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

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1. Executive summary

Analyses of operational-level, longline catch and effort data for bigeye tuna in the Western and Central Pacific Ocean were carried out under an agreement between the Secretariat of the Pacific Community and the Japan National Research Institute of Far Seas Fisheries. The objectives of the collaboration were to standardize bigeye CPUE, and to estimate the historical trend of longline catchability using a finer scale of data than had been previously available. The goal was to better understand the role of vessel effects, in particular the role of fleet composition and fishing behaviour, which are otherwise concealed when using aggregated catch and effort data. In this analysis vessel effects were estimated as the average effect over the fleet of factors such as engine type, vessel speed, well capacity, fishing techniques, targeting strategies, technology and crew effects during the modelled period.

The data used in this analysis consisted of Japanese longline logsheets from 1976-2009 with location set to the nearest 1 degree of latitude and longitude; depth of set represented by the variable "hooks between floats" (HBF); international call sign used as the vessel identifier; and fishing categories (offshore or distant water), target (swordfish, shark, other), line type and a number of other operational variables included. All sets south of 35˚S and with HBF < 5 were removed to avoid southern bluefin tuna and swordfish targeted effort, respectively. However, sets targeting albacore or yellowfin rather than bigeye tuna could not be easily distinguished. Delta lognormal and offset lognormal models were applied in the standardization with an explicit term for vessel effect. The western and central Pacific was divided into six areas and an indicative regional scaling factor was estimated for each.

The results of the analysis revealed many new and interesting perspectives on catch trends. Region 3 (western Pacific between 20˚N and 10˚S) proved difficult to characterize due to the complexities of separating yellowfin targeted from bigeye targeting operations. The analysis suggests that the trends in catch rate in this region may be affected by market factors as well as abundance. Contrary to expectations, bigeye catch rates were higher at shallower depth in the equatorial area. Also it is suspected that differences in trends between region 3 as a whole and its equatorial regions are likely to result from a combination of changes in the fleet, changes in fishing methods by individual vessels, and changes in the concentration of fishing effort. Due to lack of sufficient fishing effort, regions 5 and 6 (south of 10˚S) were not allocated reliable regional scaling factors.

Vessel effects, which were estimated broadly for the first time in this analysis, reflected both fishing power increases and the fleet's ability and intention to target bigeye, and were found to have a potentially large effect on abundance indices. Significant changes in fishing power have been caused by vessels with poor catch rates exiting the fleet. Furthermore, it was noted that given a situation in which effort becomes increasingly concentrated over time, operational data may give a consistently more optimistic trend than aggregated data because it gives more weight to regions with more sets and higher CPUE.

Given the great potential of operational data they are recommended as the basis for abundance indices in future stock assessments. In addition to confirming several advantages arising from the use of operational catch and effort data for CPUE standardization, some areas requiring further research were identified. Multivariate techniques such as principal components analysis and cluster analysis are recommended to separate effort targeted at different species and thus identify alternative fishing strategies. In addition, simulation studies are recommended to examine bias arising from lack of independence among sets from factors such an increased focus of the fleet on hot spots, changes in fishing location in response to catch rates of different species, catch rates of other vessels, and ability to locate oceanographic features. Finally, abundance indices estimated from operational data should be constructed to extend from the 1950s onward and should be weighted by the number of strata per time-area stratum.

2. Introduction

Indices of standardized catch per unit effort (CPUE) are a critical input into tuna stock assessments carried out using integrated analysis methods (Fournier and Archibald 1982; Maunder 2003), such as 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 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. Japanese longline data at the operational level have not previously been standardized to produce indices of abundance for WCPFC stock assessments. In this paper we investigate Japanese operational catch and effort data for the longline fishery for bigeye and yellowfin tuna, in order to standardize the Japanese longline CPUE for bigeye tuna and to estimate historical trends of Japanese longline catchability for bigeye tuna. We provide some diagnostics, and examine changes in fishing power through time, including changes associated with new vessels entering and old vessels leaving the fishery.

Catch and effort data are most useful for developing indices of abundance if they are at the operational level, since aggregating data results in a loss of information and can introduce bias (Maunder and Punt 2004). The aggregated data previously available for estimating indices have provided limited information on the factors that affect CPUE, compared to the variables available in operational data. For example, aggregating data combines sets that may in fact have different target species. In addition, the process of aggregating data from strata with different means, variances, and sample sizes can change the error distribution, which can bias the resulting indices. Perhaps most importantly, operational data enable characterisation of the fishery at a set-by-set level, and increase understanding of the dynamics and interactions of fishing fleets, especially the assumption of independence of observations in time and space. Using operational data therefore allows us to quantify the extent to which these assumptions are violated.

A technical meeting held to discuss issues related to the analysis of catch and effort data, identified the need to more thoroughly analyse the available operational level data (Hoyle et al. 2007). Previous work has investigated many aspects of the operational CPUE data from a limited component of the fishery (Langley 2007). In this report, CPUE indices from aggregated and operational data are compared for a broader segment of 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 6); changed configuration of the longline gear, most notably increases in the number of hooks between floats (HBF), a proxy for depth (Figure 9 and Figure 10); and changes in the principal target species.

To account for such temporal changes in species-specific catchability of the longline fishery, the data have been standardized using a variety of approaches; most recently using generalised linear modelling techniques (McCullagh and Nelder 1989; Langley 2003; Langley *et al.* 2005; Hoyle 2009). In each case an identity link function and lognormal distribution have been assumed. The resulting region-specific standardised effort series are then integrated into the Multifan-CL (MFCL) assessments of yellowfin and bigeye in the WCPO.

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 shifting targeting towards bigeye tuna (Hampton *et al.* 2005b; Bigelow and Hoyle 2009). 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 pool sets that use different methods and may target different species. Operational data make it possible 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 and Hoyle 2009, Langley paper).

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. However, rates of change and effects on the relationship between hooks set and fish caught are very difficult to estimate (Ward and 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). In this report, operational CPUE data are analysed in order to estimate one component of temporal change in fishing power – that associated with changes in the vessels that make up the fleet.

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 affect that vessel’s fishing power, and change during the period when the vessel is in the model. However, the effects of these changes will not be picked up individually by this analysis. Instead, the average effect of these factors over the modelled period will be included in estimated vessel effect.

This analysis can 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 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, we compare abundance indices estimated from operational data with those estimated from the same data in aggregated form, using the general linear models usually applied to estimate abundance indices for WCPO stock assessments.

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 April 2010 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 of bigeye tuna; and
2. Estimating the historical trend of Japanese longline catchability of bigeye tuna, using set-by-set longline operational data compiled from logsheets submitted by Japanese longline fishermen.

Research was carried out under the following conditions:

1. The usage of the data is strictly limited to the purpose of this collaborative work;
2. The data can be used only during this collaborative work;
3. The participant can use the data only on the PC prepared by Japanese scientists of NRIFSF, and any copying of the data out of the PC is not permitted; and
4. Any document or presentation derived from the result of this collaborative work should be consulted beforehand to Japanese Fisheries Agency (JFA) 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; estimates relative regional scaling for four of the six defined regions; investigates effects of covariates on catch rates; investigates how data aggregation affects abundance indices; and provides quarterly indices of regional abundance.

3. Methods

Catch and effort data for the Japanese longline fleet were provided by NRIFSF for the period 1976 to 2009. Data were stratified into six regions to match the structure of the 2009 MFCL stock assessment model for bigeye.

The following data fields were provided: Japanese vessel name, English vessel name, vessel call sign, tonnage, region code, prefecture, fishing category, licence number, number of crew, cruise start date, cruise end date, set type (target), main line materials, branch line materials, operation date, operation latitude and longitude to 1 degree, HBF, number of hooks set and bigeye, yellowfin, and albacore catch in number (Table 1 and Table 2). Descriptions 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 - 2009 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. Japanese names were available for 1976-2009, but were recorded inconsistently. English versions of the Japanese names were available from 1994, but were also inconsistent. License number was also available, but changed regularly, with many licenses changing at once. Sets without a vessel call sign (all sets from 1976-77, the majority from 1978, and a rapidly decreasing proportion after 1978 – see Table 2) were omitted from the analyses of fishing power (see Section 3.3.1), but included (with call sign of '1') in the estimates of abundance indices.

Fishing category was either reported as either offshore or distant water. Records with values other than 1 (distant water) and 3 (offshore) were deleted.

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). 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, and albacore catch in numbers were cleaned by removing outliers. Values above 10000 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. Sets with missing values were removed, and the few sets with more than 22 HBF were pooled into the 22 HBF category.

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

After data cleaning, a standard dataset was produced that was used in subsequent analyses. A modified dataset was used to generate indices of abundance, and this is described below (Section 3.3.3).

3.2. Changes in targeting and/or fishing techniques

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 to this analysis, 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.

All sets south of 35˚S were removed to avoid southern bluefin tuna targeted effort. Sets with HBF < 5 are generally targeted at swordfish or more recently blue sharks, and were also removed.

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. Data were examined spatially to identify potential changes in the proportion of albacore-targeted effort through time.

Similarly, longliners may target bigeye or yellowfin tuna, or both species. The 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. Two approaches were used - a delta lognormal approach (Lo *et al.* 1992; Dick 2006; Stefansson 1996; Hoyle and Maunder 2006) and an 'offset lognormal' approach. The delta lognormal 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 6^{th} order polynomial function.

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

In the offset lognormal approach the dependent variable in the GLMs was the natural logarithm of the catch in numbers plus a constant value of 0.5, divided by the number of hooks set: log((catch+0.5)/hooks). The GLMs all had an equivalent model structure.

The categorical variables year-quarter and 5 degree latitude-longitude square were fitted in all analyses. The continuous variable HBF was fitted as a sixth order polynomial, giving it considerable flexibility. Many analyses also included the vessel identifier (vessel id) as a categorical variable. Some analyses also included yellowfin catch rate or albacore catch rate, fitted as a 4 level categorical variable. The levels were divided at the 0.1, 0.5, and 0.1 quantiles of the population distribution.

Models were also fitted for yellowfin tuna, in order to examine the residuals and provide another way of checking for mixtures of effort types in the data.

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

3.3.1. Vessel effects and fishing power

Changes in fishing power through time were investigated by first fitting to the operational data with the approaches described above (delta lognormal and offset lognormal), and then, in each GLM, adding a term for individual vessel. For example, for the offset lognormal 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. .

$$\log\left(\frac{bet_{set} + 0.5}{hooks_{set}}\right) = c + \alpha_t + \beta_{cell} + f(HBF_{set}) + \gamma_{vessel} + \epsilon_{set}$$

For each approach, two time series of abundance indices were calculated (with and without vessel effects). After normalizing each set of indices to average 1, the ratio of the two indices was calculated for each time interval, the ratios plotted and a log-linear regression fitted. 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.

The 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, but in regions with a great deal of data N was larger (N=8 for region 3) so that the model would run within the memory constraints.

3.3.2. 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. They were also displayed as a coloured image, with higher catch rates represented by darker colours.

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.

The relationship between line type (nylon or 'other') and HBF was examined by comparing overall effects after fitting a model that included an HBF*Mainline interaction term. Line type is only available in the data from 1994, so the data for each region were fitted in 4 periods – from 1979-1985, 1986-1993, 1994-2001, and 2002-2009.

3.3.3. Indices of abundance

Further analyses were carried out with several changes designed to improve indices of bigeye tuna abundance. Sets from vessels with missing call signs were included and allocated vessel id of 1, so that indices could be estimated back to 1976. 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. Sets with HBF less than 10 were excluded, in order to increase the overall consistency of the fishing and targeting methods through time.

These changes left too few sets in region 6 to estimate any index. An index was therefore generated for region 6 based on the unchanged version of the dataset.

Indices of abundance were obtained by running the delta lognormal GLM model with the standard settings, including vessel effects. Due to evidence of different CPUE trends from 10-20˚N, apparently caused by large changes in the mixture of effort types in this area (see section 4.2), the region 3 model used only data from the equatorial area from 0 to 10˚N. Several versions of the full region 3 model were also run, but an equivalent to the final approach selected was not run successfully in the limited time available.

3.3.4. Regional scaling factors

Regional scaling factors were estimated using an adaptation of approaches described previously for bigeye (Langley et al. 2005) and yellowfin (Hoyle and Langley 2007).

The model was

$$\log\left(\left(\mathrm{bet}_{t,st} + 0.5\right)/\mathrm{hooks}\right) = c + \beta_{LL} + \gamma_{vessel} + \epsilon_{set}$$

In contrast to the individual region models, HBF was omitted from the regional scaling model because it had opposite effects in equatorial and subtropical areas, which were both included in the model. Including an interaction term HBF.region would have made it difficult to compare CPUE among regions. Hooks between floats less than 10 were removed in order to reduce any bias due to different HBF used in different areas.

The dataset remained too large to analyze within memory constraints (12GB), so several approaches were used to reduce its size, and to include only grid squares in which there was both evidence of a consistently fishable bigeye population, and in which reasonable estimates of fish density might be obtained. First, grid squares in which fewer than 5000 fish had been caught were removed. Next, data after 1990 were removed. Grid squares with less than or equal to 6 quarters of effort were excluded. Vessels that had fished in less than or equal to 16 quarters were excluded.

After fitting the model, coefficients for all 5 degree squares within each region were extracted, exponentiated, summed, and divided by the sum for region 4, to derive the indicative scaling factor for the region. Regions 5 and 6 had very few grid squares in the model, since there was little Japanese longline effort in region 6, and much of the effort in both regions used HBF less than 10. Regional scaling factors for regions 5 and 6 are therefore not considered reliable.

3.3.5. Comparisons with aggregated data analyses

The implications of using aggregated data to estimate indices of abundance were examined by comparing the results from the operational data GLM with the equivalent analysis when the same data had been aggregated. This model was similar to the GLMs used to estimate the 2009 abundance indices (Hoyle 2009) that were used in the bigeye and yellowfin stock assessments (Harley *et al.* 2009; Langley *et al.* 2009). Aggregation was carried out at the 5 degree square, year-quarter and HBF level. The few zero catches were deleted.

The natural logarithm of the catch (in numbers) at time (t), and stratum (st) defined by five degree latitude/longitude (LL) cell and HBF was predicted as follows.

$$\log\left(\left(\mathrm{bet}_{t,st} + 0.5\right)/\mathrm{hooks}\right) = c + \alpha_t + \beta_{LL} + f\left(\mathrm{HBF}_{t,st}\right) + \epsilon_{t,st}$$

The function $f(\mathrm{HBF}_{t,st})$ estimated the parameters γ_{HBF} of the ordered HBF values by fitting a sixth-order polynomial. Error $\epsilon_{t,st}$ was assumed to be normally distributed. The CPUE index was obtained by exponentiating the predicted year-quarter effect terms, and dividing through by the mean value.

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. Gradients and p values are shown on the figures. Regressions assume incorrectly that ratio values are estimated without error, so statistical significance was assumed at 0.005 rather than 0.05.

4. Results

4.1. Data summaries

Data cleaning removed a substantial amount of effort using 4 hooks between floats from regions 1 and 2, and considerable early effort from all regions that lacked vessel identifiers (Figure 1). 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 are based on the cleaned dataset.

Japanese longline fishing effort declined in all regions from the early 1980s when dataset coverage reaches a high level (Figure 2). Distant water (DW) longline effort was negligible 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 (Figure 3).

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.

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 4). 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 comparable in region 6 (Figure 5). However, in region 4 a much higher proportion of sets did not catch yellowfin, and region 3 showed considerable variation.

In regions 1, 2, and 4, bigeye catch rates have increased relative to yellowfin in the last 10 years, after long-term stability. In each of these regions the proportion of sets with no yellowfin caught has increased considerably in the last 10 years (Figure 5). The proportion of sets with zero bigeye catch has also increased in regions 1 and 2, but not to the same extent and not in all seasons. In region 4 the proportion of sets with zero bigeye catch has declined since 2000.

In regions 1 and 2 the bigeye fishery shows large seasonal variation in the probability of catching bigeye in a set, indicating that the fishery is highly 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 a dramatic reduction in the proportion of sets that caught no bigeye, but this proportion increased again after 1995. Almost all sets caught some yellowfin prior to 1995, but after this time the proportion of set with zero yellowfin catch increased.

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 large declines in regions 3, 5, and 6 (Figure 6). In region 3 the fleet contracted first north, out of the Bismarck Sea and Papua New Guinea area, and then east (Figure 7). Effort in region 5 also moved east, with recent effort mainly restricted to the far north and far south.

Longline configuration changed through time, including increasing (HBF) (Figure 8, Figure 9, and Figure 10). There was also spatial variation in HBF, reflecting different fishing methods suitable for different oceanographic conditions and target species. Nylon was introduced in the late 1980's and spread through the fleet, with larger HBF tending to have higher proportions of nylon (Figure 11 and Figure 12).

This result may be affected by the fact that mainlines were labelled 'other' when there was a mixture of line types, or when information was missing.

Offshore vessels, defined as those less than 120 tonnes (Figure 13), are restricted by regulation to west of 180 degrees longitude. Offshore vessels reported many more sets per vessel on average than distant water vessels, which may reflect a longer working life for individual offshore vessels. Offshore vessels have historically done most of the fishing in regions 1 and 3, but since about 2005 distant water effort has matched or exceeded offshore effort in region 3 (Figure 2).

Approximately 700, 1000, 800, 1400, 800, and 350 unique vessels (vessel ID's) have reported fishing in each region since 1976 (Figure 14). In each region some vessels had long effort time series. Logsheets were reported against some vessel ID's for the entire period in all regions except region 6.

In region 1, relatively few new vessels started fishing after the early 1990's, and similarly, the rate of vessel loss slowed after that time (Figure 15). In regions 2 and 4 the arrival of new vessels progressively slowed through time. The vessel loss rate in region 2 slowed between 1995 and 2005, while in region 4 the loss rate was quite stable. In region 3 over half of all vessel ID's first appeared before 1982, after which the rate of new vessel arrival was stable until 2009. The vessel loss rate was high 1984-87, but stable after that. Regions 5 and 6 saw a varying but generally decreasing rate of new vessel arrival, reflecting the low sample sizes and time-varying exploitation of these regions. Vessel loss rate was comparatively stable and decreasing.

4.2. Targeting and spatial effects

Plots of the operational level data suggested the possibility that increased effort in the north of region 3 and the south of region 1 may have affected the bigeye abundance indices. Bigeye catch rates at these latitudes are generally lower than further south and further north, and the increased effort may have been largely targeted at albacore rather than bigeye.

The western Pacific albacore longline catch increased substantially between about 35˚N and 10˚N, between 1985 and 1990. Median albacore catch rate per set by year-quarter and 5 degree square increased, beginning earlier further west and possibly further north (Figure 16 and Figure 18). Similarly, the proportions of zero albacore catch per set decreased (Figure 22 and Figure 24). CPUE per trip for albacore also increased after 1995, with almost no trips without reported albacore catch at the 15˚N-20˚N latitude (Figure 40).

At this latitude the correlation between bigeye and albacore catch per trip was negative before 1990, but close to zero or positive after 1995 (Figure 40). This suggests more uniformity in targeting or reporting practices by the fleet in this area post-1995. Further south at latitude 10-15˚N, and to a very limited extend at 5-10˚N, the trip-level correlation decreased, suggesting more diverse targeting practices. Trips with high albacore catch rate were mixed with trips with very low albacore catch rate. The distribution of albacore catch rates was very different after 1994, with far fewer zero catches and the modal trip catch higher than almost all catch rates 1978-1994 (Figure 41). Bigeye catch rates showed much less change, but from 10-15˚N (where there seemed to be a mixture of targeting) bigeye catch rates showed a broader range with both more low catch rates and more high catch rates. From 15-20˚N there was an increased proportion of low catch rates (Figure 42).

In equatorial areas there was a trend through time in the trip-level CPUE away from yellowfin and towards bigeye tuna (Figure 43).

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 0-10˚N was also standardized separately.

Logsheets were available for standardization for regions 1-6 for the period 1978-2009 (Figure 44), although sets in region 6 have been minimal since 1993. Both logsheet numbers and the number of vessels (Figure 45) have declined through time.

Analyses with the vessel effect fit the data significantly better in all regions and for all models, and by a large amount (Table 3).

For all regions, the lognormal models fit the positive component of the data reasonably well (Figure 46 to Figure 51). They also tended to give smoother residual patterns, particularly at the lower end of the distribution. The residual patterns showed similar slightly negative skewness across all analyses, suggesting that there may be a more appropriate distribution than the lognormal, although the skewness may also represent contamination with data from other target fisheries. The discrepancy was generally not large. Regions 1 and 5 showed fewer low and more high residuals than expected. Regions 4 and 6 showed the opposite pattern with more low and fewer high residuals than expected.

The residuals generally showed quite a good normal distribution for GLMs from fisheries data.

Yellowfin tuna data were standardised for comparative purposes. Results for regions 1 and 2 showed two peaks in the residuals, suggesting a mixture of fishing strategies in these regions (Figure 86 to Figure 88).

4.4. Fishing power

For all 6 regions, inclusion of the vessel effect changed the trends in the binomial, positive lognormal (Figure 52 to Figure 58), combined delta lognormal (Figure 59 to Figure 65), and offset lognormal indices. For the binomial indices the effect was a generally very small but indicated an increasing trend in bigeye fishing power in all cases except region 5. However, the overall effect on the delta lognormal abundance index was dominated by the positive lognormal component, for which fishing power was found to increase in regions 1, 3 (equatorial), 4 and 6, but decrease in regions 2 and 5.

Overall, for regions 1, 4, 6, and latitudes 0-10˚N (equatorial) of region 3, including the vessel effect resulted in a more pessimistic delta lognormal abundance index, due to the compensation for increasing fishing power. The region 3 equatorial and region 4 fishing power trends were reasonably stable with little variability. For the whole of region 3, adding the vessel effect suggested increasing fishing power before 1995 and decreasing fishing power after that time, so that the long-term result was no change in the trend after adding the vessel effect. Region 1 fishing power trends were quite variable, particularly before 1995. Region 6 trends were highly variable and the vessel effect was very large. For regions 2 and 5, including the vessel effect reduced the deline in the abundance indices; although both cases showed both short term and long term variability in the fishing power trends, with the opposite trend before about 1985.

4.5. Analyses of covariate effects

Covariate effects were examined for all models (Figure 66 to Figure 72). These covariates represent the average effects for the whole period 1978 to 2009. In region 1, higher catch rates were observed in the north and east, while region 2 catch rates were higher in the east, and lower north of 35˚N. Region 3 catch rates 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. Region 4 catch rates also showed an increasing trend to the east. 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.

Vessel effects in Regions 1, 4, and equatorial region 3 generally showed a steady increase. In region 2 however, a number of vessels with high catch rates stopped fishing in the mid-1990's, which reduced the average vessel effect. Similarly, many vessels with high catch rates stopped fishing in region 5 after about 1996. In the region 3 full region model, vessels with high catch rates were lost in the mid-1980's. After this there was a period of increasing catch rate, and then vessels with low CPUE started fishing or increased their fishing from about 1995. This caused the average vessel effect to stabilise and then decline. In region 6, the data are very sparse and it is difficult to give much weight to the results. However, a few vessels with high catch rates started fishing in the early 2000's, and a number of vessels with low catch rates stopped fishing, resulting in a much higher average vessel effect.

The HBF effects in the subtropical to temperate regions 1, 2, 5, and 6 showed increasing catch rate with higher HBF, as expected if deeper sets catch more bigeye tuna. Regions 3 and 4 however showed the unexpected result of slightly higher bigeye catch rates at lower HBF.

HBF and line type interactions were examined by modelling four separate periods 1979-85, 1986-93, 1994-2001, and 2002-2009 (Figure 73 to Figure 77). In general, mainline type had little effect on model results. An interaction was apparent between HBF and mainline type in region 1 from 1994-2001, with lower catch rates at higher HBF for nylon mainlines. However, this effect was not apparent in any other region or time period.

4.6. Indices

Further operational data analyses were carried out that (for regions 1 to 5) included data from vessels with missing call signs; excluded sets after 1994 with target reported as swordfish or sharks; and excluded sets with HBF less than 10. Region 6 analyses retained the standard dataset. The delta lognormal approach was used.

Indices were estimated for all 6 regions (Figure 78, 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 (Table 5) were used to indicate relative CVs for the delta lognormal indices.

Indices generated from the adjusted dataset were similar to those from the standard dataset, but less seasonally variable in regions 1, 2, and 5; slightly more optimistic in region 2; and slightly more pessimistic in regions 3 and 4 (Figure 78).

4.7. Regional scaling factors

Regional scaling was carried out by analysing data for the whole of the WCPFC area in a single model. Data selection requirements resulted in few 5 degree squares remaining for regions 5 and 6, so results are only considered useful for regions 1 to 4.

Results indicated higher bigeye catch rates in the east (Figure 79). Overall scaling factors for regions 1 to 3 were 0.17, 0.39, and 0.67, relative to region 4 with a value of 1. Scaling factors for regions 5 and 6 (0.042 and 0.013 respectively) were not reliably estimated. However, these were very similar to the 2009 estimates based on aggregated data, at 0.15, 0.38, 0.61, 1.00, 0.09, and 0.11.

4.8. Effects of data aggregation on indices

Results from operational data using a delta lognormal model ("operational indices") were compared with indices generated from the same data aggregated by year-quarter, 5 degree square, and HBF, and modelled using an offset lognormal GLM ("aggregated indices"). Comparisons were made both with the vessel effect (labelled 'Bigeye boat') and without the vessel effect ('Bigeye base') (Figure 80 to Figure 85).

Data aggregation resulted in considerably different indices. Aggregated indices tended to have more seasonal variability, particularly for regions 1, 2, 5, and 6.

The aggregated data indices tended to decline more than both types of indices from operational data, by an average of 0.31%, 1.3%, 1.0%, 0.32%, and 2.3% per year for the indices with vessel effect from regions 1-5. Only in the case of data-poor region 6 were the aggregated data indices more optimistic than the operational data vessel effect indices, by an average of 2.8% per year.

The indices from the aggregated data also showed different short-term trends from the operational data. For example, Region 3 indices shows strong short-term trends, including a more optimistic trend 2005-2009, followed by a more pessimistic 2008-2009. In region 5 there is a step change in about 1990, and another quite sharp transition in about 2005.

These differences are notable given that the aggregated data were created from the operational data. They appear to result from aggregation rather than from differences in the models, since similar patterns were observed when comparing the aggregated data indices with operation data indices prepared using the offset lognormal (catch + 0.5) model.

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 required developing a good understanding of the operational data, particularly since it was the first time either SPC author had worked with this complex and information-rich dataset. 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.

Some areas of region 3 showed evidence of change in the proportions of effort allocated to different fishing practices. We focused investigations of target changes on this region. The proportions of zero catch per set by species, and the distributions of catch rate per set, indicate that in the north of region 3 from 15˚N to 20˚N the albacore catch rate increased considerably after 1995. Effort at this latitude also increased. The longline North Pacific albacore stock is believed to have increased considerably during this period (Anon 2006), so the increased catch rates appear to reflect increased albacore abundance. However, the proportion of low bigeye catches in the area simultaneously increased, and the proportion of large catches dropped (Figure 42). A number of vessels with low bigeye catch rates started fishing in the non-equatorial parts of region 3 in the period after 1990 (Figure 69). It is possible that after 1995, longline vessels targeting albacore entered the north of region 3 to fish the increasing albacore stock. Given the greater uniformity of the fleet after this time (Figure 40) some vessels may have switched from targeting bigeye to albacore, or moved to other areas.

Introduction of new vessels with different targeting practices should not affect indices estimated using vessel effects. However, vessel effect analysis cannot detect changes in targeting practices by the same vessel (as opposed to targeting differences between vessels), which would affect estimated abundance indices. We were not able to rule out such changes. Furthermore, we were also unable to rule out differences in abundance trends between the equatorial areas and the northern area 10-20˚N. There is also evidence (see Harley and Hoyle 2010; Harley *et al.* 2010) that bigeye caught in the north and south of region 3 are smaller than those caught in the equatorial area. In view of these issues, fishing power analyses and index estimates tentatively focused on the equatorial parts of region 3 from 0-10˚N.

Vessels in region 3 have generally fished in 5 degree squares with above average catch rates for both yellowfin and bigeye (Harley 2009). Bigeye and yellowfin catch rates tend to be positively correlated (Figure 43), but region 3 saw large changes through time in the relative catch rates of yellowfin and bigeye, with yellowfin catch rates declining and bigeye catch rates increasing or remaining stable. In past CPUE analyses, these observed catch rate changes have been reflected in decreasing yellowfin abundance indices relative to bigeye abundance indices. However, good quality bigeye tuna are worth considerably more than yellowfin, and vessels are thought to have increasingly targeted bigeye through time in all regions, including region 3. For example, analyses of catch rates from individual sets indicate that vessels have increasingly tended to move their fishing location in response to low bigeye catch rates, but not in response to low yellowfin catch rates (Langley 2007).

This evidence suggests that the contrast between the declining yellowfin catch rates and comparatively stable bigeye catch rates may be not be due to abundance trends, but due to the increasing ability and/or motivation of vessels to target bigeye tuna. The size of the effect on the abundance indices is currently unclear, but we recommend that further investigation of this issue is given a very high priority. Standardised indices can in theory account for such changes in targeting, but only if a) the models are sufficiently sophisticated to explain complex interactions, and b) the data collected include variables that reflect the difference in targeting practices. We may lack some key variables, or need to apply more sophisticated modelling techniques to the existing data.

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.

The differences in region 3 trends for the equatorial area and the whole region illustrate the way the vessel effect can be influenced by different types of changes in fleet composition. It appears likely that albacore targeting vessels started fishing in the north of region 3 in the 1990s. Their bigeye catch rates were consistently low (Figure 69), reflecting their presumed intention to target albacore, so their arrival lowered the average vessel effect post-1995. For the equatorial part of region 3 however, as in regions 1 and 4, there was a slow but steady increase in the average vessel effect through time, reflecting an increase in either the average intention or the average ability of the fleet to target bigeye. In contrast, many vessels with high bigeye catch rates stopped fishing in region 5 in the 1990's, which caused a declining trend in the average vessel effect. This may have been associated with exclusion of Japanese vessels that targeted bigeye from the Australian fishing zone. A similar effect was observed in region 2, associated with a large decline in effort by offshore vessels west of 180 degrees (Figure 35). When vessel effects were included in the region 6 analysis, abundance trends were considerably less optimistic, although the sparseness of the data suggests that any estimate from region 6 should be treated with caution.

Vessel effects estimated by the methods in this study only account for changes in fishing power (catchability) among vessels, not changes 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 66 to Figure 72). 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.

5.3. Effects of covariates and changes through time

The spatial effects estimated within regions show some interesting features. The expected trend was observed of increasing catch rate further east. In region 1 the highest catch rates were observed between 30 and 35˚N. This is a seasonal fishery, with offshore vessels switching to target bigeye when availability and prices are high.

The effect of HBF on bigeye catch rates in the equatorial area is counter-intuitive. Bigeye are expected to be caught deeper than yellowfin and other target species (Brill 1994), so larger HBF is expected to have a higher catch rate. This effect was observed at the higher latitudes of regions 1, 2, 5, and 6, but in the equatorial regions 3 and 4 the opposite effect was observed, with slightly higher catch rates at lower HBF. Further investigation in 4 different time groups found this difference between equatorial and subtropical effects to be consistent through time.

Line type did not seem to substantially affect catch rates, or to have an important interaction with HBF. This may be because of data problems, because line type is recorded as 'nylon' or 'other', and 'other' line types include a variety of options including modern materials. In addition, there may be interactions with location, season, target species, and other aspects of fishing technique. Further investigation is recommended.

5.4. Abundance indices

Operational data contain significantly more information than aggregated data, and have the potential to provide more reliable abundance indices. 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. Analyses of the same data gave very different results when analysed in the aggregated or operational state. Assumptions about error distributions are often violated in aggregate data, since strata with more sets are likely to be less variable than those with fewer. More importantly, our 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). Which approach is more appropriate depends on the objectives of the analysis, but there are better approaches than either.

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 and overly optimistic trend (Campbell 2004). This may explain why the trends from the operational data analyses are consistently more optimistic than those from the same data, aggregated. Better approaches may involve weighting each set or stratum by 1/(the number of sets or strata per grid square x time interval). Note also that effort may have increasingly concentrated on higher bigeye densities at a scale finer than the 5 degree grid square (Langley 2007), which would add an optimistic bias to indices from both aggregated and operational data. We recommend that these issues are further investigated.

Further, we cannot assume that all grid squares (or strata) have the same abundance trends, since a) areas with more fishing pressure may be more heavily depleted, or b) the stock may contract into areas with higher quality habitat. (Trends may also differ by HBF stratum due to changes in fishing practices, but this is a separate issue). The regional abundance trend is the sum of the individual grid squares' abundance trends. An index of regional abundance may take this into account by including a grid square x time term in the analysis and summing the grid effects for each time interval. We recommend research to consider appropriate methods for such analyses.

Abundance indices from the whole of region 3 differed substantially from those for the equatorial part of region 3, showing less decline. The equatorial area is the core of the bigeye fishery in region 3, where catch rates are higher, the majority of the catch is taken, and the majority of the longline-vulnerable region 3 bigeye population can be presumed to occur. The important difference in trends is likely to result from a combination of several different processes, including changes in the fleet, changes in fishing methods by individual vessels, and changes in the concentration of fishing effort. Bigeye abundance in the northern area may also have changed, but this is currently difficult to determine given the simultaneous changes in the fleet. We recommend that results from both the equatorial area and the full region 3 should be considered.

5.5. Regional scaling factors

Regional scaling analysis was carried out to provide an alternative set of regional scaling factors for the bigeye stock assessment. However, results were comparable to those estimated using the aggregated data, despite use of a different time period and omission of HBF from the model. Regions 5 and 6 were not allocated reliable regional scaling factors, due to lack of sufficient fishing effort.

This is a difficult subject area, with no current approach seen as satisfactory. It is an important topic for future research, since it significantly affects stock assessment results.

5.6. Advantages of operational data

Operational data provide information about fishing practices that is not available from aggregated data. This information may provide important insights into the fisheries, and help identify important factors that affect CPUE indices. For example, mean and median catch rates and the proportion of sets with zero catch are informative when examined at the level of the individual trip or by year-quarter and 5 degree square. This information enabled us to identify apparent increases in albacore targeting in the north of region 3 during the mid 1990's, which had not previously been considered when preparing indices for WCPO bigeye stock assessments.

Operational data also allowed us to include the vessel effect in CPUE standardizations. In many cases this affected the indices significantly on several different time scales. Different vessels can have consistently different catch rates, so including vessel effects in the standardization must result in a better, more reliable index of abundance. However, it only accounts for consistent differences in fishing behaviour between vessels. It does not take into account any changes in fishing behaviour by individual vessels.

Operational data also permit the use of multivariate techniques such as principal components analysis and cluster analysis, which can separate effort targeted at different species (He *et al.* 1997; Langley 2007; Bigelow and Hoyle 2009). This approach is recommended in future to identify alternative fishing strategies.

In addition, operational data may be used to identify changes through time in the nature of fishing operations, such as an increased focus of the fleet on hot spots, changes in fishing location in response to catch rates of different species, catch rates of other vessels, and ability to locate oceanographic features. These data make it possible to examine bias introduced by lack of independence among sets. Simulation studies of such issues may be useful. It may also be useful to examine sets that may be more independent, such as "searching" sets, where these can be identified.

Given the great potential of operational data for improving our understanding of tuna population dynamics and the behaviour of fishing fleets, we recommend that future stock assessments should use abundance indices generated from operational data rather than aggregated data, and for the full period for which Japanese operational data are available (despite the lack of vessel identifiers for some of the period), starting in the 1950's. We also recommend that both aggregated and operational GLM analyses should be weighted by the number of strata per time-area stratum, and that further research into analysis methods is given a high priority.

5.7. Conclusion

The Japanese operational longline catch and effort dataset represents an information resource with enormous potential for improving our understanding of pelagic fish population dynamics. We are grateful for the opportunity to work with this dataset, and strongly encourage future work in these topics.

6. Acknowledgements

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7. Tables

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

Items	Type	76-93	94-09	Remarks
vessel name 1	character	YES	YES	Vessel name in Japanese
vessel name 2	character	YES	NO	Vessel name in alphabet
call sign	character	YES	YES	
tonnage	integer	YES	YES	
region code	integer	YES	YES	place of vessel registration
prefecture	character	YES	YES	prefecture of registration
fishing category	integer	YES	YES	1: distant water LL, 3: offshore LL
license no.	integer	YES	YES	this may change by year
no. crew	integer	YES	YES	
start of cruise: year	integer	YES	YES	
start of cruise: month	integer	YES	YES	
start of cruise: day	integer	YES	YES	
end of cruise: year	integer	YES	YES	
end of cruise: month	integer	YES	YES	
end of cruise: day	integer	YES	YES	
set type (type of target)	integer	NO	YES	1: swordfish, 2: shark, 3: other (tuna)
main line materials	integer	NO	YES	1: Nylon, 2: other
branch line materials	integer	NO	YES	1: Nylon, 2: other
operation year	integer	YES	YES	
operation month	integer	YES	YES	
operation day	integer	YES	YES	
operation latitude	integer	YES	YES	
operation latitude code	integer	YES	YES	N: 1, S: 2
operation longitude	integer	YES	YES	
operation longitude code	integer	YES	YES	E: 1, W: 2
no. of hooks between float	integer	YES	YES	
total no. of hooks per set	integer	YES	YES	
bigeye catch in number	integer	YES	YES	
yellowfin catch in number	integer	YES	YES	
albacore catch in number	integer	YES	YES	

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

YEAR	No. of ops	Vessel name Japanese	Vessel name2 alpha	Call sign	Tonnag e	Fishing cat	No. of crew	Cruise start date	Cruise end date
1976	96285	96285	0	0	96285	96285	0	0	96285
1977	89833	89833	0	0	89833	89833	0	0	89833
1978	84973	84973	4027	4027	84973	84973	3995	4027	84973
1979	109227	109181	109227	66065	109227	109227	109227	109227	109227
1980	120363	120363	120363	80139	120363	120363	120363	120363	120363
1981	129136	129136	129136	92043	129136	129136	129136	129136	129136
1982	111031	111031	111031	86368	111031	111031	111031	111031	111031
1983	90917	90917	90917	75115	90917	90917	90917	90917	90917
1984	98314	98314	98314	85864	98314	98314	98314	98314	98314
1985	91281	91281	91281	81025	91281	91281	91281	91281	91281
1986	79633	79633	79633	71244	79633	79633	79633	79633	79633
1987	73167	73167	73167	68095	73167	73167	73167	73167	73167
1988	83292	83292	83292	78639	83292	83292	83292	83292	83292
1989	77509	77509	77509	73784	77509	77509	77509	77509	77509
1990	70802	70802	70802	68043	70802	70802	70802	70802	70802
1991	63759	63759	63759	61982	63759	63759	63759	63759	63759
1992	56602	56602	56602	55974	56602	56602	56602	56602	56602
1993	61980	61980	61980	61729	61980	61980	61980	61980	61980
1994	56577	56577	0	56182	56577	56577	56577	56577	56577
1995	53858	53858	0	53407	53858	53858	53858	53858	53858
1996	47091	47091	0	46719	47091	47091	47091	47091	47091
1997	42438	42438	0	42165	42438	42438	42438	42438	42438
1998	45603	45603	0	45398	45603	45603	45603	45603	45603
1999	44130	44130	0	43848	44130	44130	44130	44130	44130
2000	44679	44679	0	44344	44679	44679	44679	44679	44679
2001	42981	42981	0	42687	42981	42981	42981	42981	42981
2002	41953	41953	0	41679	41953	41953	41953	41953	41953
2003	39247	39247	0	38954	39247	39247	39247	39247	39247
2004	36259	36259	0	36069	36259	36259	36259	36259	36259
2005	30095	30095	0	30042	30095	30095	30095	30095	30095
2006	27973	27973	0	27962	27973	27973	27973	27973	27973
2007	29208	29208	0	29187	29208	29208	29208	29208	29208
2008	25384	25384	0	25299	25384	25384	25384	25384	25384
2009	16165	16165	0	15951	16165	16165	16165	16165	16165

YEAR	No. of ops	Main line material	Branch line material	Set type (target)	Op date	Lat & long	HBF	Hooks per set	BET & YFT catch (n)
1976	96285	0	0	0	96285	96285	91976	96285	96285
1977	89833	0	0	0	89833	89833	86753	89833	89833
1978	84973	0	0	0	84973	84973	83446	84973	84973
1979	109227	0	0	0	109227	109227	91676	109227	109227
1980	120363	0	0	0	120363	120363	106217	120363	120363
1981	129136	0	0	0	129136	129136	125171	129136	129136
1982	111031	0	0	0	111031	111031	107410	111031	111031
1983	90917	0	0	0	90917	90917	88276	90917	90917
1984	98314	0	0	0	98314	98314	96171	98314	98314
1985	91281	0	0	0	91281	91281	88865	91281	91281
1986	79633	0	0	0	79633	79633	77367	79633	79633
1987	73167	0	0	0	73167	73167	70481	73167	73167
1988	83292	0	0	0	83292	83292	81073	83292	83292
1989	77509	0	0	0	77509	77509	74169	77509	77509
1990	70802	0	0	0	70802	70802	67115	70802	70802
1991	63759	0	0	0	63759	63759	60254	63759	63759
1992	56602	0	0	0	56602	56602	52911	56602	56602
1993	61980	0	0	0	61980	61980	58394	61980	61980
1994	56577	56577	56577	56577	56577	56577	52935	56577	56577
1995	53858	53858	53858	53858	53858	53858	48659	53858	53858
1996	47091	47091	47091	47091	47091	47091	40016	47091	47091
1997	42438	42438	42438	42438	42438	42438	35962	42438	42438
1998	45603	45603	45603	45603	45603	45603	39684	45603	45603
1999	44130	44130	44130	44130	44130	44130	39279	44130	44130
2000	44679	44679	44679	44679	44679	44679	38582	44679	44679
2001	42981	42981	42981	42981	42981	42981	37867	42981	42981
2002	41953	41953	41953	41953	41953	41953	37524	41953	41953
2003	39247	39247	39247	39247	39247	39247	34720	39247	39247
2004	36259	36259	36259	36259	36259	36259	31449	36259	36259
2005	30095	30095	30095	30095	30095	30095	26852	30095	30095
2006	27973	27973	27973	27973	27973	27973	25720	27973	27973
2007	29208	29208	29208	29208	29208	29208	26613	29208	29208
2008	25384	25384	25384	25384	25384	25384	23464	25384	25384
2009	16165	16165	16165	16165	16165	16165	15539	16165	16165

Table 3: Akaike Information Criterion (AIC) values for models with (boat) and without (base) the vessel effect. Within a model type and region, the lower AIC indicates better model fit. In each case adding the vessel effect improves the AIC.

Region	Model	boat	base	deltaAIC
1	binomial	90273	96351	-6078
2		-62566	-60800	-1766
3eq		-4132.5	2074.6	-6207.1
3all		-76566	-75172	-1394
4		-309433	-306263	-3170
5		95039	98486	-3447
6		-147.04	-14.52	-132.52
1	positive lognormal	361654	368358	-6704
2		249416	257482	-8066
3eq		853552	871266	-17714
3all		485370	492680	-7310
4		690965	707017	-16052
5		207484	213192	-5708
6		12196	12580	-384
1	offset lognormal	489002	499094	-10092
2		280768	288464	-7696
3eq		1028852	1047303	-18451
3all		558601	565396	-6795
4		759857	776338	-16481
5		315173	323014	-7841
6		16619	17132	-513

Table 4: Indices by region and year-quarter.

Year	Region 1	Region 2	Region 3 (eq)	Region 4	Region 5	Region 6
1976.125	1.046	-	0.843	1.3	-	-
1976.375	0.916	-	0.906	1.259	-	-
1976.625	0.867	-	0.732	1.156	-	-
1976.875	1.032	-	0.908	0.773	0.799	-
1977.125	2.299	-	1.068	1.315	1.114	-
1977.375	1.15	-	1.067	1.303	-	-
1977.625	0.556	-	1.226	1.24	-	-
1977.875	1.759	-	0.968	1.189	-	-
1978.125	1.352	-	1.026	1.661	-	-
1978.375	1.546	-	0.752	1.239	-	-
1978.625	0.366	-	0.506	0.966	4.282	-
1978.875	1.305	-	0.696	0.949	2.081	-
1979.125	0.919	1.109	0.692	1.182	3.284	-
1979.375	0.428	0.499	0.777	1.11	1.305	-
1979.625	0.187	0.217	0.954	1.145	1.171	-
1979.875	0.894	1.345	0.63	1.329	1.768	-
1980.125	1.096	1.245	0.884	1.152	1.316	-
1980.375	0.782	0.518	0.894	1.057	2.019	-
1980.625	0.768	-	0.69	0.915	1.904	2.591
1980.875	1	0.89	0.513	0.615	1.206	2.51
1981.125	0.873	0.668	0.66	0.869	0.988	-
1981.375	0.687	0.401	0.521	1.037	0.839	0.409
1981.625	0.709	-	0.378	0.738	0.826	1.232
1981.875	1.088	1.122	0.4	0.694	0.694	1.292
1982.125	1.089	1.248	0.658	0.984	0.625	0.263
1982.375	0.66	0.733	0.558	0.978	0.711	0.45
1982.625	0.822	-	0.569	0.853	0.945	1.228
1982.875	0.925	1.624	0.867	1.165	0.501	1.243
1983.125	1.029	1.356	0.68	1.641	0.476	-
1983.375	0.644	1.127	0.455	1.239	1.081	0.439
1983.625	0.819	0.669	0.601	1.02	1.087	1.36
1983.875	0.871	1.262	0.84	0.715	0.87	1.67
1984.125	1.074	1.308	0.865	1.165	0.888	0.527
1984.375	0.86	0.921	0.66	1.003	0.923	-
1984.625	0.863	-	0.81	0.818	1.014	1.673
1984.875	1	1.064	0.87	0.84	0.817	1.387
1985.125	0.903	1.07	0.955	1.008	0.894	-
1985.375	0.459	0.372	0.863	1.006	1.186	-
1985.625	0.374	-	0.868	0.943	1.182	1.984
1985.875	0.912	1.207	0.897	0.989	1.085	-
1986.125	1.096	1.048	0.934	1.018	0.987	-
1986.375	0.776	0.796	0.932	0.95	1.089	0.665
1986.625	0.709	-	0.923	0.923	1.203	1.227
1986.875	1.012	1.133	1.169	0.898	0.713	2.124

1987.125	1.091	0.959	1.362	1.469	1.346	0.294
1987.375	0.643	0.716	1.233	1.276	1.961	0.457
1987.625	0.502	-	1.245	1.085	1.54	1.731
1987.875	1.532	1.365	1.128	1.002	0.69	1.586
1988.125	1.055	1.02	1.089	1.015	0.767	-
1988.375	0.848	0.726	0.781	0.899	1.302	-
1988.625	0.844	-	0.699	0.66	1.112	0.701
1988.875	1.083	1.009	0.68	0.697	0.942	-
1989.125	1.136	0.835	0.845	0.937	0.733	-
1989.375	0.781	0.928	1.004	0.898	0.68	-
1989.625	0.597	0.892	1.41	0.709	0.89	1.07
1989.875	1.082	1.185	1.472	0.95	0.84	-
1990.125	1.301	1.102	1.84	1.067	0.854	-
1990.375	1.128	0.754	1.657	0.985	0.926	-
1990.625	0.782	-	1.571	0.921	0.715	1.119
1990.875	1.333	1.512	1.172	0.856	1.086	-
1991.125	1.389	1.351	1.227	0.998	2.321	-
1991.375	0.765	1.061	1.147	0.84	1.103	-
1991.625	0.772	0.984	1.099	0.718	1.174	0.883
1991.875	1.018	1.219	1.05	0.776	1.038	-
1992.125	1.249	1.13	1.329	1.198	0.831	-
1992.375	0.708	1.018	1.289	1.191	0.573	-
1992.625	1.287	-	1.315	0.926	0.943	0.478
1992.875	1.348	1.212	0.877	0.652	1.268	-
1993.125	1.738	1.738	1.228	0.855	0.92	-
1993.375	1.183	1.551	1.029	0.833	0.875	-
1993.625	1.19	-	0.928	0.926	0.749	-
1993.875	1.174	1.021	0.766	0.824	0.67	-
1994.125	1.156	0.827	0.956	0.944	0.629	-
1994.375	0.699	0.671	0.992	0.943	0.958	-
1994.625	0.661	1.172	0.931	0.909	0.958	-
1994.875	0.918	0.756	1.015	1.035	0.743	-
1995.125	0.956	0.755	1.153	1.101	0.94	-
1995.375	0.667	1.361	0.86	0.841	0.812	-
1995.625	0.861	-	0.826	0.627	0.984	-
1995.875	0.868	0.627	0.784	0.669	0.91	-
1996.125	0.973	0.35	0.917	0.771	0.649	-
1996.375	0.708	1.004	1.145	0.966	0.975	-
1996.625	0.672	-	0.903	0.84	1.616	0.535
1996.875	1.235	1.046	0.766	0.5	1.008	-
1997.125	1.578	1.088	1.118	1.135	-	-
1997.375	0.821	1.712	1.188	1.058	0.364	-
1997.625	1.388	-	0.951	1.212	1.333	-
1997.875	1.552	1.431	1.37	1.599	0.637	-
1998.125	1.215	0.912	1.455	2.552	0.809	-
1998.375	0.548	1.08	0.691	1.873	0.628	-
1998.625	1.147	-	0.856	1.406	0.869	0.673
1998.875	0.951	1.131	0.789	0.943	0.797	-

1999.125	1.103	0.678	1.006	1.073	0.959	-
1999.375	0.974	-	1.252	1.075	0.661	-
1999.625	0.718	-	1.365	0.806	0.735	0.692
1999.875	1.236	1.008	0.977	0.665	-	-
2000.125	0.845	0.632	0.935	0.681	-	-
2000.375	0.809	-	1.058	0.899	1.071	-
2000.625	0.693	-	1.028	0.737	2.4	-
2000.875	1.044	0.59	0.789	0.606	-	-
2001.125	0.757	0.469	1.11	0.771	-	-
2001.375	0.469	-	1.116	1.015	0.477	-
2001.625	0.668	-	1.261	1.211	4.124	0.821
2001.875	1.468	0.543	1.416	0.966	1.414	1.114
2002.125	1.156	0.515	1.38	1.085	1.218	-
2002.375	0.973	-	1.299	1.179	1.203	1.083
2002.625	1.367	-	1.223	1.221	1.272	0.924
2002.875	1.81	0.982	1.215	1.534	0.994	-
2003.125	0.928	1.478	1.429	1.165	0.601	-
2003.375	1.799	-	1.293	0.966	1.337	-
2003.625	1.09	1.781	1.206	0.728	1.151	0.389
2003.875	1.363	1.436	1.363	1.005	1.025	-
2004.125	0.904	0.68	1.817	1.186	0.536	-
2004.375	0.92	-	1.332	1.262	0.629	-
2004.625	0.742	-	1.478	1.238	0.977	1.272
2004.875	1.669	1.582	1	1.116	0.857	-
2005.125	0.895	1.424	1.142	1.014	0.367	-
2005.375	1.35	-	1.122	0.887	0.57	-
2005.625	0.737	-	0.627	0.707	0.59	0.992
2005.875	1.866	1.609	0.83	0.736	0.56	0.87
2006.125	1.04	0.836	1.179	0.983	-	-
2006.375	1.489	-	1.281	0.9	0.424	-
2006.625	1.622	1.021	1.001	0.617	0.853	0.451
2006.875	2.512	1.57	0.975	1.079	0.678	-
2007.125	1.195	1.169	0.934	1.267	0.499	-
2007.375	1.111	-	0.845	0.965	0.531	-
2007.625	0.478	0.979	0.679	0.916	0.568	0.894
2007.875	1.484	1.164	0.706	0.786	1.197	-
2008.125	0.737	1.007	1.201	0.722	-	-
2008.375	0.846	0.307	1.327	0.724	0.669	-
2008.625	0.549	-	0.733	0.819	0.758	0.82
2008.875	1.019	0.842	0.863	0.841	0.868	-
2009.125	0.767	0.768	1.63	0.848	0.43	-
2009.375	0.679	-	1.308	0.807	0.436	-
2009.625	-	-	1.091	-	0.374	0.469
2009.875	1.408	-	-	-	1.11	-

Table 5: CVs estimated from offset lognormal model

Year	**Region 1**	**Region 2**	**Region 3 (eq)**	**Region 4**	**Region 5**	**Region 6**
Year	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
1976.125	0.934	0.067	0.066	0.052	-	-
1976.375	0.081	0.182	0.059	0.056	-	-
1976.625	0.124	-	0.057	0.056	-	-
1976.875	0.067	0.071	0.06	0.057	1.398	-
1977.125	0.05	0.072	0.057	0.058	1.052	-
1977.375	0.07	0.175	0.055	0.054	-	-
1977.625	0.087	0.183	0.054	0.056	-	-
1977.875	0.065	0.067	0.054	0.054	-	-
1978.125	0.051	0.065	0.058	0.054	-	-
1978.375	0.077	0.127	0.053	0.052	-	-
1978.625	0.182	0.121	0.053	0.053	1.393	-
1978.875	0.058	0.064	0.052	0.057	0.994	-
1979.125	0.05	0.065	0.053	0.058	0.996	-
1979.375	0.068	0.086	0.051	0.054	0.991	-
1979.625	0.101	0.174	0.051	0.056	0.998	-
1979.875	0.051	0.068	0.056	0.056	0.987	-
1980.125	0.049	0.07	0.056	0.052	0.991	-
1980.375	0.057	0.133	0.051	0.052	0.989	-
1980.625	0.085	-	0.051	0.054	0.988	0.238
1980.875	0.049	0.068	0.053	0.054	0.986	0.14
1981.125	0.047	0.064	0.051	0.055	0.986	-
1981.375	0.051	0.095	0.05	0.052	0.986	0.141
1981.625	0.068	0.26	0.05	0.052	0.985	0.133
1981.875	0.047	0.066	0.054	0.055	0.985	0.138
1982.125	0.047	0.064	0.054	0.051	0.986	0.148
1982.375	0.051	0.083	0.05	0.051	0.986	0.127
1982.625	0.053	-	0.05	0.052	0.987	0.129
1982.875	0.047	0.067	0.057	0.051	0.992	0.137
1983.125	0.047	0.065	0.053	0.051	0.992	-
1983.375	0.052	0.084	0.051	0.05	0.988	0.146
1983.625	0.057	-	0.051	0.052	0.989	0.13
1983.875	0.048	0.066	0.057	0.052	0.987	0.149
1984.125	0.047	0.064	0.052	0.051	0.987	0.152
1984.375	0.061	0.094	0.05	0.05	0.986	-
1984.625	0.054	-	0.05	0.051	0.991	0.129
1984.875	0.047	0.066	0.051	0.052	0.989	0.153
1985.125	0.047	0.065	0.05	0.051	0.988	-
1985.375	0.057	0.087	0.05	0.05	0.987	-
1985.625	0.055	-	0.05	0.052	0.986	0.129
1985.875	0.048	0.067	0.051	0.052	0.987	-
1986.125	0.047	0.064	0.052	0.051	0.986	-
1986.375	0.056	0.09	0.053	0.05	0.987	0.13

1986.625	0.06	-	0.052	0.052	0.987	0.128
1986.875	0.048	0.067	0.056	0.053	0.994	0.133
1987.125	0.05	0.066	0.053	0.051	0.99	0.14
1987.375	0.065	0.098	0.053	0.05	1.037	0.152
1987.625	0.075	-	0.051	0.052	1.048	0.126
1987.875	0.049	0.065	0.053	0.052	0.995	0.158
1988.125	0.05	0.065	0.054	0.051	0.989	-
1988.375	0.064	0.077	0.054	0.051	0.987	-
1988.625	0.058	-	0.054	0.053	0.987	0.132
1988.875	0.049	0.065	0.053	0.058	0.987	-
1989.125	0.049	0.064	0.053	0.051	1.035	-
1989.375	0.058	0.073	0.051	0.051	0.993	-
1989.625	0.068	0.107	0.051	0.052	0.988	0.167
1989.875	0.05	0.067	0.052	0.06	0.992	-
1990.125	0.05	0.066	0.051	0.052	1.017	-
1990.375	0.06	0.084	0.051	0.051	0.988	-
1990.625	0.073	-	0.051	0.053	0.989	0.131
1990.875	0.051	0.069	0.051	0.056	1.393	0.15
1991.125	0.051	0.066	0.053	0.052	1.007	-
1991.375	0.058	0.076	0.053	0.051	0.987	0.164
1991.625	0.07	0.097	0.052	0.052	0.989	0.137
1991.875	0.049	0.069	0.053	0.063	0.992	0.146
1992.125	0.051	0.067	0.053	0.053	0.995	-
1992.375	0.061	0.079	0.053	0.052	1.102	-
1992.625	0.099	-	0.052	0.053	0.992	0.202
1992.875	0.051	0.08	0.054	0.067	0.988	-
1993.125	0.05	0.071	0.053	0.052	0.99	-
1993.375	0.056	0.103	0.053	0.052	0.987	-
1993.625	0.065	-	0.053	0.054	0.987	-
1993.875	0.05	0.072	0.055	0.056	0.989	-
1994.125	0.05	0.069	0.054	0.052	0.988	-
1994.375	0.055	0.102	0.054	0.052	0.987	-
1994.625	0.066	0.102	0.053	0.055	0.987	-
1994.875	0.05	0.078	0.057	0.054	0.988	-
1995.125	0.053	0.081	0.054	0.053	0.988	-
1995.375	0.058	0.12	0.053	0.052	0.987	-
1995.625	0.061	-	0.053	0.055	0.987	-
1995.875	0.05	0.072	0.056	0.062	0.987	-
1996.125	0.052	0.079	0.055	0.052	0.989	-
1996.375	0.056	0.11	0.053	0.053	0.988	0.229
1996.625	0.062	-	0.054	0.053	0.988	0.169
1996.875	0.052	0.08	0.059	0.054	-	-
1997.125	0.054	0.074	0.057	0.053	-	-
1997.375	0.057	-	0.057	0.052	0.998	-
1997.625	0.063	-	0.055	0.053	0.991	-
1997.875	0.051	0.079	0.057	0.054	0.995	-
1998.125	0.055	0.079	0.057	0.053	0.997	-
1998.375	0.056	0.105	0.061	0.053	0.995	-

1998.625	0.064	-	0.057	0.053	0.99	0.175
1998.875	0.055	0.073	0.057	0.055	0.991	-
1999.125	0.053	0.083	0.054	0.053	1.032	-
1999.375	0.055	-	0.054	0.053	0.999	-
1999.625	0.059	-	0.053	0.054	1.013	0.146
1999.875	0.053	0.078	0.055	0.054	-	-
2000.125	0.056	0.074	0.054	0.053	-	-
2000.375	0.062	-	0.055	0.052	0.997	-
2000.625	0.069	-	0.055	0.052	1.06	-
2000.875	0.053	0.08	0.059	0.053	-	-
2001.125	0.055	0.074	0.056	0.053	-	-
2001.375	0.076	-	0.055	0.052	1.001	-
2001.625	0.065	0.12	0.056	0.053	0.994	0.153
2001.875	0.057	0.079	0.056	0.054	0.99	0.16
2002.125	0.055	0.072	0.058	0.053	0.992	-
2002.375	0.069	-	0.055	0.052	0.989	0.189
2002.625	0.069	-	0.06	0.053	0.99	0.202
2002.875	0.055	0.082	0.065	0.054	0.996	-
2003.125	0.055	0.081	0.062	0.052	0.99	-
2003.375	0.061	-	0.056	0.054	0.99	-
2003.625	0.064	0.094	0.056	0.056	0.989	0.172
2003.875	0.059	0.074	0.063	0.056	0.989	-
2004.125	0.055	0.078	0.059	0.054	0.991	-
2004.375	0.067	-	0.057	0.054	0.99	-
2004.625	0.086	-	0.057	0.055	0.989	0.167
2004.875	0.054	0.082	0.067	0.054	0.99	-
2005.125	0.057	0.079	0.058	0.055	0.99	-
2005.375	0.069	-	0.058	0.055	0.99	-
2005.625	0.076	-	0.055	0.06	0.989	0.163
2005.875	0.058	0.076	0.062	0.06	0.991	0.157
2006.125	0.057	0.075	0.06	0.057	-	-
2006.375	0.08	-	0.059	0.057	0.99	-
2006.625	0.092	0.102	0.056	0.065	0.989	0.198
2006.875	0.054	0.081	0.066	0.069	0.991	-
2007.125	0.055	0.081	0.061	0.058	0.992	-
2007.375	0.063	-	0.061	0.056	0.989	-
2007.625	0.074	0.117	0.062	0.056	0.989	0.156
2007.875	0.053	0.08	0.086	0.06	0.991	-
2008.125	0.053	0.083	0.079	0.058	-	-
2008.375	0.063	-	0.065	0.057	0.989	-
2008.625	0.087	-	0.06	0.063	0.989	0.158
2008.875	0.054	0.082	0.078	0.063	0.991	-
2009.125	0.057	0.087	0.083	0.062	0.992	-
2009.375	0.072	-	0.065	0.073	0.99	-
2009.625	-	-	0.072	-	0.989	0.171
2009.875	0.058	-	-	-	-	-

8. Figures

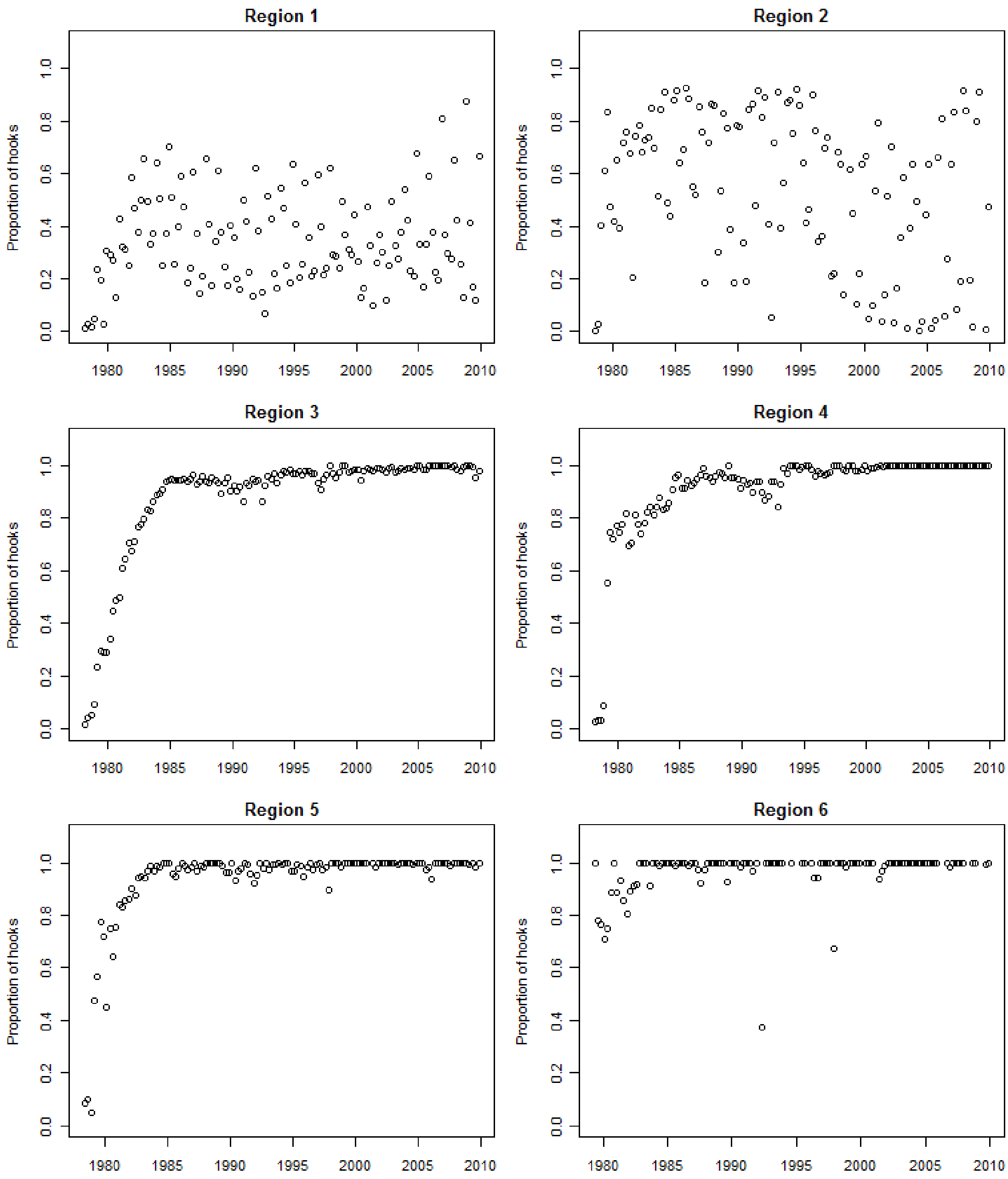

Figure 1: Proportion of effort remaining after data cleaning.

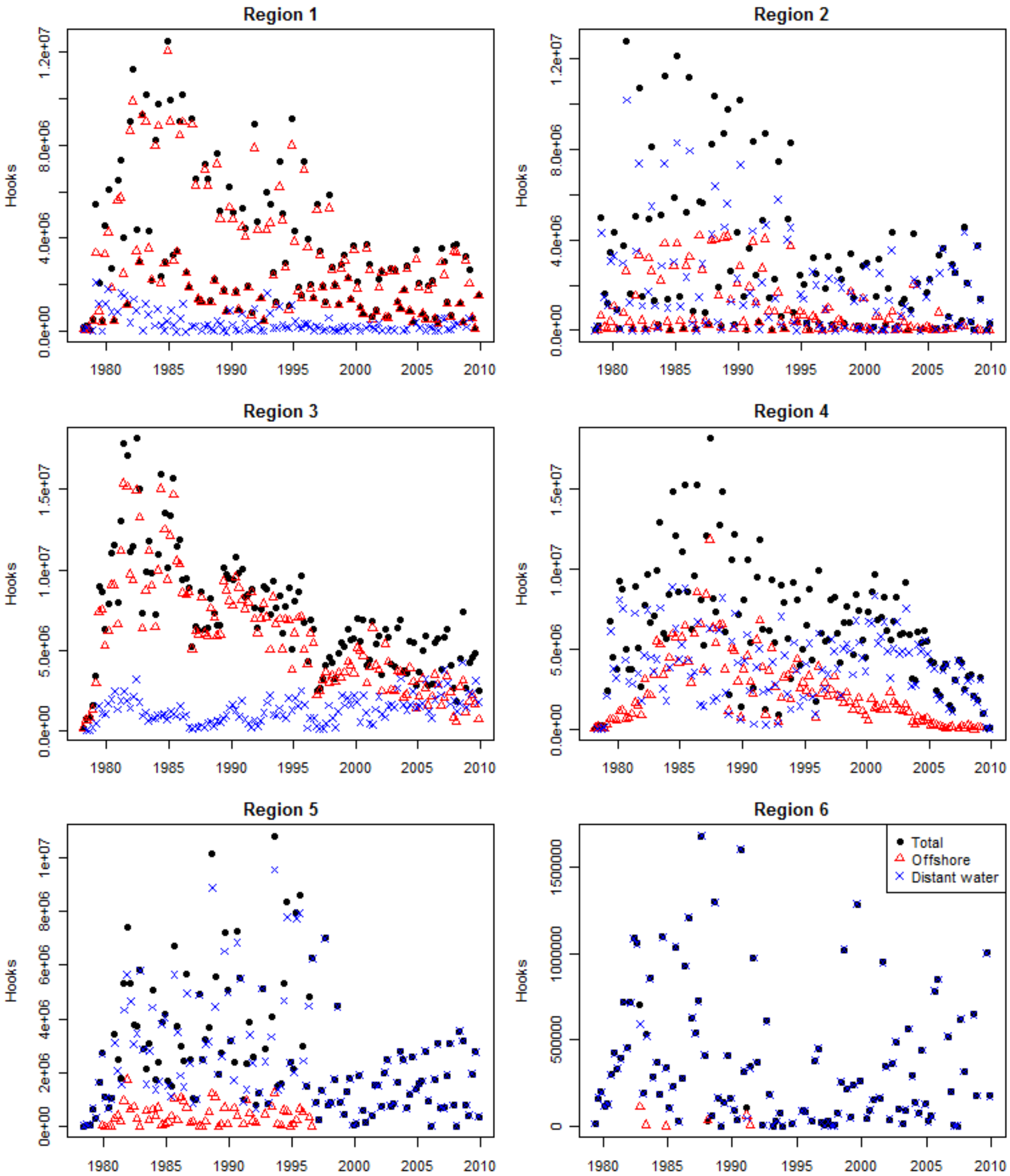

Figure 2: Effort by region, fleet, and year-quarter by the Japanese longline fleet, both distant water and offshore, as recorded in the operational dataset.

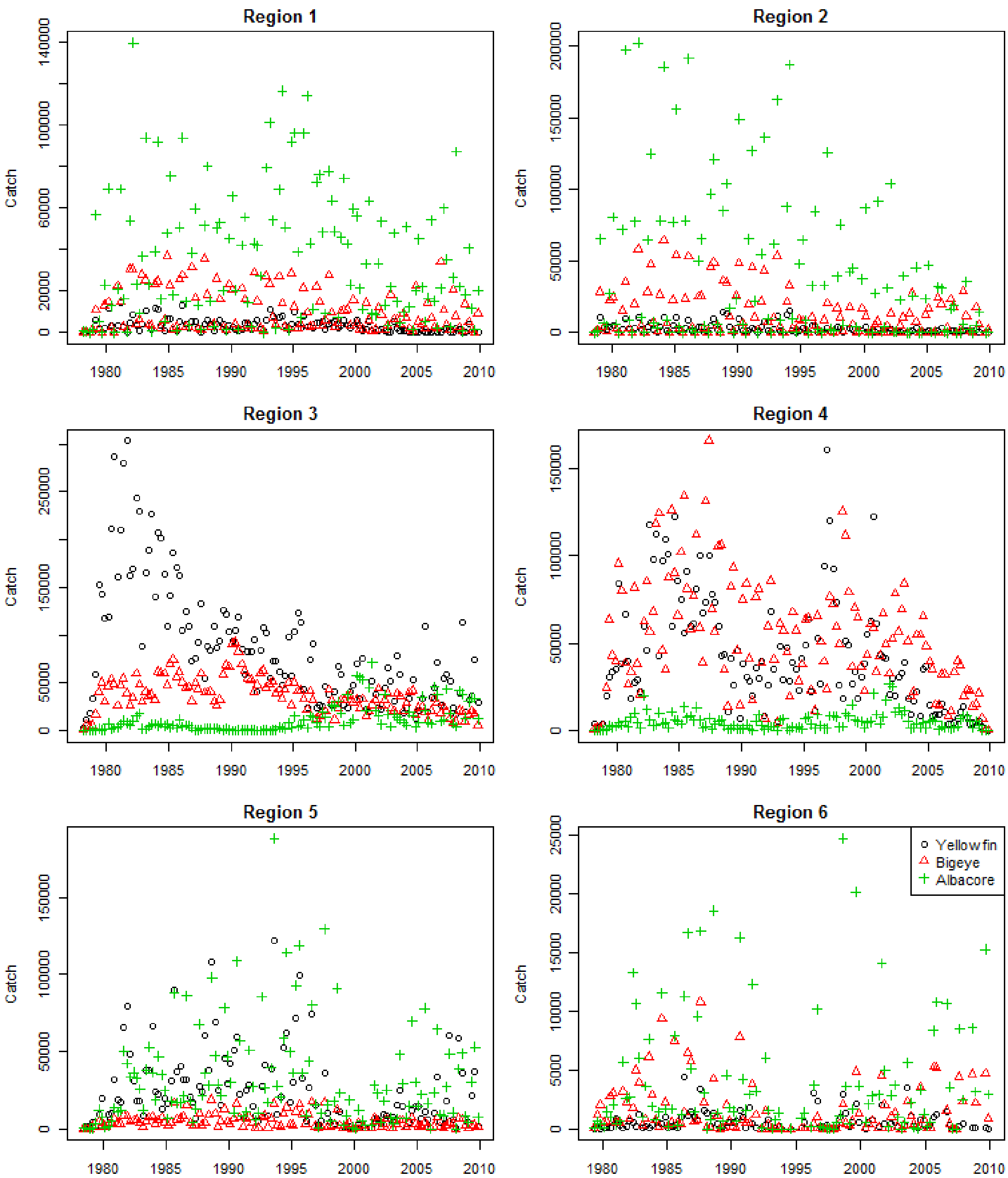

Figure 3: Catch of bigeye, yellowfin, and albacore tuna by region and year-quarter, by the Japanese longline fleet, as recorded in the operational dataset.

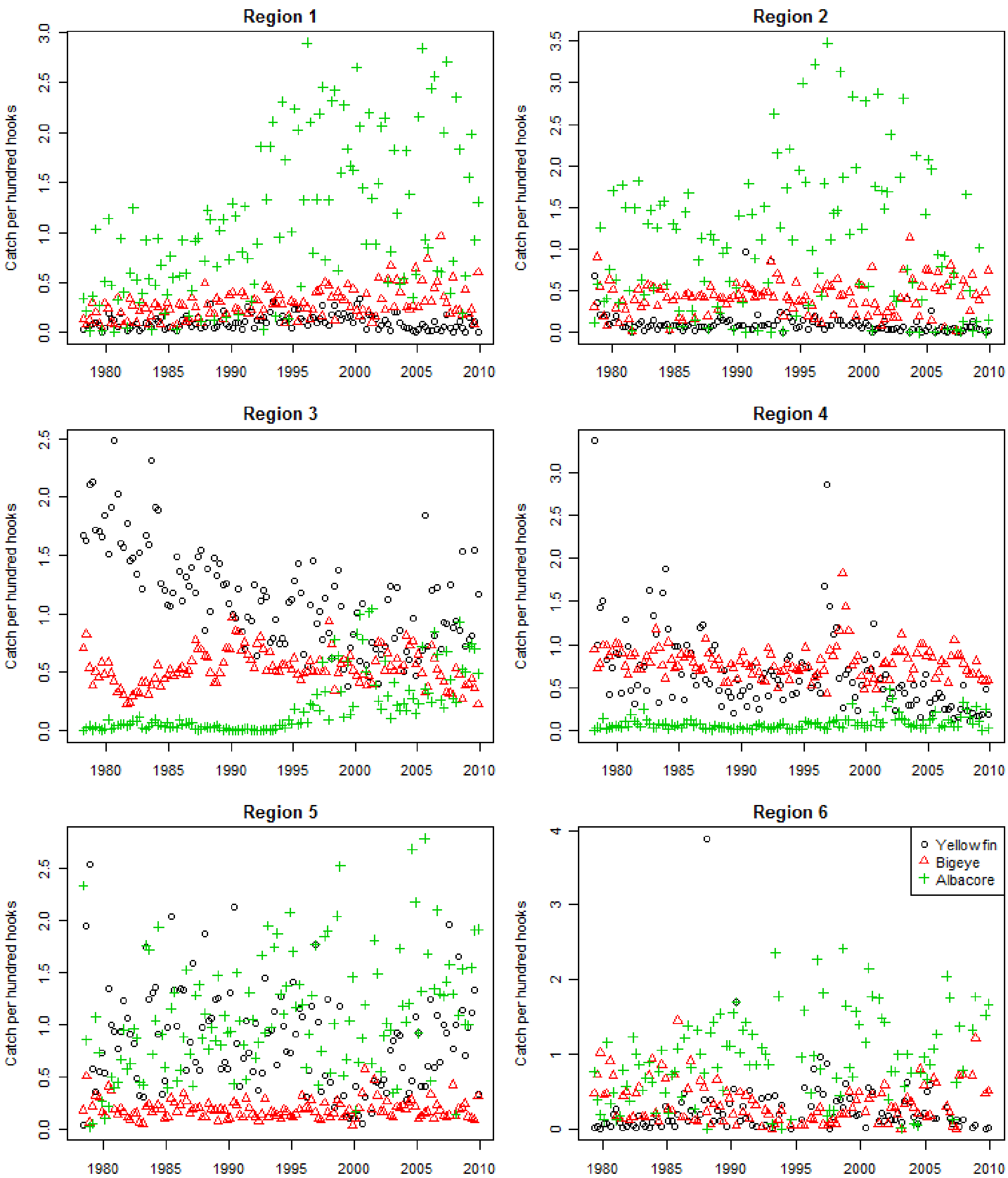

Figure 4: Nominal catch per unit of effort of bigeye and yellowfin tuna by region and year-quarter, by the Japanese longline fleet.

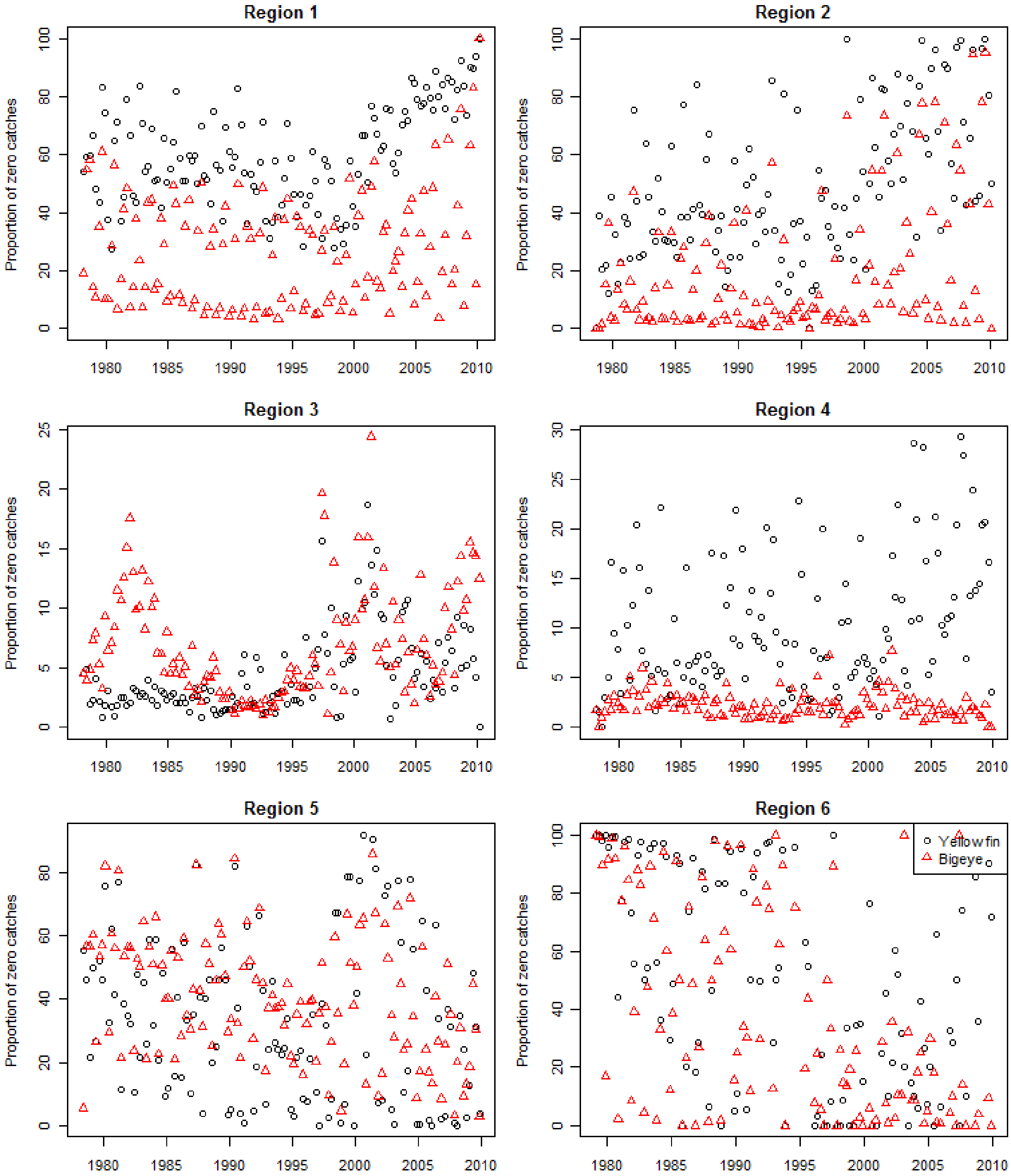

Figure 5: Proportion of reported sets that record zero catch of bigeye and/or yellowfin by year.

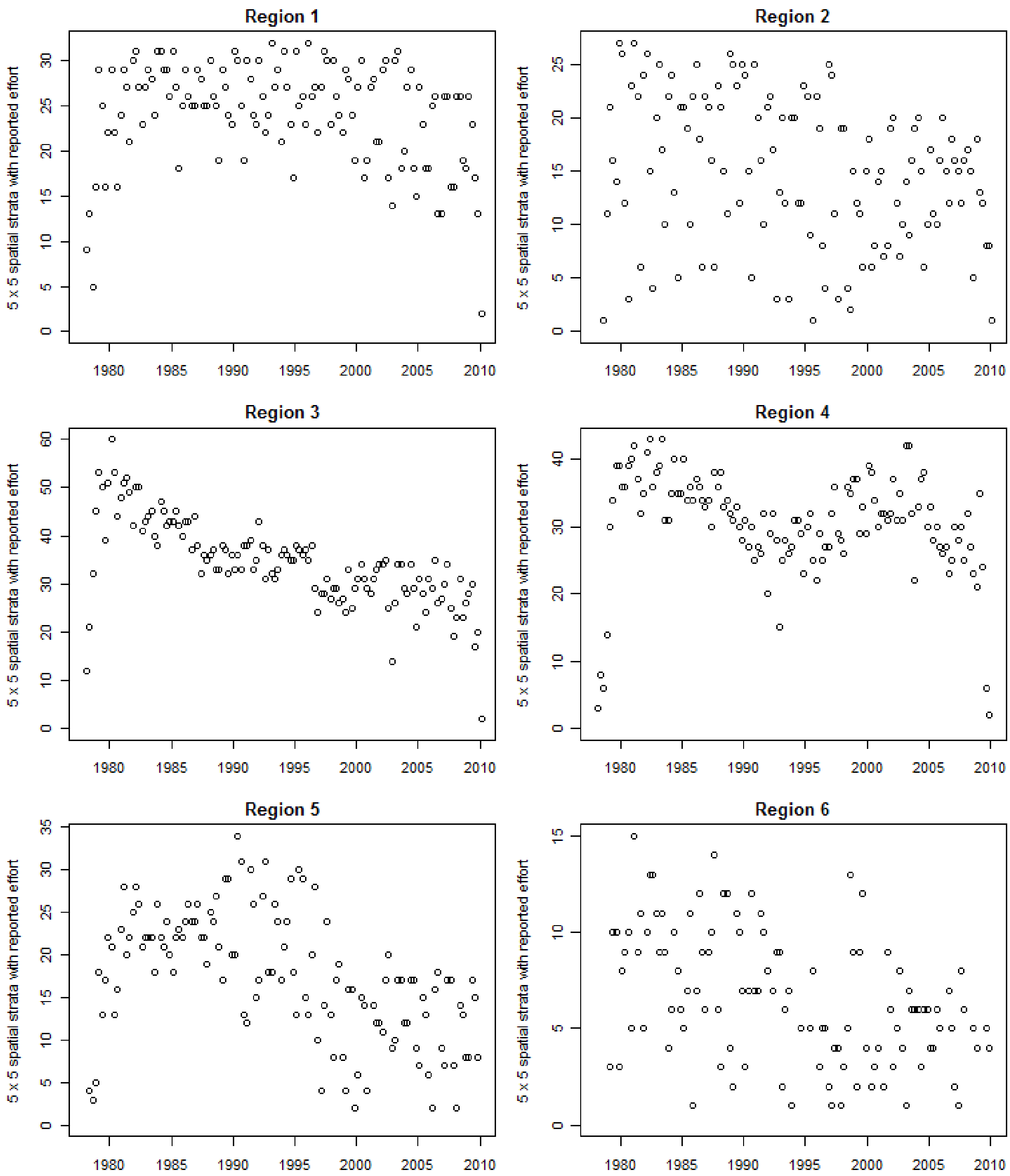

Figure 6: The number of 5° x 5°spatial strata in which effort is reported, by region and year-quarter, for the Japanese longline fleet.

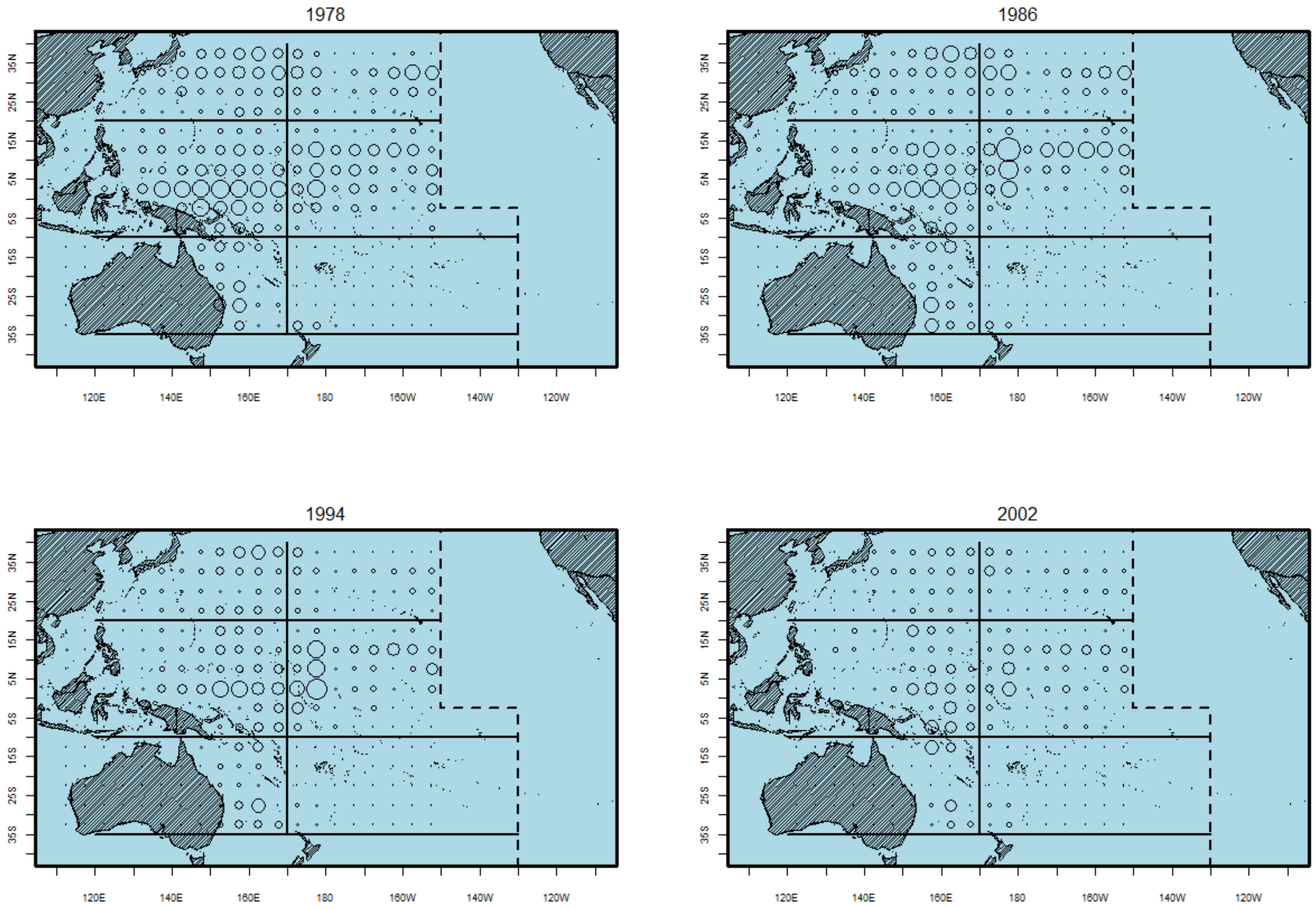

Figure 7: Maps of number of sets by 8 year period (1979-1985, 1986-1993, 1994-2001, and 2002-2009). Circle areas are proportional to the number of sets.

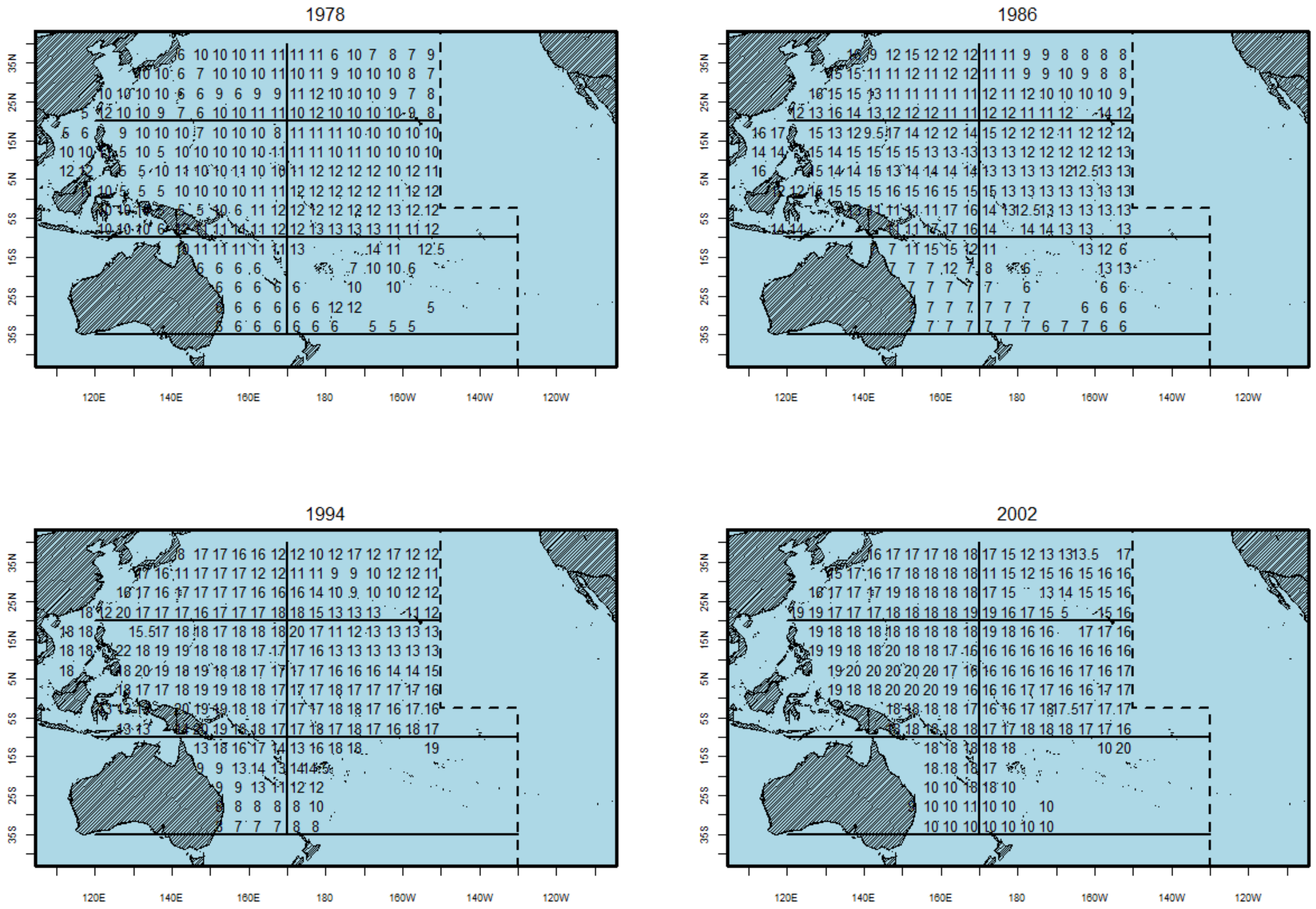

Figure 8: Median HBF by 5 degree square for four different 8-year periods (1979-1985, 1986-1993, 1994-2001, and 2002-2009).

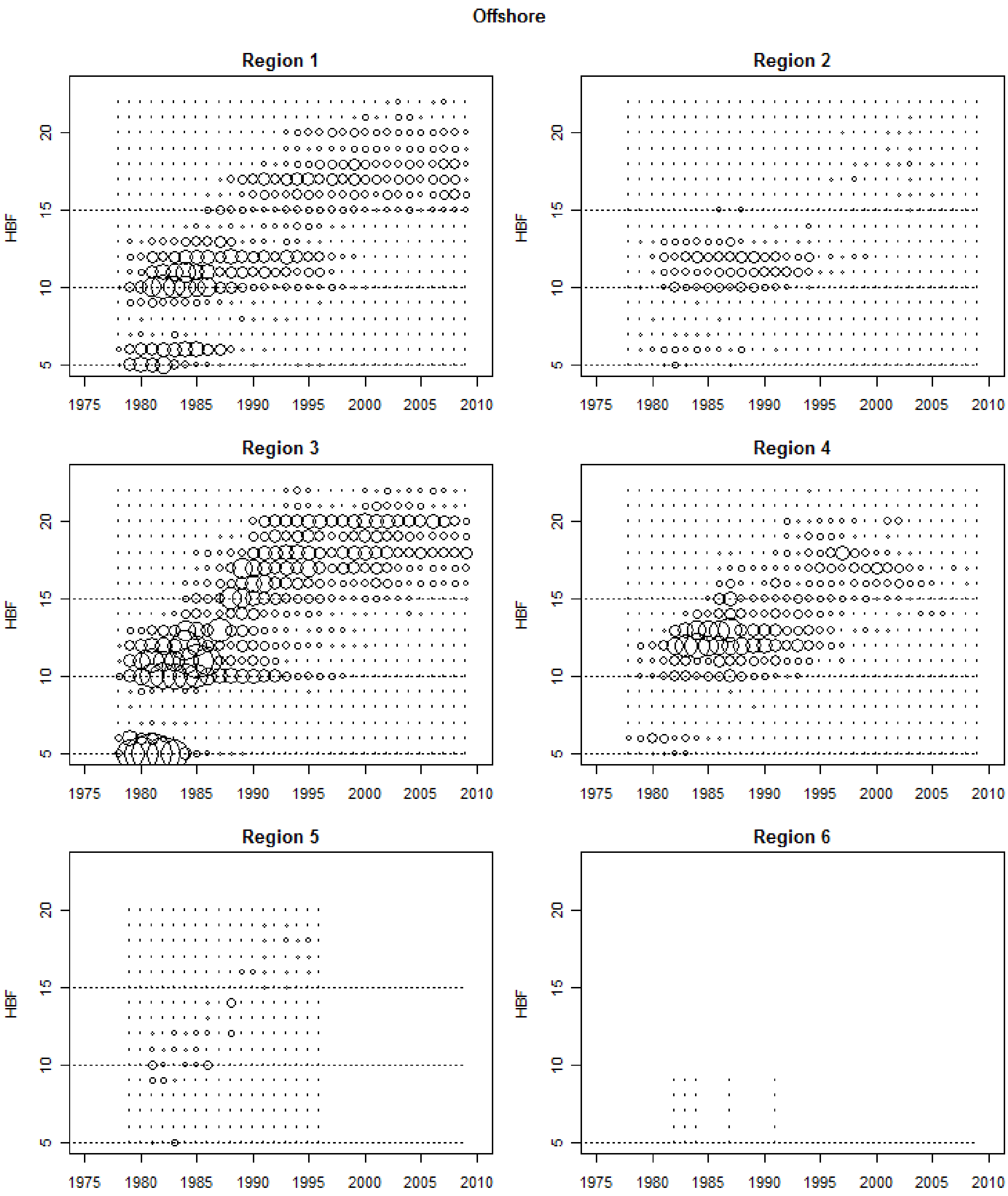

Figure 9: HBF by region by year for offshore vessels. Circle area is proportional to the number of sets.

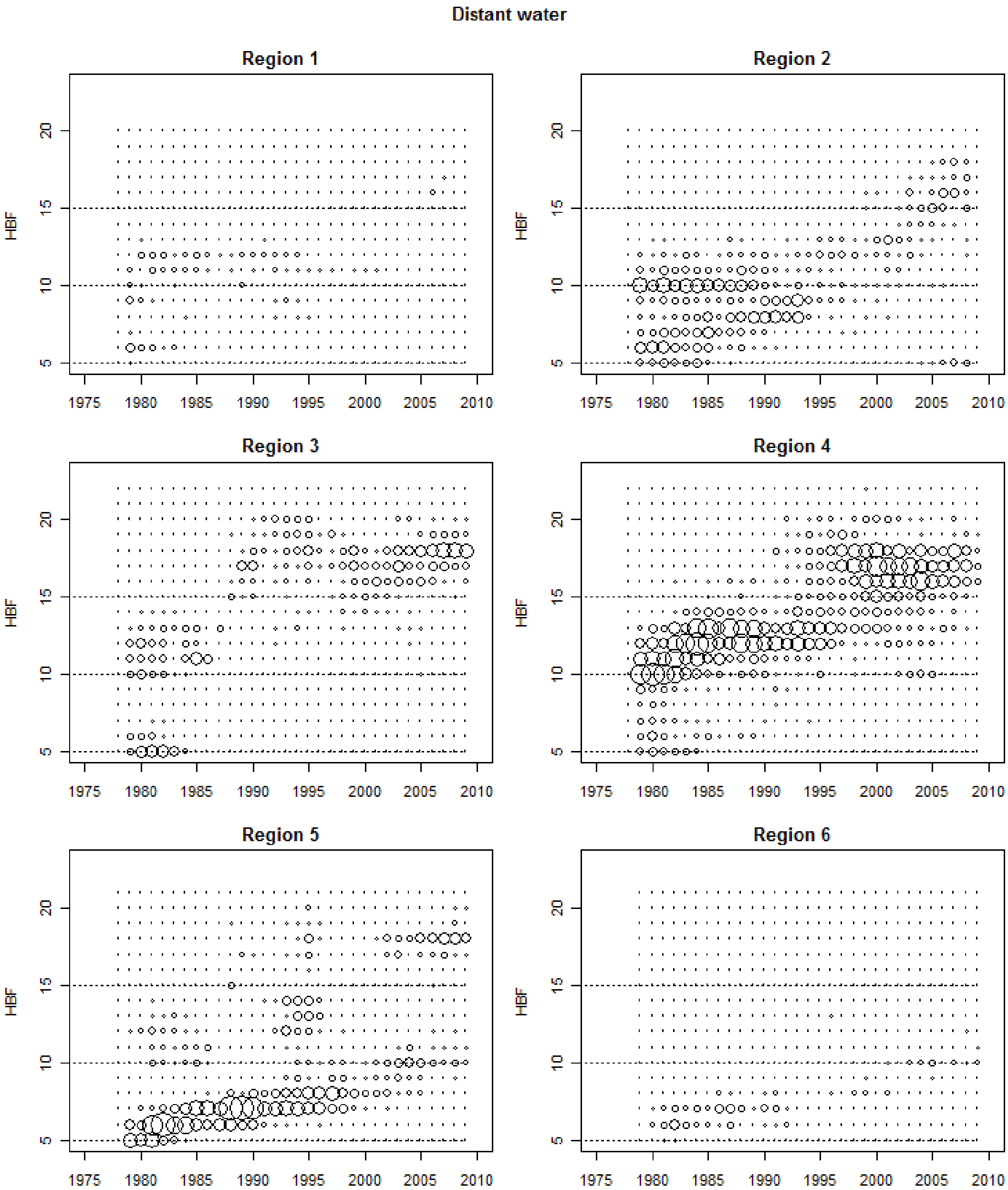

Figure 10: HBF by region by year for distant water vessels. Circle area is proportional to the number of sets.

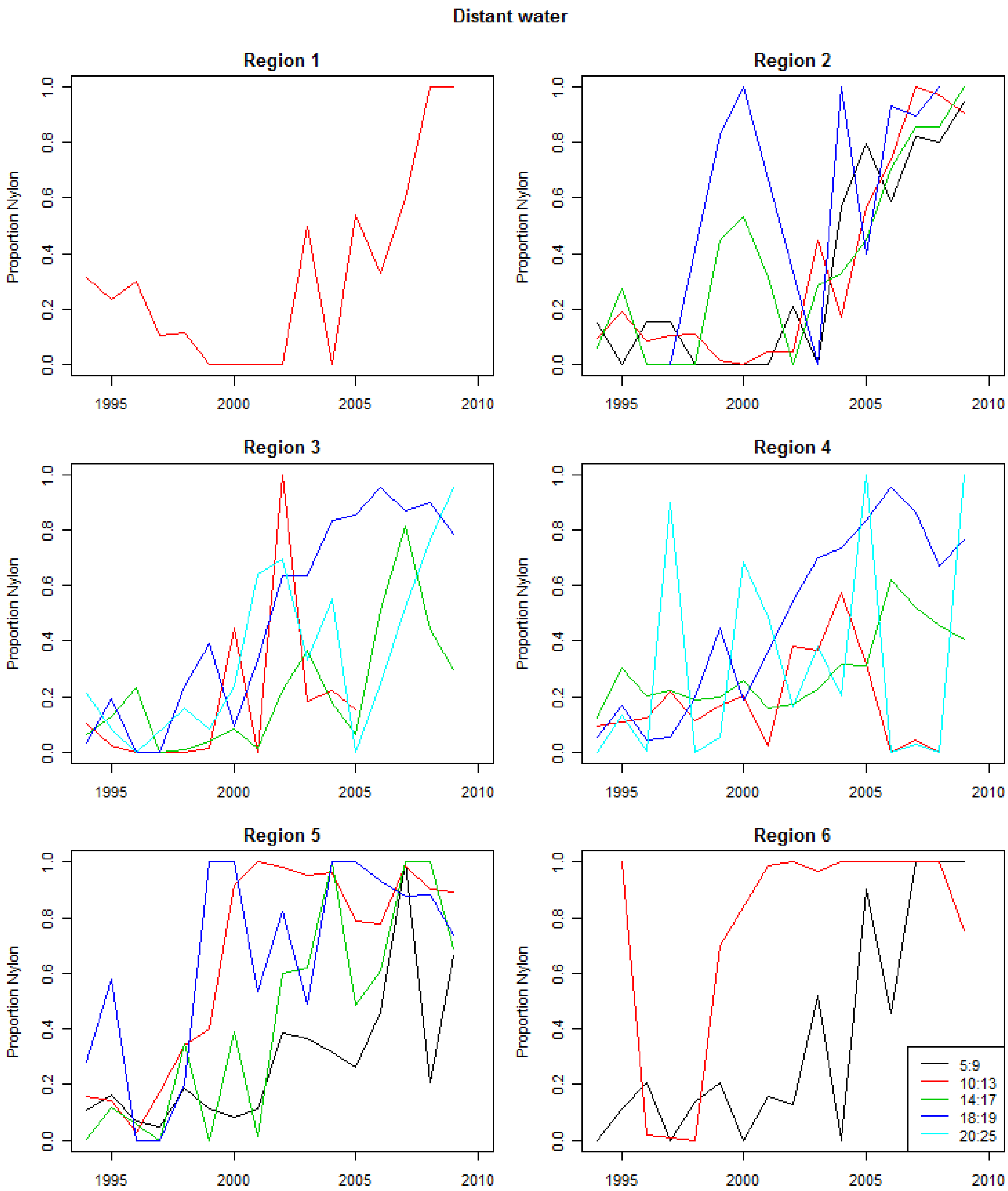

Figure 11: Proportion of sets using nylon by year and HBF, for distant water vessels.

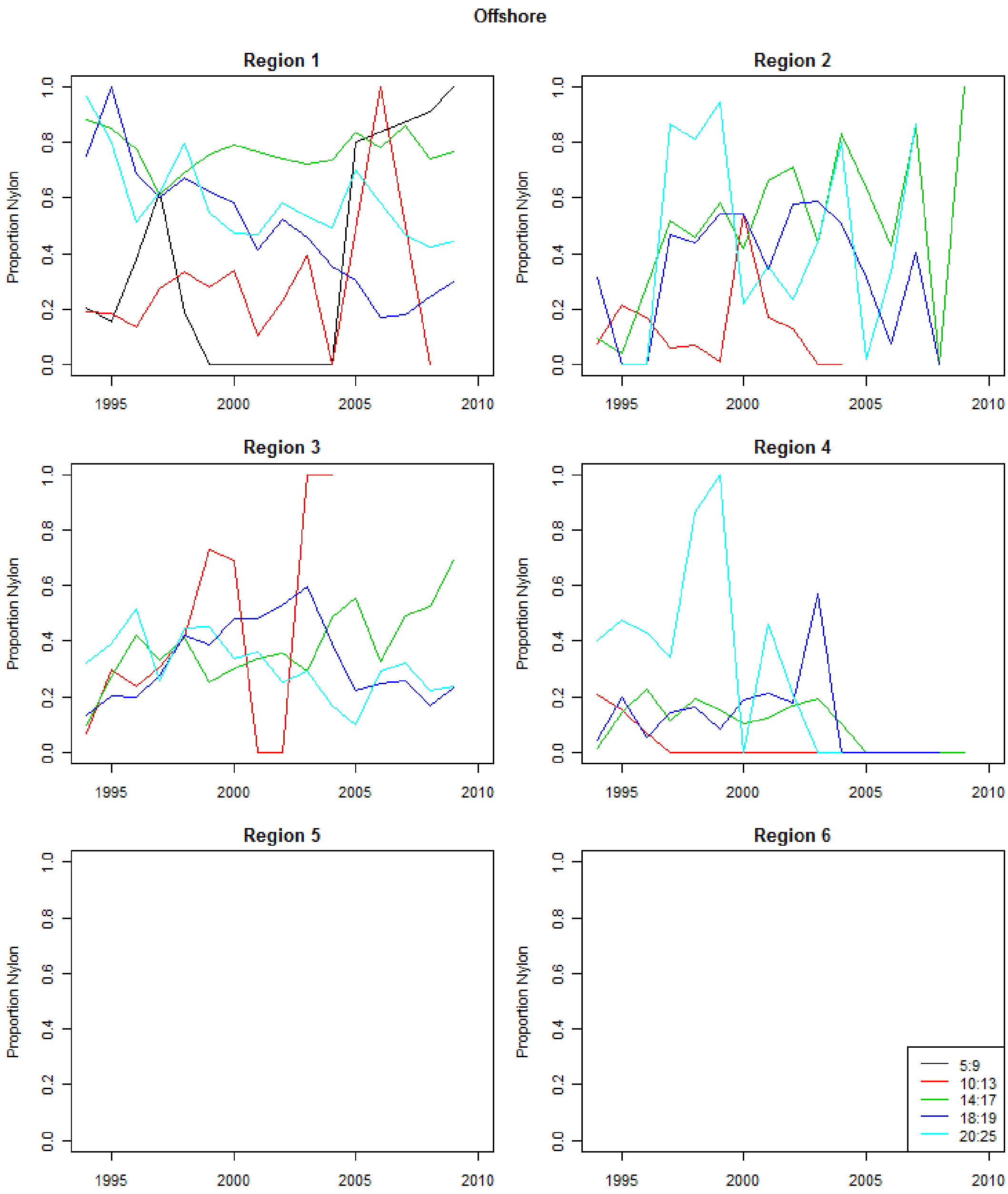

Figure 12: Proportion of sets using nylon by year and HBF, for offshore vessels.

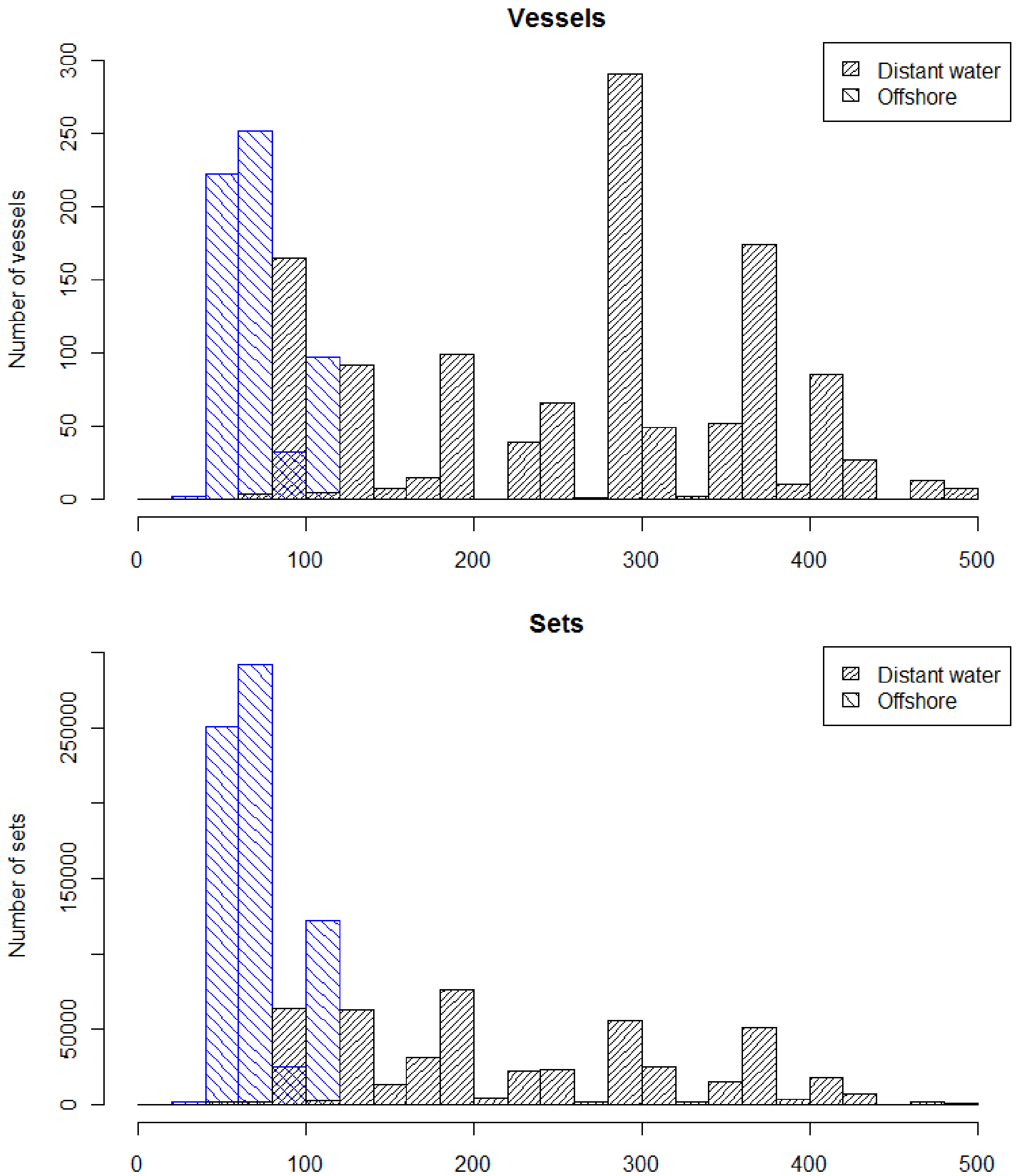

Figure 13: Number of vessels by GRT (top) and number of sets by vessel GRT (bottom) for offshore and distant water vessels.

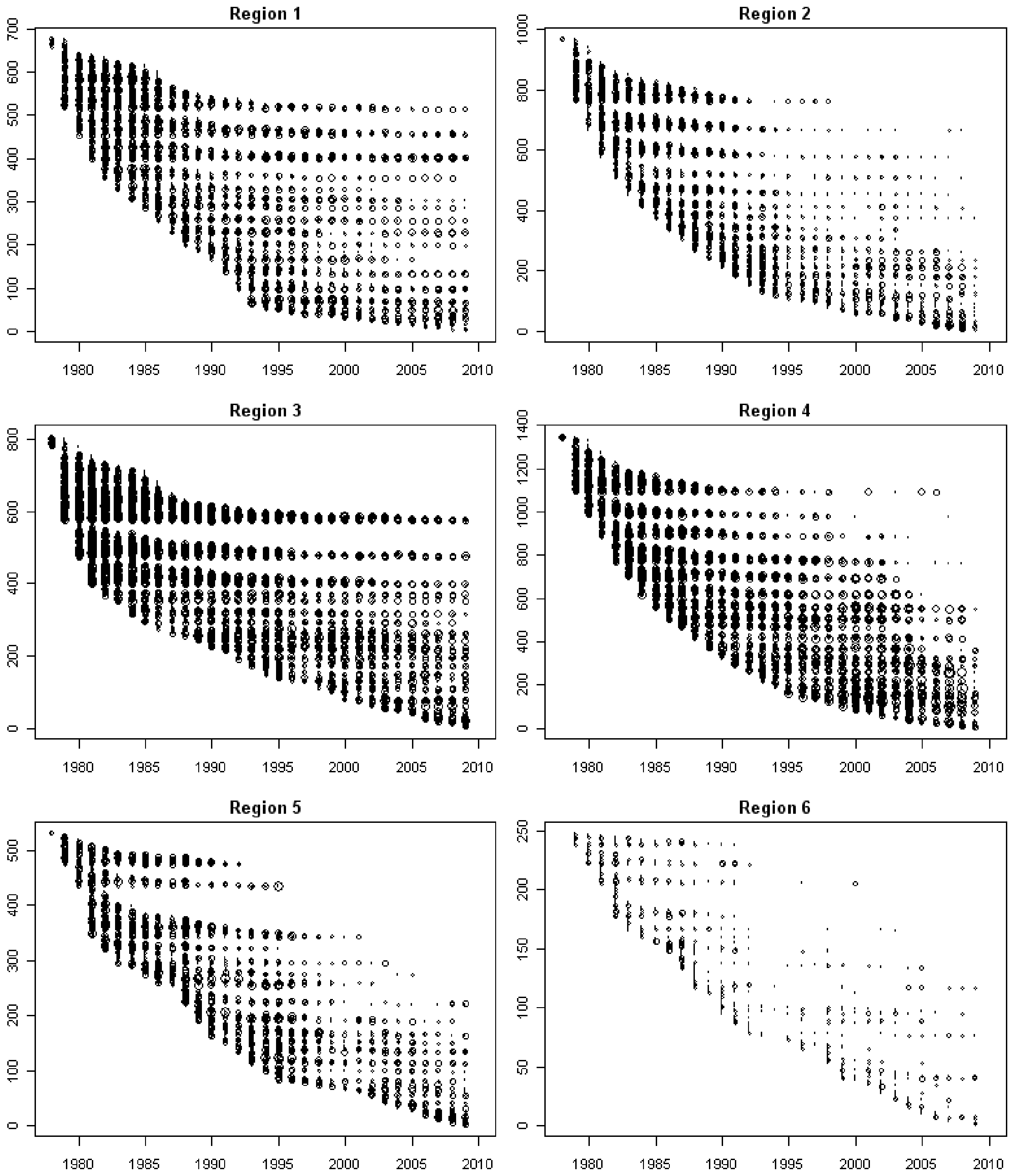

Figure 14: Logbook entry presence and absence by vessel and quarter for vessels included in the full fishing power analysis. Vessels are sorted by (a) year of first logsheet and (b) year of last logsheet. Circle area is proportional to the number of sets.

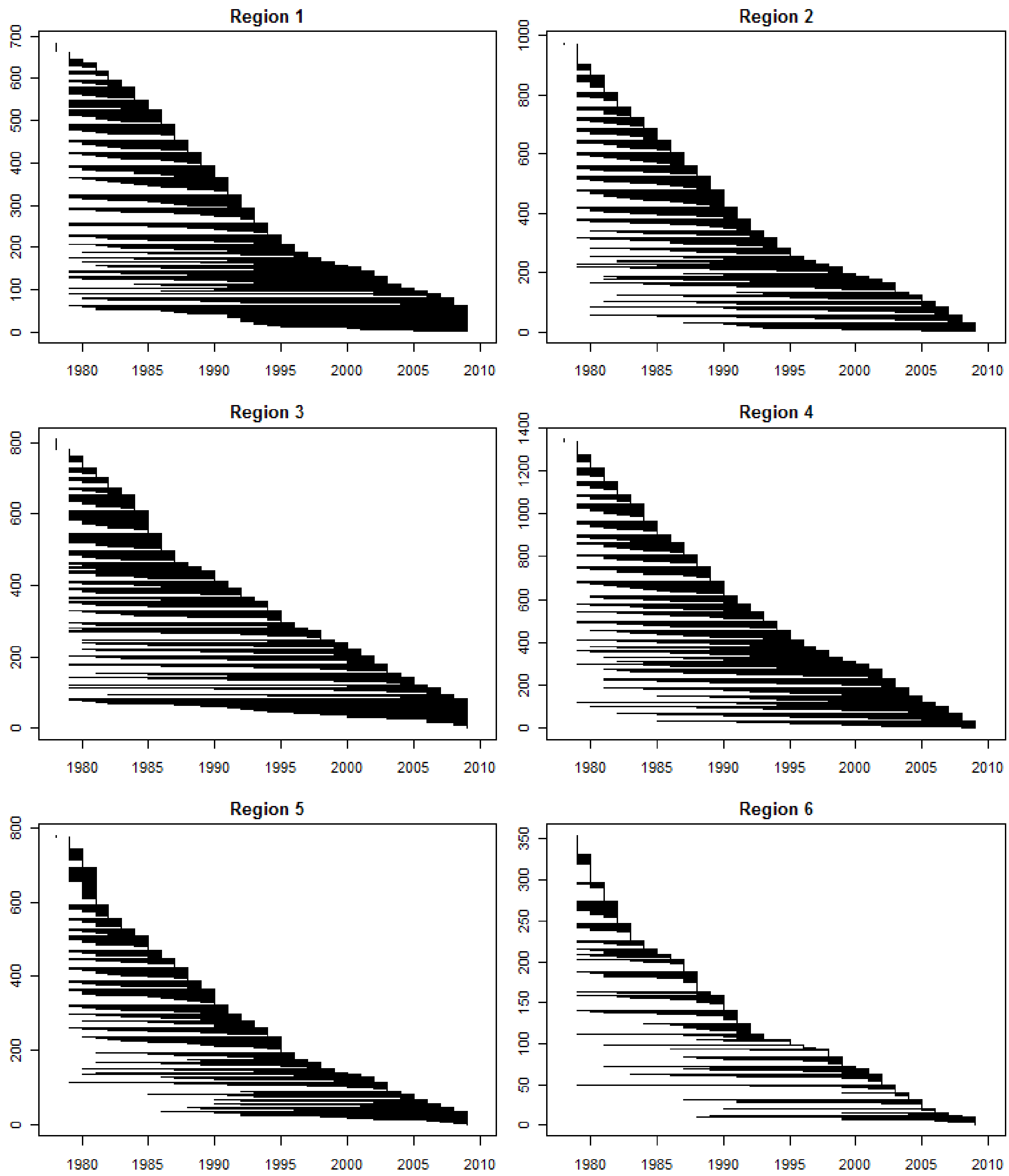

Figure 15: Distribution of first and final years of observed effort by Japanese DW LL vessels reporting effort by region, sorted by the yearof the most recent logsheet record.

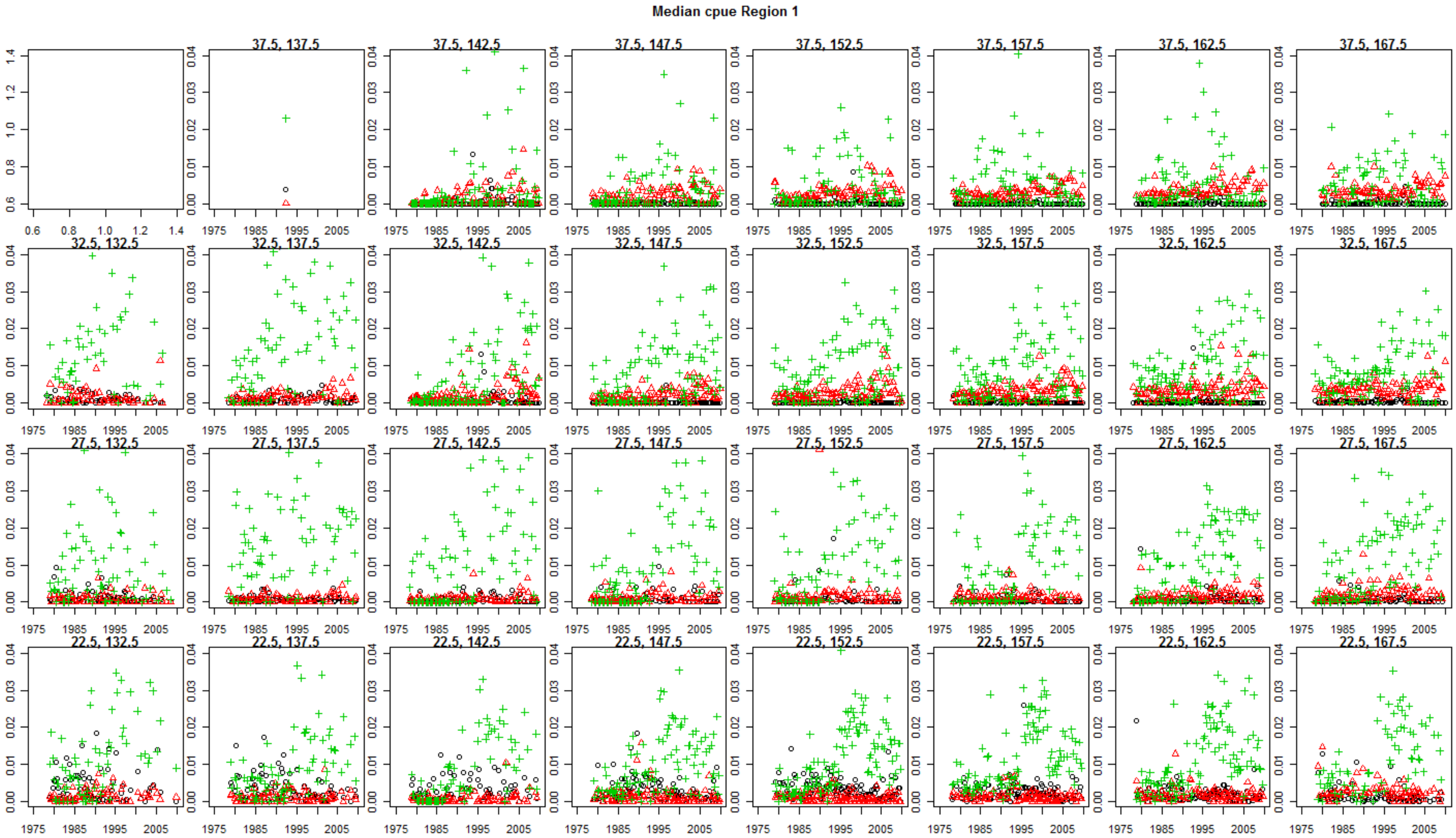

Figure 16: Median CPUE by 5 degree square in Region 1. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

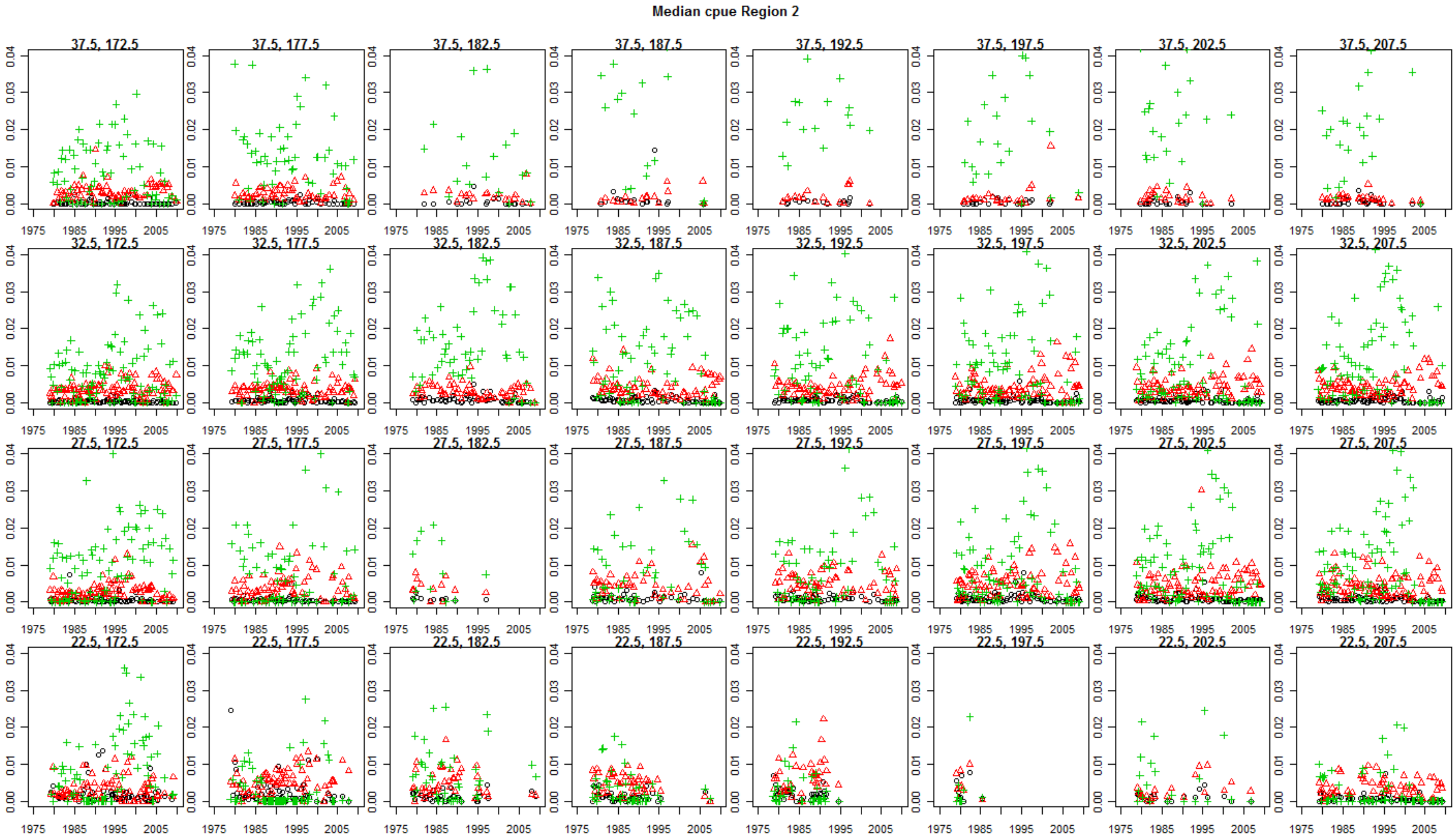

Figure 17: Median CPUE by 5 degree square in Region 2. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

[Type text]

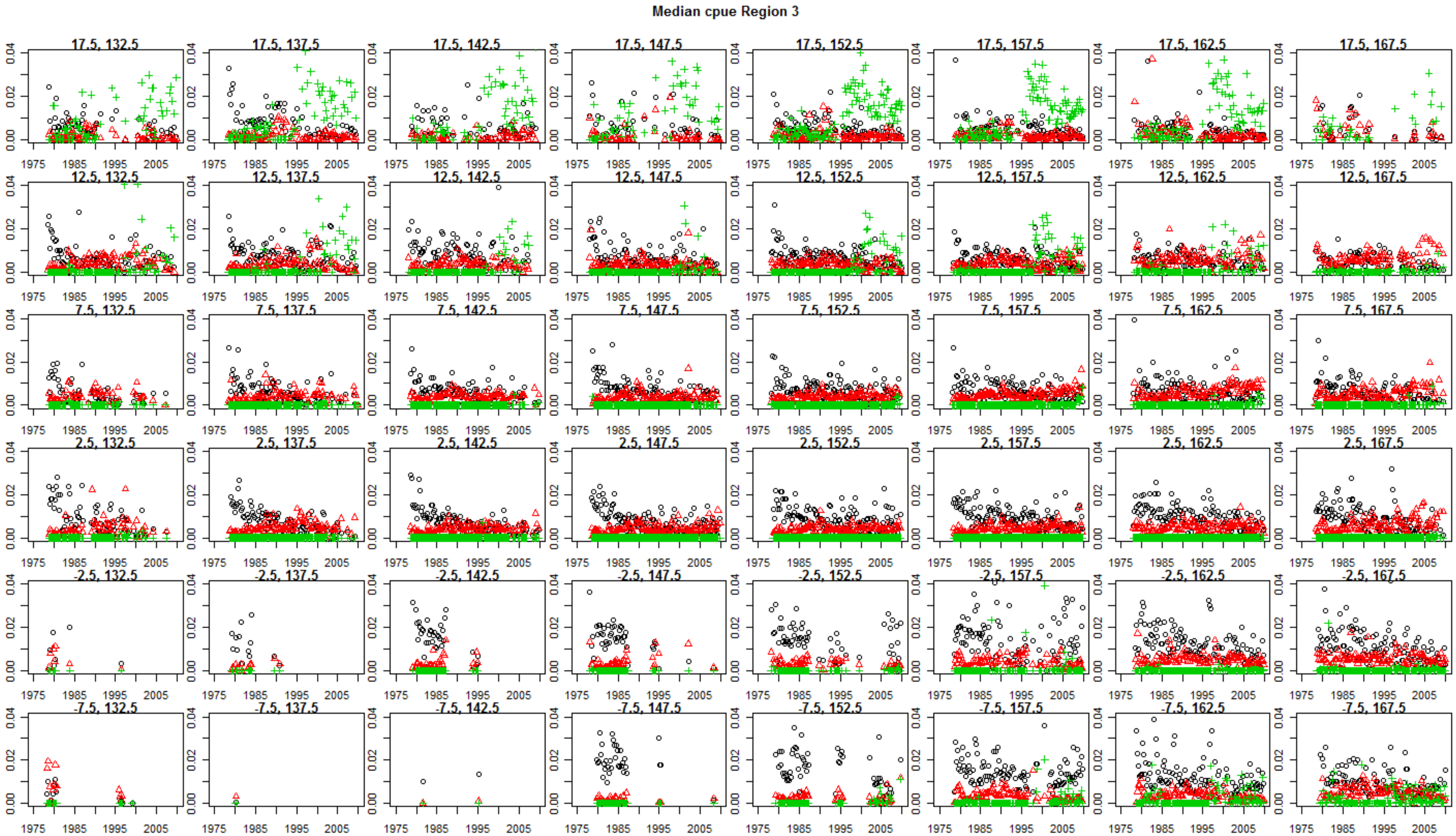

Figure 18: Median CPUE by 5 degree square in Region 3. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

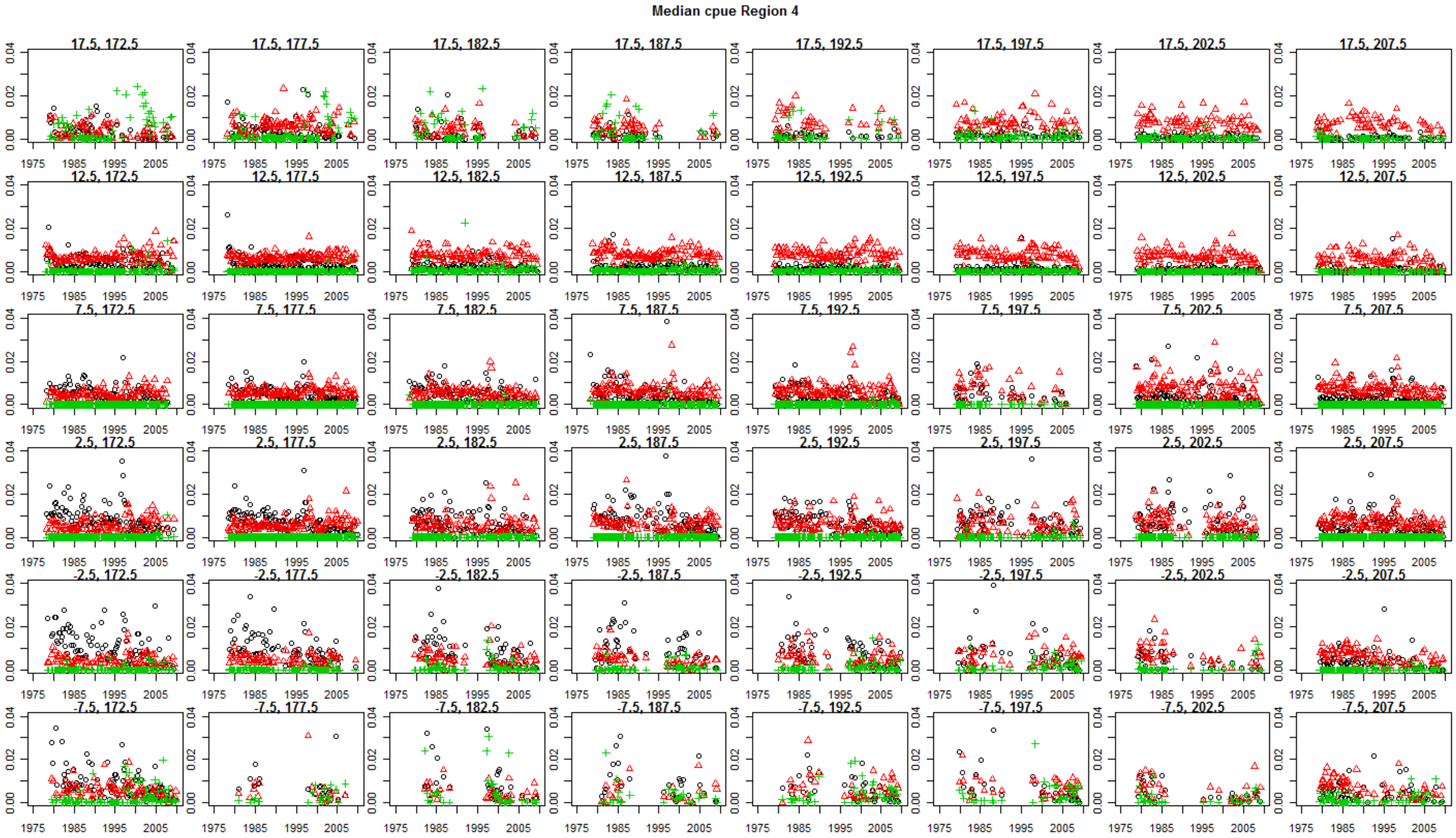

Figure 19: Median CPUE by 5 degree square in Region 4. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

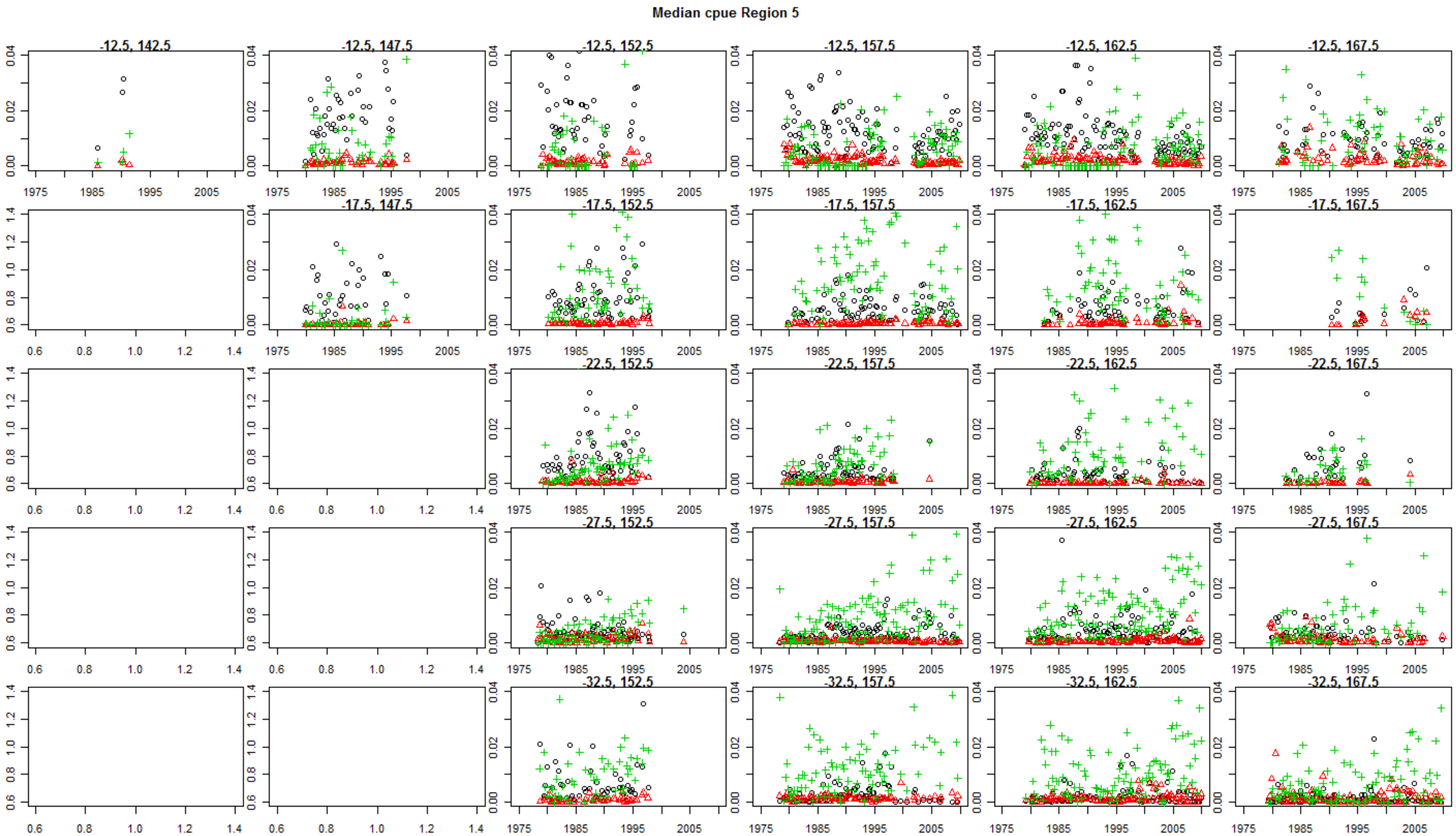

Figure 20: Median CPUE by 5 degree square in Region 5. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

[Type text]

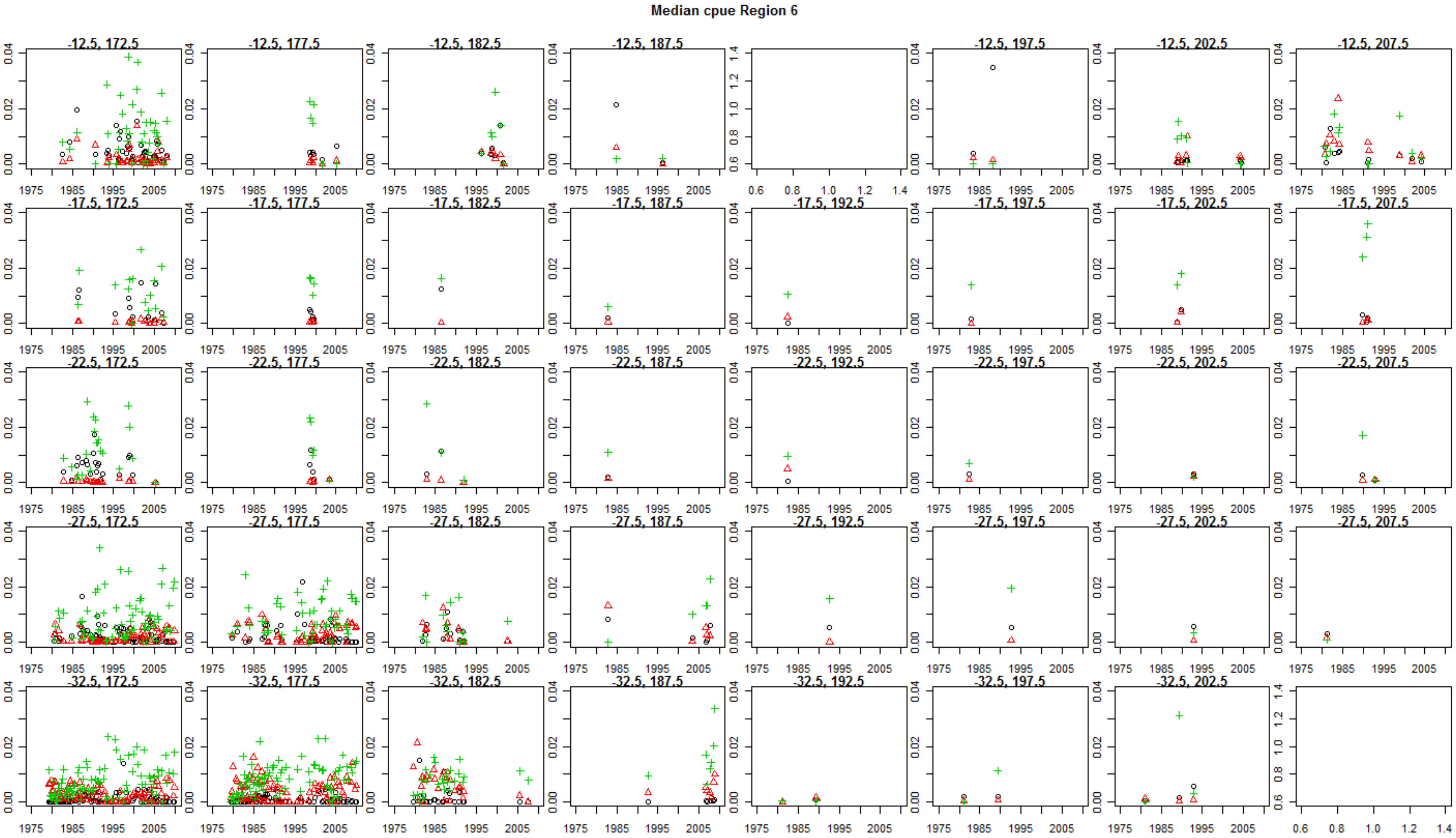

Figure 21: Median CPUE by 5 degree square in Region 6. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

[Type text]

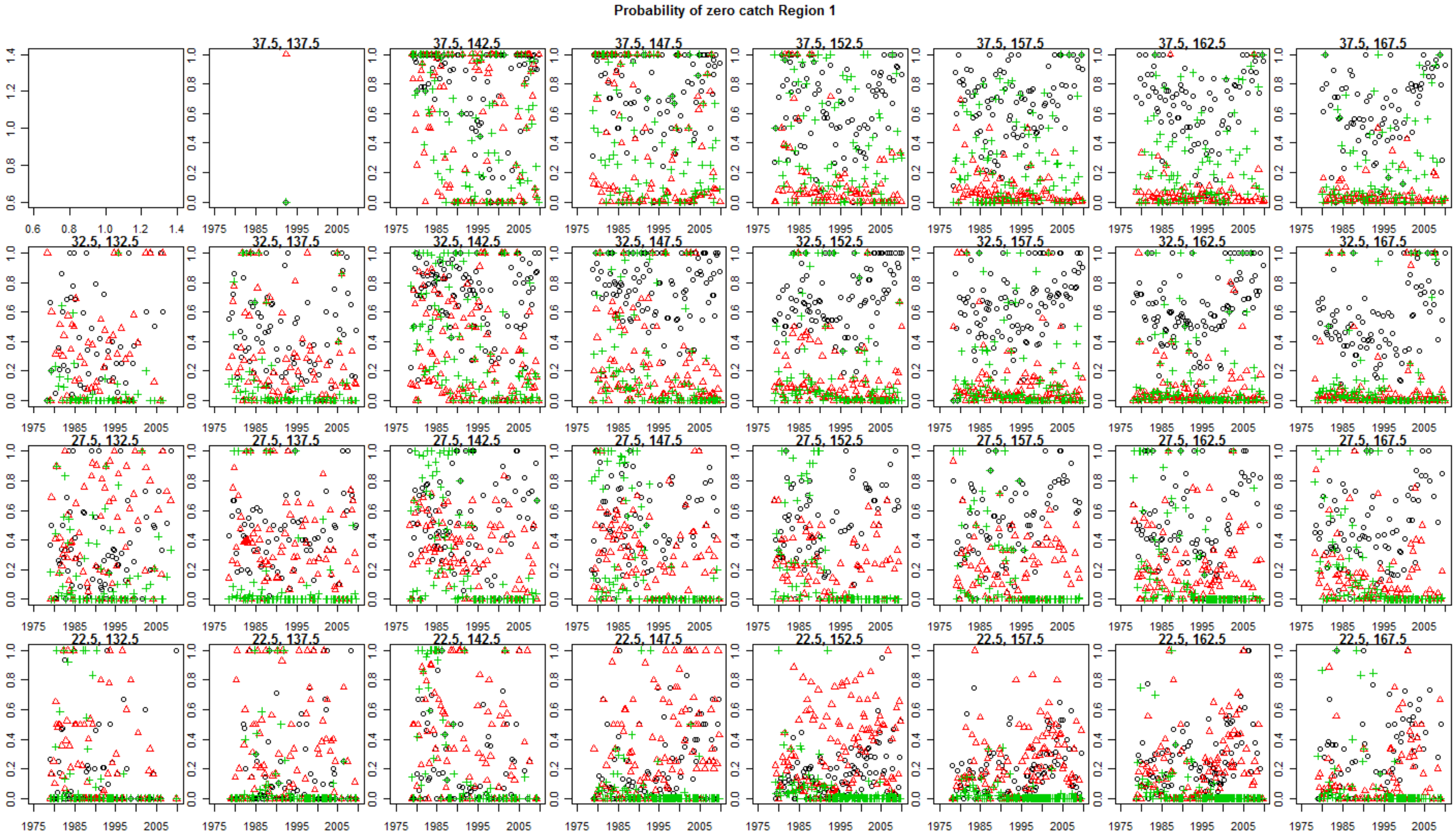

Figure 22: Proportion of zero catch in sets by quarter and 5 degree square in Region 1. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

[Type text]

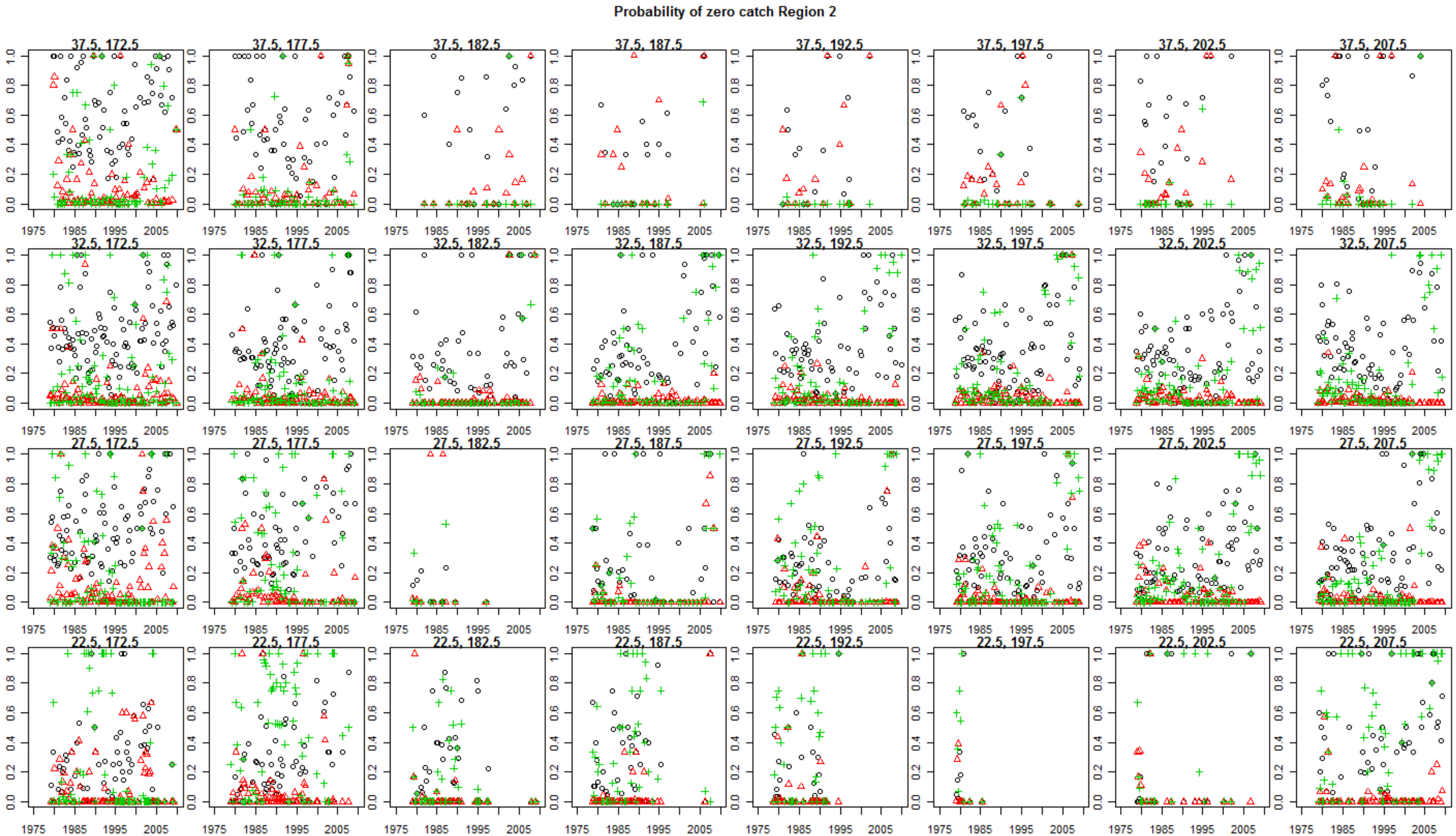

Figure 23: Proportion of zero catch in sets by quarter and 5 degree square in Region 2. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

[Type text]

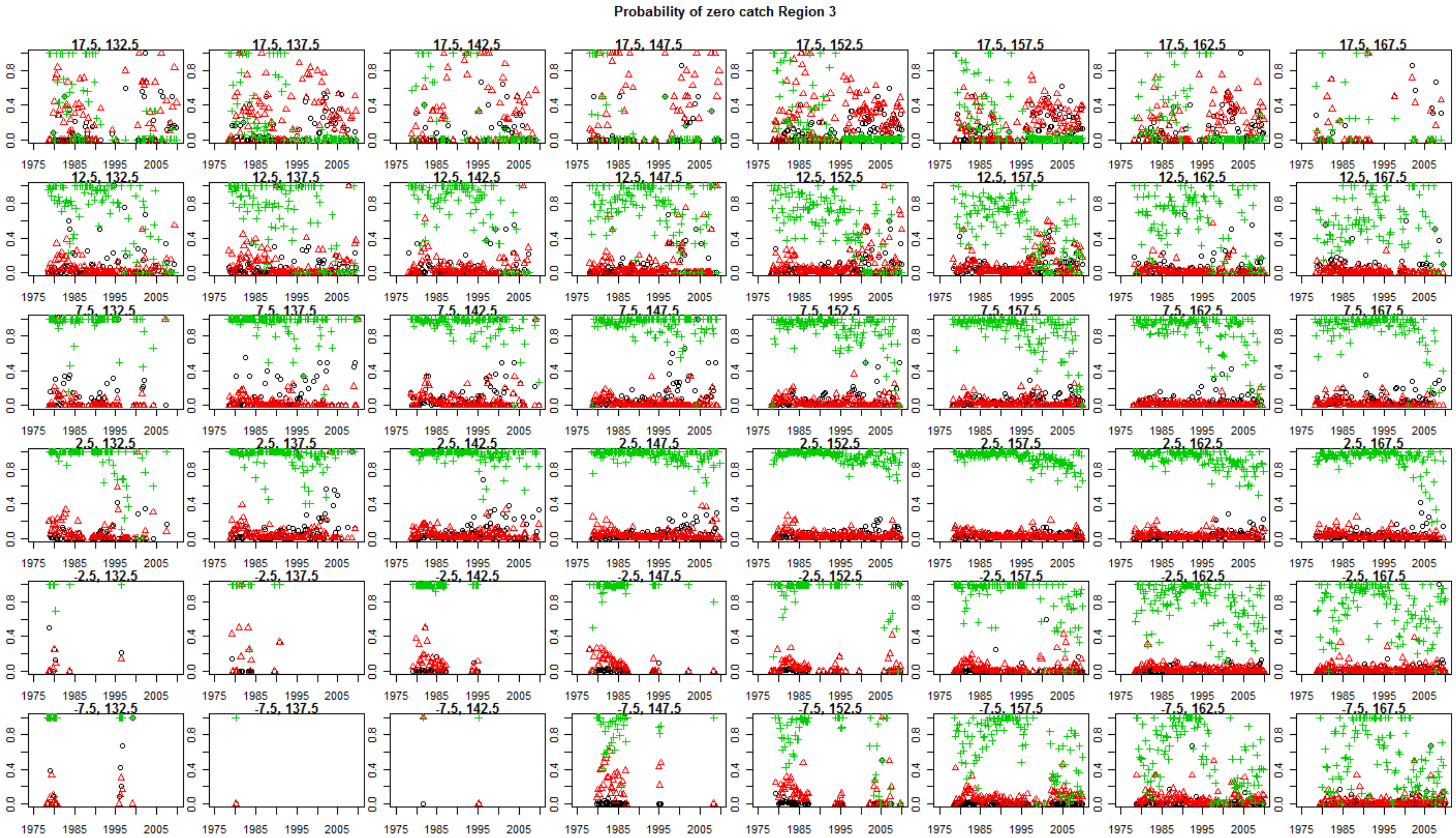

Figure 24: Proportion of zero catch in sets by quarter and 5 degree square in Region 3. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

[Type text]

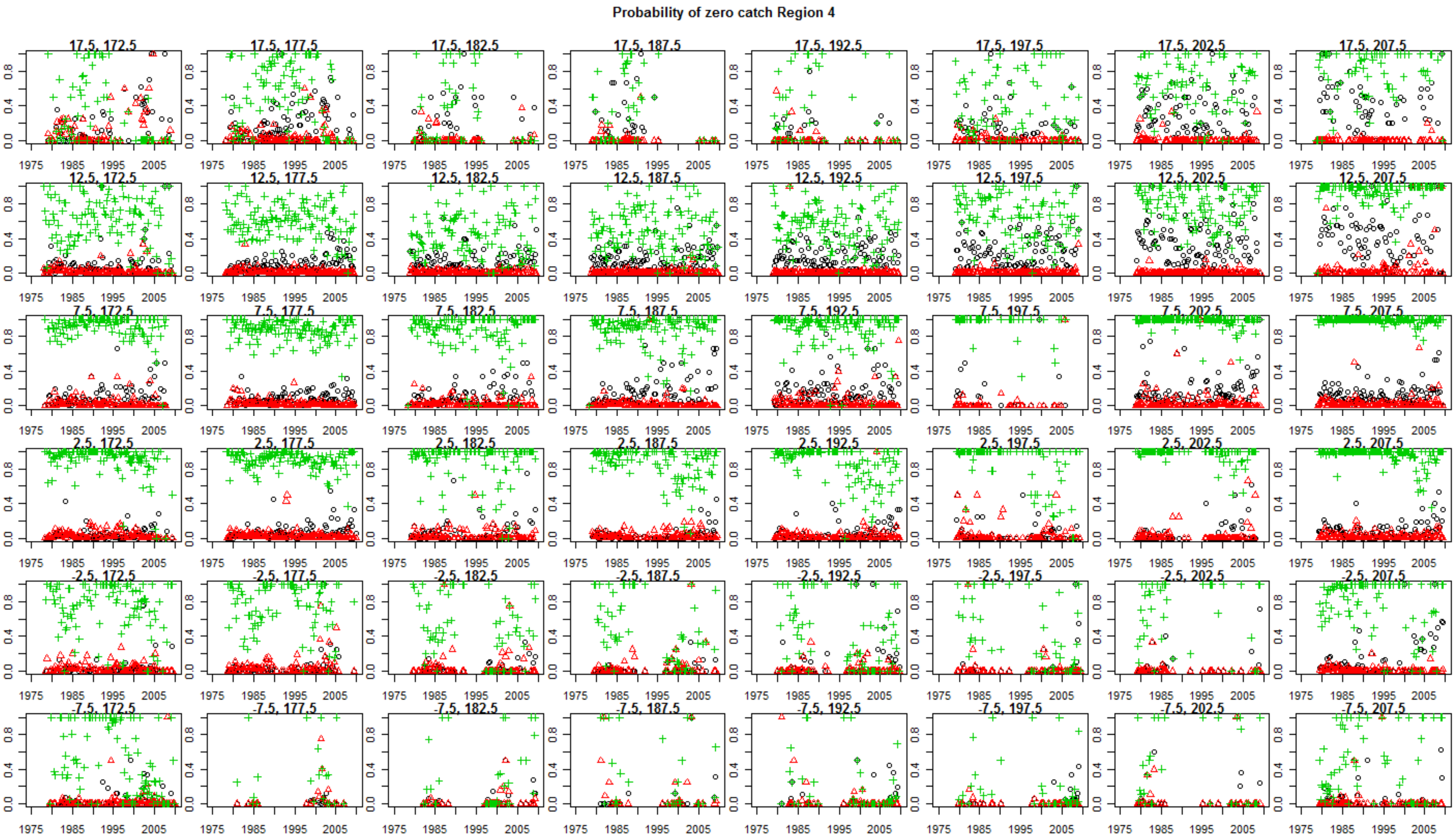

Figure 25: Proportion of zero catch in sets by quarter and 5 degree square in Region 4. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

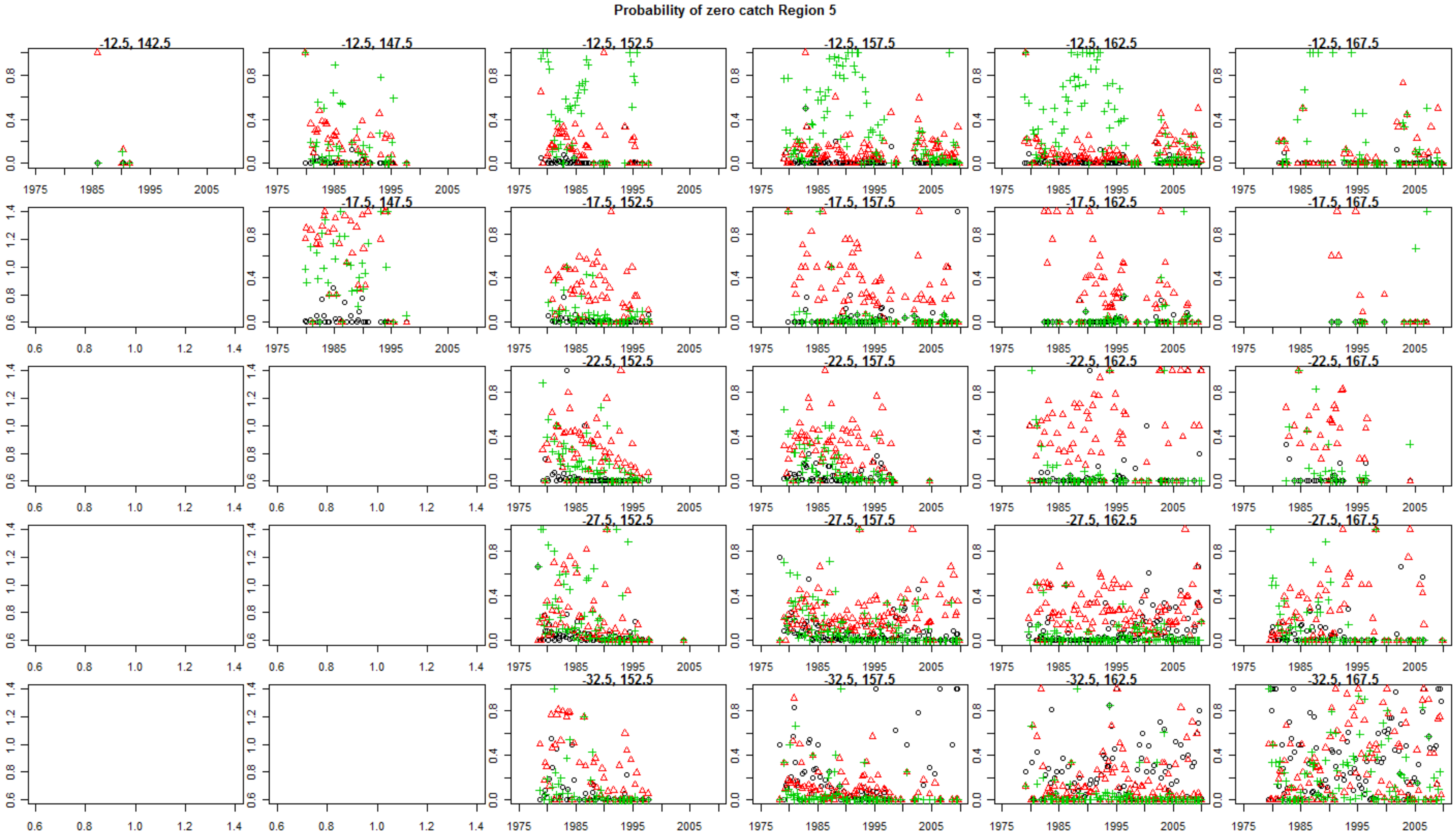

Figure 26: Proportion of zero catch in sets by quarter and 5 degree square in Region 5. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

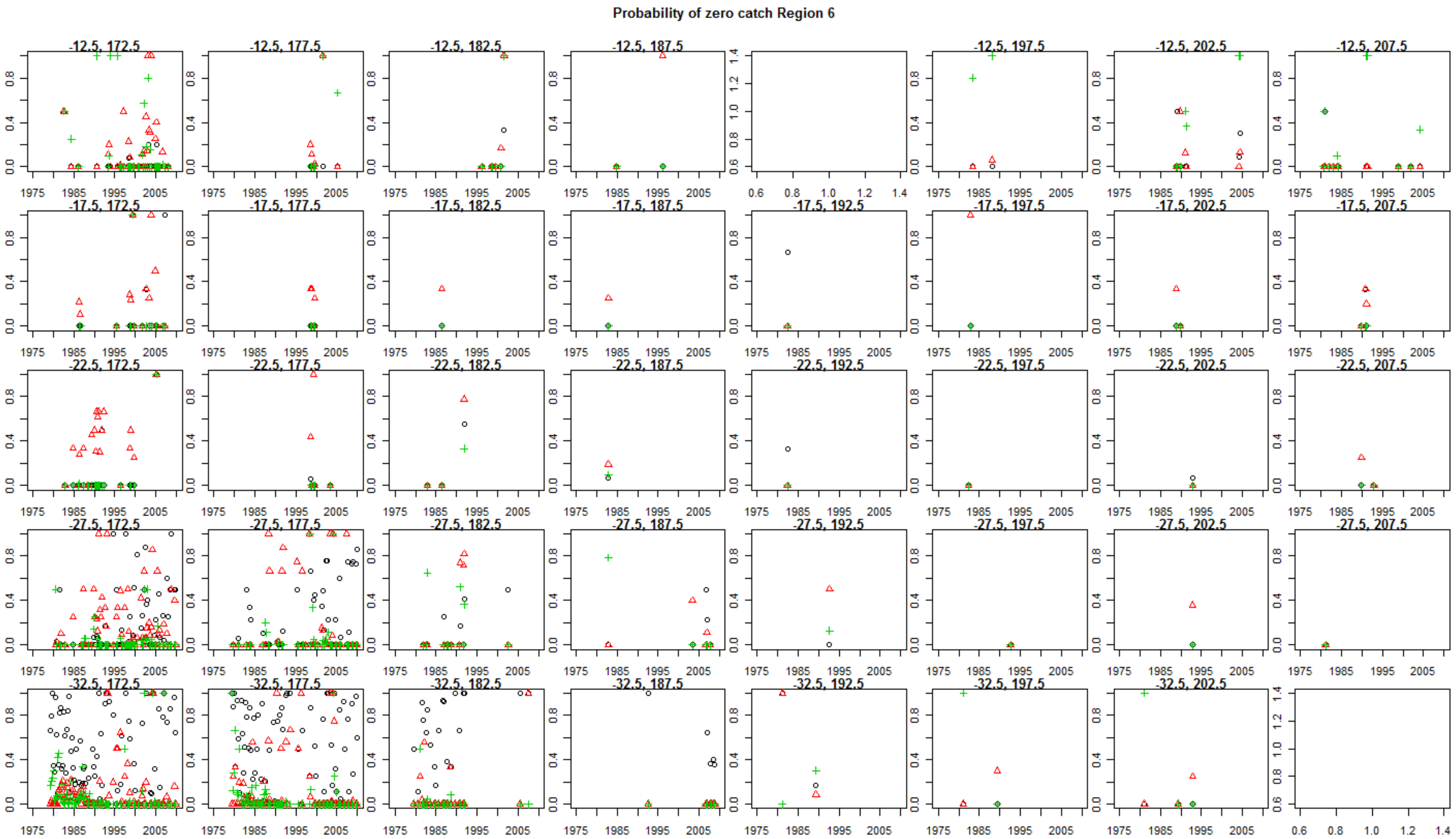

Figure 27: Proportion of zero catch in sets by quarter and 5 degree square in Region 6. Black circles are yellowfin tuna, red triangles bigeye, and green crosses albacore.

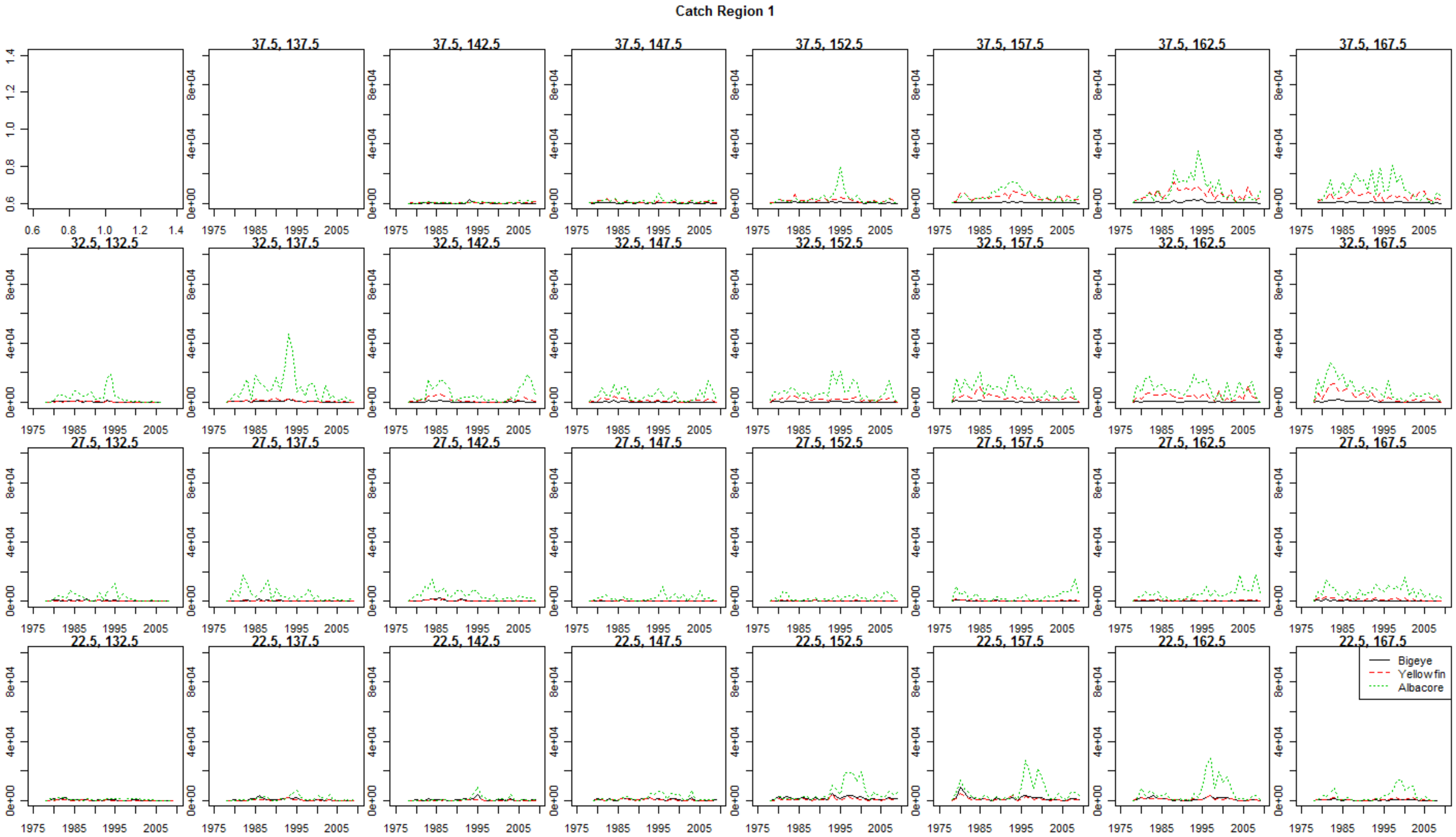

Figure 28: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 1 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

[Type text]

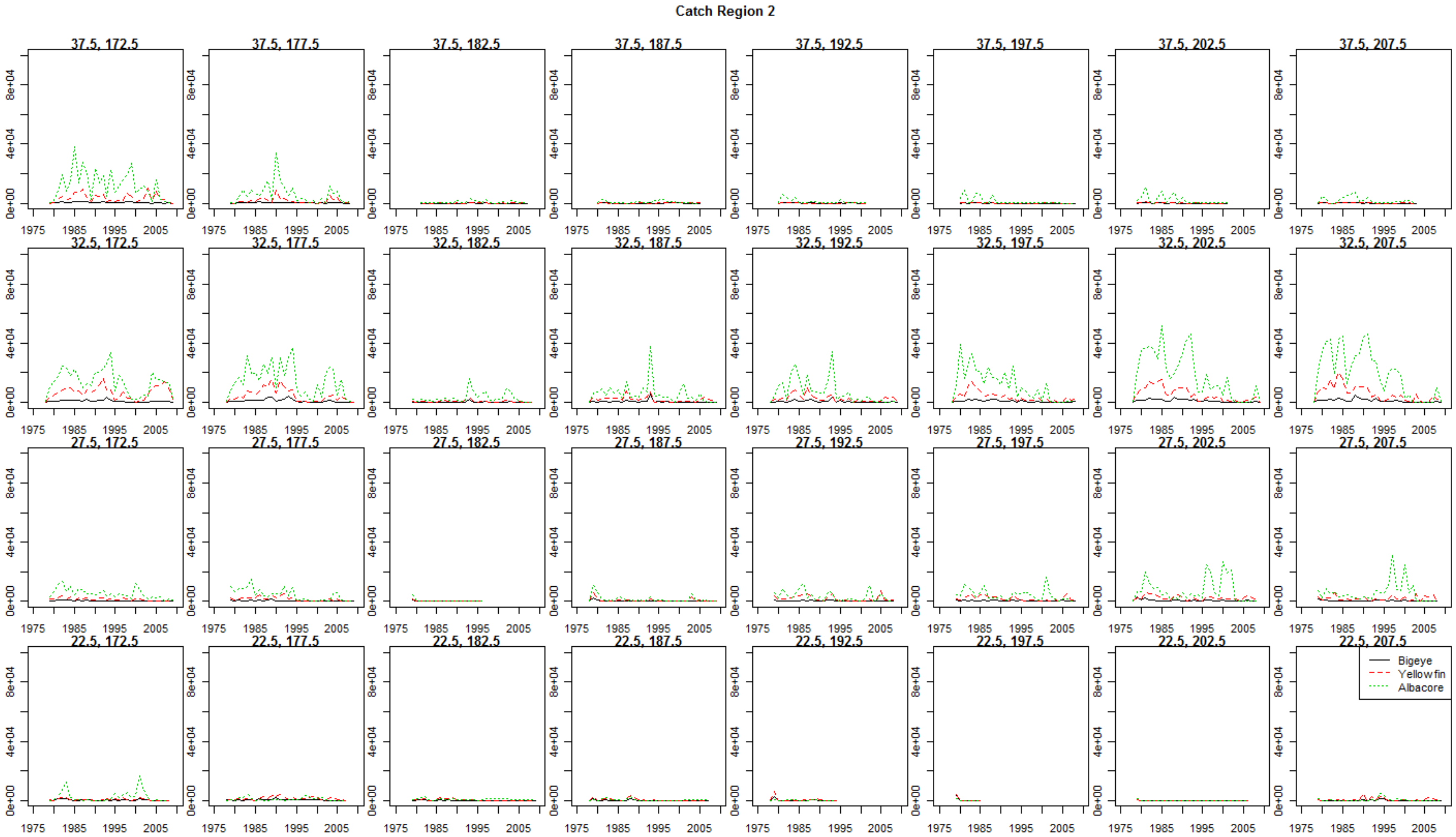

Figure 29: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 2 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

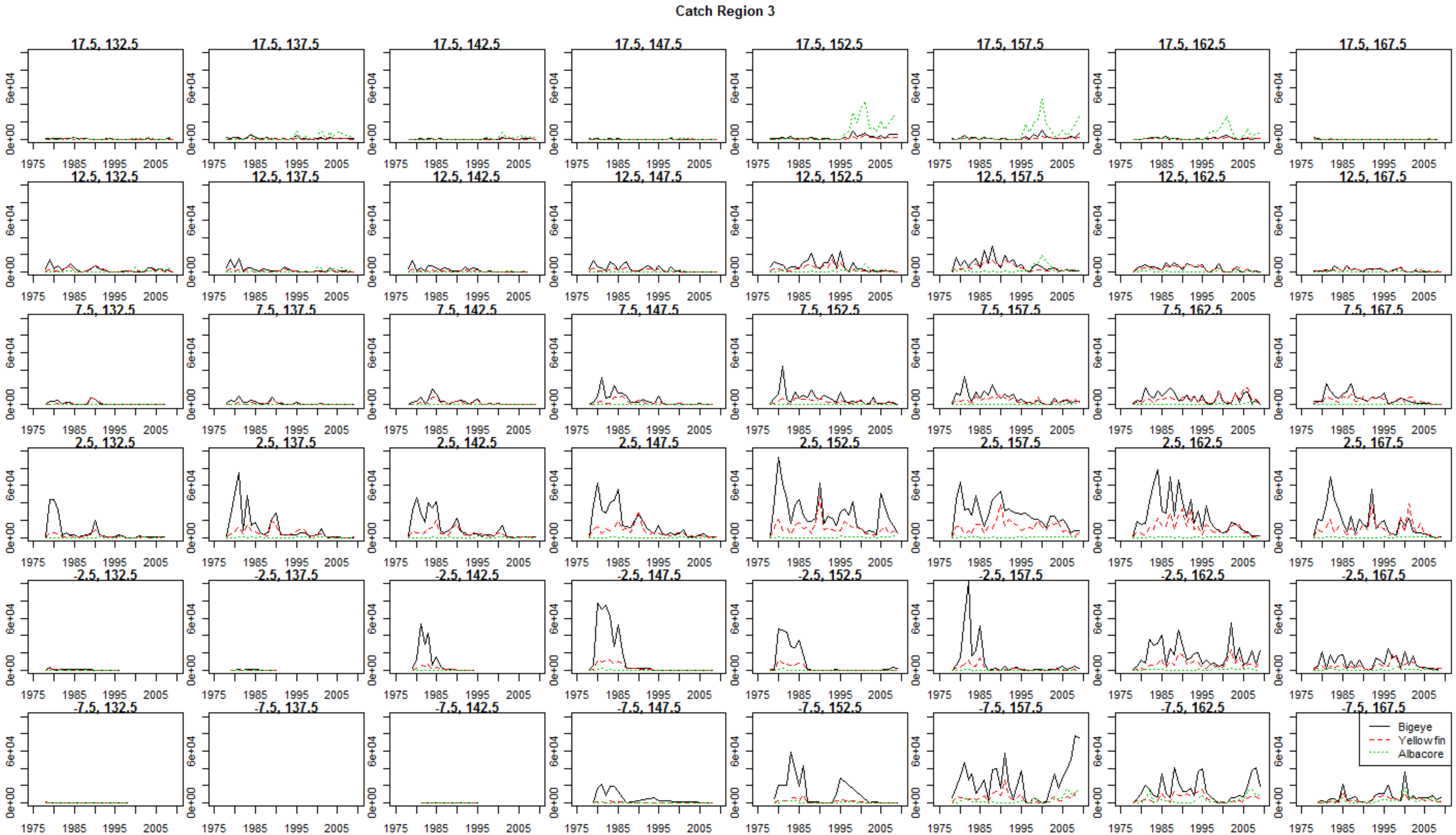

Figure 30: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 3 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

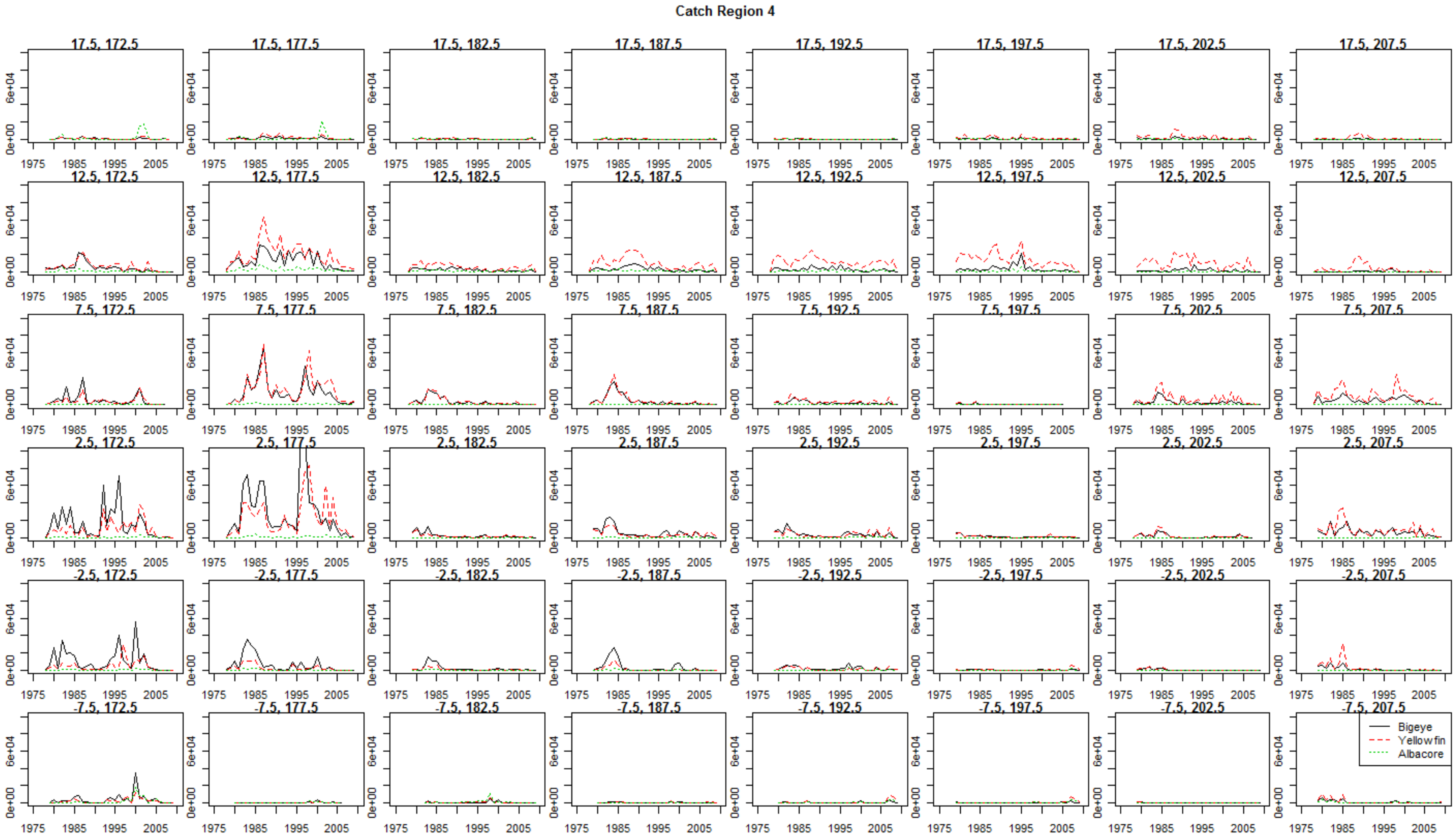

Figure 31: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 4 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

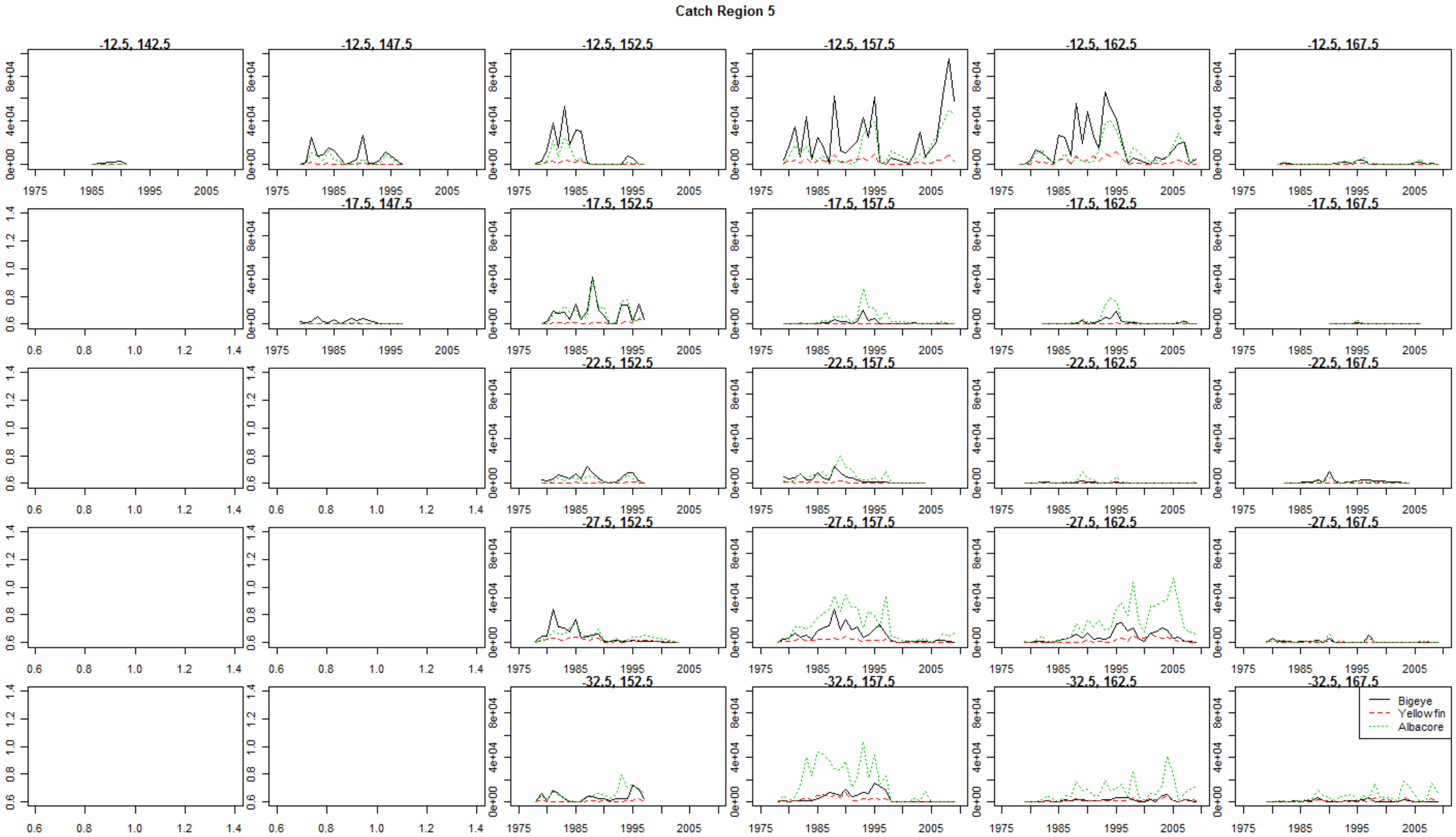

Figure 32: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 5 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

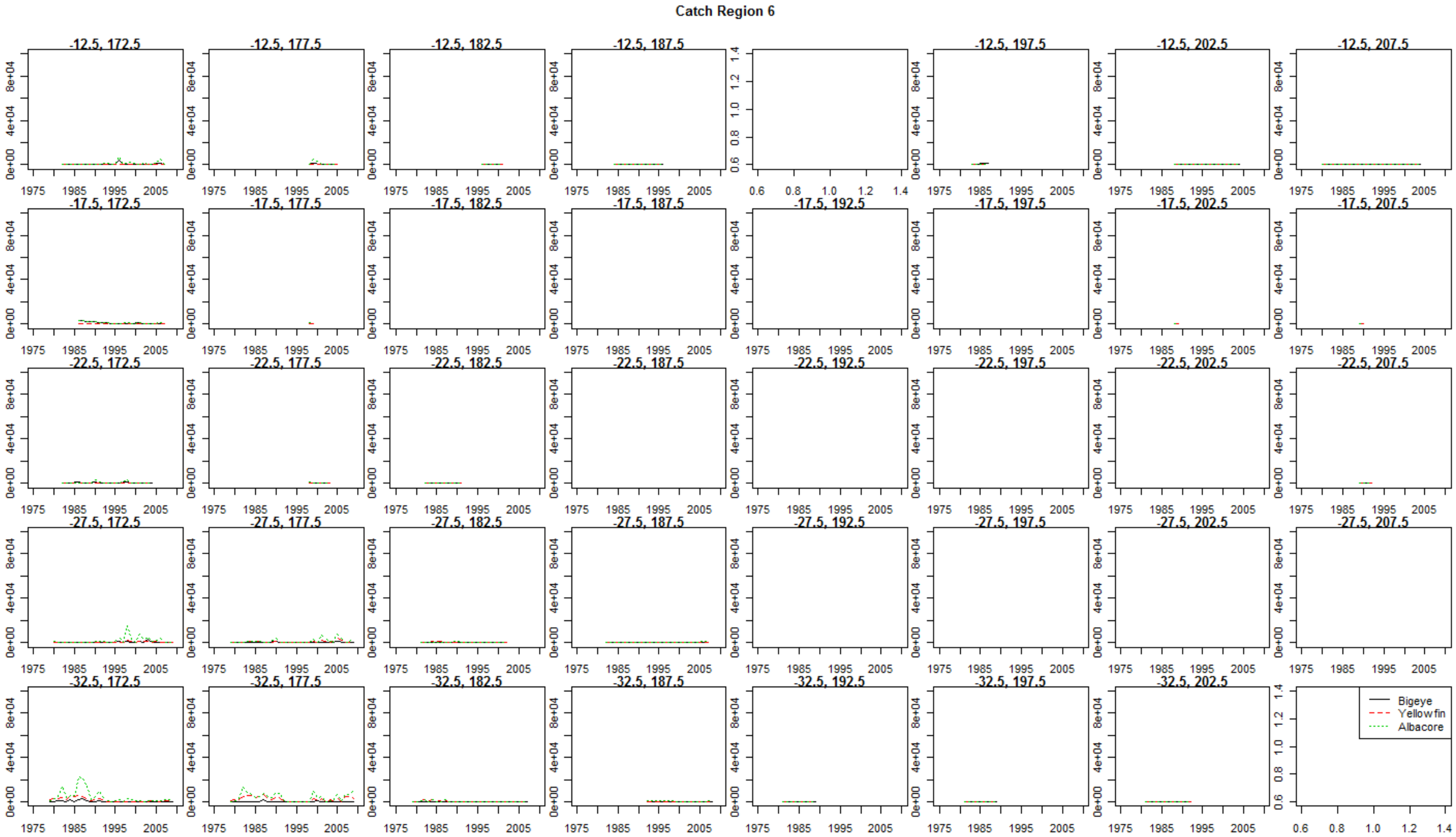

Figure 33: Catch per year in numbers by 5 degree square for albacore (green), bigeye (red) and yellowfin (black) in Region 6 (N.B. the figure legend gives bigeye and yellowfin the wrong colours).

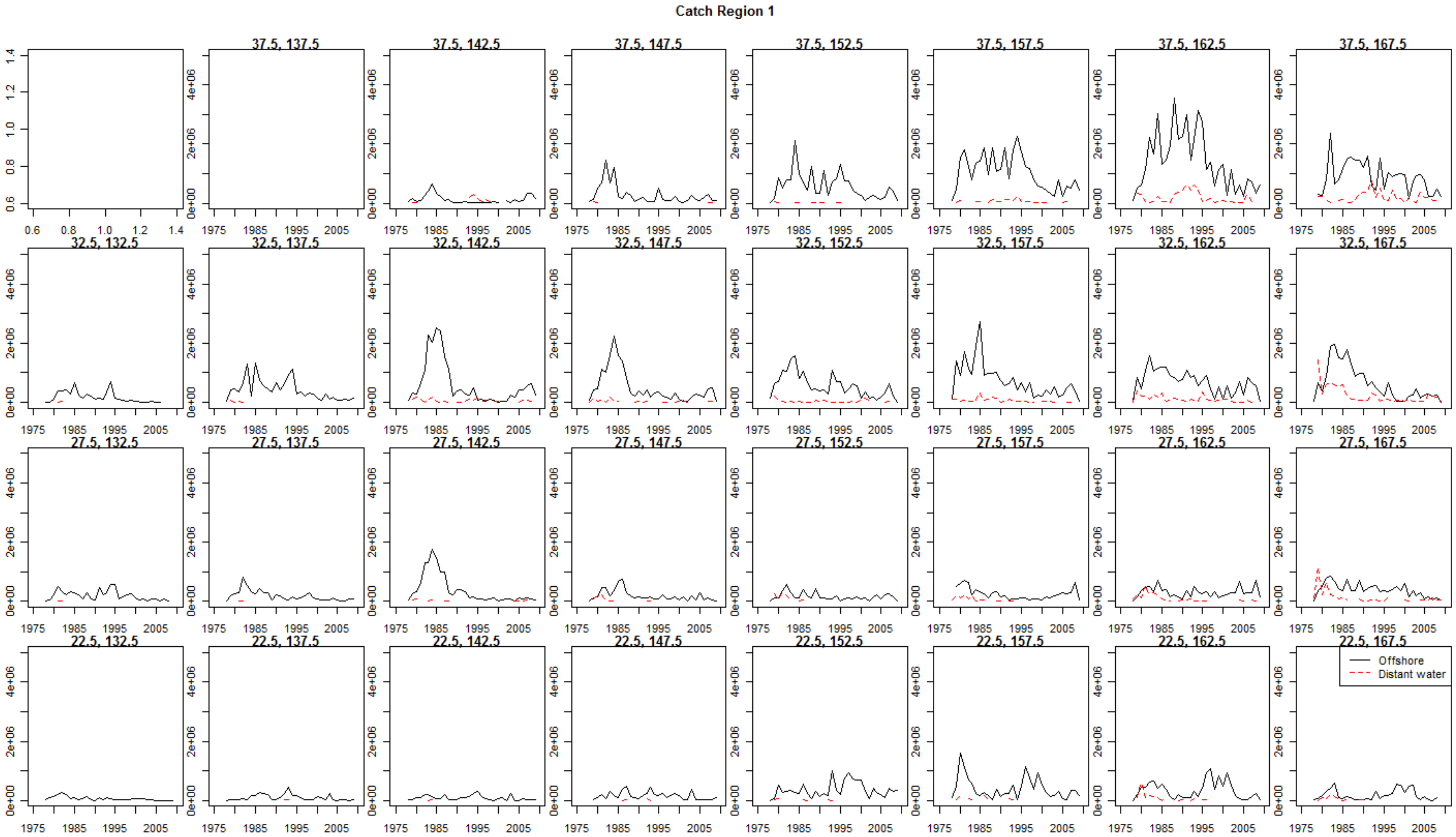

Figure 34: Region 1 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

[Type text]

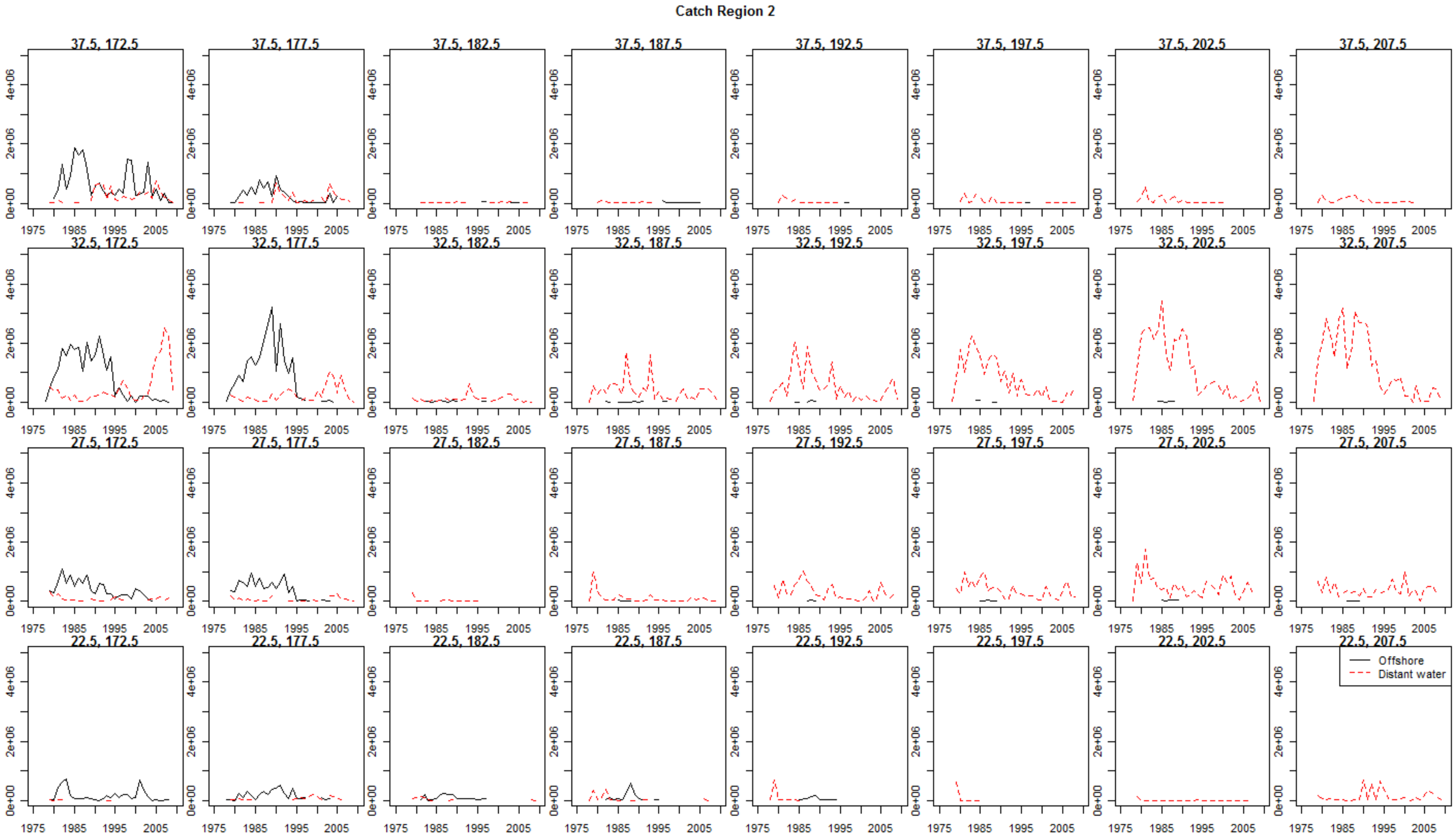

Figure 35: Region 2 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

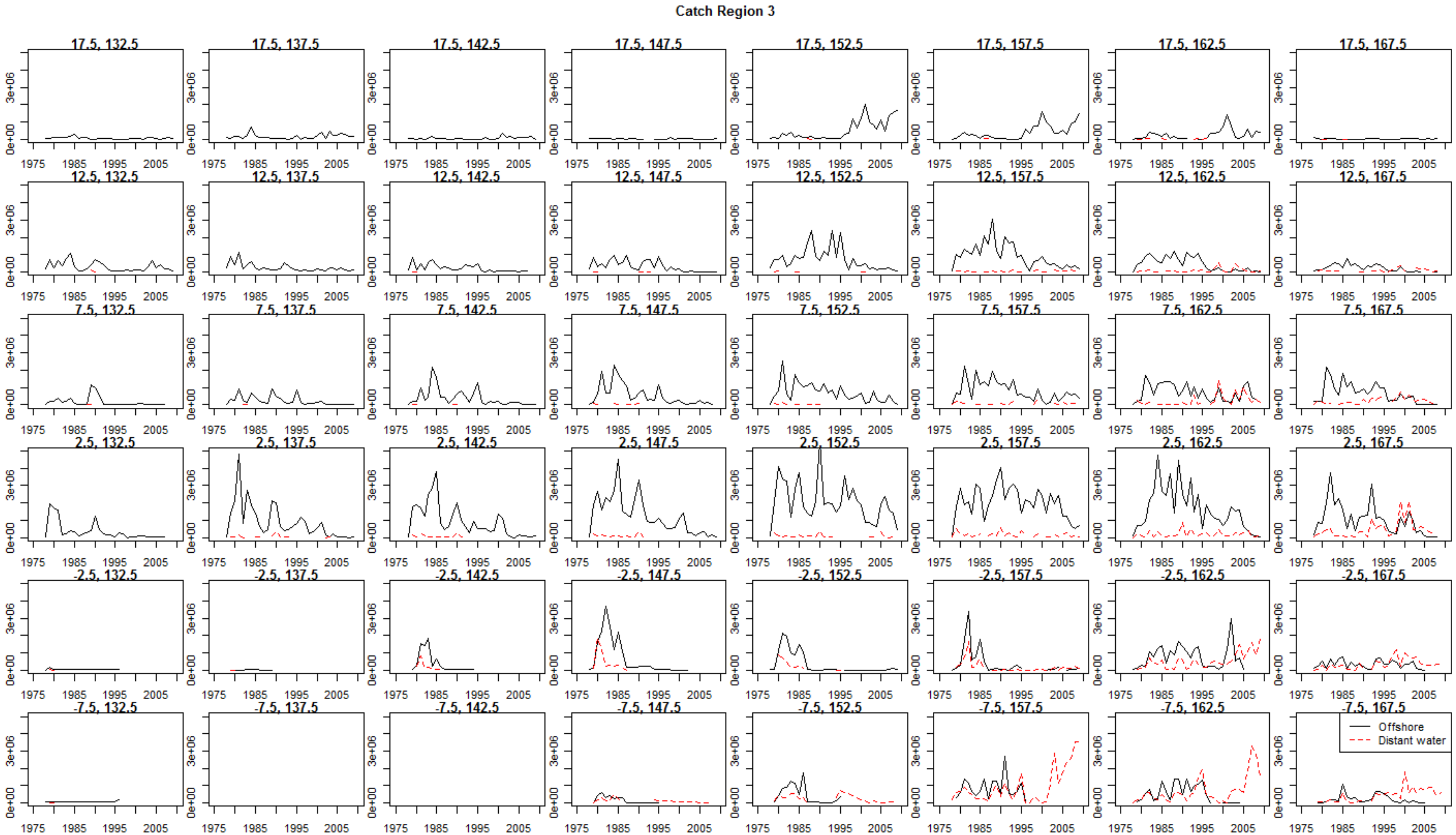

Figure 36: Region 3 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say ‘Effort’).

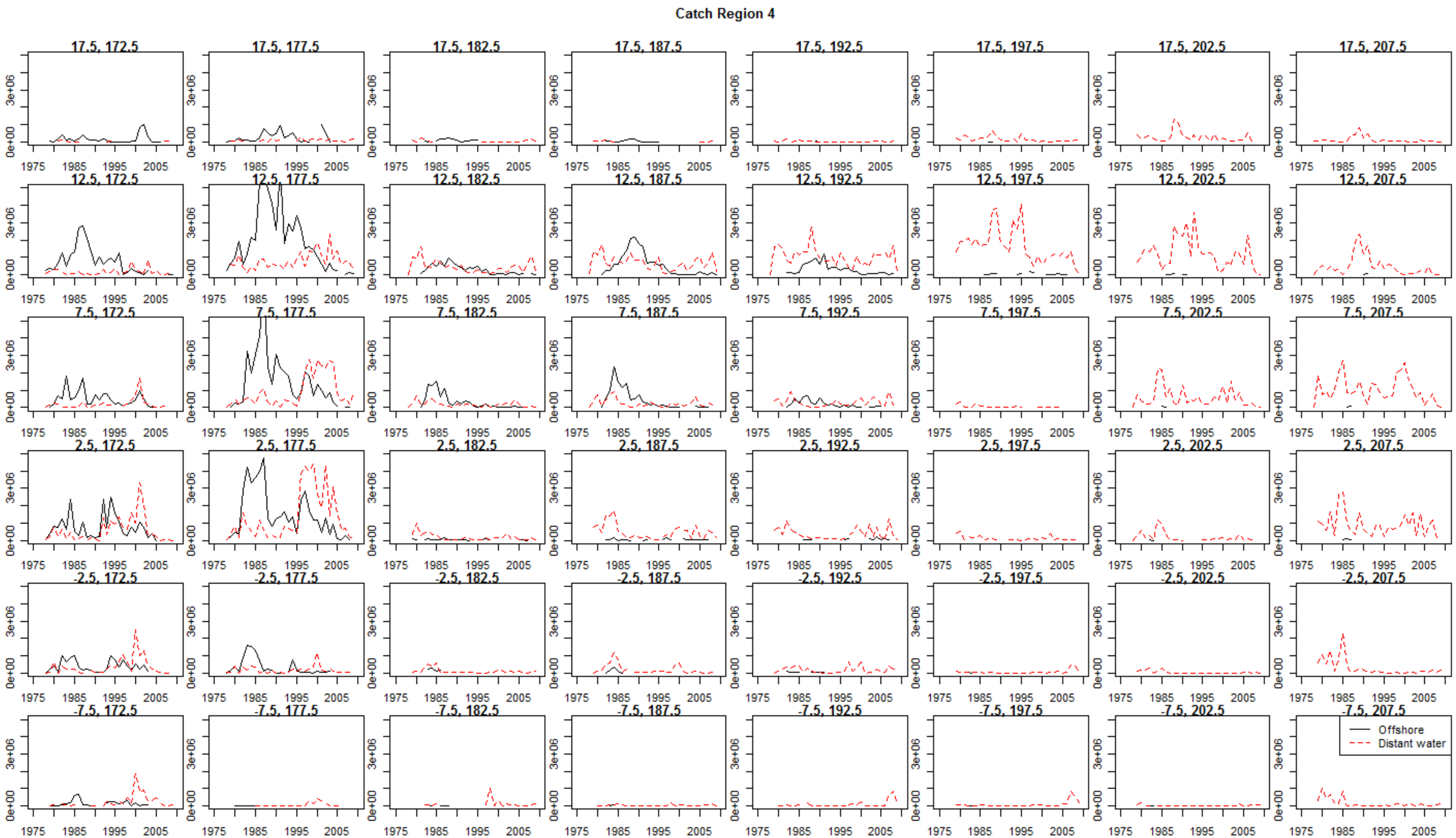

Figure 37: Region 4 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

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').

[Type text]

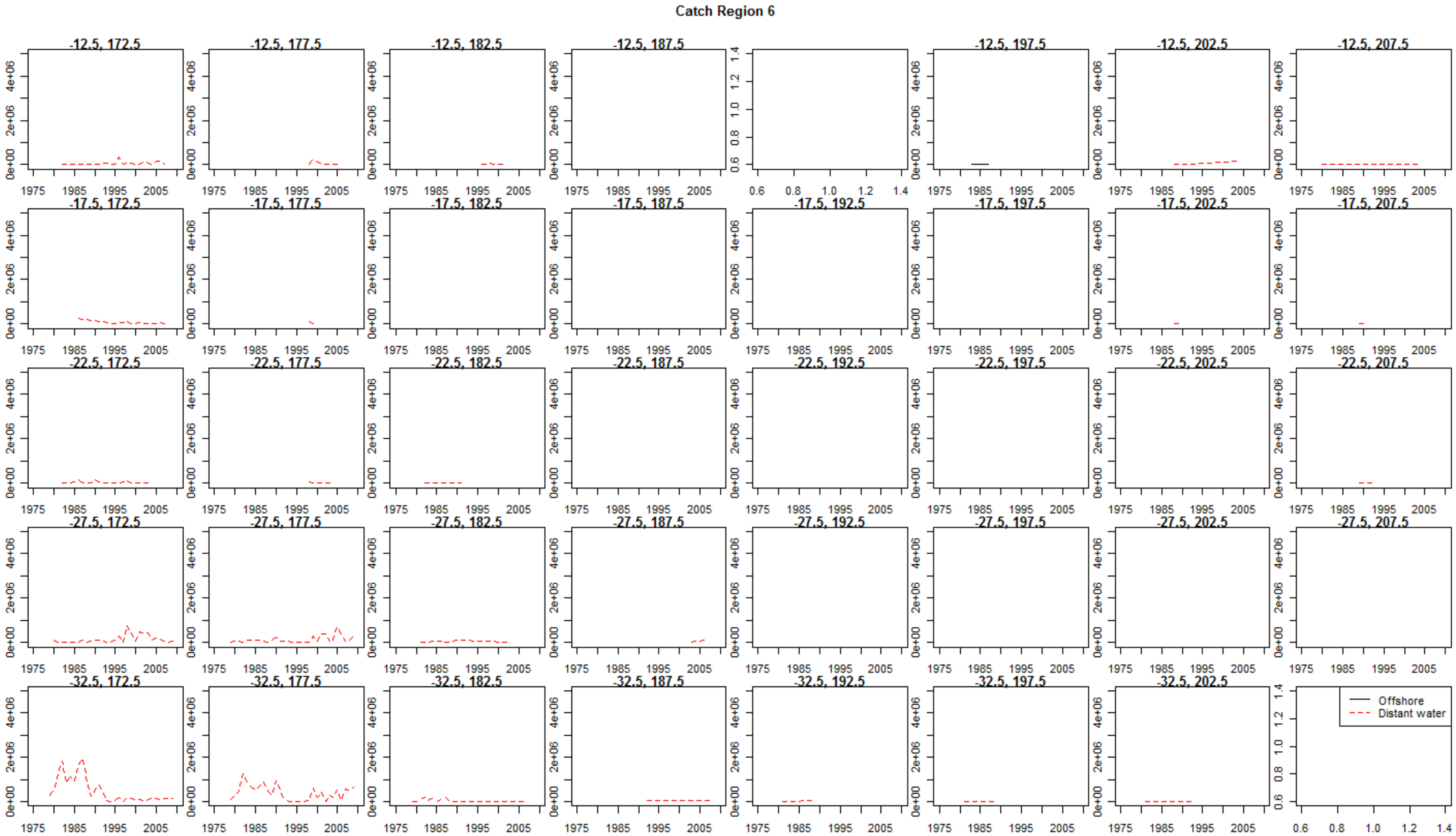

Figure 39: Region 6 effort by year and 5 degree square for offshore (black) and distant water (red) fleets (N.B. the figure title should say 'Effort').

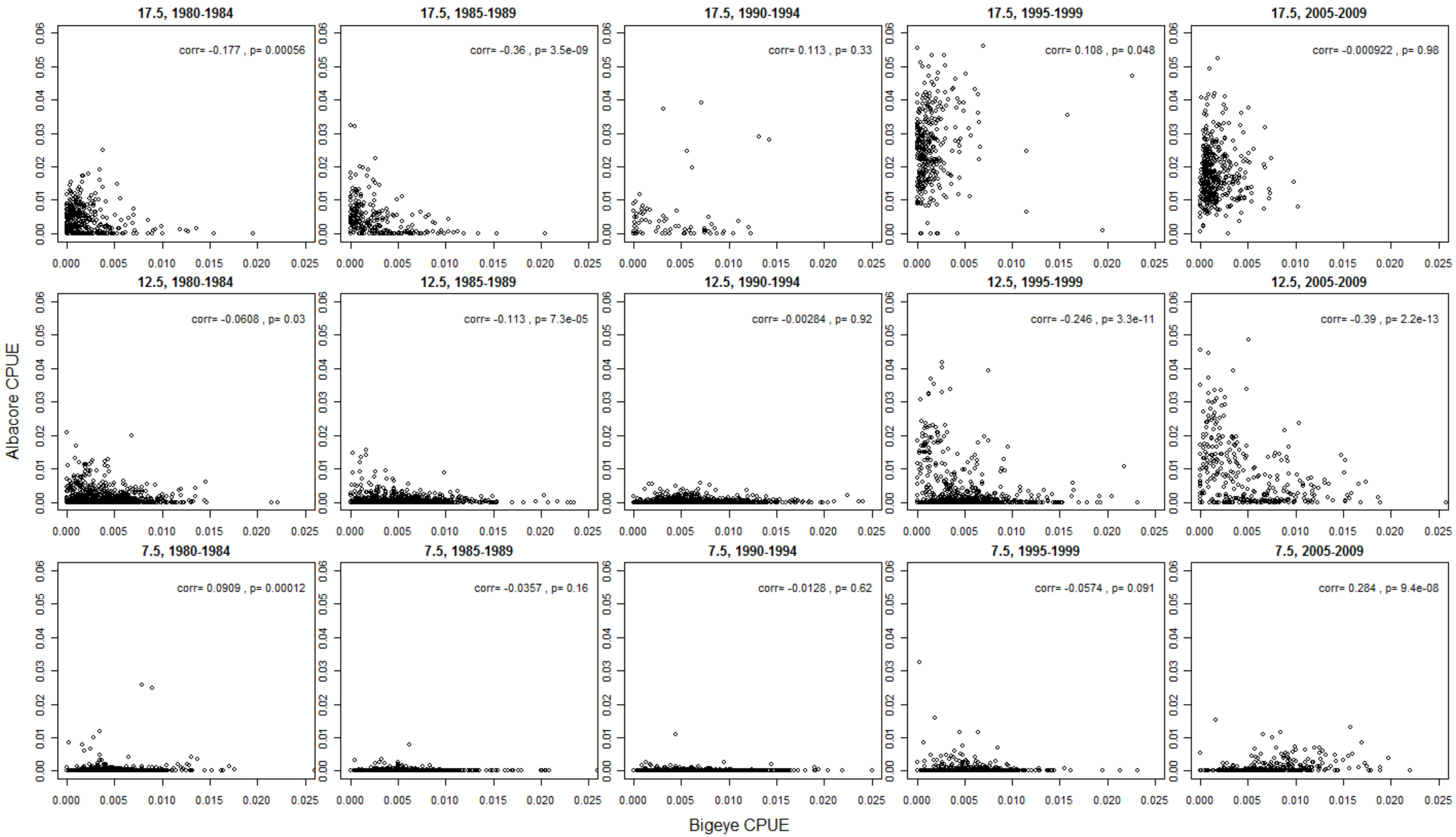

Figure 40: Bigeye CPUE per trip plotted against albacore CPUE per trip for all trips in a latitude band (Region 3), during the specified time periods.

[Type text]

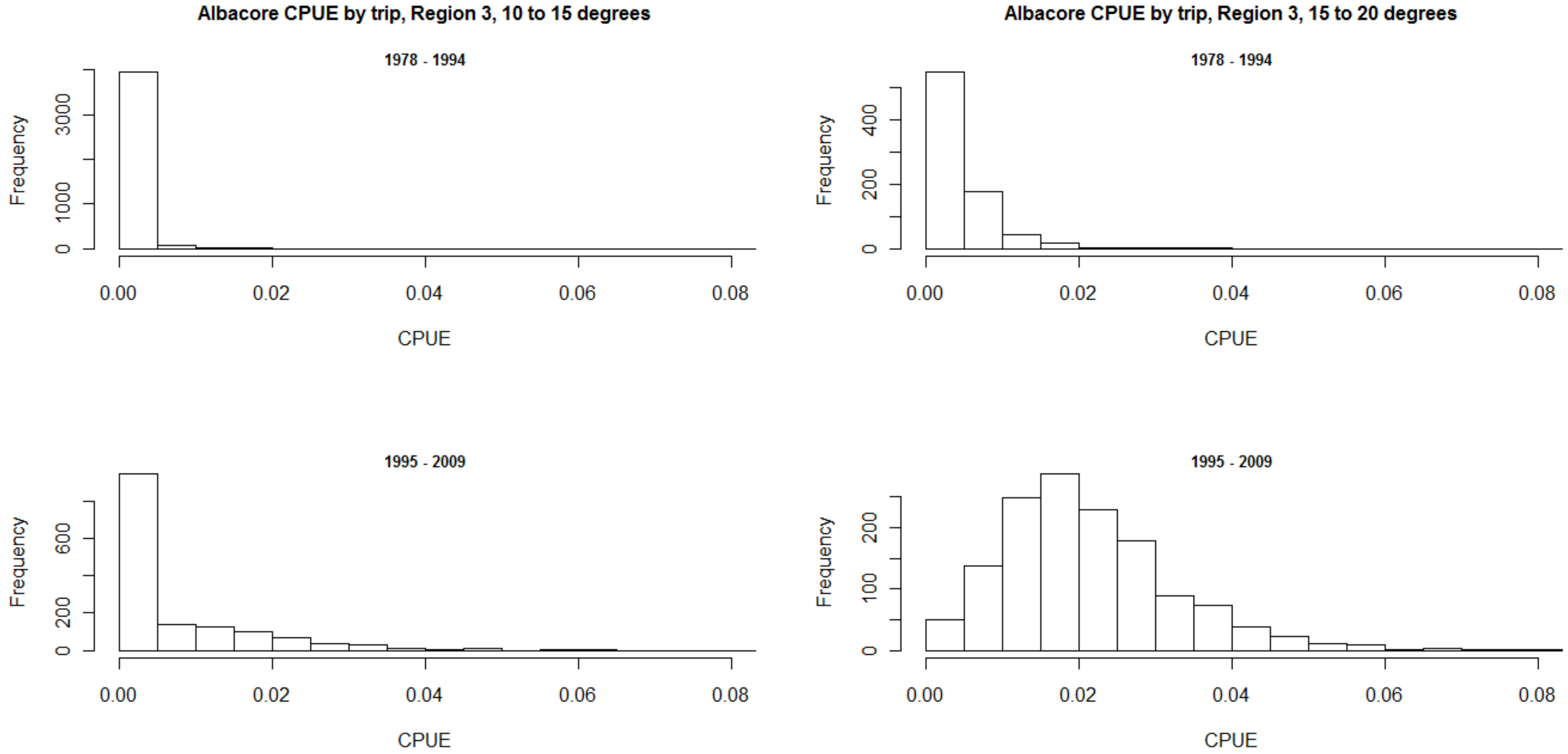

Figure 41: Frequency distributions of albacore catch rate by trip in region 3 before and after 1994, for two 5-degree latitude bands in Region 3.

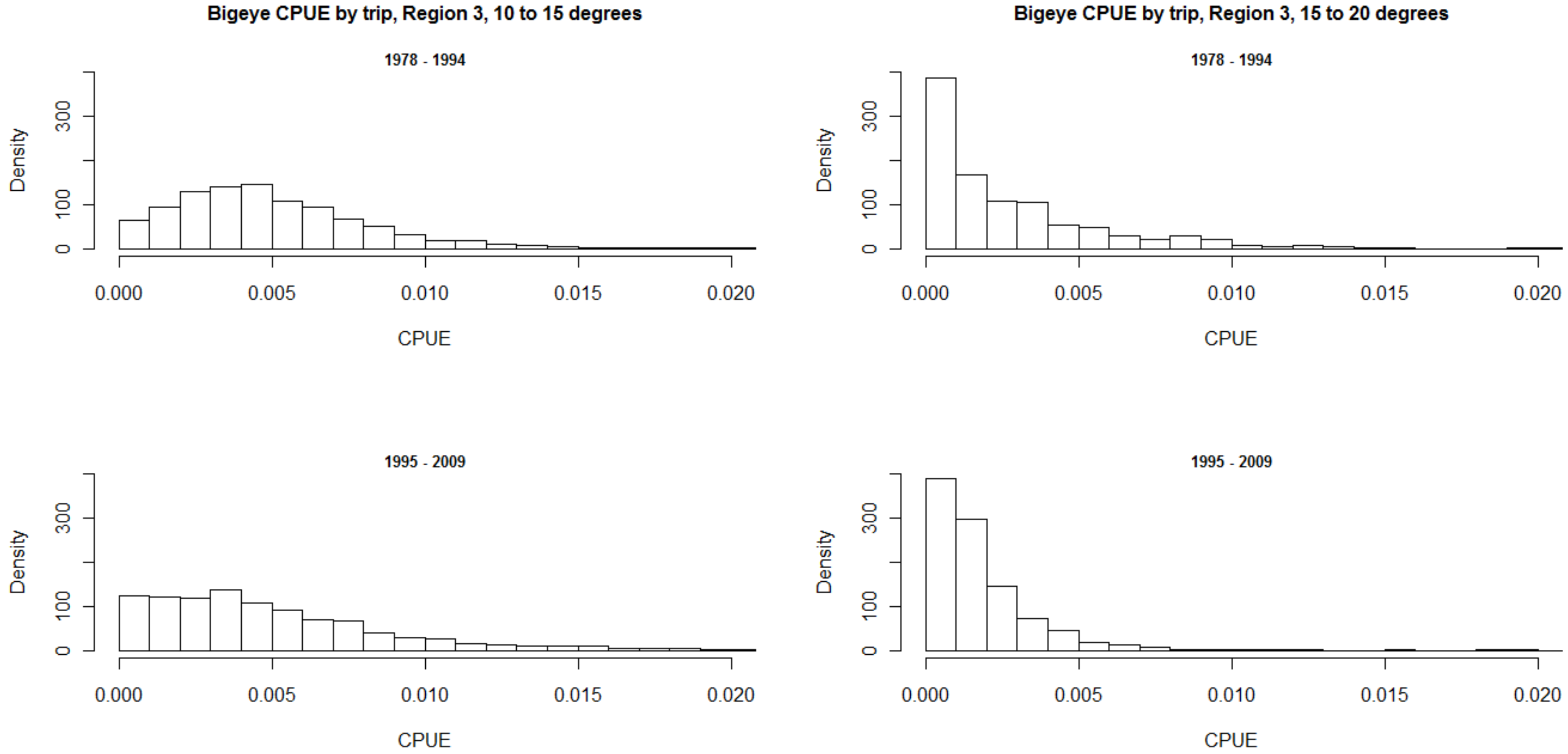

Figure 42: Frequency distributions of bigeye catch rate by trip in region 3 before and after 1994, for two 5-degree latitude bands in Region 3.

[Type text]

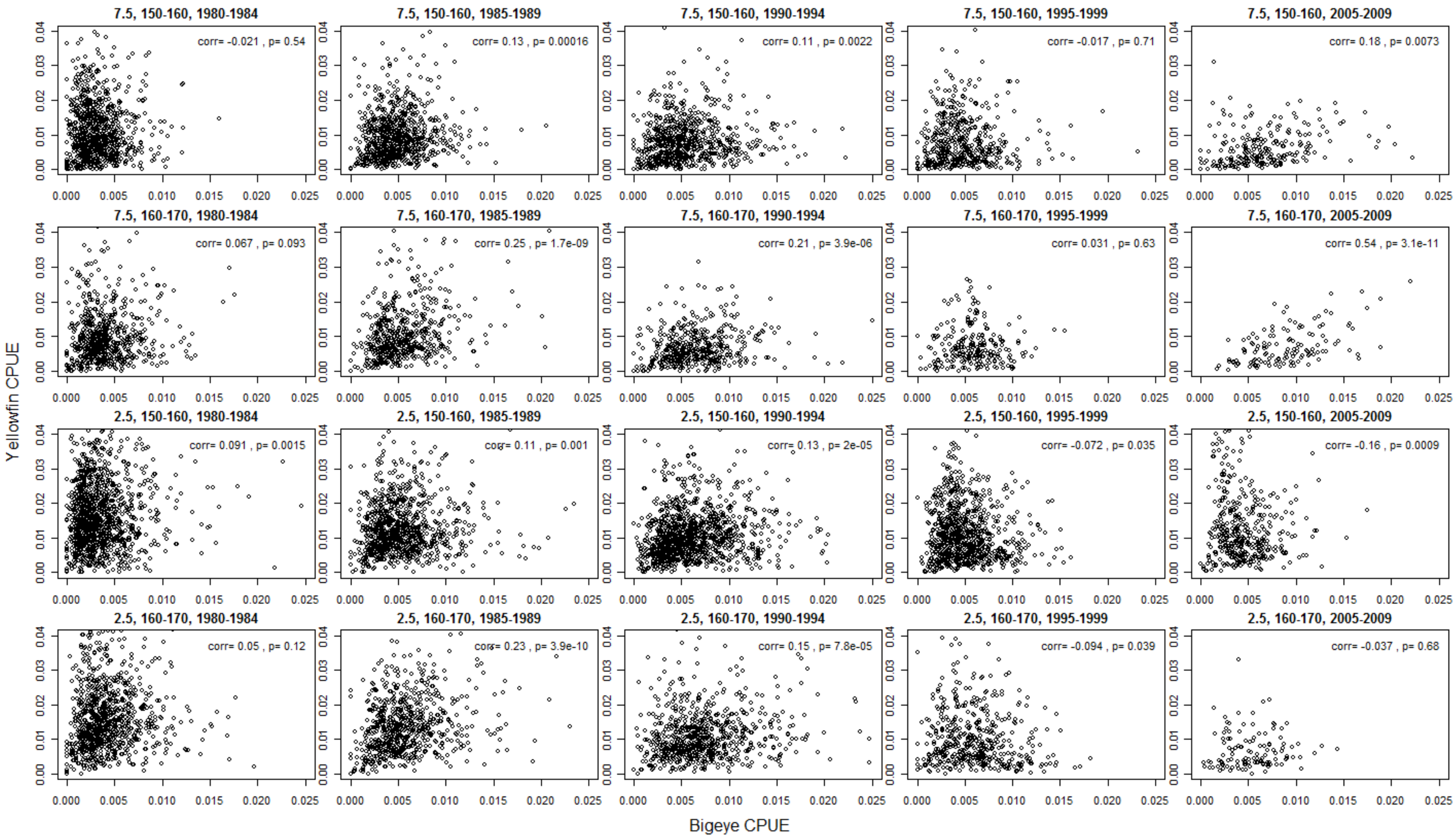

Figure 43: Bigeye CPUE plotted against yellowfin CPUE by trip for 4 equatorial 5 x 10 degree areas in Region 3, for 5 four-year periods.

[Type text]

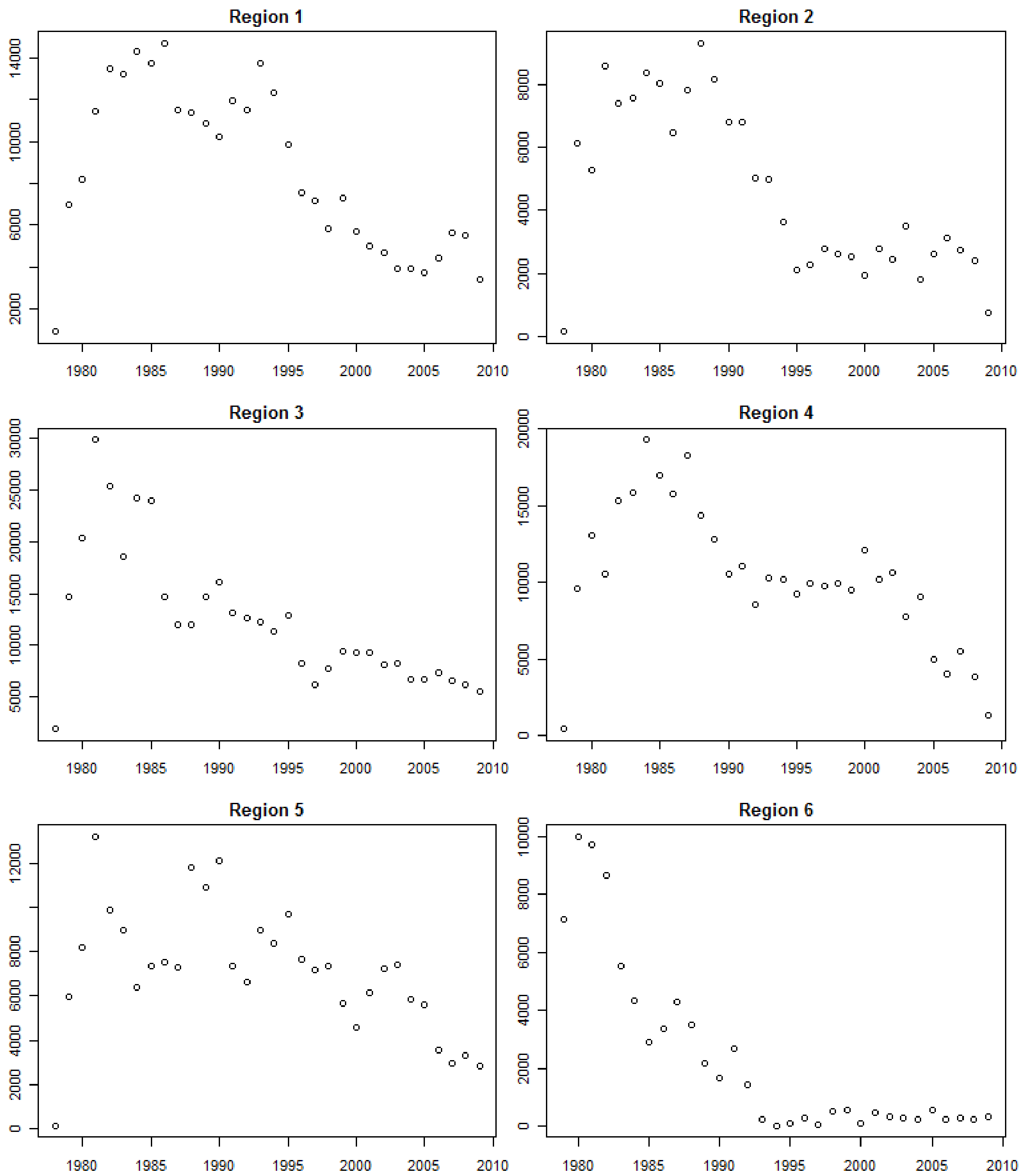

Figure 44: Number of logsheet records by year and region.

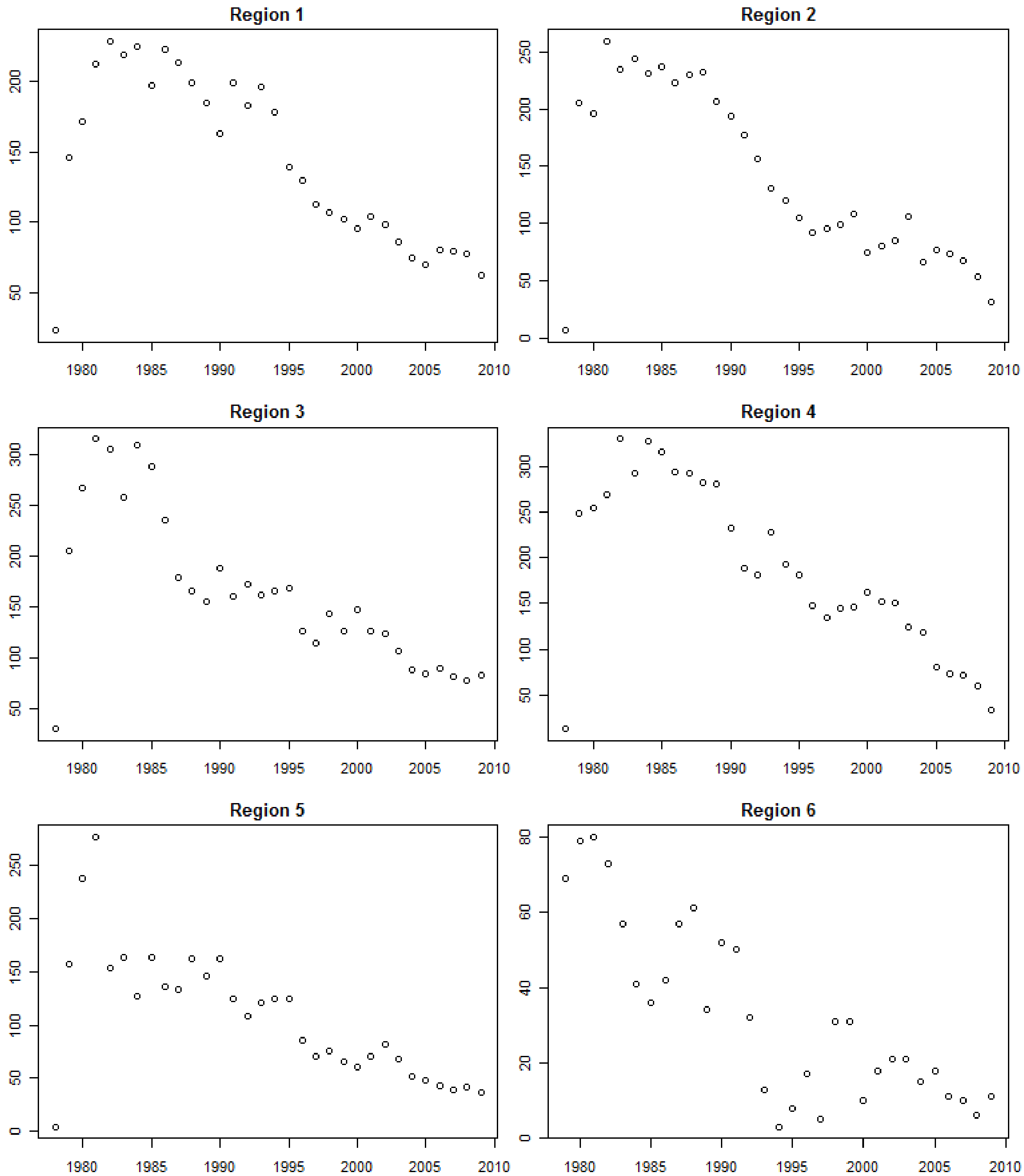

Figure 45: Number of unique vessels by year and region.

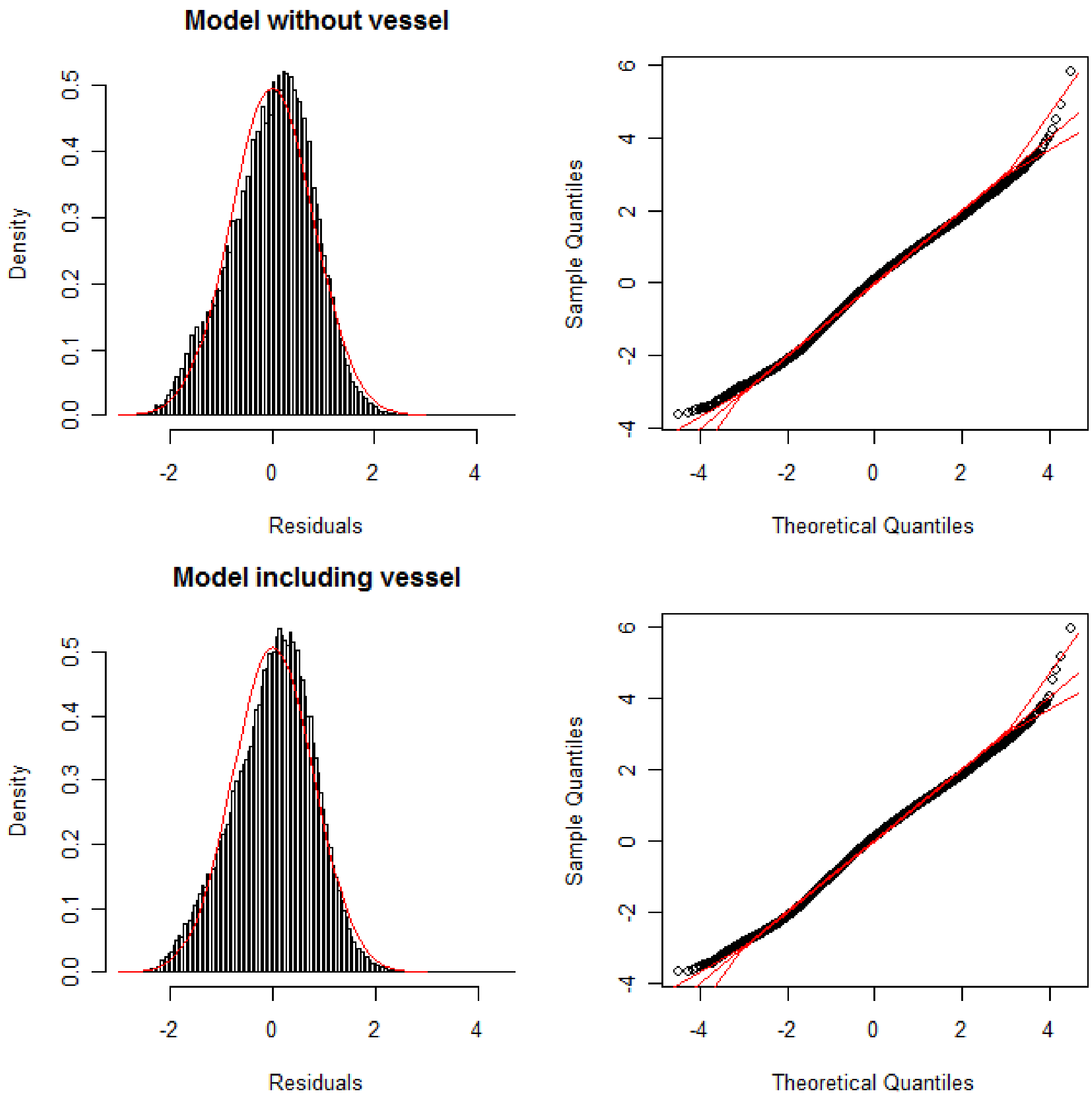

Figure 46: Region 1 density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

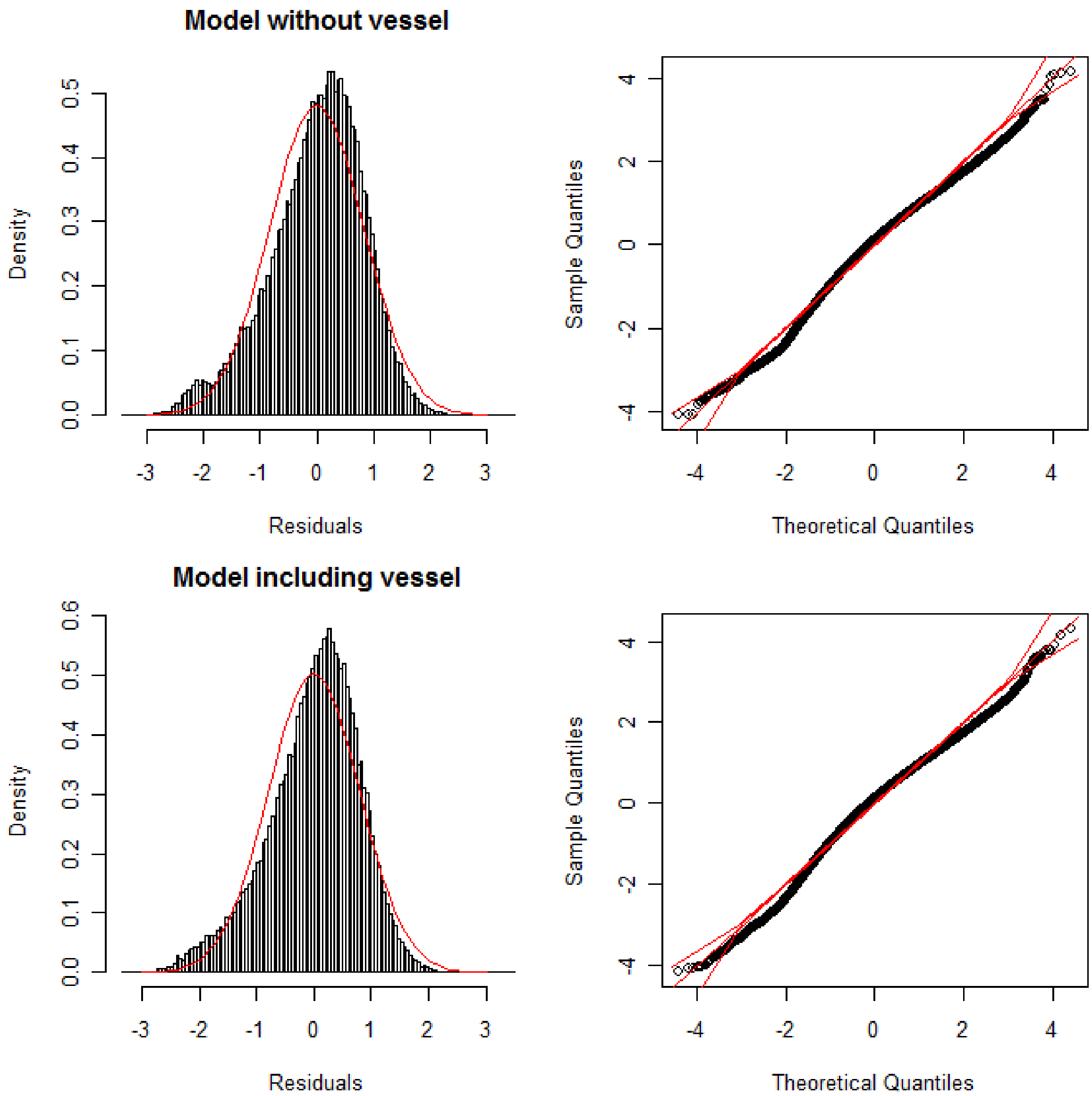

Figure 47: Region 2 density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

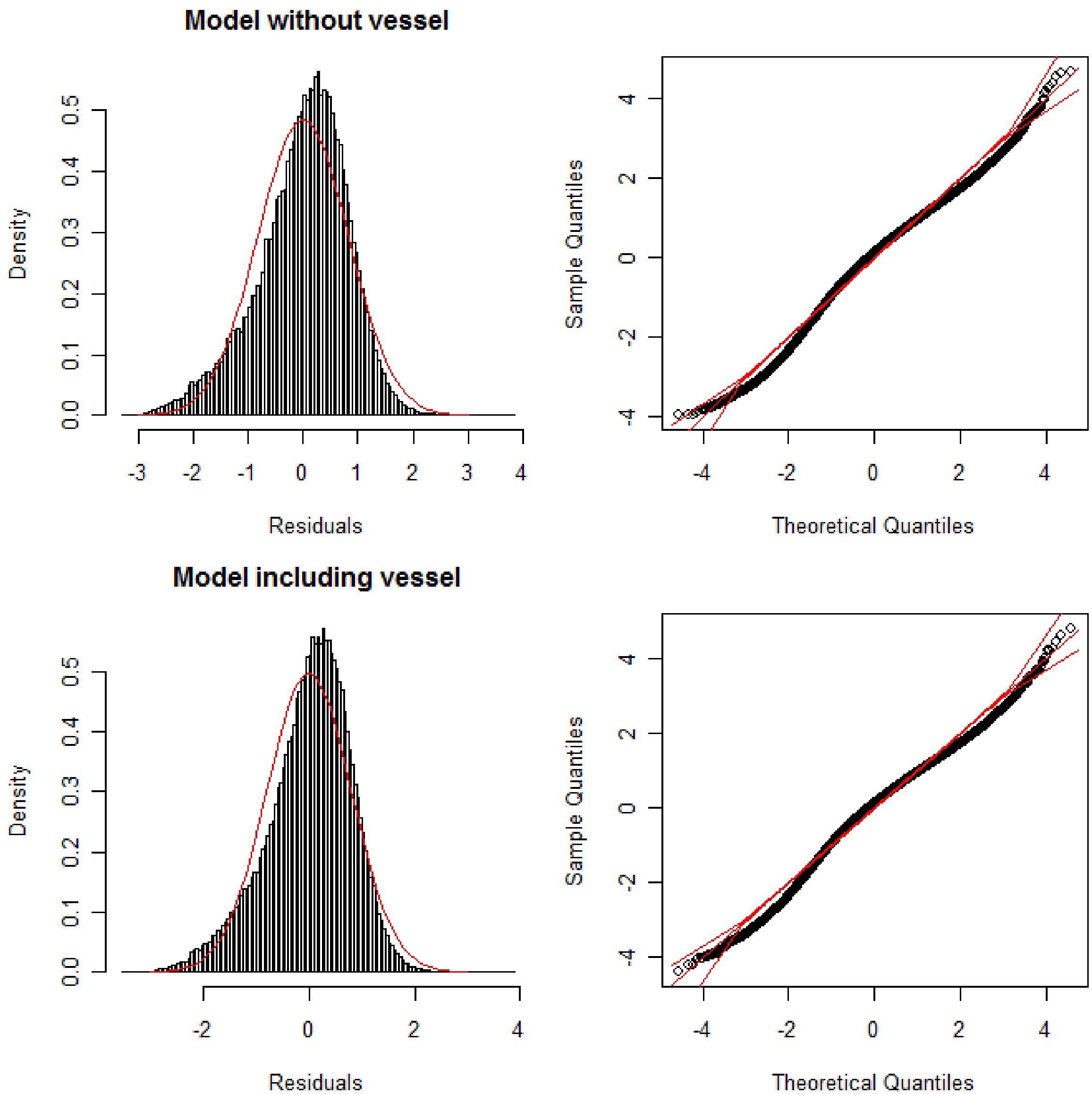

Figure 48: Region 3 equatorial model density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

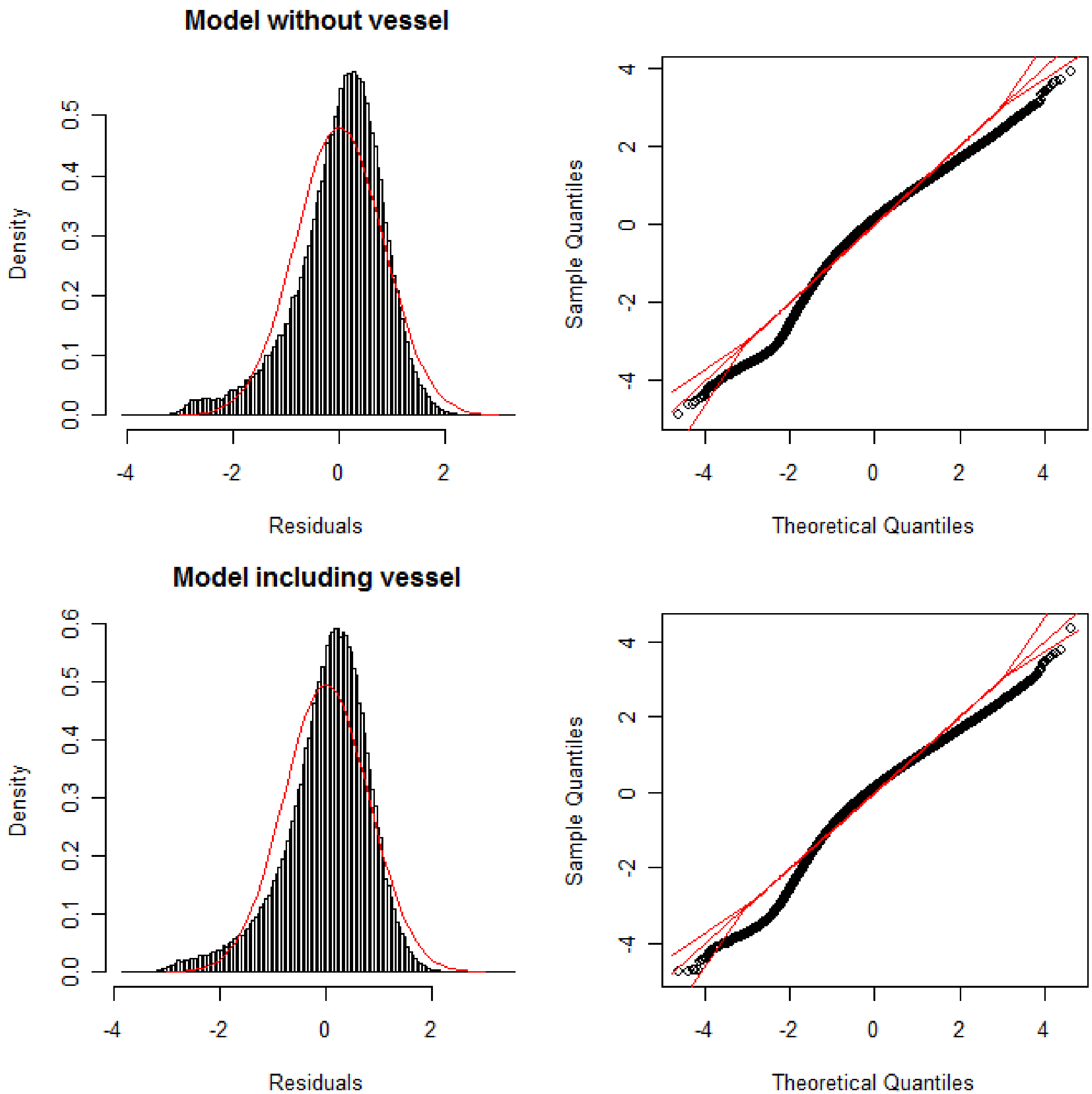

Figure 49: Region 4 density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

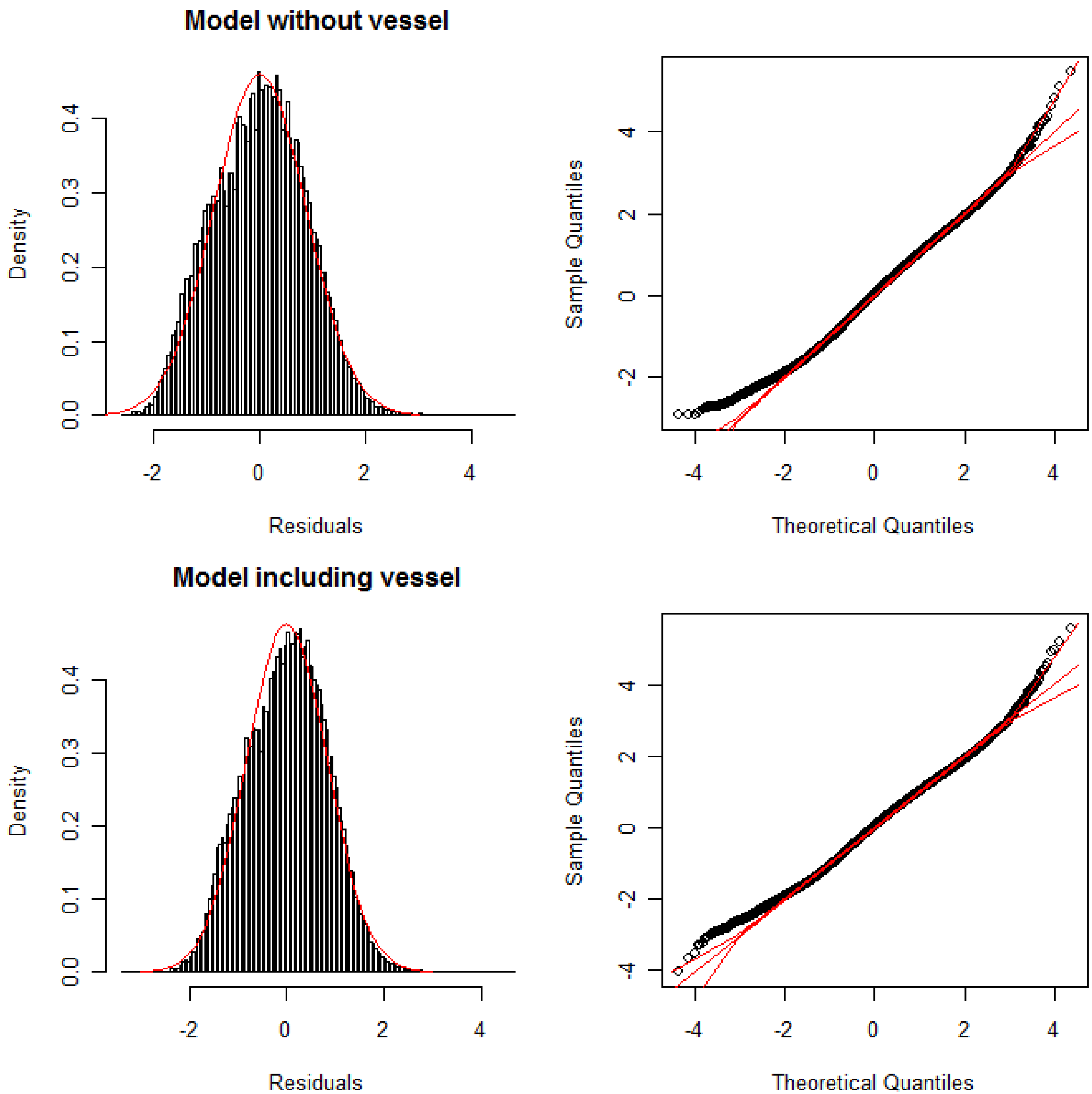

Figure 50: Region 5 density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

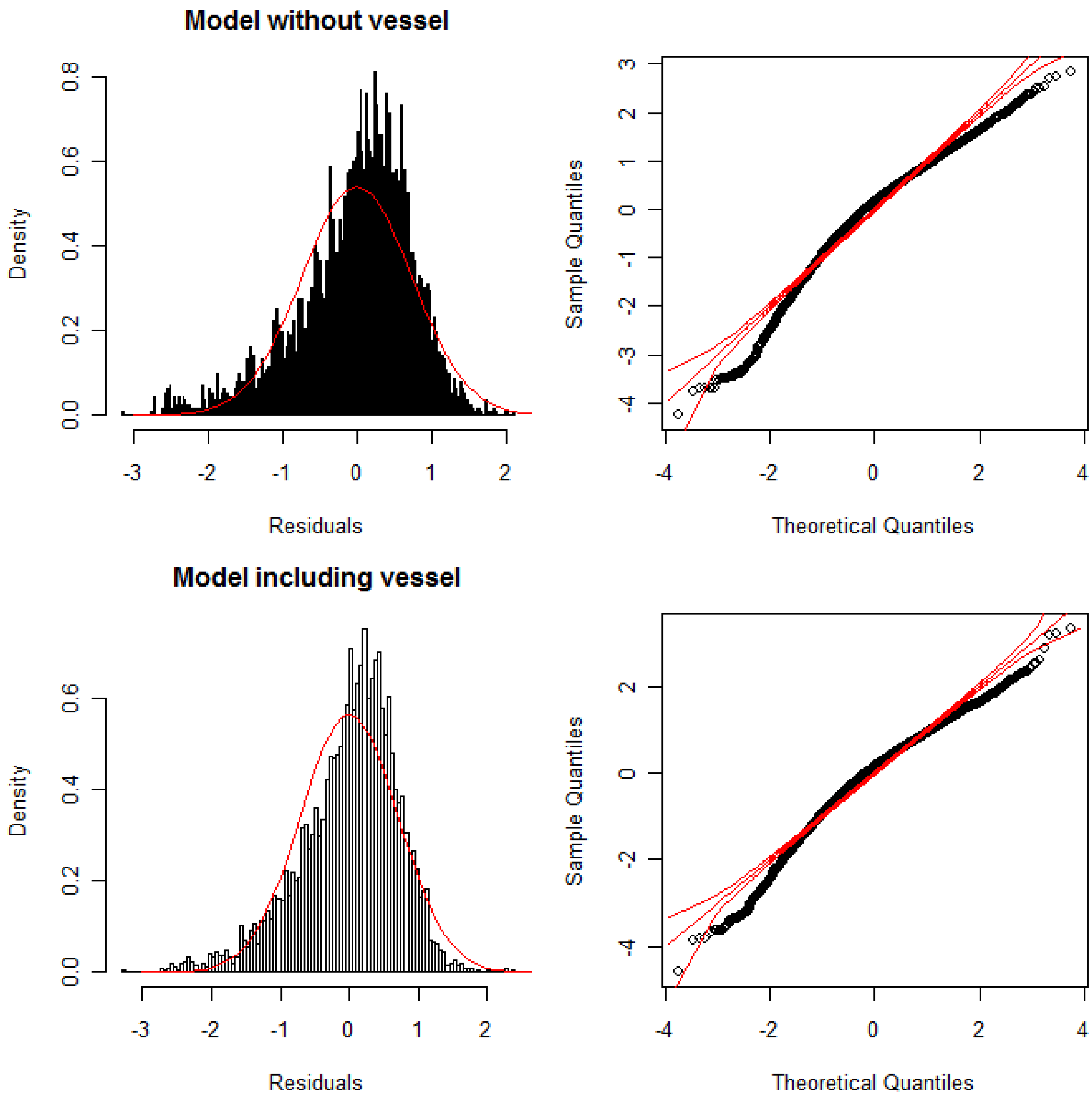

Figure 51: Region 6 density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

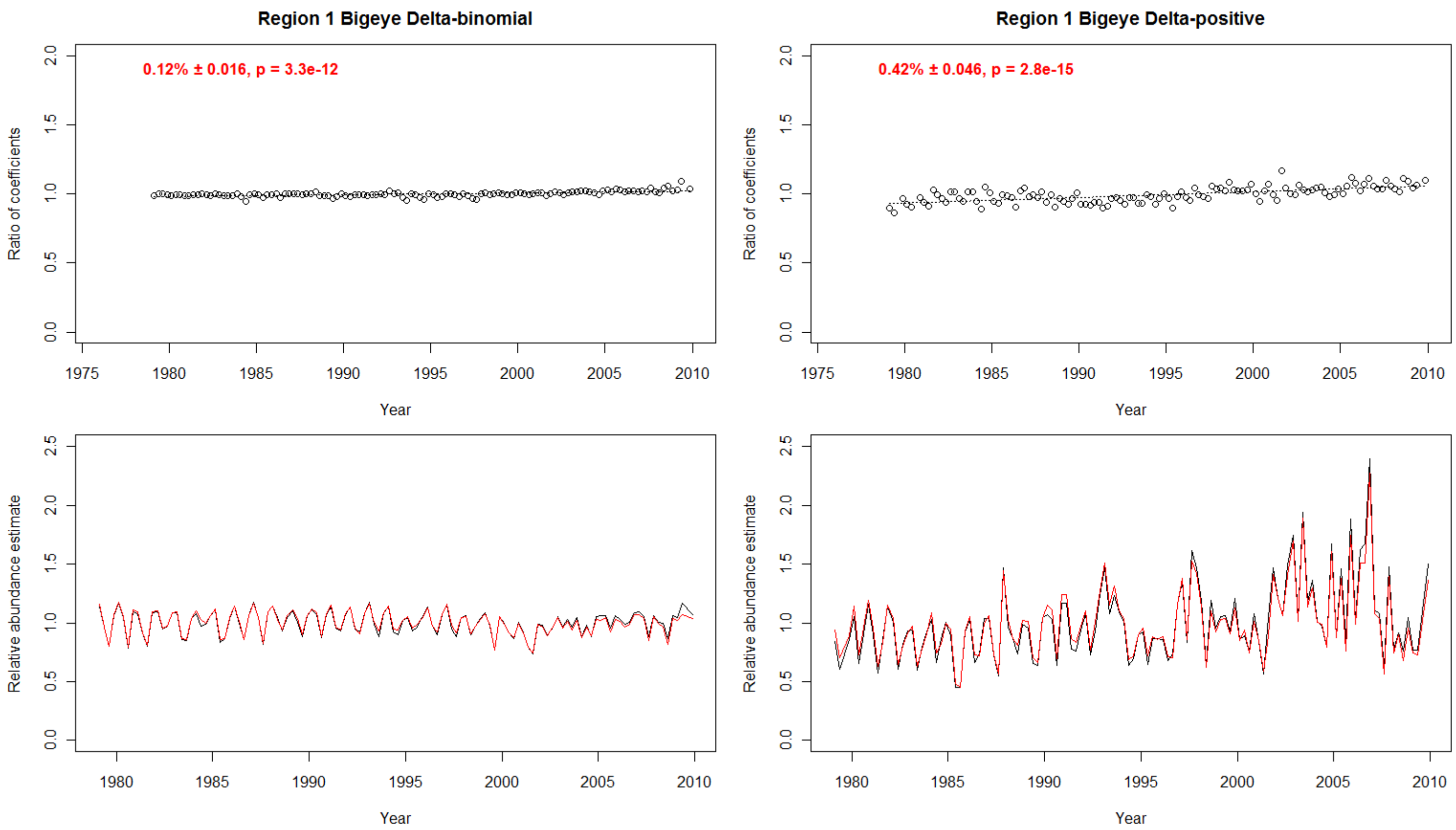

Figure 52: Region 1 comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

[Type text]

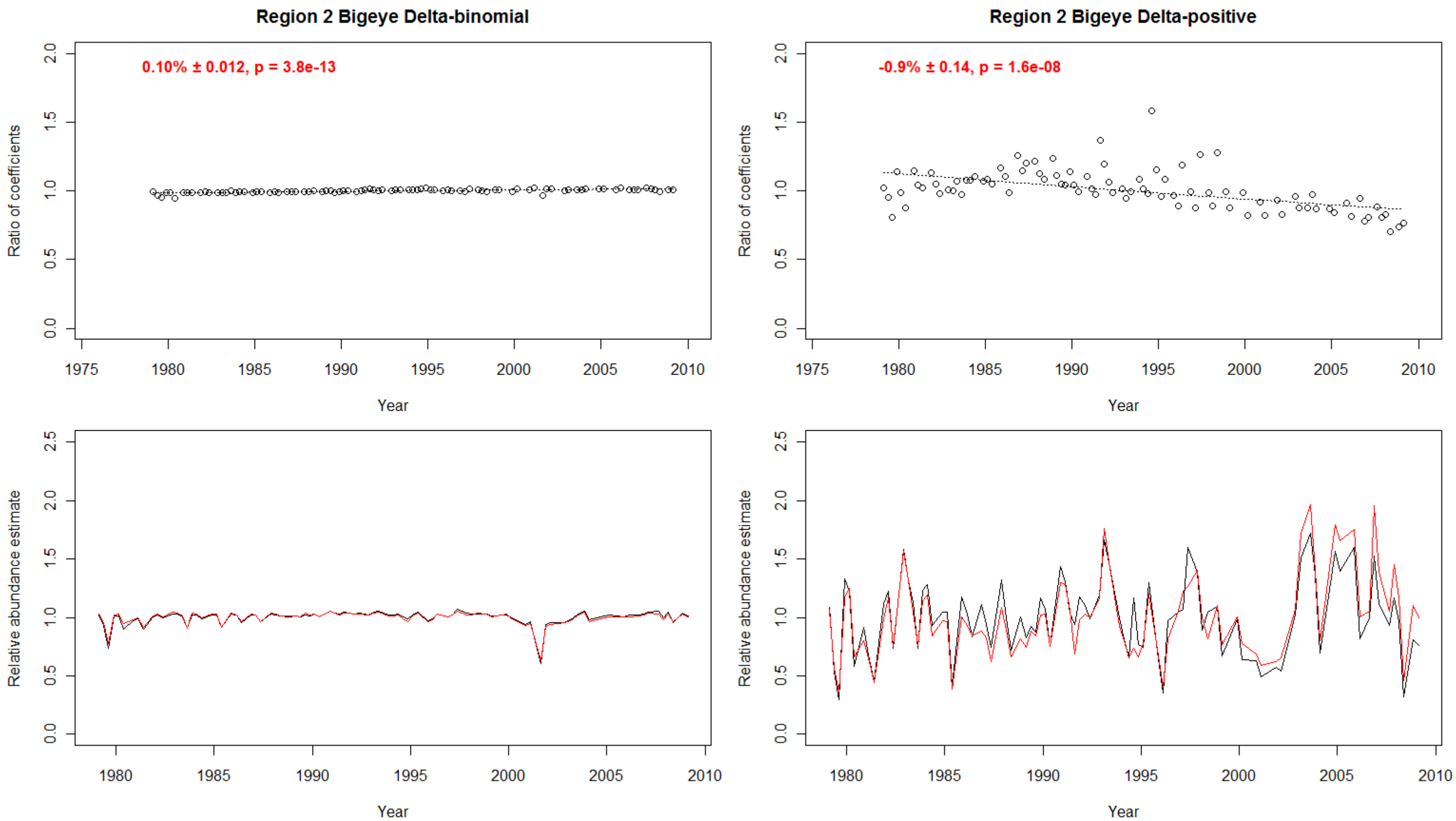

Figure 53: Region 2 comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

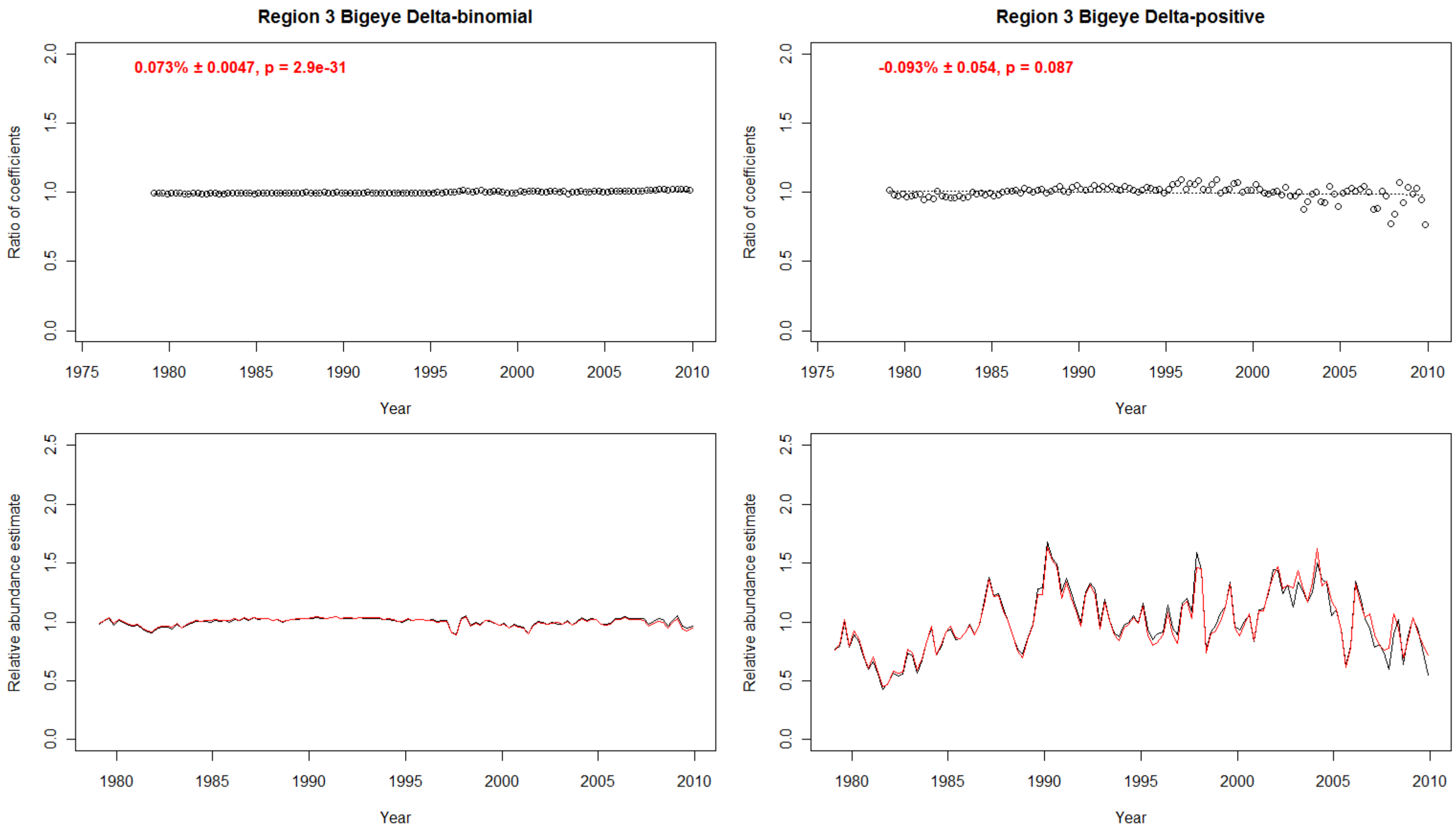

Figure 54: Region 3 (whole region) comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

[Type text]

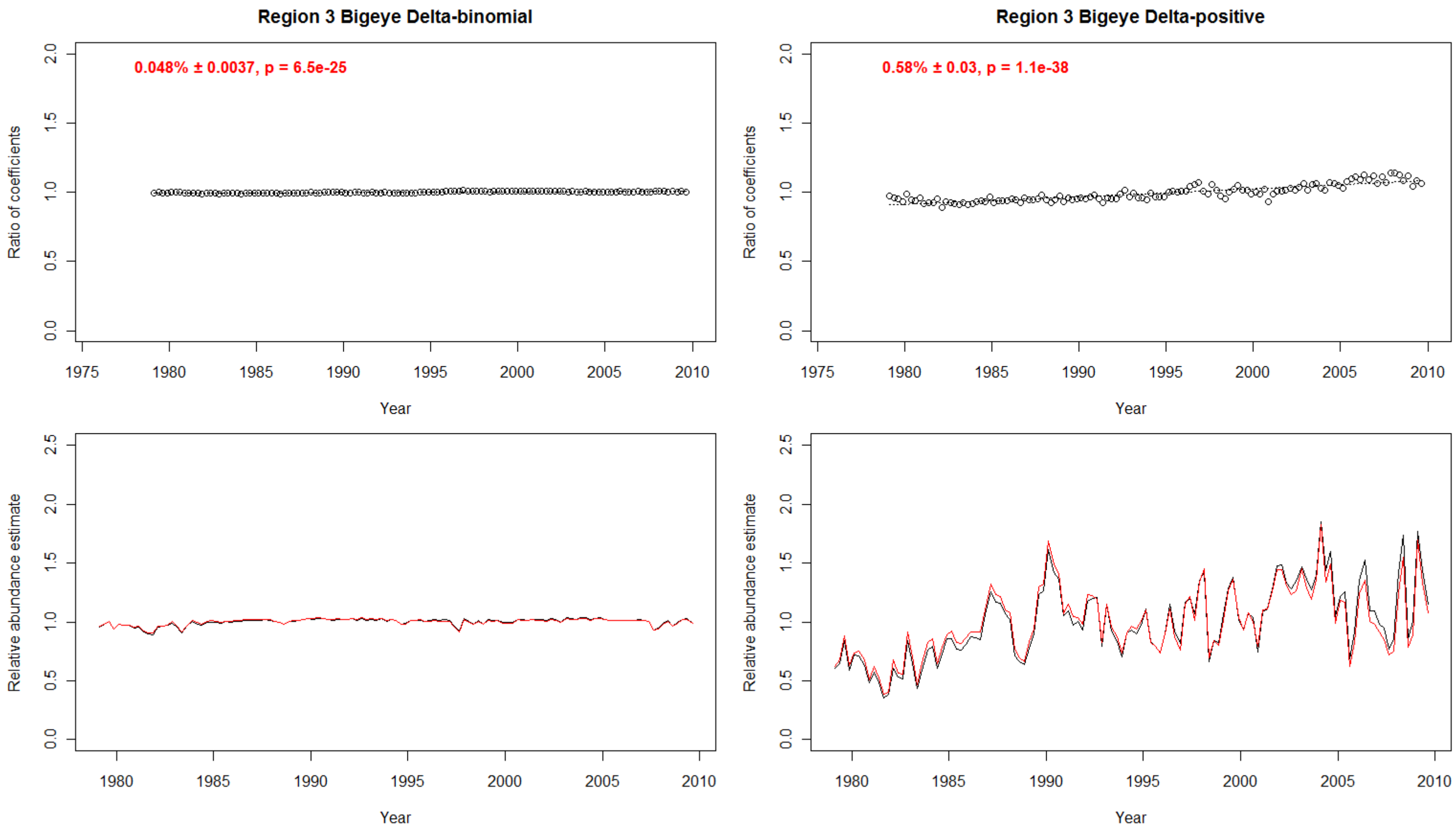

Figure 55: Region 3 (equatorial area) comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

[Type text]

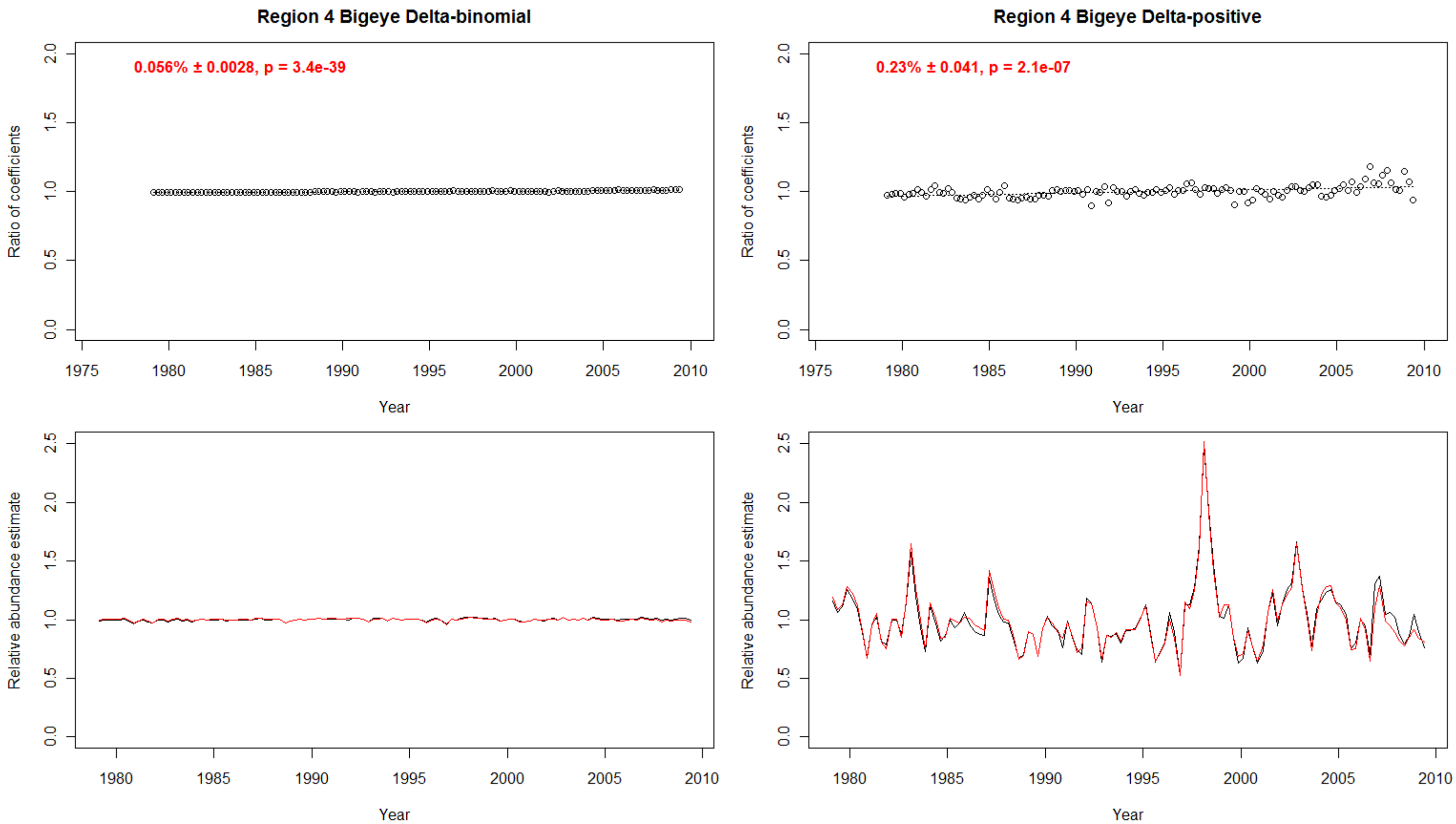

Figure 56: Region 4 comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

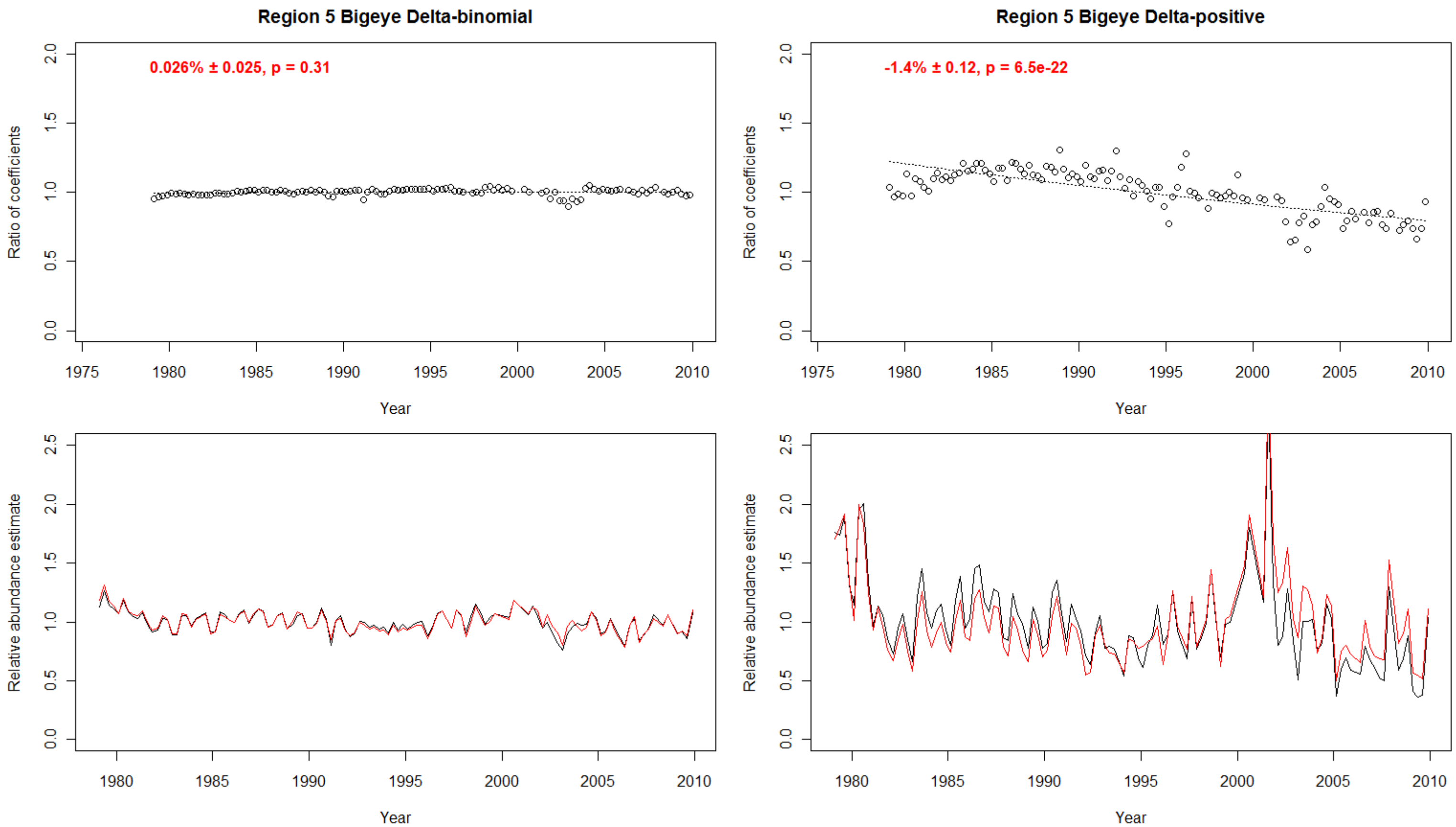

Figure 57: Region 5 comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

[Type text]

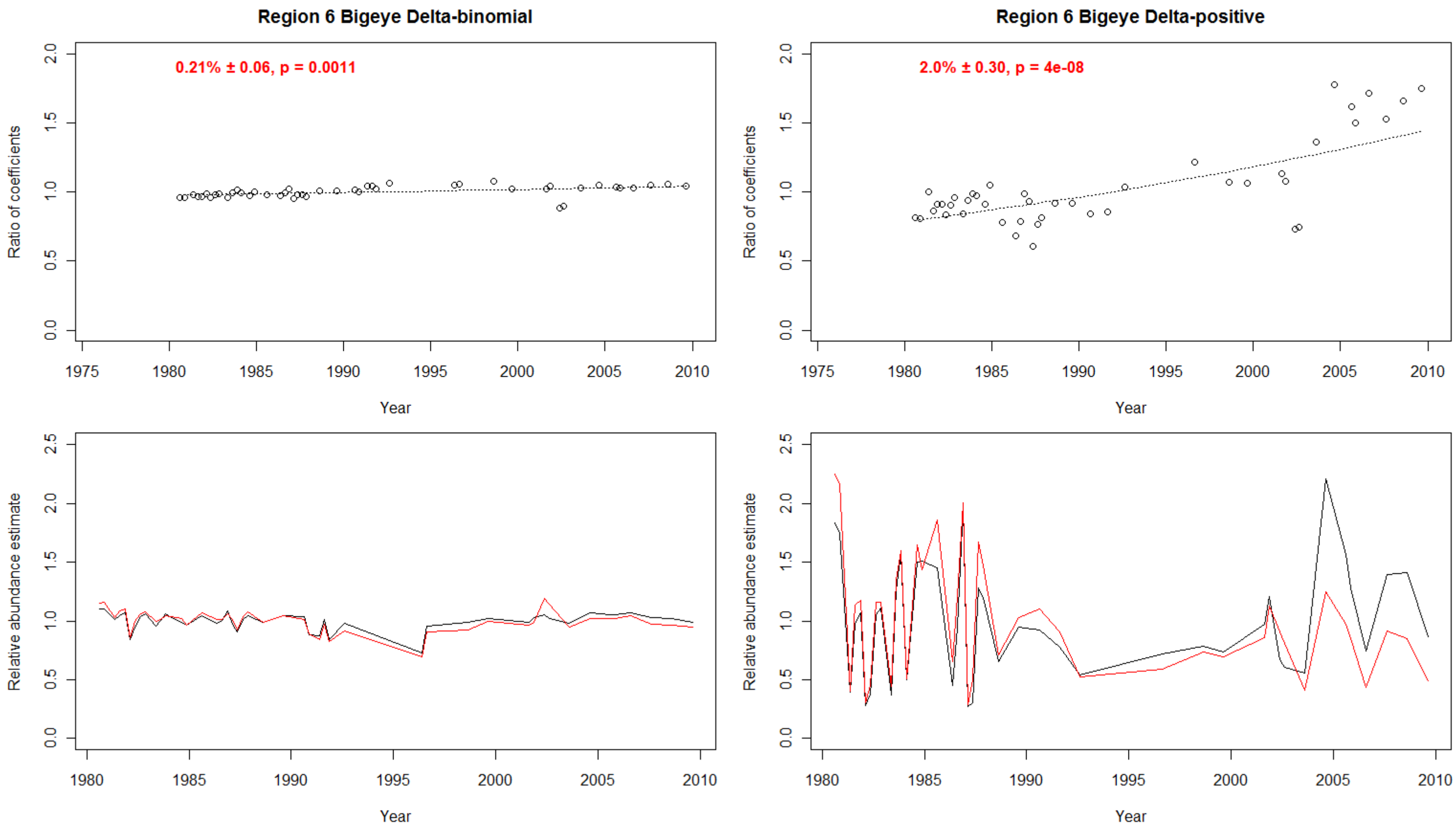

Figure 58: Region 6 comparison of standardized binomial (left) and positive lognormal (right) indices from operational data both with (lower figures, red) and without (black) the vessel effect. The figures above show the ratio of the two indices, and the estimated trends with 95% CI and p values.

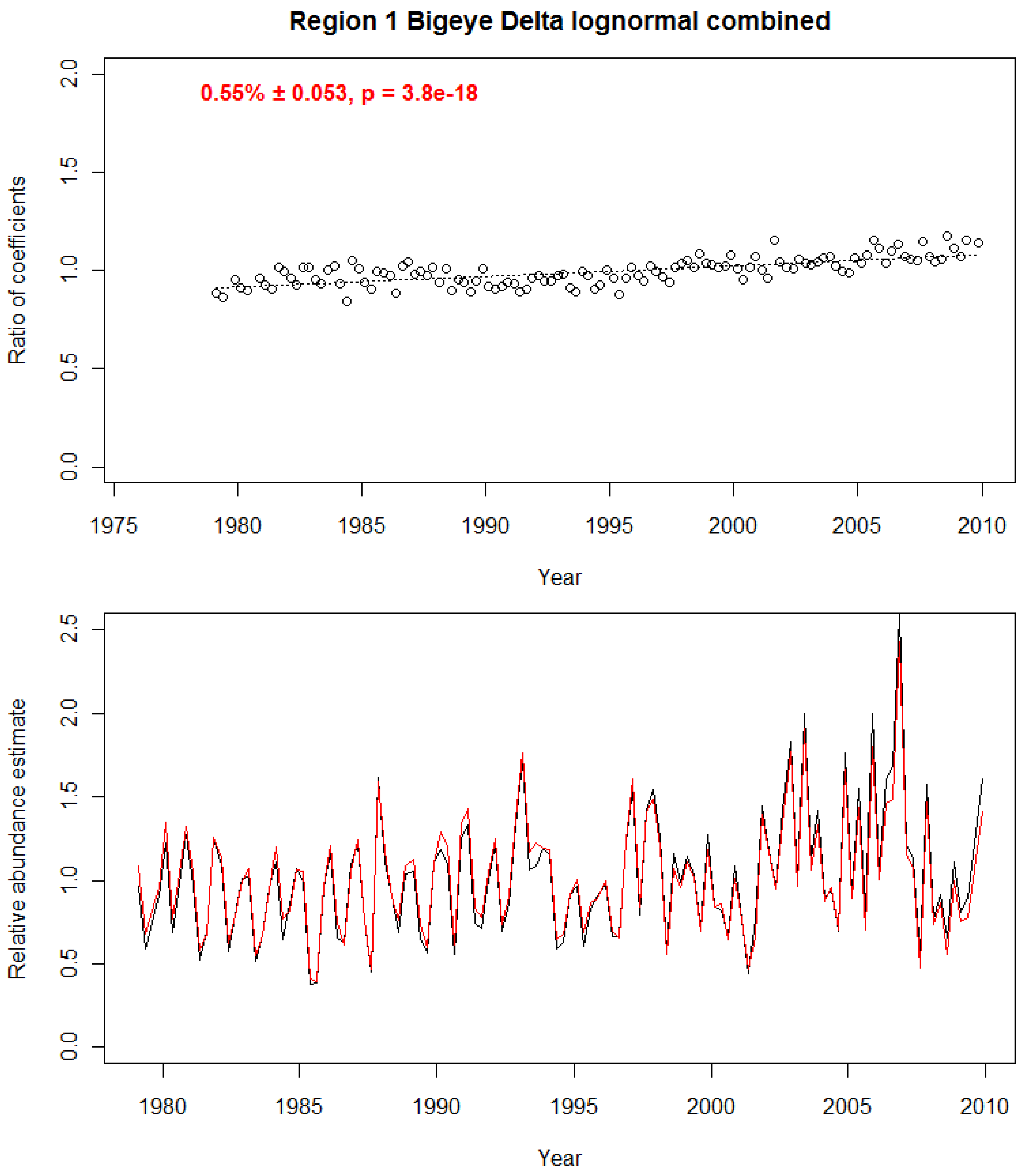

Figure 59: Region 1 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

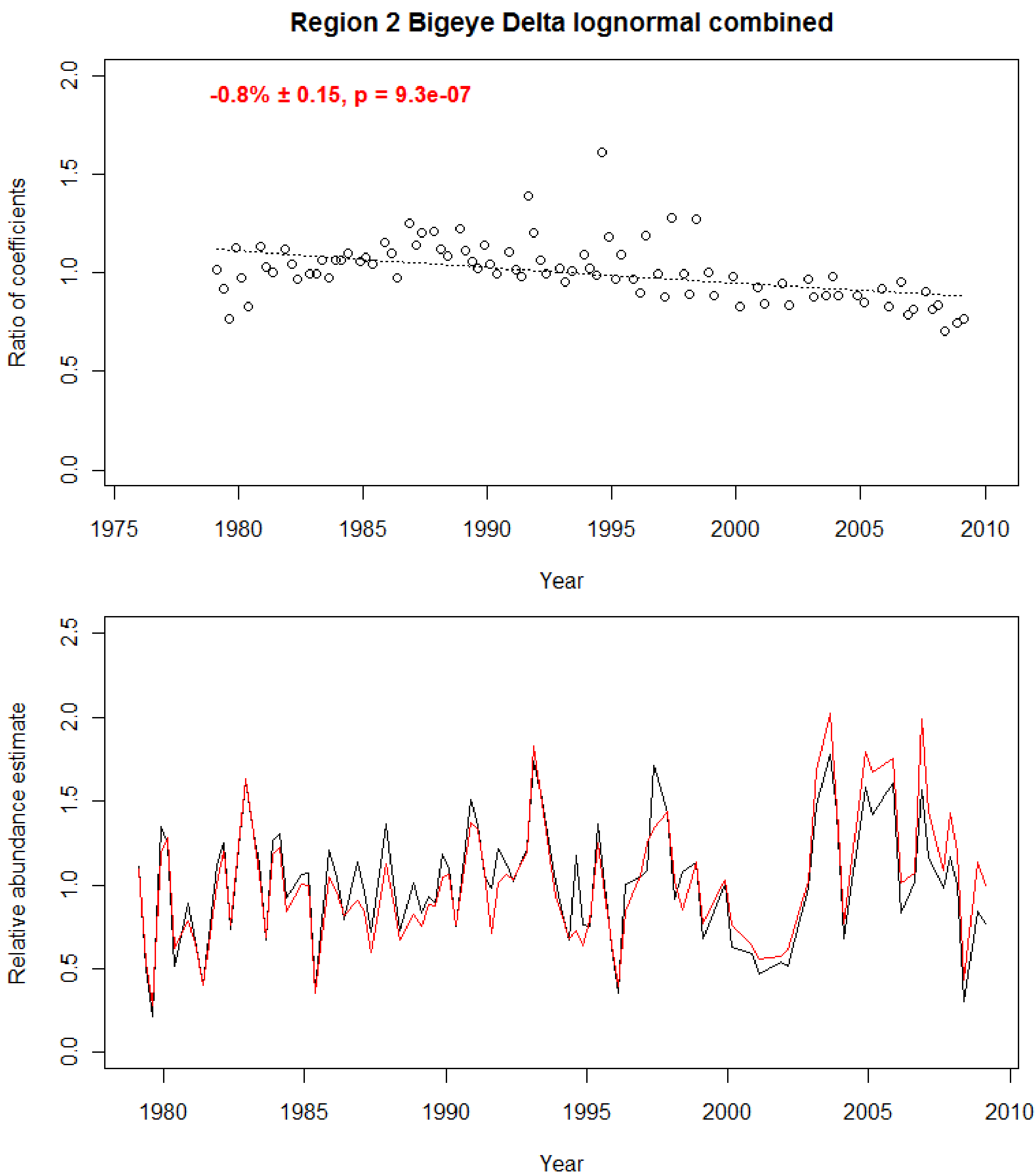

Figure 60: Region 2 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

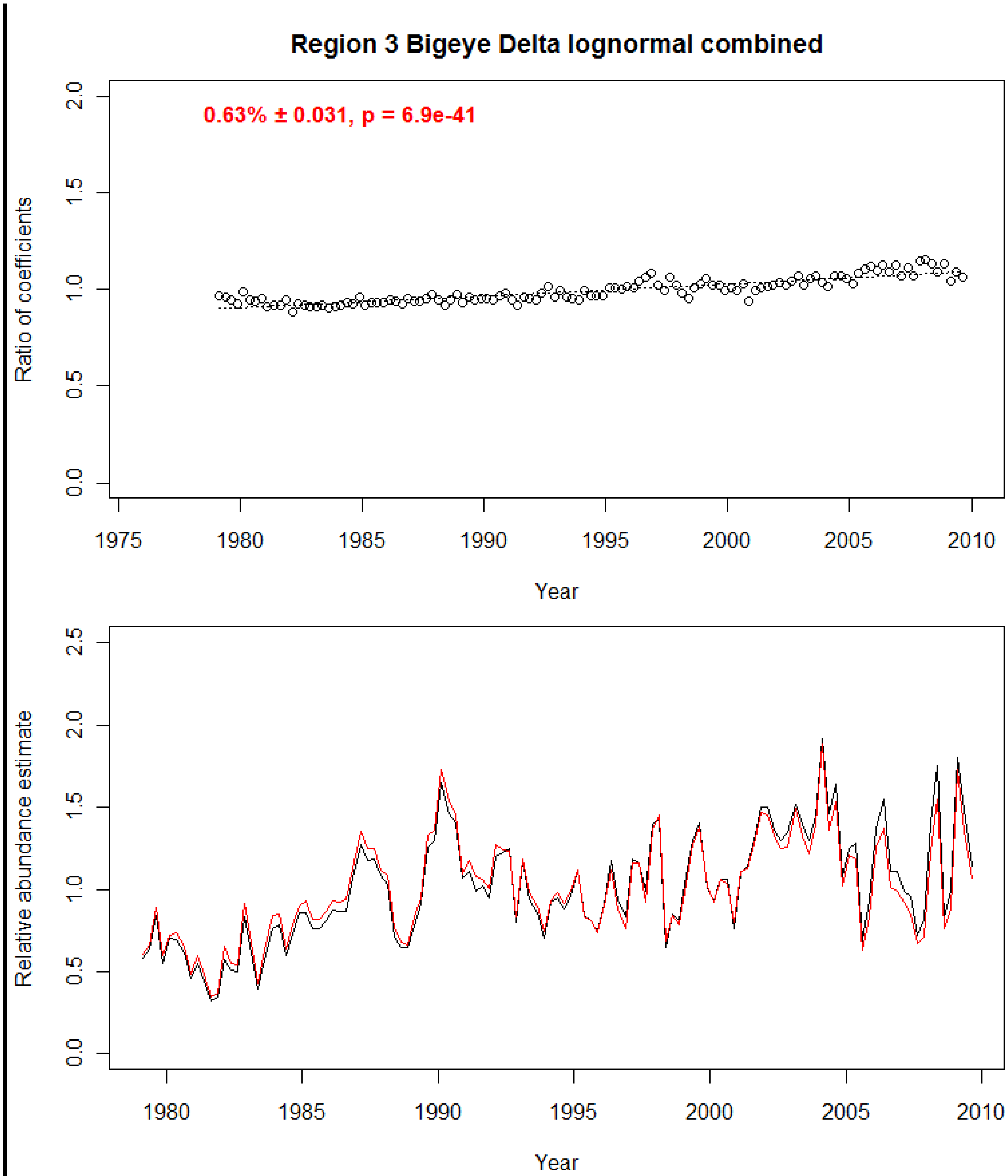

Figure 61: Region 3 equatorial (0-10N) comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

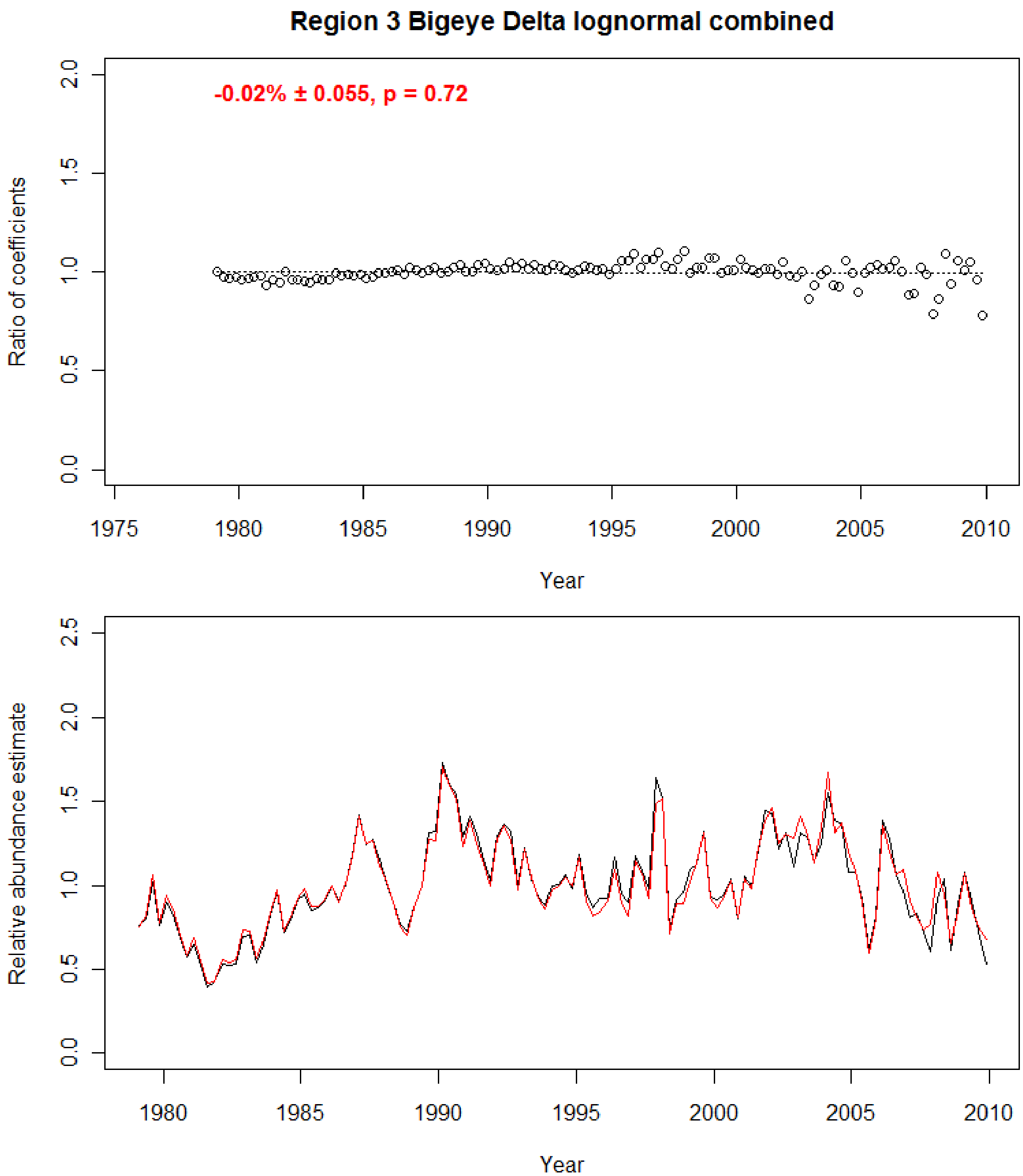

Figure 62: Region 3 (full region) comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

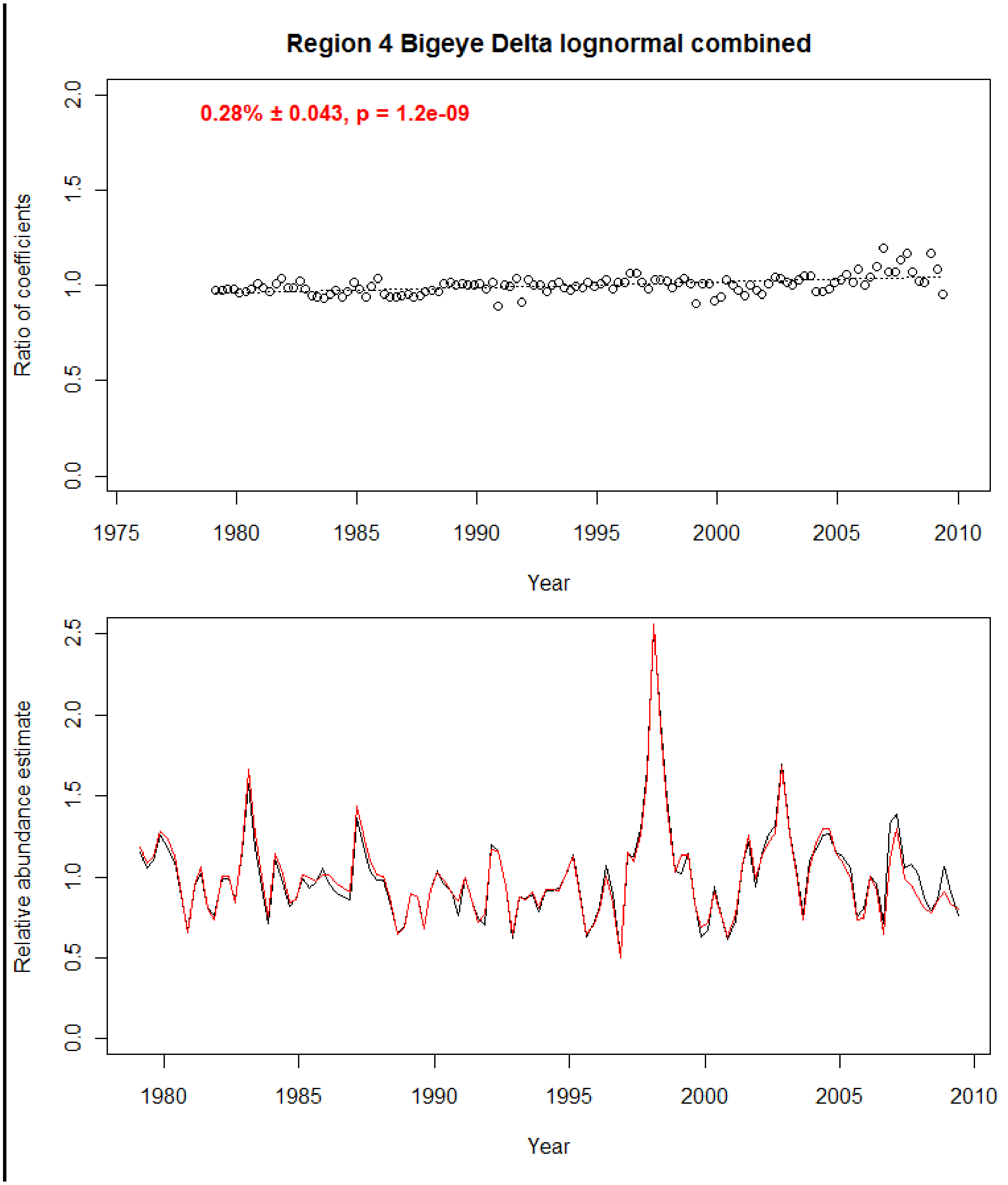

Figure 63: Region 4 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

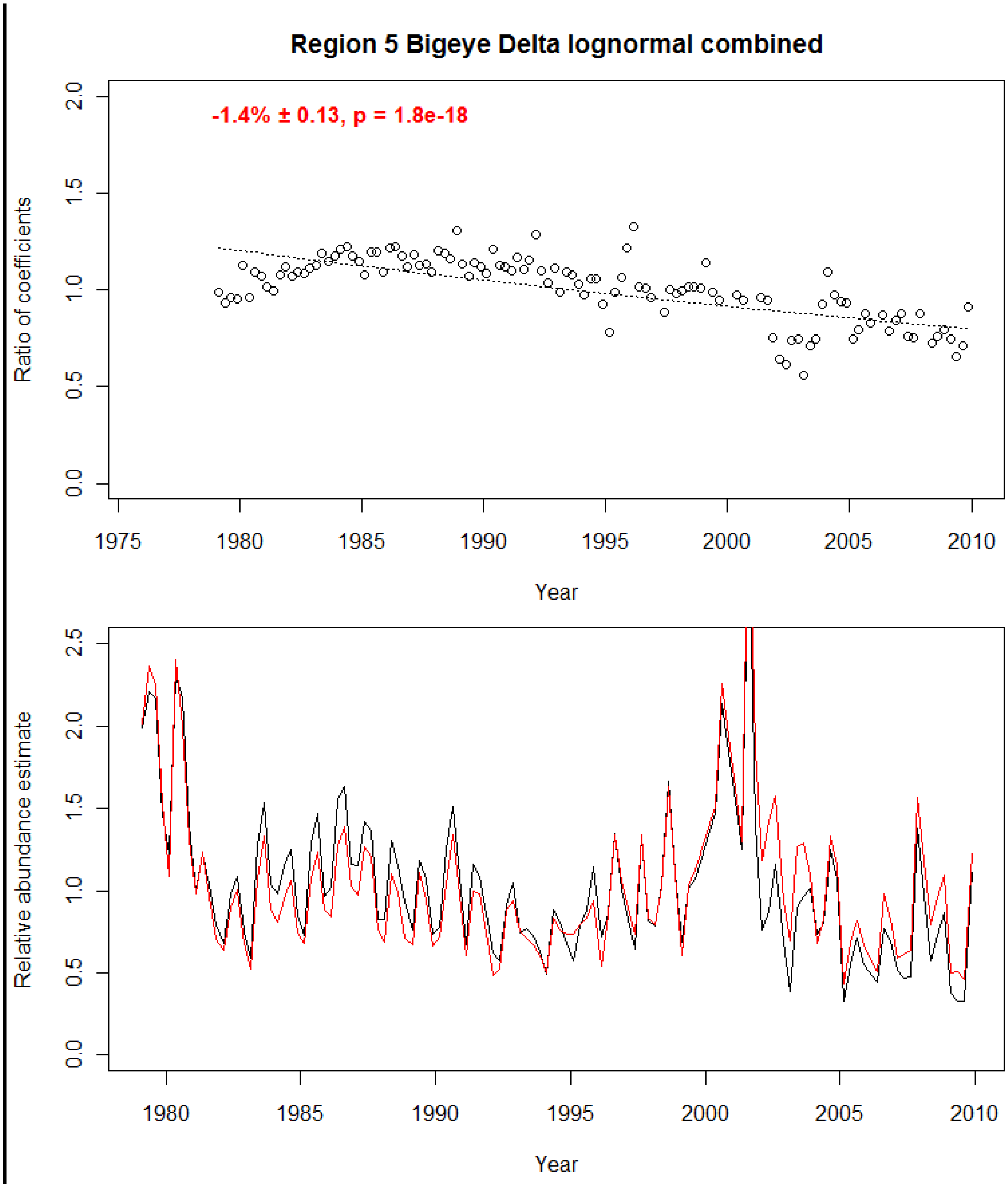

Figure 64: Region 5 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

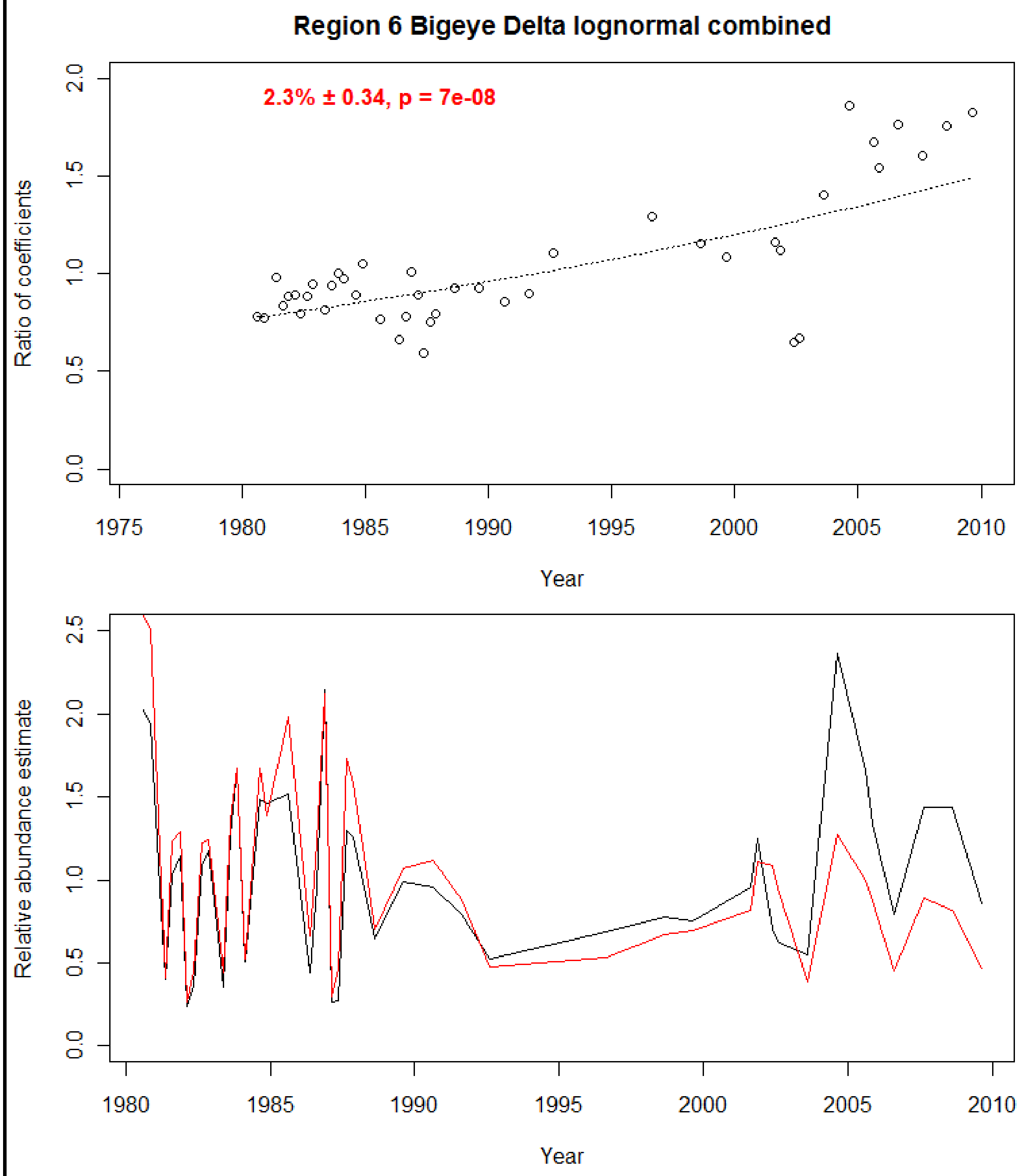

Figure 65: Region 6 comparison of standardized delta lognormal indices from operational data both with (lower figure, red) and without (black) the vessel effect. The figure above shows the ratio of the two indices, and the estimated trend with 95% CI and p value.

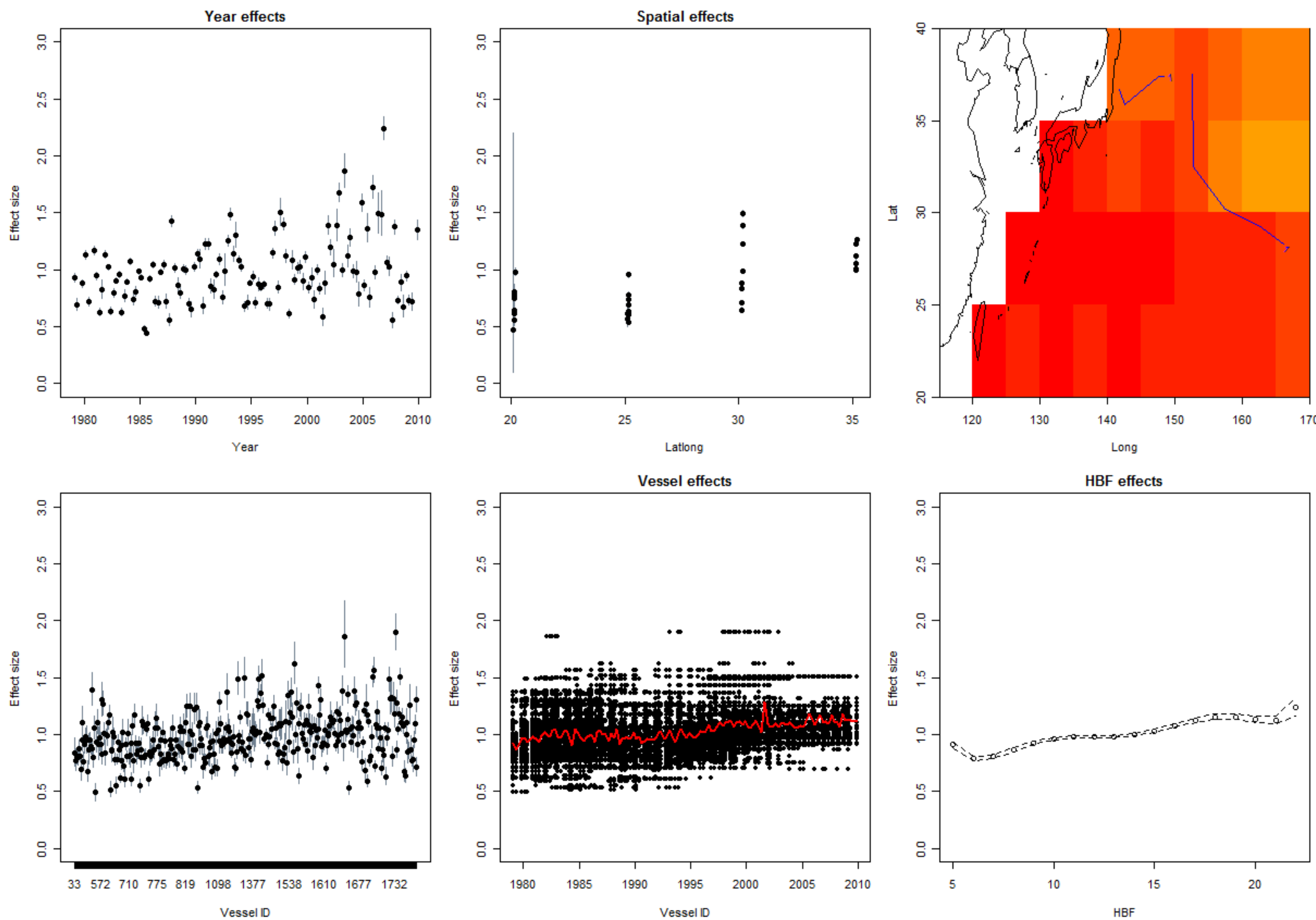

Figure 66: Estimated effects for region 1. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel 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.

[Type text]

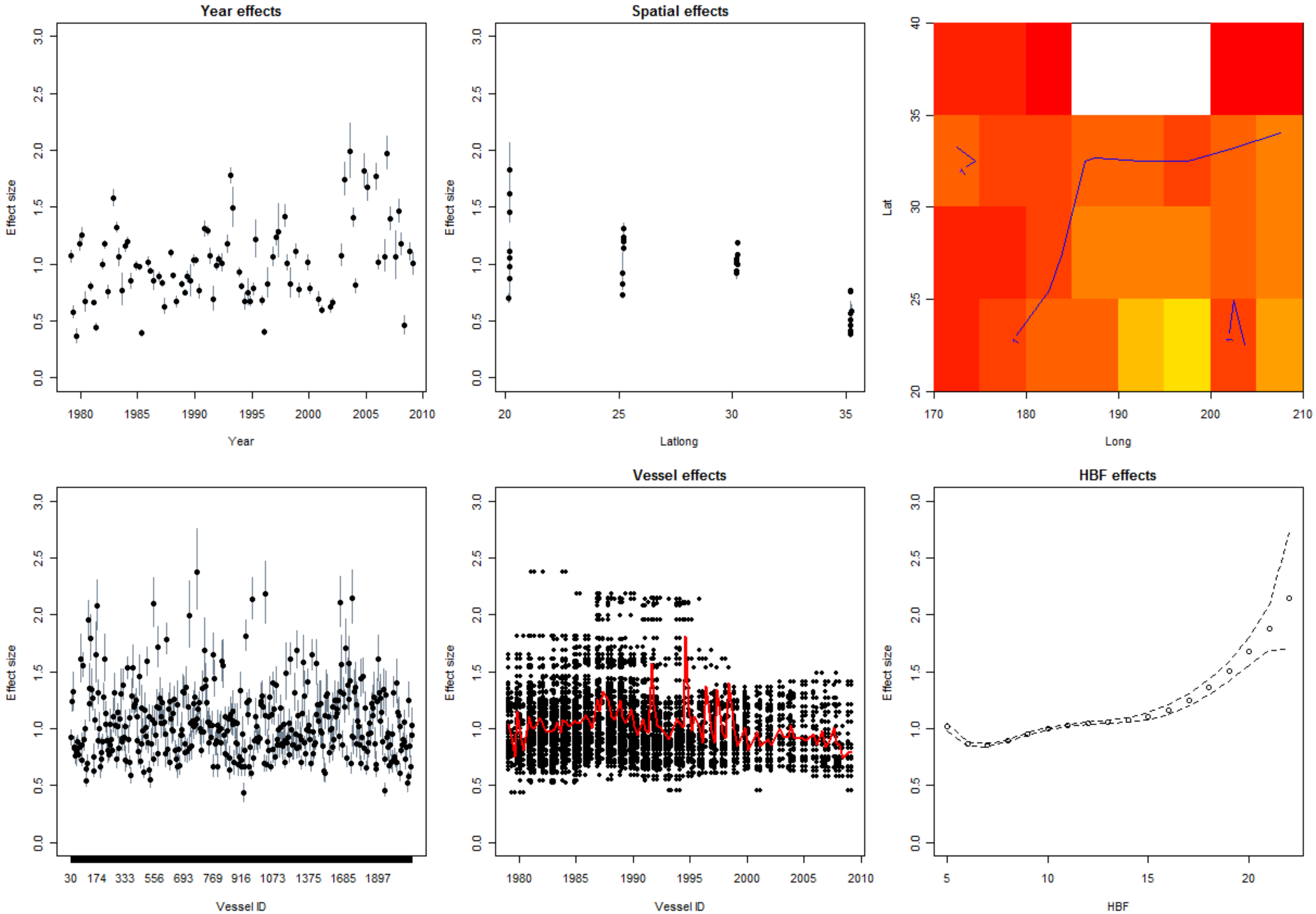

Figure 67: Estimated effects for region 2. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel 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.

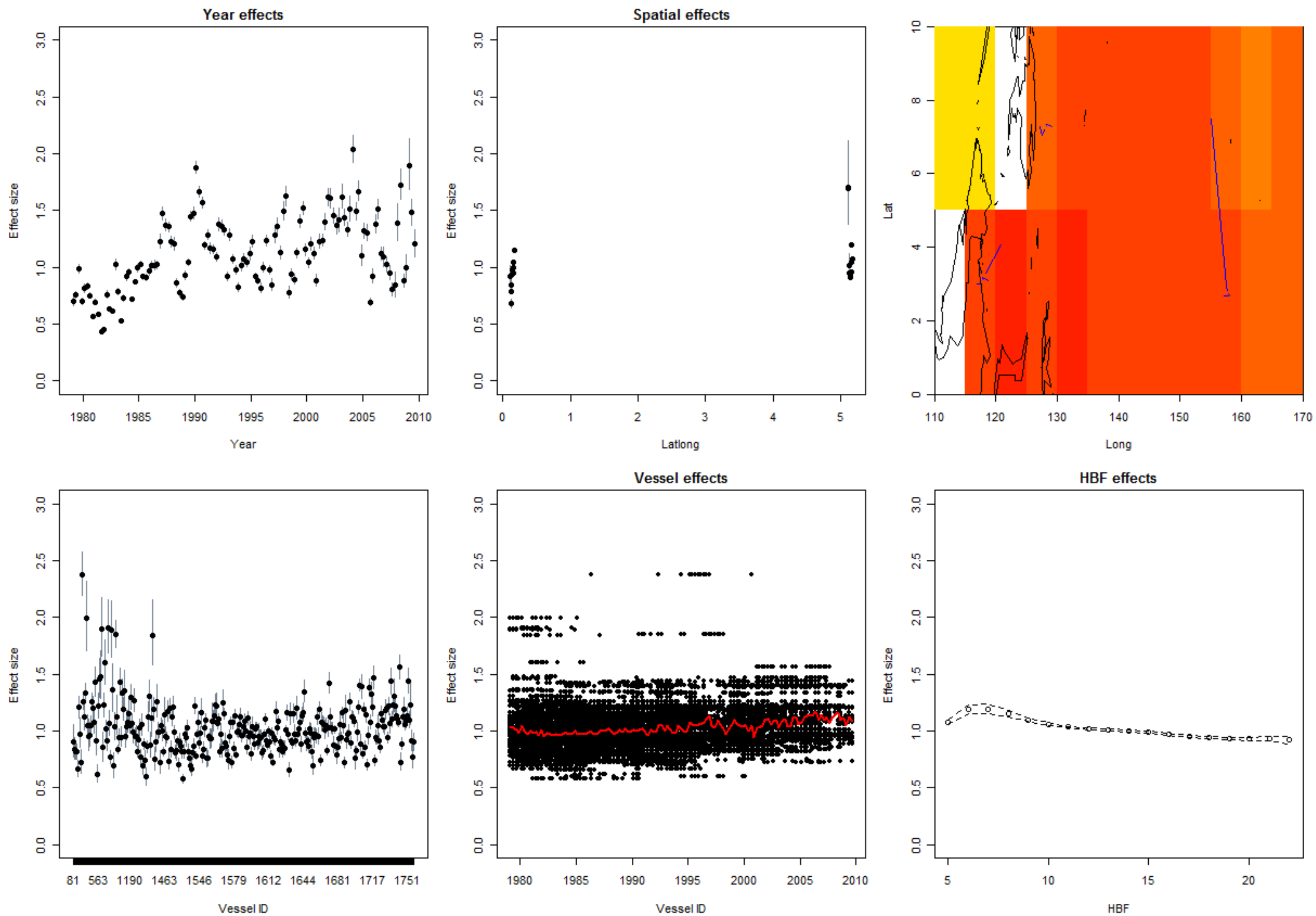

Figure 68: Estimated effects for region 3 (equatorial). From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which 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.

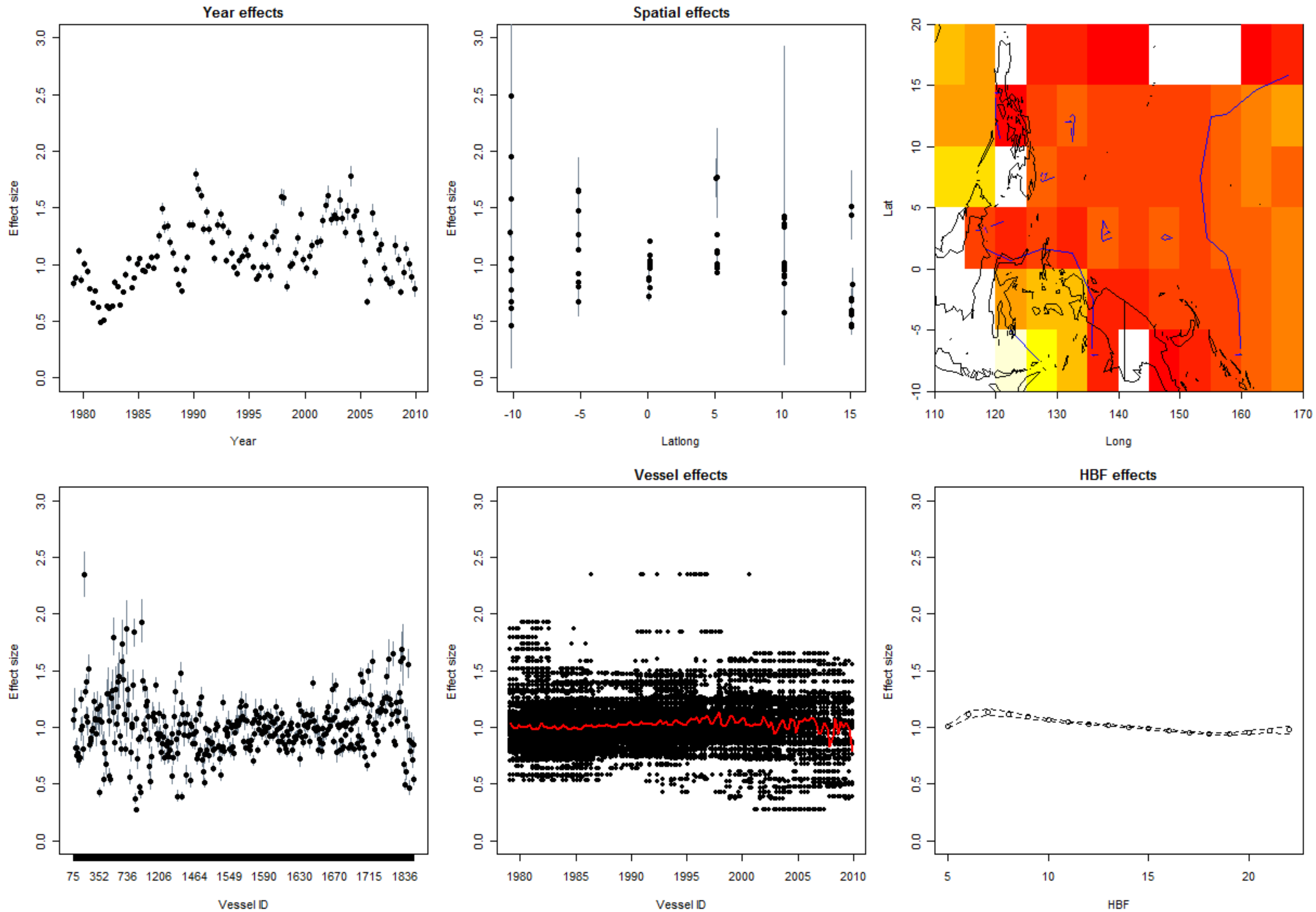

Figure 69: Estimated effects for region 3 (whole region). From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which 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.

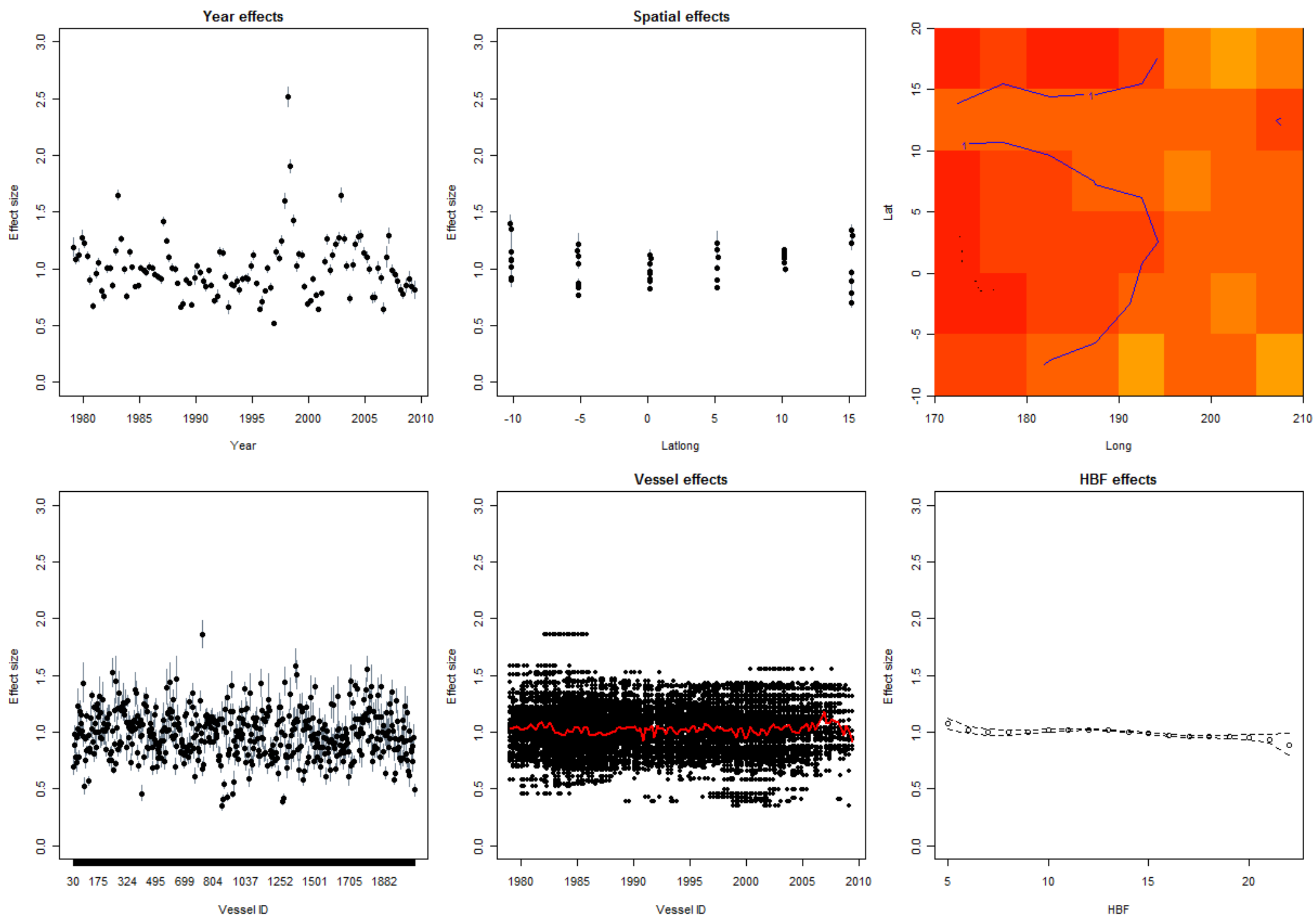

Figure 70: Estimated effects for region 4. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel 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.

[Type text]

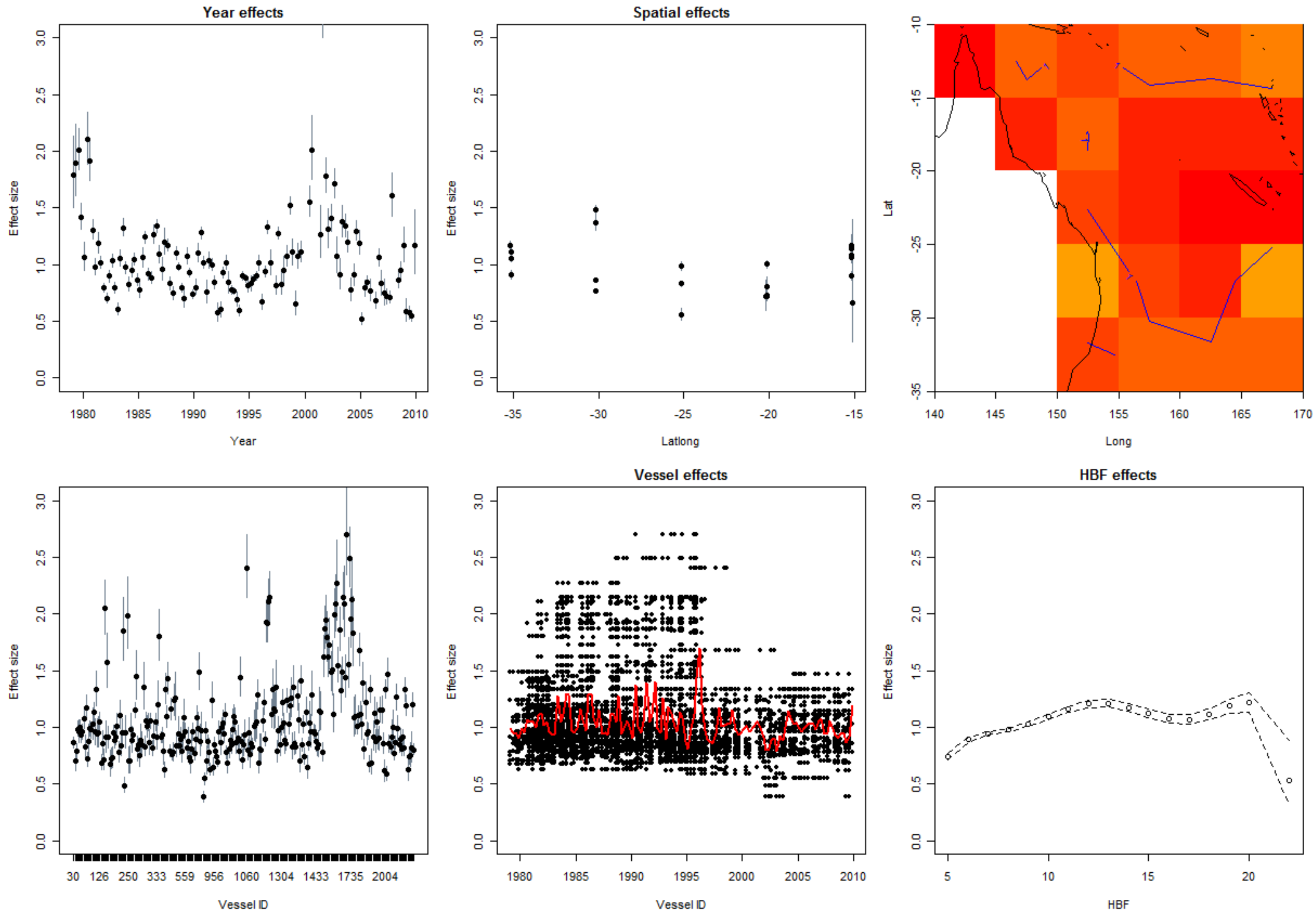

Figure 71: Estimated effects for region 5. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel 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.

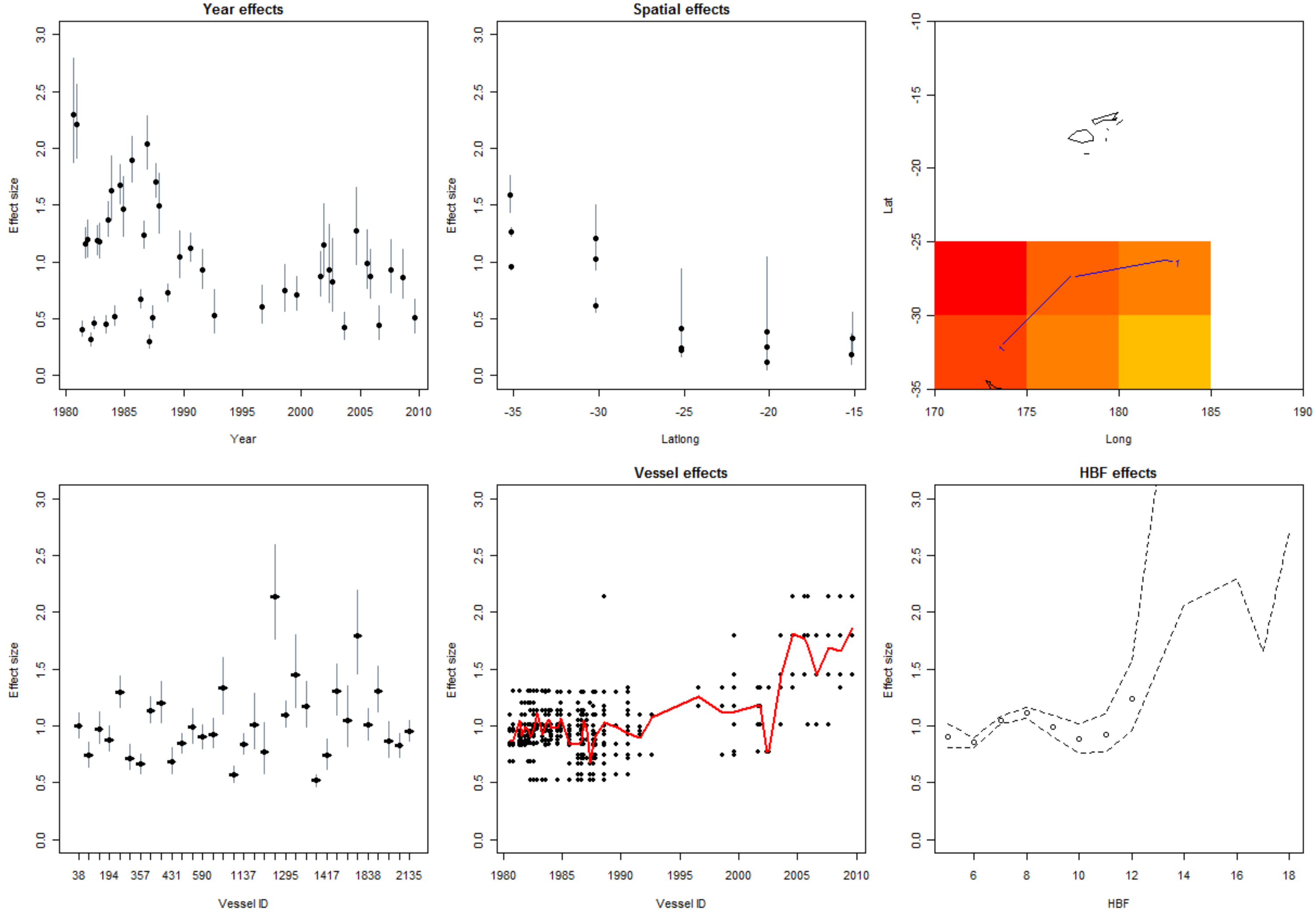

Figure 72: Estimated effects for region 6. From top left the panels represent 1. Year effects; 2. Spatial effects by latitude; 3. Mapped spatial effects, with darker colours representing lower catch rates; 4. Vessel effects by (anonymous) vessel; 5. Vessel effects by year-quarter in which the vessel 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.

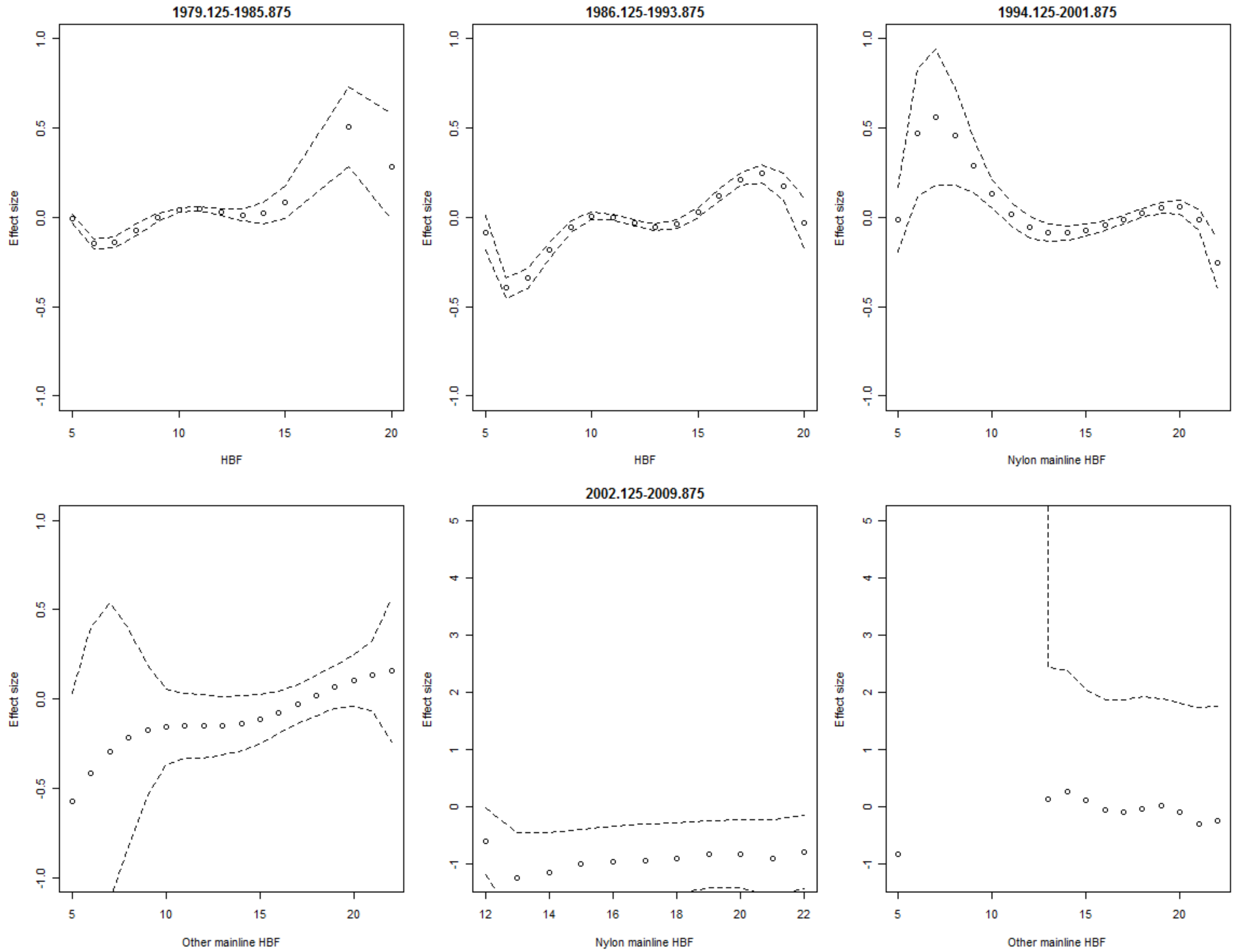

Figure 73: HBF effects by 8 year period in region 1.

[Type text]

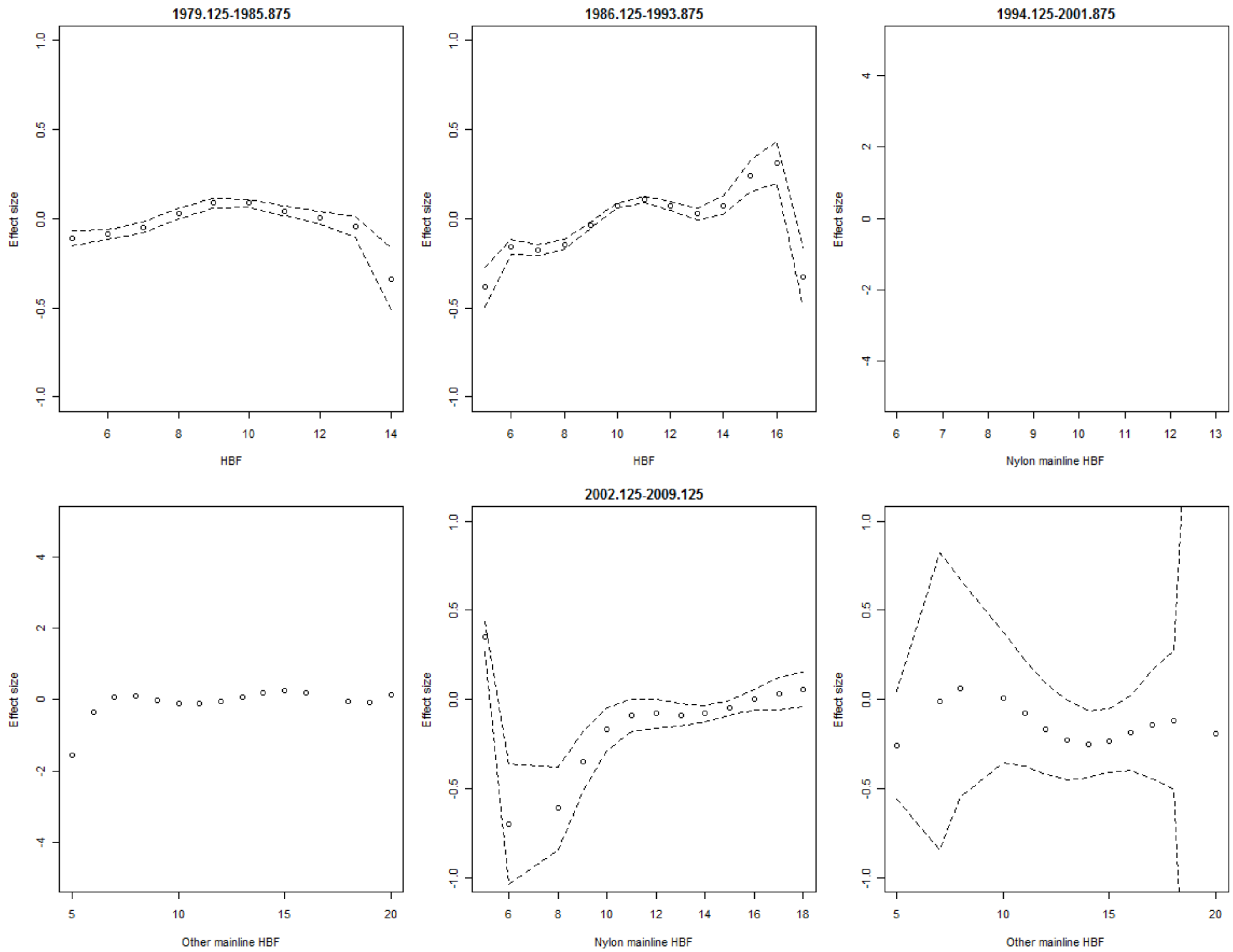

Figure 74: HBF effects by 8 year period in region 2.

[Type text]

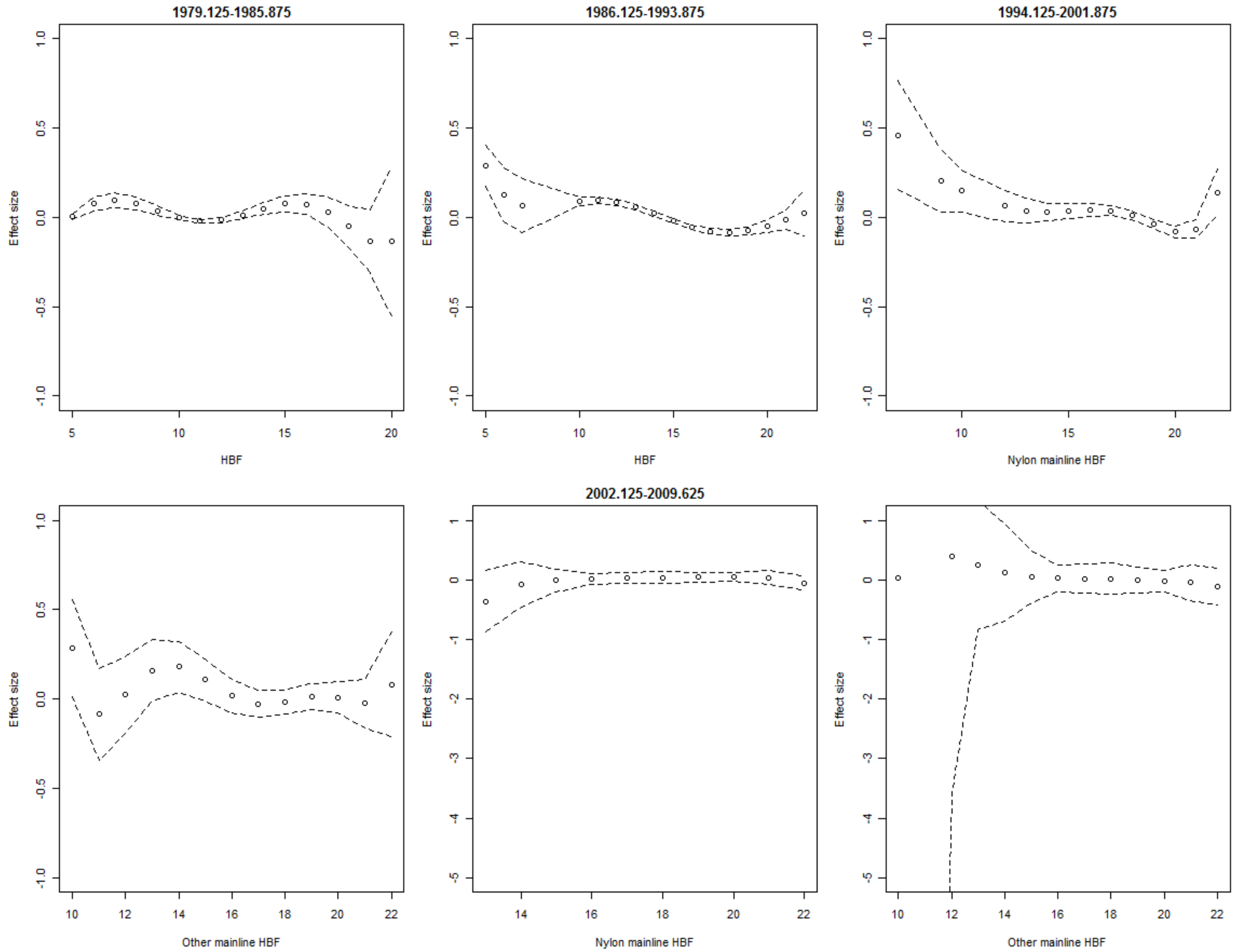

Figure 75: HBF effects by 8 year period in region 3.

[Type text]

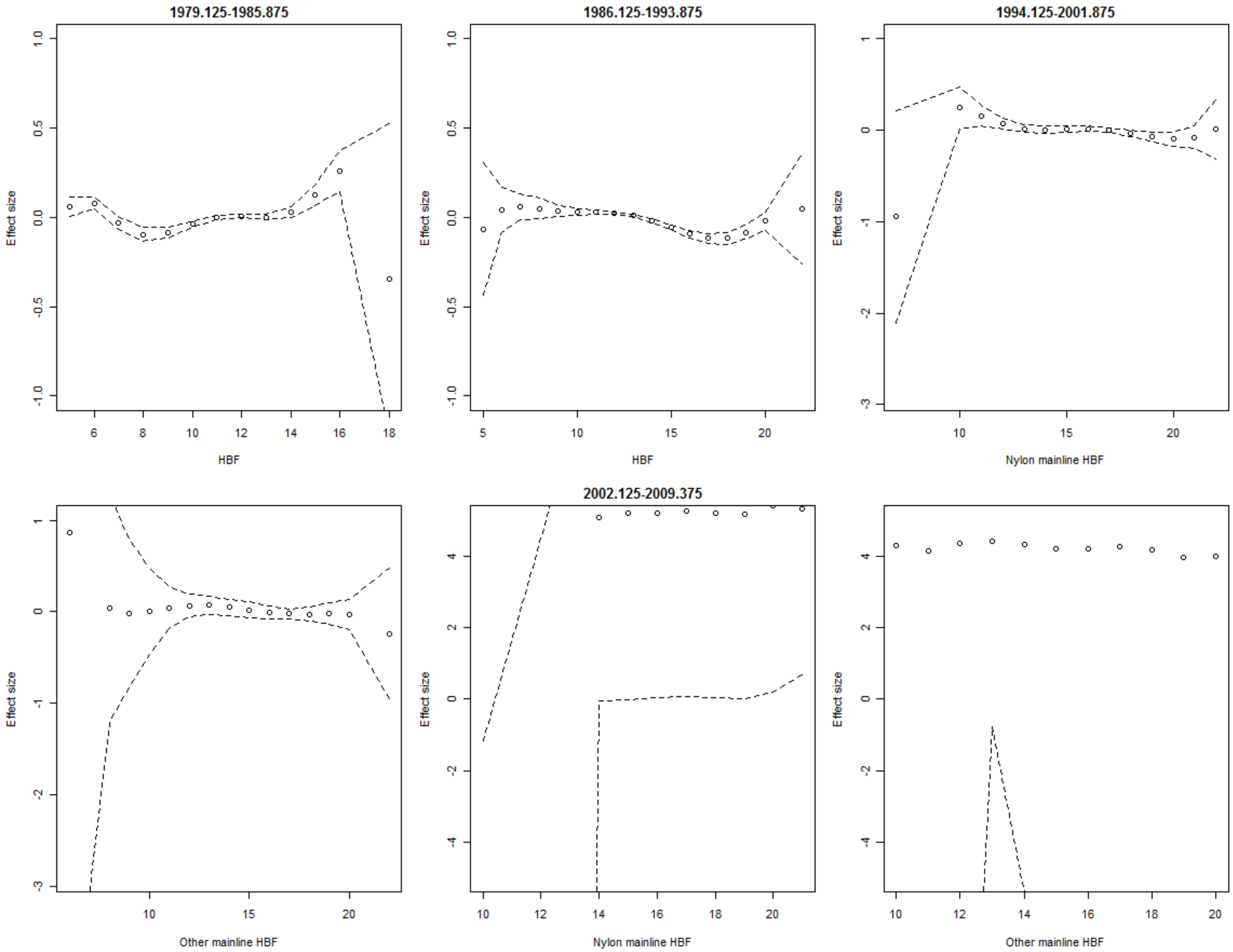

Figure 76: HBF effects by 8 year period in region 4.

[Type text]

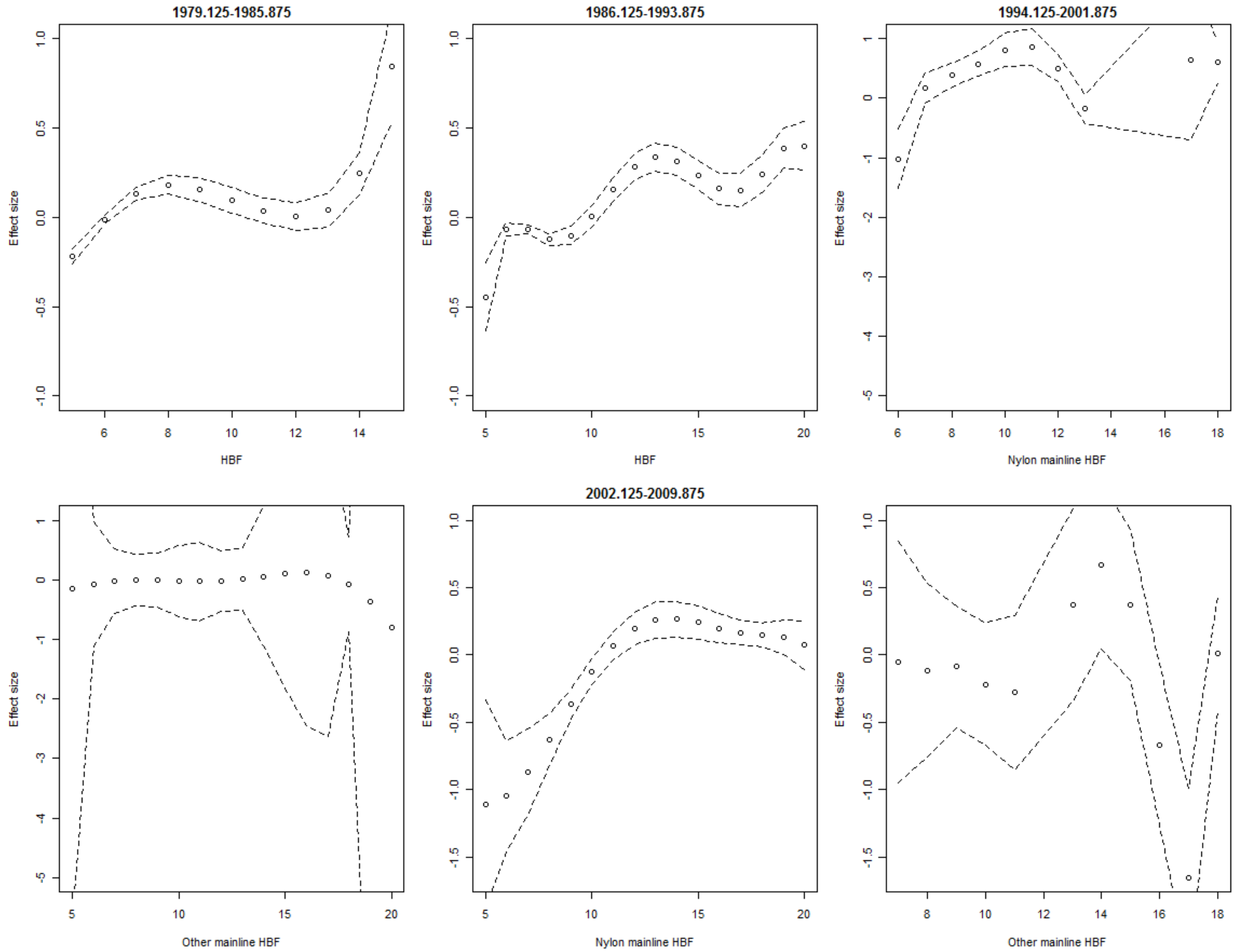

Figure 77: HBF effects by 8 year period in region 5.

[Type text]

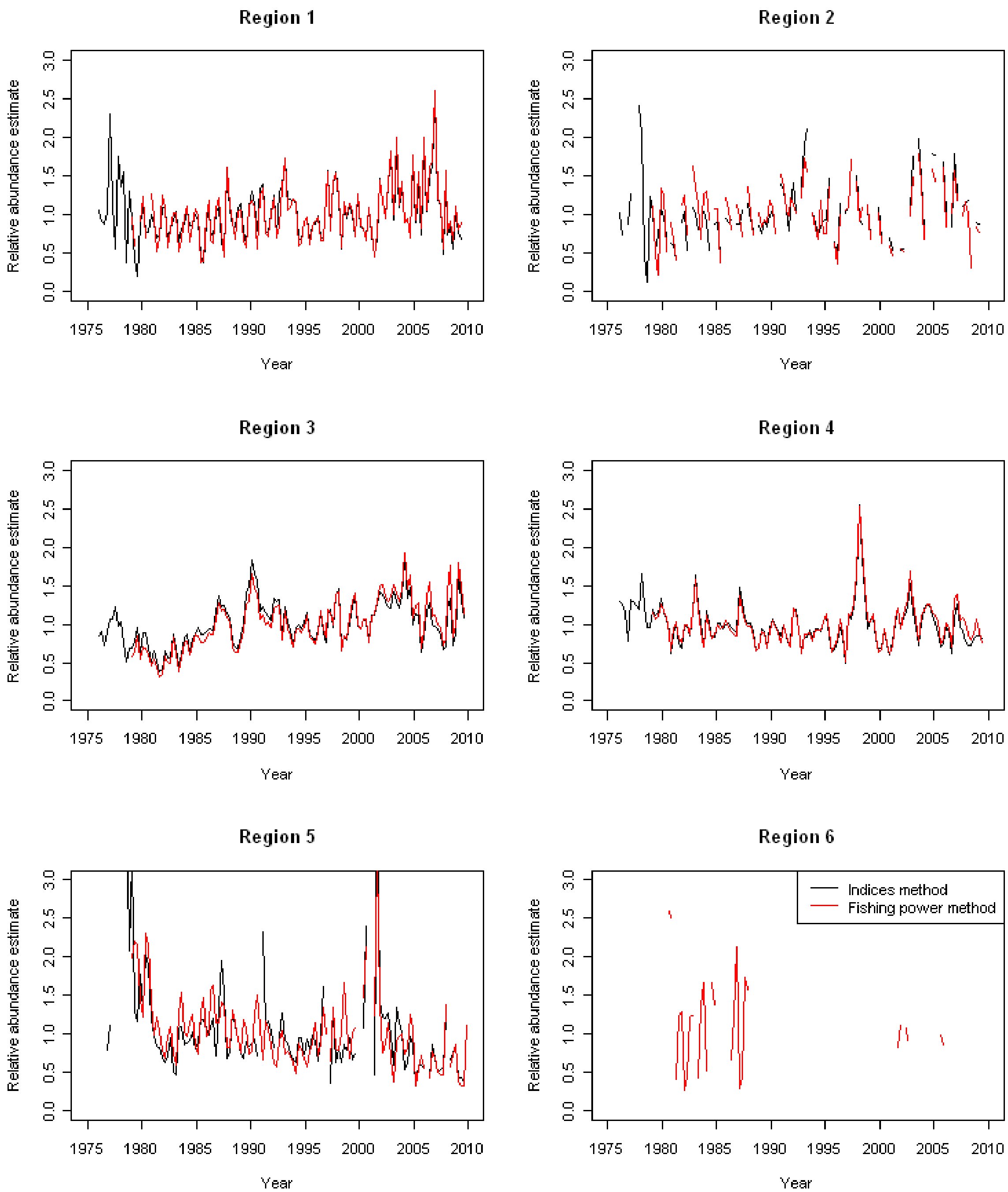

Figure 78: Comparison of regional abundance indices based on the dataset and model designed to estimate abundance indices (black) and based on the dataset and model used for the effort creep analyses (red).

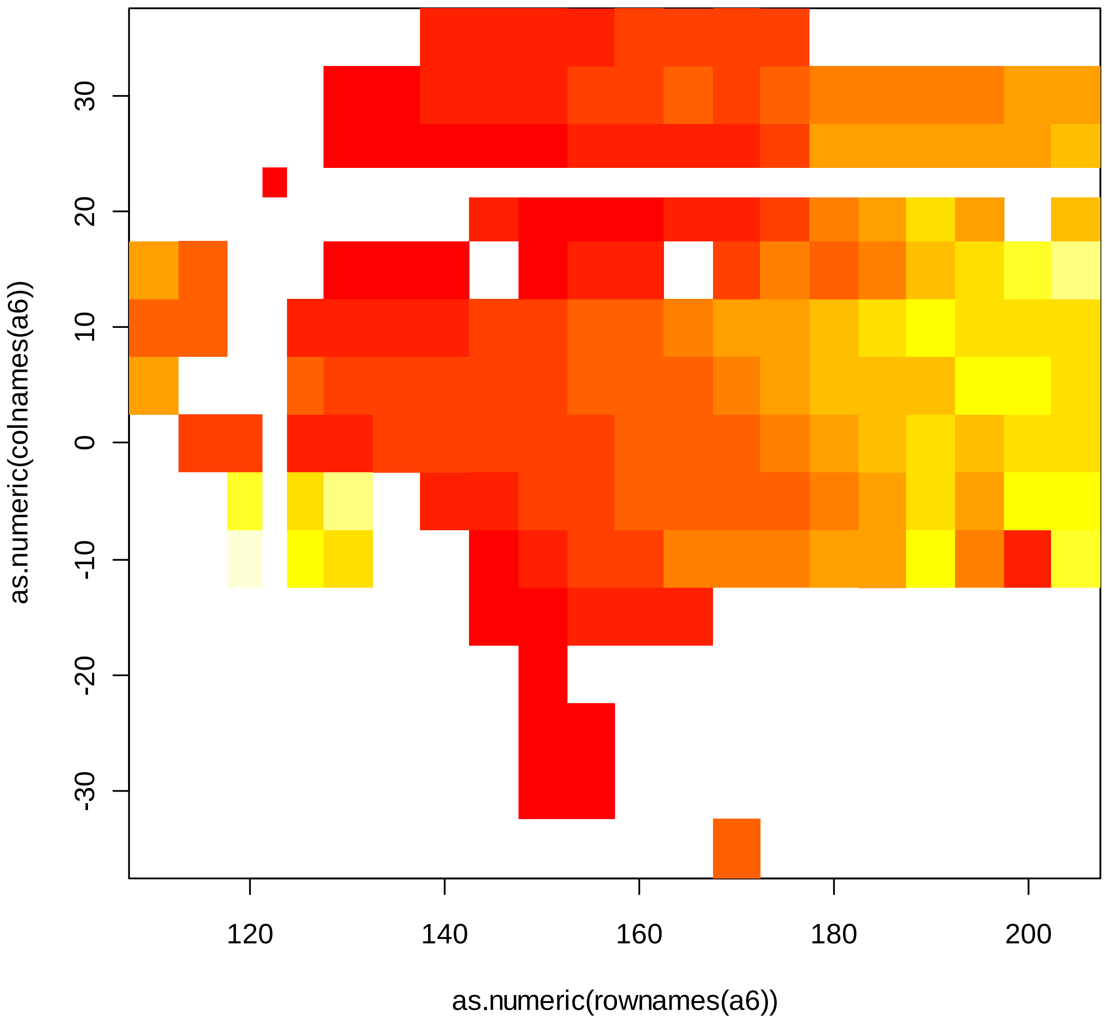

Figure 79: Area weights calculated using operational data. Darker colours represent lower catch rates.

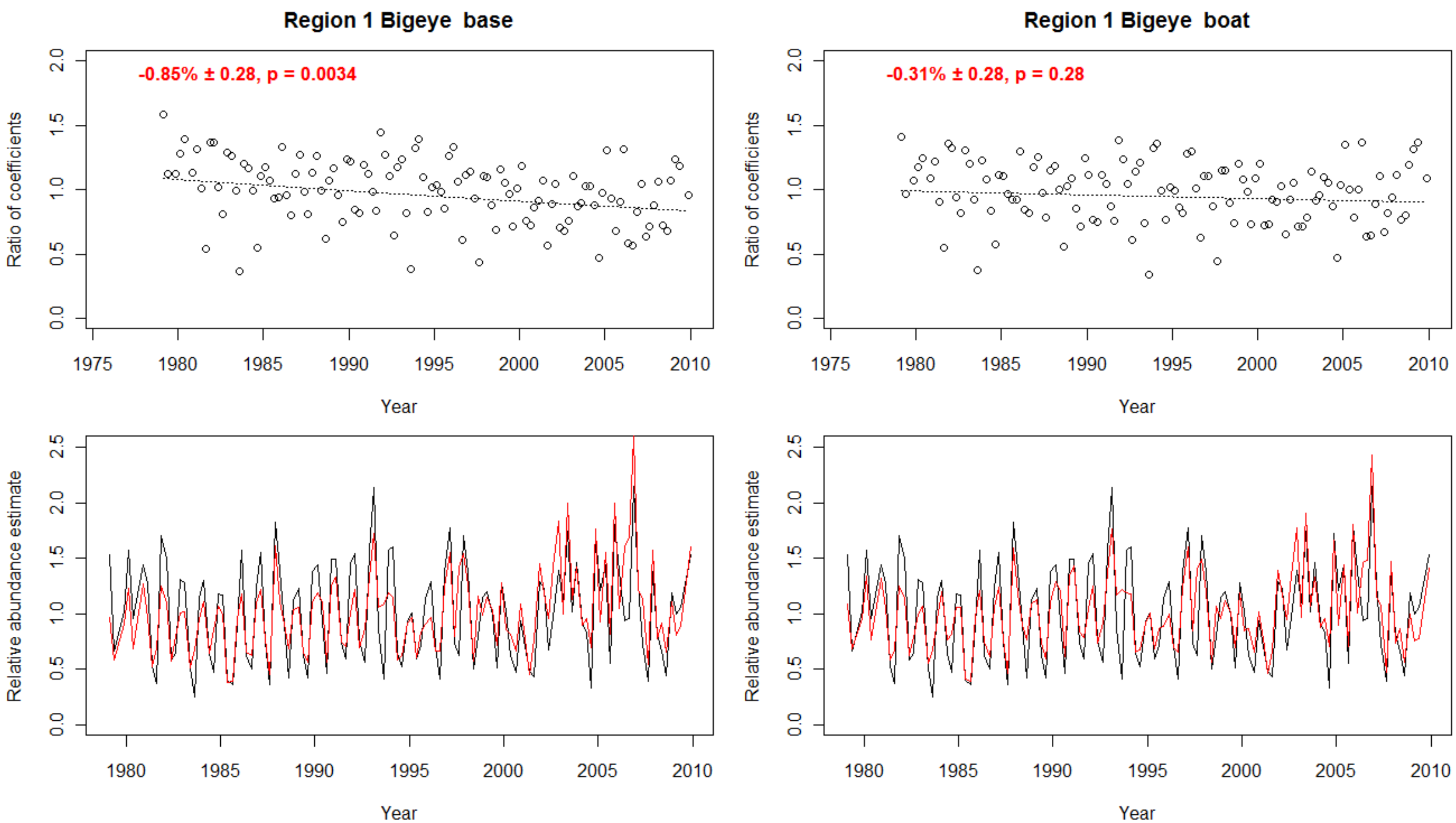

Figure 80: Comparison of standardized delta lognormal indices from operational data (red) and the same data aggregated (black) for region 1. The figures on the left compare indices from aggregated data with indices estimated from operational data using the same covariates. On the right aggregated indices are compared with indices estimated from the operational data with a model that included a vessel effect.

[Type text]

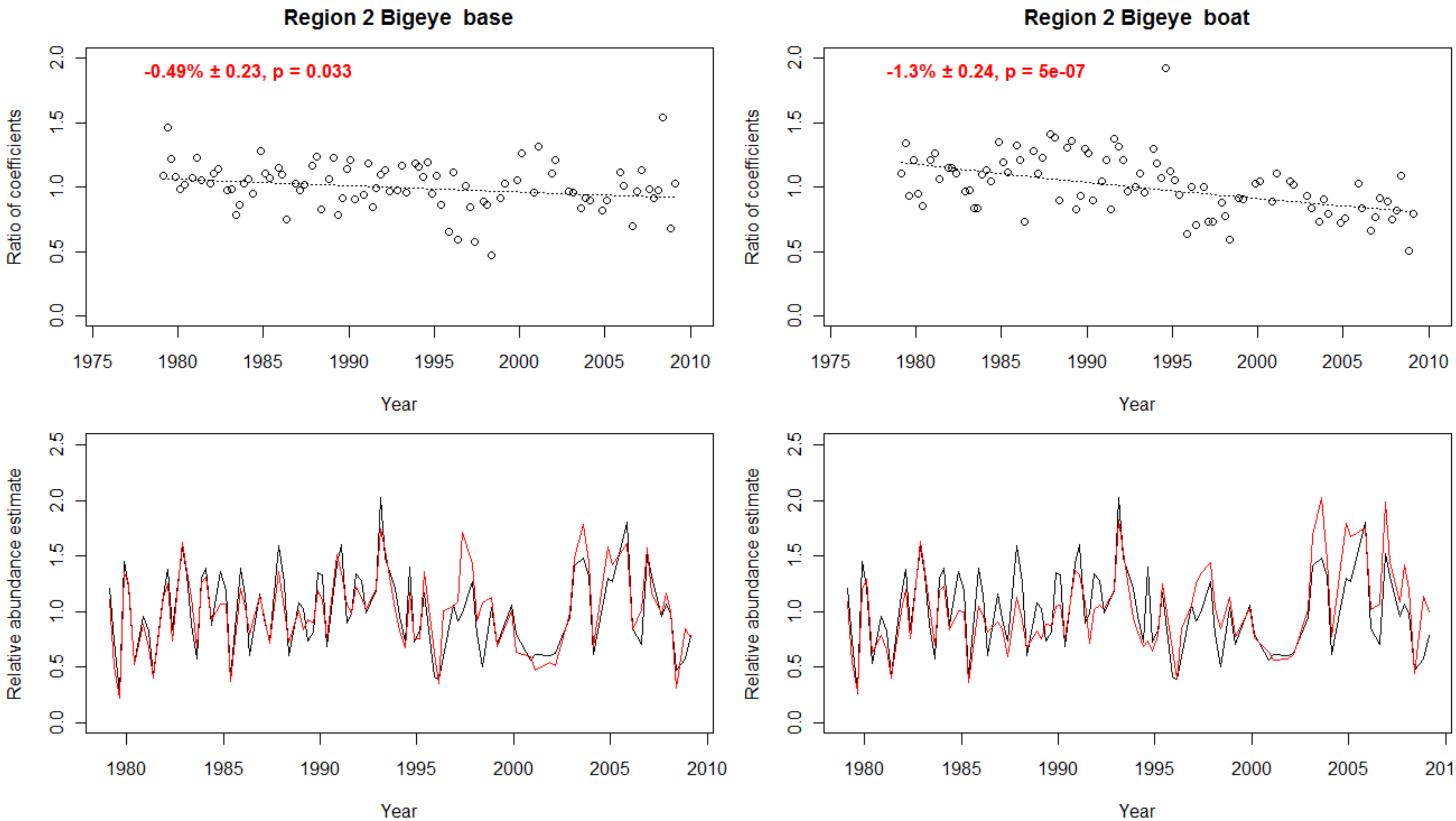

Figure 81: Comparison of standardized delta lognormal indices from operational data (red) and the same data aggregated (black) for region 2. The figures on the left compare indices from aggregated data with indices estimated from operational data using the same covariates. On the right aggregated indices are compared with indices estimated from the operational data with a model that included a vessel effect.

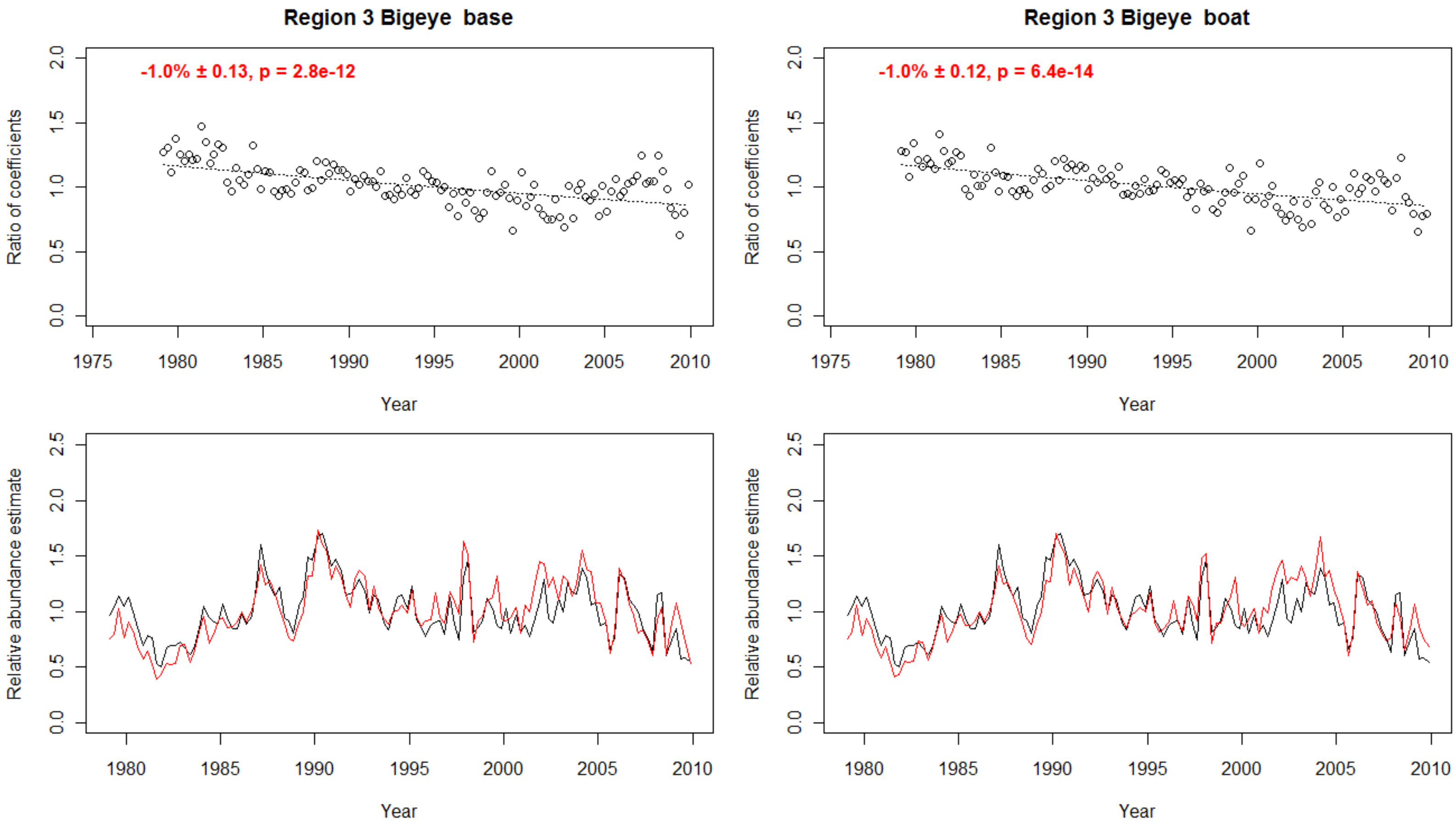

Figure 82: Comparison of standardized delta lognormal indices from operational data (red) and the same data aggregated (black) for all areas of region 3. The figures on the left compare indices from aggregated data with indices estimated from operational data using the same covariates. On the right aggregated indices are compared with indices estimated from the operational data with a model that included a vessel effect.

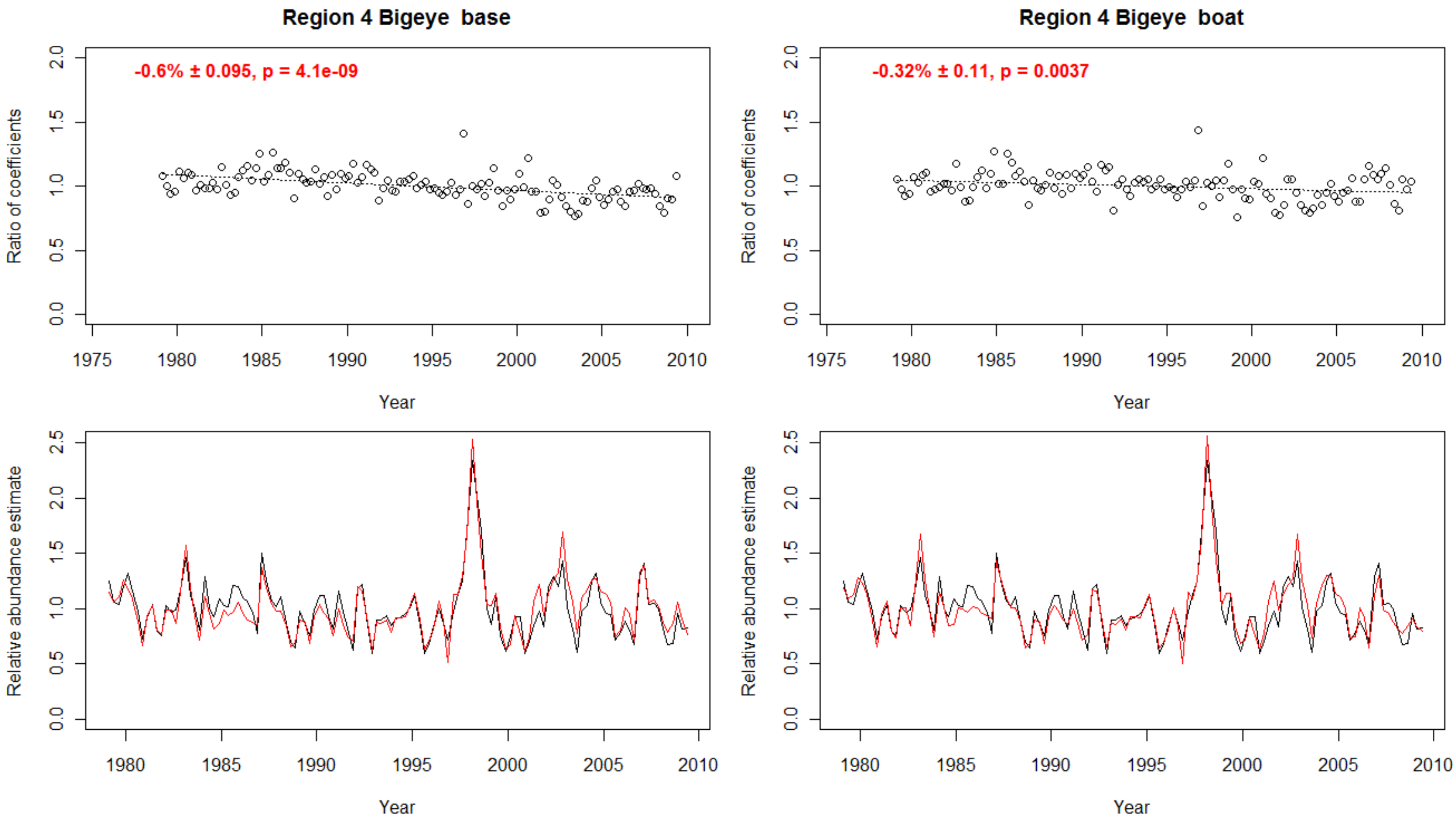

Figure 83: Comparison of standardized delta lognormal indices from operational data (red) and the same data aggregated (black) for region 4. The figures on the left compare indices from aggregated data with indices estimated from operational data using the same covariates. On the right aggregated indices are compared with indices estimated from the operational data with a model that included a vessel effect.

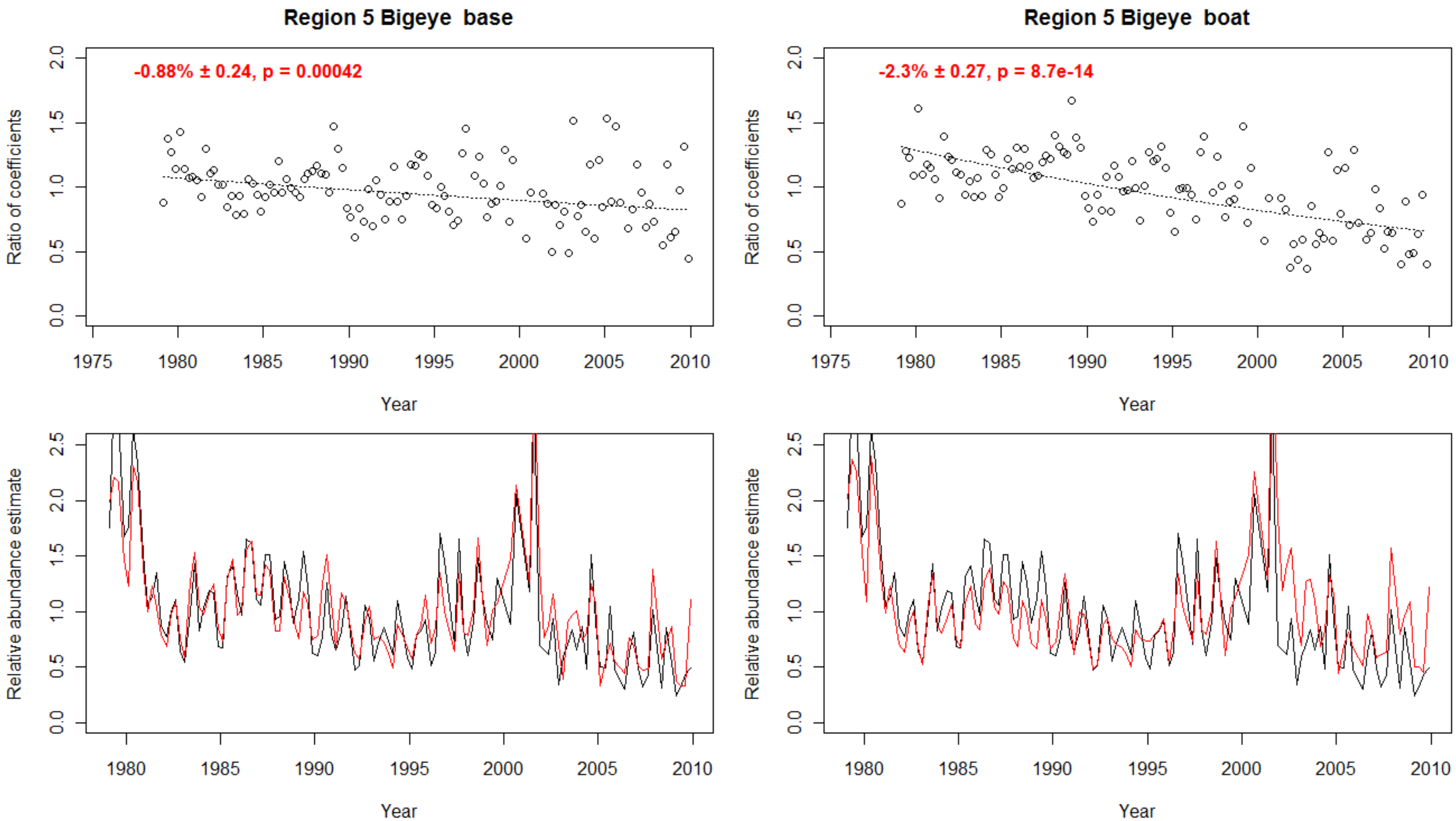

Figure 84: Comparison of standardized delta lognormal indices from operational data (red) and the same data aggregated (black) for region 5. The figures on the left compare indices from aggregated data with indices estimated from operational data using the same covariates. On the right aggregated indices are compared with indices estimated from the operational data with a model that included a vessel effect.

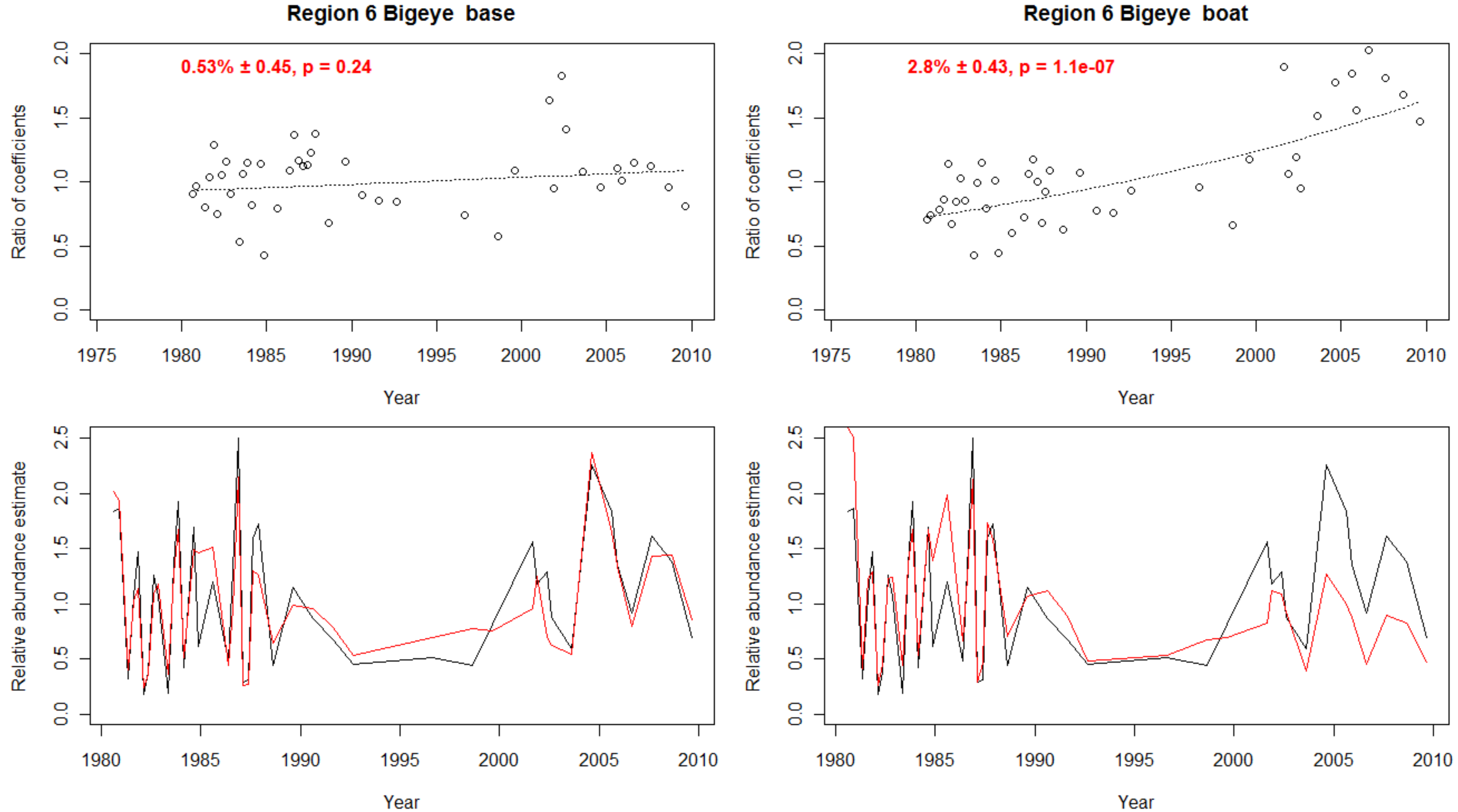

Figure 85: Comparison of standardized delta lognormal indices from operational data (red) and the same data aggregated (black) for region 6. The figures on the left compare indices from aggregated data with indices estimated from operational data using the same covariates. On the right aggregated indices are compared with indices estimated from the operational data with a model that included a vessel effect.

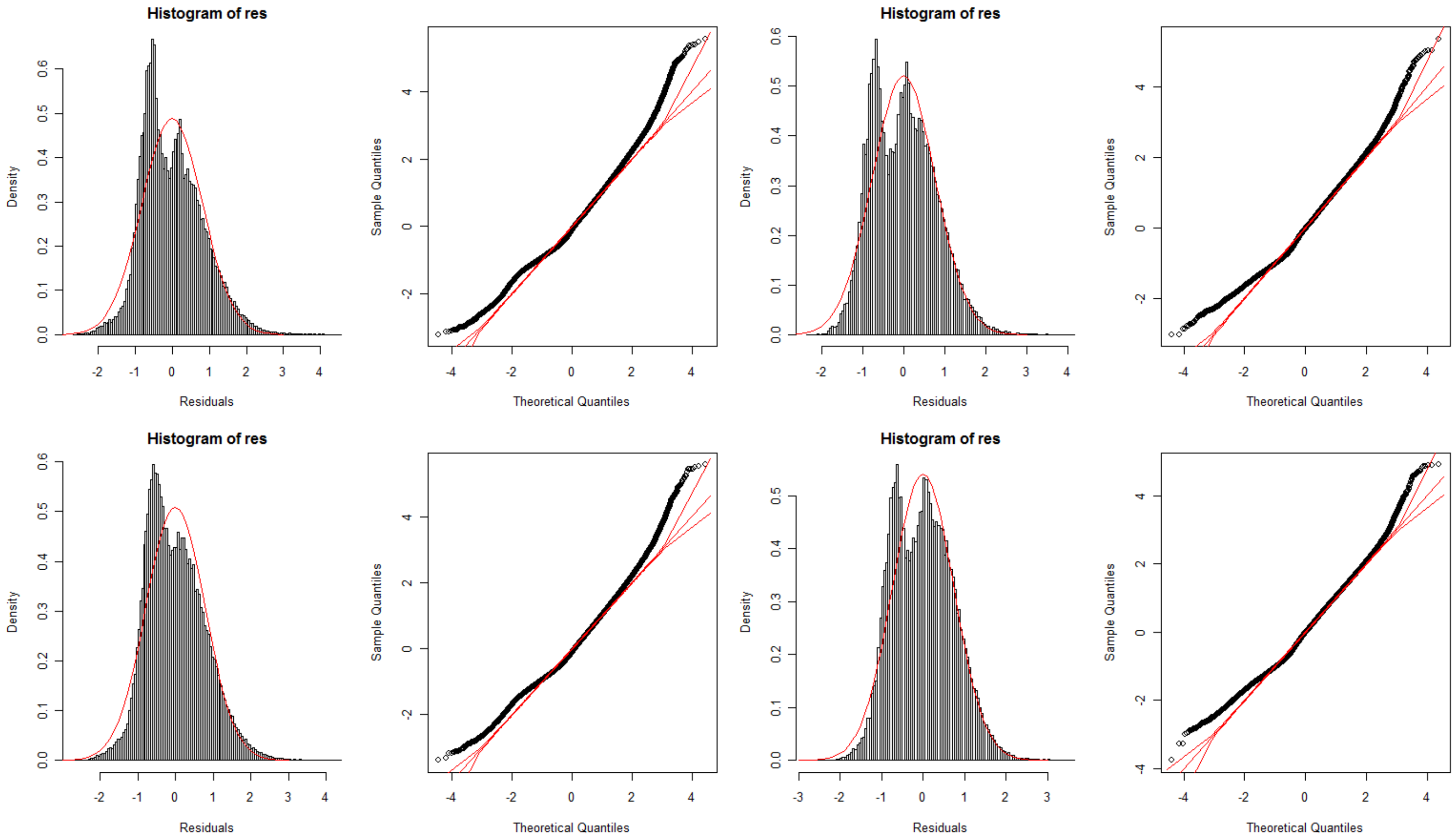

Figure 86: Residual plots for yellowfin in region 1 (left) and region 2 (right). Density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

[Type text]

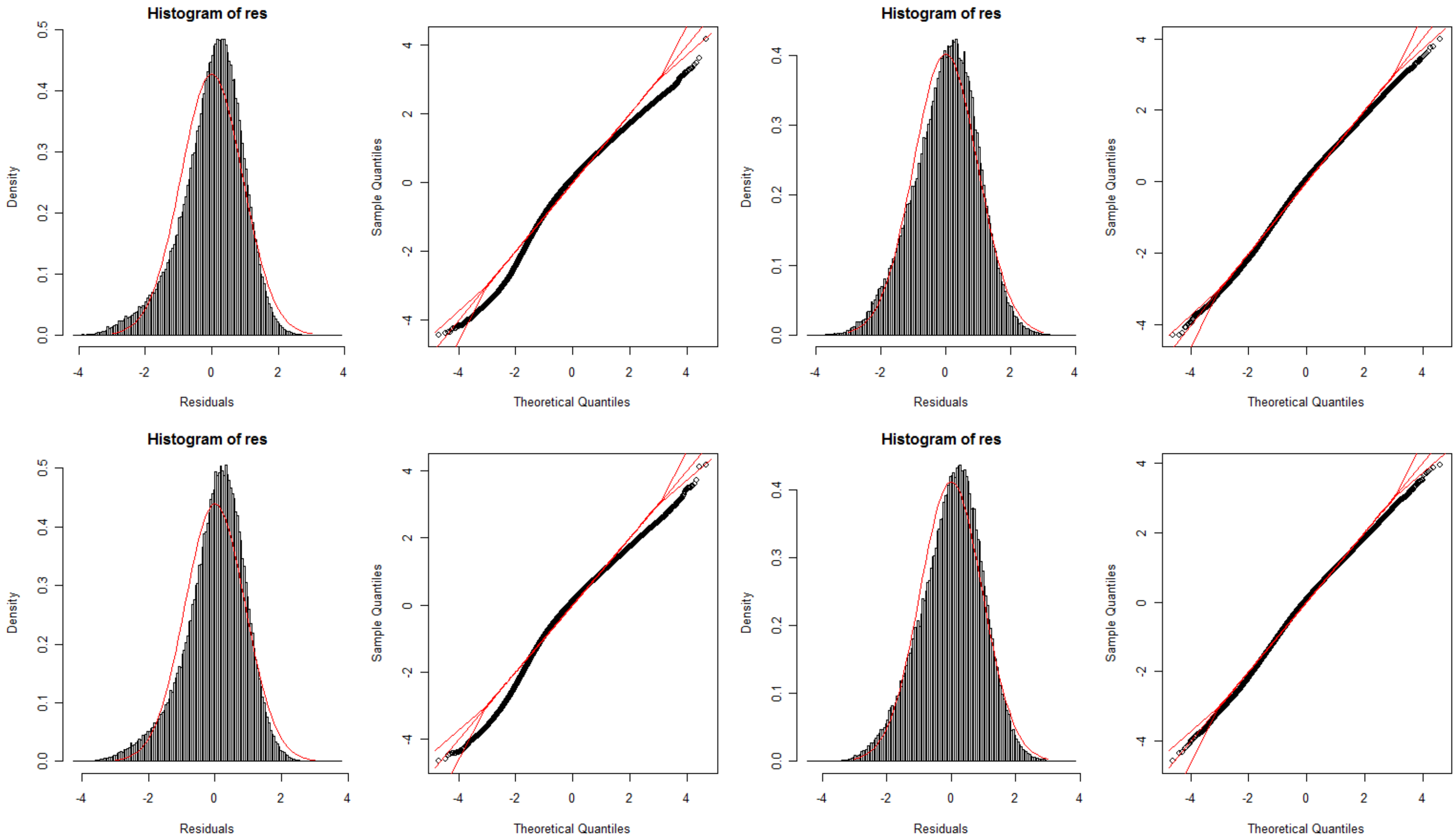

Figure 87: Residual plots for yellowfin in region 3 (left) ad region 4 (right). Density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

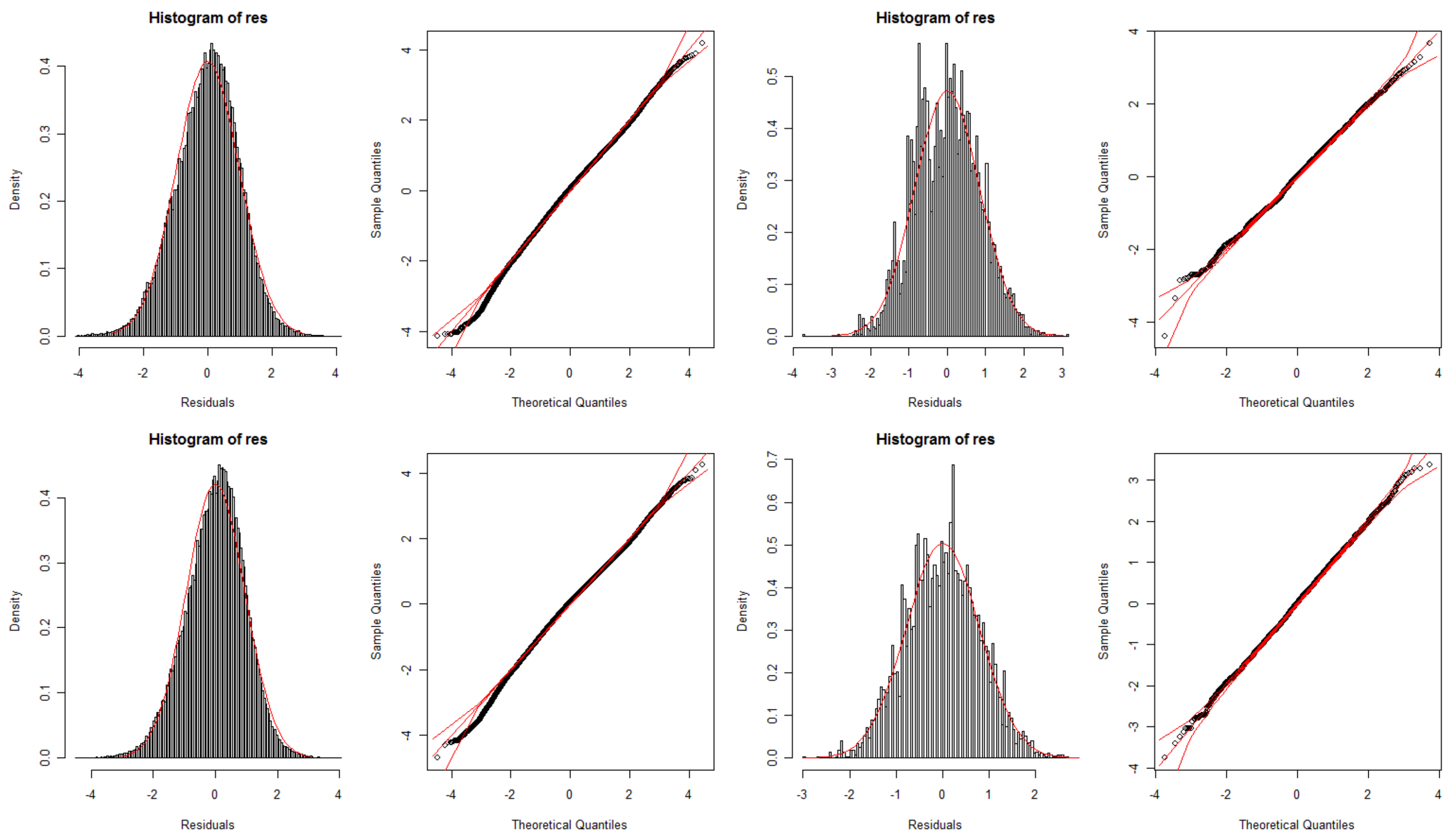

Figure 88: Residual plots for yellowfin in region 5 (left) and region 6 (right). Density histograms (left) of residual sizes from the GLMs used to estimate the indices (black) using the models with (top) and without(bottom) the vessel effect, compared with a normal distribution with mean zero and the same standard deviation as the residuals. Q-Q plots (right) of residuals, compared with the expected distributions assuming normality, with median and ± 2SD's.

[Type text]

9. Appendix 1: R functions for data cleaning and preparation

```
# Data cleaning
dataclean <- function(dat,checktg=F,allHBF=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,]
  dat[dat$fishingcat =="0",]
  dat <- dat[dat$fishingcat !=".",]
  dat <- dat[dat$fishingcat !="0",]
  dat <- dat[dat$hbf != "  .",]
  dat$hbf <- as.numeric(dat$hbf)
  if(allHBF==F) {
    dat[dat$hbf>22,]$hbf <- 22     # pool hbf > 22 into 22
    dat <- dat[dat$hbf > 4,]   # remove swordfish targeting in R1 and R2
    }
  dat$ncrew <- as.numeric(dat$ncrew)
  if(checktg) dat <- dat[dat$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$yrqtr < 2010,]
dat <- dat[dat$reg >0 & dat$reg <7,]
return(dat)
}
```

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