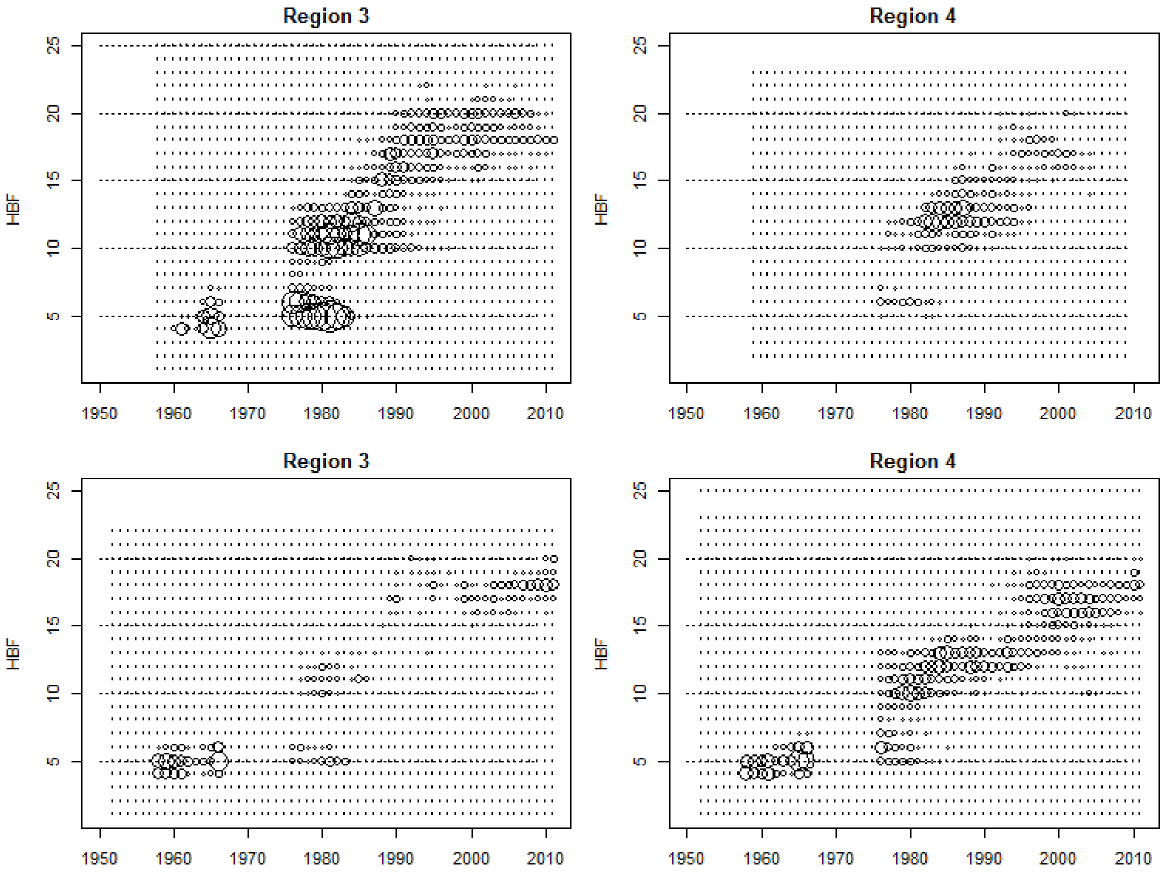

Figure 6: Hooks between floats (HBF) in the equatorial WCPO Japanese longline fleet, for offshore (top) and distant water (bottom) vessels.

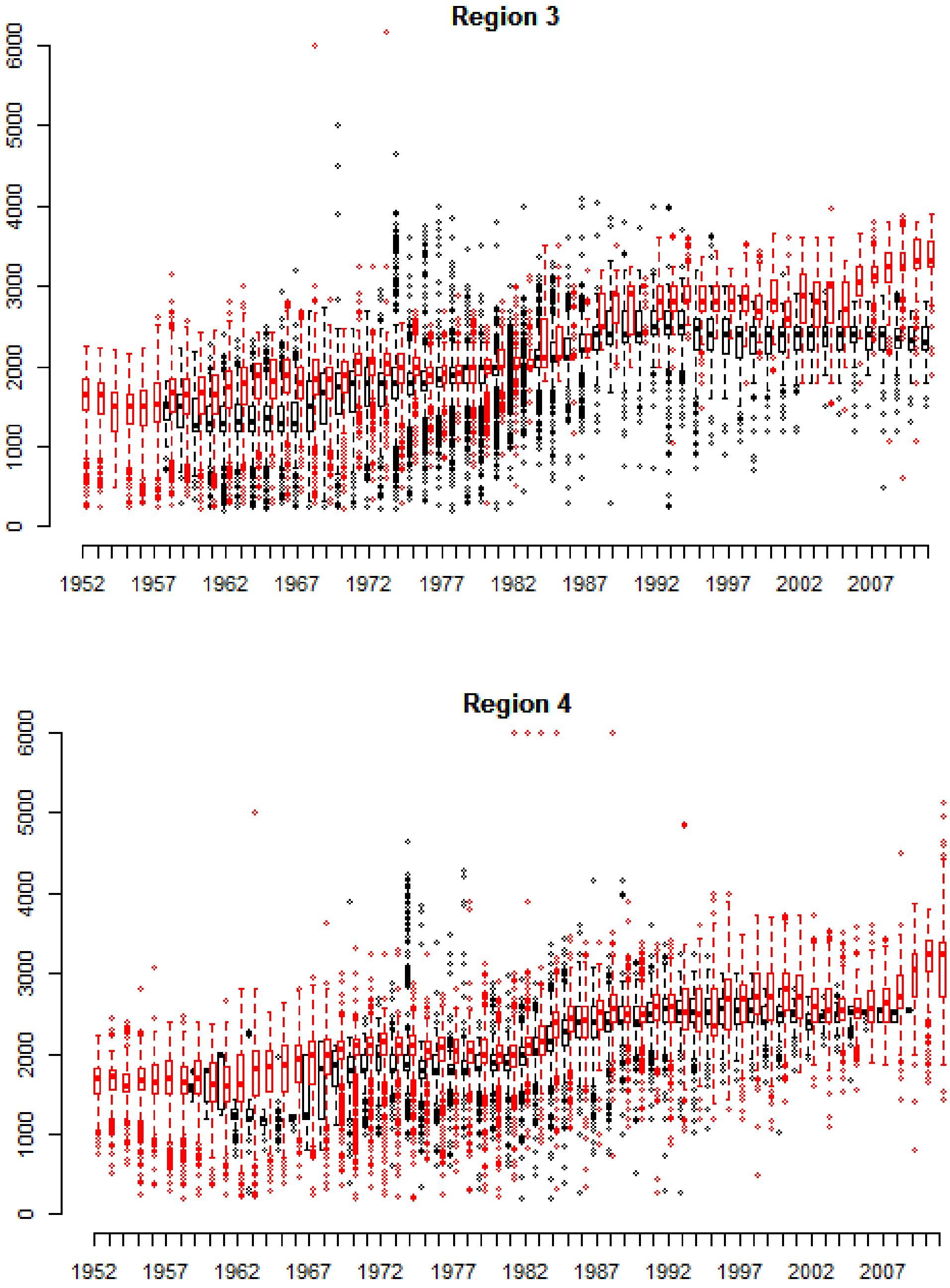

Figure 7: Box and whisker plots of hooks per set in the equatorial WCPO Japanese longline fleet, for offshore (black) and distant water (red) vessels.

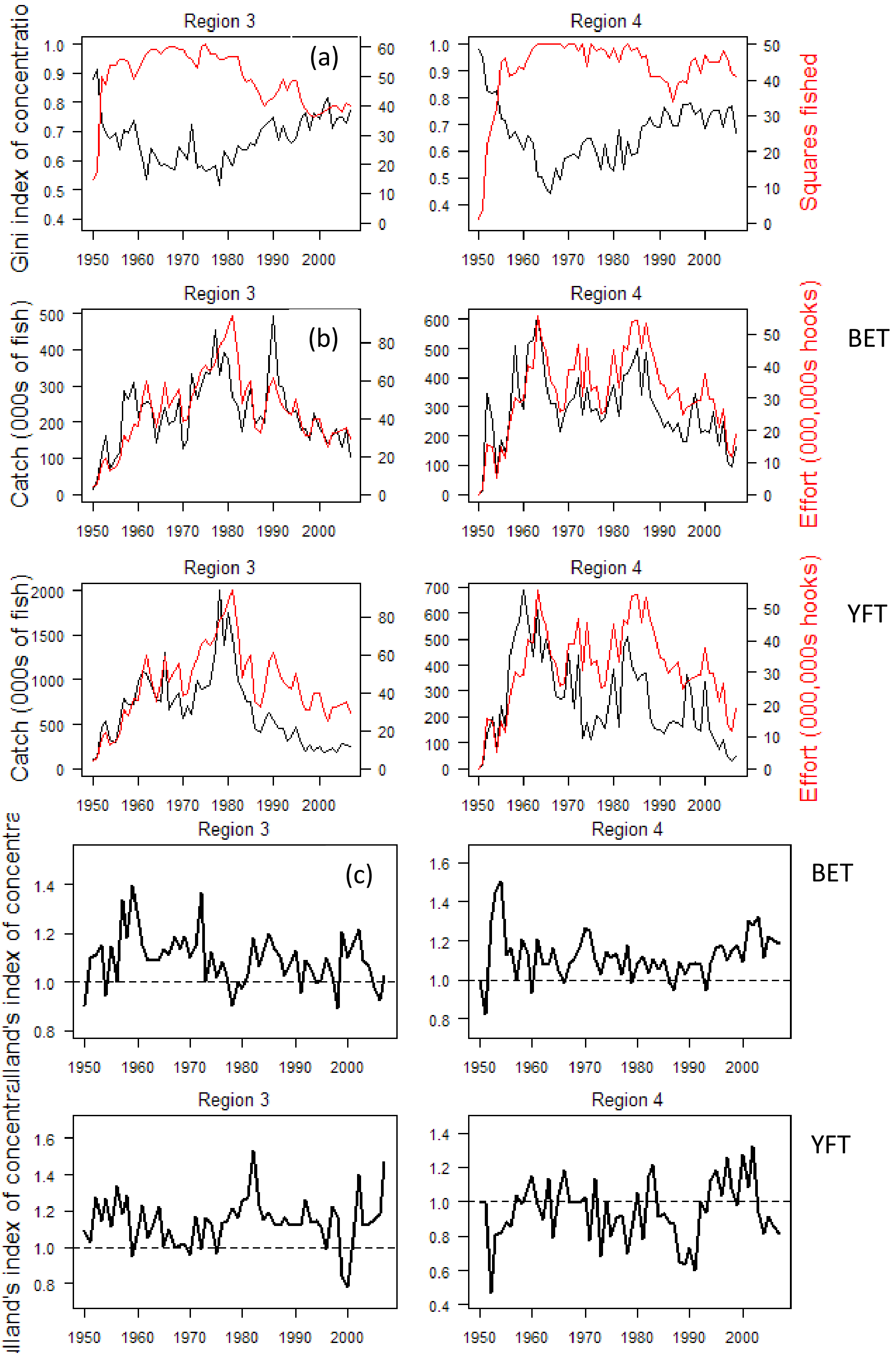

Figure 8: figures showing the following relationships by year for regions 3 and 4: a) Gini coefficient of effort concentration (black), and the numbers of squares fished (red); b) catches (black) and effort (red); Gulland's index of concentration for c) bigeye and d) yellowfin.

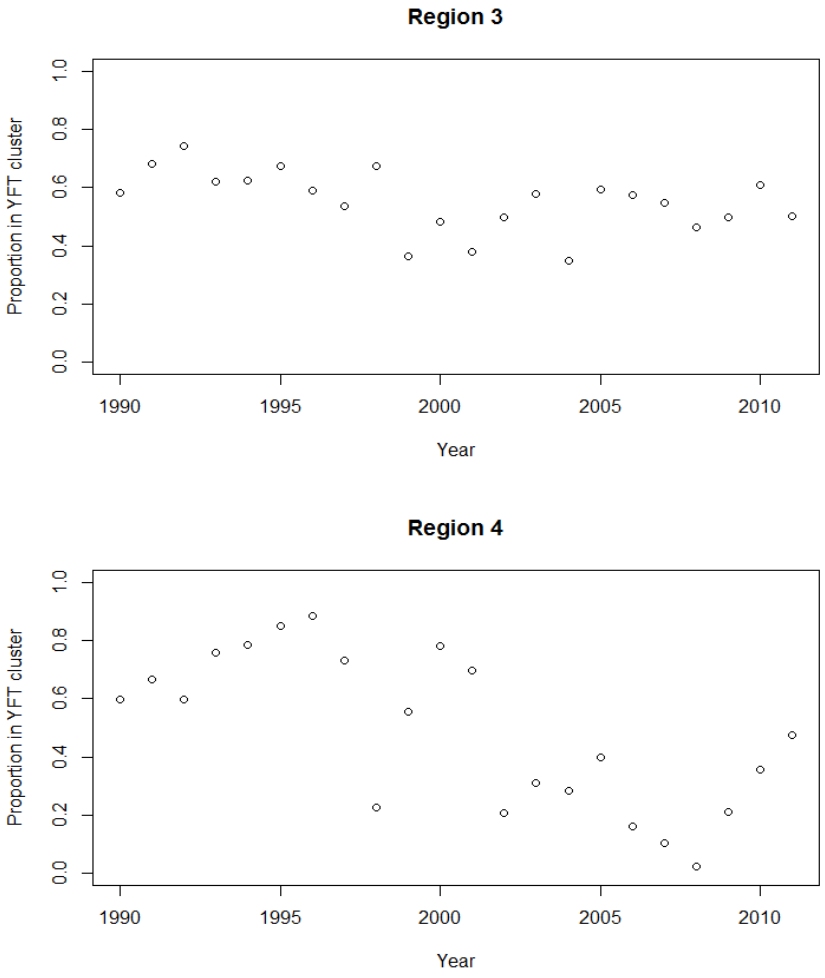

Figure 9: Proportion of effort by year in the cluster with a higher proportion of yellowfin tuna catch, for the equatorial areas of regions 3 and 4.

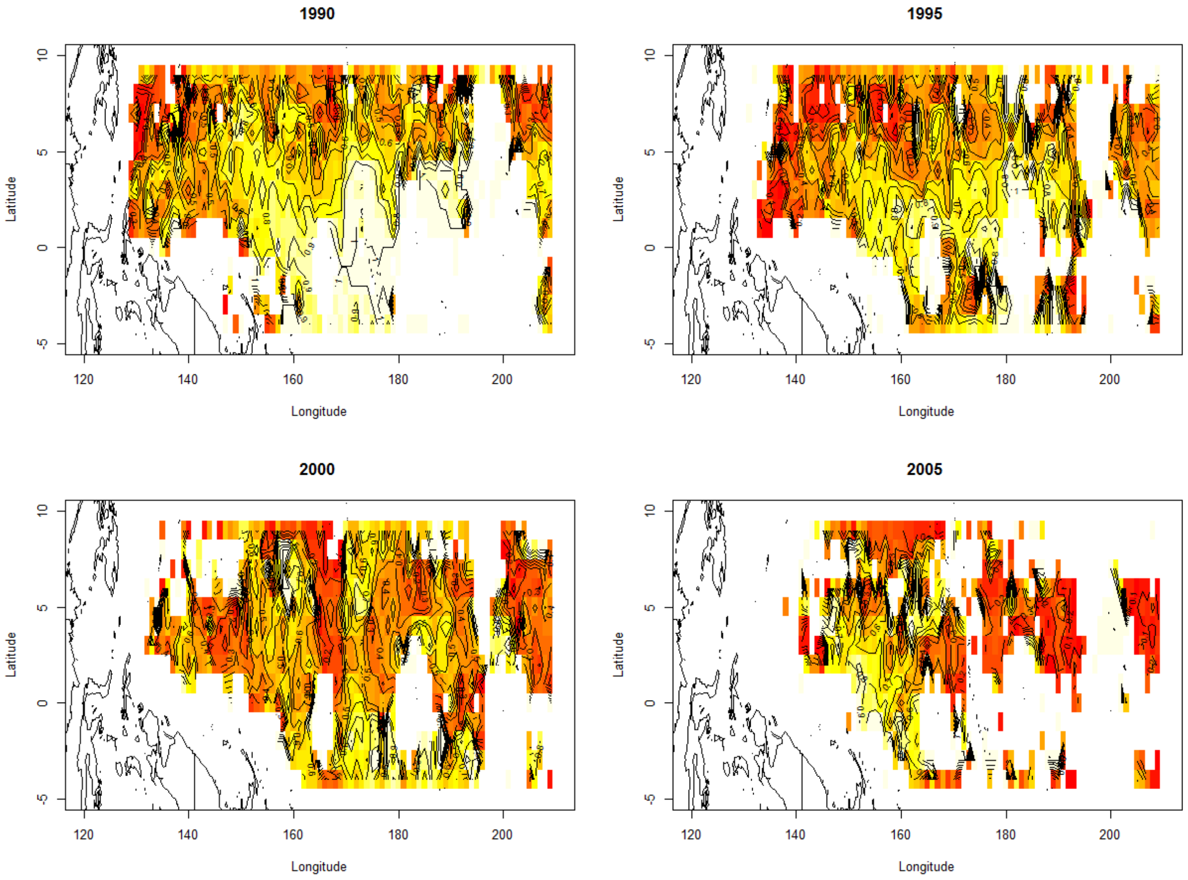

Figure 10: Proportion of effort by location and 5 year period in the cluster with a higher proportion of yellowfin tuna catch, for the equatorial areas of regions 3 and 4. The more yellow, the more effort in the yellowfin cluster.

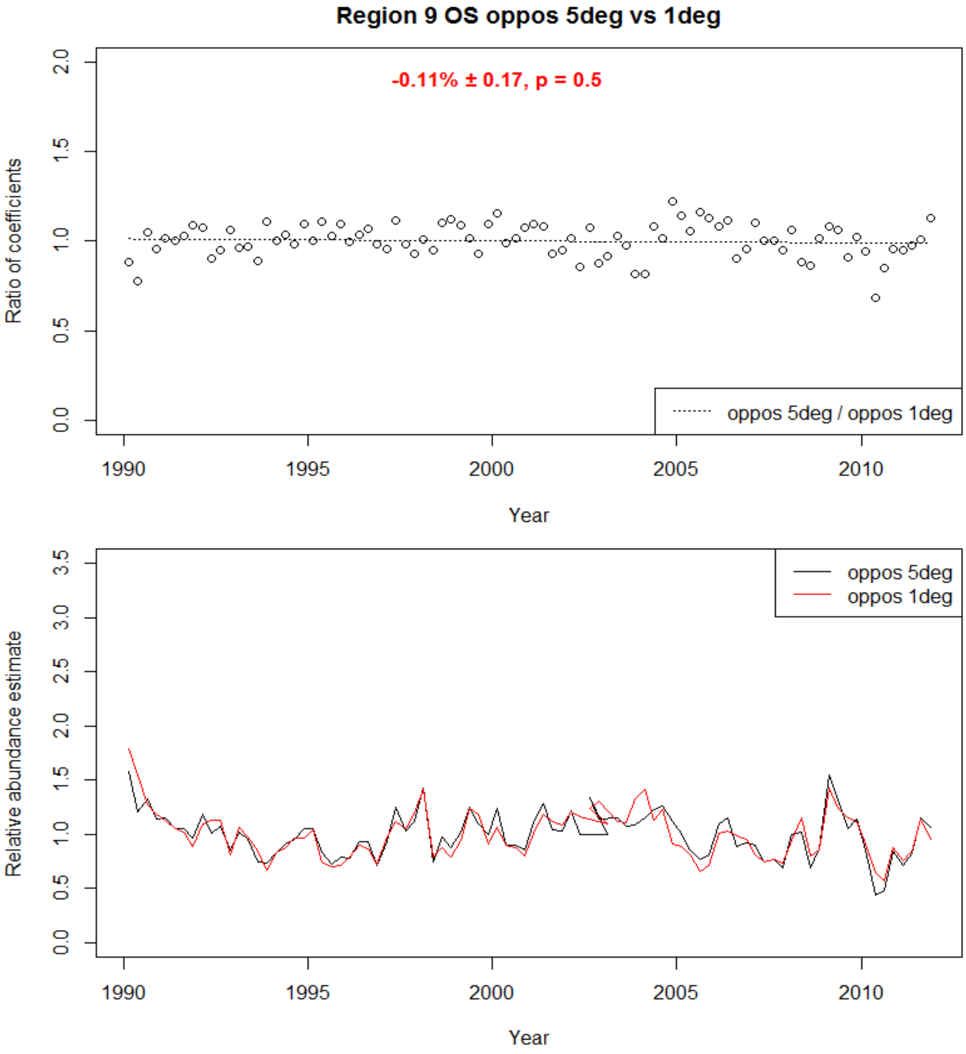

Figure 11: Plots of year-qtr indices of abundance resulting from standardization of bigeye CPUE with area effects modelled using either the standard 5° square or a 1° square. The upper plot shows the ratio of the two indices, and the lower plot shows the indices.

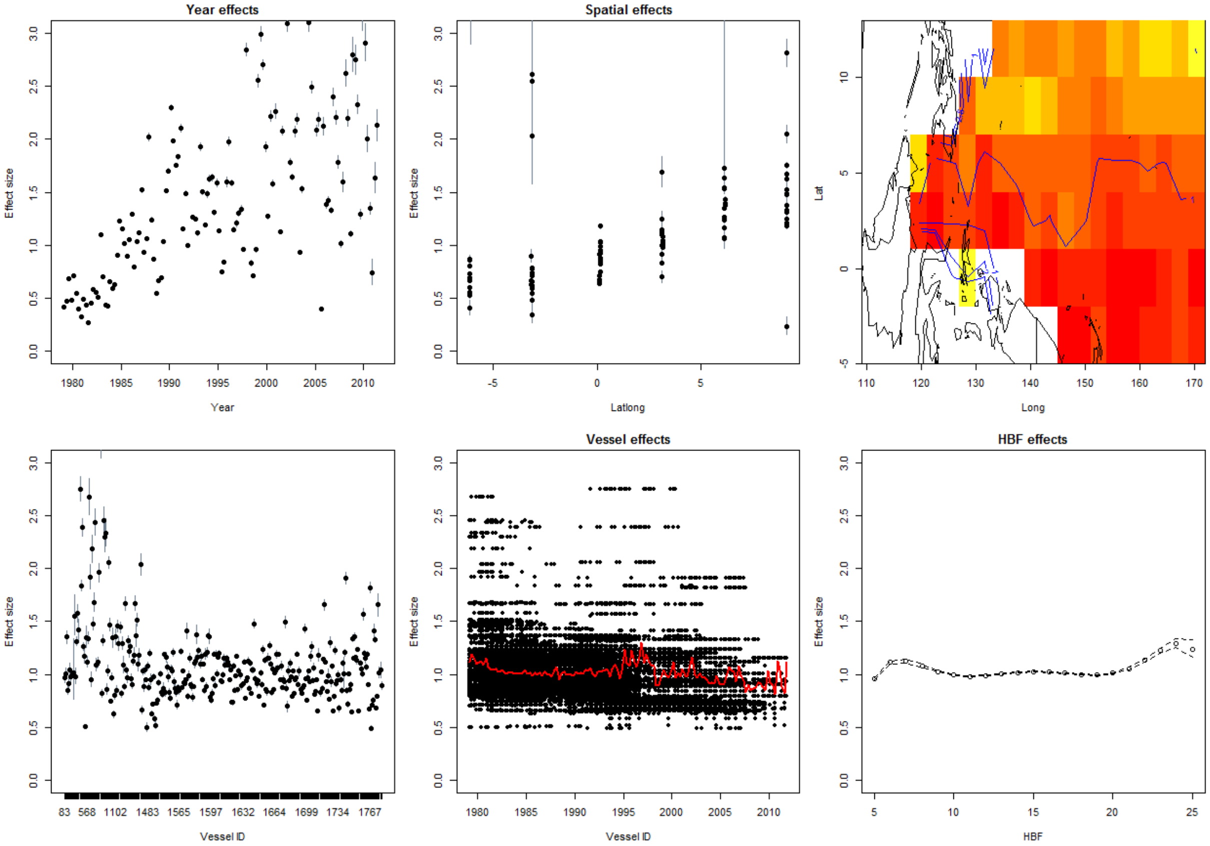

Figure 12: Estimates of covariates from a glm of region 3 species composition (BET / BET+YFT) in Japanese longline sets in the equatorial WCPO (5S to 13N) between 1979 and 2011. Covariates include (from L to R and top to bottom) year-qtr, latlong by latitude at 3° square resolution, mapped latlong, vessel effects by vessel id, vessel effects by year-qtr, and HBF.

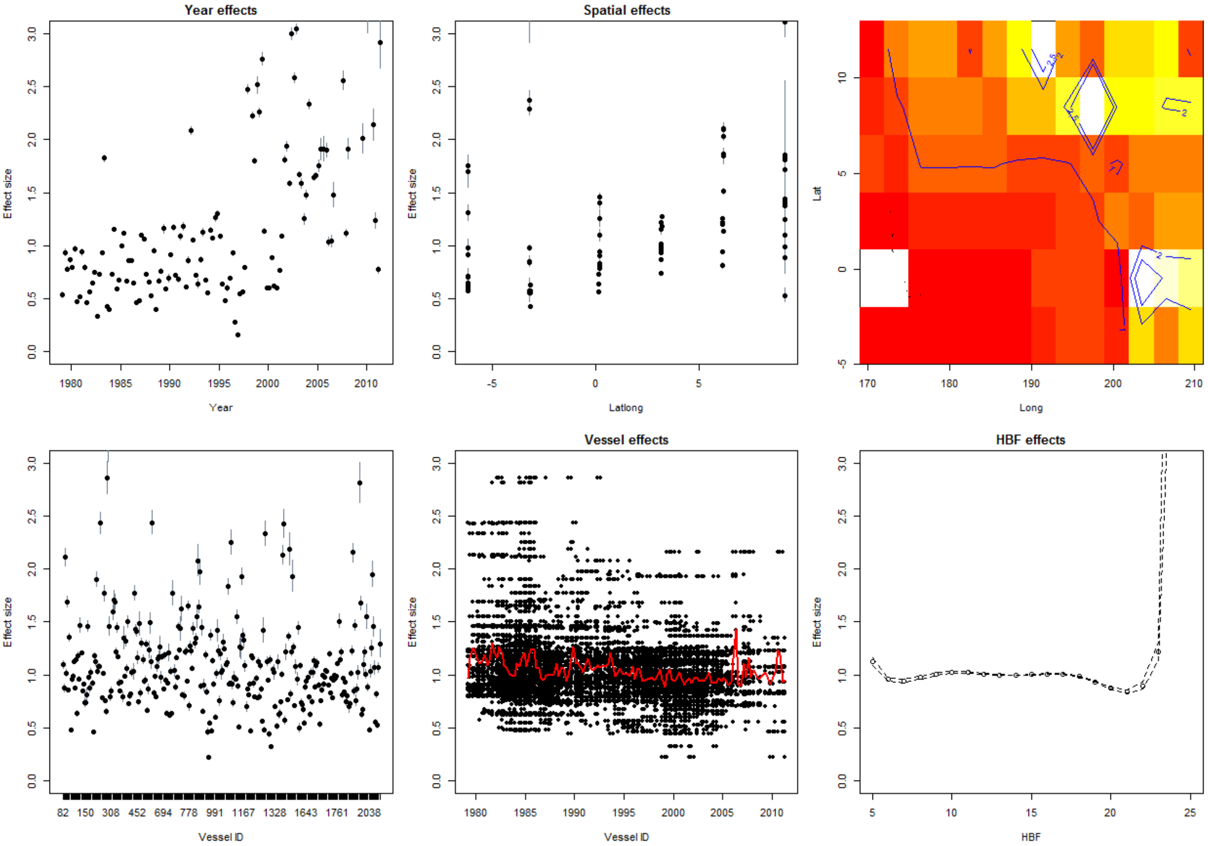

Figure 13: Estimates of covariates from a glm of region 4 species composition (BET / BET+YFT) in Japanese longline sets in the equatorial WCPO (5S to 13N) between 1979 and 2011. Covariates include (from L to R and top to bottom) year-qtr, latlong by latitude at 3° square resolution, mapped latlong, vessel effects by vessel id, vessel effects bry year-qtr, and HBF.

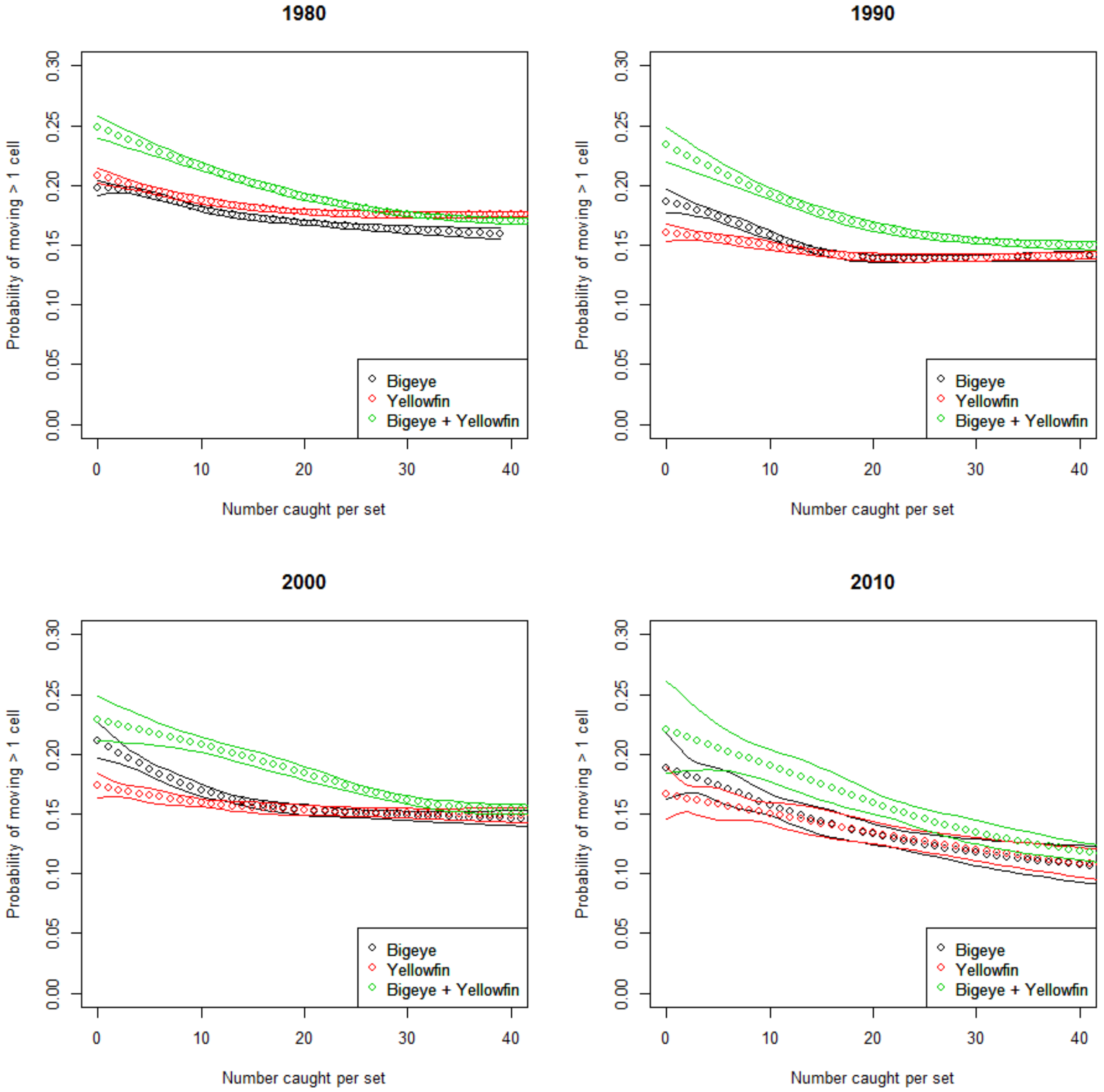

Figure 14: Figures showing, by decade, the probability of setting a longline more than 1 cell from the previous set, as a function of the number of fish caught in the first set. The green circles represents the effect of the combined bigeye and yellowfin catch, and the black and red circles represent the effect of bigeye and yellowfin respectively. The lines represent 95% confidence intervals.

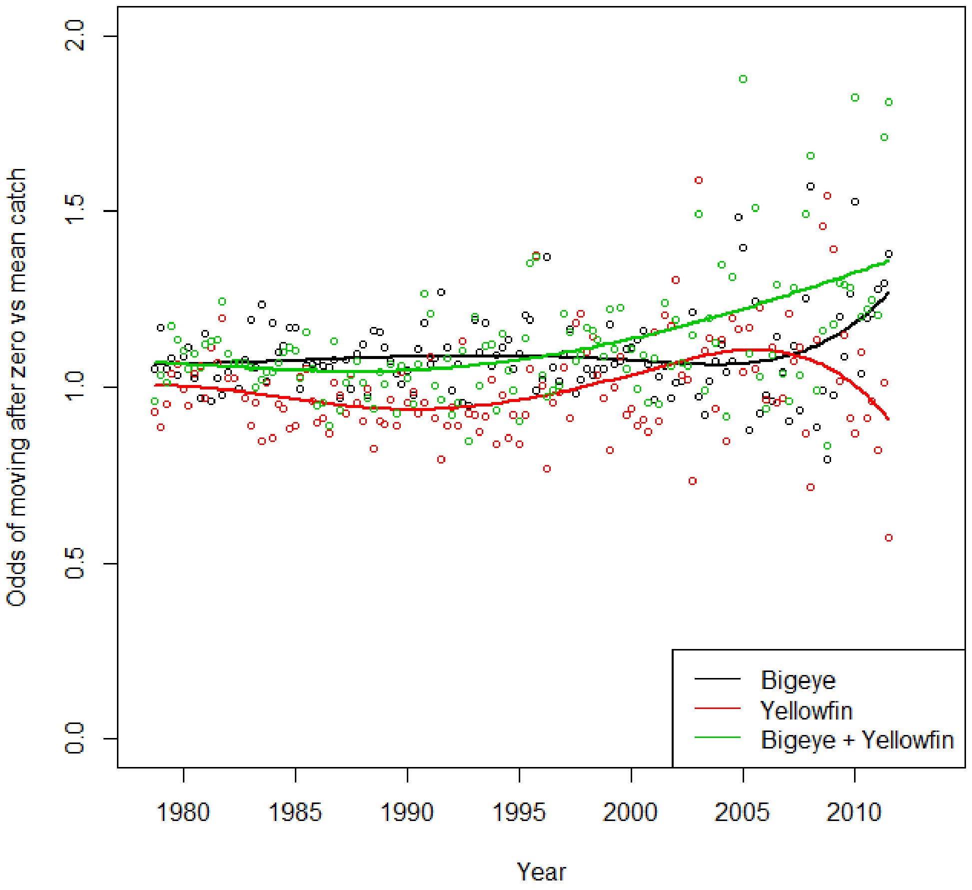

Figure 15: The relative probabilities of setting a longline more than 1 cell from the previous set after catching 0 fish vs after the mean catch, by year. The green circles represents the effect of the combined bigeye and yellowfin catch, and the black and red circles represent the effect of bigeye and yellowfin respectively. The smoothing splines indicate the overall trends.

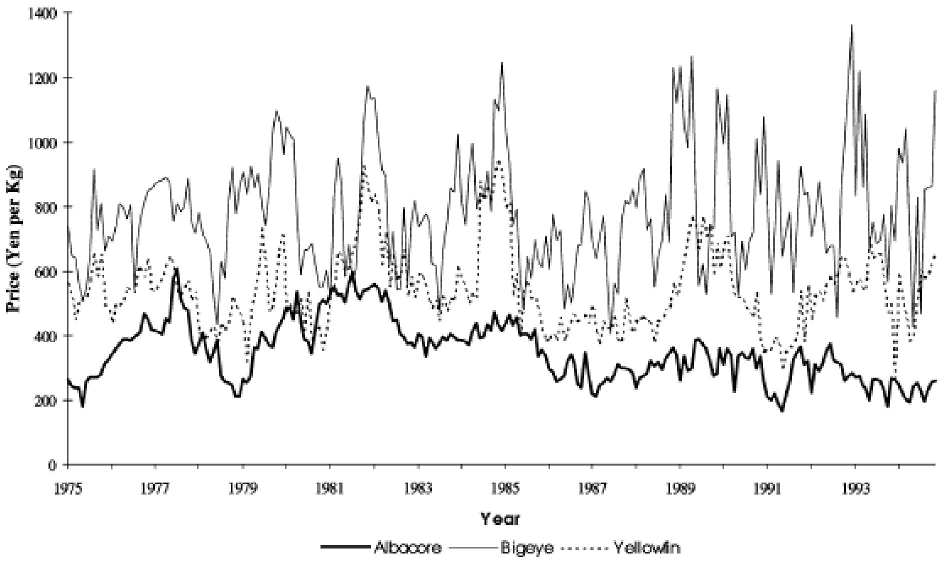

Figure 16: Monthly average nominal prices of bigeye, yellowfin, and albacore for the period January 1975 to November 1994. From Bose and McIlgorm (1996).

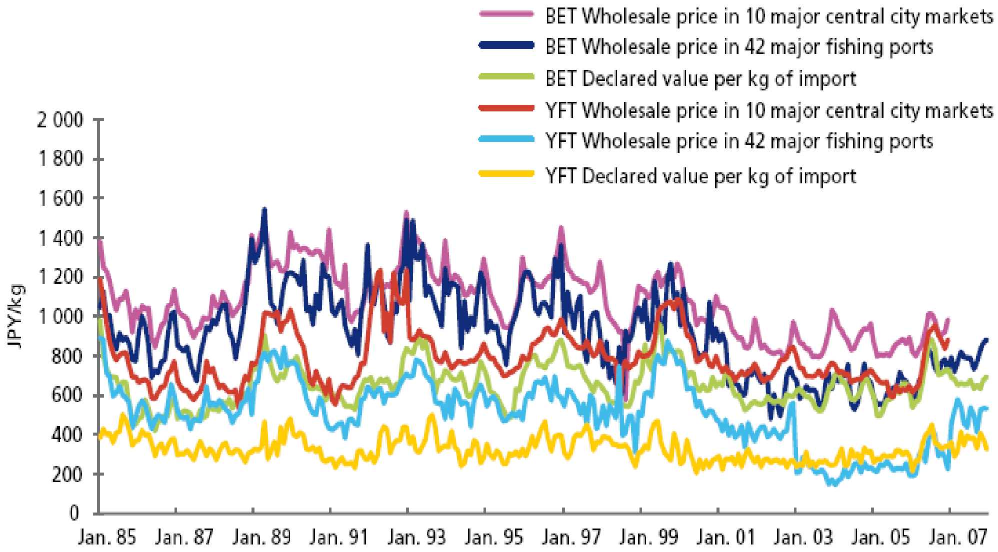

Figure 17: Average monthly wholesale price of frozen YFT and BET at various Japanese markets. From Miyake et al (2010).