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ANALYSES OF JAPANESE LONGLINE OPERATIONAL CATCH AND EFFORT FOR BIGEYE AND YELLOWFIN TUNA IN THE WCPO

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1. Abstract

Japanese longline (JPLL) operational catch and effort data for bigeye and yellowfin tuna were analyzed, in a collaboration between the Secretariat of the Pacific community (SPC) and the National Research Institute of Far Seas Fisheries (NRIFSF). The objectives were to a) improve understanding of the factors affecting catch rates, b) to develop, test and apply new methods for estimating indices of abundance, and c) to estimate abundance indices for bigeye and yellowfin tuna, for use in 2011 stock assessments for bigeye and yellowfin tuna stocks in WCPO. Data were analyzed separately for offshore and distant water vessels in each region. Figures are presented showing changes in many aspects of JPLL fisheries and tuna catches through time. A new method was developed to identify swordfish targeted effort before HBF data become available in 1976. Through time, effort has concentrated into some areas and reduced in others, and this has affected past abundance indices. A method for addressing this effort concentration was tested and applied. The effects of progressive changes since 1976 in the vessel composition of the fleet were estimated for both bigeye and yellowfin tuna. These effects have increased average catchability for yellowfin tuna in all regions, and for bigeye tuna in regions 1, 3, and 4, during the period 1976-2010. They have reduced average catchability for bigeye tuna in regions 2 and 5. Abundance indices were developed for the stock assessments of yellowfin and bigeye tuna in the WCPO for regions 1 to 6, based on data for the offshore fleet (region 1 and 3) and the distant water fleet (regions 2, 4, 5, and 6).

2. Introduction

Indices of standardized catch per unit effort (CPUE) are critical inputs into stock assessments, including those using Multifan-CL (Fournier *et al.* 1998). The Japanese longline fleet has the longest history of widespread fishing of any fleet operating in the Pacific Ocean (1952-present). The Japanese catch and effort series from distant water and offshore vessels are the principal sources of information about relative abundance for that part of the biomass that is exploited by longline fisheries. In this paper we investigate Japanese operational longline catch and effort data, in order to standardize the Japanese longline CPUE and estimate historical trends of Japanese longline catchability, for both bigeye and yellowfin tuna. We provide some diagnostics, and examine changes in fishing power through time, including changes associated with targeting and with new vessels entering and old vessels leaving the fishery.

During the history of the fishery, systematic changes in the operation of the Japanese longline fleet are likely to have influenced the catchability of tuna species. These include changes in the geographic area fished (Figure 8 to Figure 10); changed configuration of the longline gear, indicated by increases in the number of hooks between floats (HBF, Figure 13 and Figure 14) (an indicator of targeting), and changes in the number of hooks per set (Figure 40 to Figure 45); and changes in the principal target species.

To account for such temporal changes in species-specific catchability of the longline fishery, in the past the data have been standardized using a variety of approaches; most recently using generalised linear modelling techniques (McCullagh & Nelder 1989;Langley 2003;Langley *et al.* 2005;Hoyle 2009). In each case an identity link function and lognormal distribution have been assumed. Past analyses have used data aggregated at the level of 5 degree square and year-quarter. The resulting region-specific standardised effort series were then integrated into the Multifan-CL (MFCL) assessments of yellowfin and bigeye in the WCPO. The regions used in the stock assessment are shown in Figure 1.

When vessels change target species, large changes can occur in the catch rates of both target and bycatch species. For example, albacore catch rates for the Japanese and Taiwanese fleets in the south Pacific have at various times declined strongly as a result of shifted targeting towards bigeye tuna (Hampton *et al.* 2005b;Bigelow & Hoyle 2009). To achieve this, longliners may change their set depth, time of set, use of light sticks, bait type, set location, or other aspects of their gear configuration or how it is fished. However, the aggregated dataset holds information only on grid square, month, HBF, catch of main tuna species, and number of hooks. It may therefore pool fishing sets that use different methods and may target different species within a given area and month. Operational data make it possible to some extent to distinguish between vessels that target different species, or identify variation in targeting in space or time, by examining catch rates by set or vessel trip, or by conducting cluster analyses on catch rate (Bigelow & Hoyle 2009;Langley 2007)

In addition to the change in catchability derived from such fishing methods, the efficiency of some aspects of longline fishing is likely to have increased since the 1950's due to advancing technology, and changes in fleet composition. This will influence CPUE levels. However, rates of change and effects on the relationship between hooks set and fish caught are very difficult to estimate (Ward & Hindmarsh 2007;Ward 2008). In WCPO stock assessments, hypothetical scenarios of changes in fishing power have been examined when estimating the structural uncertainty associated with the model (Hampton *et al.* 2005a;Langley *et al.* 2008;Hoyle *et al.* 2008;Langley *et al.* 2009), using CPUE indices estimated from aggregated data. Operational CPUE data for a limited component of the fishery have been examined to estimate changes in fishing power for yellowfin and bigeye tuna in Region 3 of the stock assessments (Hoyle 2009). These analyses were extended to bigeye tuna catchability since 1976, for Japanese vessels in the WCPO (Hoyle *et al.* 2010). In this report, those analyses were extended to yellowfin tuna as well as bigeye tuna, and data from 1952-1976 (in which we could not identify individual vessels) were included.

In 2009 the Stock Assessment Specialist Working Group of the Scientific Committee of the WCPFC strongly encouraged the WCPFC science provider, the Oceanic Fisheries Programme of the Secretariat of the Pacific community (SPC), to collaborate with scientists from Japan and Chinese Taipei on research into longline catchability. In January 2011 an agreement on objectives and conditions for collaboration was reached between SPC and the National Research Institute of Far Seas Fisheries (NRIFSF), Fisheries Research Agency (FRA), Japan. The objectives were:

1. The standardization of Japanese longline CPUE on bigeye and yellowfin tuna, including data prior to 1976, after dealing with analysis issues identified in 2010;

2. Extend analyses of the historical trend of Japanese longline catchability to yellowfin tuna, using set-by-set longline operational data compiled from logsheets submitted by Japanese longline fishermen; and

3. Compare alternative methodologies for standardizing operational catch and effort data.

A major objective of this work is to investigate the combined contribution of all vessel effects to the estimated abundance indices. Vessel effects potentially represent a range of factors that are likely to affect fishing power. Some factors, such as vessel characteristics or equipment (e.g. engine, vessel speed, well capacity, etc), may be kept throughout the life of the vessel and have consistent effects on fishing power. Other factors such as fishing techniques, targeting strategies, new technologies and vessel equipment upgrades, or changes in the crew or fishing master may also affect that vessel's fishing power, and change during the period when the vessel is in the model. However, the effects of these changes cannot be picked up individually by this analysis. Instead, the average effect of these factors over the modelled period will be included in an estimated vessel effect.

This analysis will therefore estimate changes in the fleet's fishing power from the introduction of new technologies with new vessels, and the retirement of inefficient vessels with low catch rates, which will both tend to raise average fishing power. It can also account for changing levels of fishing by different components of the fleet with different fishing techniques and targeting strategies, which can either raise or lower average fishing power.

Another major objective is to investigate the utility of operational catch and effort data for understanding tuna population dynamics, and for estimating indices of abundance. In addressing this, and to improve abundance indices further, we investigate the issue of targeting. Catch rate of any species will depend on many characteristics of the set, and targeting strategies can significantly affect bigeye catch rates. Many of these set characteristics are unavailable, vary with location and season and over time, or do not effectively distinguish between target species. Potential target species in the Japanese longline data include albacore tuna, bigeye tuna, Pacific bluefin tuna, sharks, southern bluefin tuna, swordfish, and yellowfin tuna. Longliners do not necessarily target any one species, but seek to optimize the profitability of the catch, so changes through time in relative abundances and prices can affect fishing behaviour. The proportion of sets by fishing strategy therefore changes through time, which is likely to affect the abundance trends. We identified methods to remove swordfish-targeted effort prior to 1976, when information on hooks between floats (usually used to identify swordfish targeting) is mostly unavailable.

Further, we consider alternative standardization methods. We implement the methods of Punsly (1987) to reweight effort according to its spatial distribution, in order to compensate for changing patterns of fishing effort through time.

The research described above was carried out under the following conditions:

1. The usage of the data is strictly limited to the purpose of this collaborating work;

2. The data can be used only during this collaborating work;

3. The participant can use the data only on the PC prepared by Japanese scientists of NRIFSF, and copying of the data to media external to the PC is not permitted; and

4. Any document or presentation derived from the result of this collaborating work should be provided beforehand to Japanese Fishery Agency and NRIFSF scientists.

In summary, this report documents analyses of operational catch and effort data from the Japanese distant water and offshore longline fleets. It examines the data; estimates differences in fishing power between vessels, and the changes in average fishing power associated with changing vessels; investigates effects of covariates on catch rates; investigates factors associated with swordfish targeting, and provides quarterly indices of regional abundance for yellowfin and bigeye tuna.

3. Methods

Operational catch and effort data for the Japanese longline fleet for 1952 to 2010, held by NRIFSF, were used in this study. Data were stratified into six regions to match the structure of the 2011 MFCL stock assessments model for bigeye and yellowfin tuna.

The following data fields were provided: operation date, operation location to the 1 degree square level, vessel name in Japanese, vessel call sign, tonnage, region code, prefecture, fishing category, licence number, set type (target), main line materials, branch line materials, bait type, hooks between floats (HBF), number of hooks set and bigeye, yellowfin, albacore, and swordfish catch in number (Table 1). Availability varied through time, with different reporting regimes during the periods 1952-57, 1959-66, 1967-75, 1976-93, and 1994-2010. The number of records available for each variable by year is reported in Table **2**. Descriptions of the fields are given below, along with details of data validation.

3.1. Data preparation, cleaning, and characterization

Data were prepared, validated, and cleaned in order to provide datasets suitable for investigating vessel effects and estimating indices of abundance. Data preparation scripts are included in Appendix 1.

International call sign, available 1978 - 2010 but with comparatively few records in 1978, was selected as the vessel identifier. Call sign is unique to the vessel and held throughout the vessel's working life. It was rendered anonymous by changing each call sign to an arbitrary integer. Sets without a vessel call sign were allocated a call sign of '1'.

Fishing category was available from 1959, reported as either offshore or distant water. Records with values other than 1 (distant water) and 3 (offshore) were deleted. Fishing category is not reported before 1960. All effort before 1960 is assumed to be offshore in region 1 and distant water in other regions.

Mainline and branchline material data were available since 1994, categorised as 'nylon' and 'other'. Mainlines were labelled 'other' when there was a mixture of line types, or when information was missing.

'Target' data were available from 1994. Values 1 to 3 represent swordfish, shark, and other (including tuna) respectively. All targets were included in the fishing power analyses, since the target field was not available before 1994, and removing other targets after 1994 might have biased the results. For analyses to estimate indices of abundance, effort identified by this field as targeting swordfish or sharks was removed.

Latitude and longitude were reported truncated to 1 degree, with a code to indicate north or south, west or east. All data were adjusted to represent the south-western corner of the 1 x 1 degree square. Sets in the southern hemisphere had 1 degree added. For sets east of 180 degrees longitude, one degree was added before subtracting from 360 to give decimal degrees. Each set was allocated to a MFCL region and data outside this area removed. Location information was used to calculate the 5 degree square (latitude and longitude).

Hooks per set, and bigeye, yellowfin, swordfish, and albacore catch in numbers were cleaned by removing outliers. Values above 10000 and less than 200 hooks per set were removed, as were catches of more than 250 bigeye, yellowfin, or albacore. In each case this amounted to less than 0.05% of records.

Hooks between floats (HBF) were available for almost all sets 1976-2010, and for a number of sets 1959-1966 (Figure 46). Sets with missing values were removed, and the few sets with more than 22 HBF were pooled into the 22 HBF category.

Bait type was available from 1952-1993, identified as 1 (Pacific saury), 2 (squid), 3 (live bait), or 4 (other) (Figure 47 and Figure 48).

Date of set was used to calculate the year and quarter (year-quarter) in which the set occurred.

Sets after 1994 with target reported as swordfish or sharks were excluded, in order to improve index consistency during the recent period for which abundance trends are more important.

After data cleaning, a standard dataset was produced that was used in subsequent analyses.

3.2. Changes in targeting and/or fishing techniques

In order to reduce the effects of target change on the indices, targeting methods were investigated and data separated. All sets south of 35˚S were removed to avoid southern bluefin tuna targeted effort.

Sets with HBF < 5 are generally thought to be targeted at swordfish or more recently blue sharks (Bigelow *et al.* 2002;Hoyle *et al.* 2010), and removed to avoid targeting changes. However, data for many sets before 1976 did not report HBF, and so swordfish targeted effort could not be removed using this method. If the early data included swordfish targeting and the later data did not, then the abundance indices would be biased. We therefore investigated the data using regression trees (De'ath & Fabricius 2000) to find other factors that might be associated with swordfish targeting, and which were available during the early period.

Results of these analyses are given in detail later. However, the overall result was that before 1976, the factor most strongly associated with swordfish targeting before 1976 was reported bait type of squid (Figure 49 to Figure 51, Figure 55). Catch rates for bigeye and yellowfin differed according to bait type (Figure 56 and Figure 57). The bait type of ‘live bait’ was uncommon, but was also associated with significantly different catch rates. Two sets of analyses were carried out, one that included all bait types and another that excluded all sets using squid bait or live bait. Significant effort was removed from regions 1 and 2 up to about 1985, and regions 5 and 6 between 1970 and 1990 (Figure 47 and Figure 48).

Albacore tuna of longline-catchable size occur from 40 to approximately 10 degrees of latitude in both hemispheres. The average size of fish caught increases with proximity to the equator. Fish caught in warmer water generally have lower value, which limits the extent of the fishery. Sets targeted at albacore tuna overlap spatially and by HBF with sets targeted at bigeye, so could not be removed. Previous work has identified changes in the distribution of albacore-targeted effort through time (Hoyle *et al.* 2010).

Similarly, longliners may target bigeye or yellowfin tuna, or both species. These species overlap spatially but with varying relative abundances. Targeting strategies for these species could not be separately identified.

3.3. GLM analyses

The operational data were standardized using generalized linear models in R. Analyses were conducted separately for each region, and for each fishing category (offshore and distant water). The delta lognormal approach (Lo *et al.* 1992;Dick 2006;Stefansson 1996;Hoyle & Maunder 2006) was used. This approach uses a binomial distribution for the probability w of catch being zero and a probability distribution $f(y)$, where y was log(catch/hooks set), for non-zero catches. An index was estimated for each year-quarter, which was the product of the year effects for the two model components, $(1-w).E(y|y \neq 0)$.

$$\Pr(Y = y) = \begin{cases} w, & y = 0, \\ (1-w)\,f(y) & \text{otherwise} \end{cases}$$

g(w) = z = Intercept + Year-quarter + 5 degree square location + h(hooks between floats) + h(number of hooks set), where g is the logistic function, and h is a 6th order polynomial function.

f(y) = u = Intercept + Year-quarter + 5 degree square location + h(hooks between floats)

The categorical variables year-quarter and 5 degree latitude-longitude square were fitted in all analyses. The continuous variable HBF was fitted as a cubic spline with 6 degrees of freedom, giving it considerable flexibility. In the Binomial models the number of hooks was included as a covariate using a cubic spline with 6 degrees of freedom.

Analyses of the vessel effect included the vessel identifier (vessel id) as a categorical variable.

Models were fitted separately for both bigeye tuna and yellowfin tuna.

For both species for the positive lognormal GLMs, model fits were examined by plotting the residual densities and using Q-Q plots.

Two approaches were used to weighting the data in the GLM. In the first ‘equally-weighted’ approach, every set was given the same weight. This is the approach used in previous analyses. In the second ‘area-weighted’ approach, the weights of the sets were adjusted so that the total weight per year-quarter in each 5 degree square would sum to 1. This method was based on the approach identified using simulation by

Punsly (1987), that for set j in area i and year k, the weighting function that gave the least average bias was: $w_{ijk} = \frac{log(h_{ijk}+1)}{\sum_{j=1}^{n} \log(h_{ijk}+1)}$. Given the relatively low variation in number of hooks between sets in a stratum, we simplified this to $w_{ijk} = \frac{h_{ijk}}{\sum_{j=1}^{n} h_{ijk}}$.

Each model was run on a computer with 12GB of memory and applied to all the operational data by region, for vessels that had fished for at least N quarters. The standard level of N was 2 quarters. The number of sets was also limited to 50 sets per 5 degree square * year-quarter stratum. This was more than adequate, since testing with different numbers of sets suggested that the effects of random variation were reduced to very low levels at 30 sets per stratum (Figure 62).

Vessel effects and fishing power

Changes in fishing power through time were investigated by first fitting to the operational data and then, in each GLM, adding a term for individual vessel. For example, for the lognormal positive approach the following GLM was used, where α_t are the abundance indices, β_{cell} are the coefficients for the 5 degree lat-long squares, and γ_{vessel} is the vessel effects.

$$\log\left(\frac{\mathrm{bet_{set}}}{\mathrm{hooks_{set}}}\right) = \mathrm{c} + \alpha_{\mathrm{t}} + \beta_{\mathrm{cell}} + \mathrm{f(HBF_{set})} + \gamma_{\mathrm{vessel}} + \epsilon_{\mathrm{set}}$$

For each approach, two time series of abundance indices were calculated (with and without vessel effects). Each index was normalized to average 1.

For all model comparisons, the indices estimated for each year-quarter were compared by dividing one by the other, plotting the time series of ratios, and fitting a log-linear regression. The slope of the regression represented the average annual compounding rate of change in fishing power attributable to changes in the vessel identities; i.e. the introduction of new vessels and retirement of old vessels. Gradients are shown on the figures, together with the statistical probability (p) of obtaining the observed (or steeper) slope if there was in fact no relationship. Regressions assume incorrectly that ratio values are estimated without error, so statistical significance was assumed at 0.005 rather than 0.05.

Covariate effects

The effects of covariates were examined by plotting the predicted effects, with 95% confidence limits, of each parameter at observed values of the explanatory variables.

Spatial effects with 95% confidence intervals were plotted by latitude.

Vessel effects through time were examined by plotting each vessel's effect for each time a set by that vessel was observed. An average vessel effect over time was examined by calculating the mean of the vessel effects for all sets made by the fleet during each time period, and this was also plotted.

Indices of abundance

Indices of abundance were obtained by running the delta lognormal GLM model with the standard settings, including vessel effects. Due to evidence of different targeting changes in the area 10-20˚N, and the possibility of similar changes in the area 5˚S-0˚N, (Hoyle *et al.* 2010) (Figure 24), the region 3 model used only data from the equatorial area from 5˚S to 10˚N.

3.4. Summary of options

Analyses were carried out across a number of dimensions (Table 3) , including both yellowfin and bigeye tuna, 7 regions, 2 approaches to addressing swordfish targeting (with and without squid bait and live bait), 2 fishing categories (OS and DW), 2 weighting methods, models with and without vessel effects, and 4 model error structures. Investigating all combinations across each dimension required approximately 900 models to be run.

4. Results

4.1. Data summaries

Data cleaning removed a substantial amount of effort using 4 hooks between floats from regions 1 and 2 (Figure 2). Effort using squid bait is still included in this figure but was removed from the version used in the final analyses. A large amount of seasonal data was removed from region 2 over the last decade. Little data was removed from regions 3 to 6 after about 1985. Subsequent data summaries were based on the cleaned dataset.

The coverage of the operational data set increases to approach 100% in 1980, in comparison with raised estimates of total effort provided by NRIFSF.

This lack of full coverage affects the effort and catch estimates shown in Figure 4 and Figure 5. After 1980, Japanese longline fishing effort declined in all regions from the (Figure 4). Distant water (DW) longline effort was low in region 1 after the early 1980s, while offshore effort declined from an initially high level. In region 2, effort was high until the mid-1990’s, after which it dropped to a lower but stable level. In region 3, DW effort increased through time while offshore (OS) effort declined. Two large reductions in both OS and DW effort occurred in about 1986 and 1996, but in each case effort subsequently recovered. In region 4 DW effort dipped in the 1990’s, rose in the early 2000’s, then declined again. OS effort declined steadily after the late 1980’s. In regions 5 and 6 there was little OS effort, and none after 1997. DW effort in region 5 dropped substantially after 1997, while in region 6 it was highly variable.

Catches in regions 1, 2, and 6 were mainly albacore and bigeye tuna, while in region 5 catches were mostly albacore and yellowfin. Swordfish catch was significant in regions 1, 2, and 5 (Figure 5).

Initially, catches in region 3 were dominated by yellowfin, but bigeye catches steadily increased and yellowfin decreased until by 1990 the catches were comparable. Since that time yellowfin catches have remained about 30% higher than bigeye catches. Albacore catches in region 3 were low until the late 1990’s, when they increased to reach a level similar to bigeye catches. In region 4 bigeye catches have been consistently higher than yellowfin catches, with the ratio of bigeye to yellowfin increasing through time. Albacore catches have been consistently low.

Nominal catch rates for bigeye were higher than yellowfin in regions 1 and 2, lower in region 3 and 5, and generally comparable in regions 4 and 6 (Figure 6). Similarly, the proportions of sets that did not catch any fish were lower for bigeye in regions 1 and 2, higher in region 5, and variable in region 6 (Figure 7). In region 4 a much higher proportion of sets did not catch yellowfin, and region 3 showed considerable variation.

In regions 1 to 4, the proportions of sets with no yellowfin caught has increased considerably since 1990 (Figure 7), as has the proportions of sets with no bigeye caught in regions 1 to 3. In region 4 the proportion of sets with zero bigeye catch has declined since 2000.

In regions 1, 2, 5 and 6 the bigeye fishery shows large quarterly variation in the probability of catching bigeye in a set, indicating that the fishery is seasonal.

Patterns in region 3 have been highly variable and different from other regions. Yellowfin catch rates have increased relative to bigeye in the last 10 years, but declined substantially during the 1980's. During this transition in the 1980's there was an unusual dip in the proportion of sets with zero bigeye catch between the mid-1980's and the mid-1990's. This appears to have been caused by two factors. Effort declined in the 1980's south of the equator and west of 160, in an area where bigeye catch rates are seasonal, so the region-wide proportion of sets without bigeye declined. Then in the mid-1990s effort increased north of 10N, in particular targeting albacore, which included many sets with no bigeye catch, so the region-wide proportion if sets with no bigeye catch increased again. Prior to 1995 almost all sets caught some yellowfin, but after this time the proportion of set with zero yellowfin catch increased in line with the increase in albacore-targeted effort 10N to 20N.

Catch rates of albacore were low in the tropics but high elsewhere. They increased considerably in the 1990s in regions 1 and 2, with this increase later extending into region 3.

The geographic area fished changed through time, with early expansion throughout the WCPO, followed by large declines in regions 3, 5, and 6 (Figure 8). In region 3 the fleet contracted first north, out of the Bismarck Sea and Papua New Guinea area, and then east (Figure 9). Effort in region 5 also moved east, with recent effort mainly restricted to the far north and far south (Figure 10).

Longline configuration changed through time, including increasing HBF (Figure 11 to Figure 14). There was also spatial variation in HBF, reflecting different fishing methods suitable for different oceanographic conditions and target species.

Patterns of median bigeye, yellowfin and albacore CPUE by 5 degree square were plotted for each region (Figure 15 to Figure 21). A strong pattern previously noted was the increase in albacore CPUE post-1990 in regions 1 and 3. In region 2 the early bigeye CPUE was very high from 20N-30N, particularly further east. Albacore (and swordfish, not shown) catch rates were low at this time, in what is now seen as an albacore fishing area. In region 3 early catch rates for yellowfin were higher further south, and started much higher and have declined much further than bigeye. In region 4 there was a clear and remarkable pattern in the period 1950-1970 of higher yellowfin catch rates 5S to 5N, and higher bigeye catch rates 5N to 15N. Region 5 shows generally high albacore catch rates.

Patterns of sets with zero catches of each species were plotted for each region (Figure 22 and Figure 27). In region 2, there was a clear trend through time towards fewer catches without albacore. In region 4 there were a number of sets without yellowfin catch north of 5N through the time series, particularly further east.

Catch per year in numbers by 5 degree square is also plotted in Figure 28 to Figure 33, and effort in Figure 34 and Figure 39. There was a widespread and sharp peak in yellowfin and (to a lesser extent) bigeye catches in region 3 in about 1980. Recent yellowfin catches have been very high in two 5 degree squares in the south of region 3 and north of region 5.

4.2. Targeting and spatial effects

Regression trees were run for data from several different periods to investigate factors associated with swordfish targeted effort. Before 1976, use of squid bait explained a great deal of the variation in swordfish catch rates, and was closely associated with higher swordfish catches (Figure 49 to Figure 55). After 1976 squid bait no longer explained swordfish catch rates and was replaced by hooks, which had not previously been informative. Before 1976 higher swordfish catch rates were not associated with higher hooks per set, but after 1976 there was a clear increase in swordfish catch rates at higher hooks per set (Figure 59). HBF was not included in these analyses because data were unavailable for many sets before 1976. However, HBF was strongly associated with higher swordfish catch rates after 1976, but not between 1959 and 1966 (Figure 60 and Figure 61).

Before 1976 swordfish targeting seemed not to be distinguishable by any particular HBF or numbers of hooks, but did generally involve the use of squid bait.

Catch rates for bigeye and yellowfin differed according to bait type (Figure 56 and Figure 57). The bait type of ‘live bait’ was uncommon, but was also associated with significantly different catch rates.

4.3. Catch and effort standardization

Catch and effort data were standardized in each region using models both with and without a vessel effect. The equatorial section of Region 3 from 5˚S-10˚N was also standardized separately.

Unless otherwise stated, results for each region are presented for one fishing category only – offshore for regions 1 and 3, and distant water for regions 2, 4, 5, and 6. Most regions have been dominated by a single fishing category. In region 3 there was significant distant water effort but until recently the majority of effort has been in the offshore category (less than 120 tonnes) (Figure 4). Indices for region 3 offshore and distant water are compared later.

Logsheets were available for standardization for regions 1-6 for the period 1952-2010 (Figure 63), although sets in region 6 have been minimal since 1993. Logsheet numbers have declined since the mid-1980’s. Vessel ids have been available since 1978, with the number of unique vessels declining throughout the period (Figure 64).

For all regions, the lognormal models fit the positive component of the data reasonably well (Figure 65 to Figure 71). The residual patterns were smoothest in regions 3 and 4, indicating the greater consistency of targeting in these regions. Longline fisheries in the subtropical regions 1, 2, 5, and 6 are more diverse and the indices were less consistent, particularly for yellowfin which is less abundant outside regions 3 and 4. The residual patterns showed similar slightly negative skewness across all analyses, suggesting that there may be a more appropriate distribution than the lognormal.

4.4. Fishing power

For all 6 regions and both species, including the vessel effect changed the trends of the delta lognormal indices (Figure 72 to Figure 78). Vessel effects were only available after 1978, so most of the change to indices occurred after this time.

Overall, including the vessel effect resulted in a more declining delta lognormal abundance index for bigeye in regions 1, 3, 4, 6, and latitudes 5˚S-10˚N (core area) of region 3, and trends that declined less in regions 2 and 5. For yellowfin, including the vessel effect resulted in a more declining delta lognormal abundance index in all regions.

Ratio plots for yellowfin in region 4 (Figure 76) and bigeye in region 5 (Figure 77) show discontinuities in about 1978, when vessel callsigns began to be reported in the data. The two discontinuities occur in opposite directions. The discontinuities may occur because vessel ids were not available immediately for all vessels across the fleet. The new vessel effects were estimated relative to the fishing power of one another, and of the '0' vessel. If the fishing power of the 0 vessel (i.e. the average of the vessels not reporting a callsign) differs from the average of the vessels that start reporting a callsign (i.e. vessels that start reporting a callsign have different catchability from those that do not), then year-quarter effects will be offset, as we observe in the ratio plots. For this reason, year-quarter effects for region 4 yellowfin and region 5 bigeye were adjusted in the indices, in order to line up the ratio plots. An adjustment factor was calculated by dividing the mean ratio for the first 4 years before callsigns were available by the mean ratio for the first 4 years after callsigns were available. This adjustment factor was applied to all year-quarter effect after callsigns were available.

For both bigeye and yellowfin, analyses in the core area of Region 3, where bigeye and yellowfin targeting is thought to be more consistent, suggested more increase in fishing power than analyses that covered the whole of Region 3. Region 1 fishing power trends were a little more variable for both bigeye and yellowfin, with most of the increase in average catchability occurring in the mid 1990's. Region 2 has contrasting patterns for bigeye and yellowfin, with bigeye catchability appearing to decline after 1990 as yellowfin catchability increased. Region 4 showed variable catchability trends with an increase from 1980 to 1990 followed by stable or declining catchability. Region 5 also showed contrasting patterns for bigeye and yellowfin, with bigeye catchability appearing to decline from 1980 while yellowfin catchability increased, with significant variation in the trend. With little data for Region 6 catchability trends are not very useful or realistic.

4.5. Analyses of covariate effects

Covariate effects were examined for the lognormal positive models (Figure 79 to Figure 92). The figures present the effects of time, location, vessel, and HBF. The spatial effects are displayed as a coloured image, with higher catch rates represented by brighter colours.

In region 1, higher catch rates were observed for bigeye in the northeast and southwest, while yellowfin catch rates were much higher further south and west.

For bigeye, region 2 catch rates increased to the east, and peaked between 30 and 35˚N. Yellowfin showed considerably higher catch rates in the south of the region.

Region 3 catch rates for bigeye were highest to the west of Papua New Guinea and the Philippines, but were lower east of the Philippines and Papua New Guinea and showed an increasing trend further east. Yellowfin showed a strong pattern of increasing catch rate further south, particularly around the Solomon Islands.

Bigeye region 4 catch rates also showed an increasing trend to the east, and were highest in a latitudinal band 10˚N to 15˚N. Yellowfin catch rates peaked further south between 5˚S and 5˚N, and trended higher further west.

Region 5 effects were quite spatially variable, but with lower catch rates 15 to 25˚S. Catch rates in region 6 generally increased further south. Yellowfin catch rates consistently declined further south and east, with highest CPUE north of 15˚S.

Description of the vessel effects parallels the earlier description of the observed changes in indices when vessel effects were included, so will not be repeated here. It is notable however how the mean vessel effect is highly variable in regions 2 and 5, presumably reflecting seasonal movements of the fleet.

The HBF effects in the subtropical to temperate regions 1, 2, 5, and 6 showed increasing catch rate with higher HBF for bigeye, as expected if deeper sets catch more bigeye tuna. Similar to last year's analyses which combined distant water and offshore effort (Hoyle *et al.* 2010), regions 3 and 4 showed a different picture, with bigeye catch rates similar bigeye catch rates across a range of HBF levels. The contrast was less marked than in the 2010 analyses.

For yellowfin, CPUE declined with increasing HBF in regions 2, 3, and 4. However, in regions 1 and 5 there was a substantial increase in CPUE with increasing HBF.

4.6. Indices

Further operational data analyses were carried out that excluded sets after 1994 with target reported as swordfish or sharks, and excluded sets that used squid bait or live bait.

Indices were estimated for all 6 regions (Table 4). The delta lognormal model combines the binomial and positive lognormal indices, and joint CVs (e.g. Shono 2008) were not estimated due to lack of time. Instead, CV estimates from the offset lognormal (catch+0.5) model were used to indicate relative CVs for the delta lognormal indices.

Indices were compared with the indices estimated from aggregated data held by SPC, which have been used in the past to prepare indices for WCPO stock assessments (e.g. Langley *et al.* 2005;Hoyle 2010). For bigeye, the operational indices showed more decline than the aggregated indices in regions 3, 4, and 5, and significantly less decline in regions 1 and 2 (Figure 93). For yellowfin, the operational indices showed more decline in regions 3, 4, and 5, but patterns were variable through time in regions 1 and 2 (Figure 94).

The effects of weighting sets by area rather than giving equal weighting to all sets also varied by region and species. For bigeye (Figure 95 and Figure 96), the region 2 indices were quite strongly affected given the variability of the effort distribution, but there was little overall trend. In regions 1, 3, and 5 however the new approach resulted in significantly more decline, presumably due to increasing concentration of effort in regions with higher catch rates. For yellowfin (Figure 97 and Figure 98), area weighted indices showed less decline in region 2, more decline in region 1, and variable patterns in region 5. There was little change to the trends in regions 3 and 4.

We compared indices from the core area of region 3 with those from the whole of region 3 (Figure 99). For bigeye, core indices declined by more than whole R3 indices in the period up to 1990, after which they declined considerably less. For yellowfin, core indices generally declined more than whole R3 indices.

For both configurations of region 3 we also compared the indices from offshore vessels with distant water indices (Figure 100). To make the comparison effective, the distant water indices were normalized to average 1 over the same period as the offshore indices, rather than for the whole of the time series.

In general the distant water indices declined more than the offshore indices, except for bigeye in the core area of region 3, but apart from this the patterns were quite similar. The distant water indices tended to be more variable than the offshore indices, particularly in the core area, given the much larger sample sizes of offshore sets.

5. Discussion

This collaboration had two main objectives: to standardize Japanese operational longline catch and effort data for bigeye tuna, and to identify the effect of changes in fleet fishing power due to changes in the fleet composition on bigeye catch rates.

Meeting these objectives in the 2 weeks available required developing a good understanding of the operational data. A better understanding of the data will improve any analysis, and is particularly important when working with such a complex fishery. The Japanese longline fleet has many components fishing in all areas of the WCPO, targets multiple species, and has used a variety of fishing techniques and technologies over time. A wide range of plots have been included in this report, in order to show some of the important features of the dataset.

5.1. Fishing strategy and target changes through time

Changes in fishing technique, such as may occur with changing target species, are a vitally important issue for CPUE standardization. When fishing techniques change, catch rates are likely to change as well, and these may be confused with changes in species abundance.

The data used in CPUE analyses should ideally be homogenous in terms of targeting and fishing techniques in each region analysed. Where the data are not homogeneous in terms of fishing techniques, we require variables that classify the data components into individual homogeneous components. This is an important benefit of including the vessel identifier: individual vessels are more likely to be consistent in their fishing techniques than the overall fleet. However, if there is evidence that individual vessels have changed their fishing technique, it may be appropriate to remove these vessels from the analysis in order to improve homogeneity.

As described in analyses presented in 2010 (Hoyle *et al.* 2010), fishing power analyses and index estimates tentatively focused on the equatorial parts of region 3 from 5S-10˚N. The 2010 core area 0 -10N was extended south by 5 degrees, because the area from 5S to the equator included little albacore effort.

Investigation of factors affecting swordfish catch rates showed that use of squid bait was a reliable indicator of swordfish targeted effort before 1976, when HBF data were mostly unavailable. In fact HBF may not have been a useful indicator of swordfish targeting before 1976, even if available, since low HBF is not associated with higher swordfish catch rates 1959-66.

5.2. Changes in average fishing power

Introducing vessel effects greatly increased the explanatory power of the models, and changed the abundance trends for all regions, either in terms of long-term trends, short term trends, or short term variation. Vessel effects comprise several different factors, which can be summarized as variation among vessels in their intention (on the one hand) and their ability (on the other) to target a species. This also reinforces the point that the vessel effects estimated here are species-specific.

Changes in fishing power directly affect the abundance indices, since the expected catch rate in a region is the sum of the vessel effects, the time effects, and other effects. If the average vessel effect for a year-quarter is above average, then a model with vessel effects will give a lower abundance index for that year-quarter than a model without vessel effects.

Vessel effects estimated by the methods in this study only account for changes in relative fishing power (catchability) among vessels, not changes in absolute fishing power by an individual vessel. Furthermore, one vessel has only one averaged vessel effect to cover the entire period it is included in the model, which may span decades. Some factors, such as vessel characteristics or equipment (e.g. engine, vessel speed, well capacity, etc), may be kept throughout the life of the vessel and have consistent effects on fishing power. However, other factors such as fishing techniques, targeting strategies, new technologies and vessel equipment upgrades, or changes in the crew or fishing master will affect vessels' catchability on a shorter time scale and may vary through time for an individual vessel, as well as among vessels. We recommend research to develop better ways to consider short-term changes in individual vessels' catchability.

The pattern of the vessel effects in most regions (expect region 6) suggests that much of the increasing trend in vessel effect may be due to departure of vessels with poor catch rates, perhaps more than introduction of new vessels with higher catch rates (Figure 79 to Figure 91). As the number of vessels in the regions' fleets decline through time, in regions 1, 4, and equatorial region 3 the vessels with low vessel effects seem to thin out, while there is less evidence for vessels with substantially higher vessel effects entering the fishery.

In future it may be useful to separately investigate the area to the west of 180 degrees, in both region 2 and region 4, where much of the effort is carried out by the smaller vessels of the offshore fleet. The offshore fleet should not and generally does not fish east of 180 degrees. There appears to be an area with low effort between 180 and 185 degrees, and it would be useful to investigate any differences in fishing practices on either side of this longitude.

The period before 1978 must also be considered. Without vessel identification, this method for estimating fishing power changes is not applicable. It may be possible to obtain vessel identity information by examining the original data records.

5.3. Abundance indices

Operational data contain significantly more information than aggregated data, and have the potential to provide more reliable abundance indices. Perhaps their greatest benefit is that they permit far deeper understanding of the processes involved in fishing. The process of aggregation itself can cause indices to differ in important respects from indices based on operational data, even when the same model is used for both analyses. Previously, analyses of the same data gave very different results when analysed in the aggregated or operational state (Hoyle *et al.* 2010). The analyses of aggregated data gave the same weight to data from each stratum (time x grid square x HBF), whereas the operational data analyses gave the same weight to each set. Grid squares with more strata were therefore given more weight in the aggregate analyses, while those with more sets were given more weight in the operational data analyses (Campbell 2004). Giving more weight to regions with more sets and higher CPUE, when effort becomes increasingly concentrated through time, and is more concentrated in areas of higher abundance (Harley 2009), is likely to result in a biased trend with reduced abundance decline (Campbell 2004).

Our analyses with area weighting used resulted in similar total weights being given to each area (Punsly 1987). This compensated for the effect of effort aggregation, and resulted in indices that declined more than the indices from equally weighted sets. As a result the trends from operational data no longer declined less than those from the same data, aggregated (unpublished data). Further work should examine the utility of weighting at finer spatial scales than the 5 degree square.

5.4. Conclusions

The Japanese operational longline catch and effort dataset represents an information resource with great potential for improving our understanding of pelagic fish population dynamics. The information on mean and median catch rates and the proportion of sets with zero catch revealed interesting spatial patterns in early catch rates. Its use in generating CPUE indices allowed us to resolve several problems in the indices previously available. Inclusion of vessel effects affected the indices significantly on several different time scales. Use of regression trees was effective for identifying and removing swordfish-targeted effort. Further work is hoped to be continued to identify features representing alternative fishing strategies.

Given the potential of operational data for improving our understanding of tuna population dynamics and the behaviour of fishing fleets, we believe that bigeye and yellowfin stock assessments should use abundance indices generated from operational data, for the full period starting 1950's as for the Japanese longline data (despite the lack of vessel identifiers for some of the period). Regarding GLM analyses, it seems to be more reasonable to use area weighting rather than equal weighting although further research into analysis methods is given a high priority.

We are grateful for the opportunity to work with this dataset, and strongly encourage further collaborating work in the future on these topics.

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6. Tables

Table 1: Characteristics of variables provided in the operational data.

Items	Type	Column	1952-57	1959-66	1967-75	1976-93	1994-2010	Remarks
operation year	integer	1-4	YES	YES	YES	YES	YES	
operation month	integer	5-6	YES	YES	YES	YES	YES	
operation day	integer	7-8	YES	YES	YES	YES	YES	
operation latitude	integer	9-10	YES	YES	YES	YES	YES	
operation latitude code	integer	11	YES	YES	YES	YES	YES	N: 1, S: 2
operation longitude	integer	12-14	YES	YES	YES	YES	YES	
operation longitude code	integer	15	YES	YES	YES	YES	YES	E: 1, W: 2
vessel name	character	16-35	NO	YES	NO	YES	YES	Vessel name in Japanese
call sign	character	36-41	NO	NO	NO	YES	YES	
tonnage	real	42-48	NO	YES	NO	YES	YES	
fishing category	integer	49	NO	YES	YES	YES	YES	1952-57, NONE 1959-66, 1: OS, 2&3: DW, 4-7: other 1967-70, 1: OS, 2: DW, 3-4: other 1971-93, 1: OS, 2&3: DW, 4-6: other 1994-2010, 1&2: DW, 2: OS, 3-6: other
licence no.	integer	50-54	NO	YES	NO	YES	YES	this may change by year
set type (type of target)	integer	55	NO	NO	NO	NO	YES	1: swordfish, 2: shark, 3: other (tuna)
main line materials	integer	56	NO	NO	NO	NO	YES	1: Nylon, 2: other
branch line materials	integer	57	NO	NO	NO	NO	YES	1: Nylon, 2: other
bait type	integer	58	YES	YES	YES	YES	NO	1: Pacific saury, 2: squid, 3: live bait, 4: other
no. of hooks between float	integer	59-61	NO	YES	NO	YES	YES	
total no. of hooks per set	integer	62-67	YES	YES	YES	YES	YES	
albacore catch in number	integer	68-70	YES	YES	YES	YES	YES	
bigeye catch in number	integer	71-73	YES	YES	YES	YES	YES	
yellowfin catch in number	integer	74-76	YES	YES	YES	YES	YES	
swordfish catch in number	integer	77-79	YES	YES	YES	YES	YES	

Table 2: Number of available records by variable in the operational data

YEAR	Operation Date	Latitude	Longitude	Call sign	Tonnage	Fishing category	Licence	Target	Material (main & branch)	Bait Type	HBF	Hooks per set	ALB catch in number	BET catch in number	YFT catch in number	SWO catch in number
1952	19411	19411	19411	0	0	0	0			19411	0	19411	8471	12740	7638	7006
1953	25066	25066	25066	0	0	0	0			25066	0	25066	11032	17154	11907	8446
1954	45271	45271	45271	0	0	0	0			45271	0	45271	26684	31725	23635	16244
1955	50020	50020	50020	0	0	0	0			50020	0	50020	27994	39721	26643	16929
1956	45463	45463	45463	0	0	0	0			45463	0	45463	22962	37819	24929	16189
1957	45720	45720	45720	0	0	0	0			45720	0	45720	23064	38409	28312	14743
1958	573	573	573	0	530	573	0			573	389	573	341	528	390	214
1959	61258	61258	61258	0	52802	61061	3			61250	39258	61257	31487	50355	41934	22124
1960	69964	69964	69964	0	59923	61485	0			69881	35438	69961	36380	55818	47384	24197
1961	68856	68856	68856	0	58213	68693	0			68856	35496	68854	35602	52711	46764	20421
1962	78593	78593	78593	0	68460	78396	585			78593	20800	78545	42674	59632	59221	21791
1963	84518	84518	84518	0	82902	84518	73382			84518	26965	84518	45757	66463	56730	24107
1964	106701	106701	106701	0	106651	106701	106026			106698	49684	106520	52181	79960	73858	33057
1965	109587	109587	109587	0	109587	109563	109520			109563	101979	109491	51477	77179	68170	38084
1966	98696	98155	98696	0	98672	98696	98653			98696	93797	98696	55632	69903	61889	35189
1967	89982	89938	89982	0	4053	89982	4053			89982	3896	89982	49482	67976	51499	33953
1968	76642	76642	76642	0	0	76642	0			76642	0	76642	37694	53651	43783	26701
1969	66695	66695	66695	0	0	66695	0			66695	0	66695	31054	46558	35692	23190
1970	77475	77475	77475	0	0	77475	0			77475	0	77475	35243	51684	47413	24159
1971	71563	71563	71563	0	0	71563	0			71563	0	71563	29768	46033	38090	24218
1972	65271	65271	65271	0	0	65271	0			65271	0	65271	26365	45331	36034	21697
1973	58477	58477	58477	0	0	58477	0			58477	0	58477	22601	40766	33554	18559
1974	68884	68884	68884	0	0	68884	0			68884	0	68884	28824	50966	46220	22880

1975	63287	63287	63287	0	0	63287	0			63287	0	63287	22237	48885	42925	20034
1976	96285	96285	96285	0	96285	96285	96285			96285	92078	96285	36546	70584	58349	32657
1977	89833	89833	89833	0	89833	89833	89833			89833	86903	89833	29399	70592	55844	28485
1978	84973	84973	84973	4027	84973	84973	84973			84973	83712	84973	29484	70307	58666	28196
1979	109227	109227	109227	66065	109227	109227	109227			109227	92243	109227	38879	86834	76104	34339
1980	120363	120363	120363	80139	120363	120363	120363			120363	106629	120363	41402	92516	85375	33734
1981	129136	129136	129136	92043	129136	129136	129136			129136	125966	129136	54228	96979	90053	36301
1982	111031	111031	111031	86368	111031	111031	111031			111031	108247	111031	51344	88208	78247	32856
1983	90917	90917	90917	75115	90917	90917	90917			90917	89232	90917	39646	71352	60725	29531
1984	98314	98314	98314	85864	98314	98314	98314			98314	96858	98314	40155	84268	73824	33662
1985	91281	91281	91281	81025	91281	91281	91281			91281	89581	91281	35193	77932	65675	37305
1986	79633	79633	79633	71244	79633	79633	79633			79633	78141	79633	35827	67994	56302	35110
1987	73167	73167	73167	68095	73167	73167	73167			73167	71957	73167	30124	60563	49577	31887
1988	83292	83292	83292	78639	83292	83292	83292			83292	81764	83292	41337	71206	60945	34149
1989	77509	77509	77509	73784	77509	77509	77509			77509	74615	77509	34488	66791	56299	31494
1990	70802	70802	70802	68043	70802	70802	70802			70802	67338	70802	30904	60573	49954	28181
1991	63759	63759	63759	61982	63759	63759	63759			63759	60536	63759	30921	54526	46187	23923
1992	56602	56602	56602	55974	56602	56602	56602			56602	53237	56602	25213	49170	41368	23469
1993	61980	61980	61980	61729	61980	61980	61980			61980	60545	61980	30622	54834	49942	25672
1994	56577	56577	56577	56182	56577	56577	56577	56577	56577		52935	56577	56577	56577	56577	56577
1995	53858	53858	53858	53407	53858	53858	53858	53858	53858		48659	53858	53858	53858	53858	53858
1996	47091	47091	47091	46719	47091	47091	47091	47091	47091		40016	47091	47091	47091	47091	47091
1997	42438	42438	42438	42165	42438	42438	42438	42438	42438		35962	42438	42438	42438	42438	42438
1998	45603	45603	45603	45398	45603	45603	45603	45603	45603		39684	45603	45603	45603	45603	45603
1999	44130	44130	44130	43848	44130	44130	44130	44130	44130		39279	44130	44130	44130	44130	44130
2000	44679	44679	44679	44344	44679	44679	44679	44679	44679		38582	44679	44679	44679	44679	44679
2001	42981	42981	42981	42687	42981	42981	42981	42981	42981		37867	42981	42981	42981	42981	42981

2002	41953	41953	41953	41679	41953	41953	41953	41953	41953		37524	41953	41953	41953	41953	41953
2003	39247	39247	39247	38954	39247	39247	39247	39247	39247		34720	39247	39247	39247	39247	39247
2004	36259	36259	36259	36069	36259	36259	36259	36259	36259		31449	36259	36259	36259	36259	36259
2005	30095	30095	30095	30042	30095	30095	30095	30095	30095		26852	30095	30095	30095	30095	30095
2006	27973	27973	27973	27962	27973	27973	27973	27973	27973		25720	27973	27973	27973	27973	27973
2007	29208	29208	29208	29187	29208	29208	29208	29208	29208		26613	29208	29208	29208	29208	29208
2008	25326	25326	25326	25241	25326	25326	25326	25326	25326		23406	25326	25326	25326	25326	25326
2009	21954	21954	21954	21470	21954	21954	21954	21954	21954		20912	21954	21954	21954	21954	21954
2010	20259	20259	20259	19435	20259	20259	20259	20259	20259		19410	20259	20259	20259	20259	20259

Table 3: Dimensions included in the analyses, which included all combinations of options 1 to 7, or approximately 900 models.

	Type of option	Option 1	Option 2	Option 3
1	Species	Bigeye	Yellowfin	
2	Regions	6 regions , plus the core area of region 3 10S to 10N.		
3	Swordfish targeting	Without squid and live bait	All bait types	
4	Fishing category	Offshore	Distant water	
5	Weighting method	By area	Equal weights	
6	Vessel effects	With	Without	
7	Model error structure	Delta lognormal (i.e. binomial & lognormal)	Over-dispersed Poisson	Aggregated

Table 4: Indices by species, region and year-quarter.

	BET Indices							YFT indices						
Yrqtr	R1	R2	R3	R3eq	R4	R5	R6	R1	R2	R3	R3eq	R4	R5	R6
1952.125	2.163	-	-	-	2.991	-	-	0.666	-	-	0.982	-	-	-
1952.375	1.043	-	-	-	2.179	-	-	0.880	-	-	0.524	-	-	-
1952.625	2.335	1.531	-	-	2.481	-	-	1.097	0.172	-	0.930	-	-	-
1952.875	3.103	2.683	-	-	1.714	-	-	2.058	0.693	-	1.561	-	-	-
1953.125	1.784	3.246	-	-	2.071	1.362	-	0.694	0.374	-	1.266	4.095	-	-
1953.375	1.034	-	-	-	1.821	3.191	-	1.260	-	-	1.785	3.397	-	-
1953.625	1.336	-	-	-	1.917	2.044	-	1.041	-	-	1.789	3.608	-	-
1953.875	2.195	2.378	-	-	1.506	1.143	-	1.407	0.941	-	1.412	5.212	-	-
1954.125	1.518	1.663	-	-	1.401	1.657	-	0.825	0.281	-	1.070	3.306	-	-
1954.375	1.343	-	-	-	1.045	2.321	-	2.256	-	-	0.922	2.333	-	-
1954.625	1.709	2.724	-	-	1.451	1.842	1.315	1.692	1.156	-	1.185	2.446	0.956	-
1954.875	3.090	2.789	-	-	0.991	1.577	1.150	1.361	0.506	-	0.714	2.367	2.166	-
1955.125	1.754	2.300	-	-	1.597	1.521	0.577	0.799	0.183	-	0.974	2.489	3.876	-
1955.375	0.848	-	-	-	1.345	-	1.775	1.789	-	-	1.558	-	2.084	-
1955.625	1.526	2.191	-	-	0.932	1.809	1.110	1.247	0.424	-	1.680	1.552	1.153	-
1955.875	3.328	2.260	-	-	1.095	1.298	1.563	1.687	0.652	-	1.099	2.310	2.167	-
1956.125	2.875	2.887	-	-	1.166	1.022	0.547	1.267	0.453	-	1.159	2.322	2.366	-
1956.375	1.206	2.186	-	-	1.163	1.704	1.422	1.302	0.121	-	2.116	2.264	1.789	-
1956.625	1.561	1.560	-	-	1.861	2.196	1.875	1.024	0.149	-	1.591	2.566	1.548	-
1956.875	4.015	2.712	-	-	1.192	1.599	2.638	1.763	0.400	-	0.972	2.567	1.255	-
1957.125	2.941	4.883	-	-	1.444	1.489	1.010	0.727	0.222	-	1.479	2.774	1.927	-
1957.375	1.333	2.370	-	-	1.739	-	1.788	1.588	0.454	-	1.654	-	2.173	-
1957.625	3.407	1.340	-	-	1.539	2.332	1.423	2.074	0.159	-	2.607	3.183	1.362	-
1957.875	3.949	2.183	-	-	1.423	1.667	1.324	1.116	0.360	-	1.529	2.394	1.581	-
1958.125	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1958.375	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1958.625	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1958.875	1.843	-	-	-	-	-	-	1.199	-	-	-	-	-	-
1959.125	1.750	2.241	2.044	-	1.403	-	0.783	2.080	1.821	1.357	1.726	-	2.107	-
1959.375	0.841	2.365	0.954	2.219	1.388	1.525	-	3.552	0.716	2.407	2.534	2.409	-	1.115
1959.625	1.661	1.528	1.420	3.920	1.019	1.703	0.933	4.505	1.299	2.681	2.212	1.107	2.368	3.033
1959.875	2.082	2.885	1.493	2.001	1.245	1.581	0.968	2.306	1.695	2.386	1.888	1.006	0.505	2.467
1960.125	1.613	2.248	1.529	1.474	1.287	-	0.772	1.788	1.558	1.475	1.460	-	0.524	1.648
1960.375	1.053	1.331	1.125	1.205	1.567	-	0.375	3.271	1.061	1.125	1.547	-	1.176	1.706
1960.625	1.082	0.909	1.363	1.349	1.398	1.861	0.619	1.649	0.990	1.338	1.833	2.009	1.147	1.683
1960.875	2.029	1.881	1.603	1.474	1.284	1.090	0.335	1.888	0.567	1.272	1.362	1.706	0.892	1.332
1961.125	1.450	2.296	1.440	1.634	1.362	-	0.826	0.605	0.956	1.035	1.703	-	2.878	1.148
1961.375	0.681	0.717	0.944	1.391	1.704	-	-	1.609	1.373	1.732	1.830	-	-	2.085
1961.625	0.876	1.094	0.884	0.910	1.319	1.156	0.480	1.130	0.131	1.488	1.847	1.244	0.351	1.648
1961.875	1.773	1.906	1.048	1.066	1.013	1.062	0.541	1.348	0.452	1.419	1.066	1.302	0.384	1.547
1962.125	1.180	1.202	1.078	1.024	1.324	1.246	0.506	1.579	0.735	1.144	1.206	1.285	0.655	1.100
1962.375	0.388	1.011	0.902	0.946	1.535	2.616	1.332	1.427	1.536	0.948	1.153	2.739	0.838	1.205
1962.625	1.289	0.439	0.997	1.025	1.261	1.932	0.887	2.243	1.029	1.746	1.813	2.035	0.750	2.166
1962.875	1.696	1.214	1.011	1.048	1.410	1.220	0.787	1.461	0.471	1.639	1.178	1.377	0.585	1.706
1963.125	1.593	1.274	1.204	1.287	1.604	1.450	0.786	0.698	0.619	1.151	1.024	1.665	0.784	1.217
1963.375	0.695	0.188	0.943	1.112	1.292	2.064	1.190	0.507	0.852	1.443	0.968	1.743	2.129	1.759
1963.625	1.233	0.487	0.954	0.993	1.155	1.822	1.235	1.523	0.574	1.299	0.999	1.528	0.745	1.568
1963.875	1.800	0.755	1.159	1.124	1.115	1.310	1.142	1.544	0.504	1.353	1.041	1.461	0.791	1.453
1964.125	1.641	1.099	1.096	1.014	1.516	1.082	1.345	0.883	0.731	1.266	1.042	1.290	0.989	1.281
1964.375	0.761	0.090	1.133	0.954	1.180	1.601	1.050	2.055	0.428	1.553	0.899	1.644	1.782	2.343

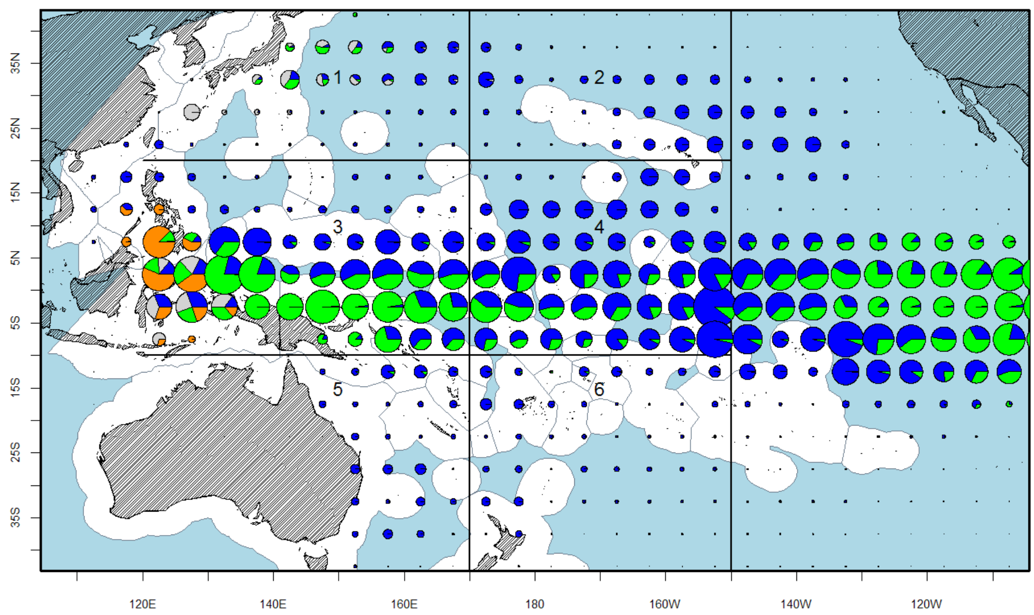
Yrqtr	BET Indices							YFT indices						
	R1	R2	R3	R3eq	R4	R5	R6	R1	R2	R3	R3eq	R4	R5	R6
1964.625	0.854	0.312	0.936	0.895	1.059	1.325	1.095	2.031	0.756	1.565	1.252	1.794	1.445	1.640
1964.875	1.870	1.051	0.953	0.951	1.056	1.169	1.281	1.738	1.495	1.196	1.528	1.105	1.079	1.232
1965.125	1.223	1.445	0.976	0.975	1.176	-	0.977	1.190	3.478	1.028	1.597	-	1.152	1.211
1965.375	0.641	0.092	0.843	0.944	1.240	2.068	-	1.125	0.602	1.336	1.369	2.037	-	1.986
1965.625	0.881	0.339	0.958	1.023	1.196	1.610	0.899	1.127	1.306	1.349	1.426	1.363	1.177	1.703
1965.875	1.382	1.335	0.940	0.995	1.102	1.094	1.028	1.255	1.855	1.415	0.989	0.923	0.749	1.747
1966.125	1.618	1.721	1.193	0.944	1.424	1.319	0.813	0.845	2.377	1.952	1.013	1.691	0.939	2.809
1966.375	0.771	0.055	0.549	0.442	1.178	1.899	1.301	1.371	0.694	1.194	1.344	1.723	1.898	1.218
1966.625	1.877	1.414	0.806	0.896	0.854	1.188	0.887	1.499	1.735	1.295	1.425	0.787	0.801	1.338
1966.875	1.817	1.354	0.916	0.905	0.966	1.043	1.352	0.842	0.792	1.175	1.216	0.767	0.678	1.190
1967.125	1.348	1.082	1.057	0.985	1.299	1.135	1.273	0.551	0.959	0.966	1.029	0.664	0.853	1.128
1967.375	0.717	0.257	0.800	0.783	1.176	1.555	1.391	0.543	0.471	0.810	0.995	0.391	1.197	1.131
1967.625	0.602	0.478	0.833	0.801	0.955	1.745	1.281	0.457	0.729	1.187	1.138	0.922	0.934	1.336
1967.875	1.397	1.188	0.860	0.776	0.933	1.258	1.457	0.866	0.737	1.309	1.205	0.712	0.421	1.286
1968.125	1.091	1.051	1.008	1.049	1.173	1.269	0.937	0.629	0.716	1.230	1.034	0.511	0.894	1.548
1968.375	0.620	0.074	0.662	0.752	1.026	2.175	1.237	0.863	0.709	0.951	1.496	0.666	1.352	1.143
1968.625	0.515	0.335	0.833	1.033	0.876	1.405	0.913	0.480	0.458	0.777	1.169	0.466	0.830	1.066
1968.875	1.247	0.880	0.998	0.939	0.947	0.876	1.225	0.343	0.387	0.916	1.231	0.647	0.559	1.075
1969.125	1.105	1.796	0.971	0.950	1.400	1.320	0.848	0.308	0.703	0.633	1.337	0.621	1.108	0.737
1969.375	0.428	0.070	0.958	1.029	1.271	1.734	0.970	0.652	0.401	0.939	1.082	0.701	0.453	1.623
1969.625	0.851	1.050	0.792	0.902	1.080	1.551	1.389	1.153	1.032	1.470	0.969	0.815	0.568	1.791
1969.875	1.363	1.243	0.742	0.702	1.166	0.925	-	1.070	0.498	1.590	1.020	0.823	-	1.765
1970.125	1.099	1.374	0.759	0.745	0.956	1.056	-	0.635	1.376	1.201	1.836	0.799	-	1.289
1970.375	0.605	0.054	0.750	0.898	0.772	1.711	0.896	1.842	1.866	1.087	1.911	0.915	0.701	1.002
1970.625	0.622	0.157	0.576	0.610	0.671	1.403	0.837	1.649	2.124	0.930	1.134	1.150	1.392	1.069
1970.875	1.013	0.981	0.662	0.589	0.825	0.859	1.302	1.449	1.895	1.216	1.054	1.007	1.912	1.345
1971.125	0.860	0.766	0.728	0.699	0.774	-	-	0.429	3.170	1.029	0.844	-	-	1.196
1971.375	0.327	-	0.873	0.941	1.002	1.168	-	0.673	-	0.906	0.929	1.172	-	1.184
1971.625	0.382	0.459	0.773	0.795	0.771	1.152	0.946	0.596	0.737	0.879	0.696	1.155	1.675	1.096
1971.875	1.308	1.039	0.846	0.826	0.925	0.808	1.441	0.661	0.509	1.220	0.924	0.572	1.323	1.490
1972.125	1.218	0.947	1.147	1.158	1.035	1.158	0.811	0.386	1.168	0.838	0.873	0.645	1.276	0.939
1972.375	0.548	0.141	1.155	1.296	1.051	1.887	0.936	0.441	2.924	0.805	0.914	0.655	1.204	0.928
1972.625	0.498	0.824	0.921	1.004	1.044	1.292	0.902	0.340	0.259	0.690	0.964	0.534	0.615	0.692
1972.875	0.964	1.209	0.993	1.191	0.913	0.828	0.951	0.459	0.371	0.995	0.671	0.647	0.241	1.033
1973.125	0.906	0.918	1.209	1.071	1.223	1.346	-	0.281	0.579	0.829	0.534	0.548	-	1.040
1973.375	0.378	-	1.050	0.966	0.900	1.445	-	0.804	-	0.994	0.504	0.491	-	1.160
1973.625	0.364	0.437	0.852	0.768	0.816	1.455	-	0.960	0.907	1.015	0.695	0.726	-	1.231
1973.875	1.077	0.450	0.833	0.782	0.655	0.920	-	0.703	0.578	1.128	1.090	0.808	-	1.172
1974.125	0.897	0.727	0.930	0.822	0.865	0.975	-	1.108	1.317	1.004	0.859	0.675	-	1.015
1974.375	0.372	-	1.016	1.016	0.936	1.212	-	1.069	-	0.736	0.630	1.104	-	0.785
1974.625	0.454	0.090	0.940	0.913	0.759	0.857	-	0.558	1.042	0.719	0.439	0.968	-	0.731
1974.875	0.958	0.339	0.984	0.913	0.930	0.622	-	0.689	0.575	1.105	0.591	0.504	-	0.899
1975.125	1.145	0.277	1.171	1.071	0.949	0.573	-	0.572	1.572	0.763	0.509	0.454	-	0.793
1975.375	0.311	-	1.270	1.268	0.856	0.931	-	0.596	-	1.039	0.365	0.450	-	1.013
1975.625	0.524	-	0.999	1.038	0.785	0.731	-	0.478	-	0.792	0.592	0.693	-	0.820
1975.875	1.191	1.225	0.984	1.036	1.020	0.586	-	0.763	1.401	0.898	0.571	0.585	-	0.890
1976.125	1.153	0.971	0.929	0.903	0.836	0.546	-	1.332	1.745	1.001	0.932	0.648	-	0.971
1976.375	0.458	0.574	1.109	1.183	1.138	1.136	-	0.684	0.671	1.109	0.876	0.552	-	1.166
1976.625	0.569	0.412	1.068	1.024	0.825	1.195	-	0.454	0.800	1.194	0.959	0.708	-	1.308
1976.875	1.443	1.122	1.283	1.173	0.774	1.053	-	0.874	0.837	1.260	1.191	0.797	-	1.331
1977.125	2.015	0.837	1.335	1.283	0.961	-	-	1.029	1.895	1.232	0.942	-	-	1.219
1977.375	0.526	-	1.595	1.466	1.349	-	-	0.636	-	1.456	0.496	-	-	1.392

Yrqtr	BET Indices							YFT indices						
	R1	R2	R3	R3eq	R4	R5	R6	R1	R2	R3	R3eq	R4	R5	R6
1977.625	0.562	0.739	1.566	1.522	0.876	-	-	0.454	0.565	1.512	0.969	-	-	1.839
1977.875	1.536	2.301	1.469	1.398	1.456	0.528	-	0.583	0.925	1.320	1.469	0.607	-	1.351
1978.125	1.294	1.059	1.180	1.166	1.242	-	-	0.726	1.329	1.193	1.383	-	-	1.205
1978.375	0.420	0.040	1.081	0.985	0.944	1.165	-	0.803	1.201	1.994	0.736	0.443	-	2.172
1978.625	0.321	0.351	0.953	0.825	0.802	1.554	-	0.785	0.628	1.662	0.946	2.161	-	1.598
1978.875	1.204	1.007	1.108	1.028	0.967	0.989	-	0.886	0.877	1.730	1.504	1.136	-	1.742
1979.125	1.116	0.736	1.030	0.906	1.230	0.916	-	1.035	2.054	1.201	1.497	1.021	-	1.255
1979.375	0.308	0.350	1.179	1.020	1.221	1.734	-	0.997	2.073	1.329	1.180	0.714	-	1.471
1979.625	0.363	0.634	1.034	0.994	0.956	1.605	-	0.455	1.231	1.220	1.197	0.786	-	1.197
1979.875	1.231	0.744	1.092	1.012	1.371	0.923	-	0.997	1.266	1.311	1.651	1.150	-	1.556
1980.125	0.881	0.614	1.217	1.117	1.143	1.088	-	1.416	1.503	1.087	1.317	0.851	-	0.958
1980.375	0.425	0.177	0.994	0.968	0.968	2.205	-	1.397	2.014	1.761	0.812	0.738	-	1.681
1980.625	0.840	0.580	0.790	0.681	0.705	1.320	-	0.824	2.082	1.377	1.122	1.213	-	1.549
1980.875	0.924	0.354	0.795	0.686	0.713	1.099	-	1.146	1.125	1.049	0.856	1.377	-	1.069
1981.125	0.716	0.268	0.804	0.671	1.011	0.716	-	1.217	1.157	0.975	0.656	0.816	-	0.996
1981.375	0.281	0.037	0.692	0.607	0.786	1.028	-	0.739	1.208	1.352	0.820	0.719	-	1.245
1981.625	0.997	0.552	0.517	0.451	0.576	0.757	1.891	1.270	0.788	1.044	0.789	0.950	0.071	0.984
1981.875	1.157	0.827	0.549	0.580	0.824	0.621	-	0.764	1.384	0.754	1.088	0.841	-	0.766
1982.125	0.759	0.854	0.638	0.638	1.019	0.575	0.372	0.821	1.872	0.671	0.952	1.080	0.412	0.700
1982.375	0.382	0.483	0.686	0.646	0.901	0.824	0.531	0.795	2.309	0.729	1.231	0.752	0.452	0.823
1982.625	0.630	1.557	0.695	0.594	0.930	0.724	1.177	0.508	2.006	0.656	1.794	0.592	0.048	0.711
1982.875	0.936	1.068	0.795	0.839	1.259	0.477	-	1.228	1.293	0.943	1.352	0.439	-	0.820
1983.125	0.897	0.936	0.724	0.599	1.150	0.566	0.166	0.856	1.152	0.996	0.972	0.473	0.350	0.816
1983.375	0.242	1.126	0.818	0.678	1.066	1.216	-	0.783	2.145	1.151	0.755	0.375	-	1.294
1983.625	0.496	0.706	0.852	0.813	0.799	0.947	1.639	1.118	1.067	1.443	1.510	1.538	0.102	1.413
1983.875	0.976	0.941	1.100	1.063	0.642	0.636	-	1.267	1.248	1.535	1.338	1.645	-	1.441
1984.125	0.889	0.648	0.999	0.910	0.941	0.642	0.357	1.336	1.451	1.380	1.283	1.213	1.358	1.285
1984.375	0.479	1.991	0.936	0.677	0.777	1.092	-	1.247	1.530	0.958	0.600	0.508	-	0.775
1984.625	0.852	0.736	0.893	0.886	0.830	0.632	0.920	0.722	1.583	0.922	1.258	0.612	0.186	0.909
1984.875	0.935	0.792	1.185	1.031	0.752	0.648	-	0.827	1.702	0.981	1.089	0.528	-	0.859
1985.125	0.832	0.334	0.969	0.860	0.890	0.737	-	0.749	1.164	1.051	0.733	1.199	-	0.911
1985.375	0.251	0.046	0.931	0.881	0.875	1.075	0.809	0.636	1.178	0.952	0.579	1.238	0.595	0.779
1985.625	0.334	0.992	0.913	0.889	0.935	1.089	3.542	0.546	0.934	0.811	0.880	1.895	0.341	0.916
1985.875	0.861	0.759	0.961	0.970	1.000	0.892	-	0.849	1.215	0.757	0.665	1.108	-	0.704
1986.125	0.923	0.433	1.105	0.959	0.884	0.785	0.389	1.452	0.995	0.993	0.947	1.449	1.779	0.787
1986.375	0.294	0.256	1.001	0.965	0.798	1.659	0.406	1.095	1.670	1.294	1.283	0.860	0.814	1.125
1986.625	0.470	0.591	1.111	1.060	0.902	1.256	2.464	0.769	0.402	1.346	1.861	1.507	0.152	1.262
1986.875	1.177	0.596	1.595	1.555	0.760	1.010	-	0.925	0.889	1.263	1.538	1.123	-	1.205
1987.125	1.002	0.481	1.386	1.344	1.468	0.810	0.252	0.766	0.966	1.132	0.716	1.200	1.691	0.966
1987.375	0.250	0.149	1.347	1.277	0.935	1.652	0.167	0.902	0.984	1.408	0.848	1.272	0.549	1.371
1987.625	0.342	0.786	1.223	1.219	0.912	0.978	2.968	0.723	1.013	1.119	0.976	2.159	1.460	1.146
1987.875	1.307	0.804	1.239	1.113	0.856	0.628	-	1.267	1.126	0.899	0.903	1.553	-	0.691
1988.125	0.841	0.546	1.230	0.884	0.589	0.685	-	0.992	1.505	1.054	0.708	1.635	-	1.224
1988.375	0.440	0.023	0.935	0.734	0.598	1.047	0.162	1.072	1.529	1.284	0.636	0.982	1.109	1.185
1988.625	0.492	0.680	0.759	0.680	0.610	0.820	0.923	0.775	3.133	1.393	0.937	2.189	0.763	1.143
1988.875	1.079	0.395	0.897	0.625	0.754	0.437	-	0.871	2.317	1.518	0.994	1.399	-	1.372
1989.125	0.840	0.407	1.017	0.984	0.717	0.606	-	1.354	1.911	1.305	0.651	0.867	-	1.151
1989.375	0.393	0.265	1.262	1.198	0.648	1.257	-	1.846	0.900	1.203	0.497	0.764	-	1.174
1989.625	0.412	0.450	1.353	1.412	0.568	0.661	2.691	1.356	1.046	1.091	0.804	0.897	0.358	0.992
1989.875	1.347	0.883	1.466	1.369	1.085	0.442	-	0.743	1.239	0.922	0.993	0.425	-	0.753
1990.125	1.203	0.676	1.714	1.578	0.947	0.775	-	0.815	0.954	1.055	0.980	0.698	-	0.936
1990.375	0.387	0.397	1.465	1.187	0.847	0.811	-	0.980	1.489	0.983	0.649	1.084	-	0.878

Yrqtr	BET Indices							YFT indices						
	R1	R2	R3	R3eq	R4	R5	R6	R1	R2	R3	R3eq	R4	R5	R6
1990.625	0.598	0.248	1.510	1.320	0.856	0.883	0.441	0.677	0.382	0.853	0.839	0.789	0.254	0.704
1990.875	1.844	0.987	1.431	1.046	0.979	0.535	-	0.992	0.341	0.541	1.141	0.562	-	0.392
1991.125	1.186	0.947	1.451	1.114	0.739	0.364	-	1.286	0.535	0.839	0.886	1.108	-	0.542
1991.375	0.376	-	1.290	0.992	0.715	0.489	-	2.239	-	0.929	0.773	0.826	-	0.728
1991.625	0.863	0.953	1.098	0.909	0.612	0.756	0.061	1.051	0.755	1.010	0.930	0.806	0.240	0.765
1991.875	1.296	0.945	1.125	1.000	1.007	0.240	-	1.018	1.268	0.773	0.918	0.589	-	0.706
1992.125	1.227	0.436	1.356	1.106	0.887	0.318	-	0.766	0.883	0.651	0.492	1.381	-	0.504
1992.375	0.348	-	1.253	0.916	0.921	0.507	-	1.277	-	1.132	0.589	0.942	-	1.035
1992.625	0.851	2.286	1.017	0.927	0.580	0.591	0.087	0.971	0.950	1.268	0.945	1.170	0.039	0.931
1992.875	1.690	1.795	0.989	0.845	0.803	0.757	-	1.210	1.327	0.937	1.372	0.943	-	0.857
1993.125	1.366	1.740	1.046	0.859	0.763	0.518	-	1.692	1.756	0.624	1.039	0.660	-	0.448
1993.375	0.412	-	1.014	0.964	0.853	0.568	-	1.963	-	1.016	0.631	0.825	-	0.859
1993.625	0.588	0.889	0.819	0.695	0.944	0.577	-	1.307	0.927	0.759	1.263	0.983	-	0.654
1993.875	1.307	0.653	1.077	0.980	0.741	0.442	-	0.975	3.066	0.911	0.788	0.453	-	0.758
1994.125	0.912	0.682	1.112	0.883	0.653	0.411	-	1.052	1.331	0.910	0.719	1.103	-	0.742
1994.375	0.416	-	1.119	0.966	0.669	0.775	-	0.920	-	0.659	0.383	0.607	-	0.602
1994.625	0.441	0.727	1.116	0.874	0.637	0.562	-	0.595	0.446	0.862	0.487	0.690	-	0.851
1994.875	0.809	0.519	1.139	1.076	0.807	0.407	-	0.873	0.943	0.738	1.705	0.541	-	0.536
1995.125	0.993	0.770	1.112	0.959	0.770	0.492	-	1.855	2.440	1.018	1.294	1.061	-	0.844
1995.375	0.371	1.377	1.054	0.800	0.514	0.663	-	1.614	1.040	1.289	0.866	1.019	-	1.111
1995.625	0.677	1.573	0.763	0.648	0.318	0.560	-	1.407	1.911	0.716	0.743	1.016	-	0.632
1995.875	0.809	0.171	0.770	0.701	0.556	0.460	-	1.313	1.951	0.543	0.630	0.724	-	0.471
1996.125	0.755	0.318	0.947	0.874	0.533	0.368	-	0.483	2.769	0.517	0.723	0.552	-	0.498
1996.375	0.303	0.792	0.948	0.960	0.707	0.969	-	1.145	0.673	0.980	1.024	0.656	-	0.880
1996.625	0.470	0.639	0.790	0.755	0.596	1.200	0.003	0.875	0.607	0.875	2.062	1.424	0.229	0.688
1996.875	1.590	1.142	0.869	0.838	0.640	-	-	0.946	0.646	0.620	2.374	-	-	0.562
1997.125	0.962	1.383	1.002	0.992	0.830	0.366	-	1.140	0.781	0.593	1.994	1.726	-	0.689
1997.375	0.322	1.279	0.738	0.932	1.039	0.888	-	0.969	1.091	0.721	1.852	0.900	-	0.781
1997.625	0.536	1.510	0.777	0.838	1.165	1.225	-	0.494	1.080	0.751	1.656	0.794	-	0.669
1997.875	1.148	0.925	1.176	1.290	1.545	-	-	0.767	2.047	0.469	0.656	-	-	0.451
1998.125	0.645	0.661	1.173	1.229	1.980	0.575	-	1.418	1.199	0.642	0.534	0.290	-	0.302
1998.375	0.272	1.515	0.781	0.671	1.573	0.604	-	1.534	1.138	1.080	0.853	0.385	-	0.689
1998.625	0.498	0.956	0.810	0.889	1.146	1.161	0.017	1.394	1.074	1.158	0.692	0.365	0.053	1.137
1998.875	0.905	0.661	0.816	0.820	0.956	0.962	-	1.388	0.929	0.807	0.711	0.442	-	0.595
1999.125	0.736	0.537	1.107	1.232	0.783	0.665	-	1.205	2.188	0.387	0.522	0.288	-	0.302
1999.375	0.417	-	0.917	1.012	0.842	0.697	-	0.640	-	0.429	0.374	0.091	-	0.397
1999.625	0.272	1.351	0.930	1.126	0.535	0.979	0.866	0.901	0.501	0.641	0.537	0.113	0.606	0.495
1999.875	1.025	0.741	0.989	0.985	0.714	-	-	1.416	0.929	1.099	0.919	-	-	0.564
2000.125	0.769	0.290	0.957	1.035	0.649	0.387	-	2.060	1.064	0.985	0.929	0.073	-	0.719
2000.375	0.204	-	0.869	0.901	0.817	0.858	-	0.734	-	0.610	1.087	0.055	-	0.504
2000.625	0.434	0.871	0.874	0.908	0.676	1.506	-	0.781	0.190	0.665	1.079	0.078	-	0.731
2000.875	0.761	0.485	0.792	0.907	0.543	-	-	0.695	0.249	0.506	1.260	-	-	0.360
2001.125	0.380	0.125	0.879	1.121	0.562	-	-	0.942	0.329	0.655	0.637	-	-	0.482
2001.375	0.107	-	0.857	1.133	0.856	-	-	0.529	-	0.870	0.740	-	-	0.995
2001.625	0.383	0.175	0.850	0.909	0.787	1.942	1.306	0.589	0.055	0.294	0.791	0.402	0.108	0.312
2001.875	1.180	0.361	1.052	0.979	0.680	1.082	-	0.387	0.283	0.474	0.572	0.291	-	0.377
2002.125	0.640	0.244	1.197	1.220	0.771	0.924	-	0.523	0.159	0.461	0.499	0.166	-	0.342
2002.375	0.528	0.722	1.193	1.230	1.043	0.709	0.201	0.509	0.443	0.744	0.326	0.172	-	0.617
2002.625	0.765	0.196	0.782	1.028	1.041	0.914	-	0.754	0.233	0.521	0.292	0.108	-	0.594
2002.875	1.508	1.365	1.355	1.143	1.009	0.400	-	0.539	0.347	0.864	0.615	0.259	-	0.607
2003.125	0.554	2.476	1.267	1.173	0.771	0.641	-	1.070	0.507	1.282	0.719	0.250	-	1.129
2003.375	1.408	-	1.153	1.078	0.491	0.596	-	1.587	-	1.380	0.343	0.160	-	1.364

Yrqtr	BET Indices							YFT indices						
	R1	R2	R3	R3eq	R4	R5	R6	R1	R2	R3	R3eq	R4	R5	R6
2003.625	0.594	1.349	0.908	1.092	0.667	0.702	0.001	0.914	0.134	0.528	0.314	0.501	3.339	0.487
2003.875	0.941	1.171	1.111	1.235	0.788	0.511	-	0.612	0.877	0.328	0.577	0.695	-	0.208
2004.125	0.517	0.245	1.185	1.236	0.950	0.461	-	0.282	0.882	0.417	0.376	0.222	-	0.273
2004.375	0.488	-	1.143	1.309	1.151	0.421	-	0.226	-	0.404	0.293	0.168	-	0.363
2004.625	0.484	0.835	0.954	1.220	1.090	0.894	1.841	0.108	0.153	0.286	0.841	0.555	0.675	0.260
2004.875	1.294	1.160	1.277	1.226	0.838	0.359	-	0.285	0.337	0.358	0.678	0.655	-	0.324
2005.125	0.521	1.556	0.818	0.862	0.758	0.201	-	0.378	0.279	0.484	0.575	0.144	-	0.431
2005.375	0.677	-	0.706	0.801	0.608	0.262	-	0.568	-	0.719	0.444	0.102	-	0.785
2005.625	0.667	1.667	0.651	0.703	0.700	0.533	1.809	0.315	0.070	1.005	0.392	0.246	0.291	0.899
2005.875	1.193	1.293	0.906	1.018	0.704	0.125	-	0.341	0.605	0.422	0.579	0.227	-	0.429
2006.125	0.800	0.332	1.118	1.028	0.677	0.171	-	0.218	0.560	1.029	0.924	0.044	-	0.947
2006.375	1.160	0.449	1.019	1.116	0.693	0.269	-	0.534	0.145	0.623	0.920	0.093	-	0.813
2006.625	1.751	0.653	0.947	0.957	0.491	0.469	0.008	0.366	0.053	0.470	0.636	0.381	0.033	0.529
2006.875	1.962	1.600	1.061	0.905	0.875	0.517	-	0.263	0.582	0.278	0.331	0.391	-	0.259
2007.125	0.800	0.532	0.940	0.988	0.953	0.170	-	0.293	0.345	0.573	0.270	0.355	-	0.360
2007.375	0.423	0.013	0.580	0.747	0.566	0.373	-	0.339	0.006	0.392	0.267	0.267	-	0.364
2007.625	0.479	0.902	0.665	0.668	0.920	0.427	0.069	0.161	0.092	0.497	0.484	0.306	0.290	0.539
2007.875	1.147	0.671	0.744	0.782	0.646	0.739	-	0.376	0.215	0.505	0.685	0.266	-	0.445
2008.125	0.492	0.552	1.023	1.129	0.631	0.291	-	0.582	0.982	0.773	0.393	0.360	-	0.494
2008.375	0.487	-	0.752	0.807	0.544	0.667	-	0.436	-	0.542	0.299	0.222	-	0.327
2008.625	0.445	0.901	0.460	0.569	0.737	0.542	1.474	0.163	0.626	0.509	0.197	0.157	0.030	0.534
2008.875	0.896	0.753	0.973	1.357	0.704	0.371	-	0.391	0.494	0.629	0.208	0.274	-	0.451
2009.125	0.484	0.445	0.767	1.610	0.768	0.166	-	0.969	0.466	0.642	0.201	0.096	-	0.403
2009.375	0.526	-	0.422	0.870	0.633	0.370	-	0.253	-	0.409	0.180	0.063	-	0.442
2009.625	0.440	1.037	0.632	0.883	0.897	0.341	0.008	0.239	0.363	0.513	0.600	0.196	0.009	0.729
2009.875	1.451	1.133	0.708	0.959	0.672	0.311	-	0.188	0.287	0.447	0.357	0.128	-	0.292
2010.125	0.744	4.183	0.471	0.340	0.921	0.198	-	0.373	0.348	0.570	0.353	0.043	-	0.247
2010.375	0.442	-	0.413	0.412	0.574	0.284	-	0.736	-	0.675	0.167	0.166	-	0.358
2010.625	0.238	-	0.446	0.403	0.490	0.366	0.001	0.318	-	0.338	0.469	0.225	0.002	0.238
2010.875	1.256	-	0.803	0.955	-	-	-	0.262	-	0.897	-	-	-	1.007

7. Figures



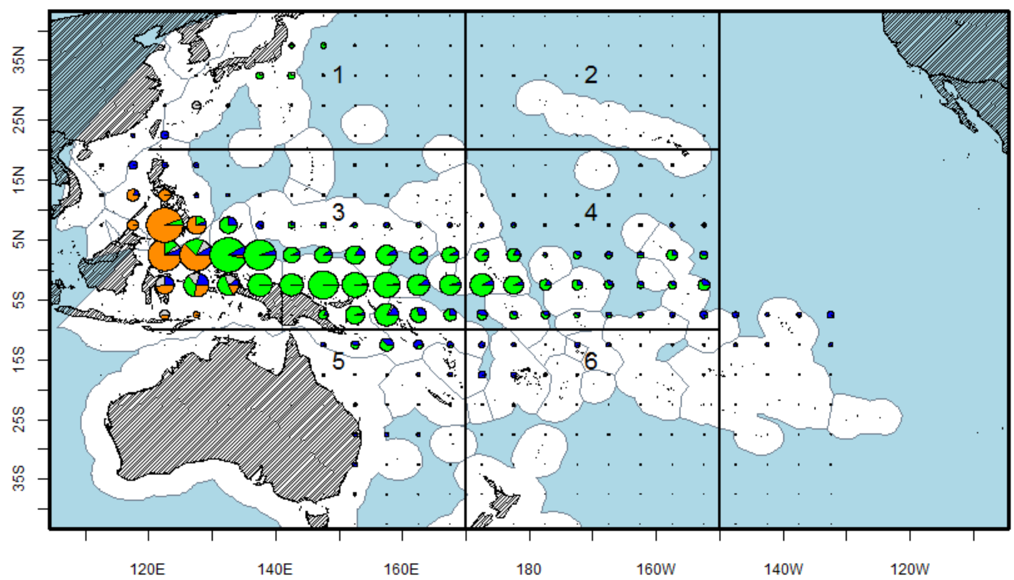


Figure 1: Maps showing the regions defined for bigeye (top) and yellowfin (bottom), along with the distribution of catch by fishing method (purse seine – green, longline –blue, pole and line – grey, and other – orange). The relationship between circle size and catch is different for each species.

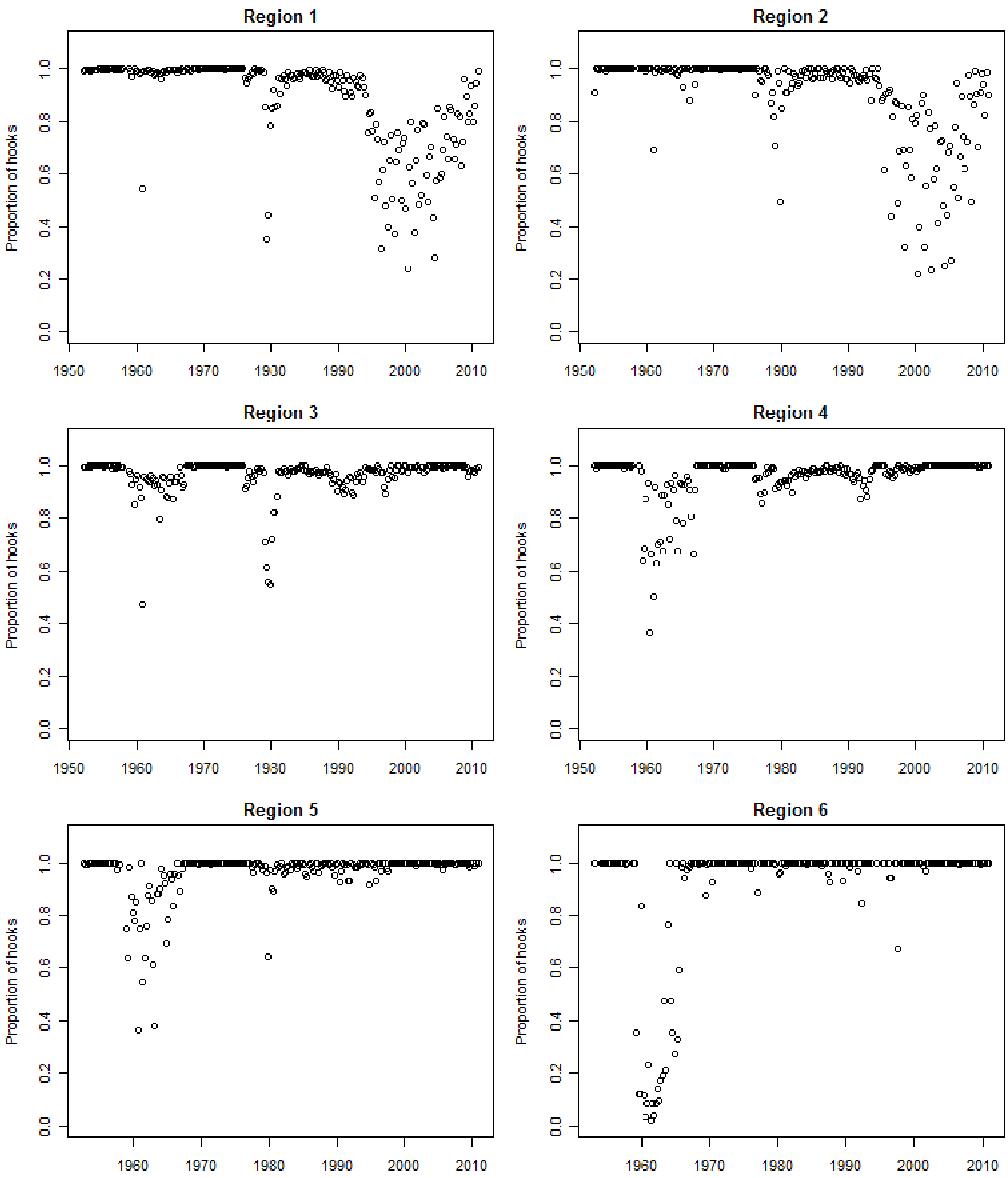


Figure 2: Proportion of effort remaining after data cleaning.

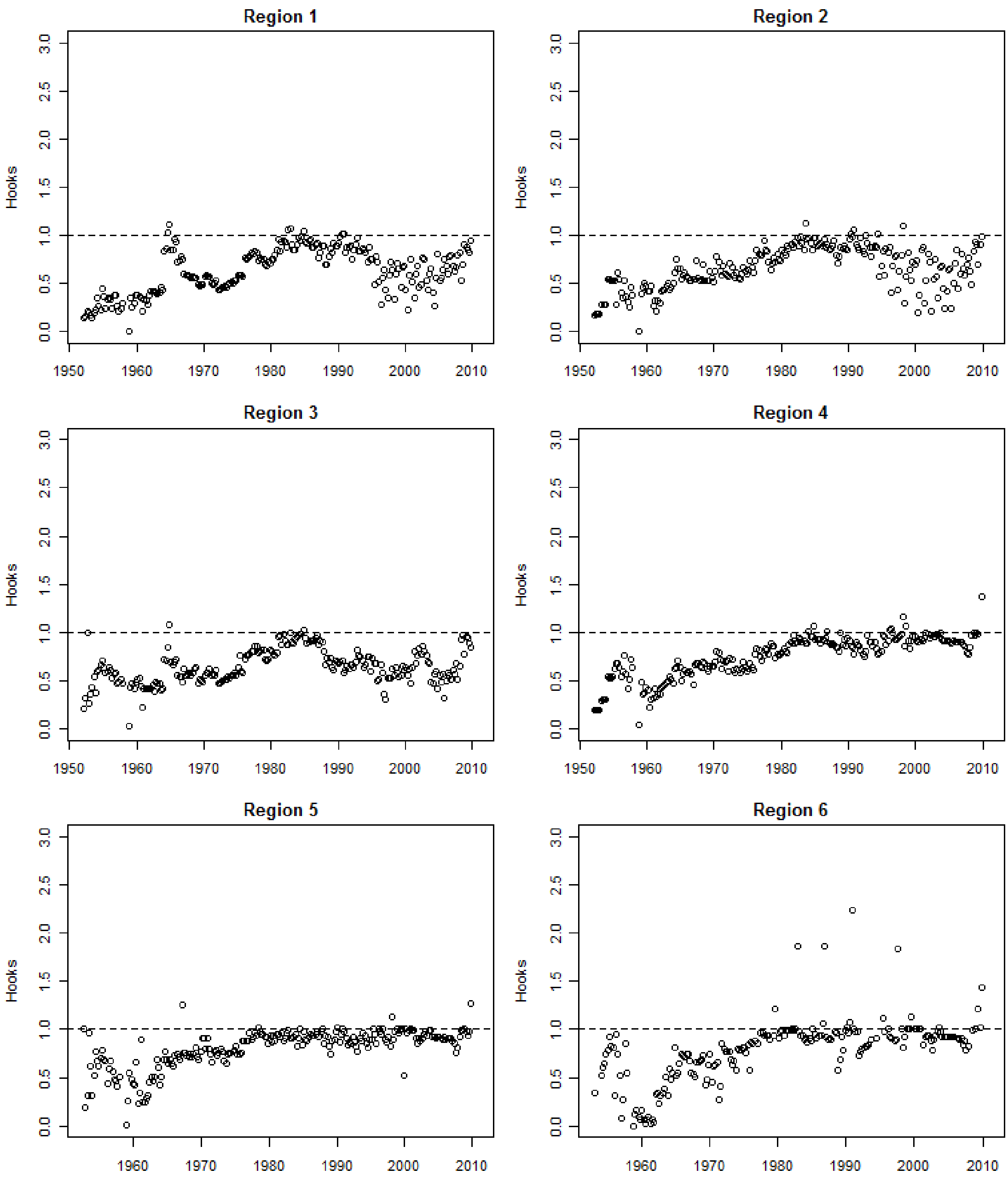


Figure 3: Effort coverage by region and yrqtr.

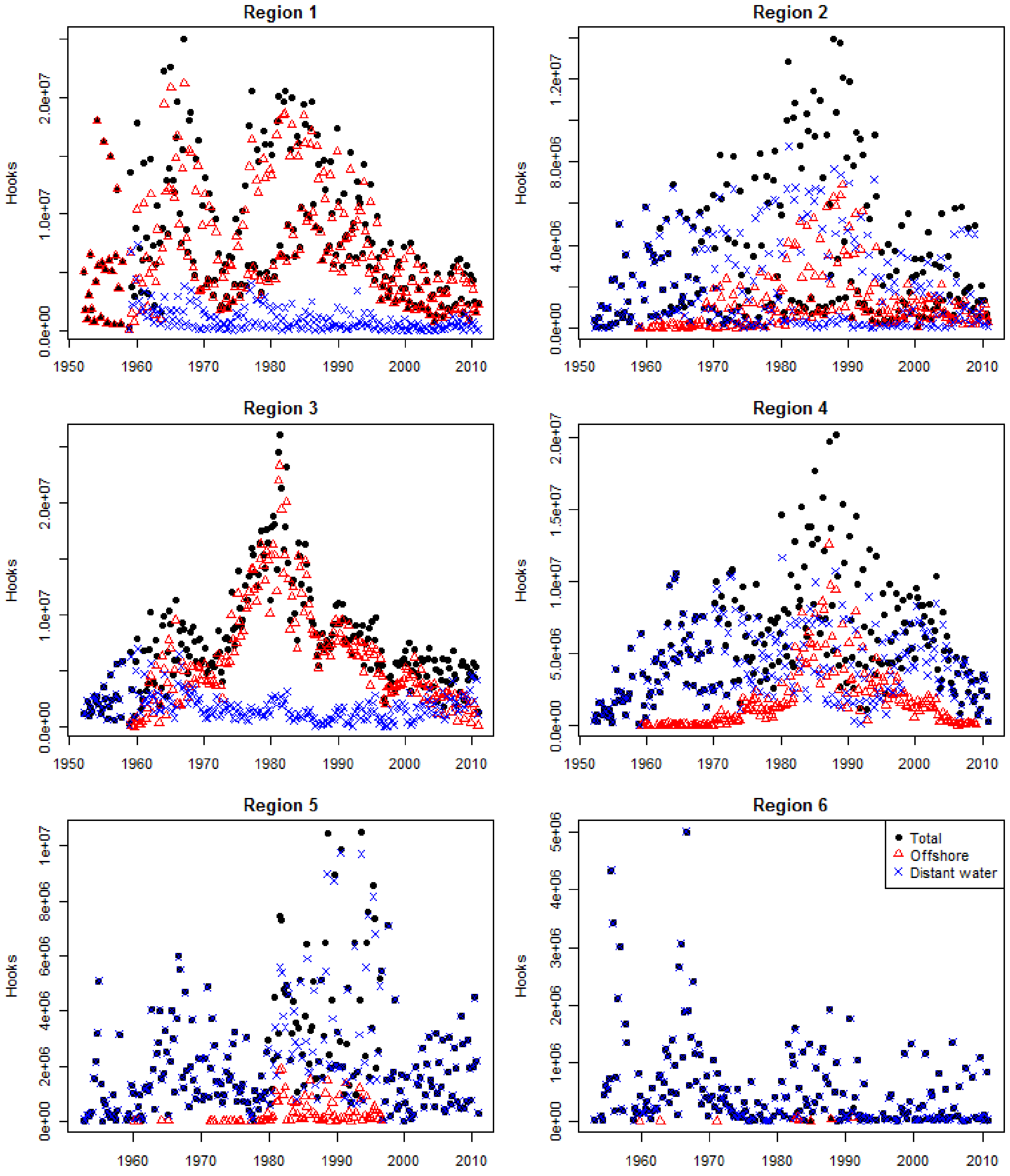


Figure 4: Effort by region, fleet, and year-quarter by the Japanese longline fleet, both distant water and offshore, as recorded in the operational dataset.

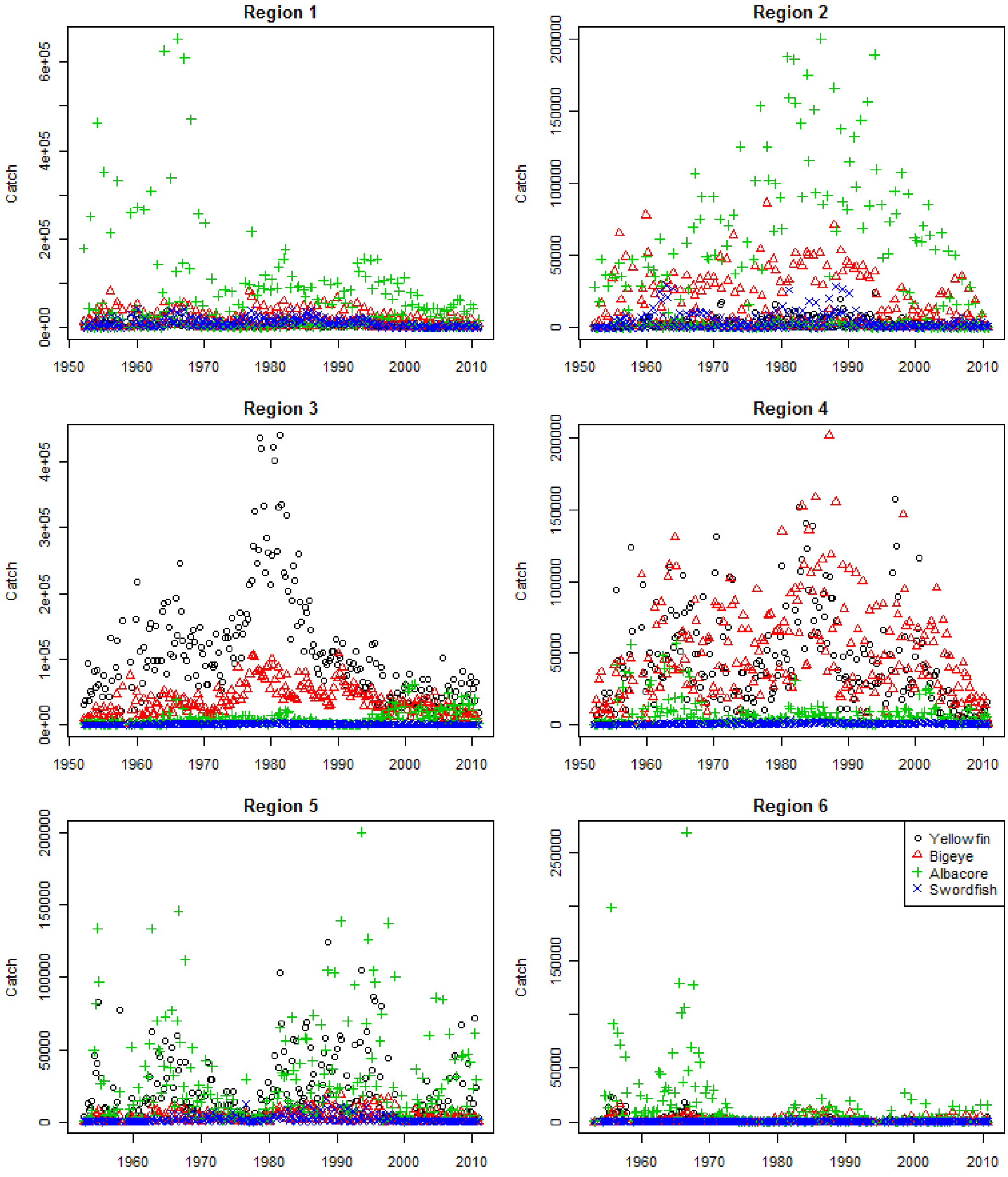


Figure 5: Catch of bigeye, yellowfin, and albacore tuna, and swordfish by region and year-quarter, by the Japanese longline fleet, as recorded in the operational dataset.

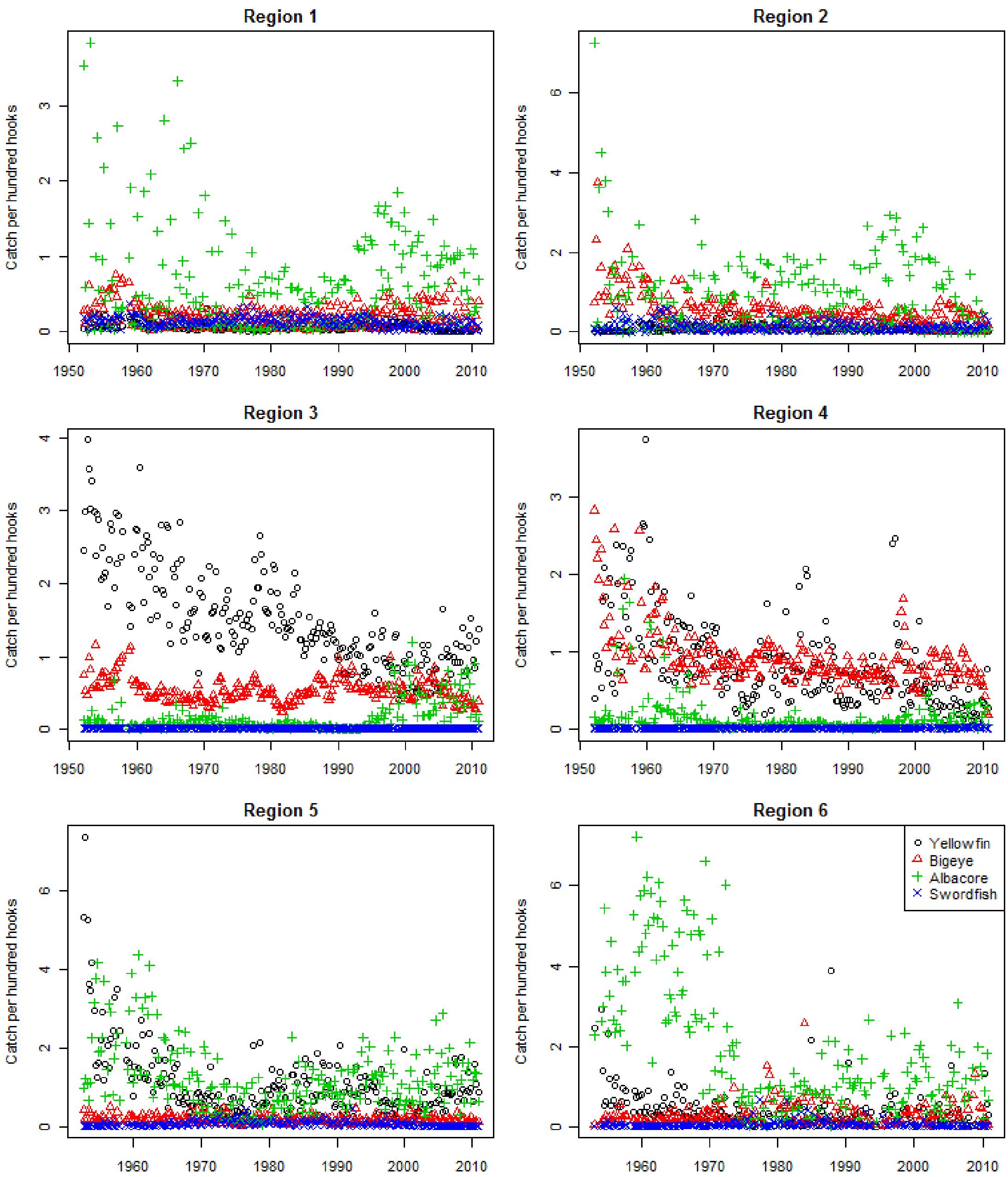


Figure 6: Nominal catch per unit of effort of bigeye, yellowfin, and albacore tuna, and swordfish, by region and year-quarter, by the Japanese longline fleet.

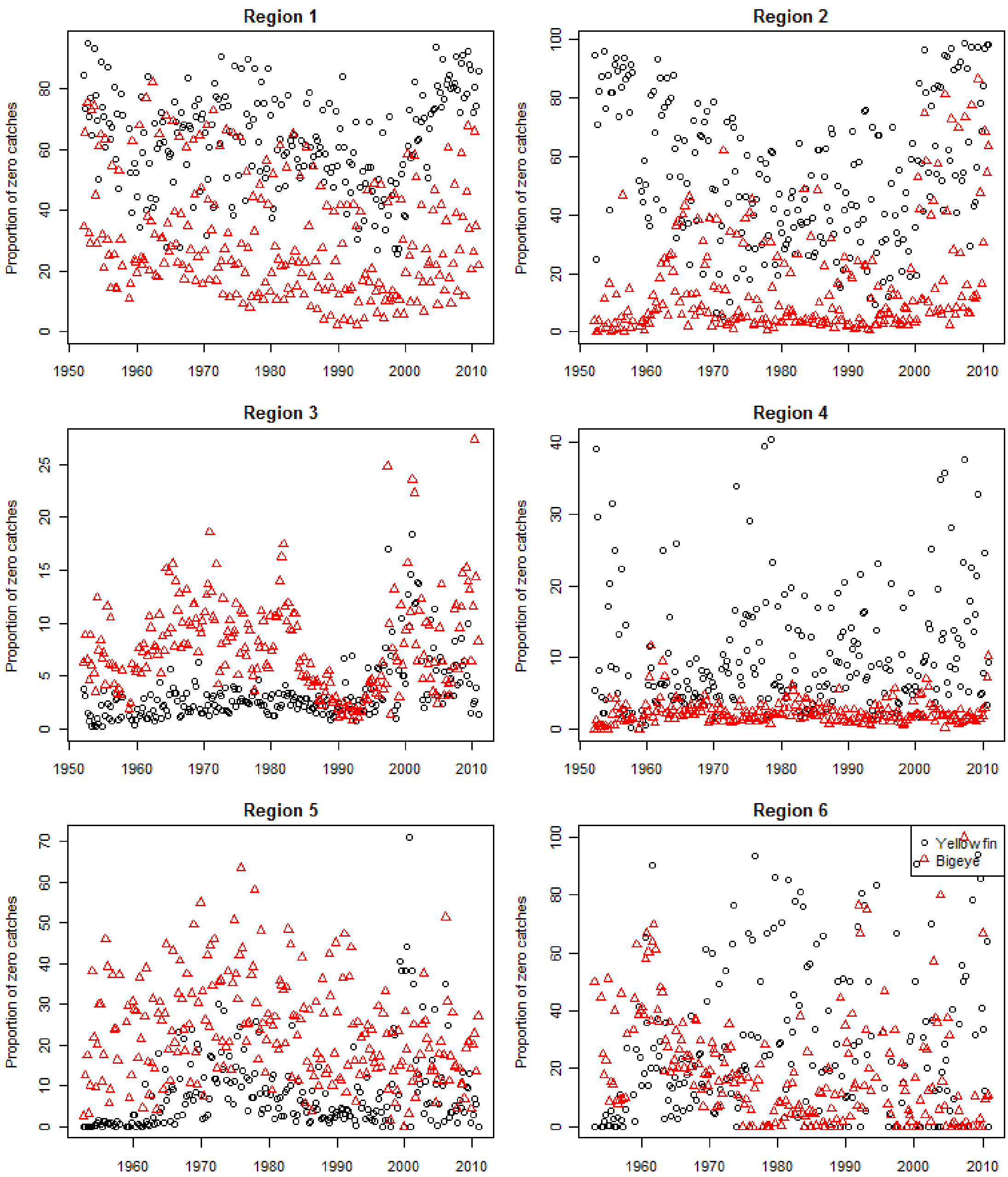


Figure 7: Proportion of reported sets that record zero catch of bigeye and/or yellowfin by year.

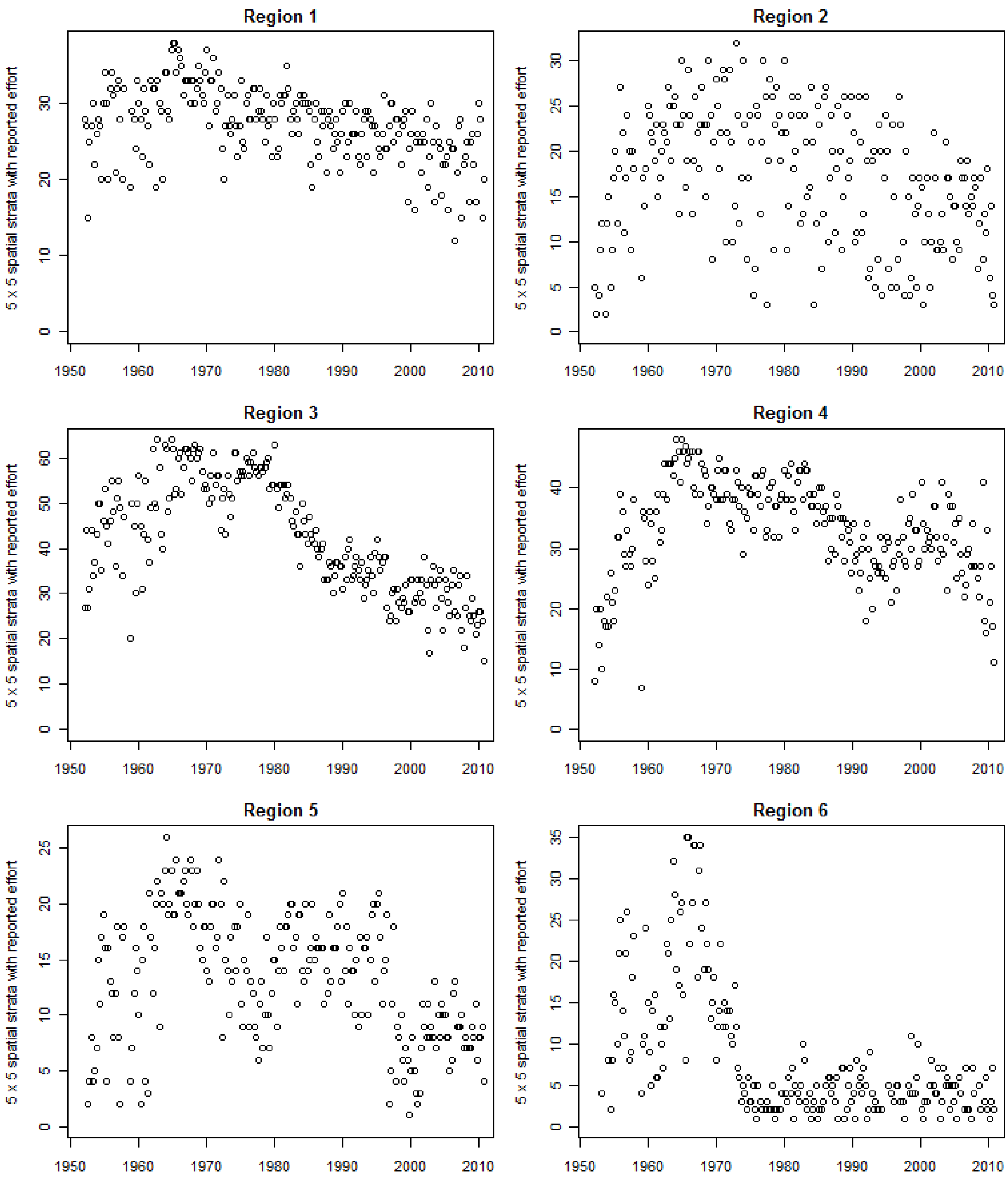


Figure 8: The number of 5° x 5°spatial strata in which effort is reported, by region and year-quarter, for the Japanese longline fleet.

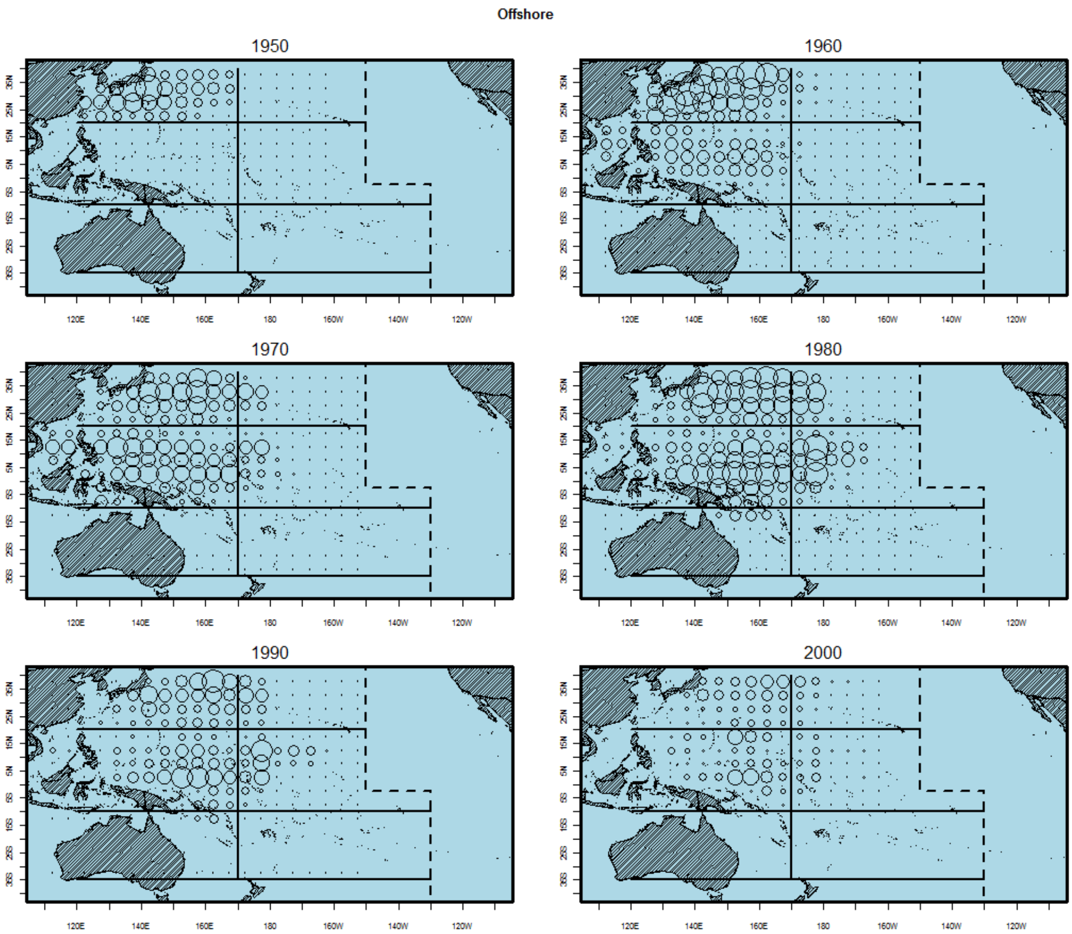


Figure 9: Maps for offshore number of sets by decade (e.g. 1950-1959). Circle areas are proportional to the number of sets.

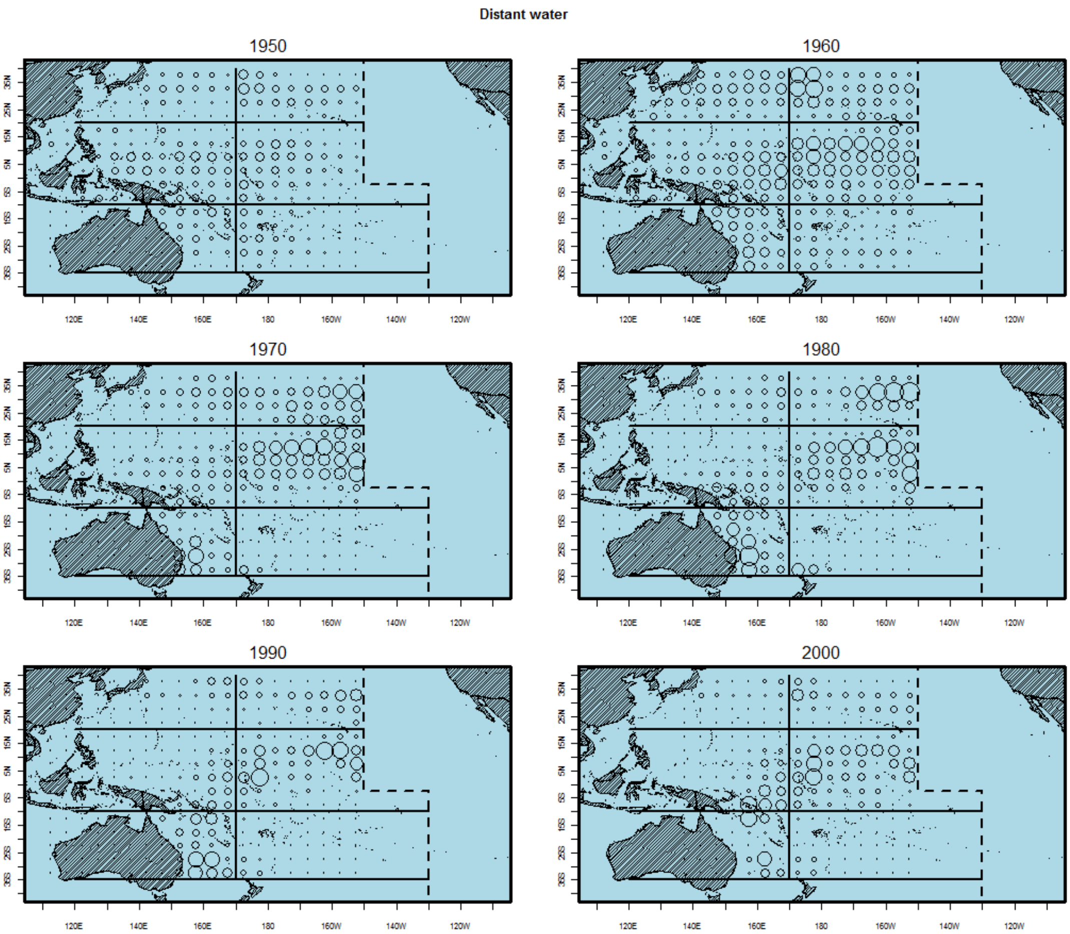


Figure 10: Maps for distant water vessels of number of sets by decade (e.g. 1950-1959). Circle areas are proportional to the number of sets.

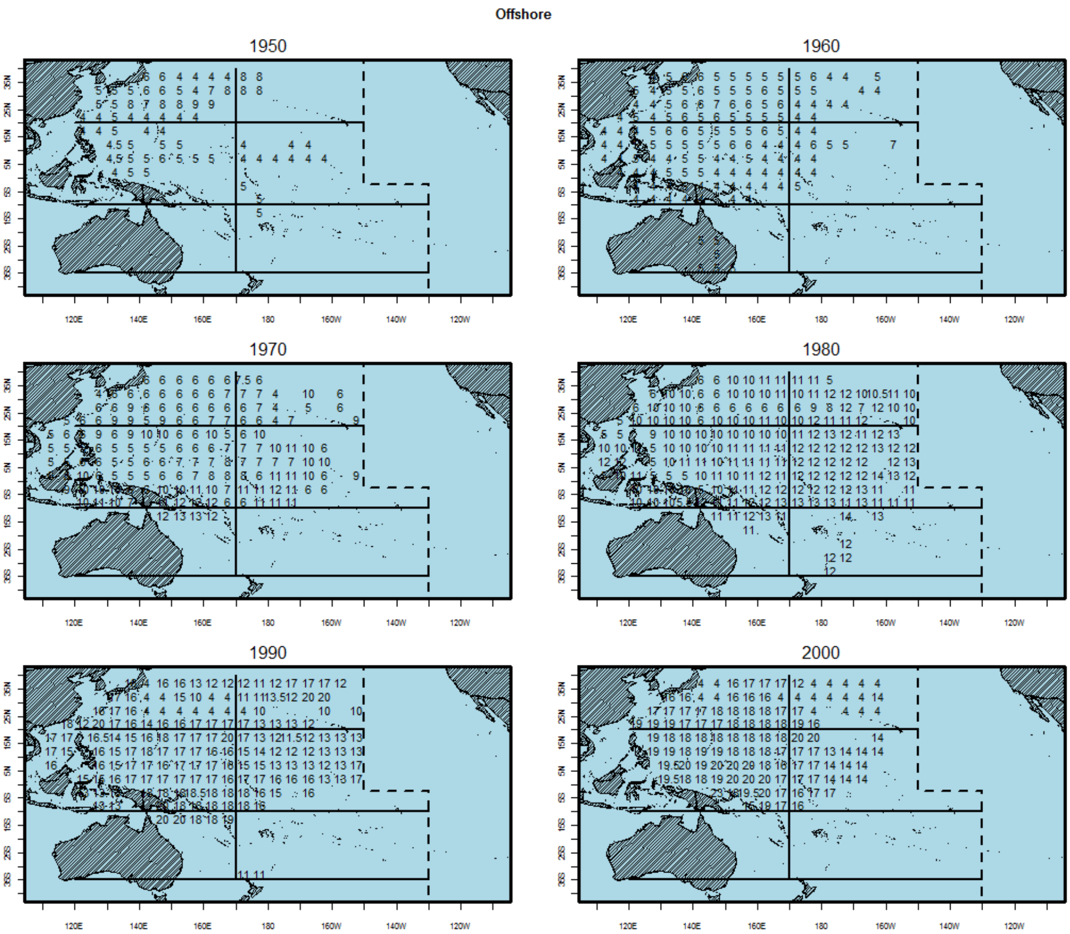


Figure 11: Median HBF for offshore vessels by 5 degree square by decade (e.g. 1950-1959). Circle areas are proportional to the number of sets.

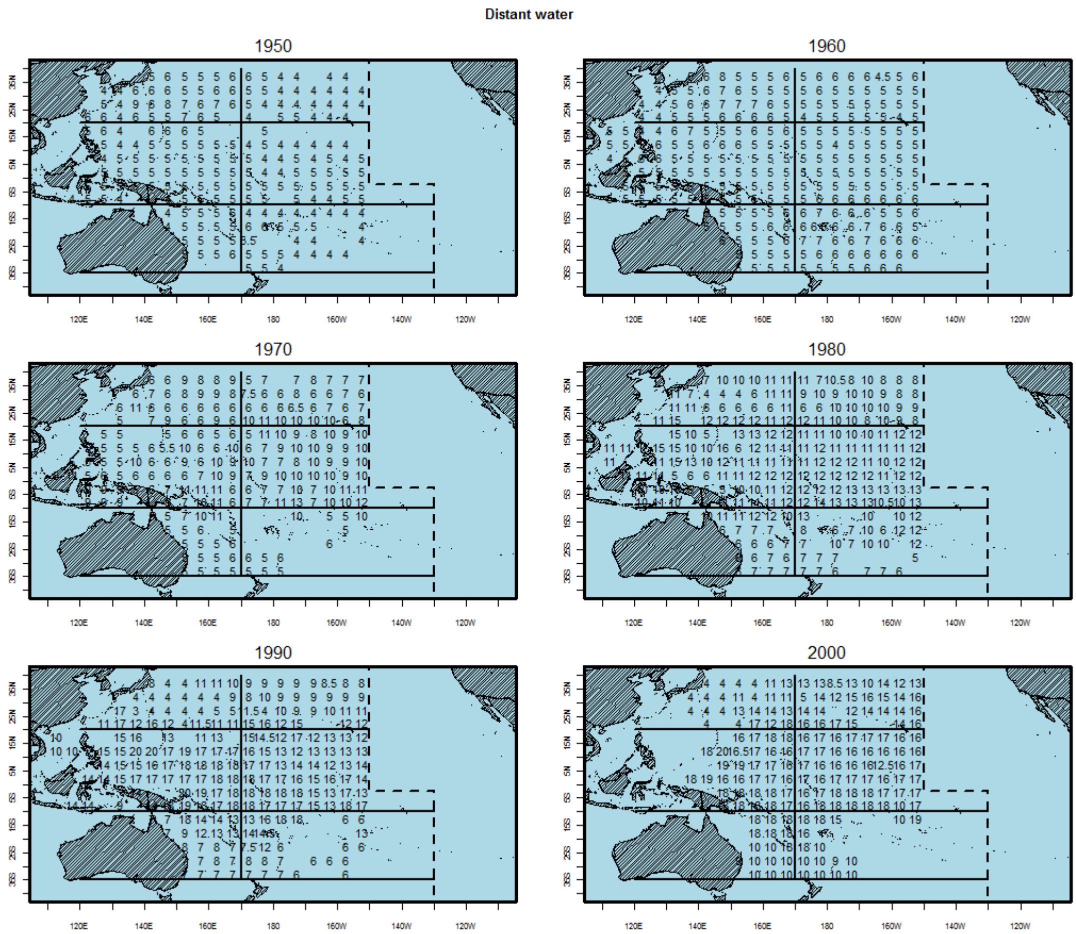


Figure 12: Median HBF for distant water vessels by 5 degree square by decade (e.g. 1950-1959). Circle areas are proportional to the number of sets.

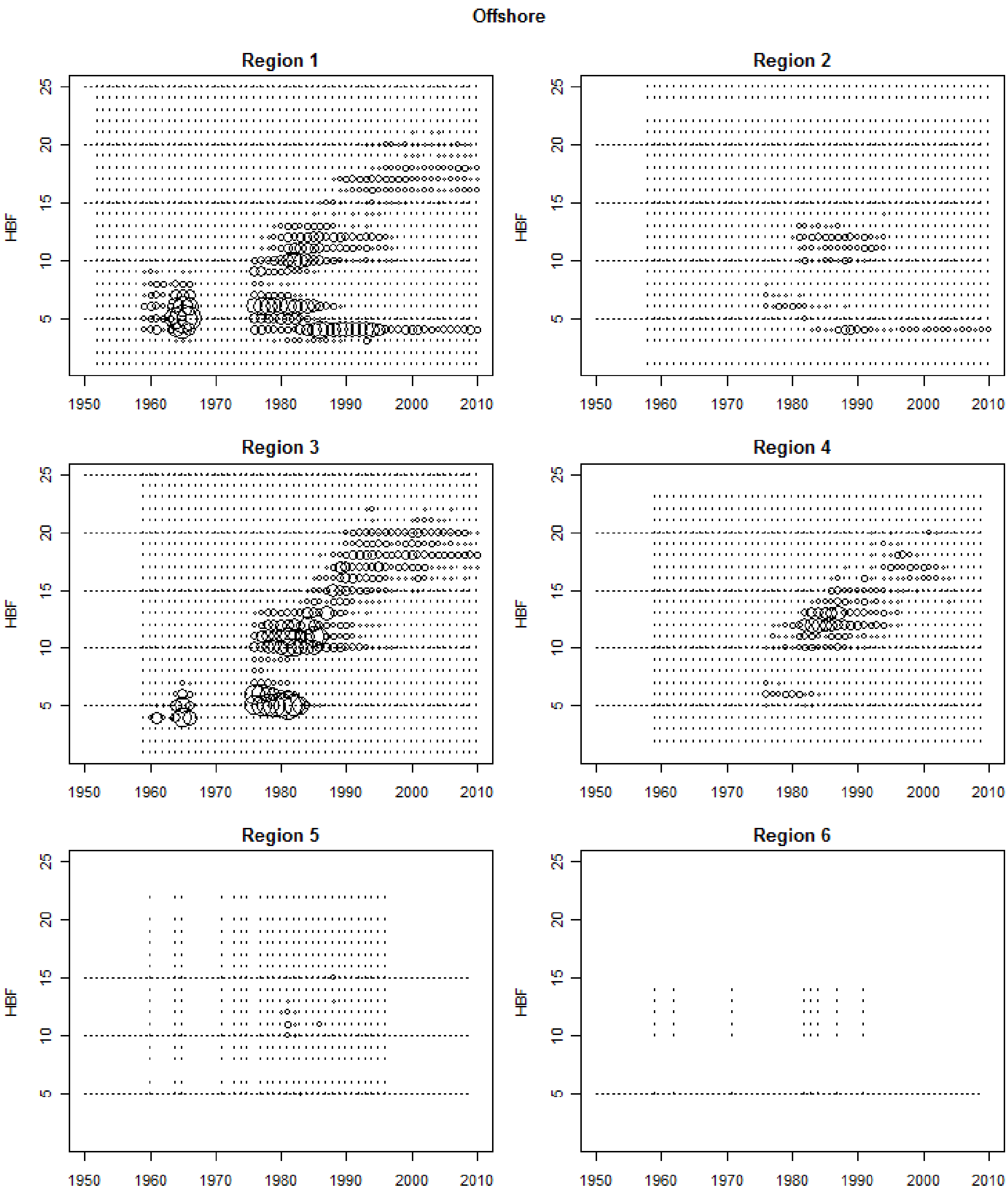


Figure 13: HBF by region by year for offshore vessels. Circle area is proportional to the number of sets.

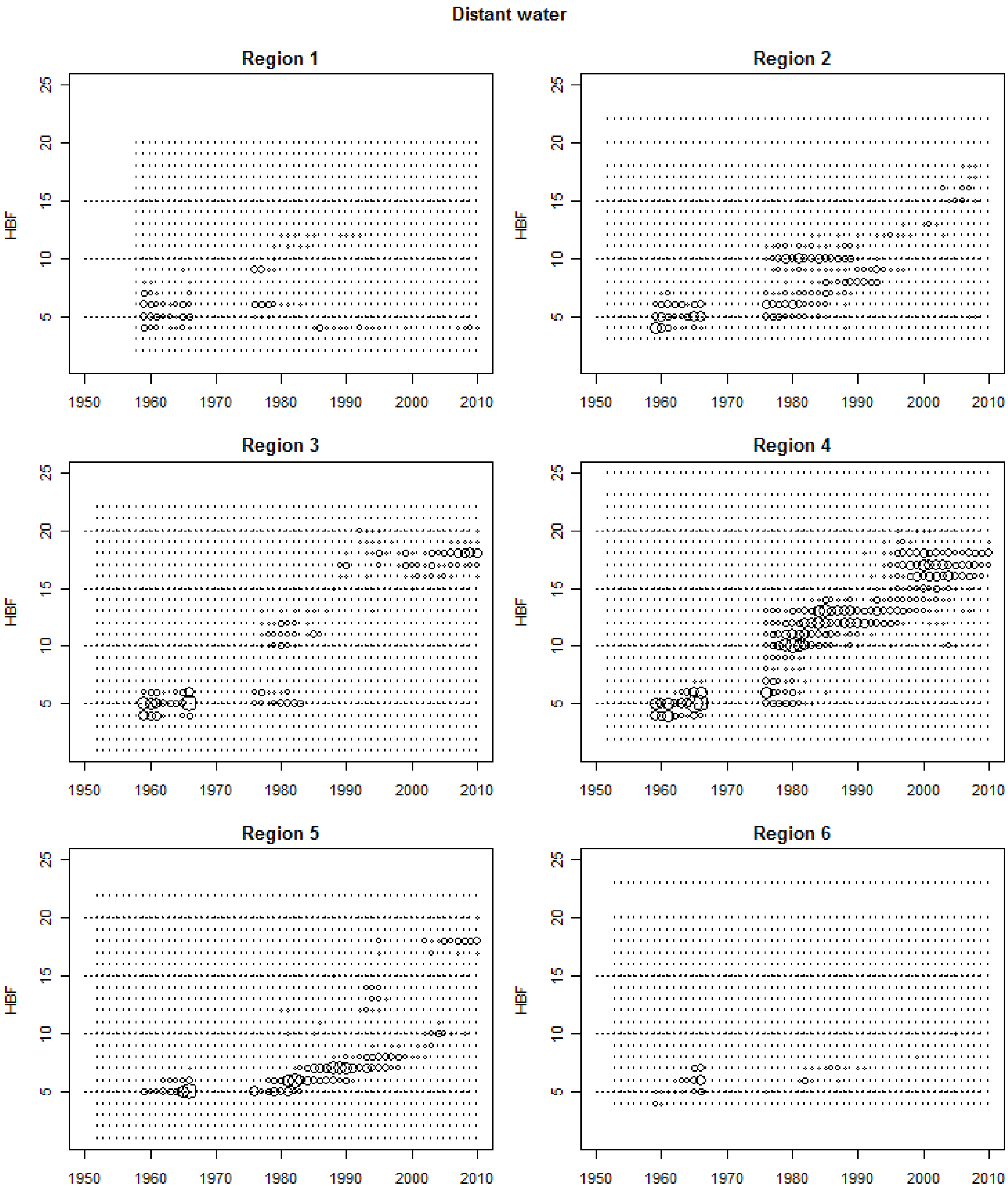


Figure 14: HBF by region by year for distant water vessels. Circle area is proportional to the number of sets.

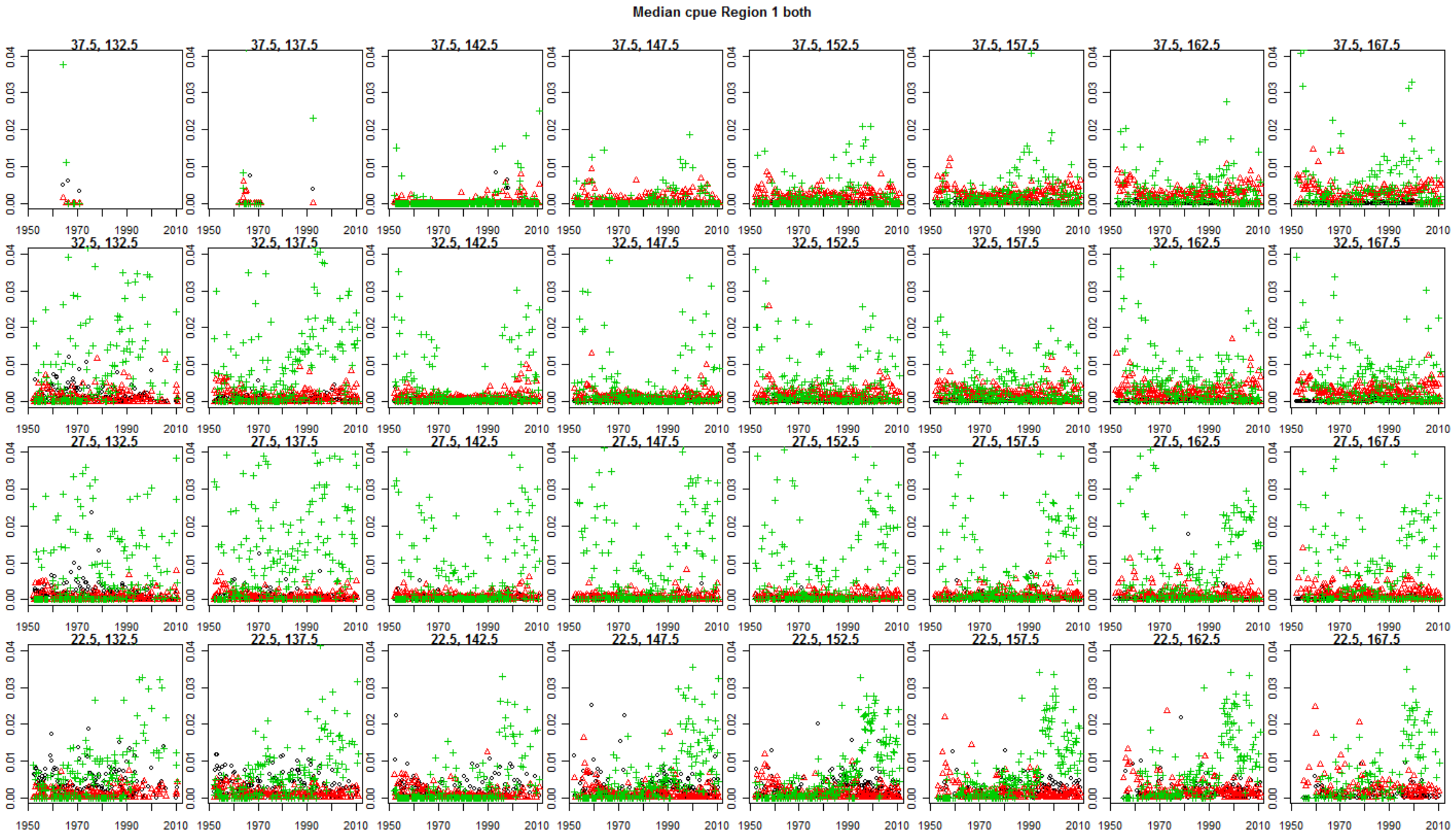


Figure 15: Median CPUE by 5 degree square in Region 1. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore. \

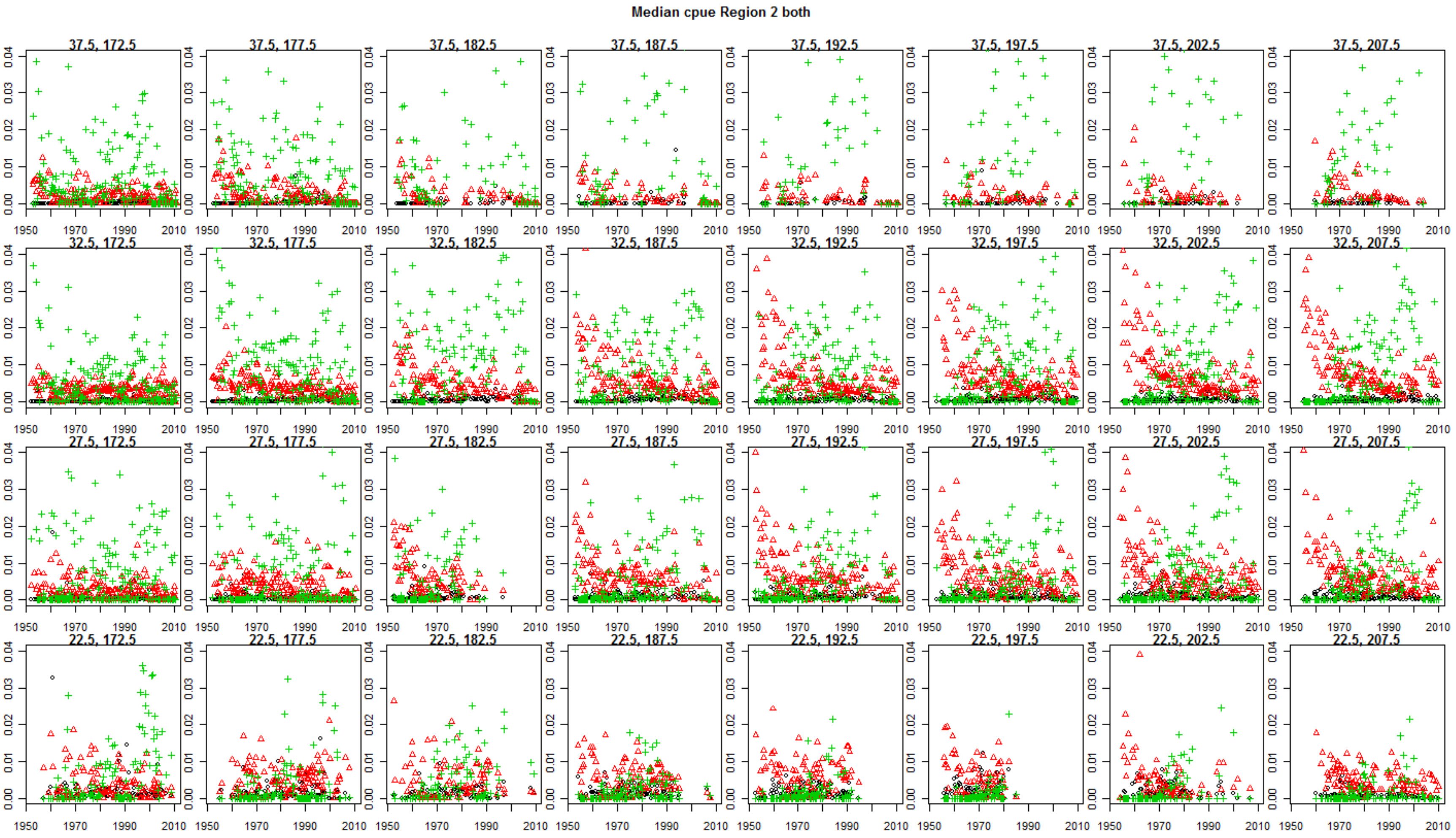


Figure 16: Median CPUE by 5 degree square in Region 2. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

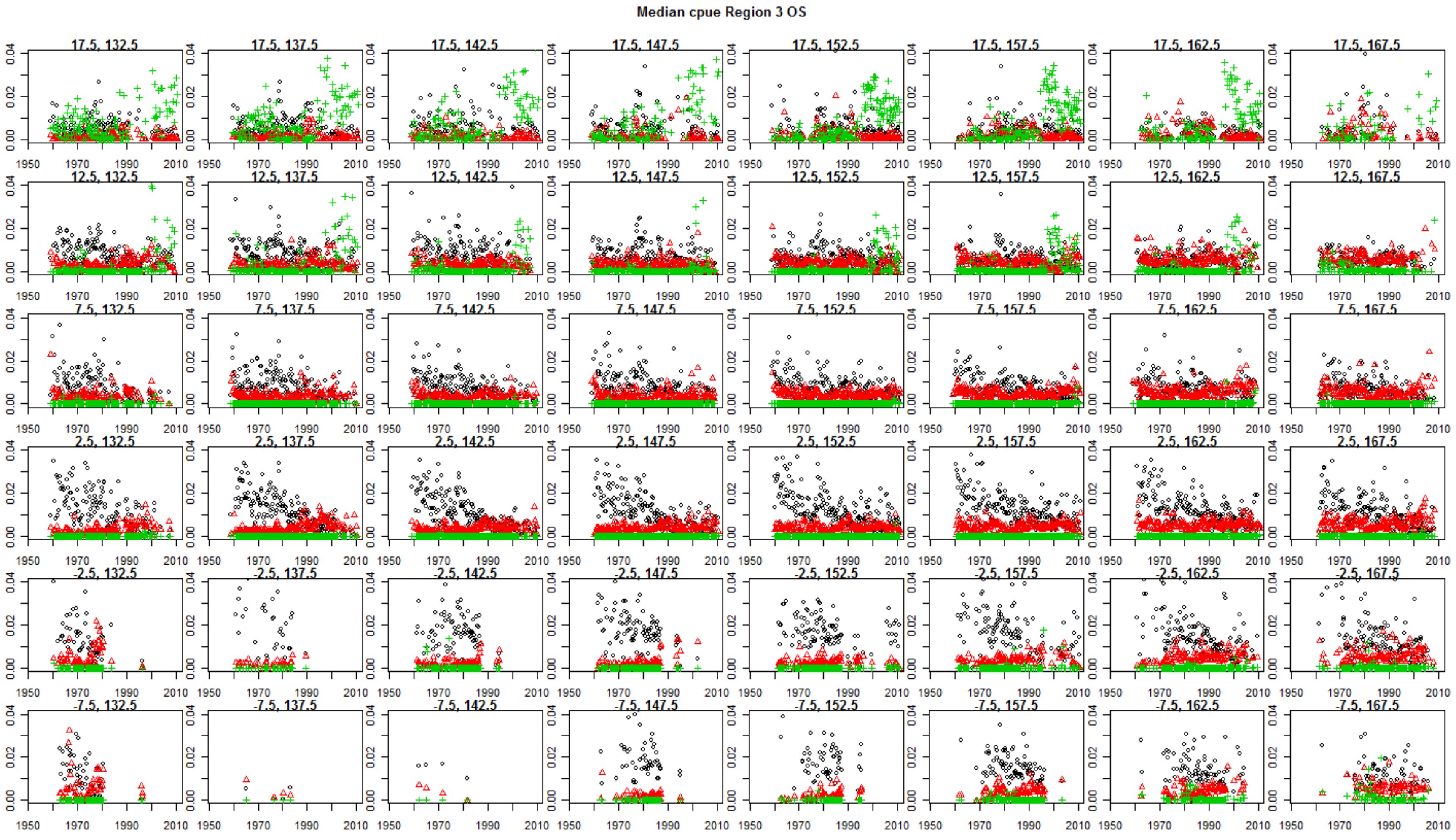


Figure 17: Median OS CPUE by 5 degree square in Region 3. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

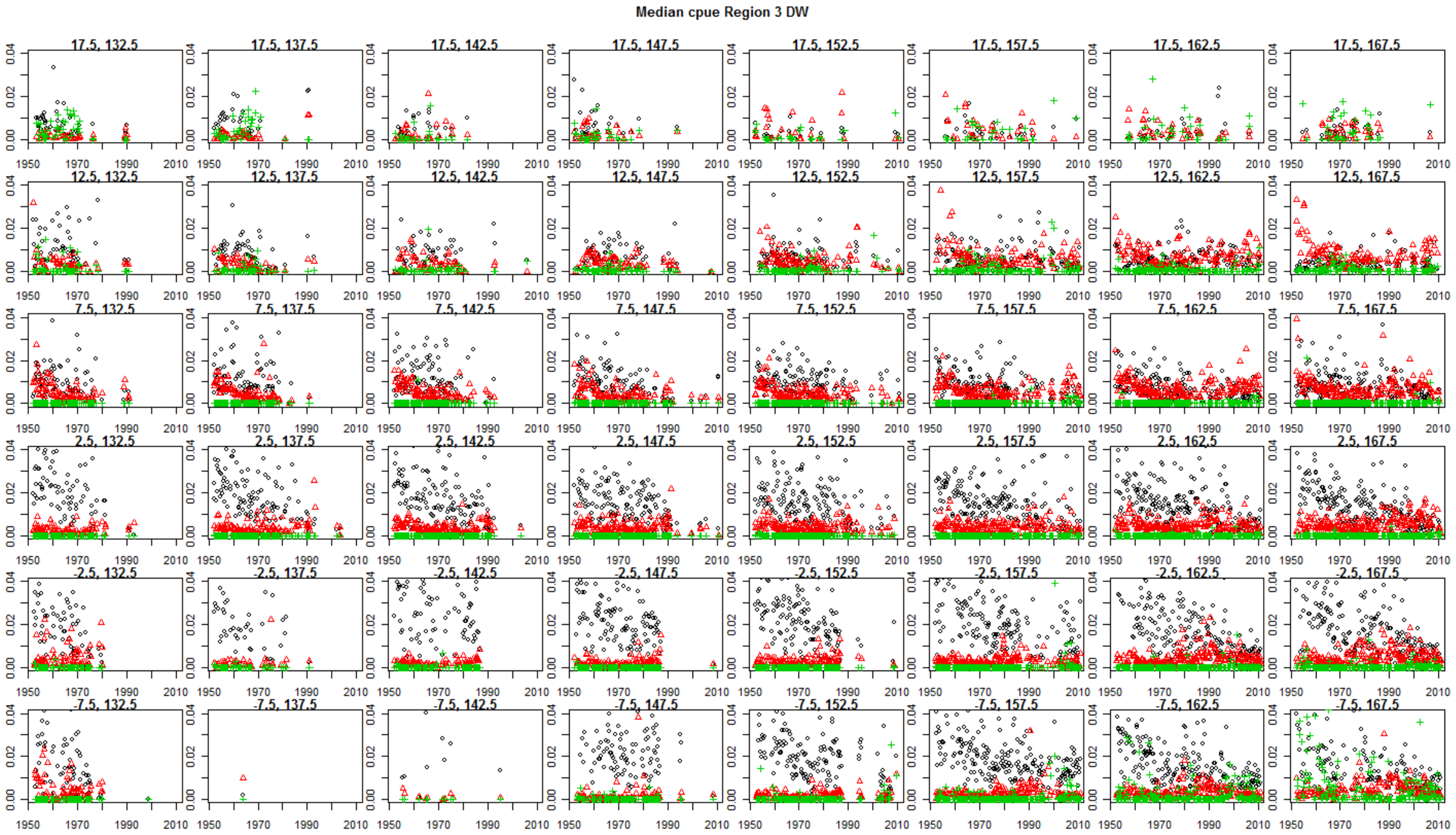


Figure 18: Median DW CPUE by 5 degree square in Region 3. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

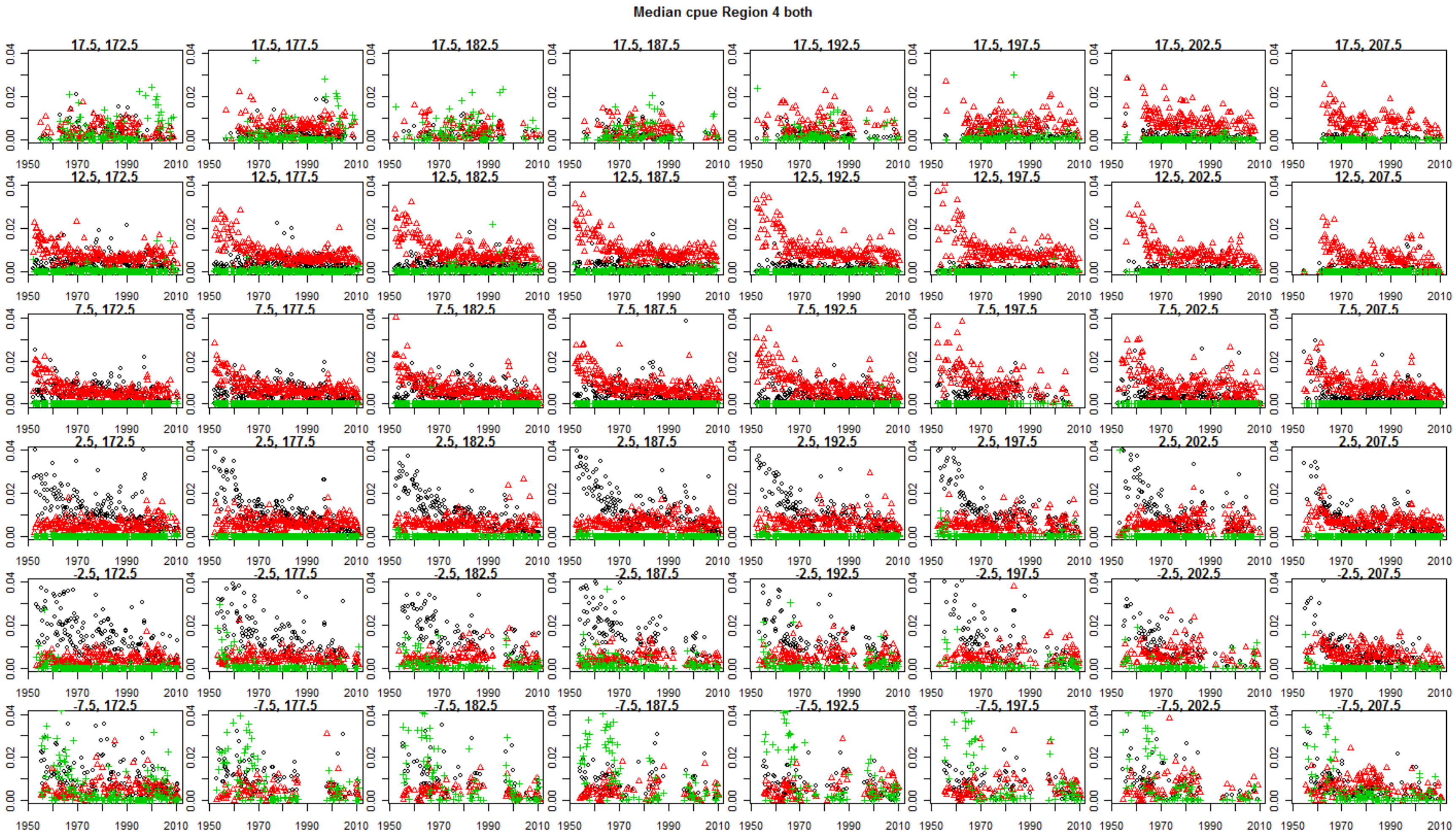


Figure 19: Median CPUE by 5 degree square in Region 4. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

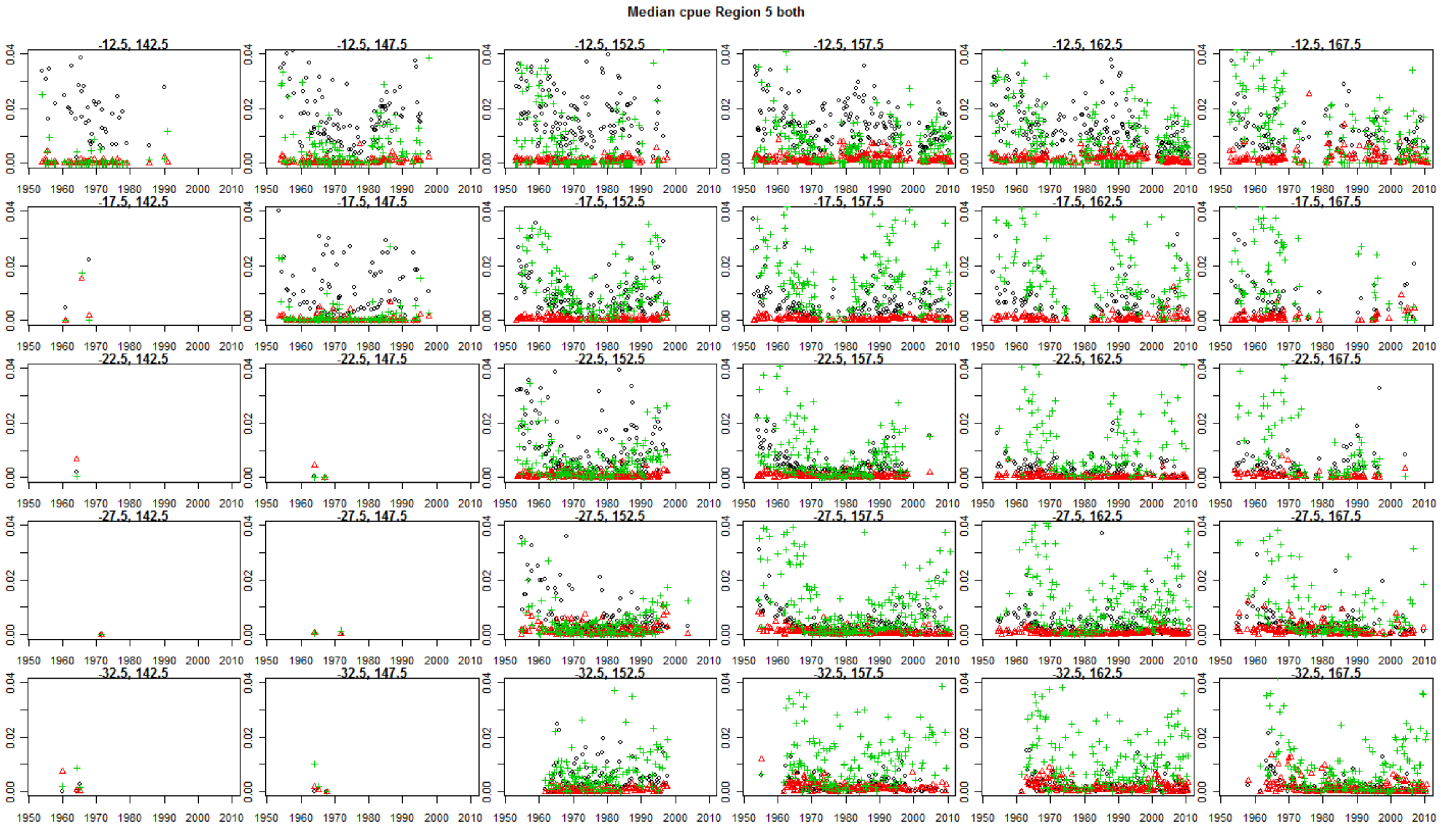


Figure 20: Median CPUE by 5 degree square in Region 5. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

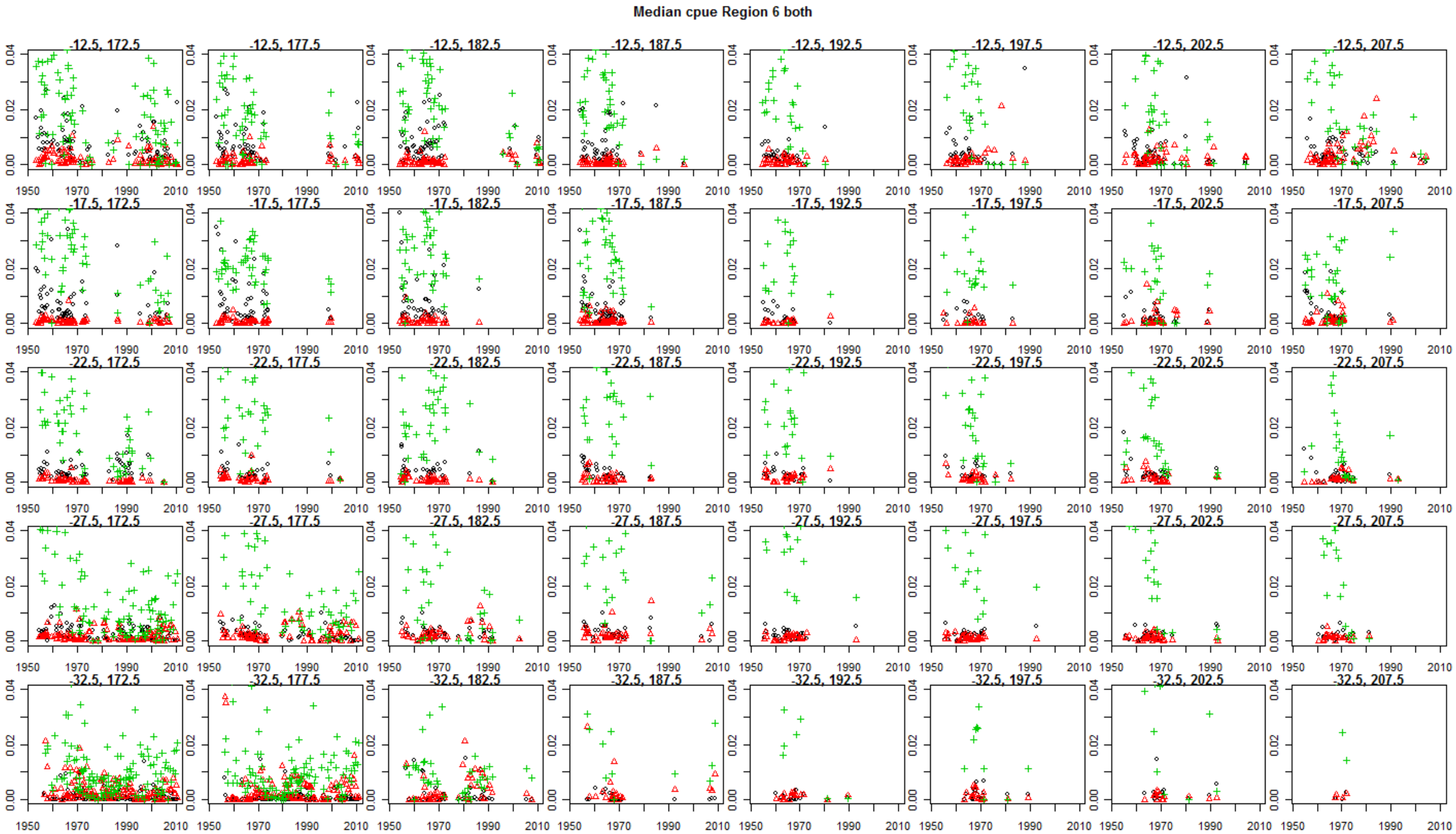


Figure 21: Median CPUE by 5 degree square in Region 6. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

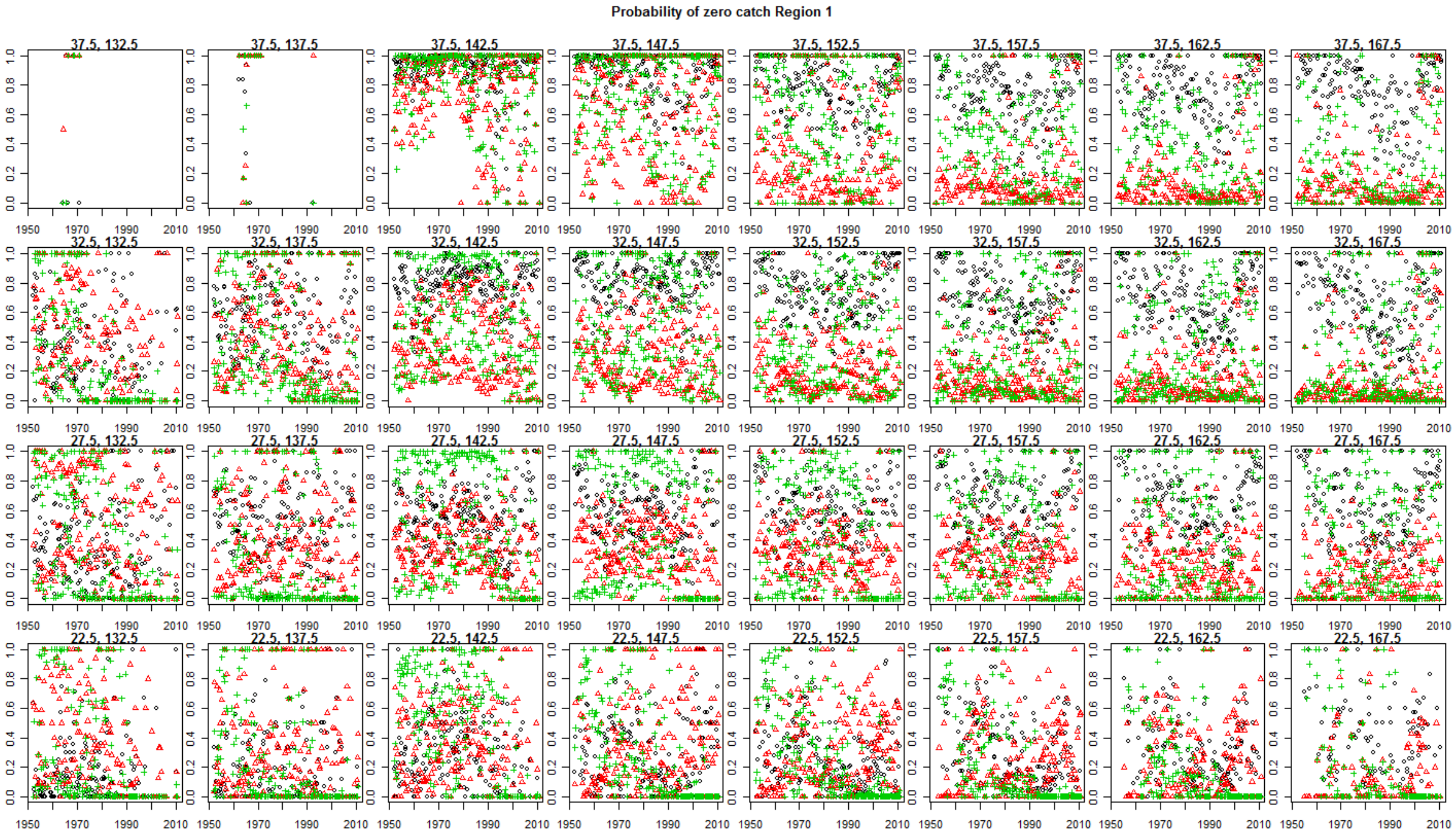


Figure 22: Proportion of zero catch in sets by quarter and 5 degree square in Region 1. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

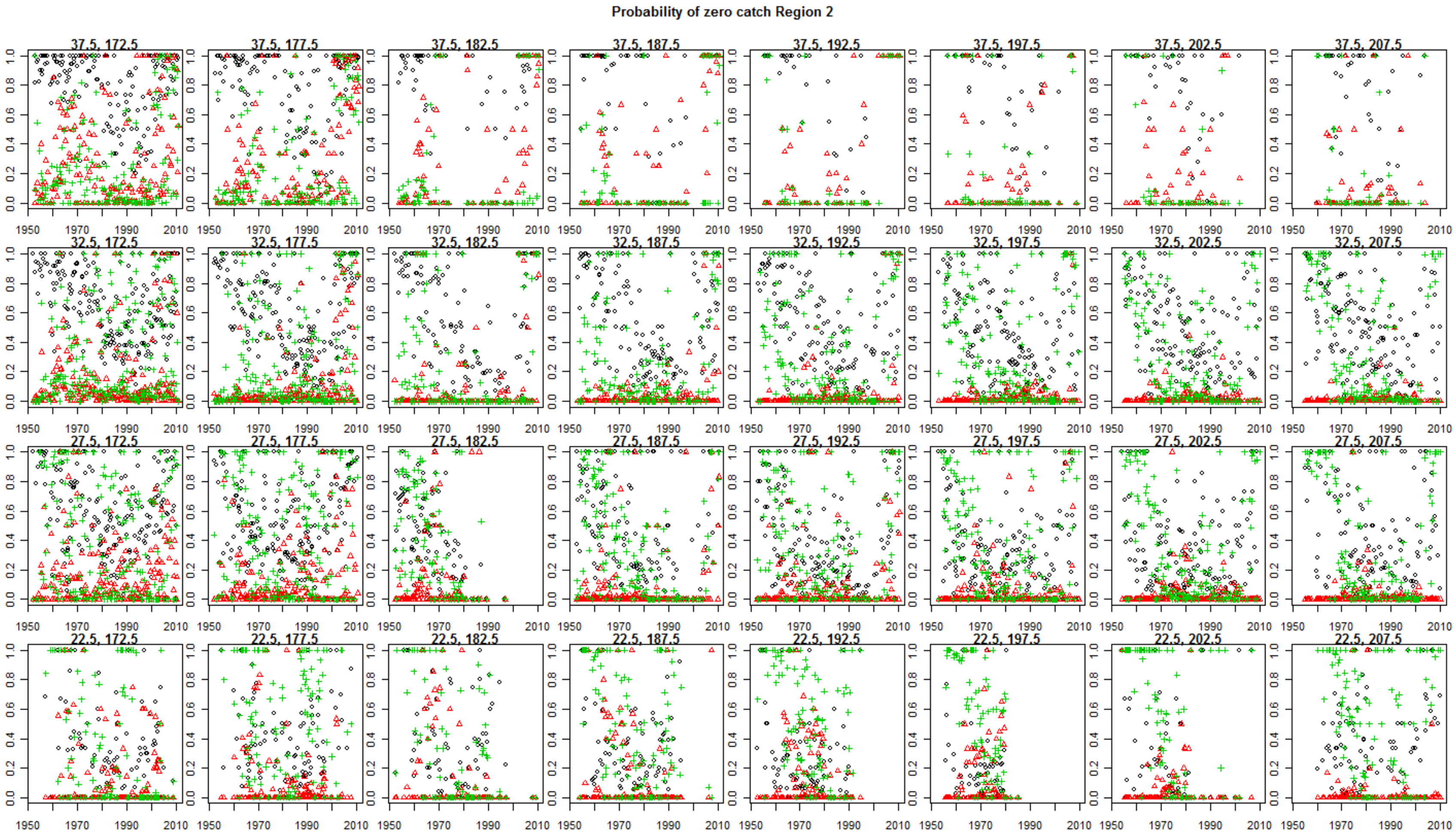


Figure 23: Proportion of zero catch in sets by quarter and 5 degree square in Region 2. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

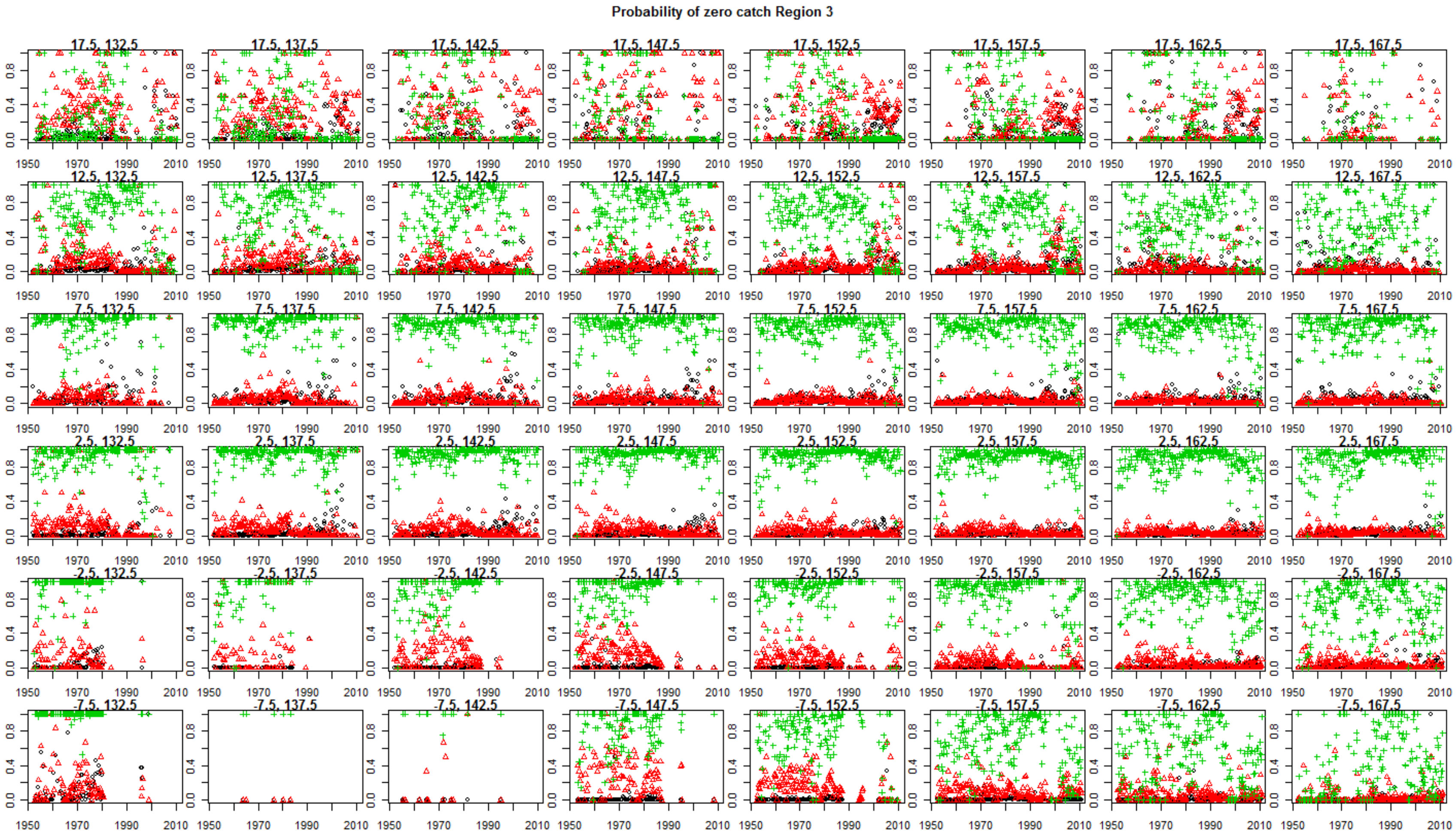


Figure 24: Proportion of zero catch in sets by quarter and 5 degree square in Region 3. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

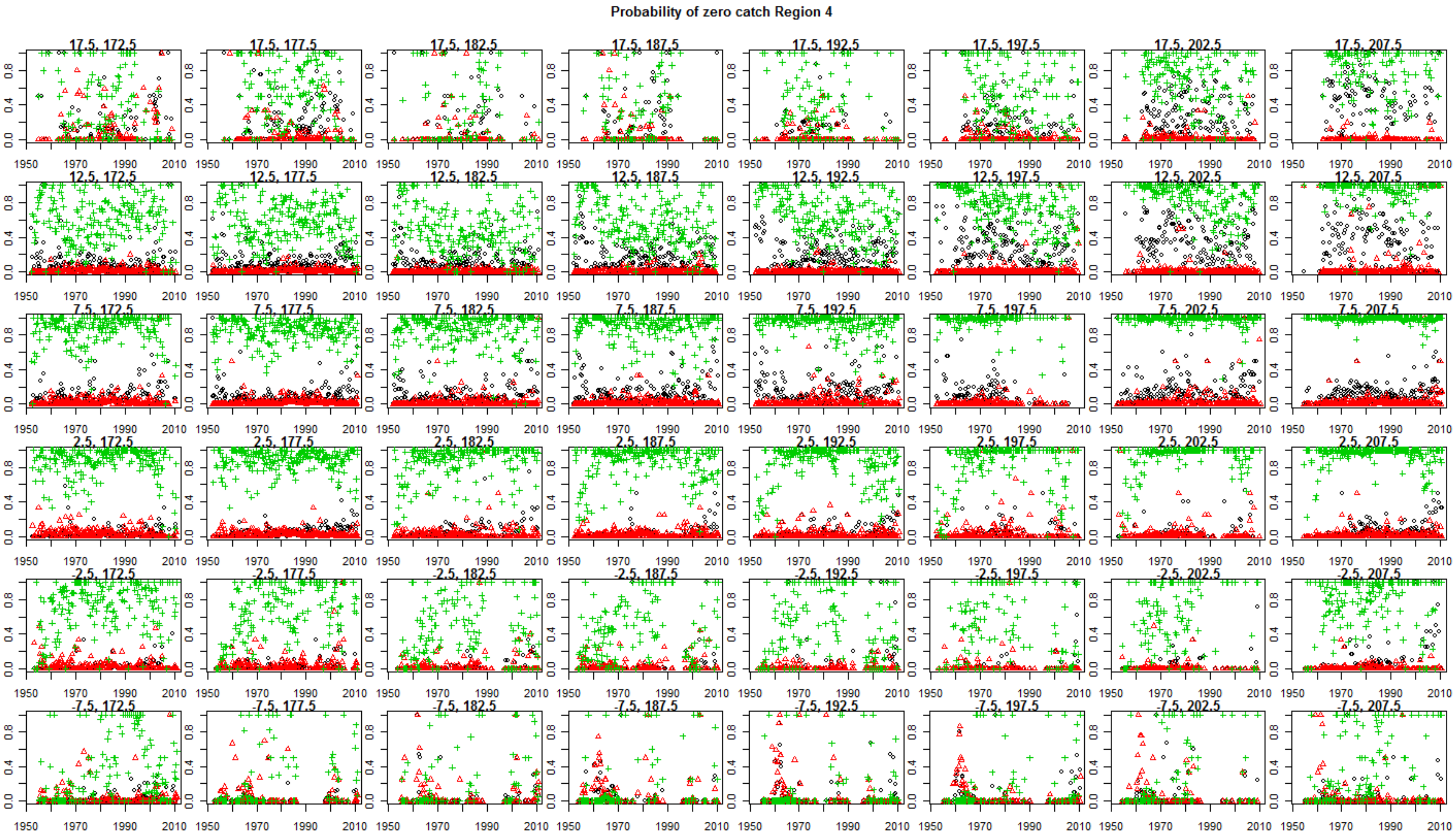


Figure 25: Proportion of zero catch in sets by quarter and 5 degree square in Region 4. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

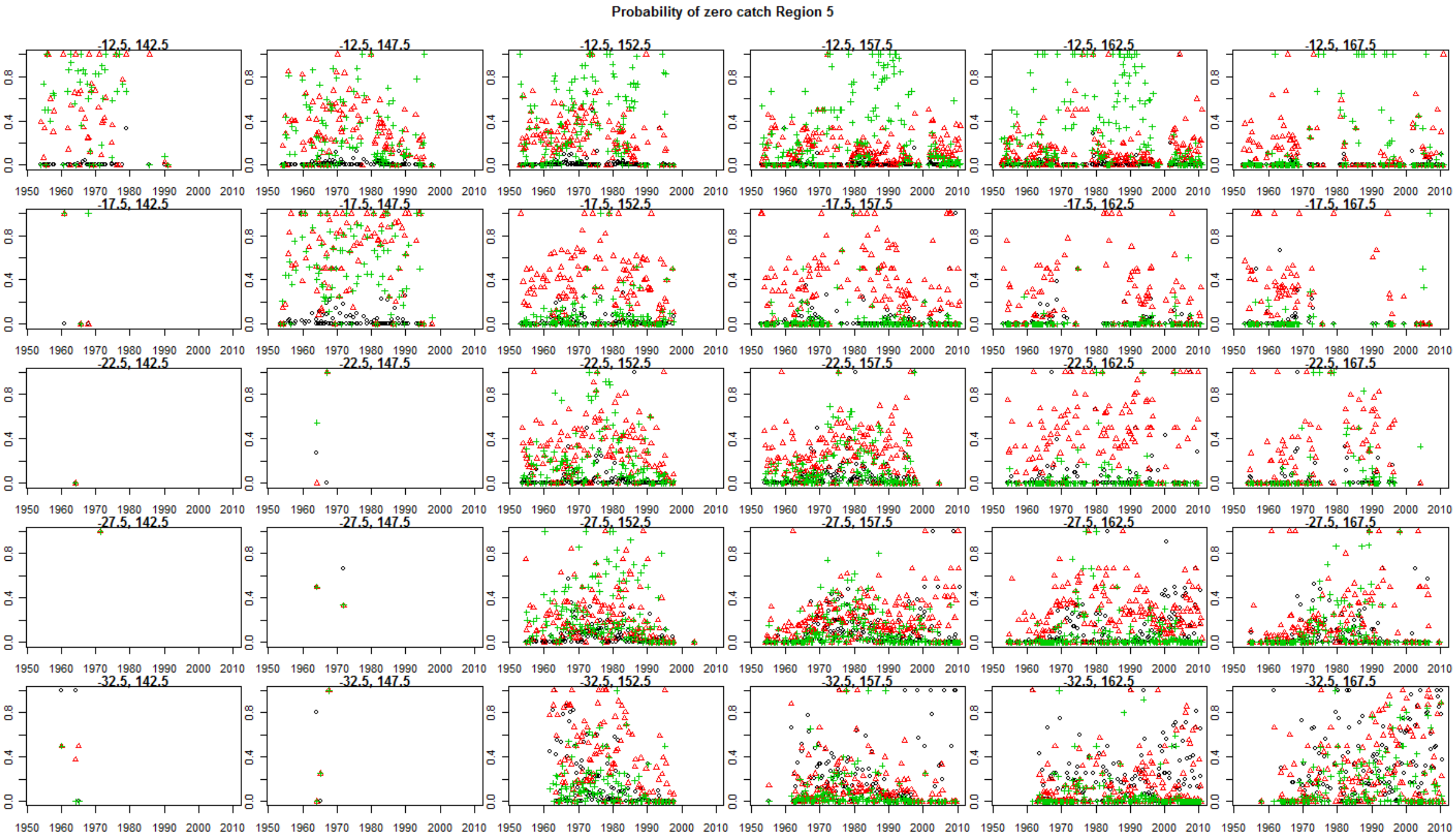


Figure 26: Proportion of zero catch in sets by quarter and 5 degree square in Region 5. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

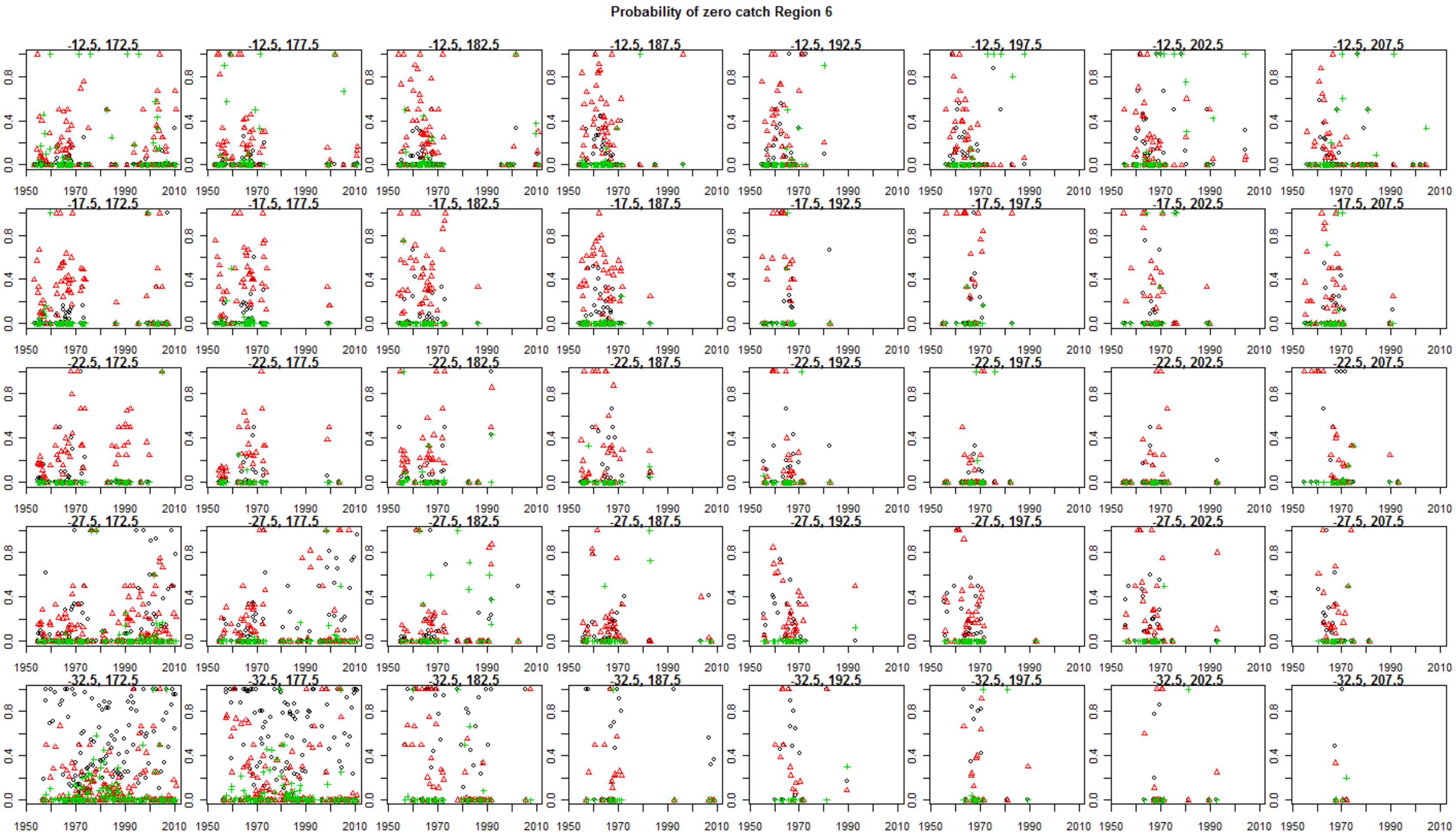


Figure 27: Proportion of zero catch in sets by quarter and 5 degree square in Region 6. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

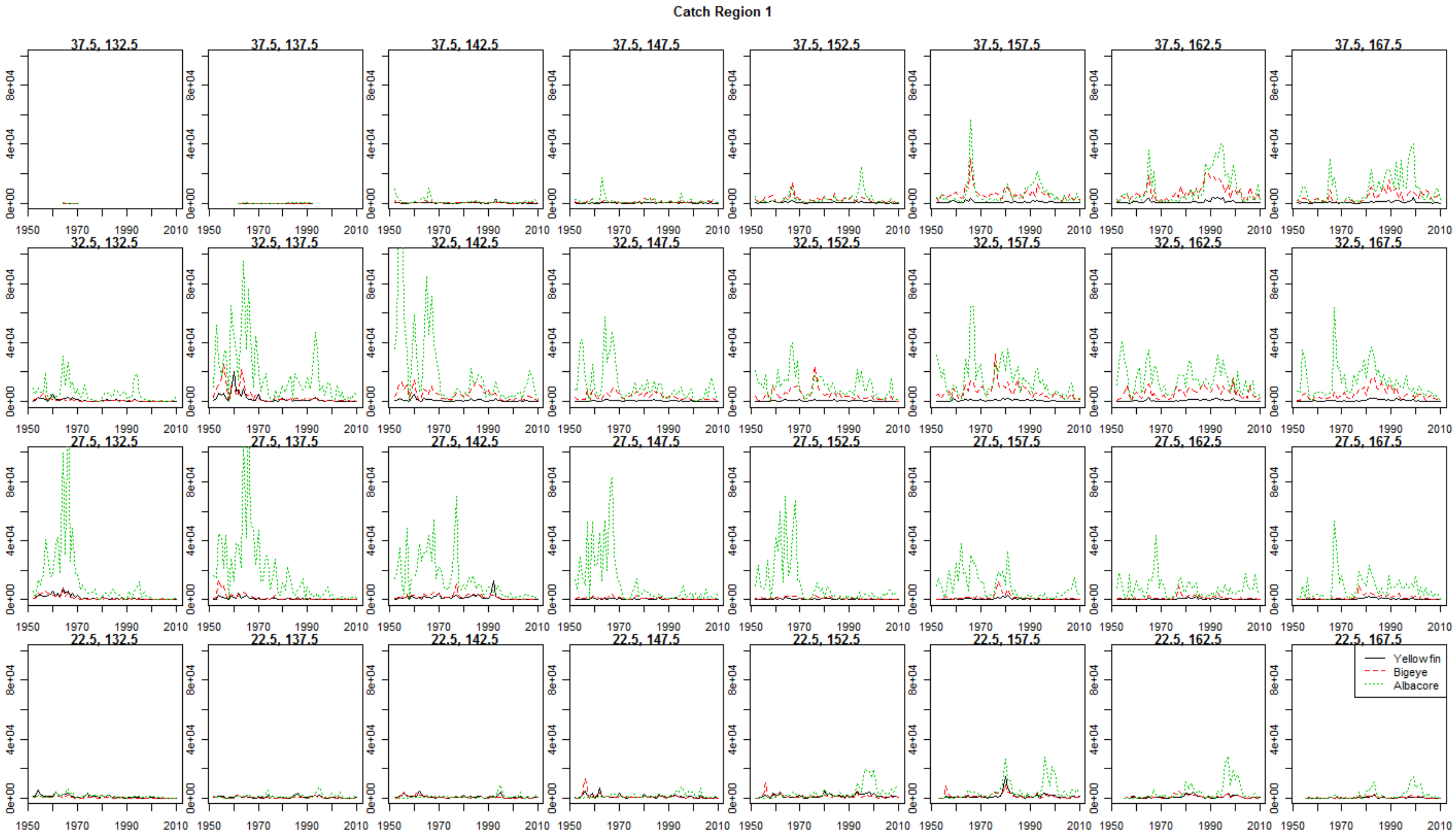


Figure 28: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 1 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

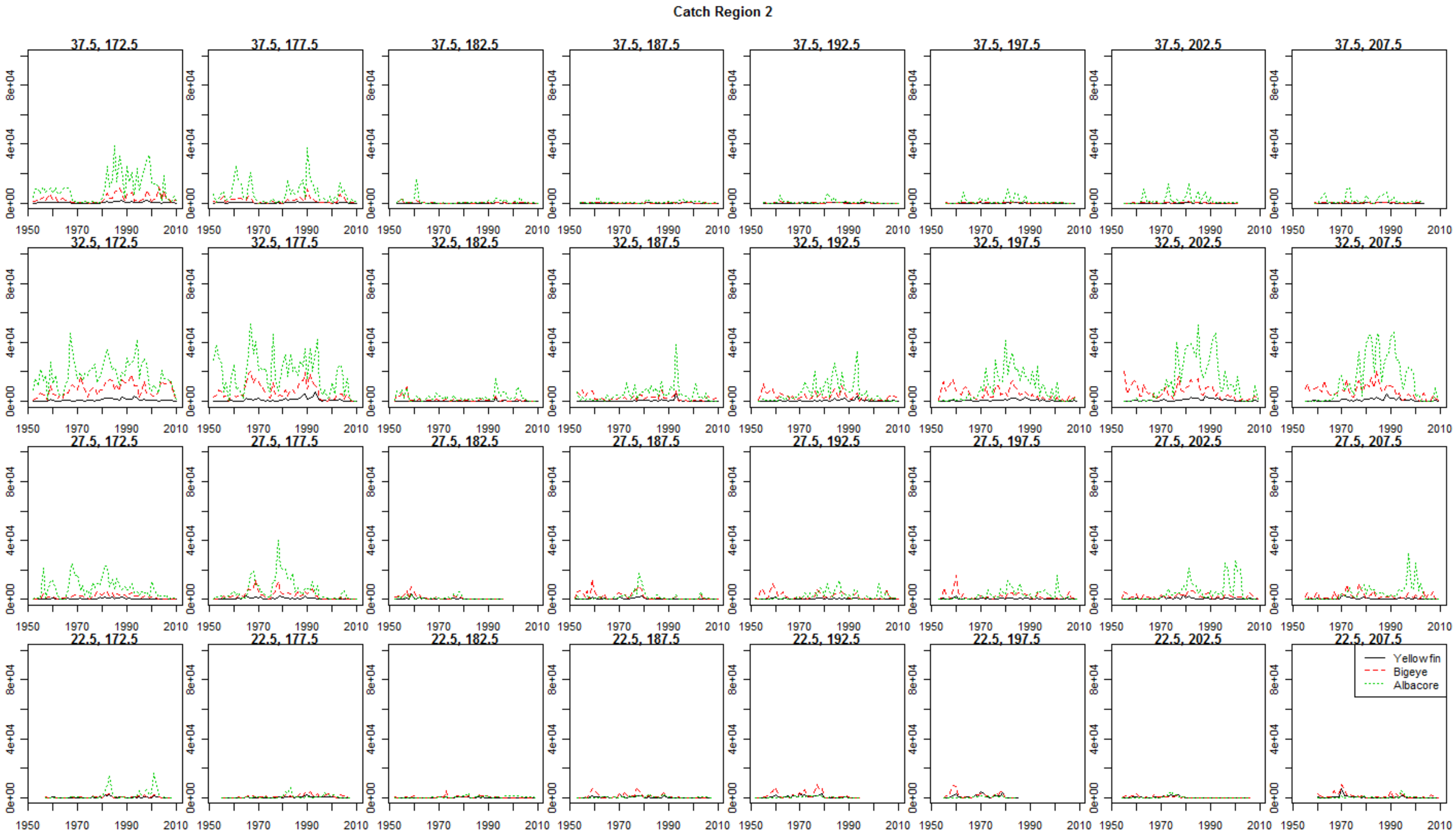


Figure 29: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 2 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

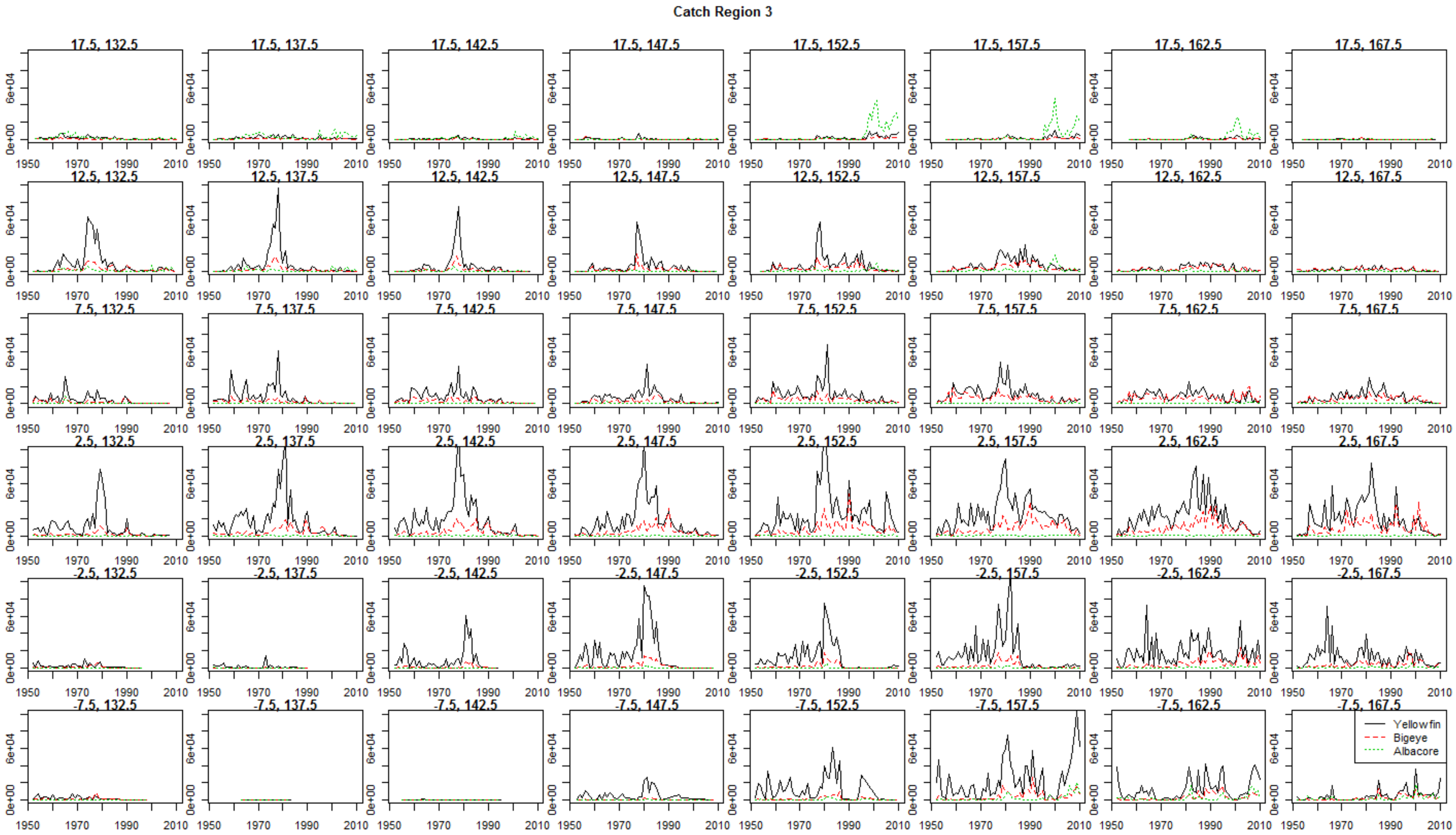


Figure 30: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 3 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

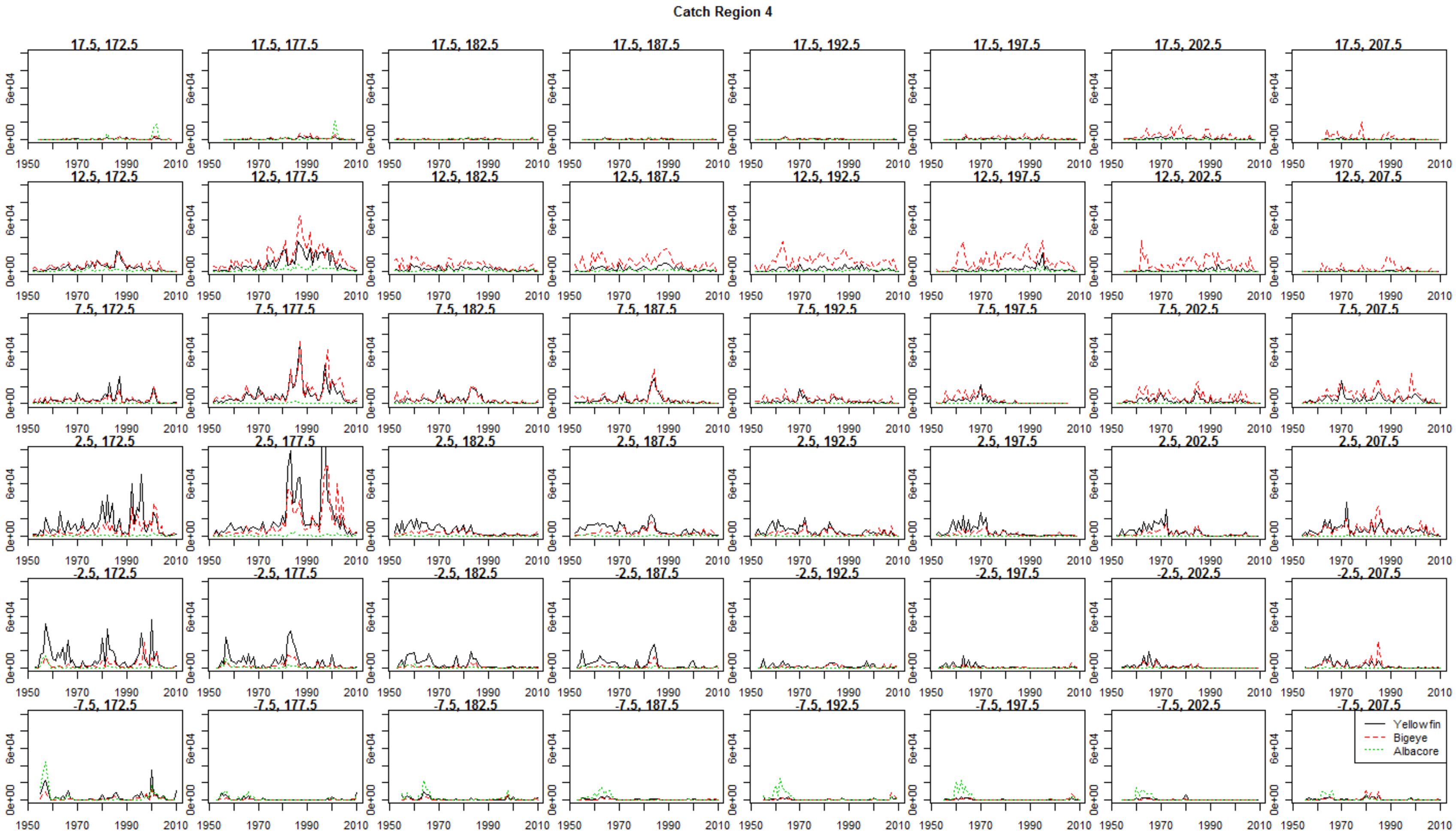


Figure 31: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 4 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

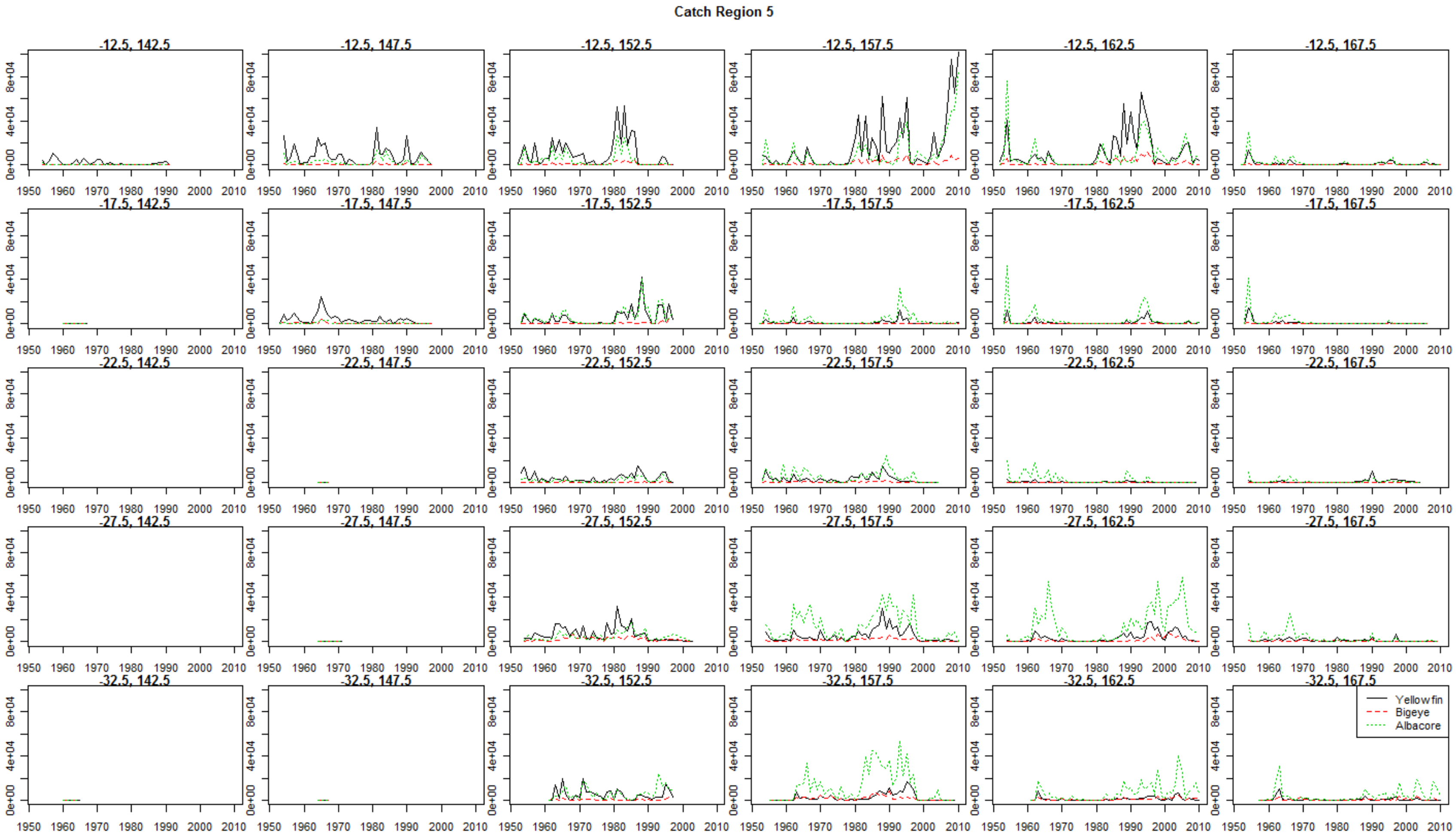


Figure 32: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 5 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

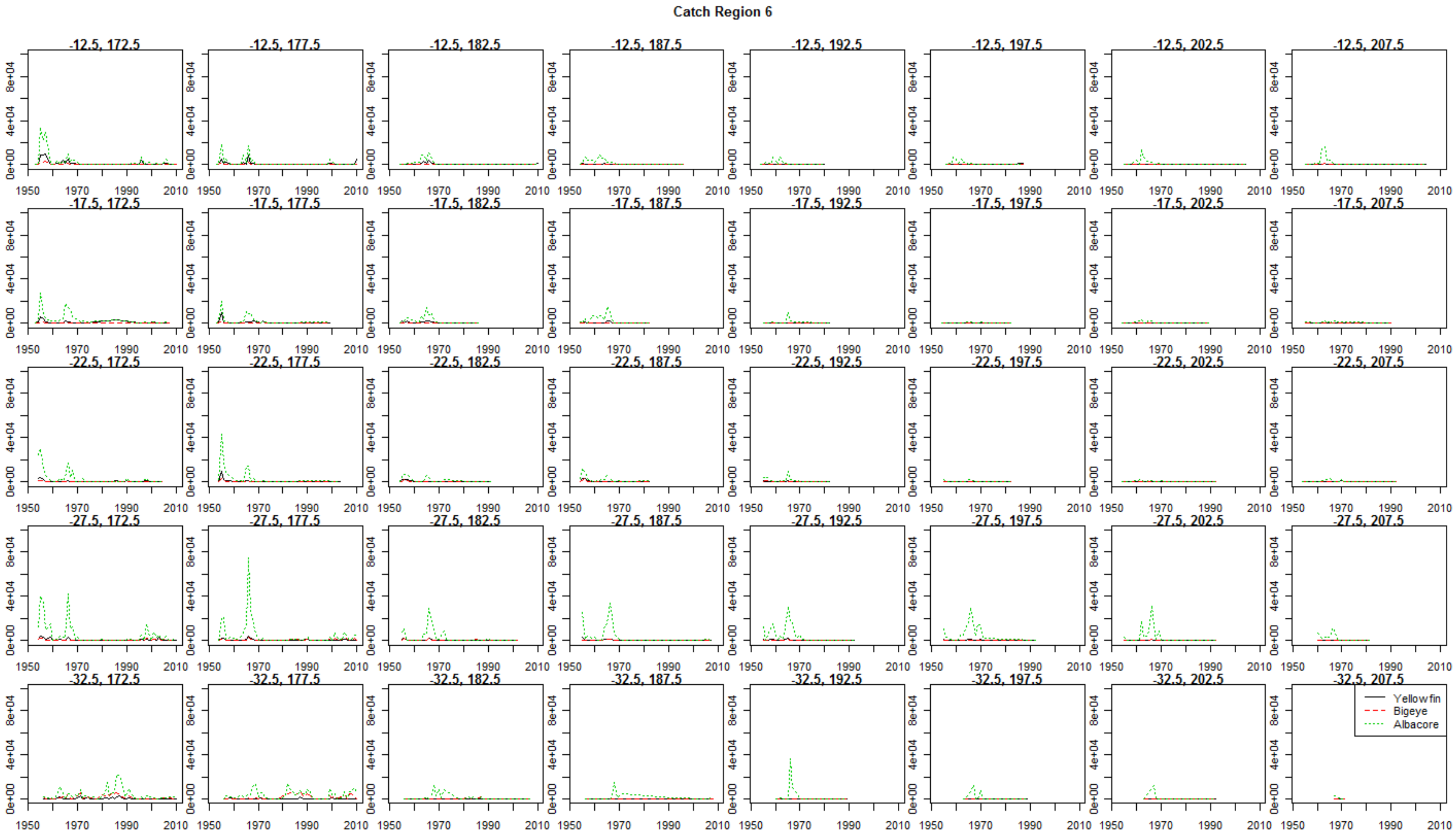


Figure 33: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 6 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

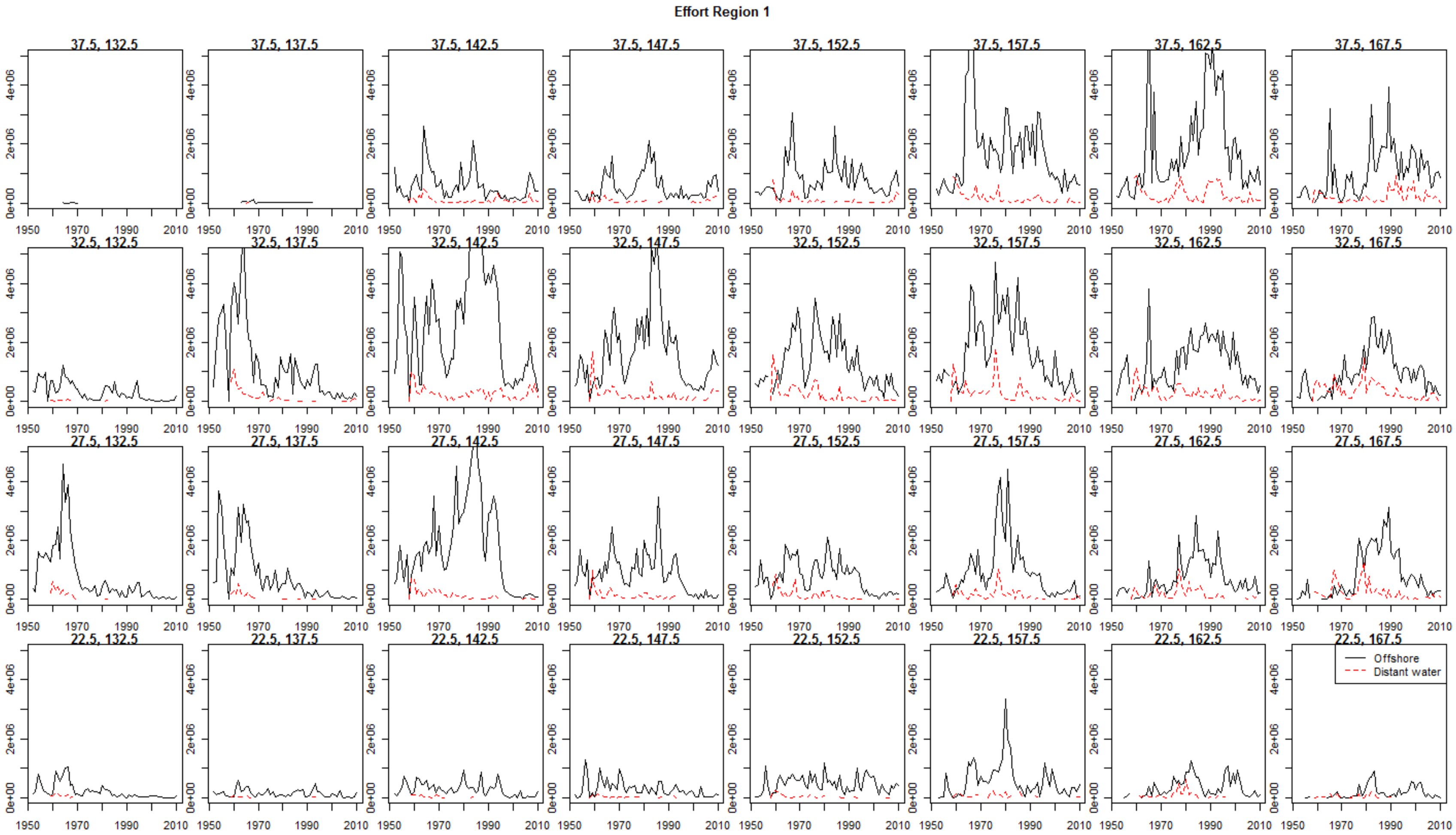


Figure 34: Region 1 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

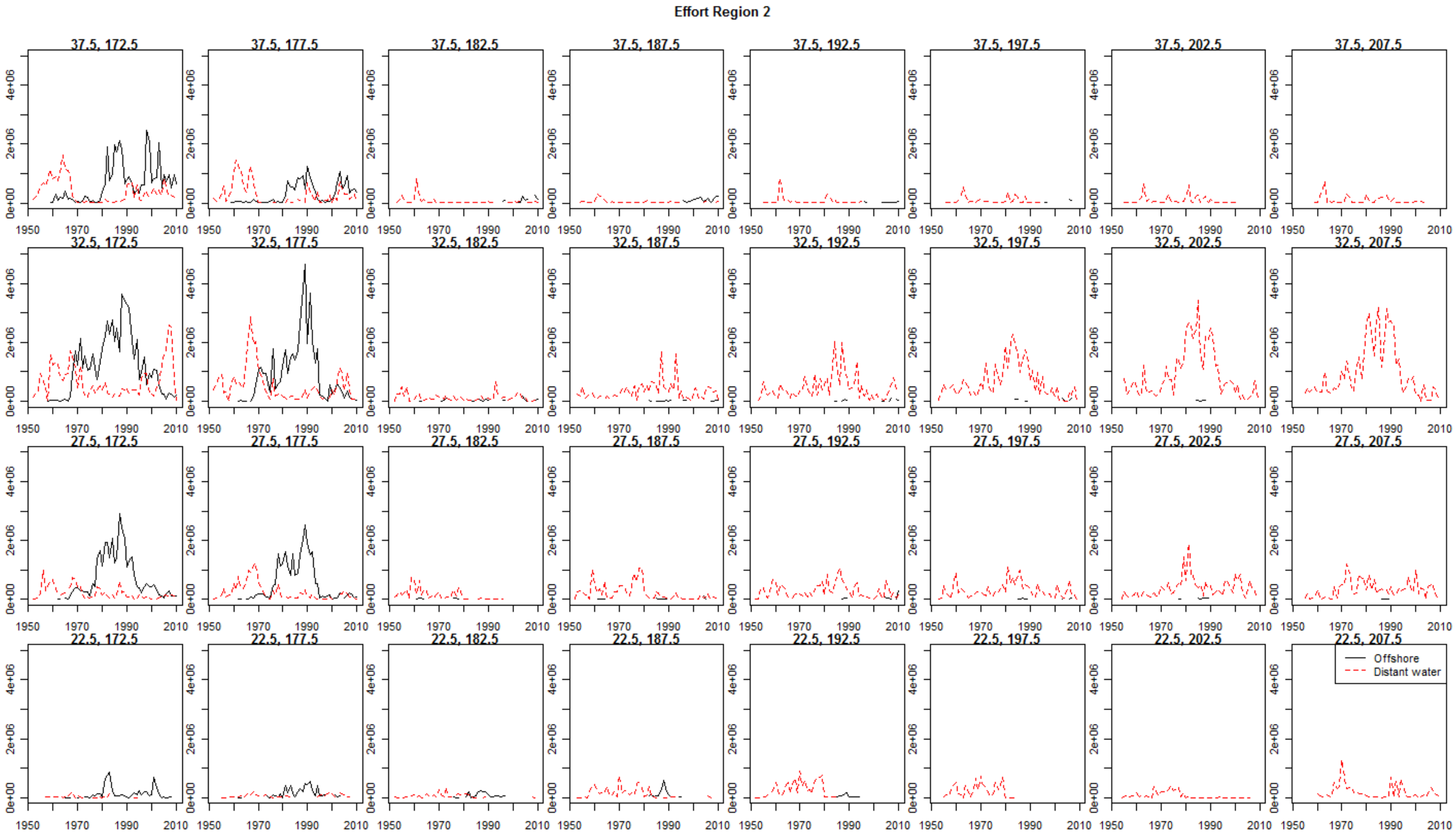


Figure 35: Region 2 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say ‘Effort’).

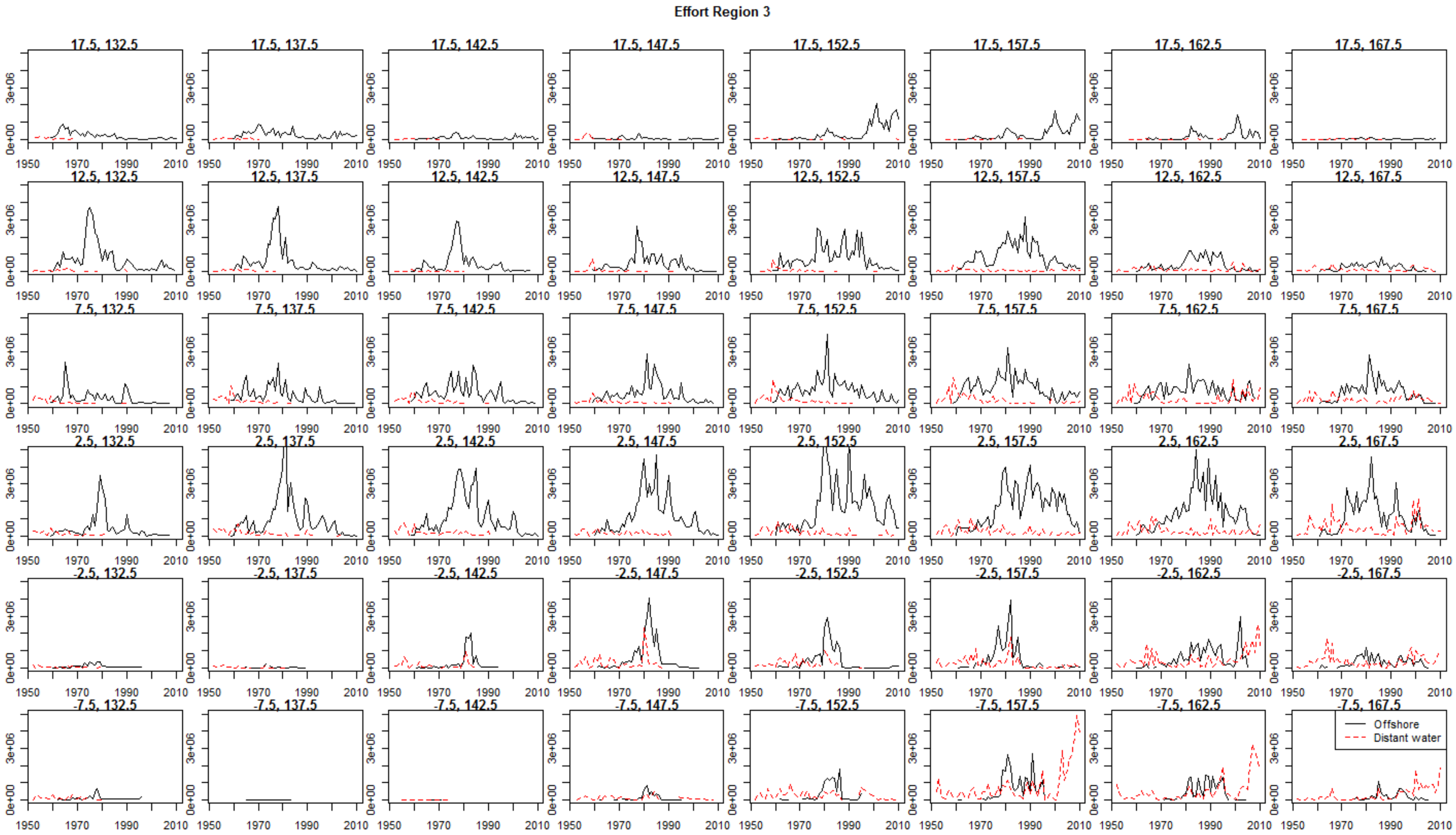


Figure 36: Region 3 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say ‘Effort’).

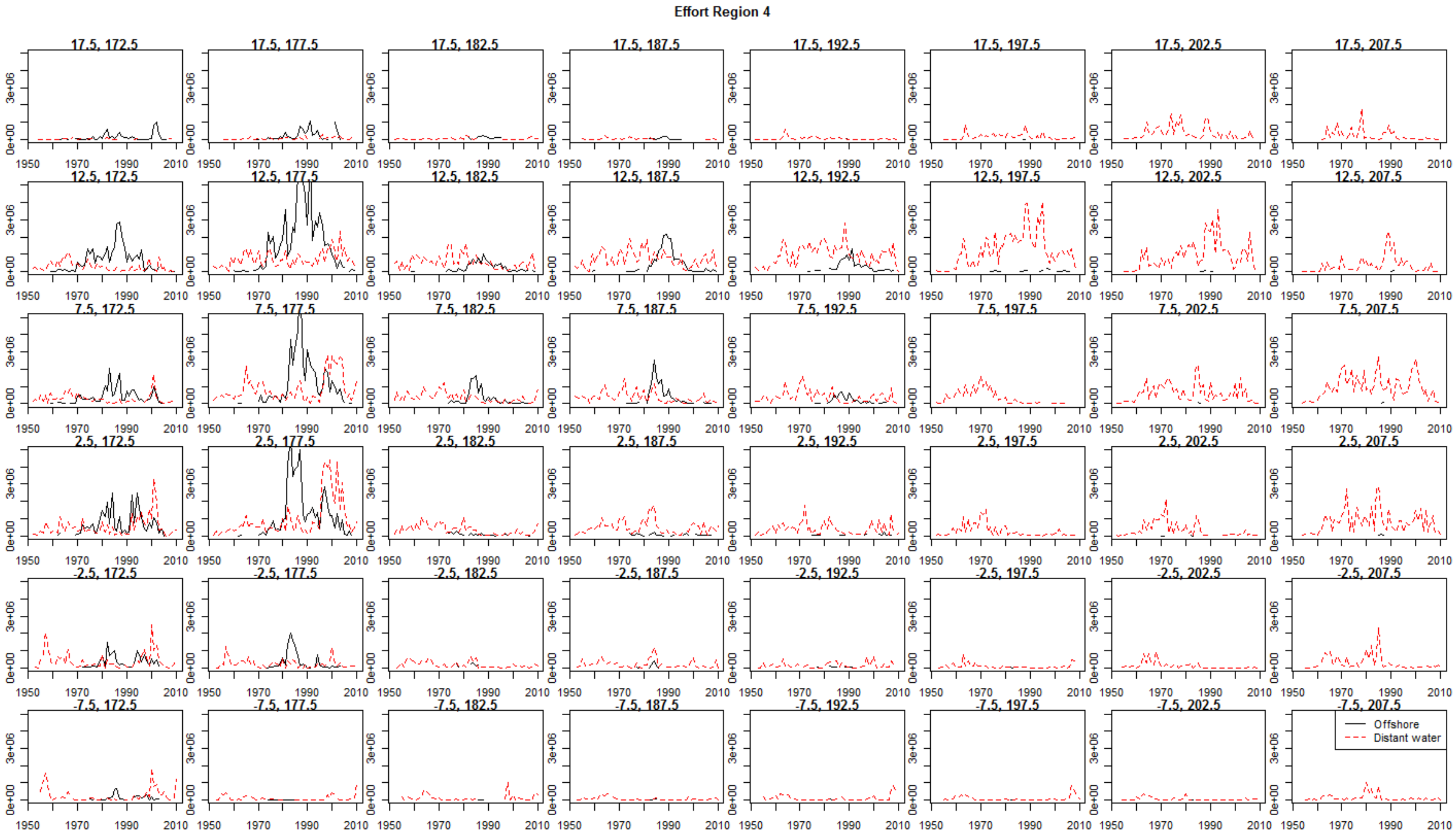


Figure 37: Region 4 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

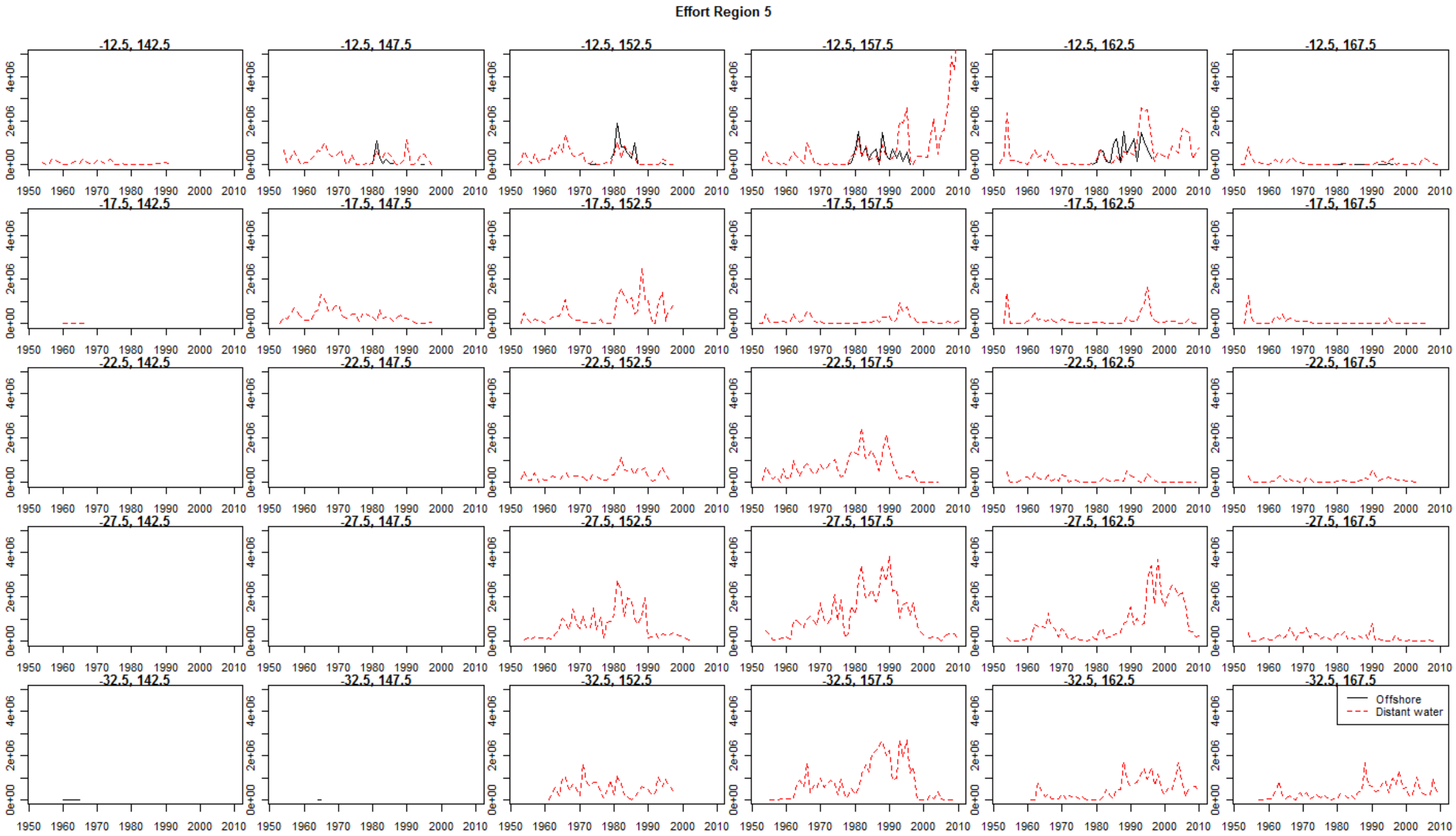


Figure 38: Region 5 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

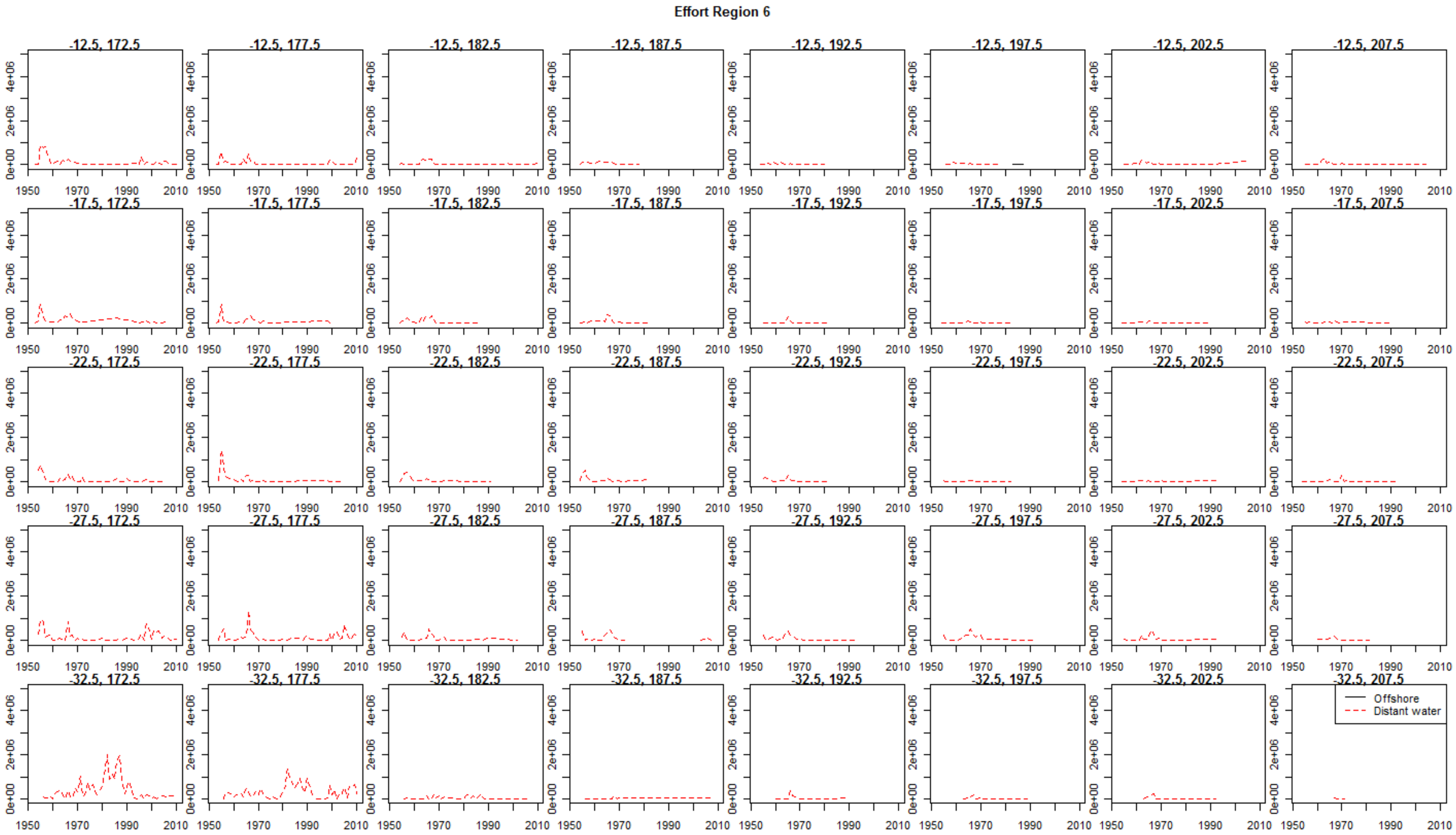


Figure 39: Region 6 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say ‘Effort’).

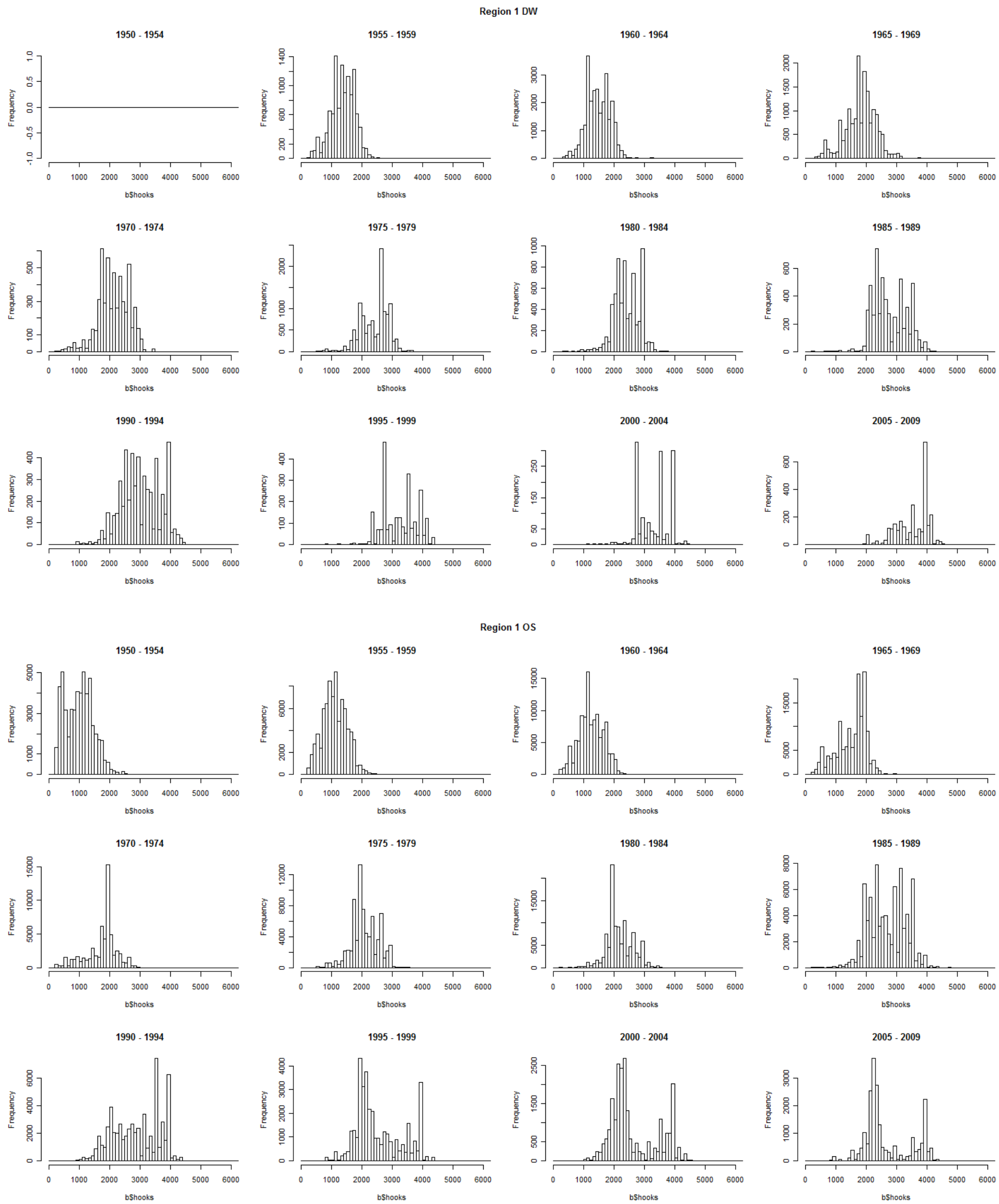


Figure 40: Numbers of hooks per set through time for distant water (top) and offshore (bottom) vessels fishing in Region 1.

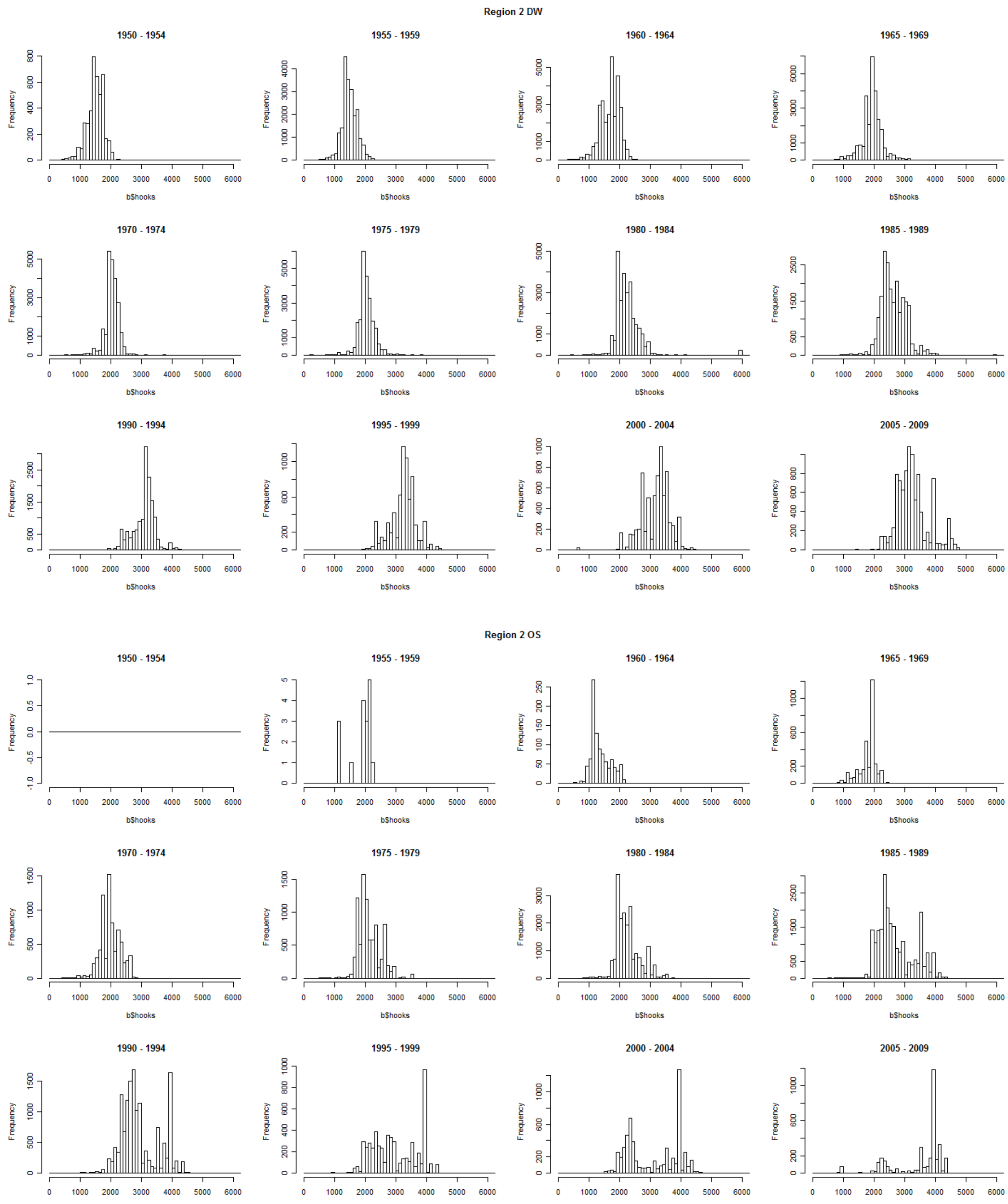


Figure 41: Numbers of hooks per set through time for distant water (top) and offshore (bottom) vessels fishing in Region 2.

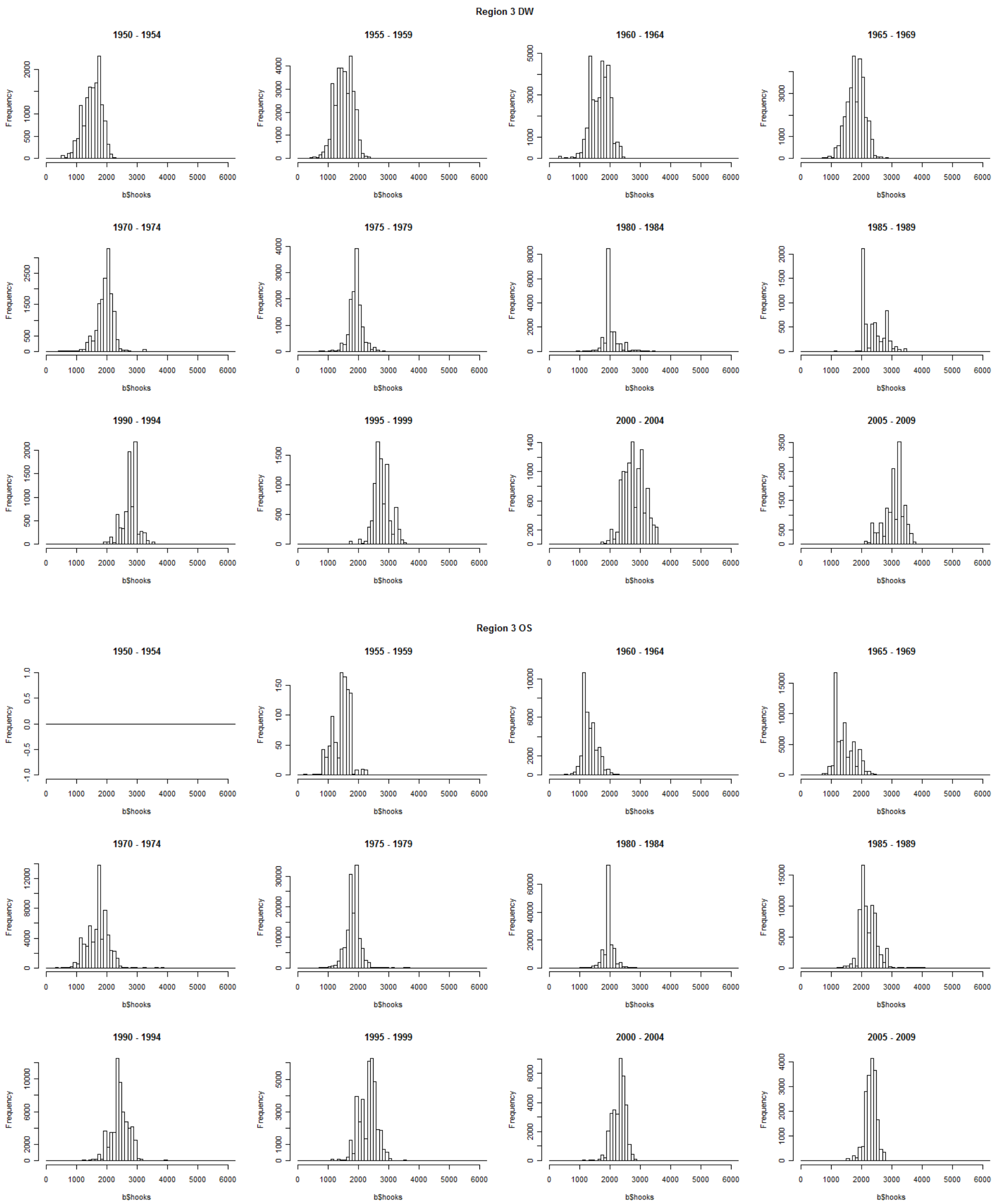


Figure 42: Numbers of hooks per set through time for distant water (top) and offshore (bottom) vessels fishing in Region 3.

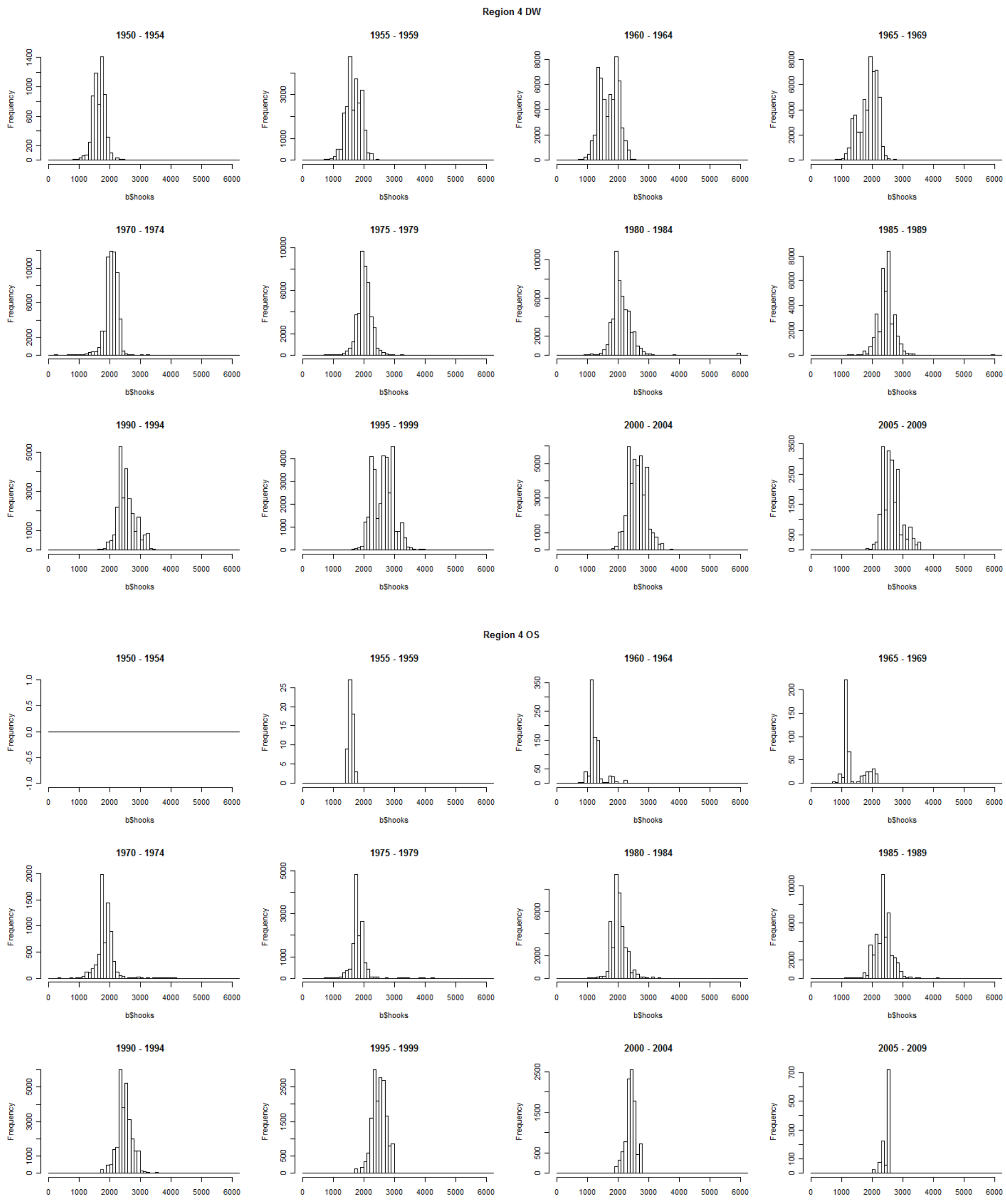


Figure 43: Numbers of hooks per set through time for distant water (top) and offshore (bottom) vessels fishing in Region 4.

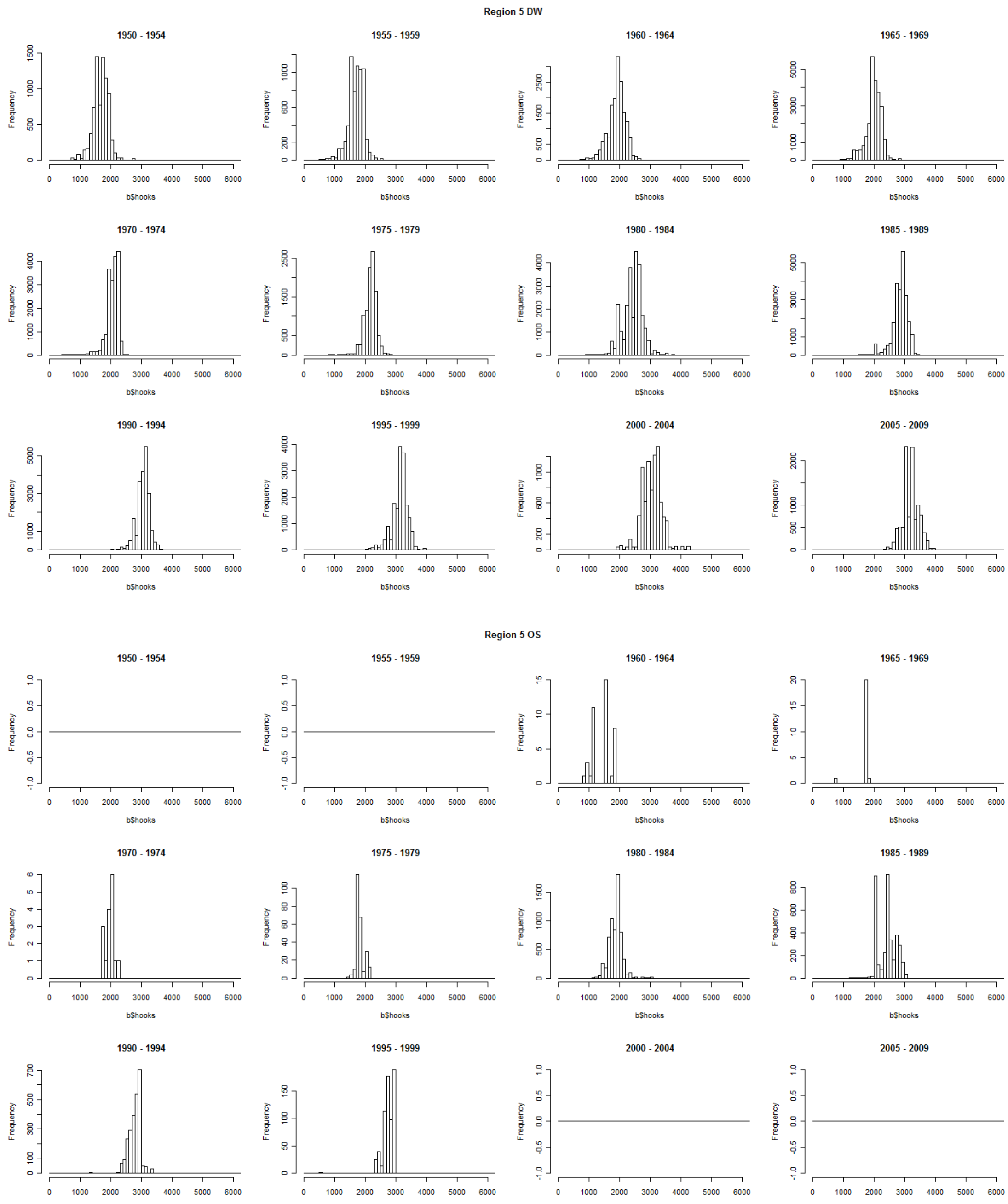


Figure 44: Numbers of hooks per set through time for distant water (top) and offshore (bottom) vessels fishing in Region 5.

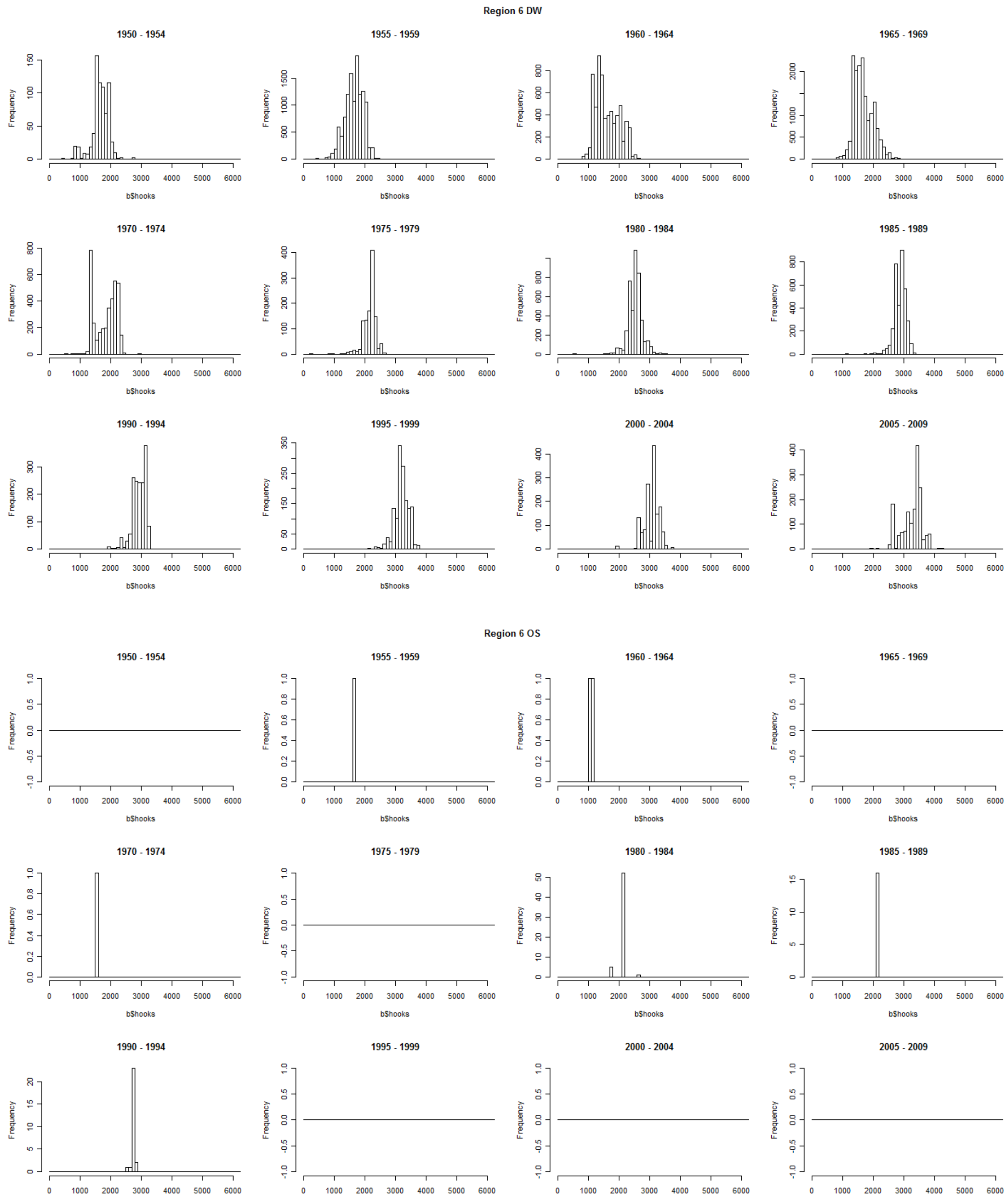


Figure 45: Numbers of hooks per set through time for distant water (top) and offshore (bottom) vessels fishing in Region 6.

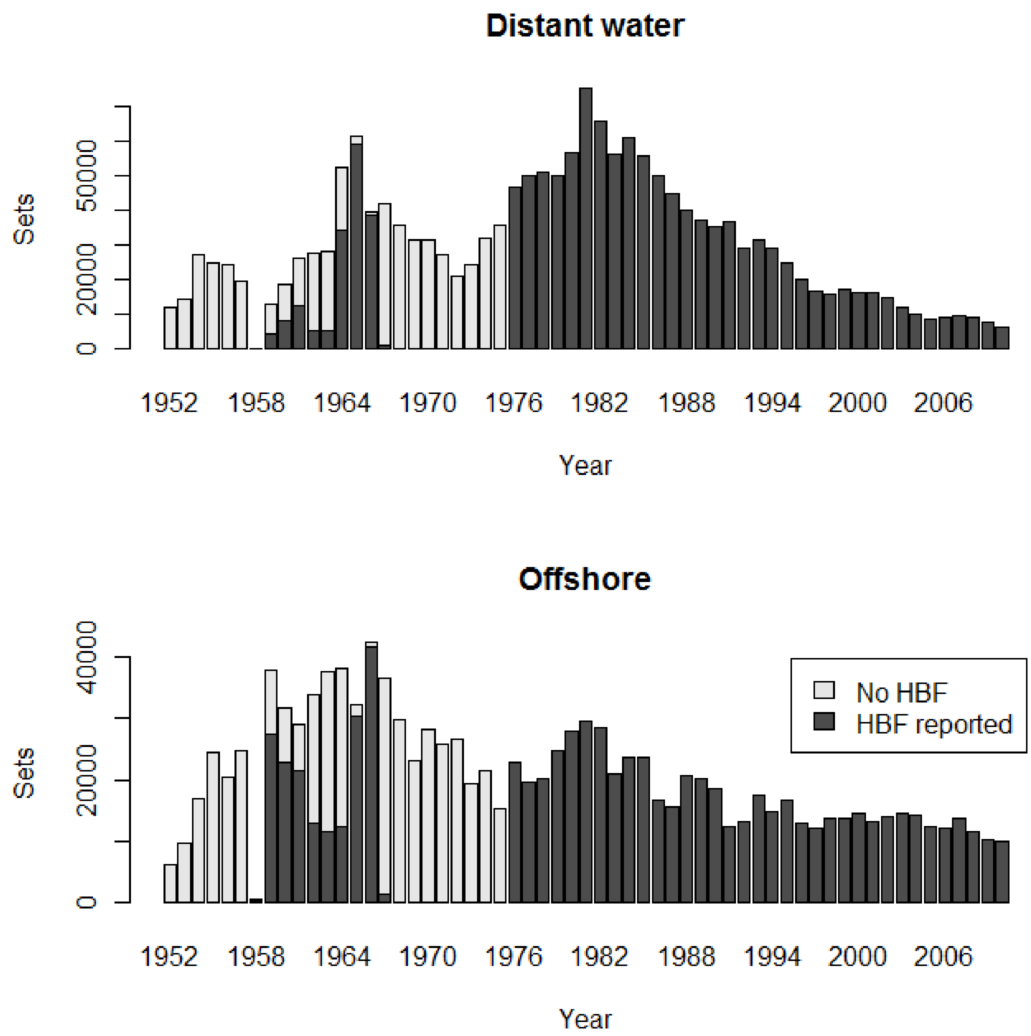


Figure 46: Sets with and without HBF reported, by year and fishing category.

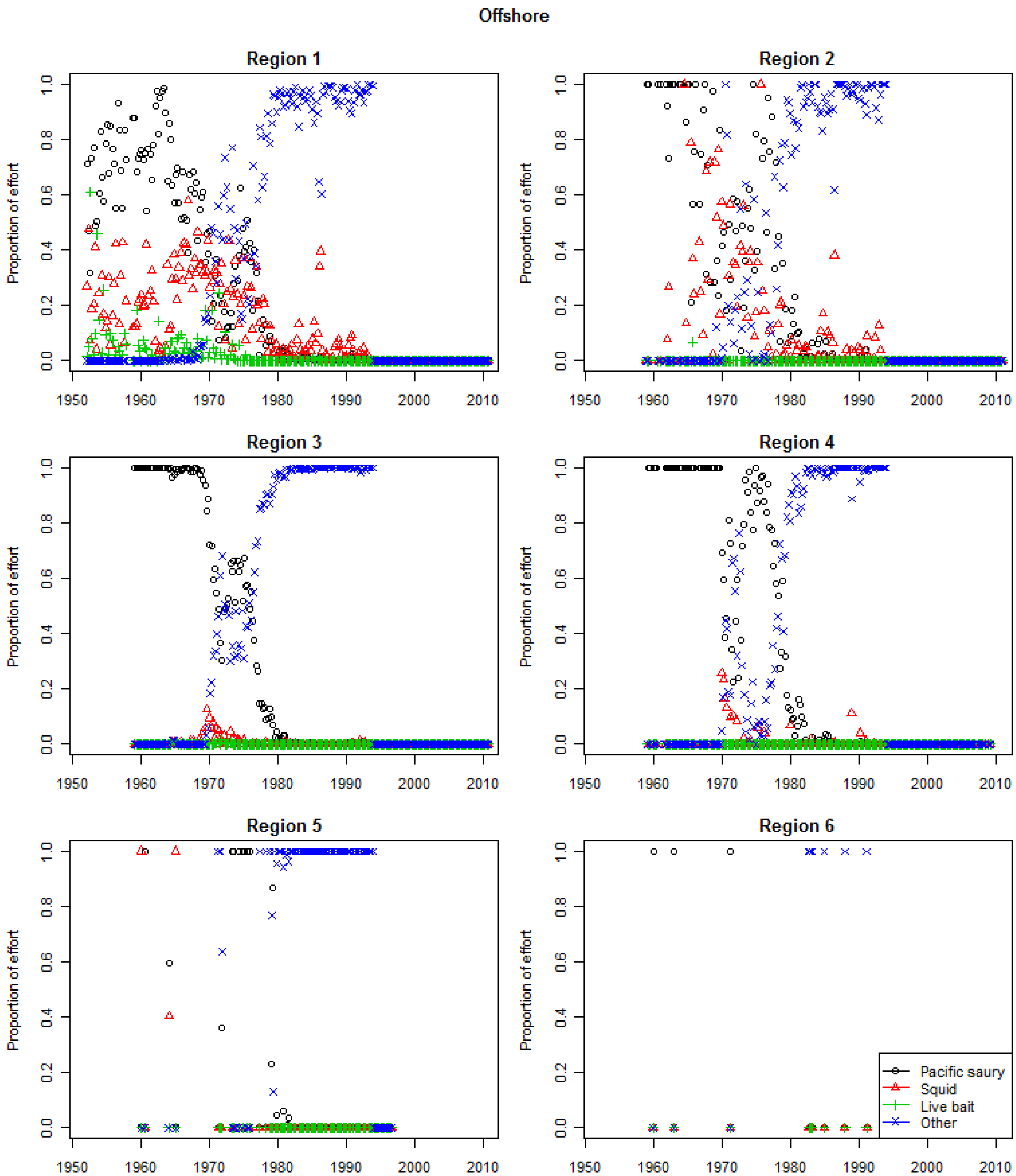


Figure 47: Proportion of OS effort reporting use of the bait types Pacific saury, squid, live bait, or other, by region.

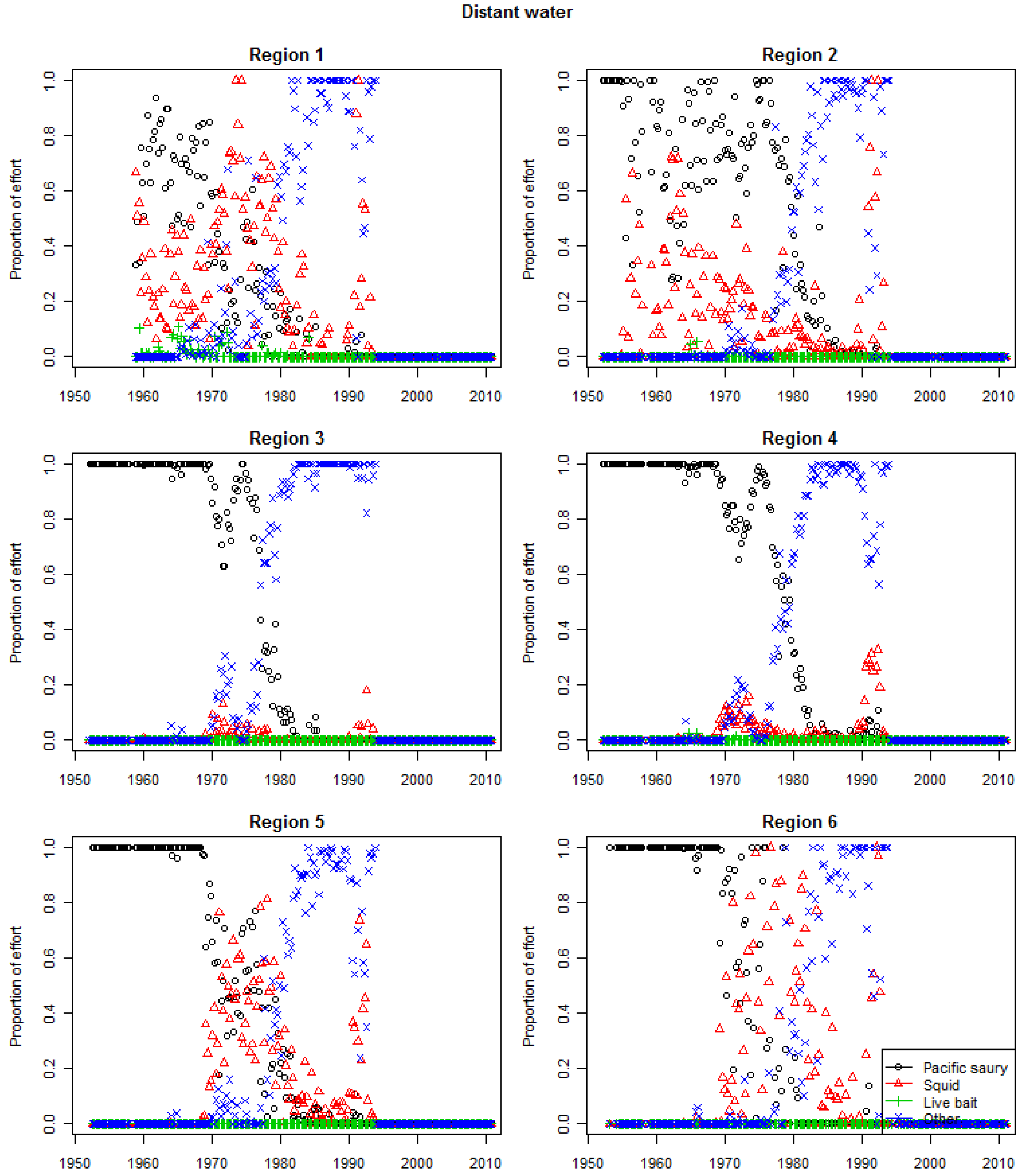


Figure 48: Proportion of DW effort reporting use of the bait types Pacific saury, squid, live bait, or other, by region.

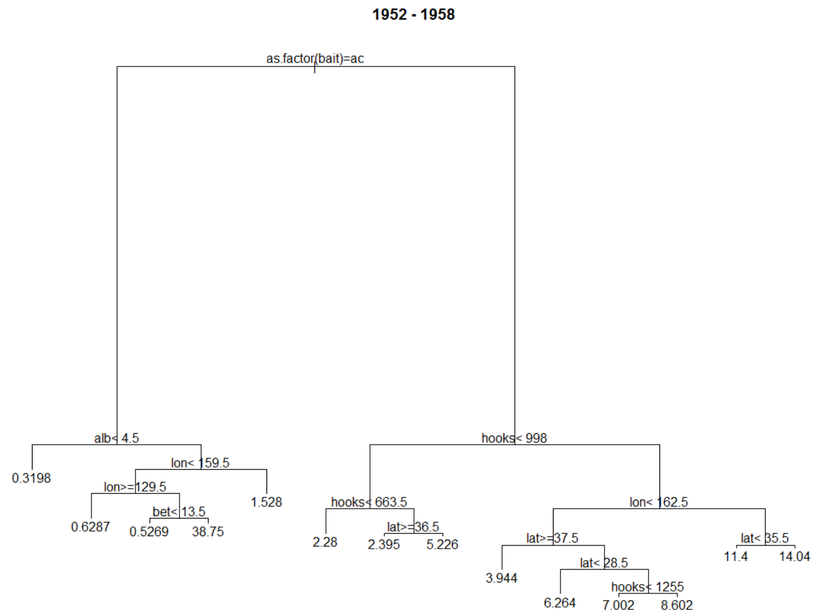


Figure 49: Regression tree for 1952-1958 showing factors affecting swordfish CPUE in the north Pacific. The model included only the variables that were available for the early part of the time series.

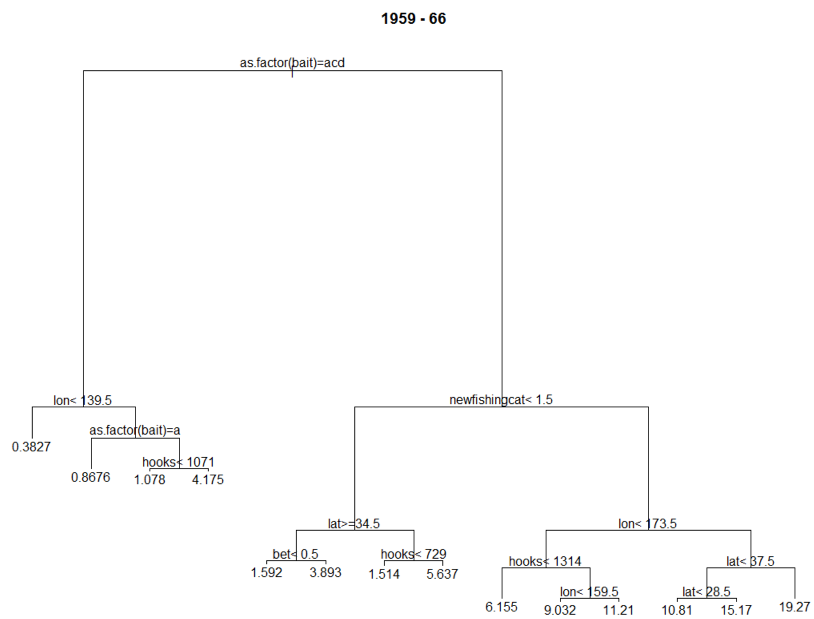


Figure 50: Regression tree for 1959-1966 showing factors affecting swordfish CPUE in the north Pacific. The model included only the variables that were available for the early part of the time series.

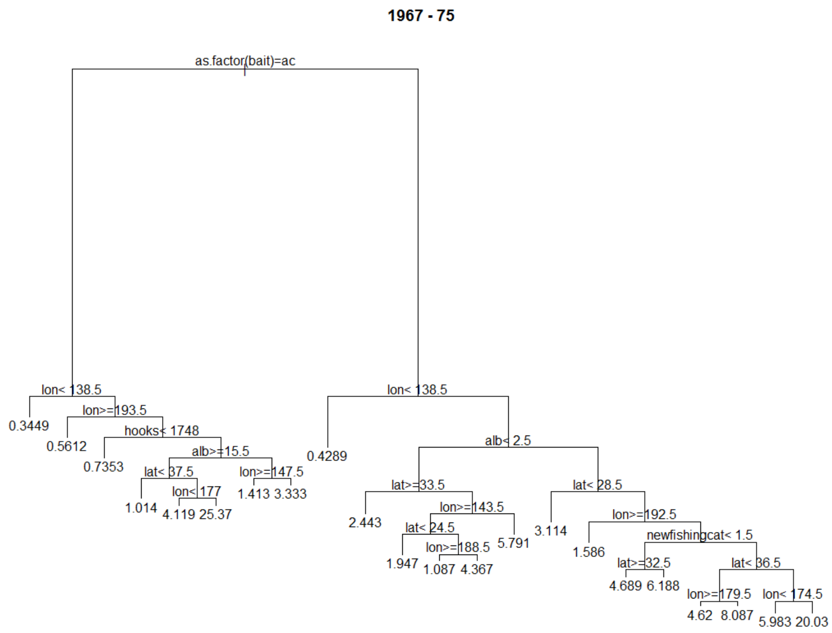


Figure 51: Regression tree for 1967-1975 showing factors affecting swordfish CPUE in the north Pacific. The model included only the variables that were available for the early part of the time series.

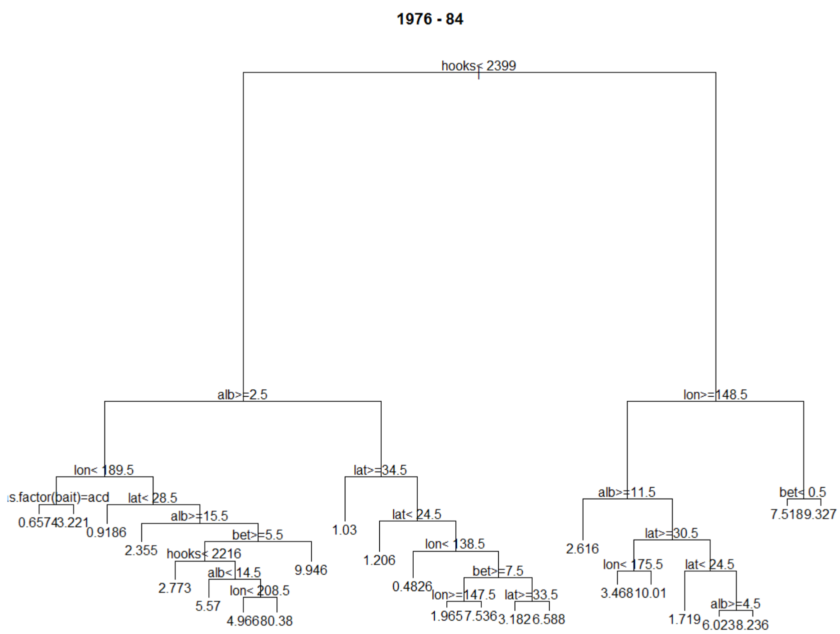


Figure 52: Regression tree for 1976-1984 showing factors affecting swordfish CPUE in the north Pacific. The model included only the variables that were available for the early part of the time series.

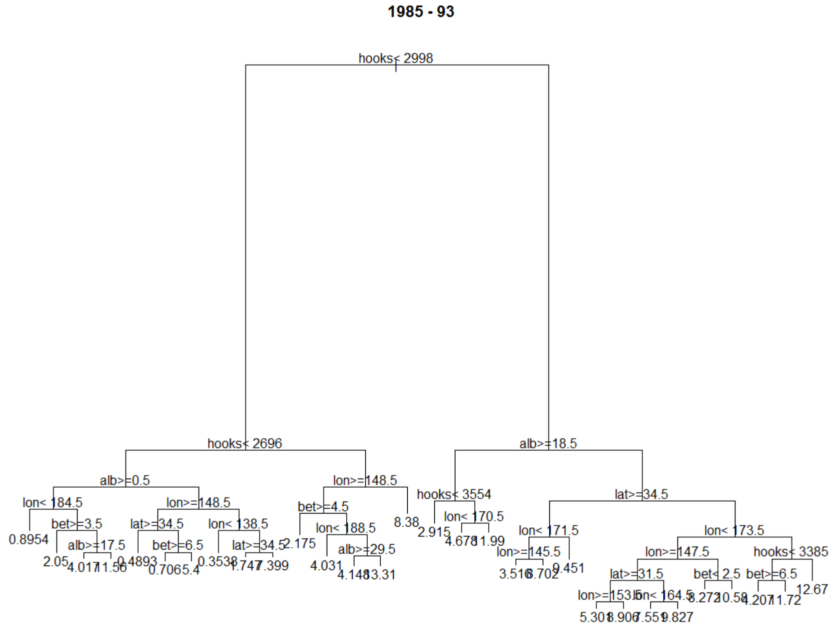


Figure 53: Regression tree for 1985-1993 showing factors affecting swordfish CPUE in the north Pacific. The model included only the variables that were available for the early part of the time series.

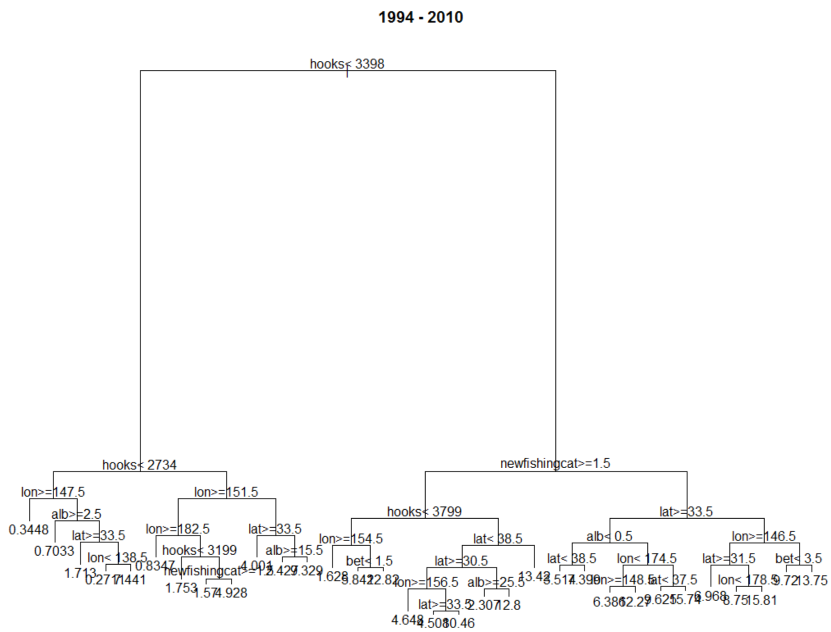


Figure 54: Regression tree for 1994-2010 showing factors affecting swordfish CPUE in the north Pacific. The model included only the variables that were available for the early part of the time series.

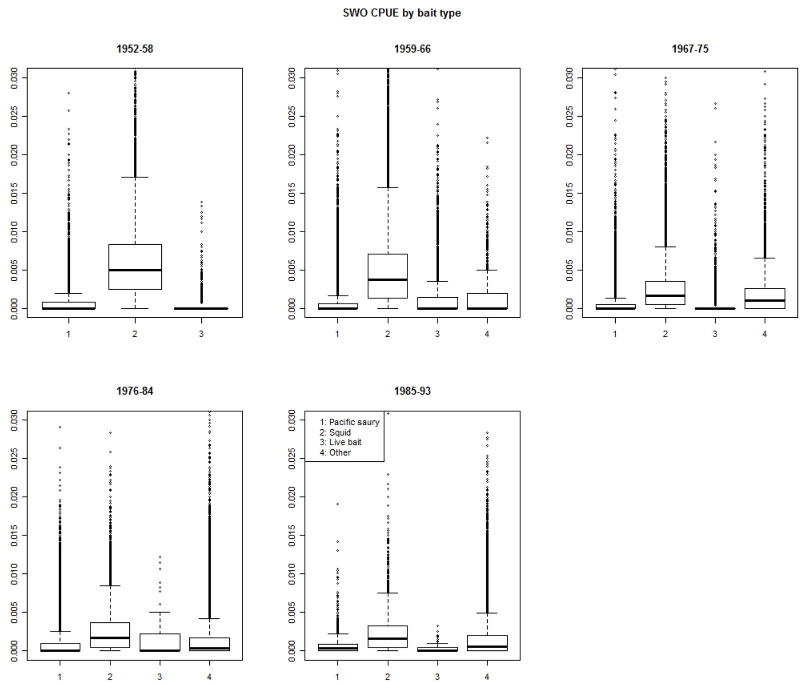


Figure 55: Box plot showing swordfish catch rate in regions 1 and 2 by bait type for 5 periods since 1952. Catch rates are generally higher for effort using squid bait (particularly before 1967) and 'other' bait types, suggesting swordfish targeting.

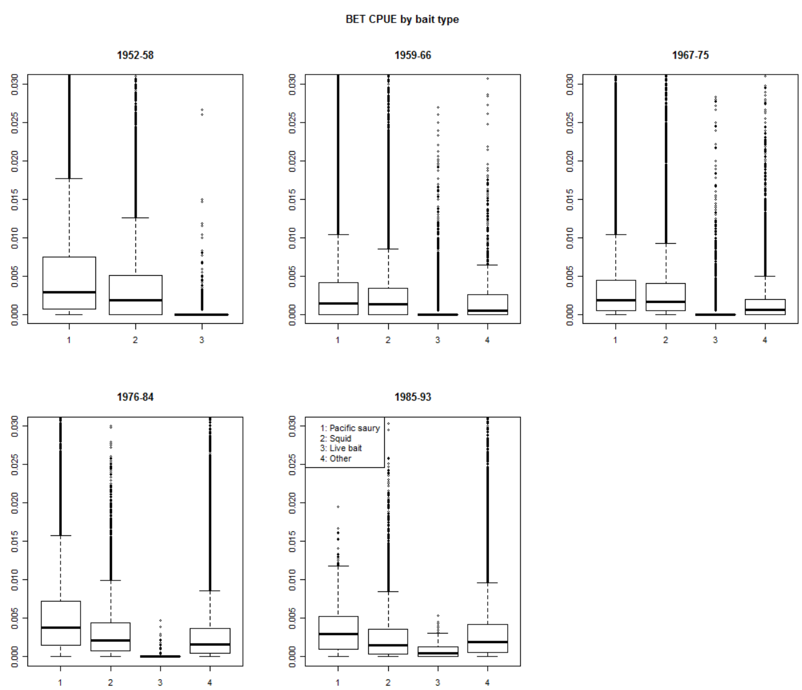


Figure 56: Box plot showing bigeye catch rate in regions 1 and 2 by bait type for 5 periods since 1952.

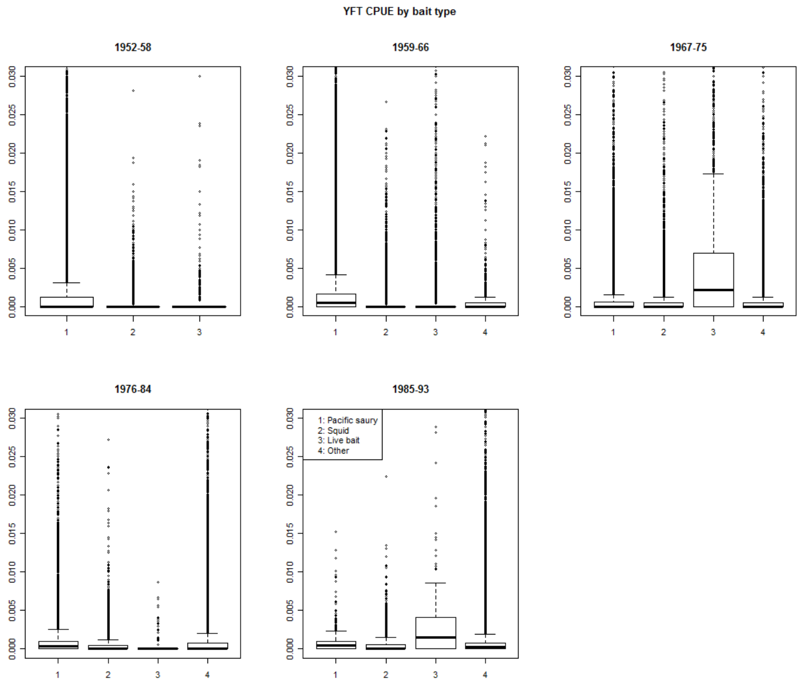


Figure 57: Box plot showing yellowfin catch rate in regions 1 and 2 by bait type for 5 periods since 1952.

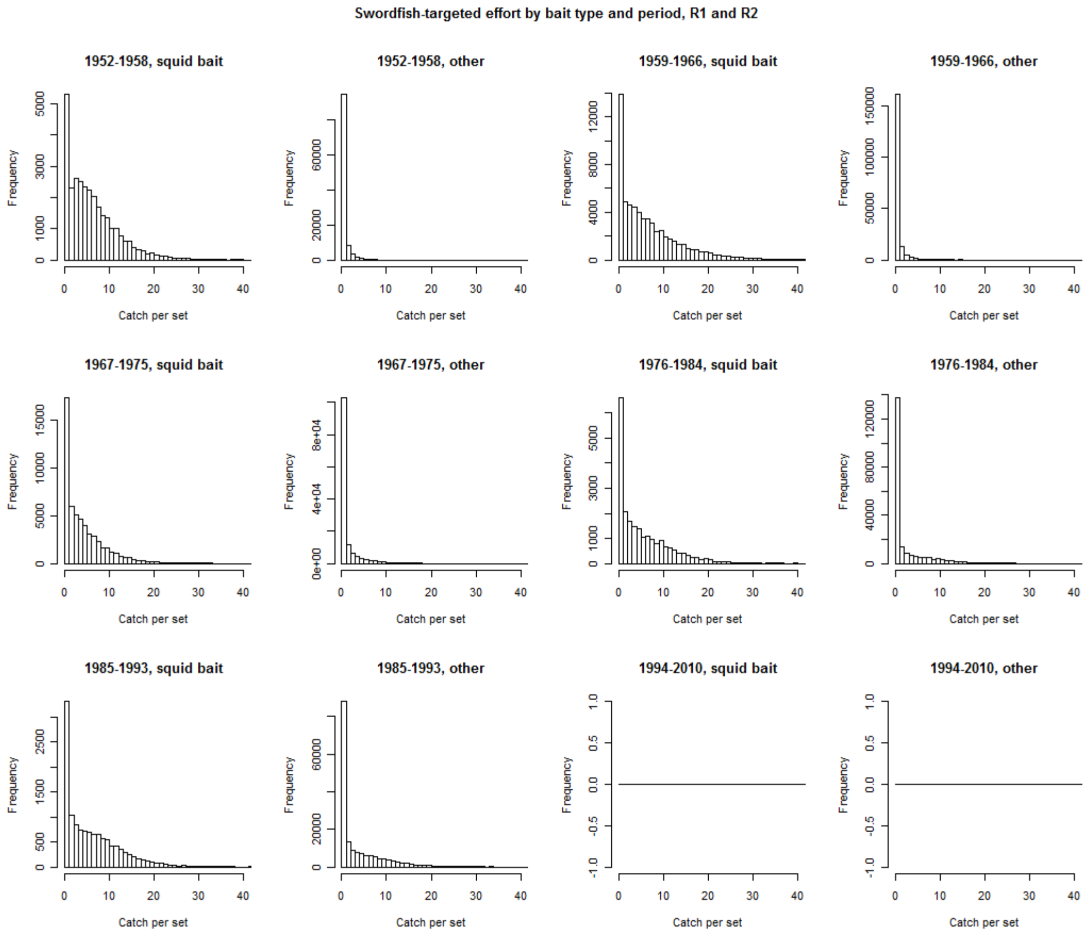


Figure 58: Histograms of swordfish catches in sets using squid bait vs any other bait type, for several periods in regions 1 and 2.

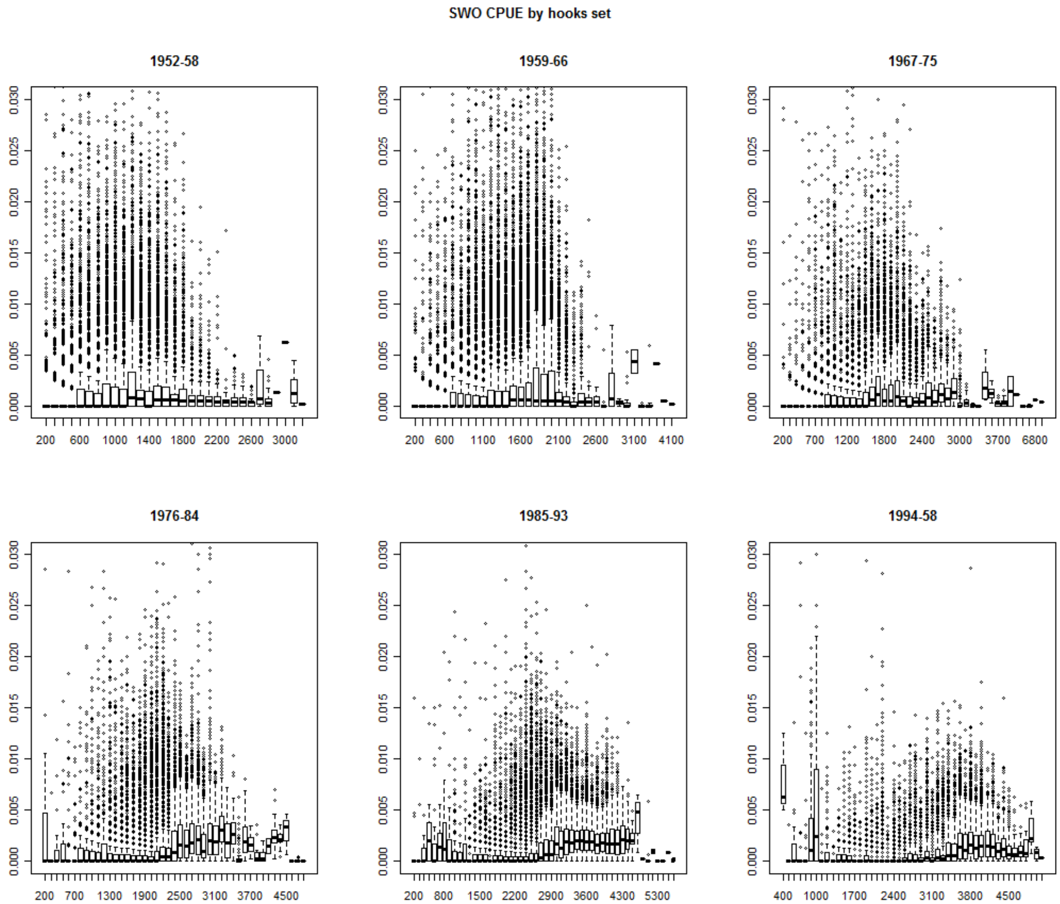


Figure 59: Boxplots showing changes in the relationship between hooks per set and swordfish catch rates through time. Before 1976 higher swordfish catch rates do not appear to be associated with higher hooks per set. After 1976, however, longline setting behaviour appears to change with a clear increase in swordfish catch rates at higher hooks per set.

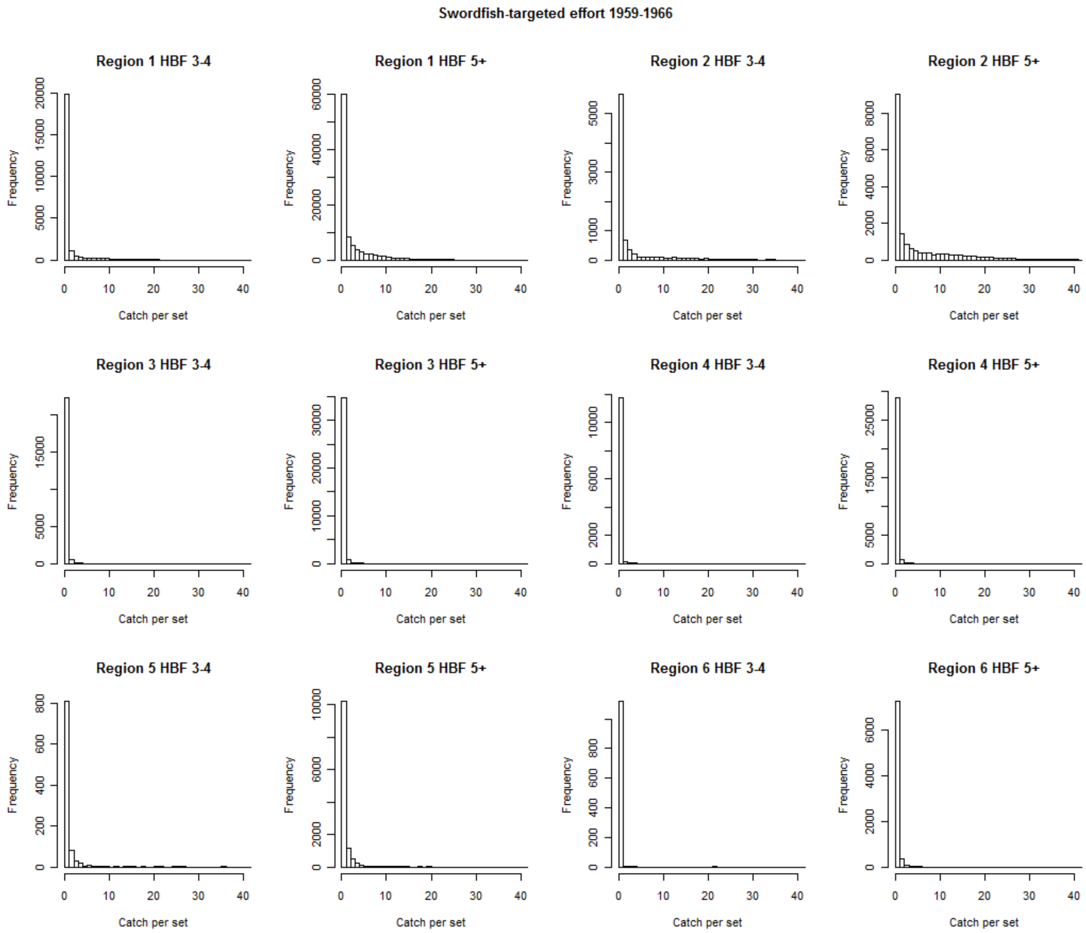


Figure 60: Histograms of swordfish catches in sets with less than 5 HBF vs 5 or more HBF, in regions 1 and 2 between 1959 and 1966.

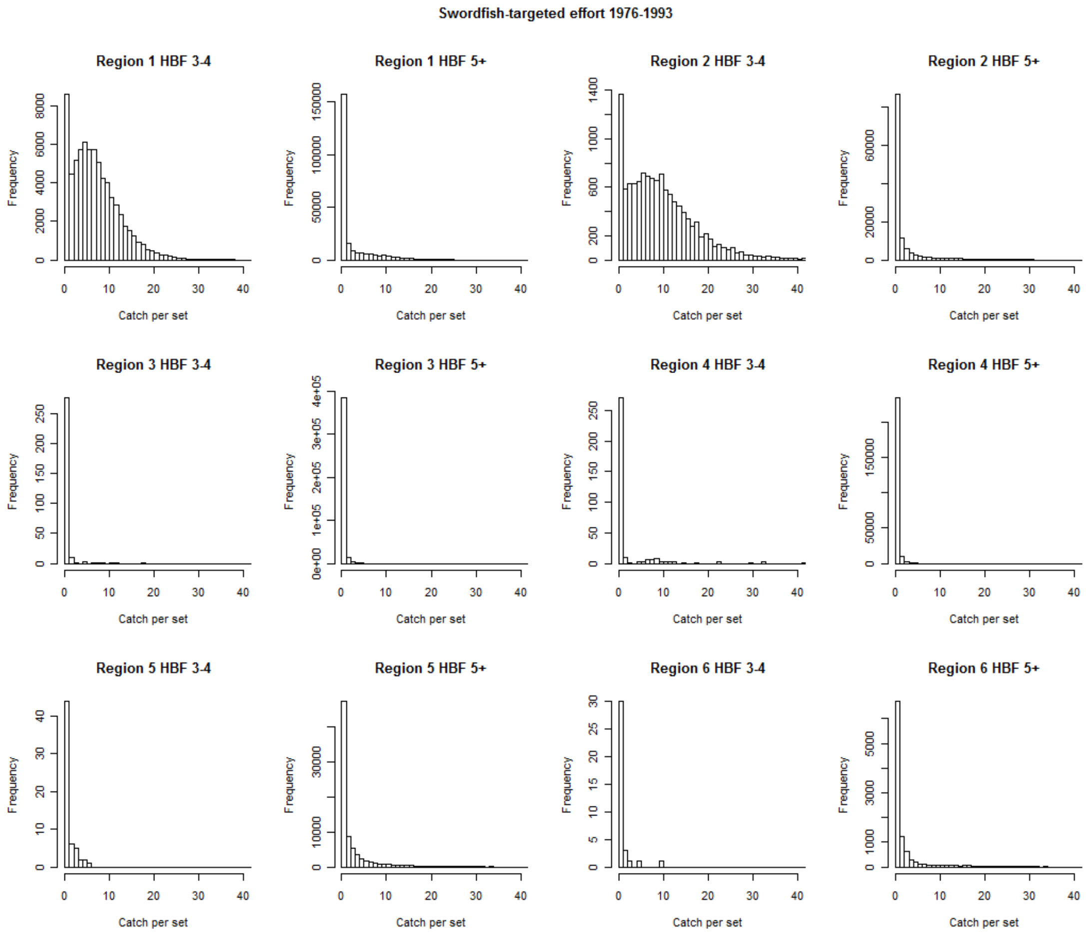


Figure 61: Histograms of swordfish catches in sets with less than 5 HBF vs 5 or more HBF, in regions 1 and 2 between 1976 and 1993.

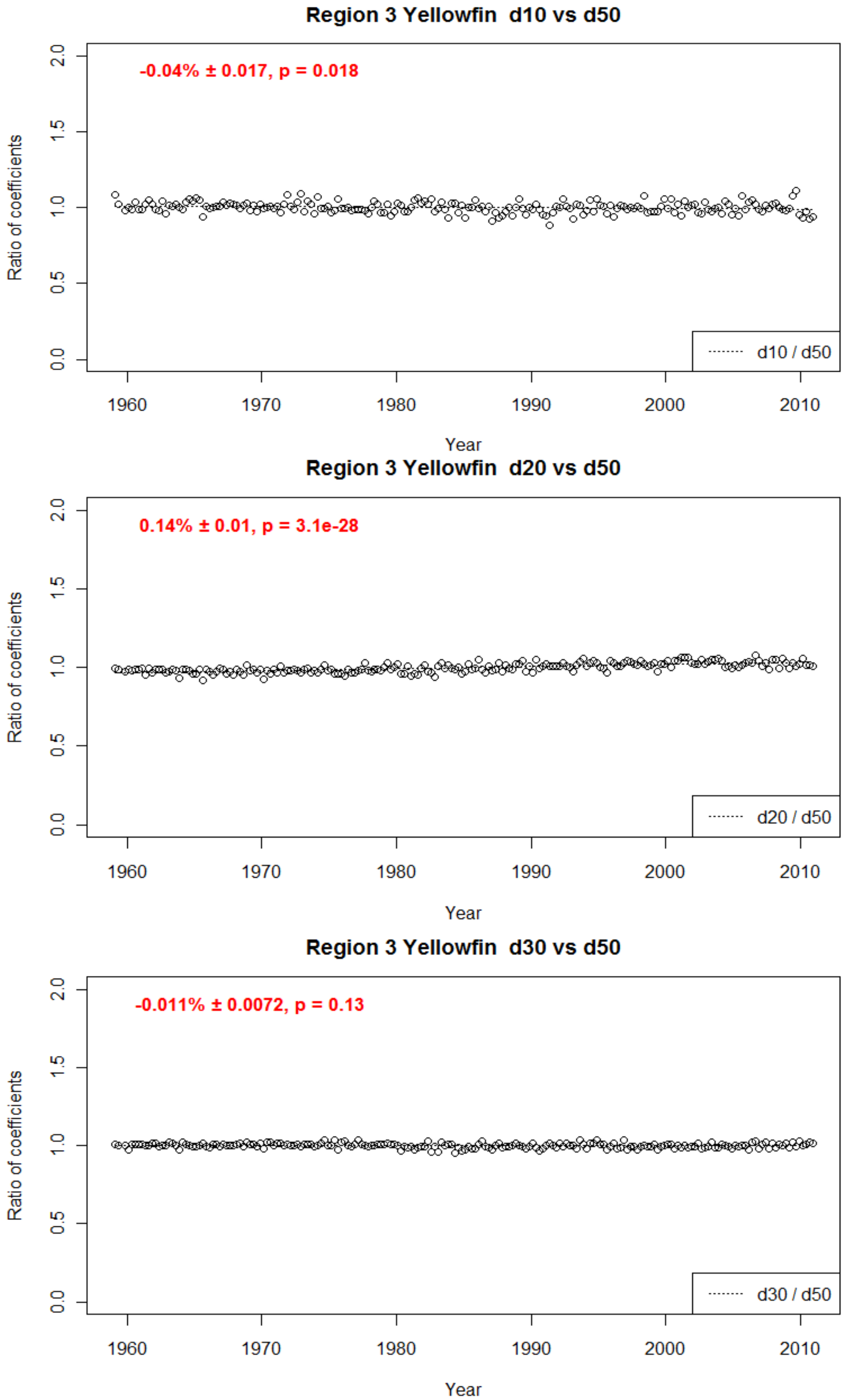


Figure 62: Ratio plots between yellowfin abundance indices for region 3 estimated using different numbers (n) of sets per stratum. In the three plots, indices estimated with n = 10, 20, and 30 are compared with indices estimated with n=50. As n increases, the random variation in the ratios declines.

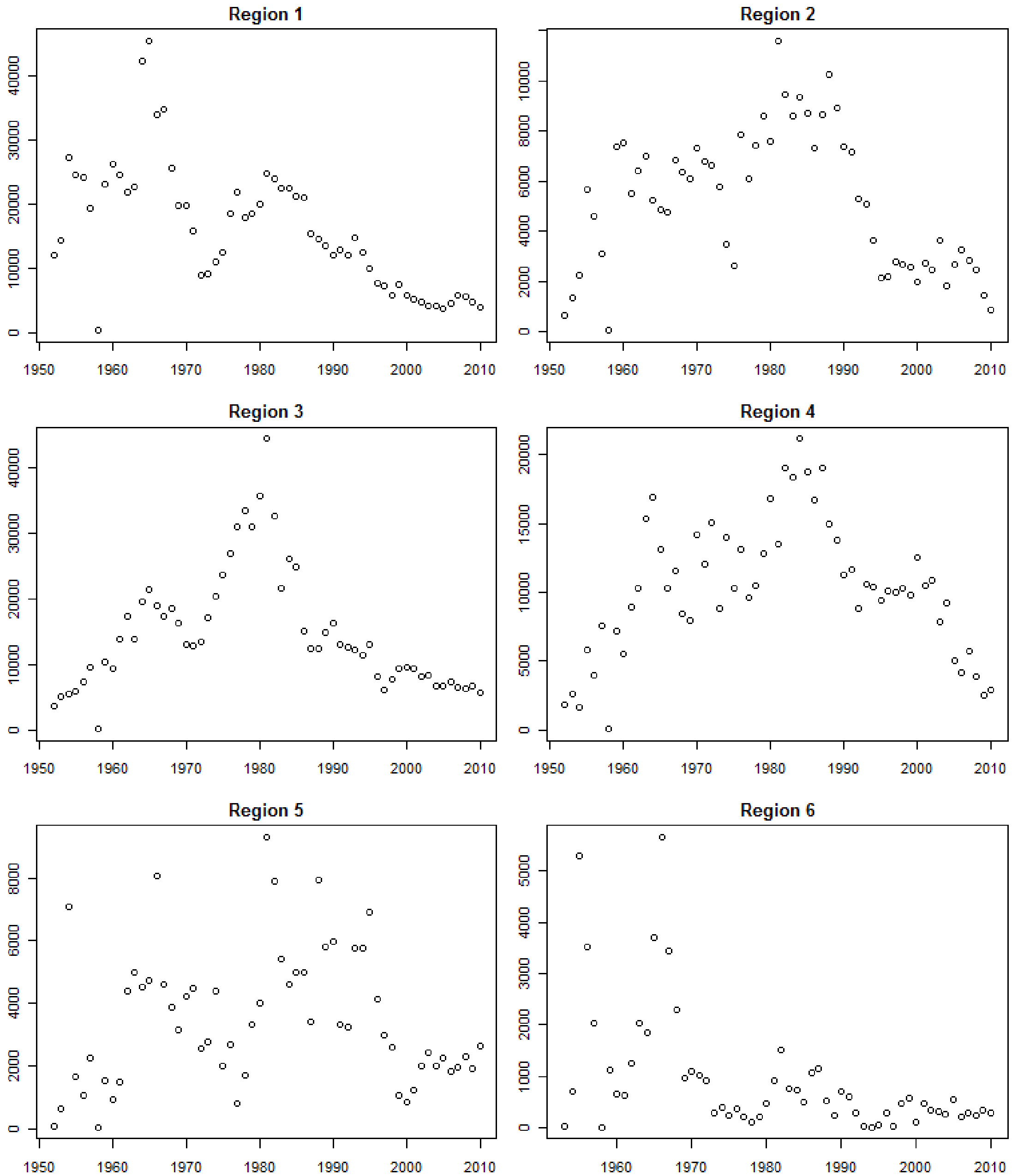


Figure 63: Number of logsheet records by year and region.

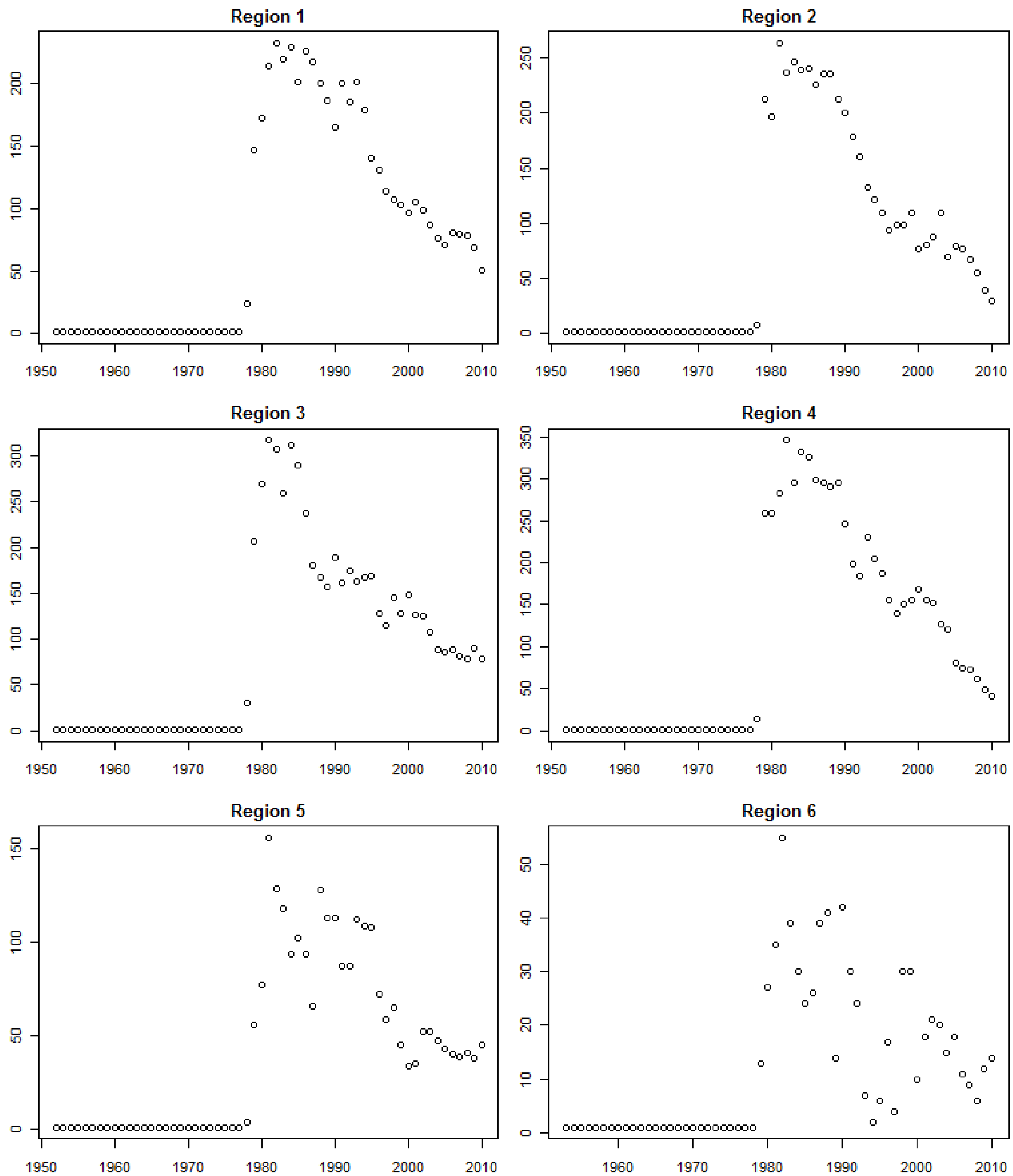


Figure 64: Number of unique vessels by year and region.

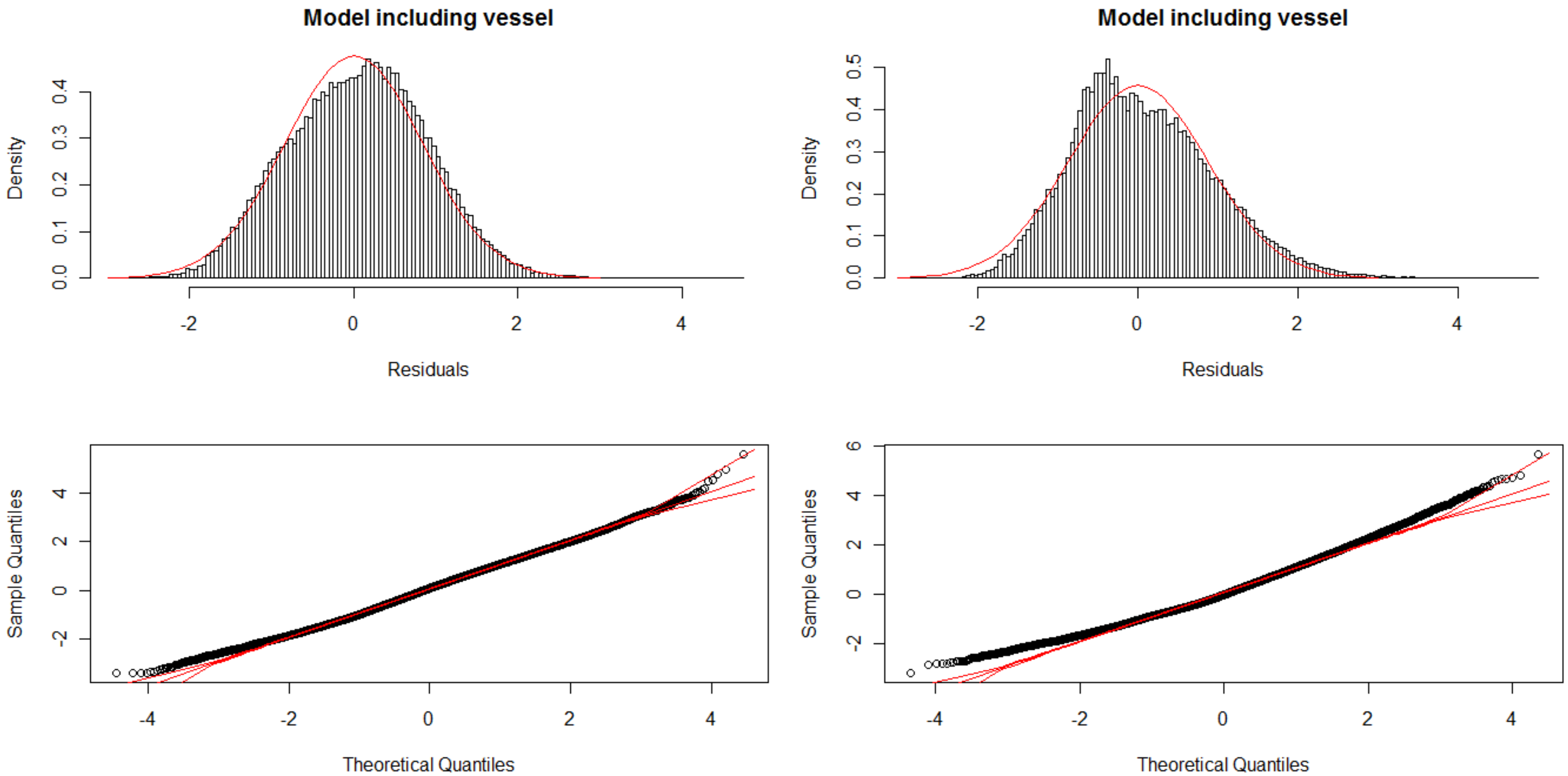


Figure 65: Region 1 residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

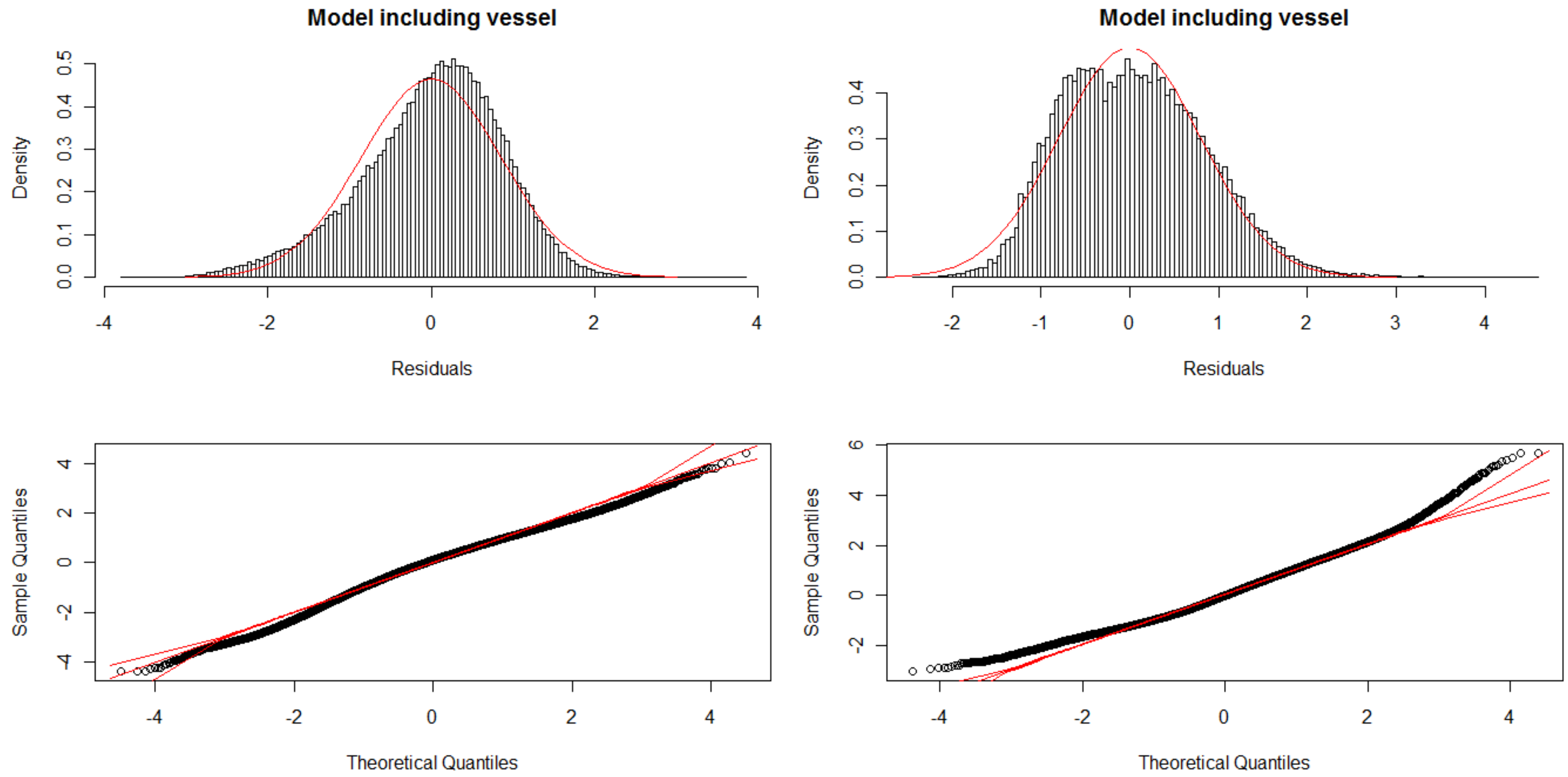


Figure 66: Region 2 residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD’s.

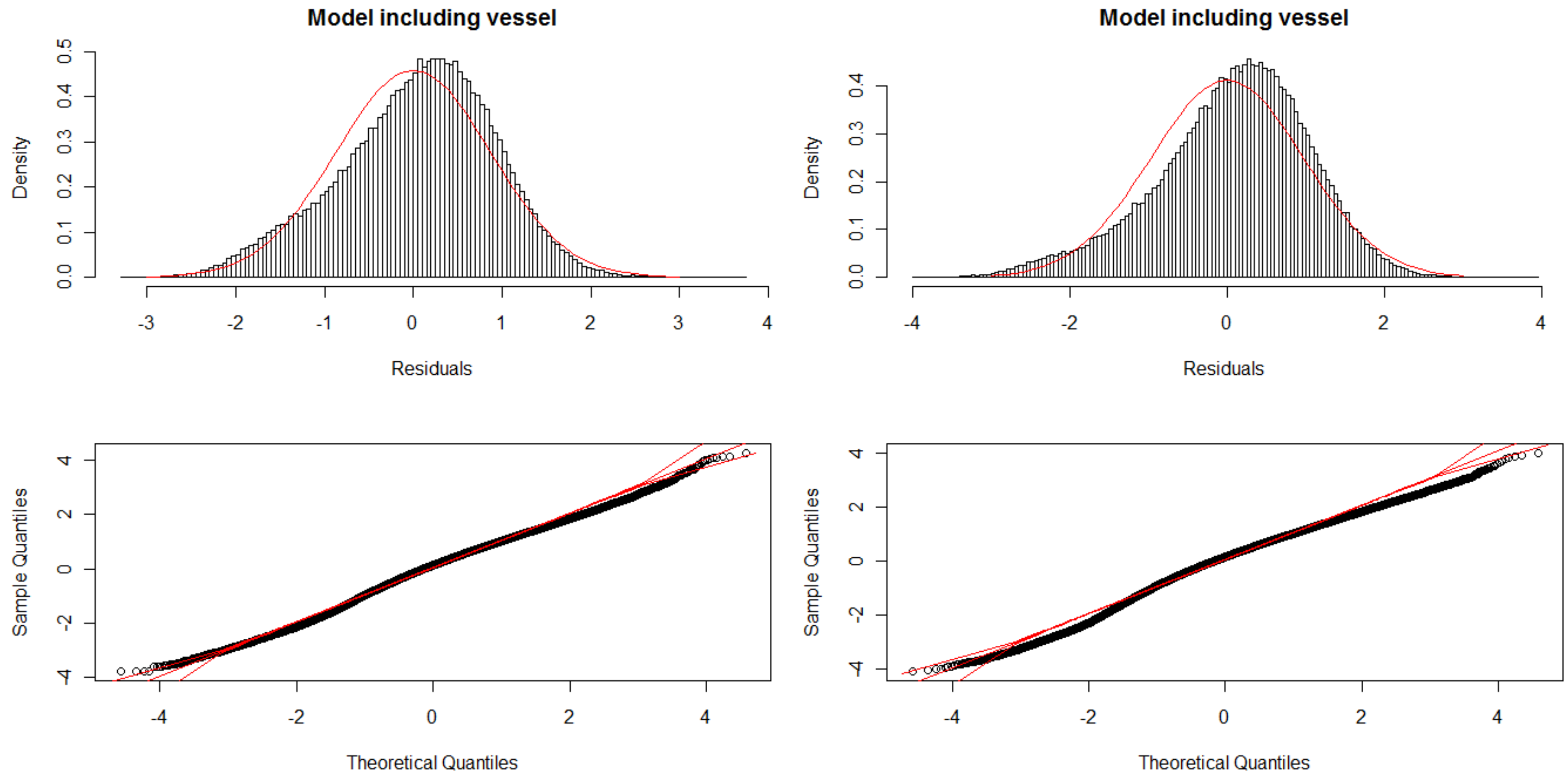


Figure 67: Region 3 residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

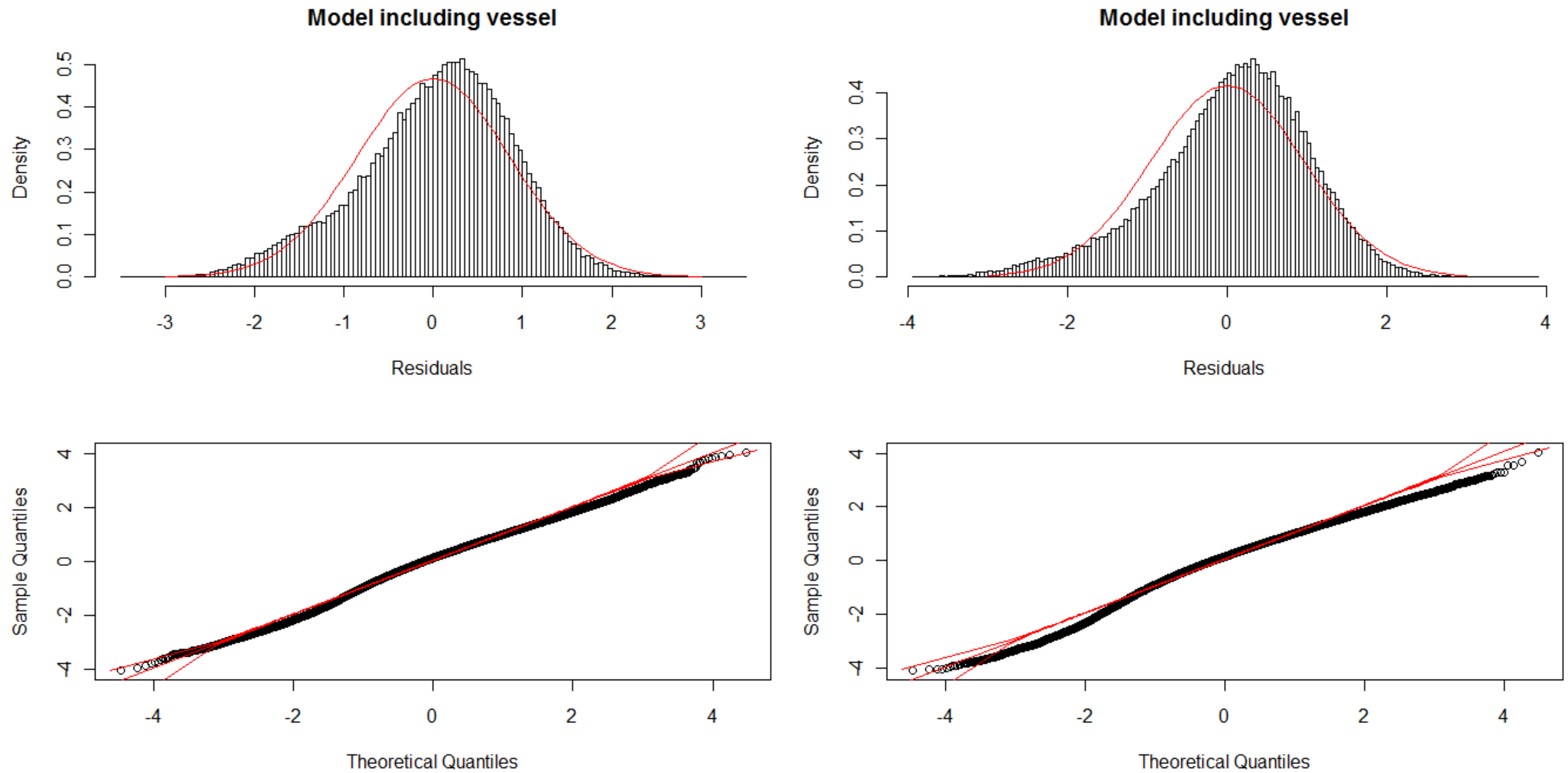


Figure 68: Region 3 equatorial (core area) residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

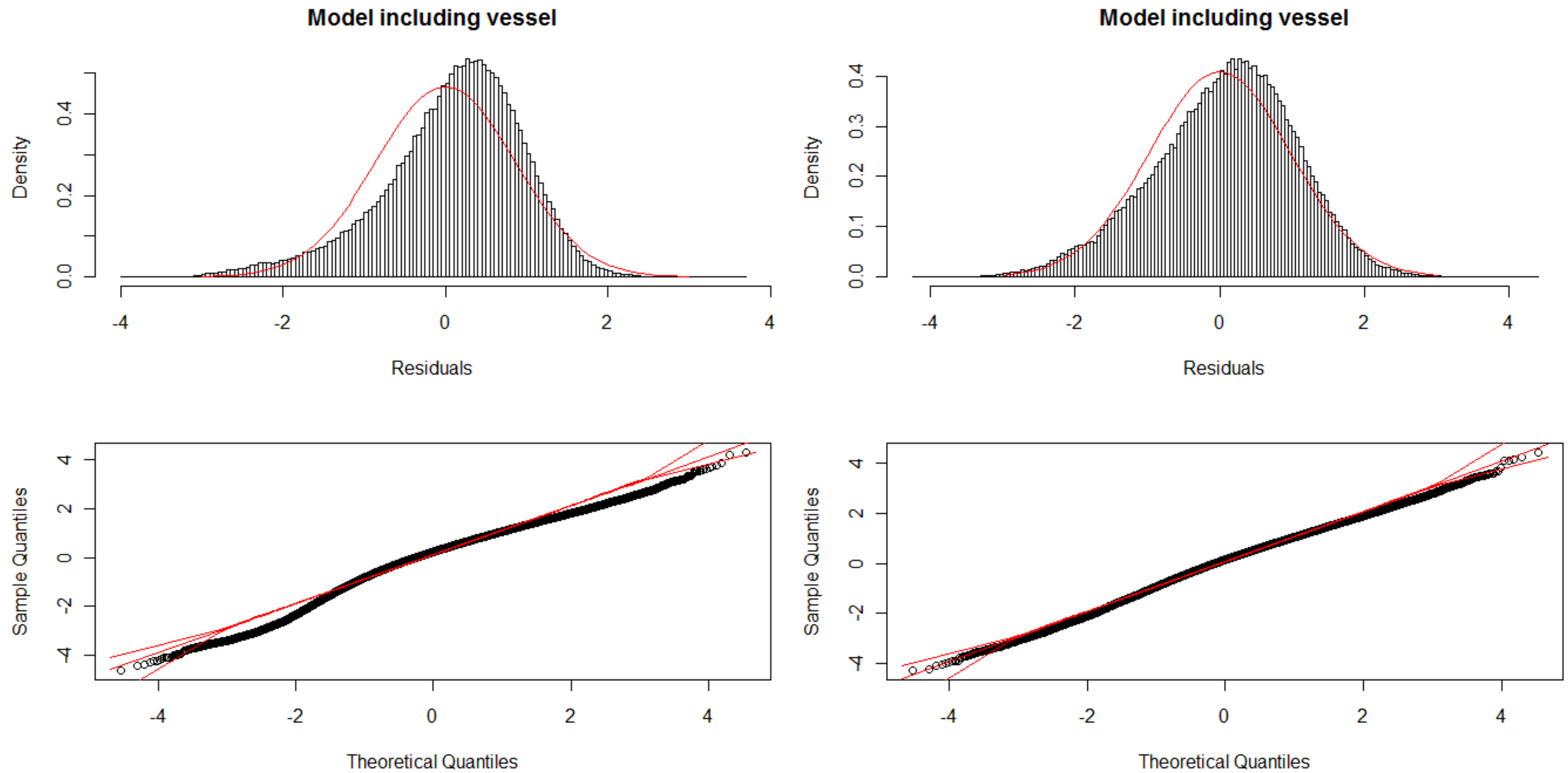


Figure 69: Region 4 residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

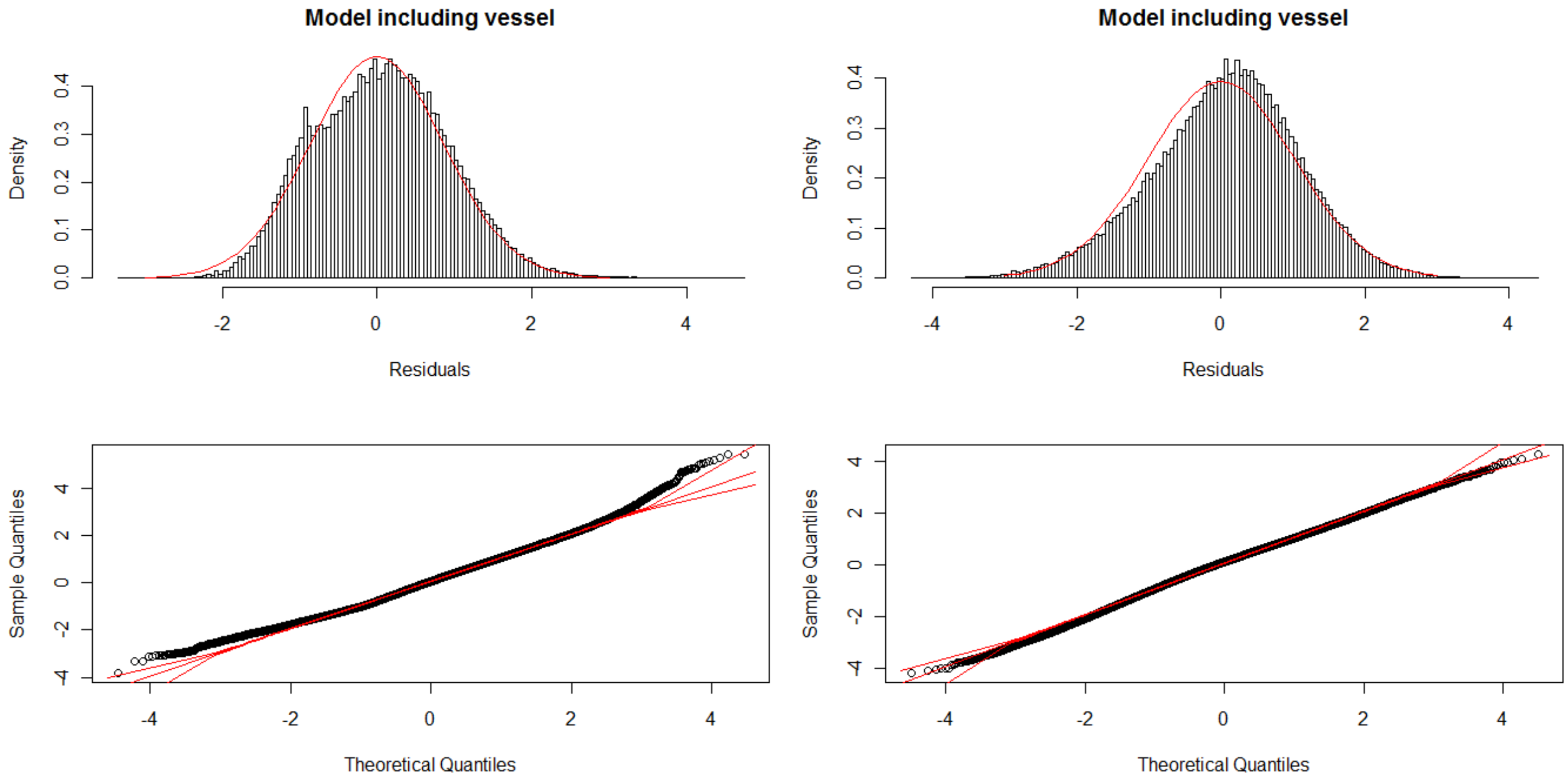


Figure 70: Region 5 residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

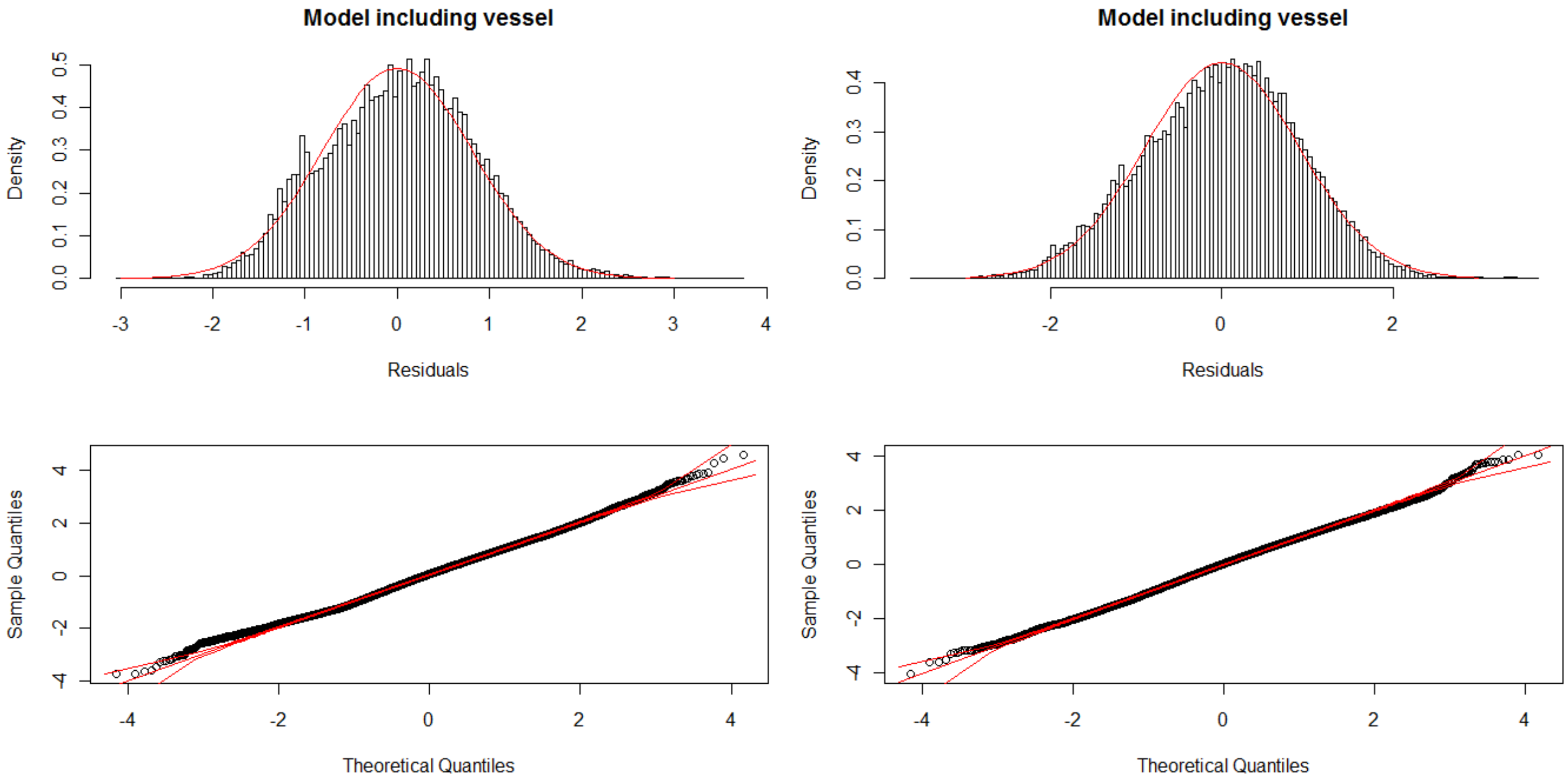


Figure 71: Region 6 residual density histograms for bigeye (left) and yellowfin (right), from the positive components of models that included the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (below) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

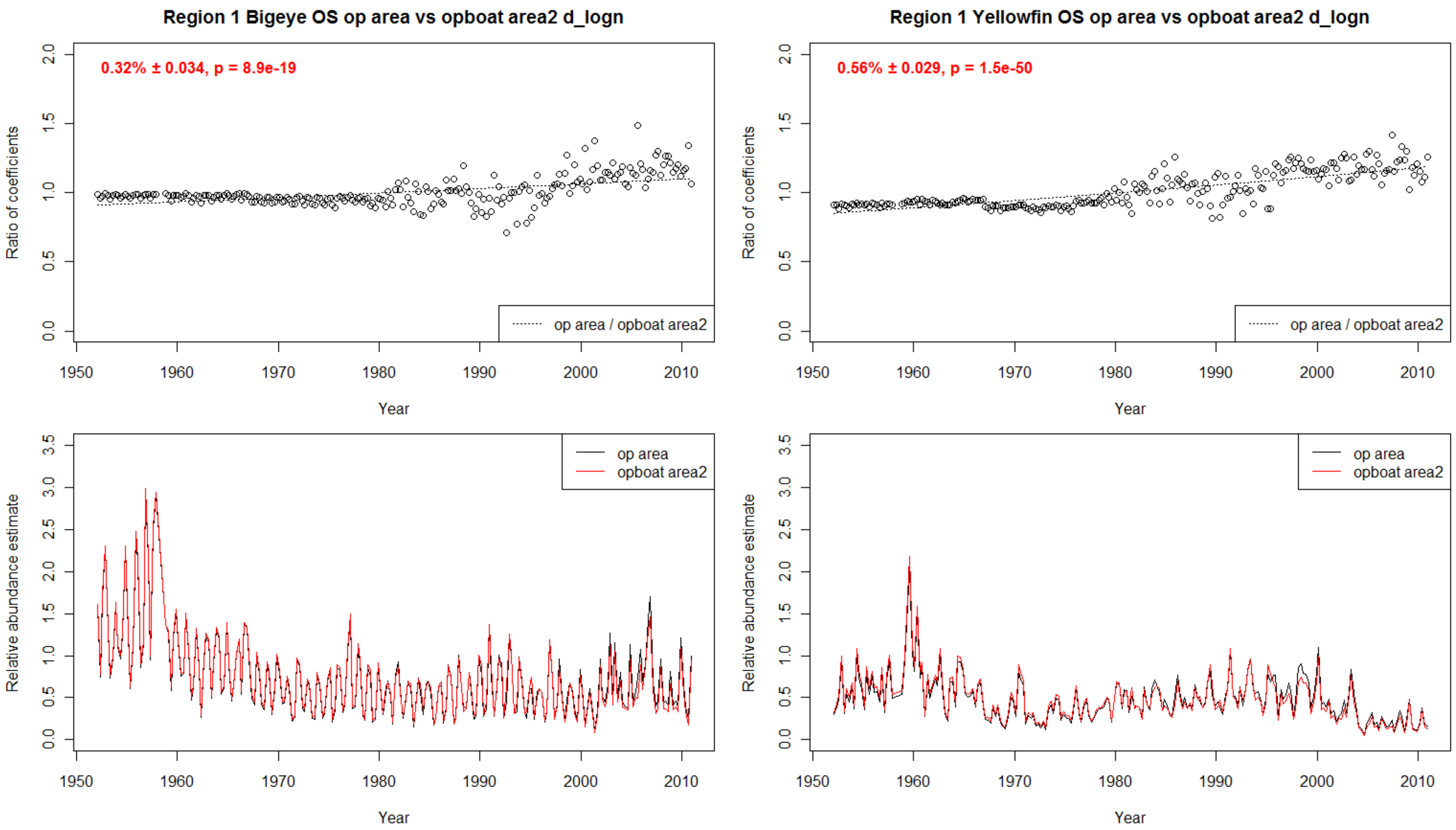


Figure 72: Region 1 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

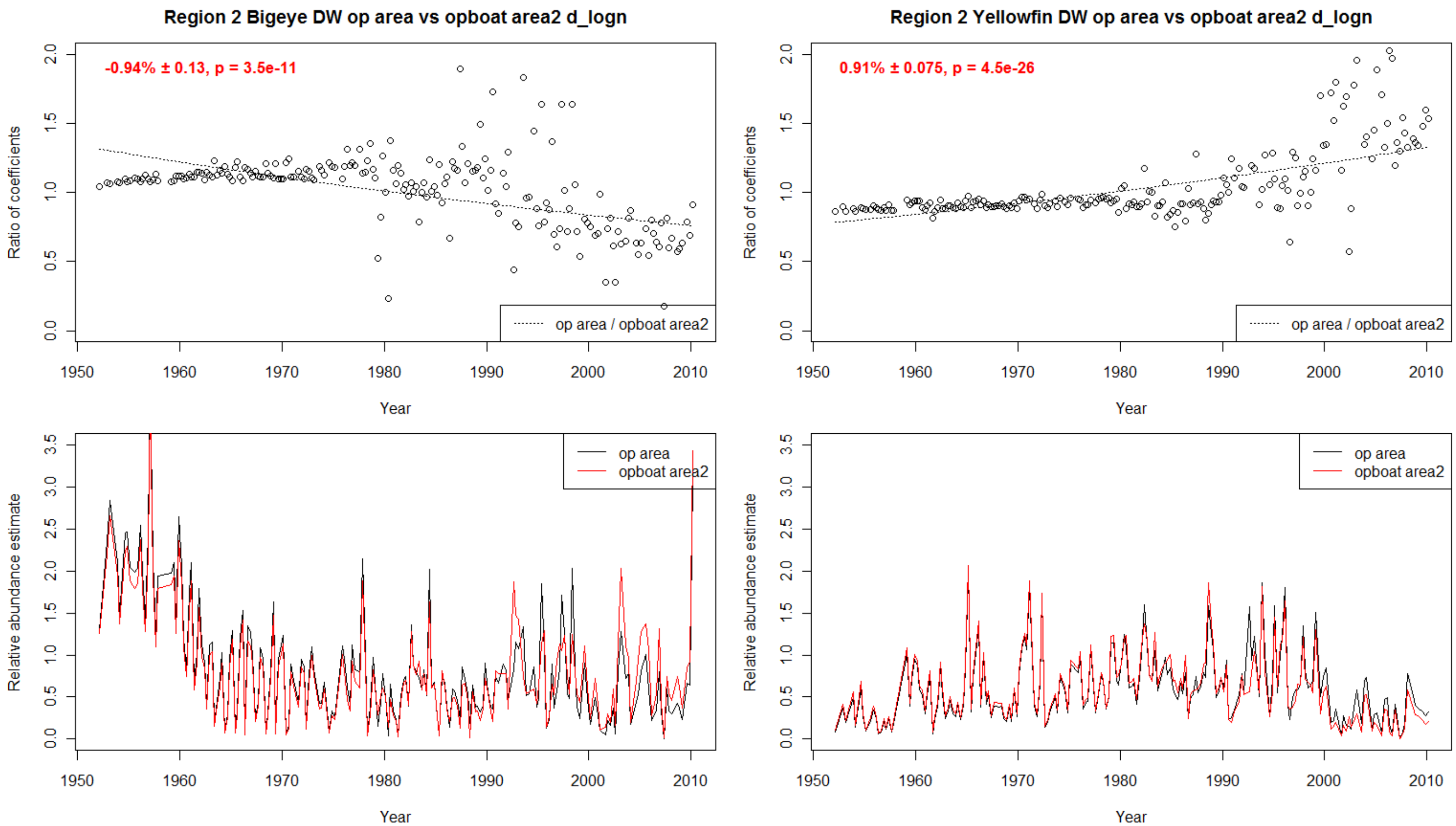


Figure 73: Region 2 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

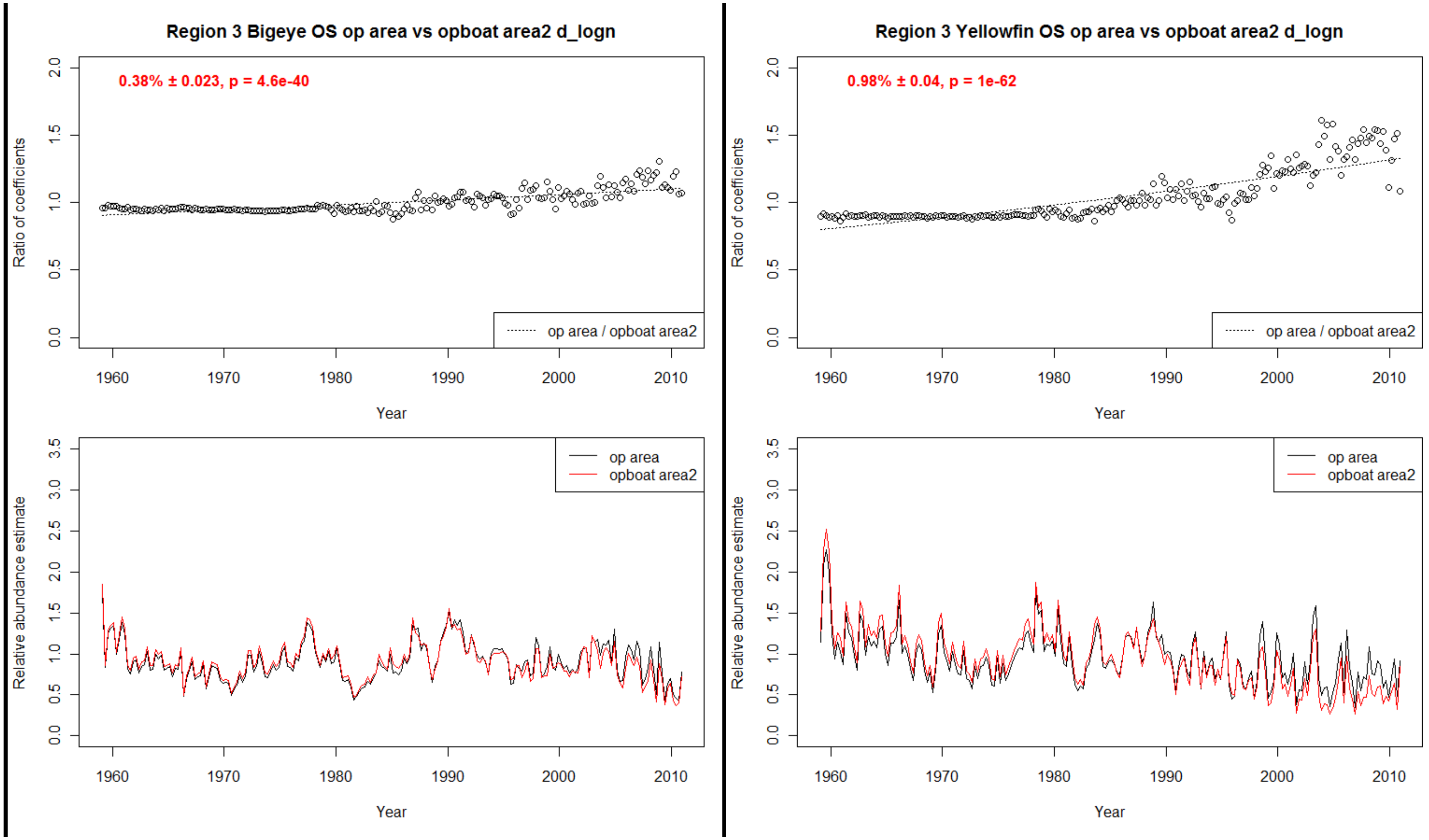


Figure 74: Region 3 (whole area) comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

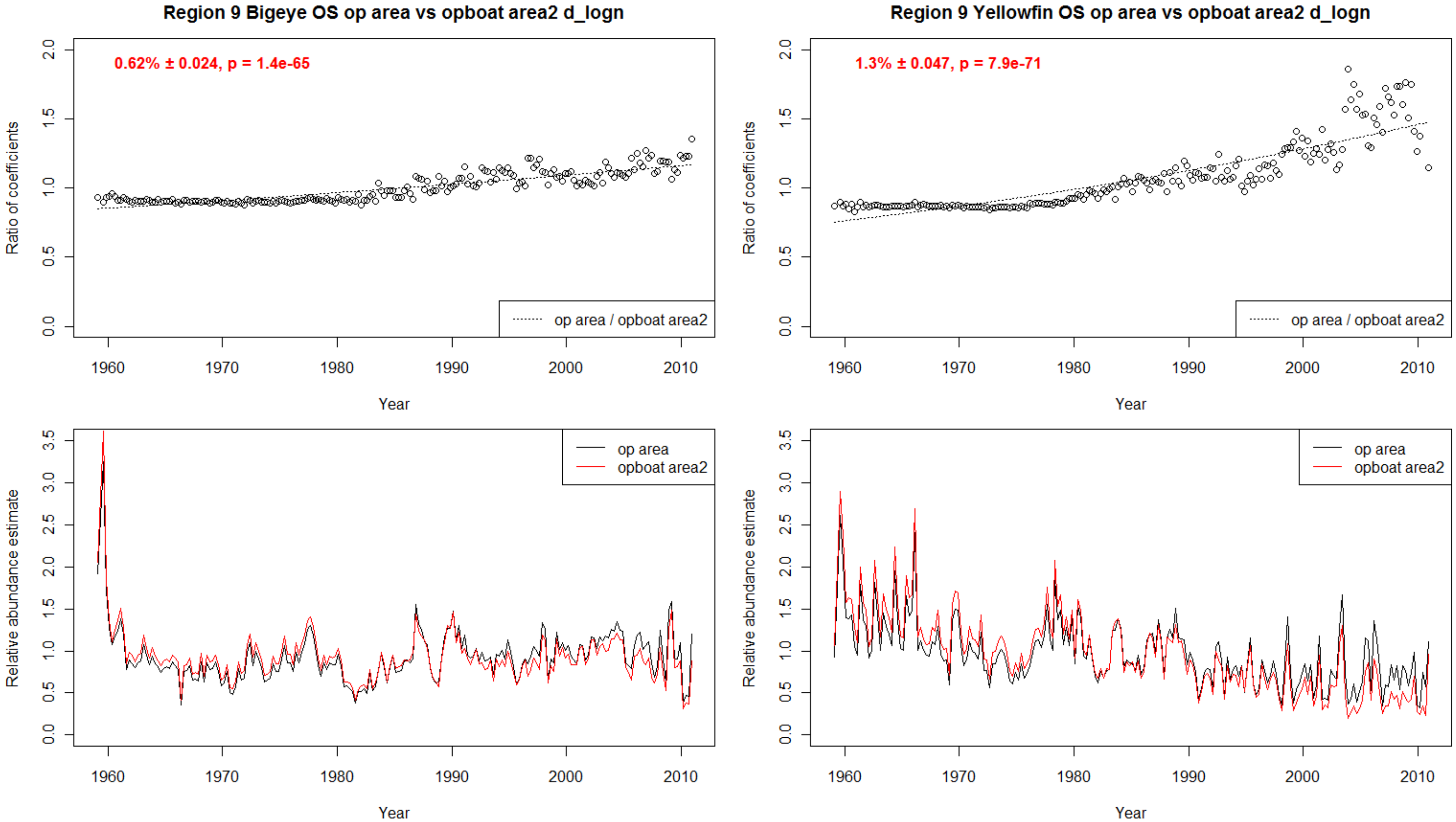


Figure 75: Region 3 (core area 5S to 10N) comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

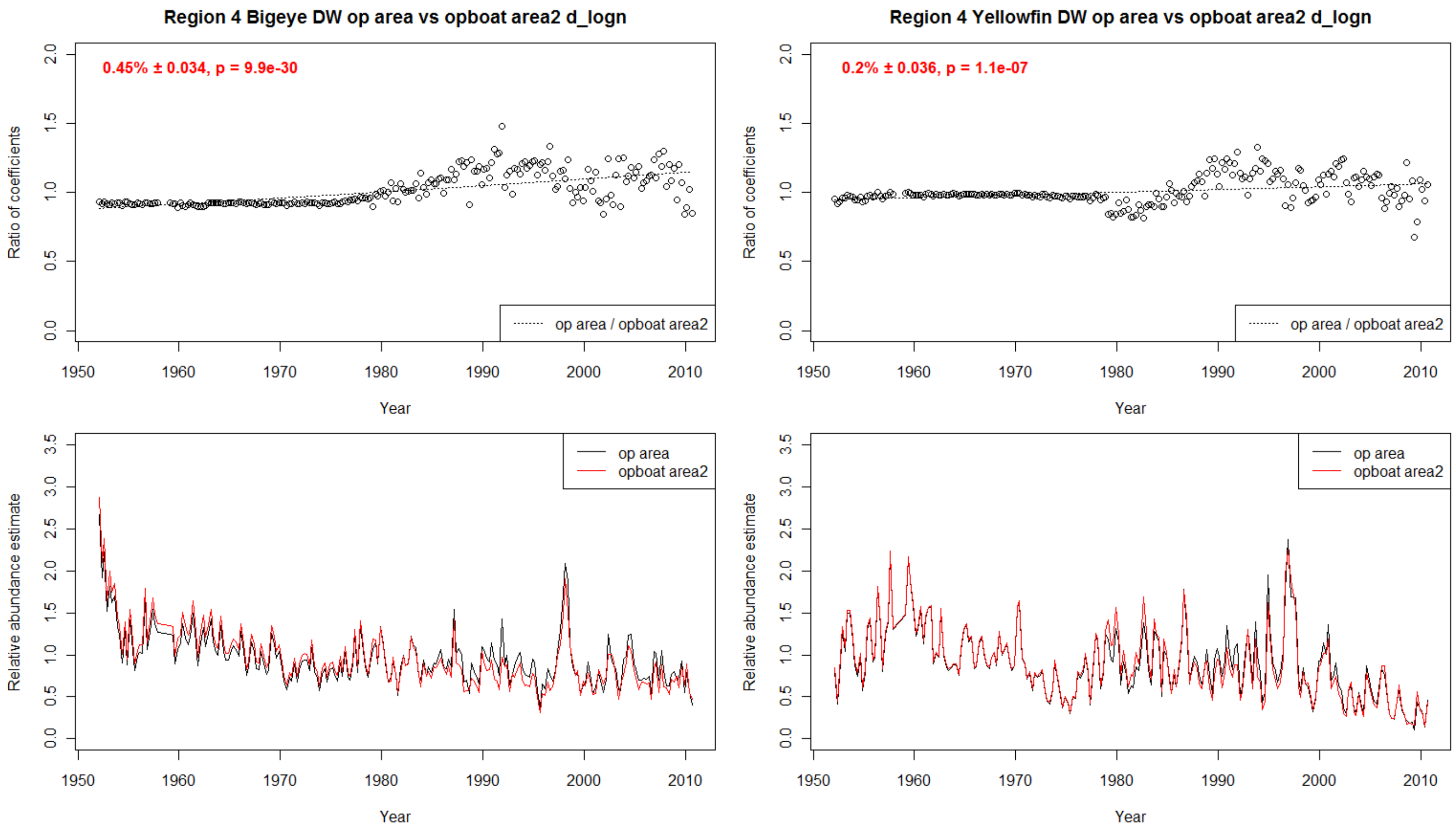


Figure 76: Region 4 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

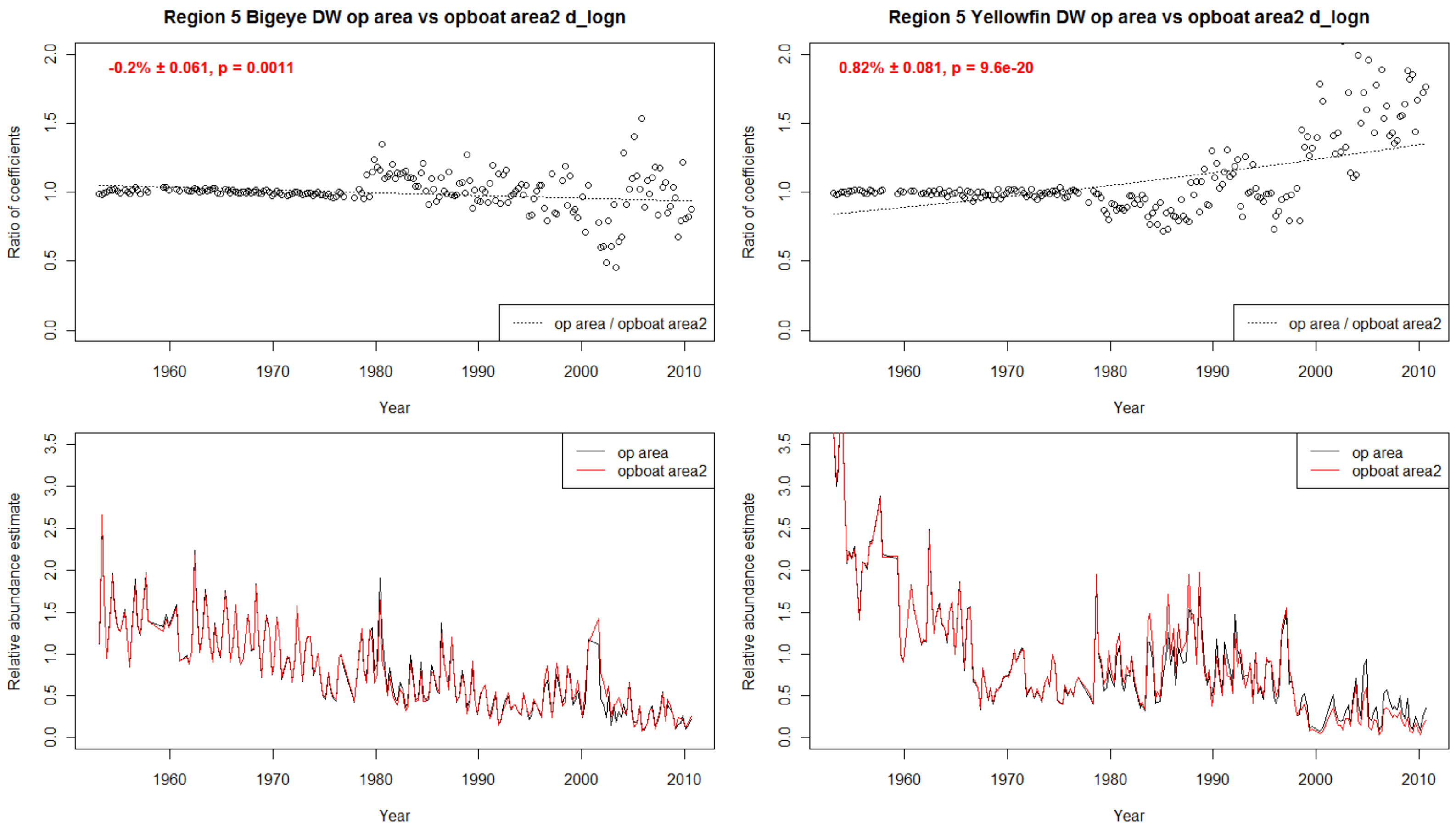


Figure 77: Region 5 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

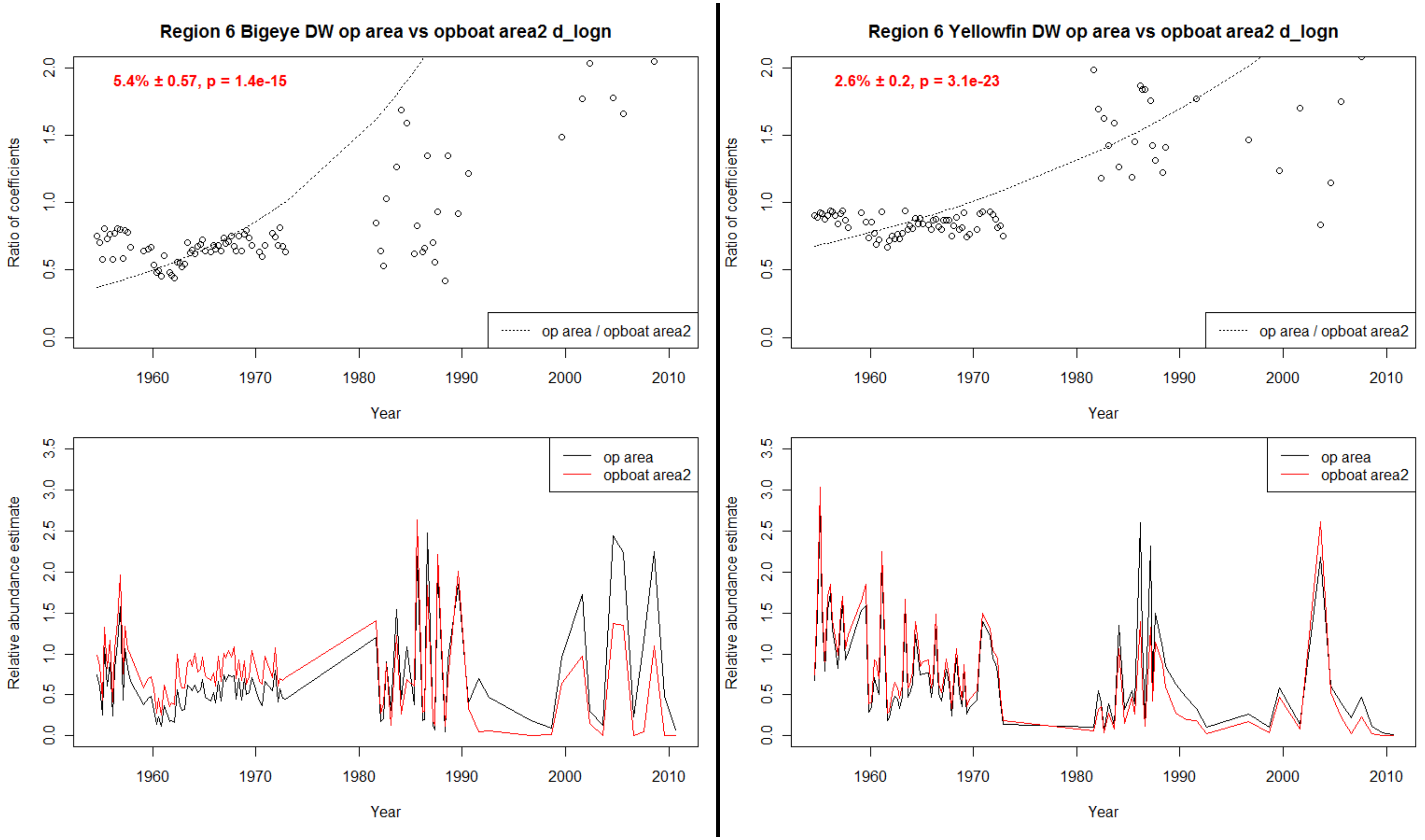


Figure 78: Region 6 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value. The trend is an average for the whole time period 1952-2010.

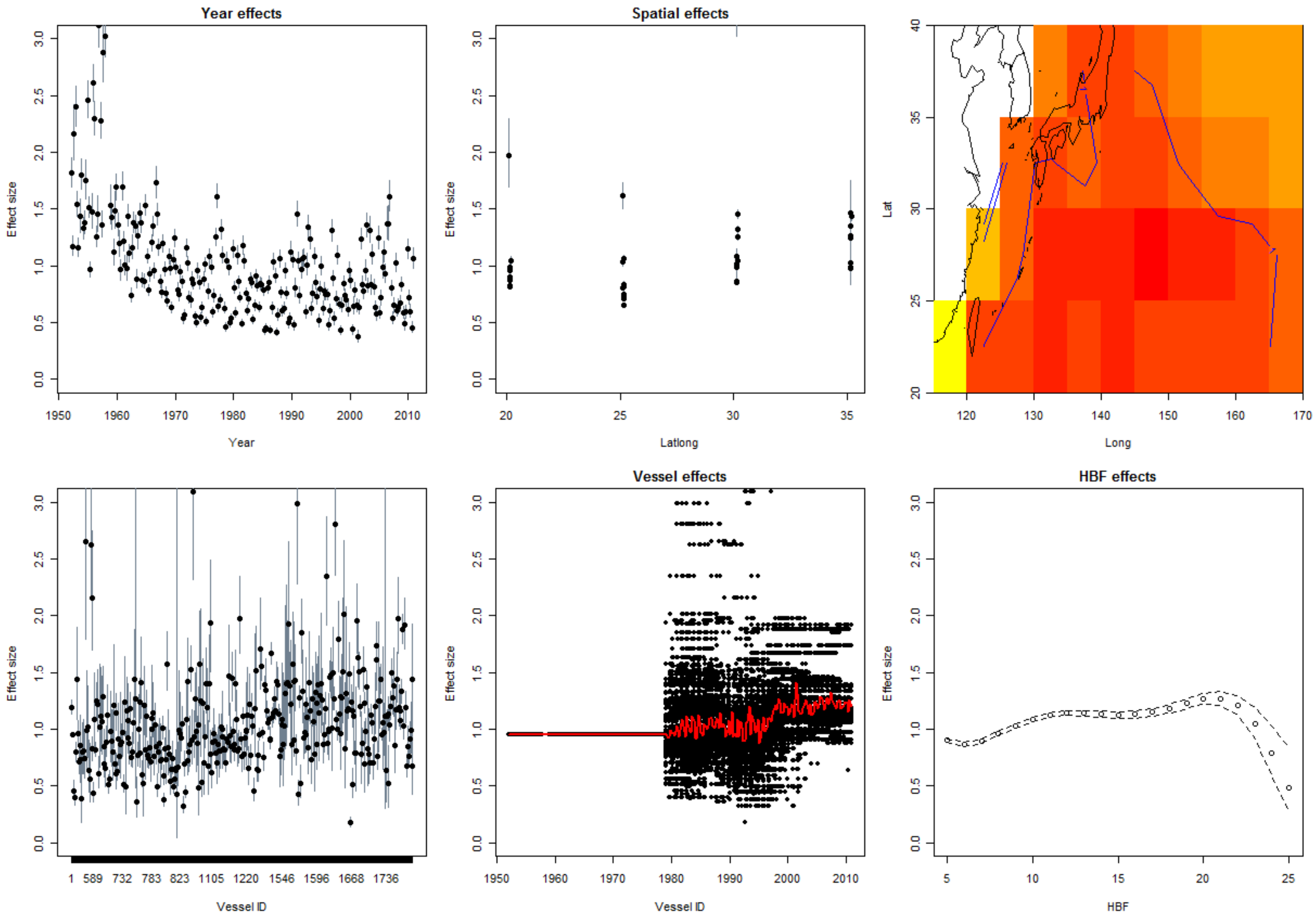


Figure 79: Estimated effects for region 1 bigeye OS. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

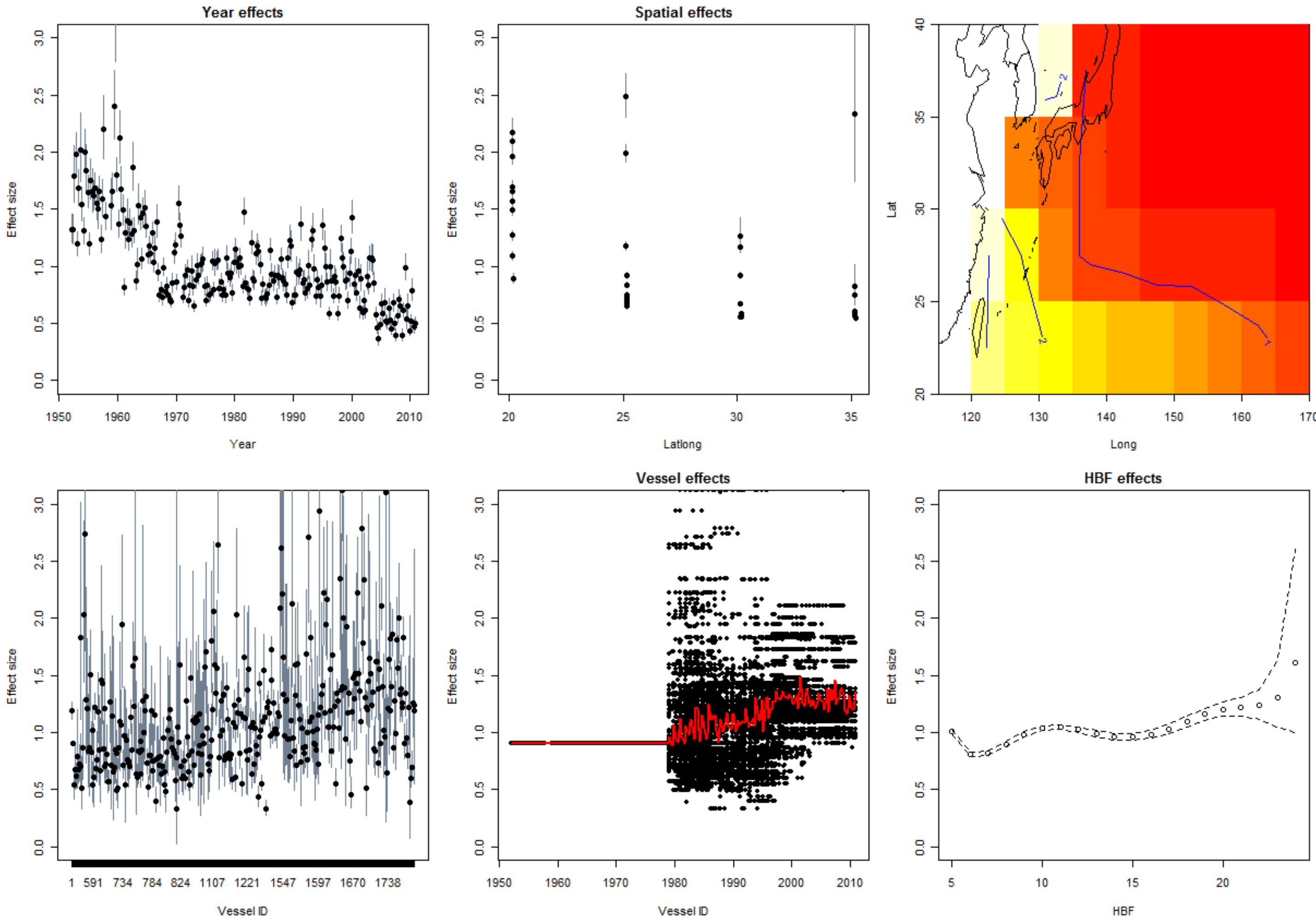


Figure 80: Estimated effects for region 1 yellowfin OS. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

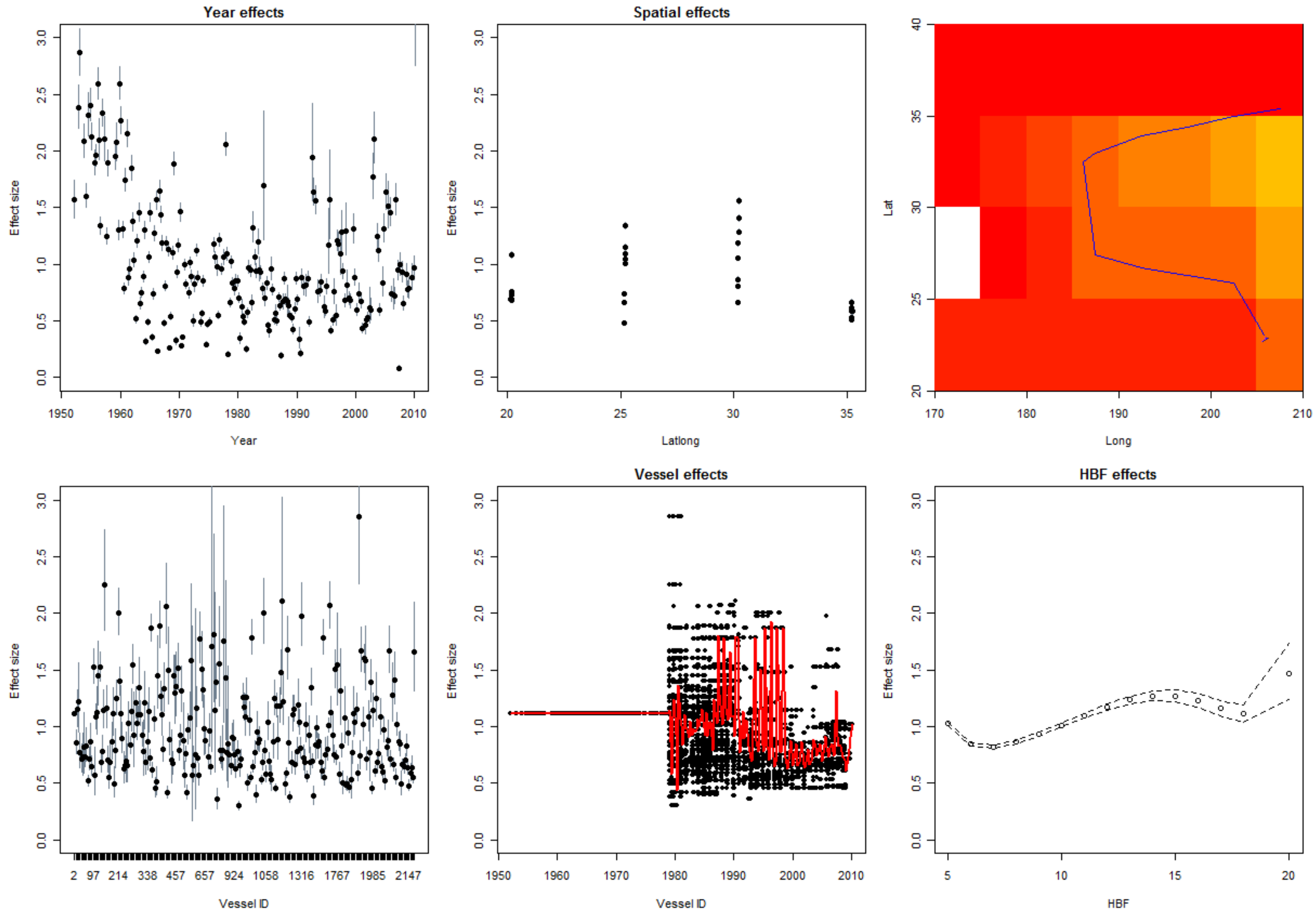


Figure 81: Estimated effects for region 2 bigeye DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

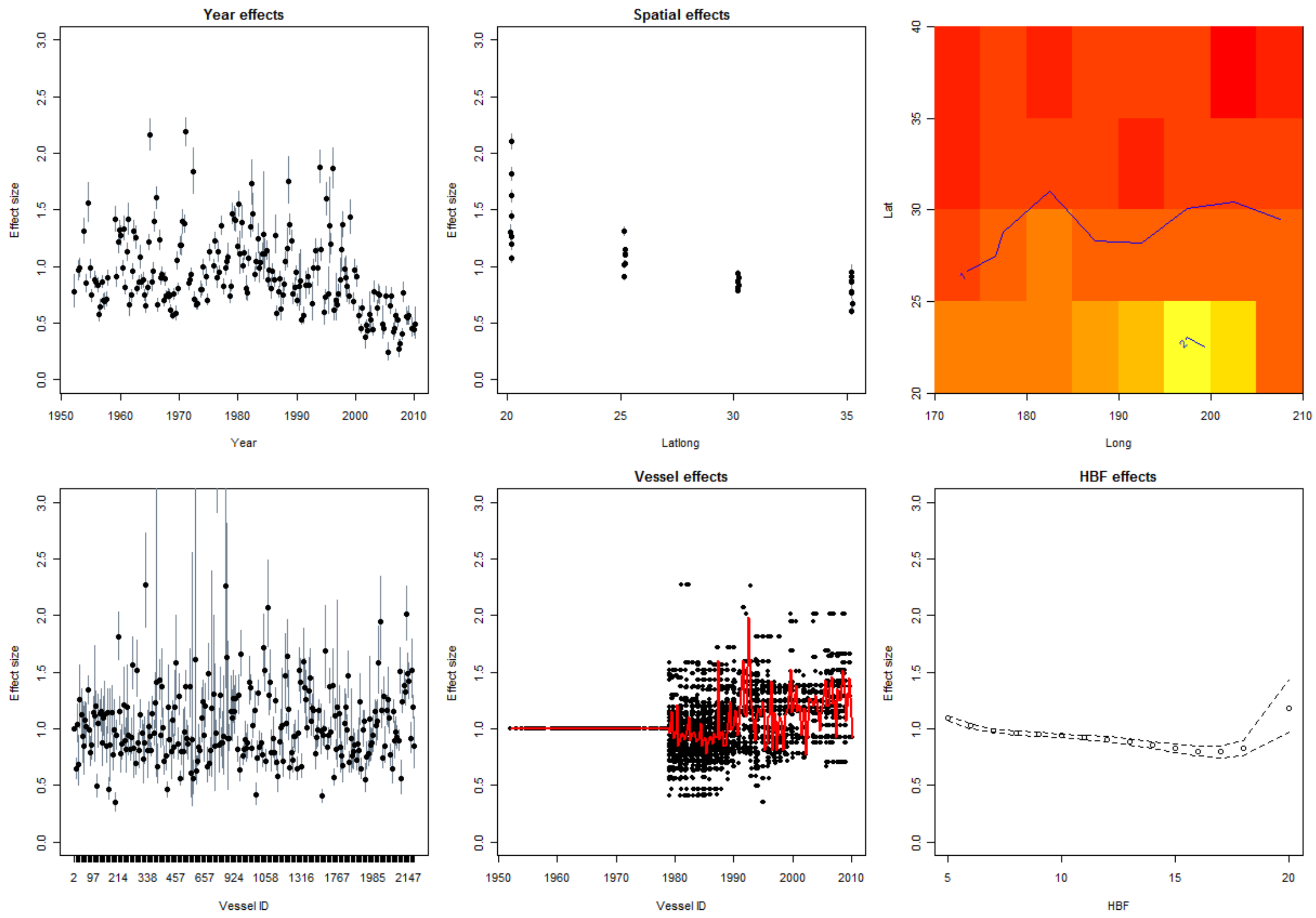


Figure 82: Estimated effects for region 2 yellowfin DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

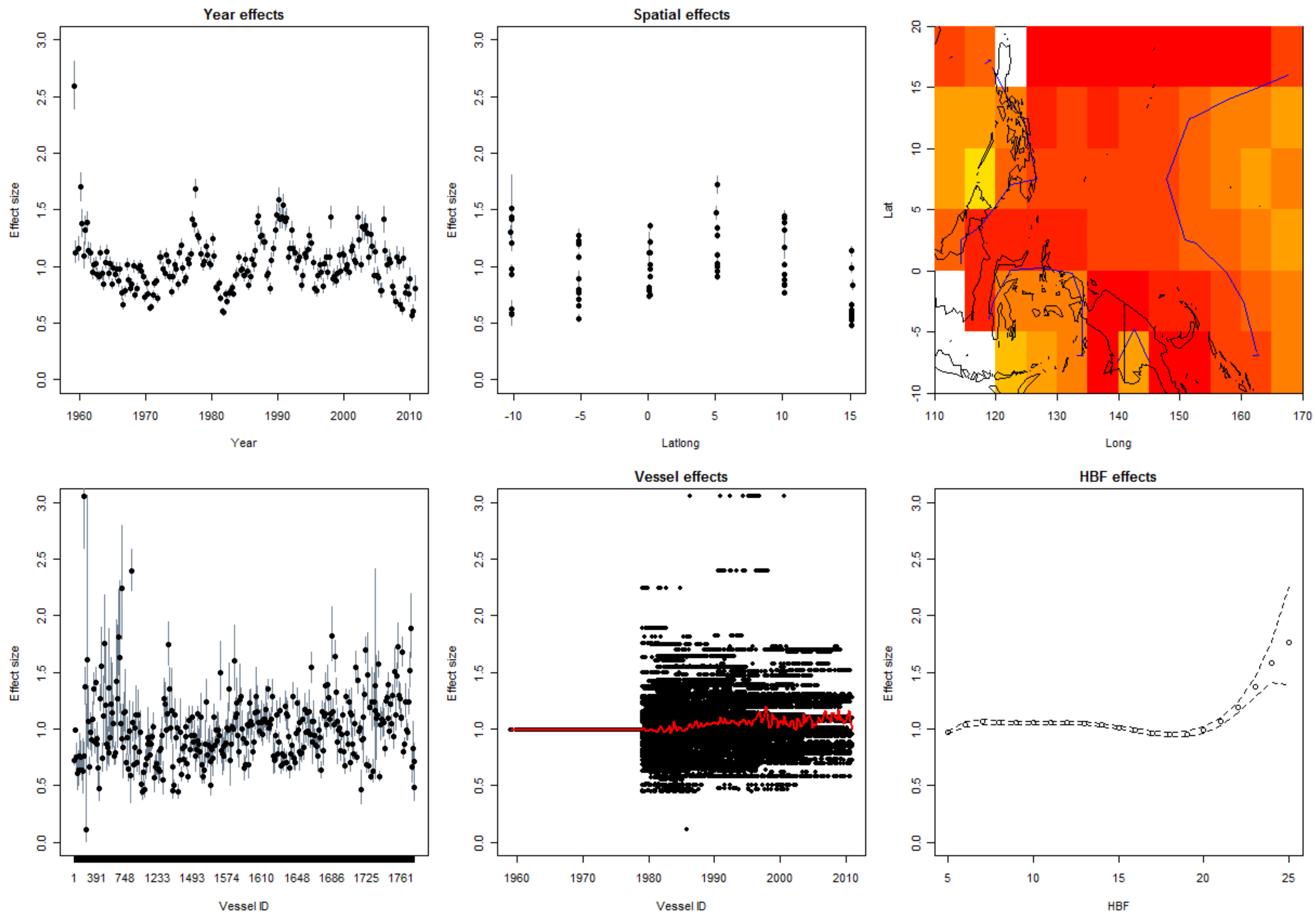


Figure 83: Estimated effects for region 3 (whole region) bigeye OS. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

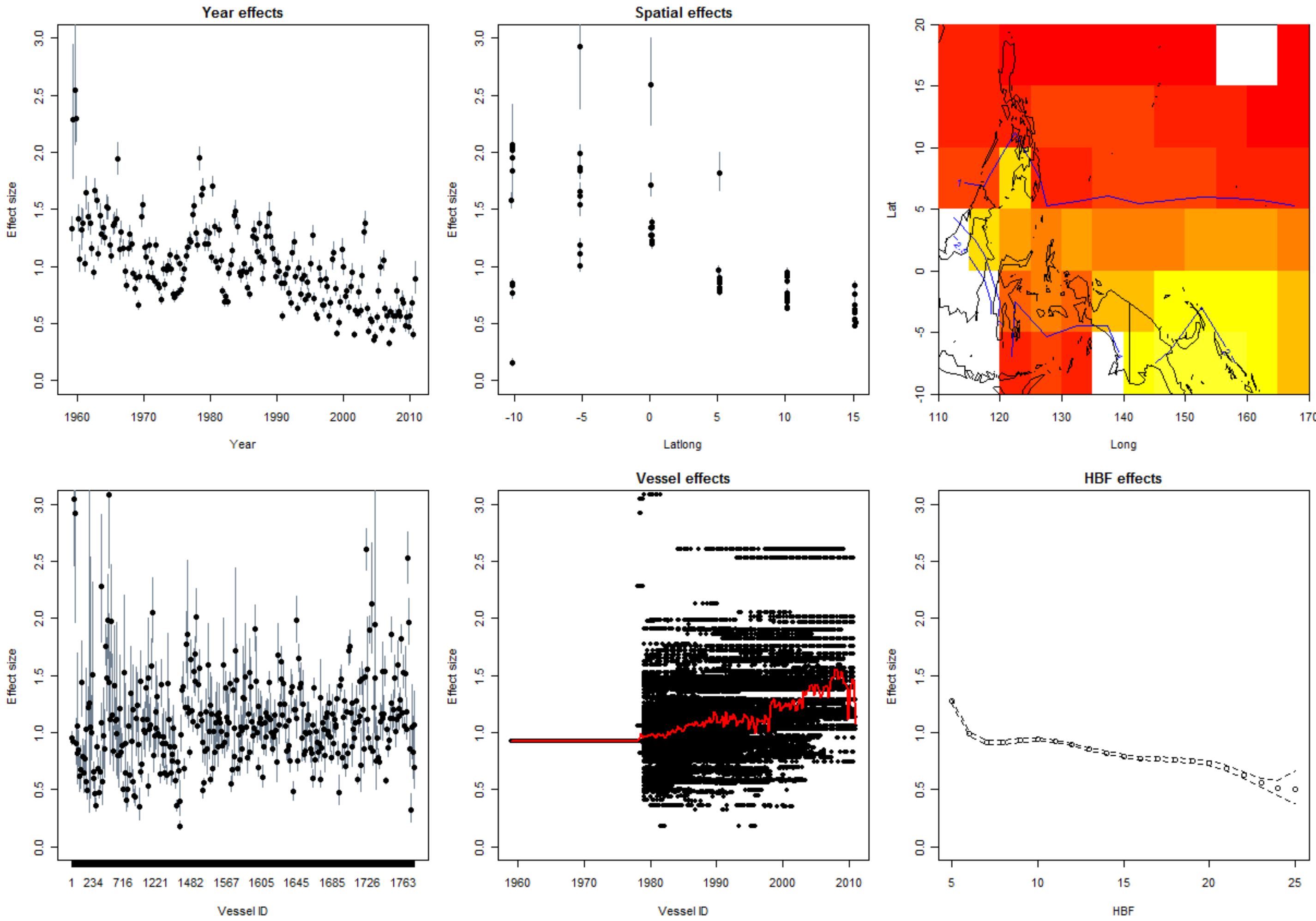


Figure 84: Estimated effects for region 3 (whole region) yellowfin OS. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

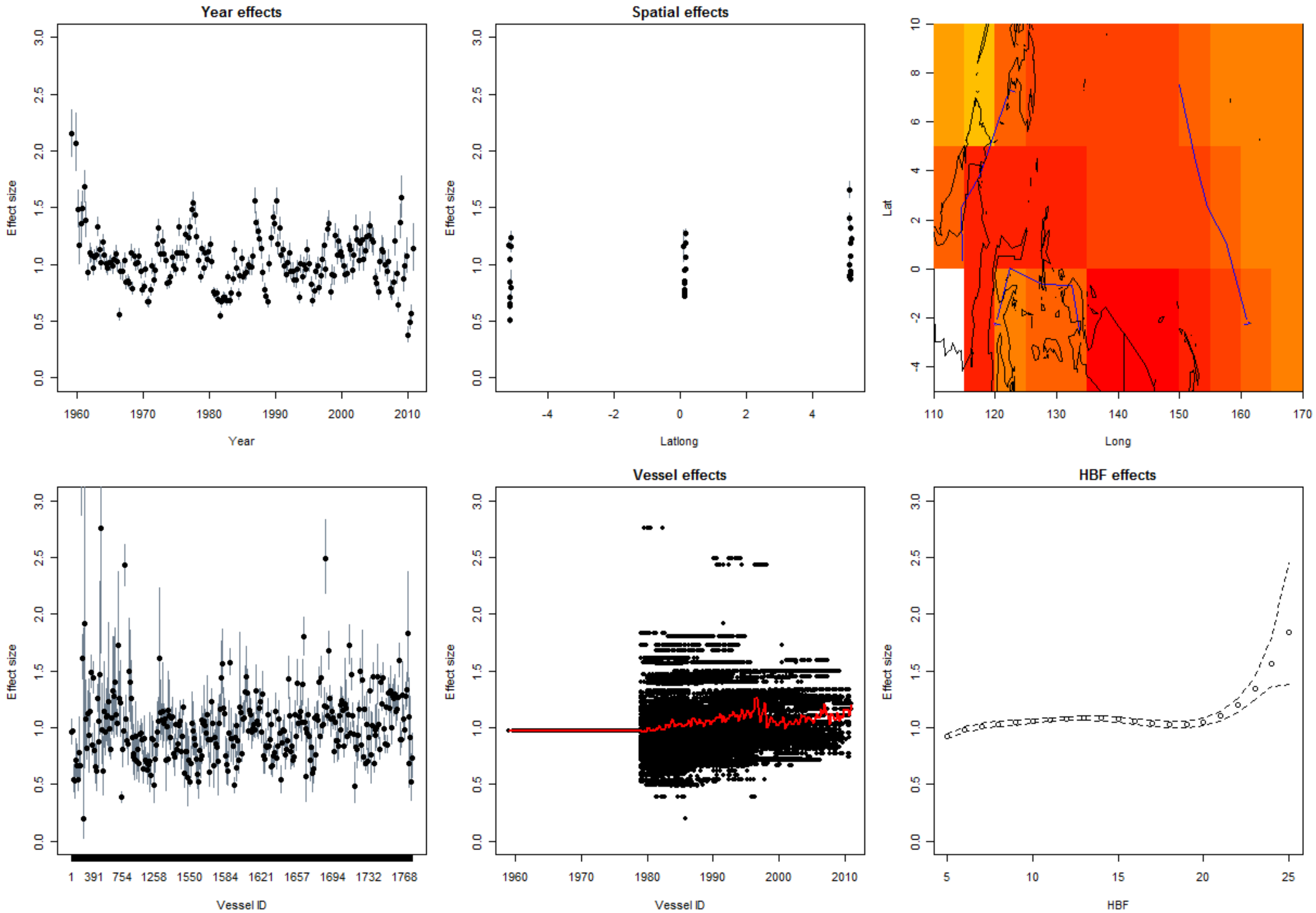


Figure 85: Estimated effects for region 3 (equatorial) bigeye OS. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

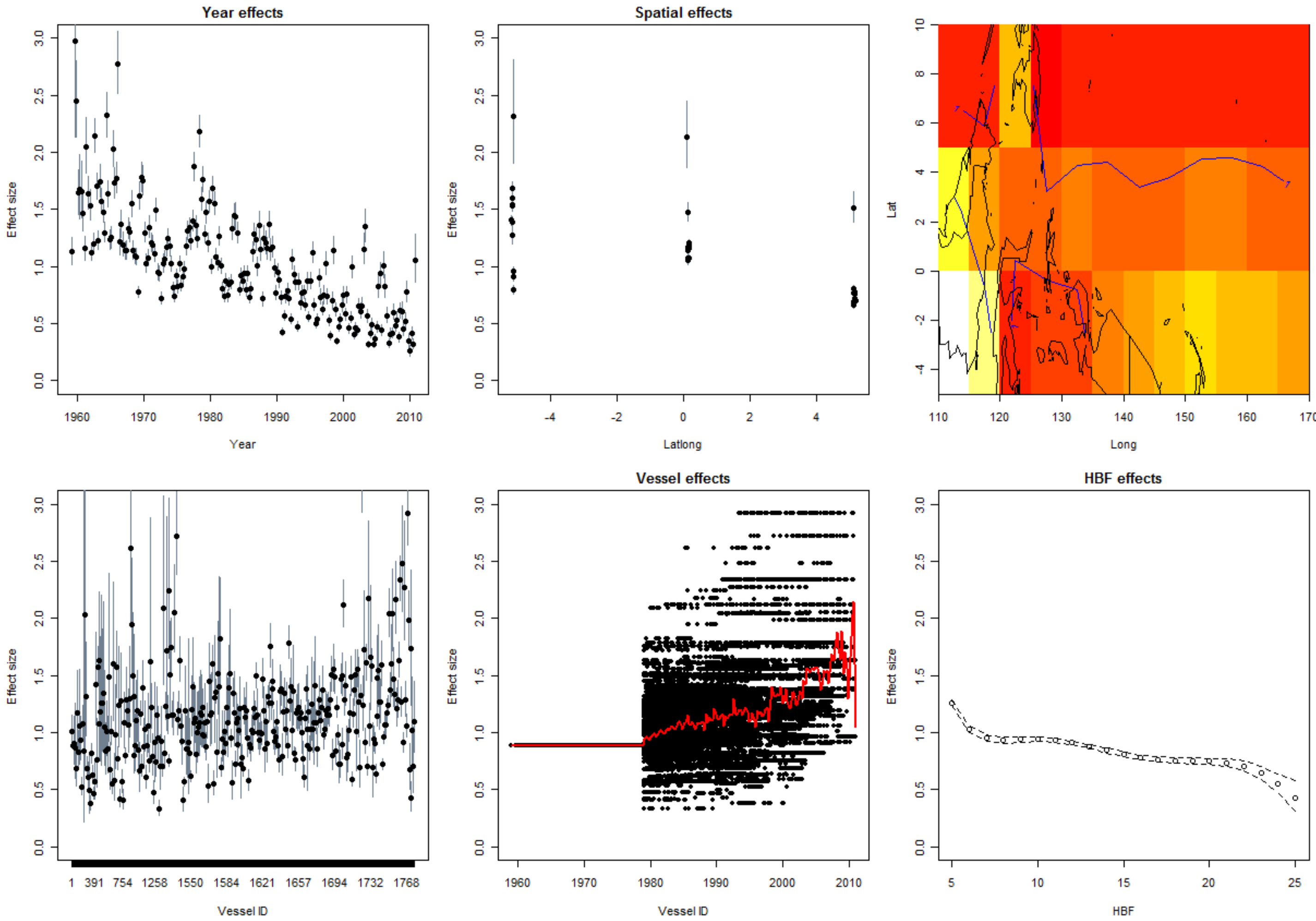


Figure 86: Estimated effects for region 3 (core equatorial area) yellowfin OS. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

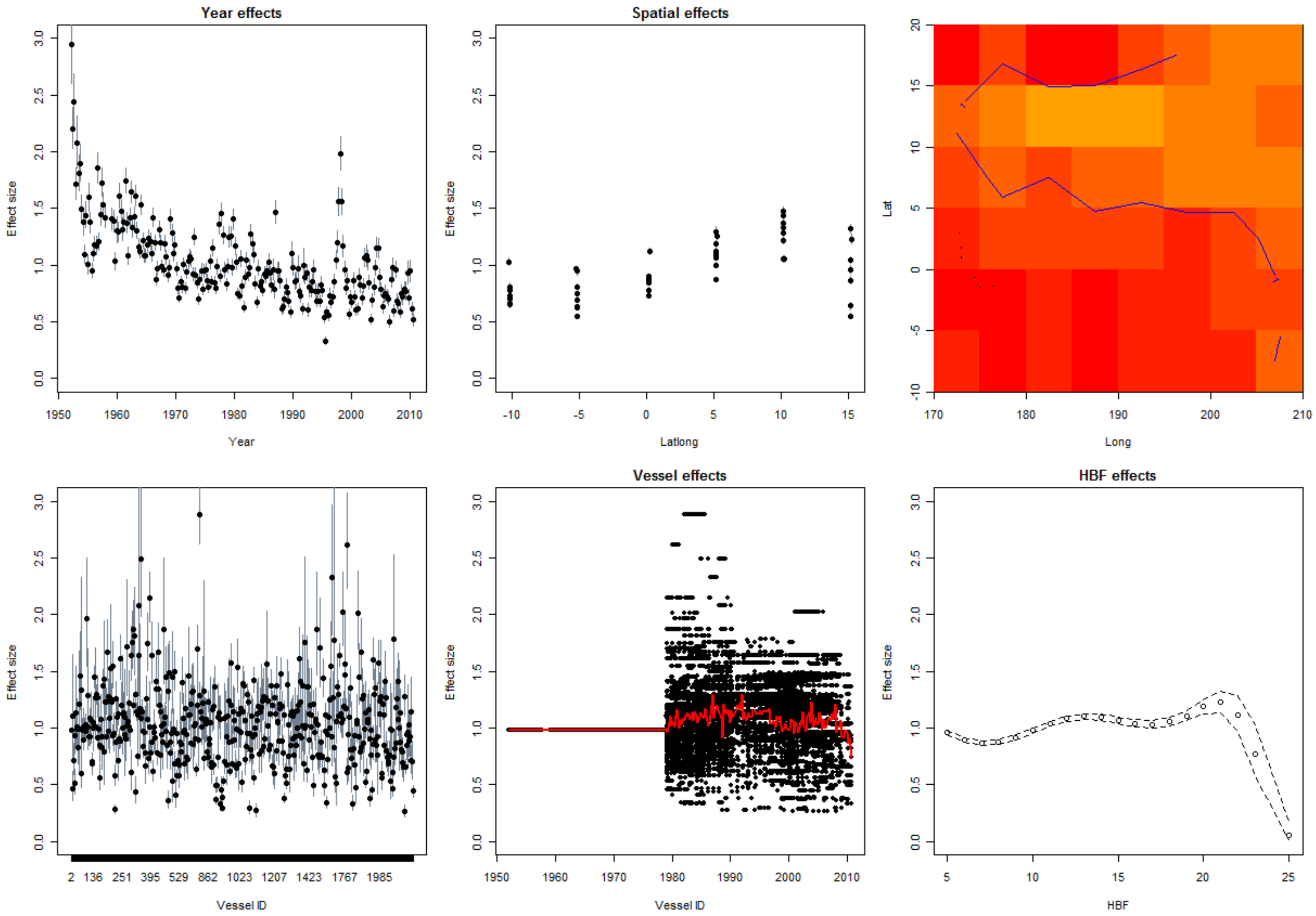


Figure 87: Estimated effects for region 4 bigeye DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

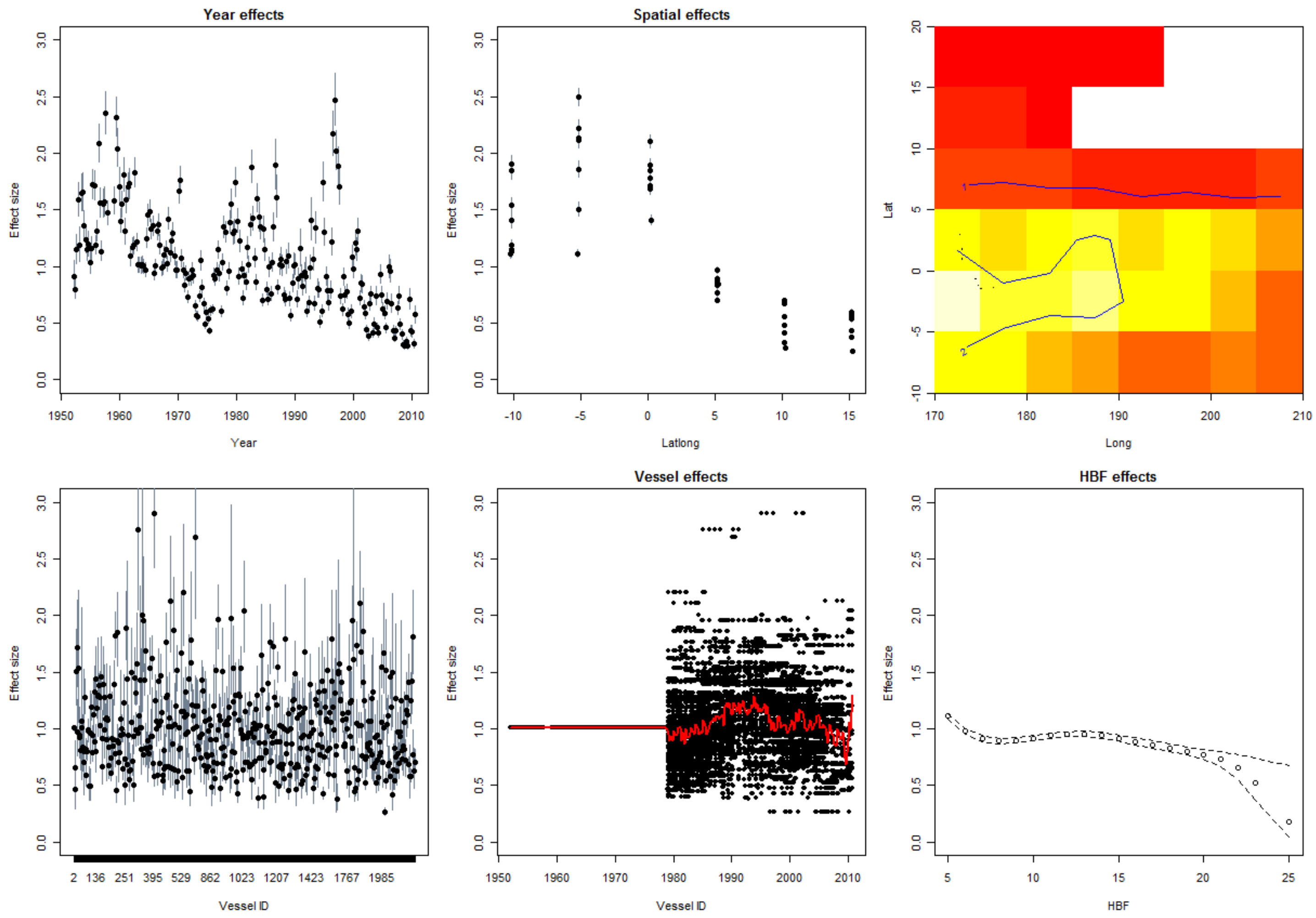


Figure 88: Estimated effects for region 4 yellowfin DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

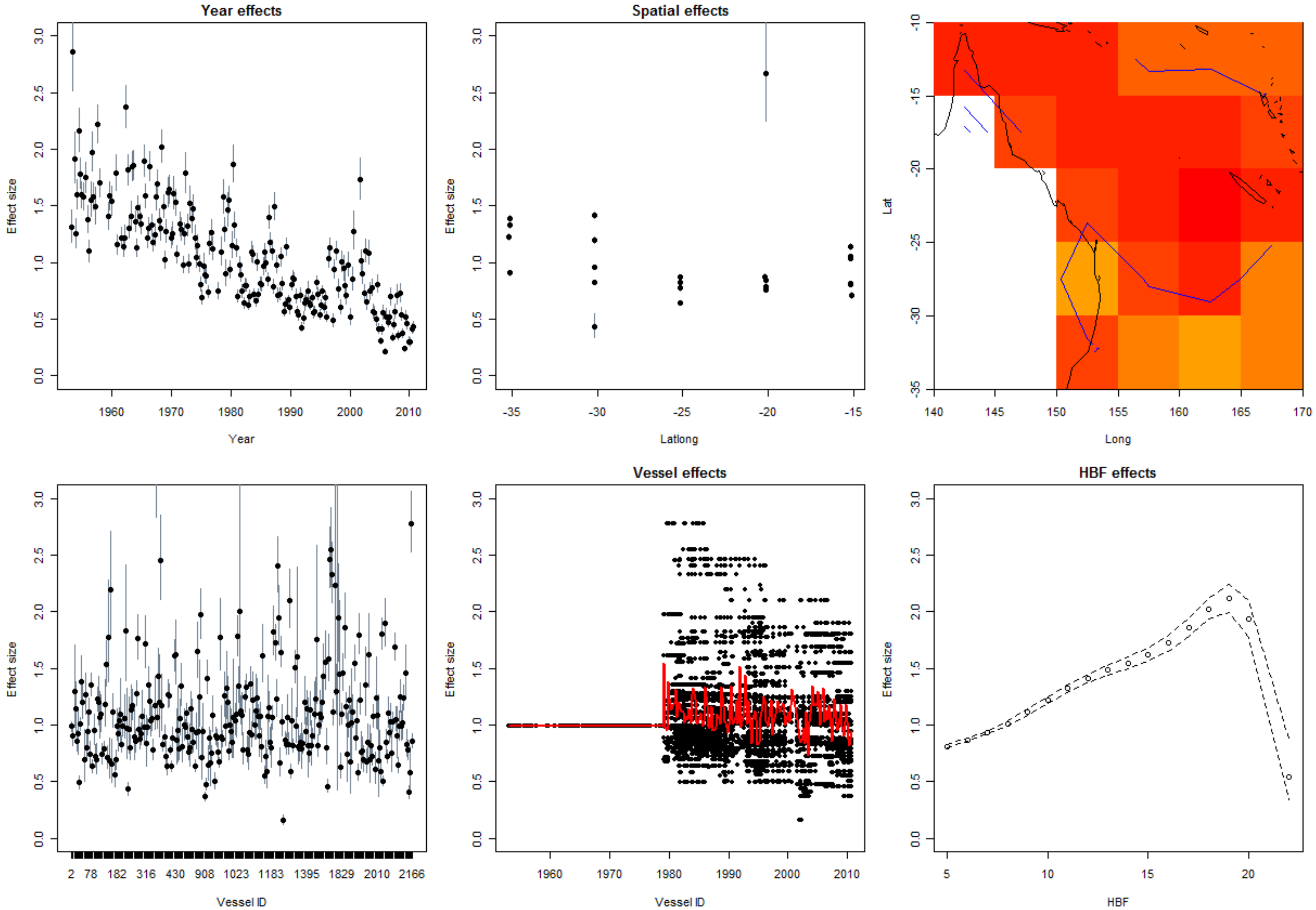


Figure 89: Estimated effects for region 5 bigeye DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

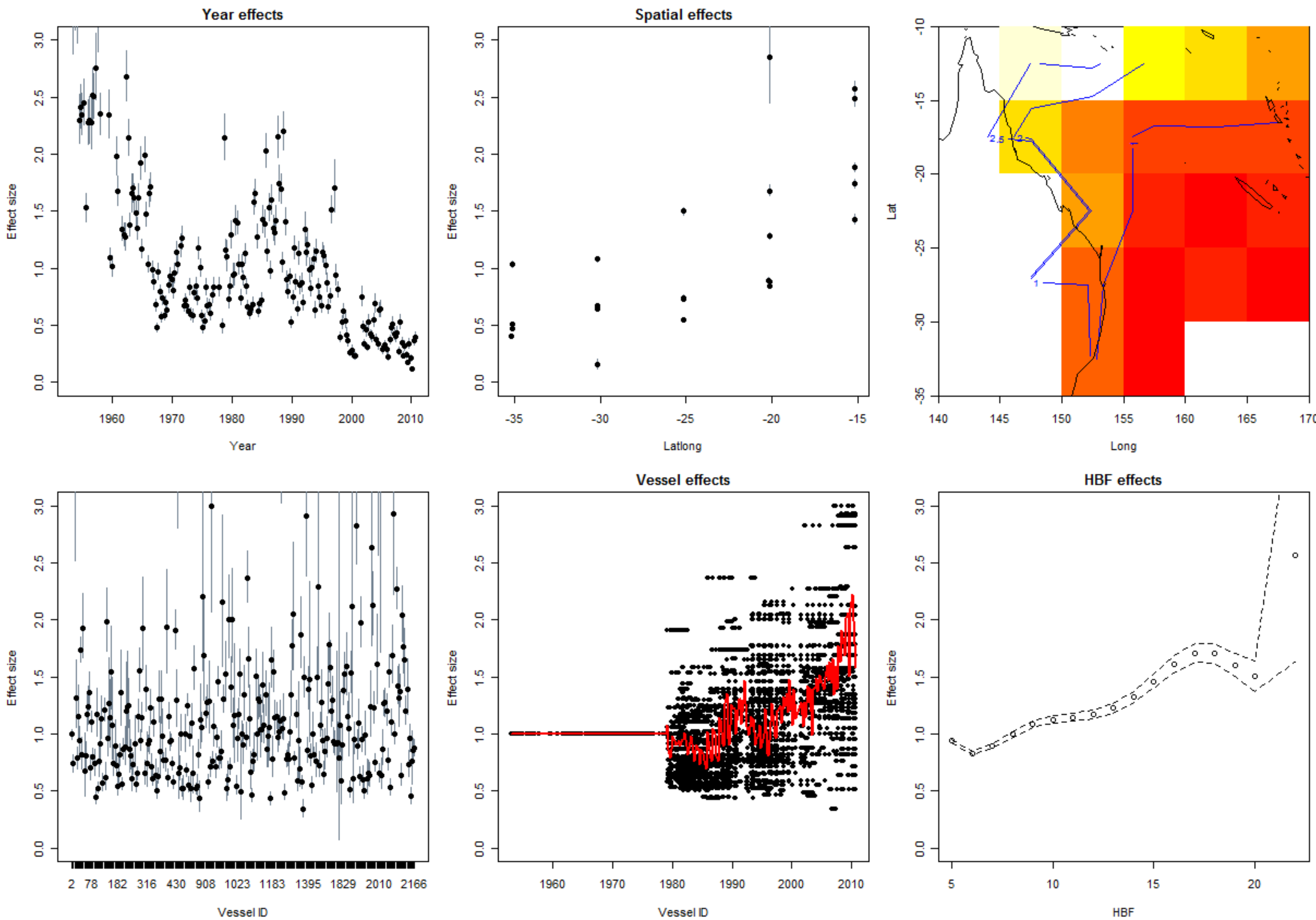


Figure 90: Estimated effects for region 5 yellowfin DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

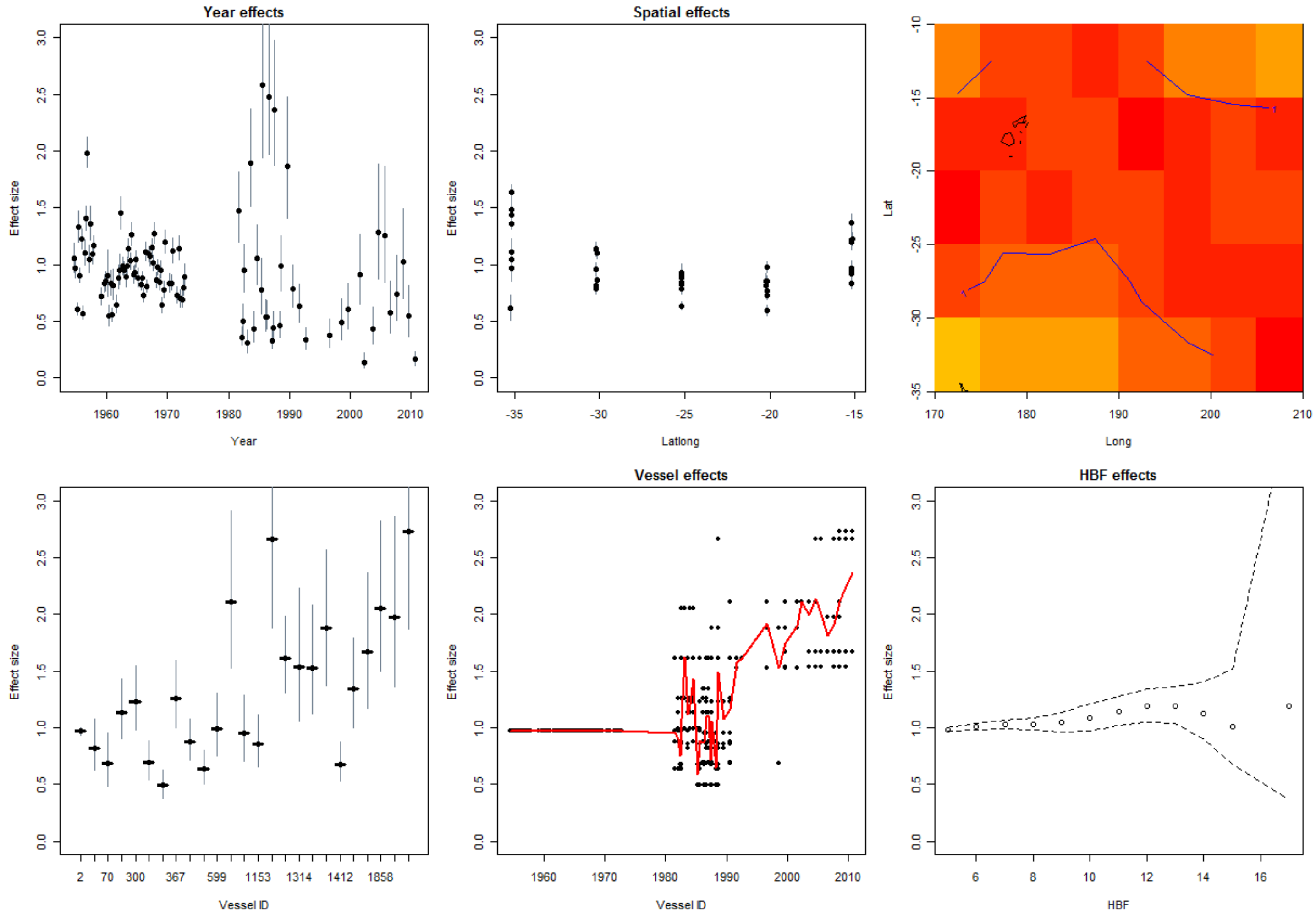


Figure 91: Estimated effects for region 6 bigeye DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

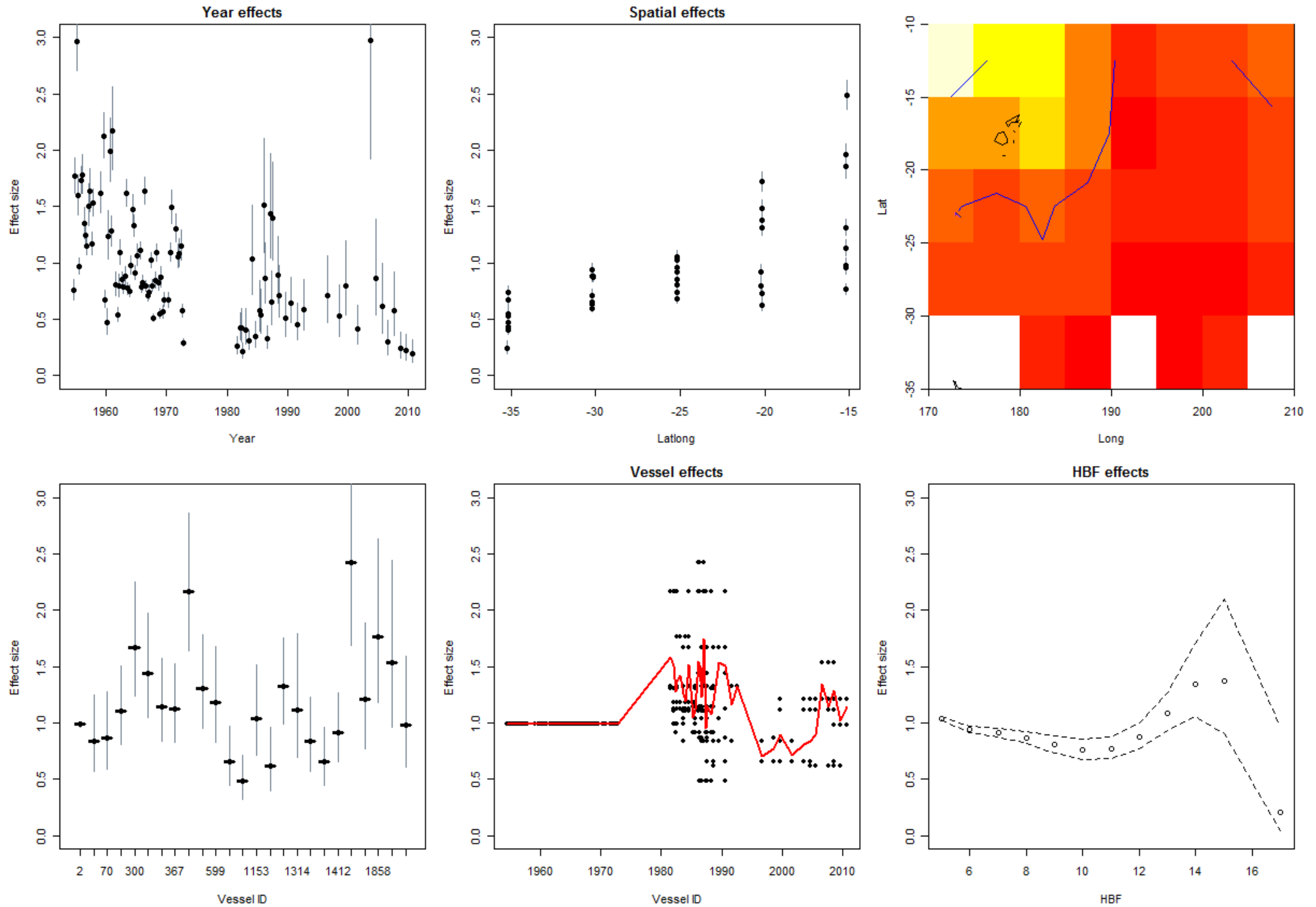


Figure 92: Estimated effects for region 6 yellowfin DW. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel made a set (black) and the mean vessel effect per year-quarter calculated across all sets by the fleet (red); and 6. HBF effects. The 95% CI is reported in panels 1, 4, and 6.

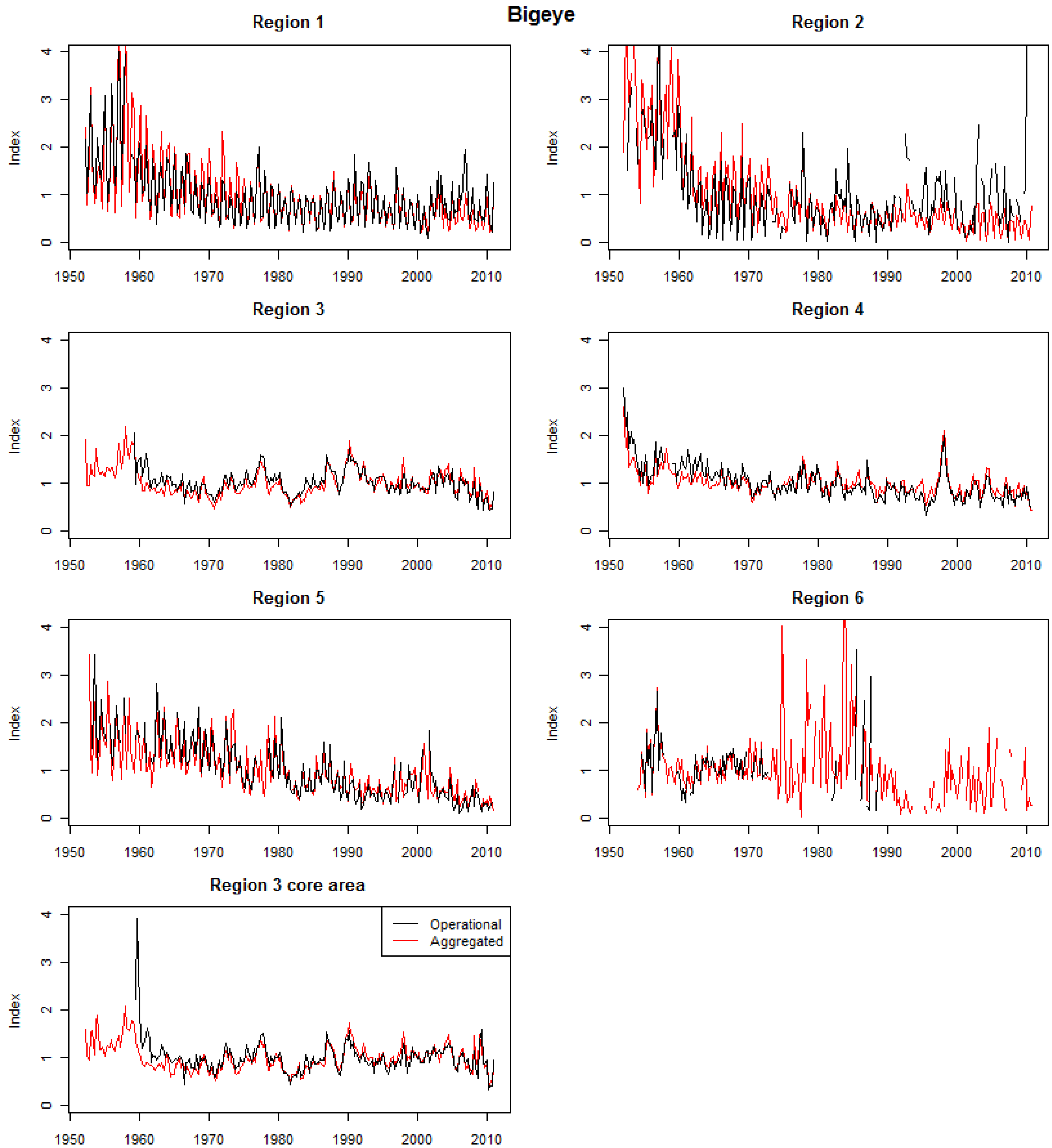


Figure 93:Comparison of bigeye abundance indices estimated from aggregated data held by SPC (red) and operational data held by NRIFSF.

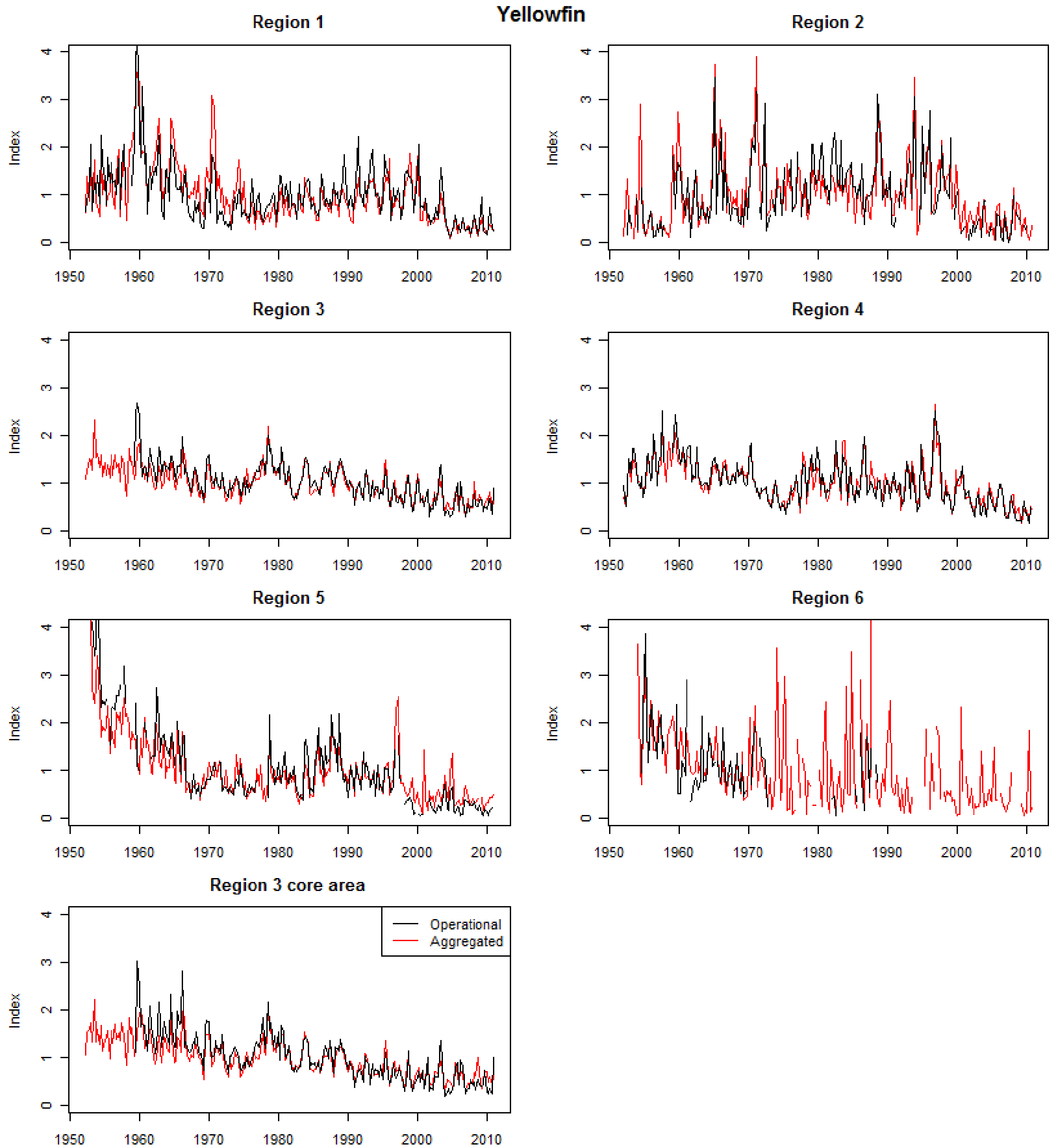


Figure 94: Comparison of yellowfin abundance indices estimated from aggregated data held by SPC (red) and operational data held by NRIFSF.

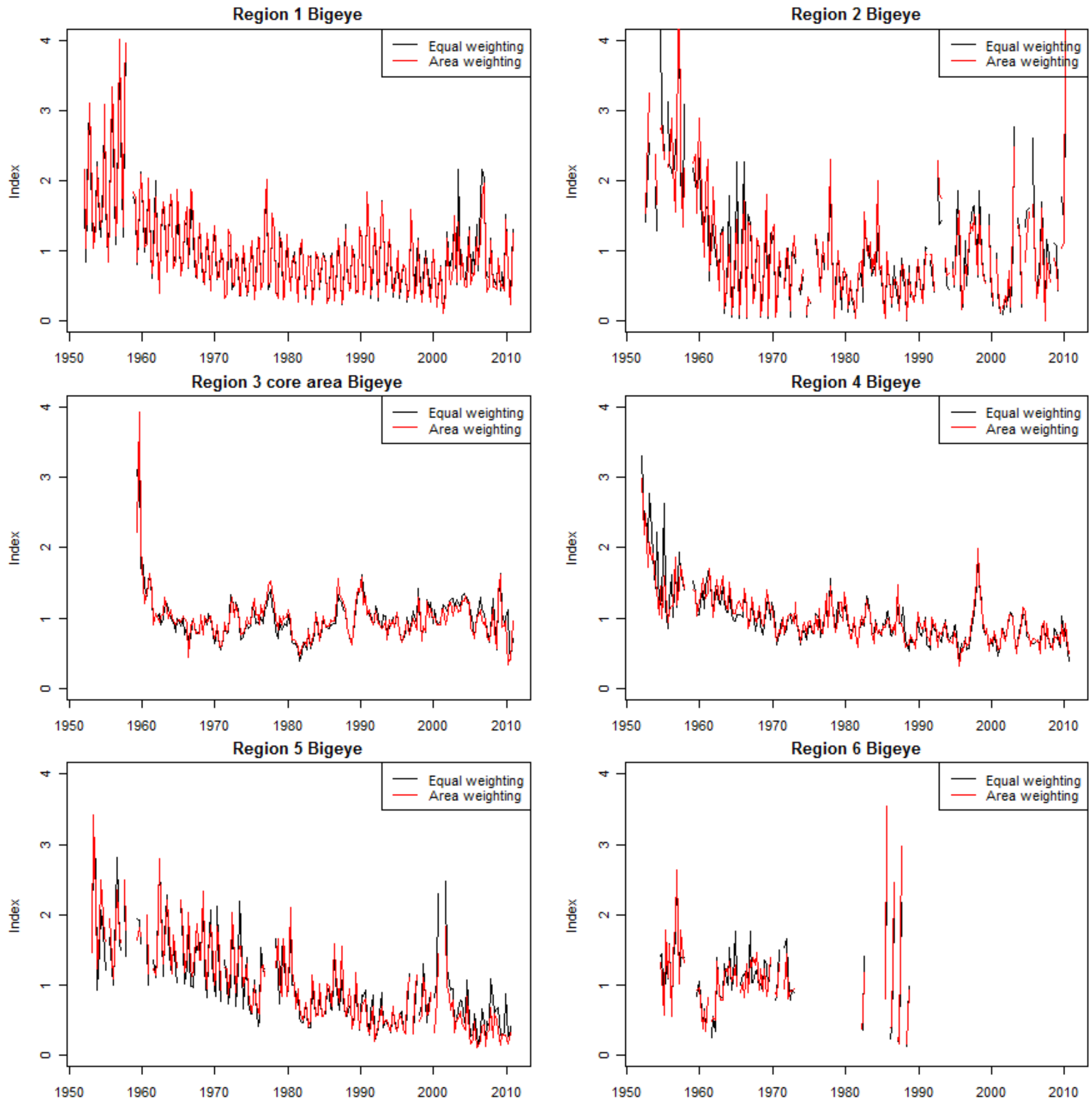


Figure 95: Comparison of bigeye abundance indices estimated using equal weighting (black) vs area weighting (red). All indices are estimated from operational data held by NRIFSF, with a model that includes vessel effects.

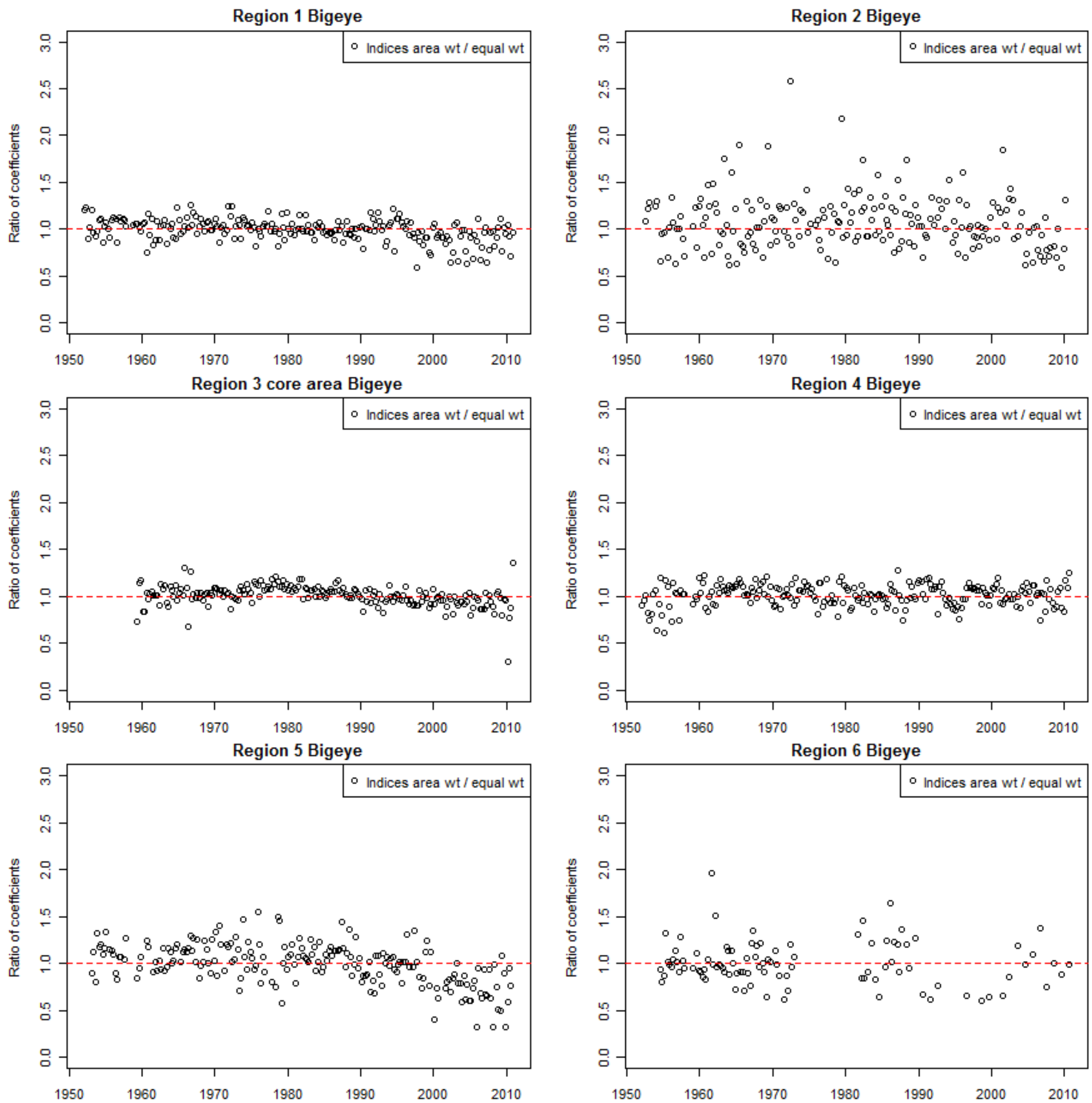


Figure 96: Ratios of bigeye abundance indices estimated using equal weighting and area weighting. All indices are estimated from operational data held by NRIFSF, with a model that includes vessel effects.

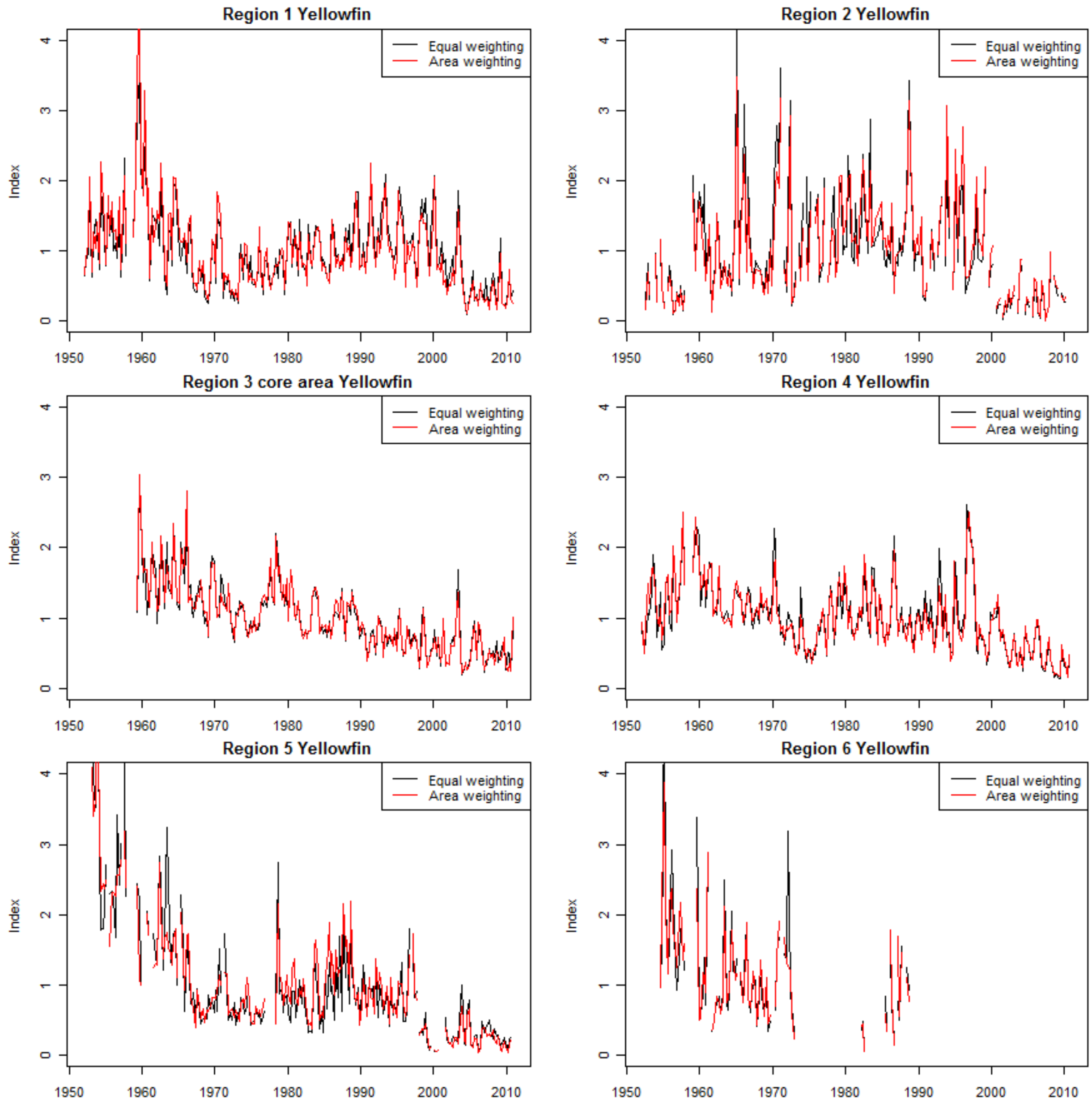


Figure 97: Comparison of yellowfin abundance indices estimated using equal weighting (black) vs area weighting (red). All indices are estimated from operational data held by NRIFSF, with a model that includes vessel effects.

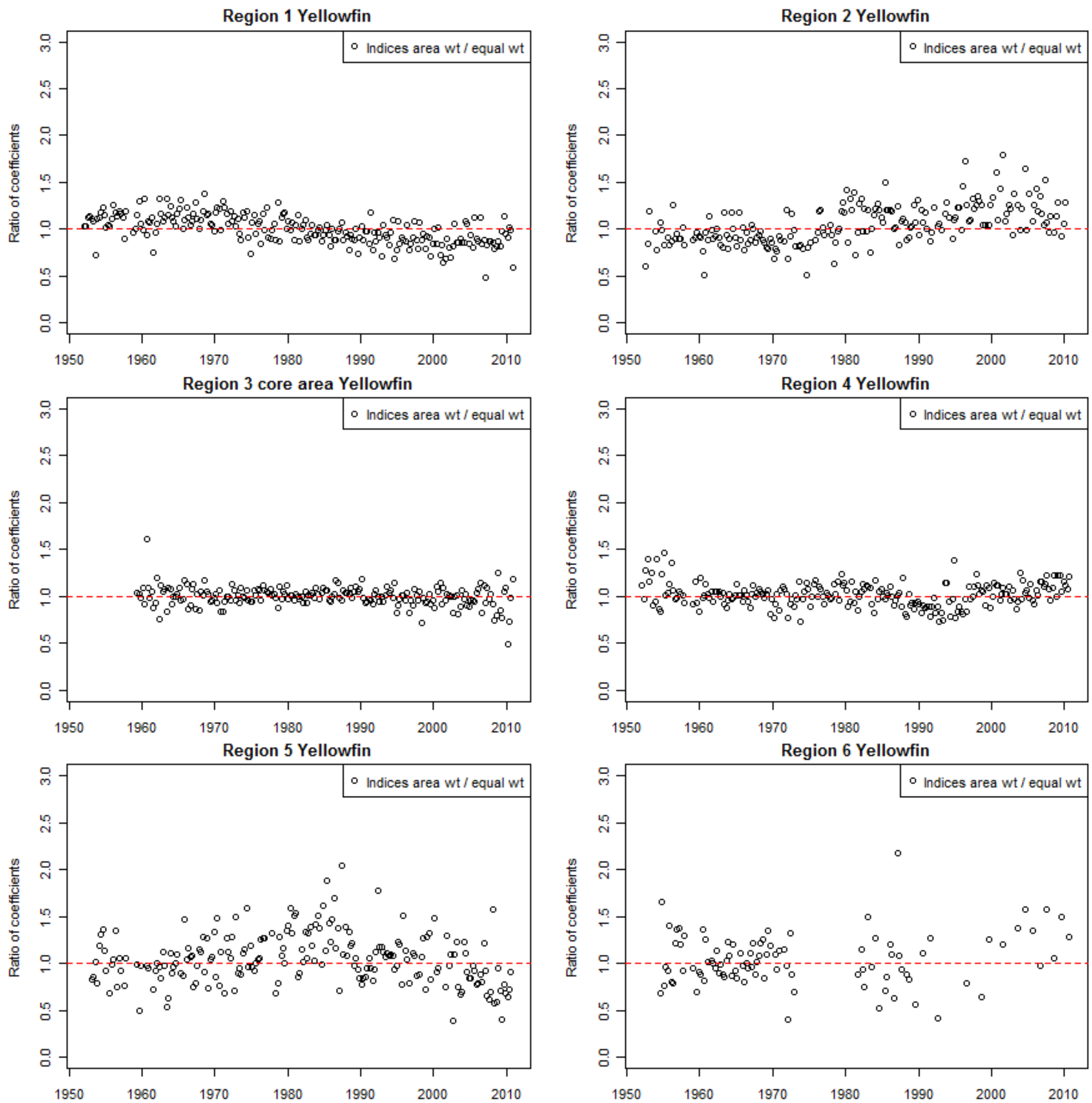


Figure 98: Ratios of yellowfin abundance indices estimated using equal weighting and area weighting. All indices are estimated from operational data held by NRIFSF, with a model that includes vessel effects.

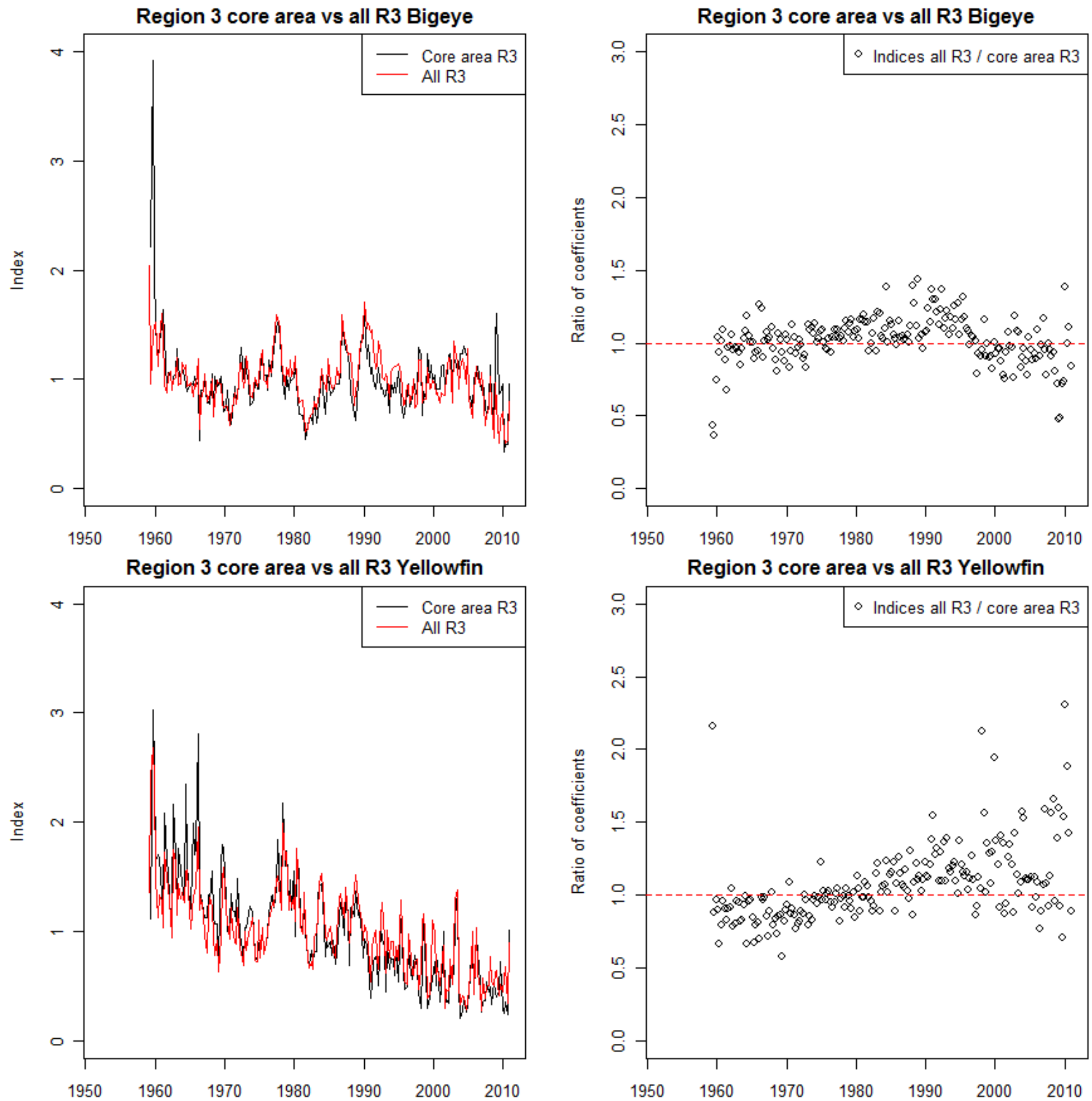


Figure 99: Comparison (left) of bigeye and yellowfin abundance indices estimated for the core area of Region 3 (black) vs the whole of region 3(red). The core area of Region 3 includes the latitudes from 5S to 10N. The ratios of the indices are also shown (right). All indices are estimated from operational data held by NRIFSF, based on the offshore fleet, with a model that includes vessel effects and area weighting.

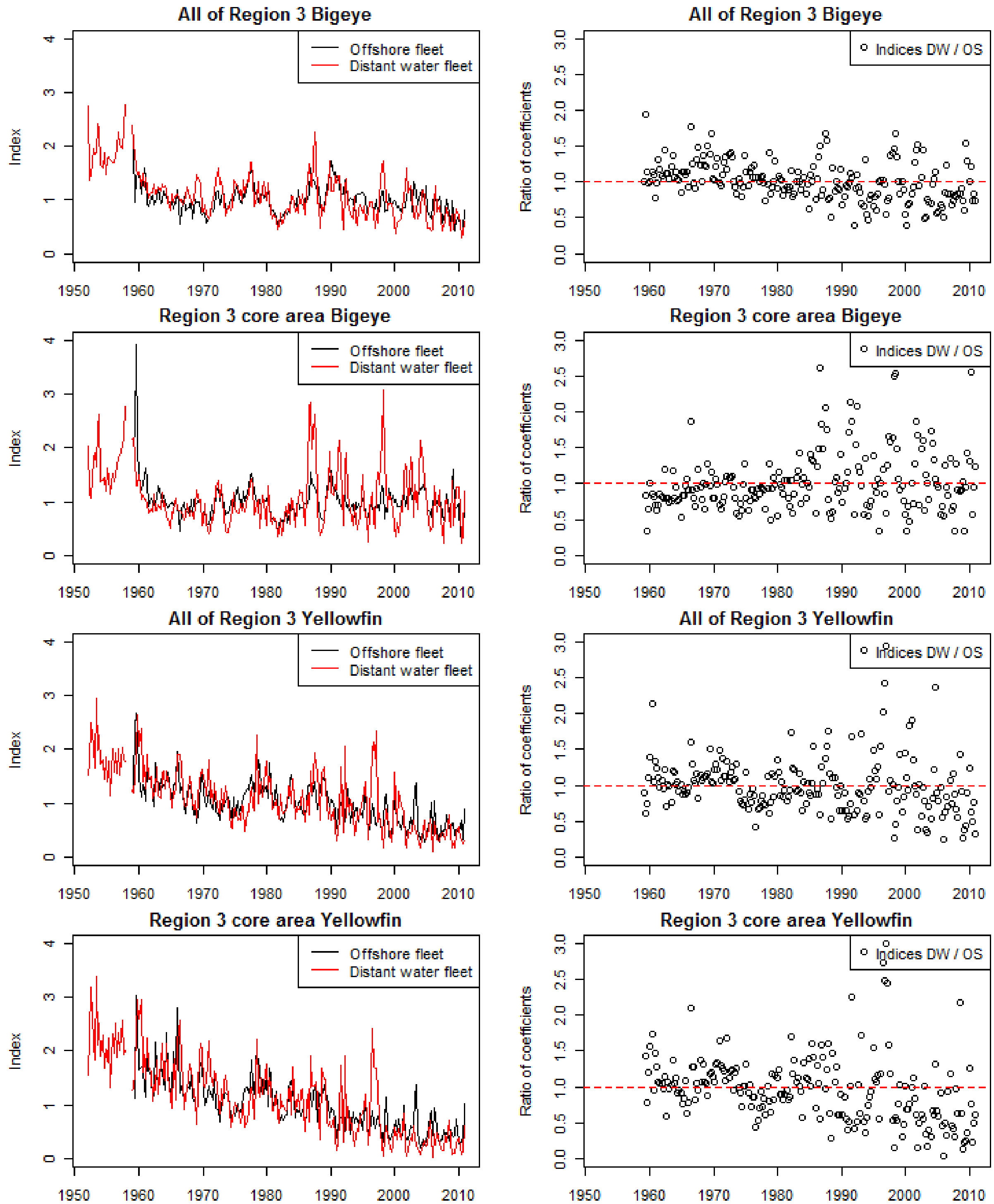


Figure 100: Comparison (left) of bigeye and yellowfin abundance indices estimated for the offshore fleet (black) vs the distant water fleet (red) in Region 3 and the Region 3 core area. The ratios of the indices are also shown (right). All indices are estimated from operational data held by NRIFSF, with a model that includes vessel effects and area weighting.

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9. Appendix 1

```
# Data cleaning
dataclean <- function(dat,checktg=F,allHBF=F) {
 dat$lat <- as.numeric(dat$lat)
 dat$hbf <- as.numeric(dat$hbf)
 dat$tonnage <- as.numeric(dat$tonnage)
 dat$hooks <- as.numeric(dat$hooks)
 dat$alb <- as.numeric(dat$alb)
 dat$bet <- as.numeric(dat$bet)
 dat$yft <- as.numeric(dat$yft)
 dat$swo <- as.numeric(dat$swo)
 dat[is.na(dat$lat)==T,]$lat <- 0
 dat[is.na(dat$alb)==T,]$alb <- 0
 dat[is.na(dat$bet)==T,]$bet <- 0
 dat[is.na(dat$yft)==T,]$yft <- 0
 dat[is.na(dat$swo)==T,]$swo <- 0
 dat <- dat[is.na(dat$hooks)==F,]
 dat <- dat[dat$hooks<10000,] # clean up outliers
 dat <- dat[dat$hooks>200,]
 dat <- dat[dat$yft<250,]
 dat <- dat[dat$bet<250,]
 dat <- dat[dat$alb<250,]
 dat <- dat[dat$tonnage<50000 | is.na(dat$tonnage)==T,]
 dat <- dat[dat$fishingcat !="0",]
 dat <- dat[is.na(dat$hbf)==F | dat$op_yr < 1976,]
 dat <- dat[dat$hbf < 26 | is.na(dat$hbf)==T,]
 if(checktg) dat <- dat[dat$target == 3 | is.na(dat$target),] # tuna target  (remove to avoid a
change in 1994 - but recent trend is more important)
 return(dat)
 }

# Data preparation
dataprep <- function(dat,alldat=F) {
 dat$lat_raw <- dat$lat
 dat$lon_raw <- dat$lon
 dat$lat[dat$latcode==2] <- (dat$lat_raw[dat$latcode==2]+1) * -1
 dat$lon[dat$loncode==2] <- 360 - (dat$lon_raw[dat$loncode==2] + 1)
 dat$lat5 <- 5 * floor(dat$lat/5)
 dat$lon5 <- 5 * floor(dat$lon/5)
 dat$reg <- 0
 dat[dat$lat <  40 & dat$lat >=  20 & dat$lon >= 110 & dat$lon < 170,]$reg <- 1
 dat[dat$lat <  40 & dat$lat >=  20 & dat$lon >= 170 & dat$lon < 210,]$reg <- 2
 dat[dat$lat <  20 & dat$lat >= -10 & dat$lon >= 110 & dat$lon < 170,]$reg <- 3
 dat[dat$lat <  20 & dat$lat >= -10 & dat$lon >= 170 & dat$lon < 210,]$reg <- 4
```

```
 }

 dat[dat$lat < -10 & dat$lat >= -35 & dat$lon >= 140 & dat$lon < 170,]$reg <- 5
 dat[dat$lat < -10 & dat$lat >= -35 & dat$lon >= 170 & dat$lon < 210,]$reg <- 6
 #dat[dat$lat <  40 & dat$lat >=  20 & dat$lon >= 210,]$reg <- 7
 dat[dat$lat <  20 & dat$lat >= -40 & dat$lon >= 210,]$reg <- 8

 dat$subreg <- 0
 dat[dat$lat <  40 & dat$lat >=  20 & dat$lon >= 110 & dat$lon < 170,]$subreg <- 1
 dat[dat$lat <  40 & dat$lat >=  20 & dat$lon >= 170 & dat$lon < 210,]$subreg <- 2
 dat[dat$lat <  20 & dat$lat >=   0 & dat$lon >= 110 & dat$lon < 150,]$subreg <- 3.1
 dat[dat$lat <  20 & dat$lat >=   0 & dat$lon >= 150 & dat$lon < 170,]$subreg <- 3.2
 dat[dat$lat <   0 & dat$lat >= -10 & dat$lon >= 110 & dat$lon < 150,]$subreg <- 3.3
 dat[dat$lat <   0 & dat$lat >= -10 & dat$lon >= 150 & dat$lon < 170,]$subreg <- 3.4
 dat[dat$lat <  20 & dat$lat >= -10 & dat$lon >= 170 & dat$lon < 180,]$subreg <- 4.1
 dat[dat$lat <  20 & dat$lat >= -10 & dat$lon >= 180 & dat$lon < 210,]$subreg <- 4.2
 dat[dat$lat < -10 & dat$lat >= -35 & dat$lon >= 140 & dat$lon < 170,]$subreg <- 5
 dat[dat$lat < -10 & dat$lat >= -35 & dat$lon >= 170 & dat$lon < 210,]$subreg <- 6
# dat[dat$lat <  40 & dat$lat >=  20 & dat$lon >= 210,]$subreg <- 7
 dat[dat$lat <  20 & dat$lat >= -40 & dat$lon >= 210,]$subreg <- 8

 dat$vessid <- as.numeric(as.factor(paste(dat$callsign)))
 if (alldat==F) dat <- dat[dat$vessid != 1,]
 dat$vessid <- as.numeric(as.factor(dat$vessid))

 dat$yrqtr <- dat$op_yr + floor((dat$op_mon)/3)/4 + 0.125
 dat$latlong <- paste(dat$lat5,dat$lon5,sep=".")
 dat <- dat[dat$yrqtr < 2011,]
 dat <- dat[dat$reg %in% 1:6,]

 dat$newfishingcat <- NA
 dat <- dat[dat$fishingcat<=3,]
 dat <- dat[dat$op_yr < 1967 | dat$op_yr > 1970 | dat$fishingcat < 3,]
 dat <- dat[dat$op_yr <= 1957 | dat$fishingcat != ".",]
 dat[dat$op_yr <=1957 & dat$reg %in% c(1),]$newfishingcat <- 1
 dat[dat$op_yr <=1957 & dat$reg %in% c(2:6),]$newfishingcat <- 2
 dat[dat$op_yr >1957 & dat$op_yr<=1993 & dat$fishingcat==1,]$newfishingcat <- 1
 dat[dat$op_yr >1993 & dat$fishingcat==3,]$newfishingcat <- 1
 dat[dat$op_yr >1957 & dat$op_yr<=1966 & dat$fishingcat %in% c(2,3),]$newfishingcat
<- 2
 dat[dat$op_yr >1966 & dat$op_yr<=1970 & dat$fishingcat %in% c(2),]$newfishingcat <-
2
 dat[dat$op_yr >=1971 & dat$op_yr<=1993 & dat$fishingcat %in% c(2,3),]$newfishingcat
<- 2
 dat[dat$op_yr >1993 & dat$fishingcat %in% c(1,2),]$newfishingcat <- 2
 return(dat)
 }
```