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CPUE STANDARDISATION FOR BIGEYE AND YELLOWFIN TUNA IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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Executive summary

Indices of catch per unit effort are presented for bigeye and yellowfin tuna in the WCPO from 1952 to 2007, based on analyses of Japanese distant water longline data. Several improvements have been made to the methods for estimating indices of abundance for the bigeye and yellowfin stock assessments. These changes affected the CPUE trends, which for yellowfin declined slightly less than based on the 2007 method, and for bigeye declined significantly less than based on the 2008 method.

In addition, exploratory analyses suggested that work is needed in several areas to improve the indices. First, targeting is a particularly important area, and one that cannot be dealt with effectively when using aggregated data. Cluster analysis can be used to separate datasets into appropriate subsets, but the minimum requirement is data at the trip level. Second, the indices appeared to be affected by the aggregation process. The significance of this is not yet clear, so further analyses of both the operational and the aggregated data will be necessary. Third, preliminary results suggest that fishing power has increased in region 3, particularly for yellowfin tuna. Since this analysis only considered changes in fishing power due to changes in vessels, and ignored factors such as the equipment used on vessels, it is likely to be a minimum rate of increase. Further analyses of these data will also be necessary, given potential confounding between vessel effects and other factors, such as changing fishing grounds and HBF through time. Finally, work is required on several issues not explored in these analyses, such as causes of the large medium-term changes in the region 3 CPUE of both species; the evidence that (within regions) areas of high CPUE have been depleted more than areas of low CPUE; and reasons why nominal indices decline at the same rate or more steeply than standardized indices in regions 3 and 4.

1. Introduction

Indices of standardized catch per unit effort (CPUE) are a critical input into stock assessments carried out using integrated analysis methods (Fournier and Archibald 1982; Maunder 2003), such as Multifan-CL (Fournier *et al.* 1998). Indices for previous assessments have been prepared using generalized linear modelling and habitat-based standardization of data from the Japanese longline fleet (Langley 2003; Bigelow *et al.* 2004; Langley *et al.* 2005). Indices are required for the 2009 yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) stock assessments (Langley *et al.* 2009; Harley *et al.* 2009). I describe the methods used to prepare these indices, and investigate changes to the analysis methods previously used (q.v. recommendations by Hoyle *et al.* 2007).

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 (Figure 1 to Figure 3) represent the principal indices of relative abundance for that part of the biomass that is exploited by longline fisheries. These data are collected by the Japan Fisheries Agency and reported in an aggregated state, as described below. During the history of the fishery there have been systematic changes in the operation of the Japanese longline fleet that are likely to have influenced the catchability of the two species. These include changes in the geographic area fished (Figure 4); changed configuration of the longline gear, most notably increases in the number of hooks between floats (HBF); and changes in the principal target species. In recent years Japanese fishing effort has declined considerably, as has the area fished.

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). 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 changing target 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. A variety of techniques have been used in the yellowfin and bigeye CPUE standardizations in an attempt to adjust for the effects of targeting changes. For example, the CPUE or proportion of 'other' species (i.e. species not the subject of the analysis) have been included in the GLM, either at the nominal level or categorized. In this report the effects on the indices of various approaches are compared, and a new approach recommended.

Aggregated data provide limited information on the factors that affect CPUE. The aggregation can conceal the effects of important factors, which will bias the resulting indices. For example, the aggregation 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. 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 (Langley 2007). In this report, CPUE indices from aggregated and operational data are compared.

The efficiency of some aspects of longline fishing has undoubtedly increased since the 1950's due to advancing technology. 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 previous assessments, hypothetical effort creep scenarios have been examined when estimating the structural uncertainty associated with the model (Hampton *et al.* 2005a; Langley *et al.* 2008; Hoyle *et al.* 2008). 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 identity of the vessels fishing.

In summary, this report documents the analyses undertaken to provide indices for the 2009 stock assessments, including modifications made to the GLM approach. It examines the methods currently used, makes changes in order to improve them, and suggests areas in which further improvements might be made. Many of the analyses presented are preliminary, and all issues require further investigation.

2. Methods

The essentials of the method were as summarised in Langley et al (2005). Catch and effort data for the Japanese longline fleet for the period 1952 to 2007 are available aggregated by year, month, and spatial cell. Prior to 1966, the data are available at a five degree spatial resolution, i.e., aggregated by spatial cells of dimensions five degrees of latitude and longitude. From 1966, data are available at one degree spatial resolution. For years 1975 onwards, data are also stratified by the gear configuration of the longline (number of hooks between floats, HBF). In this analysis I assumed that all longline sets before 1975 had similar gear configuration to that deployed during the early 1970s, i.e., shallow sets deploying five HBF. Catch was recorded as the number of fish caught and effort as the number of hooks set.

The 2009 MFCL stock assessment models for bigeye and yellowfin were stratified into six regions (1–6). The catch (bigeye and yellowfin catch in number) and effort (in hundreds of hooks) data were aggregated by year, quarter, five degree latitude and longitude cell, and HBF category. Spatial cells with few records (five or less) were excluded from the data set.

With separate analyses for each species and region, GLM indices were calculated by quarter for 1952–2007. The dependent variable in the GLMs was the natural logarithm of the catch (in numbers). Records with zero catch of the species of interest were excluded, but these were few given the high level of aggregation. The GLMs all had an equivalent model structure, including the categorical variables year/quarter, latitude/longitude, and the HBF, and the number of hooks as a continuous variable.

For yellowfin, the natural logarithm of the catch (in numbers) per year-quarter (*t*), and stratum (*st*) defined by five degree latitude/longitude (LL) cell and HBF was predicted as follows.

$$\log\left(\mathrm{yft}_{t,st}\right) = c + \alpha_t + \beta_{LL} + f\left(\mathrm{HBF}_{t,st}\right) + g\left(\log\left(\mathrm{hooks}_{t,st}\right)\right) + h\left(\mathrm{tg}_{t,st}\right) + \epsilon_{t,st}$$

The function $f(HBF_{t,st})$ estimated the parameters γ_{HBF} of the ordered HBF values by fitting a third-order polynomial. Similarly $g\left(\log(\text{hooks}_{t,st})\right)$ fitted a cubic spline with 10 parameters to $\log(\text{hooks}_{t,st})$, and $h(\text{tg}_{t,st})$ fitted a third-order polynomial to the target indicator variable $tg_{t,st}$ (defined below). Error $\epsilon_{t,st}$ was assumed to be normally distributed. The equivalent GLM was applied to predict region-specific bigeye catches $bet_{t,st}$. The CPUE index was the exponentiated year/quarter coefficients (a) from the region-specific GLM. The relationships between predicted catch and the dependent variables included in the GLM were examined for each model. Regional scaling factors were estimated and applied using approaches described previously for yellowfin (Hoyle and Langley 2007) and bigeye (Langley *et al.* 2005).

Several changes were made from the models used in previous years. First, log(hooks) was used instead of hooks. Second, a new target-species indicator was used, as described below.

2.1. Targeting

In previous years, in addition to the third-order polynomial on HBF, adjustment for targeting was applied by fitting (as a third-order polynomial) a function of the catch of the 'other' species (i.e., catch of yellowfin when estimating bigeye CPUE, and vice versa). Several functions were applied in different years. The catch rate ($\text{yft}_{t,st}/\text{hooks}_{t,st}$) was used for the most recent yellowfin assessment in 2007 (Langley *et al.* 2007), and the catch as a proportion of the reported catch in the stratum ($\text{yft}_{t,st}/(\text{yft}_{t,st} + \text{bet}_{t,st} + 1)$) was used for the most recent bigeye assessment in 2008 (Langley *et al.* 2008).

Either of these targeting options may cause problems (Hoyle *et al.* 2007). Catch rate of the other species is affected not only by targeting but also by local abundance, and stock assessments indicate that abundances of both species have seen large changes through time. Therefore, using the catch rate of the other species may introduce a spurious time trend into the abundance index of the species of interest. Using catch of the other species as a proportion of the reported catch is even more problematic, since this results in a model with catch of the species of interest on both sides of the equation.

For this study a new approach was introduced (the CPUE offset method), which adjusted the target species indicator based on the CPUE of the other species for the other species abundance at time *t*. The catch rate of the other species was offset by its abundance as estimated from the most recent stock assessment: $\frac{\text{yft}_{t,st}}{\text{hooks}_{t,st}} \cdot \frac{1}{\text{Nyft}_t}$, where Nyft_t is the predicted number of yellowfin available for exploitation in the relevant regional longline fishery at time t.

Results from the three approaches described above were compared.

2.2. Use of aggregated data

The implications of using aggregated data to estimate indices of abundance were examined by fitting a GLM to operational (set by set logsheet) catch and effort data, and comparing the results with the equivalent analysis when the same data had been aggregated.

Operational catch and effort data were obtained from the regional fisheries database held by the Secretariat of the Pacific Community's Oceanic Fisheries Programme (SPC-OFP). Foreign longline vessels, principally the fleets of Japan, Korea, and Taiwan, are required to provide operational level catch and effort reports of fishing activity in the waters of national jurisdiction of Pacific Island countries. This information is reported via the South Pacific Regional Longline Logsheet form, which records vessel details, date and time of set, gear configuration (number of hooks and hooks-between-floats), and the catch (number and weight) of the main species caught (albacore, bigeye, yellowfin, striped marlin, blue marlin, and black marlin and sharks and other species). Copies of the logsheets are provided to SPC-OFP and entered in the regional fisheries database.

For these analyses only those data submitted by the Japanese distant water longline fleet (JP-DW) were used. This fleet principally fishes in the western equatorial waters of the WCPO, including the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), Palau, and the Solomon Islands. These analyses used data only for region 3 of the bigeye and yellowfin stock assessments. Data from 1980 to 2007 were extracted.

Up to 16GB of computer memory was required to analyze a full dataset of this size, so most analyses were carried out on data subsets. Analyses were applied to a) all 10 × 10 degree subareas of region 3, and b) random subsamples of 100 000 records from the 287 000 in the dataset.

Standardization was carried out using the following model:

$$\log\left(\frac{\mathrm{yft_{set}} + 0.5}{\mathrm{hooks_{set}}}\right) = \mathrm{c} + \alpha_{\mathrm{t}} + \beta_{\mathrm{cell}} + \mathrm{f(HBF_{set})} + \mathrm{h(tg_{set})} + \epsilon_{\mathrm{set}}$$

In this case the $\mathrm{f(HBF_{set})}$ function used a sixth-order polynomial.

I also applied a delta lognormal model (Dick 2006; Stefansson 1996; Hoyle and Maunder 2006). This model uses a binomial distribution for the probability *w* of catch being zero and a probability distribution *f(y)* for non-zero catches. An index was estimate for each year-quarter, which was the product of the back-transformed least-squares means for the two model components, $(1 - w).E(y|y \neq 0)$. The variance of the likelihood function was weighted by effort.

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

w = g(Year*quarter, latitude*longitude, hooks between floats, effort)

f(y) = h(Year*quarter, latitude*longitude, hooks between floats)

The operational data were then aggregated by five degree square, quarter, and HBF - the strata by which data used in CPUE standardization for the stock assessments are aggregated.

The following model was fitted to the aggregated data, with the functions f and g taking the same form as for the operational data. Strata with zero catch in the aggregated data were removed from both the operational and the aggregated data.

$$\log\left(\frac{\mathrm{yft}_{t,st}}{\mathrm{hooks}_{t,st}}\right) = c + \alpha_t + \beta_{cell} + f(\mathrm{HBF}_{t,st}) + h(\mathrm{tg}_{t,st}) + \epsilon_{t,st}$$

The investigated approaches to targeting are identified in Table 1.

Table 1: Targeting methods investigated using both aggregated and operational (set by set) data.

Targeting method	Equation	Function	Plot labels	
			Aggregated	Operational
None			Agg just HPB	Op none
CPUE	$\frac{yft}{hooks}$	Third-order polynomial	Agg yftCPUE	Op CPUE
Proportion	$\frac{yft}{yft + bet + 1}$	Third-order polynomial	Agg YFTprop	NA
CPUE offset	$\frac{yft}{hooks} \cdot \frac{1}{Nyft}$	Cubic spline, 4 df	Agg yftCPUEoff	Op offset

The indices estimated for each year and quarter were compared by dividing one by the other and fitting a linear regression to the ratio. 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.

2.3. Effort creep.

Effort creep, or the progressive increase in fishing power through time, was investigated as follows. The approach was applied to both bigeye and yellowfin, separately for each 10 × 10 degree square with data on at least 2000 sets in region 3, including only vessels that had fished at least 25 quarters. First, a model was fitted to the operational data with the model described above, using the CPUE offset targeting approach.

$$\log\left(\frac{\mathrm{yft}_{set} + 0.5}{\mathrm{hooks}_{set}}\right) = c + \alpha_t + \beta_{cell} + f(\mathrm{HBF}_{set}) + h(\mathrm{tg}_{set}) + \epsilon_{set}$$

Then a term for individual vessel was added.

$$\log\left(\frac{\mathrm{yft}_{set} + 0.5}{\mathrm{hooks}_{set}}\right) = c + \alpha_t + \beta_{cell} + f(\mathrm{HBF}_{set}) + h(\mathrm{tg}_{set}) + \gamma_{vessel} + \epsilon_{set}$$

Temporal indices of abundance were calculated from the results of both models. The ratio of the two indices was calculated for each time interval, the ratios plotted and a linear regression fitted. The slope of the regression represented the average annual rate of change in fishing power (non-compounding) 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 probability (p) of obtaining the observed (or steeper) slope if there was in fact no relationship. Regressions assumed incorrectly that ratio values were estimated without error, so statistically significant non-zero slope was assumed at p=0.005 rather than 0.05.

Finally, the model was run on a computer with 16GB of memory and applied to all the operational data for region 3, for vessels that had fished for at least 10 quarters. The analysis was tested for the effects of the adjustment for zeros (i.e., adding 0.5) by rerunning the analysis on the full dataset using a delta lognormal model.

3. Results

3.1. Indices

Comparing models using AIC suggested that using log(effort) rather than effort resulted in much better fit to the data (Table 2 and Table 3). The resulting relationship between catch and effort was close to linear (Figure 6), which suggests that models may use catch divide by effort as the response variable without substantial loss of accuracy.

Table 2: Akaike Information Criteria (AIC) by region for three models of bigeye CPUE. The model used in 2008 was changed progressively by first replacing effort with log(effort), and then by changing the targeting indicator.

Region	2008 approach (effort + YFT proportion	Log(effort)	YFT offset
1	56320	41023	42210
2	30985	22108	23784
3	68512	38034	49778
4	57976	31021	36461
5	19334	14760	16262
6	8471	6576	7125

Table 3: Akaike Information Criteria (AIC) by region for three models of yellowfin CPUE. The model used in 2007 was changed progressively by first replacing effort with log(effort), and then by changing the targeting indicator.

Region	2007 approach (effort + BET CPUE)	Log(effort)	BET offset
1	50206	42529	42220
2	27162	23111	23010
3	75889	55029	54879
4	59302	46957	46858
5	21009	16858	16552
6	8268	6991	6973

In comparison with the approaches used for the previous assessments, the targeting indicator based on the CPUE of other species with an offset for abundance (CPUE offset) fitted the data better than the indicator CPUE using alone (see Table 3), but worse than the indicator that used catch proportions (Table 2). However, the indicator using catch proportions had the species of interest on both sides of the equation, so the good fit probably resulted from confounding rather than better indication of targeting.

For bigeye, the switch from effort to log(effort) produced indices that in general declined less (Figure 5 and Figure 6). Using the yellowfin CPUE with the abundance offset instead of yellowfin proportion changed the overall shape of the trends in a non-linear way, and resulted in trends that in general declined less (Figure 7 and Figure 8). The combined effect of both model changes produced CPUE indices that declined less than those produced using the method used in 2008, particularly in region 4 (Figure 9 and Figure 10). Surprisingly, the trends in regions 3 and 4 were quite close to nominal CPUE (Figure 11 and Figure 12).

Residuals from the 2009 GLM indicated positive kurtosis (i.e., distributions with a higher peak and longer tails than a normal distribution with the same mean) (Figure 13), and slight negative skewness (Figure 14). The negative residuals were very few in number and appear unlikely to bias the results of the model. The residuals generally show quite a good normal distribution for a GLM from fisheries data.

The combined bigeye indices, adjusted by regional scaling factors, are shown in Figure 15.

For yellowfin, the switch for effort to log(effort) also resulted in indices that declined less (Figure 17 and Figure 18). Using the bigeye CPUE with the abundance offset instead of bigeye CPUE (which was used for the 2007 assessment) had a minor effect on the indices, with more change outside tropical regions 3 and 4 (Figure 19 and Figure 20). Seasonal variation increased, and the indices declined a little more. The combined effect of both changes was CPUE indices that declined slightly less than indices estimated using the 2007 approach (Figure 21 and Figure 22). The trends in regions 3 and 4 declined considerably less than nominal CPUE (Figure 23 and Figure 24).

Residuals from the 2009 GLM for yellowfin were very similar to those for bigeye, with positive kurtosis (Figure 25), and some negative skewness (Figure 26).

The combined yellowfin indices, adjusted by regional scaling factors, are shown in Figure 27.

3.2. Targeting and aggregated data

Results using different targeting indicators with both operational and aggregated data are shown in Figure 28 and Figure 29. With operational data, the targeting indicators based on CPUE had only minor, and similar, effects on abundance indices, changing the trend by 0.3 – 0.4% per year. There was also little difference between the CPUE and the CPUE-offset targeting indicators when applied to aggregated data. However, the indicator based on catch proportion changed the abundance trend substantially.

The overall trends of the indices from the aggregated data were similar to those from the operational data, but showed considerable variability and different short-term trends from the operational data. These trends are notable given that the aggregated data were created from the operational data.

The results from the delta lognormal model applied to operational data were compared with those from the other models applied to operational and aggregated data. For bigeye, the long term trend was similar from the delta lognormal model and the equivalent operational and aggregated models (those without a catch-based targeting indicator). Results of the two operational data approaches diverged when there were more zeroes in the operational data (Figure 30 and Figure 31). A trend was apparent early in the time series when there were a lot of zeroes in the operational data.

For yellowfin, trends from the delta lognormal method showed slightly less decline than the equivalent operational and aggregated models (Figure 32). As with bigeye, short-term trends were apparent in the ratios of results of the operational delta approach and the equivalent aggregated approach.

3.3. Fishing power

Logsheets were available in the database for approximately 1400 vessel identity codes (vessel ID's), for fishing effort by Japanese distant water longliners in region 3 between 1980 and 2007 (Figure 33). Over two thirds of these vessel ID's first occurred in 1980-1982. The appearance rate of new vessel ID's was slower but quite stable from 1985 to about 1995, but slowed thereafter until 2006. No new vessel ID's appeared in 1998 (Figure 34).

Logsheets were reported against some vessel ID's for almost the entire period from 1980 to 2007, but some significant gaps occurred (Figure 35). Gaps in logsheets for a number of vessels began in 2000. The number of logsheet records declined steeply from its high in the 1980's, and was very low in 2000 before rising slightly (Figure 36, left panel). The number of unique vessels ID's also reached a low in 2000 (Figure 36, right panel).

For the analyses of bigeye CPUE by 10 × 10 area within region 3, significant positive changes in fishing power were observed in seven of nine squares, at between 0.36 and 0.98 % per year, with one outlier (with small sample size) at 6% per year (Figure 37). The effects in two squares were not significant.

For the yellowfin CPUE analyses, significant positive trends were estimated for effort creep of yellowfin in five of nine squares, at between 0.9 and 2.2% per year (Figure 38). Significant negative effects were observed in the 2 squares surrounding Palau and in the western FSM. The patterns in these squares were nonlinear but averaged -2.0 and -1.0% per year. Non-significant effects were observed in two squares.

Analysis of bigeye CPUE for the whole of region 3, based on vessels that had fished at least 10 quarters, indicated fishing power increasing at an average rate of 0.5% per year between 1980 and 1998 (Figure 39), representing about a 9% increase. When the period after 1998 was included, the estimated rate of increase declined to 0.08% per year.

Analysis of yellowfin CPUE using the same approach indicated fishing power increasing at an average rate of 1.4% per year from 1980 to 1998, representing an increase of about 25%, and at 0.74% per year when the period after 1998 was included (Figure 40).

4. Discussion

Several improvements have been made to the methods for estimating indices of abundance for the bigeye and yellowfin stock assessments. These changes affected the CPUE trends, which for yellowfin declined slightly less than based on the 2007 method, and for bigeye declined significantly less than based on the 2008 method.

In addition, exploratory analyses suggested that work is needed in several areas to improve the indices. First, targeting is a particularly important area, and one that cannot be dealt with effectively when using aggregated data. Cluster analysis can be used to separate datasets into appropriate subsets, but the minimum requirement is data at the trip level. Second, the indices appeared to be affected by the aggregation process. The significance of this is not yet clear, so further analyses of both the operational and the aggregated data will be necessary. Third, preliminary results suggest that fishing power has increased in region 3, particularly for yellowfin tuna. Since this analysis only considered changes in fishing power due to changes in vessels, and ignored factors such as the equipment used on vessels, it is likely to be a minimum rate of increase. Further analyses of these data will also be necessary, given potential confounding between vessel effects and other factors, such as changing fishing grounds and HBF through time. Finally, work is required on several issues not explored in these analyses, such as causes of the large medium-term changes in the region 3 CPUE of both species; the evidence that (within regions) areas of high CPUE have been depleted more than areas of low CPUE; and reasons why nominal indices decline at the same rate or more steeply than standardized indices in regions 3 and 4.

Three changes were made to the methods used for preparing the indices. First, log(effort) rather than effort was used as a predictor, which affected the abundance trends. Models using log(effort) fitted the data considerably better, which is unsurprising given that we typically expect a linear relationship between effort and catch. Second, the indicator based on species proportions, previously used for bigeye, was replaced with one based on CPUE. This change was motivated by confounding in the GLM model, and the change affected abundance trends.

Third, an offset for abundance was added to the indicator based on CPUE of the ‘other’ species. This change made only a small difference. There are some concerns about confounding with this approach as well, since yellowfin abundance trends from the most recent assessment are partly based on yellowfin CPUE indices (using bigeye CPUE as a targeting indicator) from the Japanese DW LL fishery. Nevertheless, the average yellowfin CPUE was clearly higher in 1960 than in 2005, so an ‘other species’-based targeting indicator that takes this change into account should perform better than one that does not. Targeting is to some extent an ‘either-or’ process, so it may be useful in future to make this indicator categorical and fit it as a categorical variable.

However, any targeting indicator based on aggregated data is likely to be problematic, since all effort in a stratum (five degree spatial square by HBF by year-quarter) may use a mixture of fishing techniques, with some proportion of the effort targeting each species. Thus, targeting within a stratum is not an ‘either-or’ process. Stratifying the data by HBF does increase the probability that each stratum will target one species, but HBF does not explain targeting completely. For example, oceanographic (and hence spatial) variation interacts with HBF, and vessels may change their fishing behaviour according to the local oceanography.

The over-riding issue is the effect on the catch rate of unknown changes in fishing methods. The data available for analysis are quite limited. Even some of the operational data lack information on many factors that can significantly affect catch rate, such as line type. Aggregation removes further information, leaving only a few variables at coarse spatial and temporal scales.

Given our limited ability to identify targeting in aggregated data, analyses of operational data are preferable. Cluster analysis has the potential to separate effort targeted at different species (Langley 2007; Bigelow and Hoyle 2009), and should be investigated further for bigeye and yellowfin. Biases were also introduced by the process of aggregating the data. These results emphasise the benefits if more comprehensive datasets of operational data become available for analysis. Currently, region 3 is the only region with enough JP LL operational data for a representative analysis.

Results of the fishing power analysis suggest that fishing power in the Japanese DW longline fishery has increased since 1980. This estimate of effort creep represents only the component associated with changing vessel (or vessel ID’s) in the Japanese fleet. It does not include improvements to existing vessels, such as might result from better information from satellite data, better communication between vessels, the widespread adoption of better gear materials such as monofilament and modern stainless steels. It also omits factors such as the effects of changes (increases or decreases) in the expertise of crews and fishing masters.

In general, there appears to have been a higher rate of effort creep for yellowfin tuna than for bigeye in region 3. The nonlinear changes in fishing power in the Palau and western FSM regions may reflect temporal changes in targeting, since a number of vessels have switched to targeting bigeye in this area. The results for region 3 have been applied in the stock assessment. Further analyses are needed in other regions and for other fleets.

A discontinuity in the rate of effort creep occurs in about 1998, but the reasons for this are not clear. The number of logsheets and the number of unique vessels reaches a minimum at this time, and there is also a gap in many vessels’ logsheets. Further investigation is needed, such as examining the distributions of vessel indices for the vessels that report logsheets through this period. Possible explanations include problems in the resolution of the model due to low sample sizes, data problems such as new vessels sharing a vessel ID with an older vessel, significant upgrades to existing vessels in the late 1990’s, changes in reporting methods, and other changes in the Japanese fleet.

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6. Figures

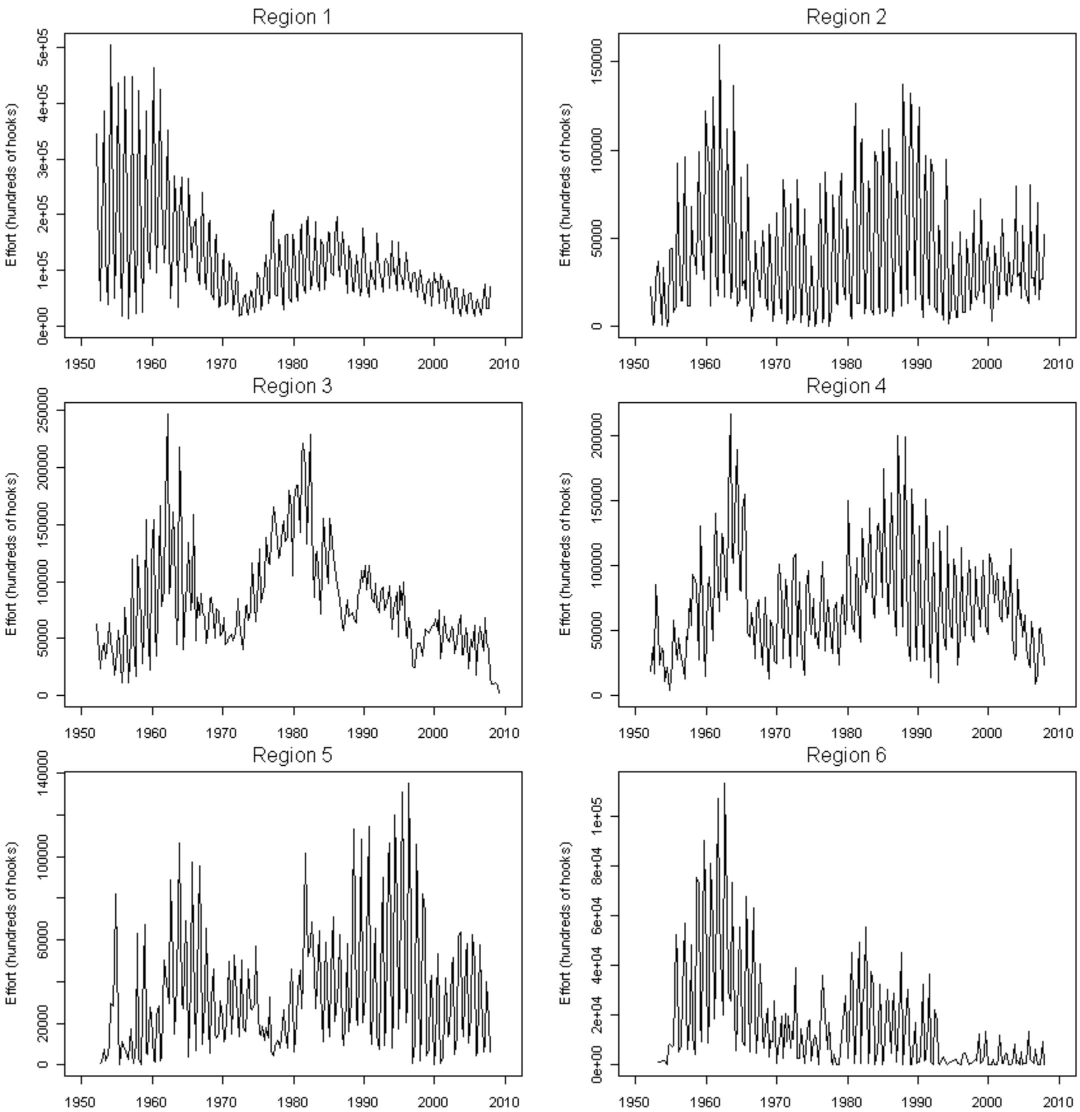


Figure 1: Effort by region and year-quarter by the Japanese distant-water longline fleet, as recorded in the aggregated dataset.

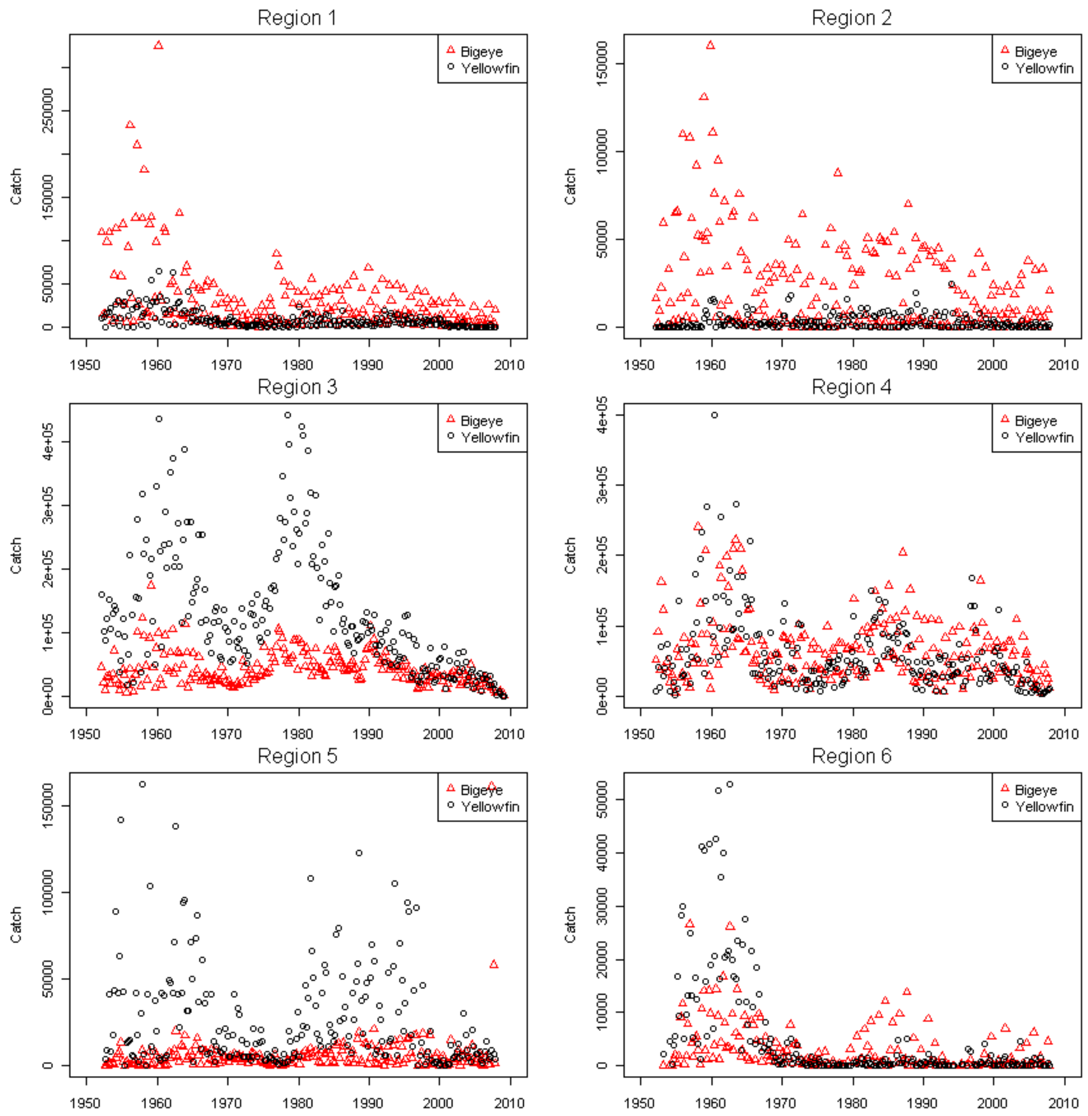


Figure 2: Catch of bigeye and yellowfin tuna by region and year-quarter, by the Japanese distant-water longline fleet, as recorded in the aggregated dataset.

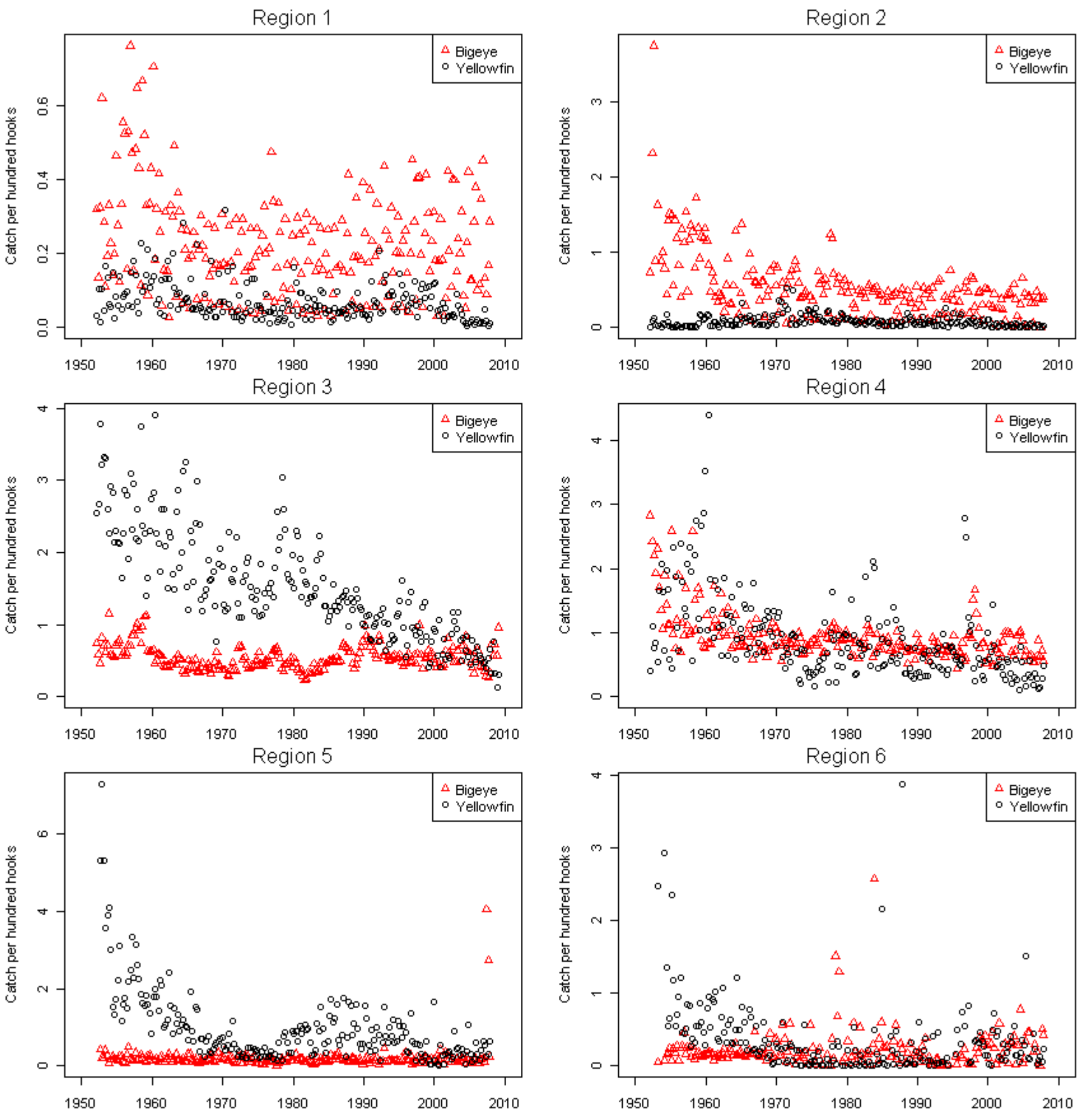


Figure 3: Nominal catch per unit of effort of bigeye and yellowfin tuna by region and year-quarter, by the Japanese distant-water longline fleet, as recorded in the aggregated dataset.

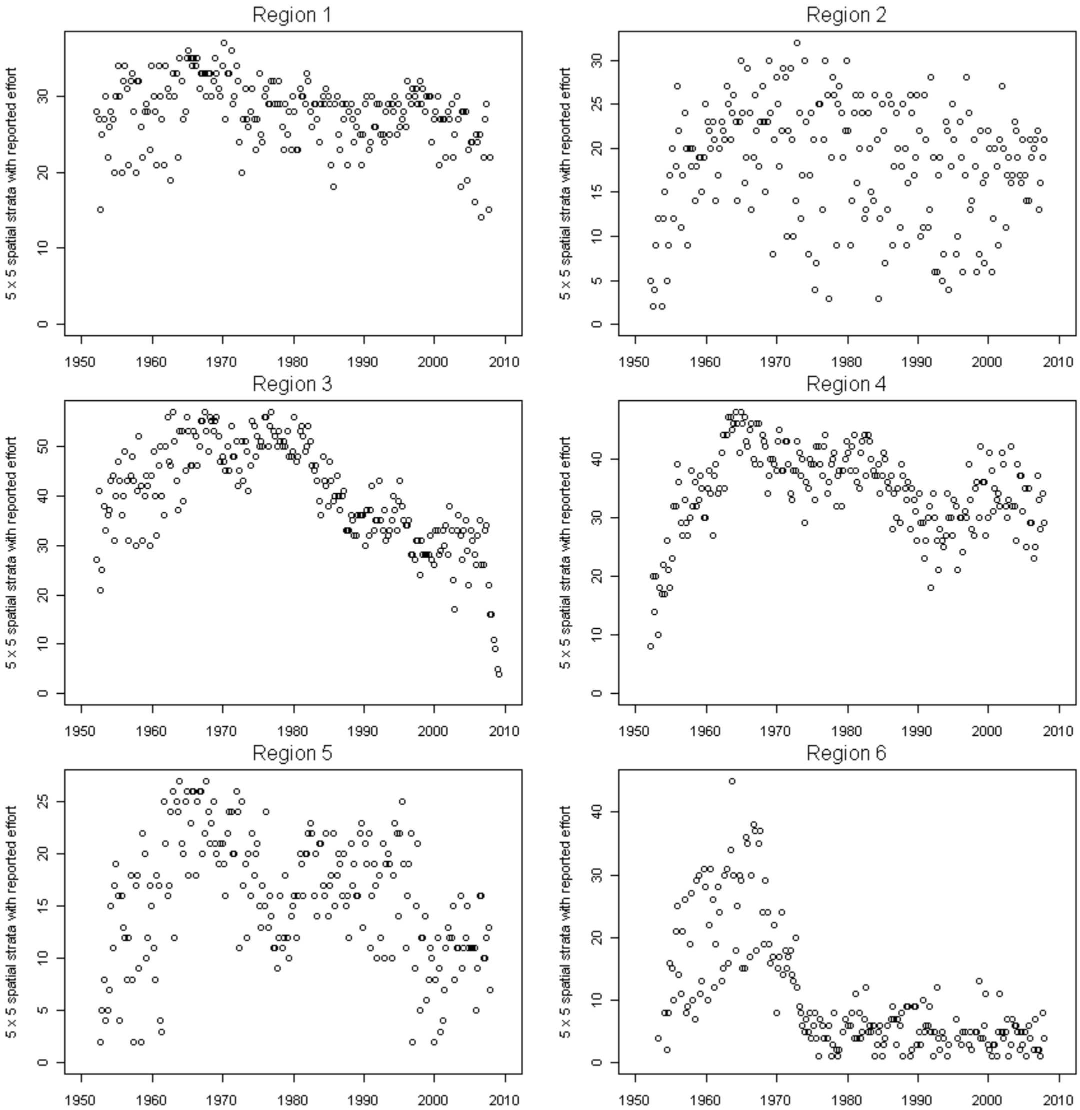


Figure 4: The number of 5° x 5°spatial strata in which effort is reported, by region and year-quarter, for the Japanese distant-water longline fleet, as recorded in the aggregated dataset.

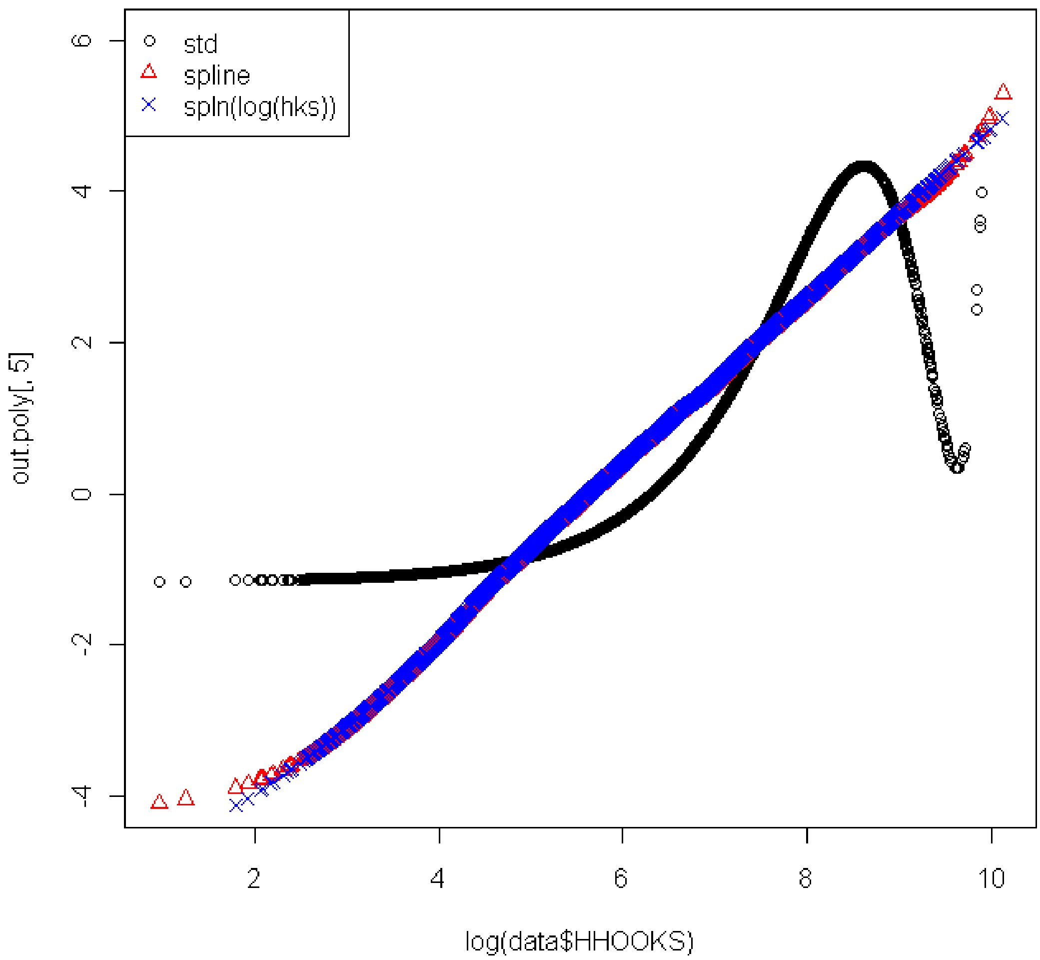


Figure 5: Relationship between log(effort) (hooks) and log(catch) (y axis) for several approaches to modelling effort. These are: a) a third-order polynomial on effort (black circles); b) a cubic spline on effort (red triangles); and c) a cubic spline on log(effort) (blue crosses). The best fit was obtained with the cubic spline on log(effort).

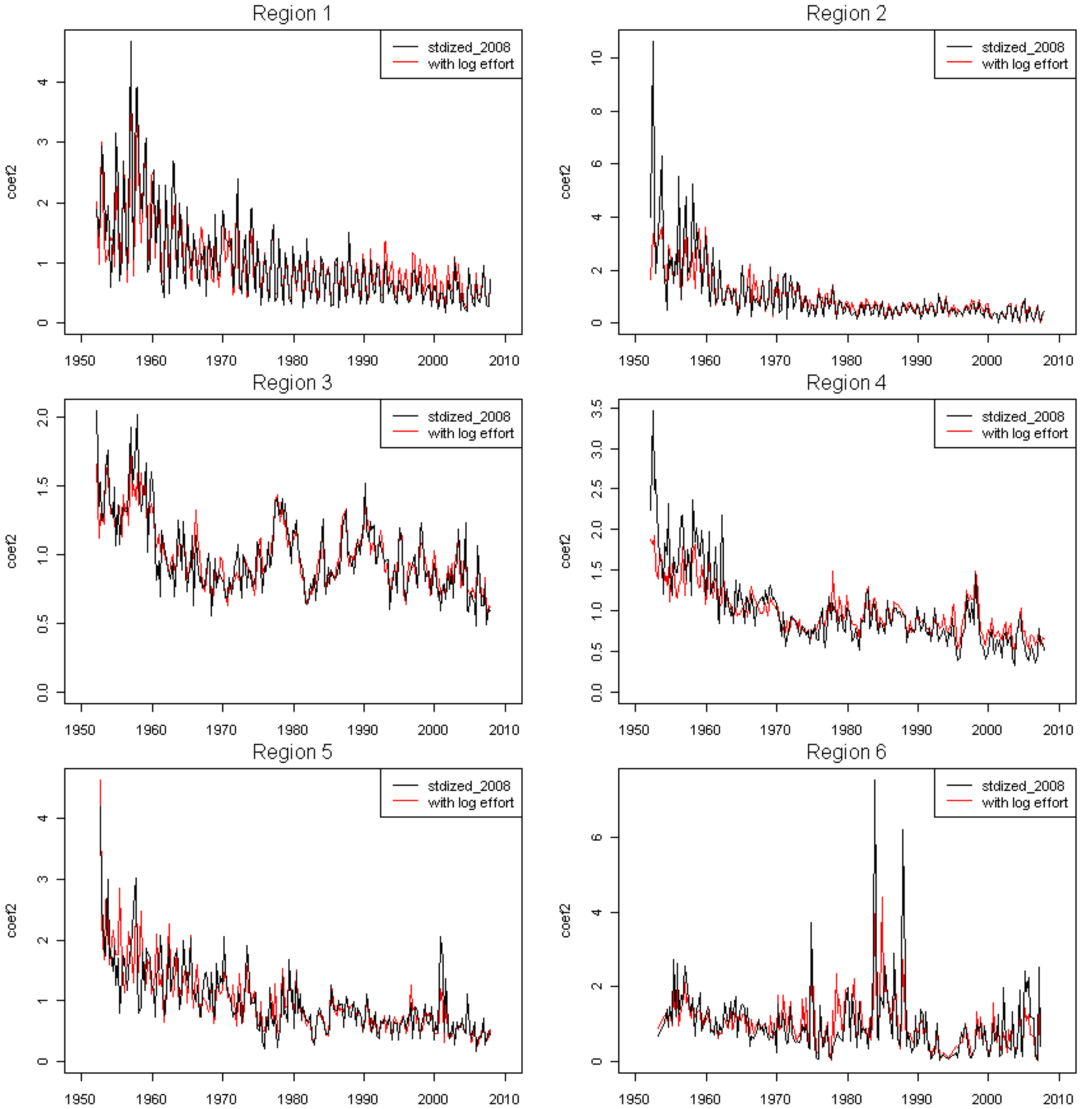


Figure 6: Standardized indices of bigeye CPUE by region, estimated using the 2008 approach (black) and the same approach changed to use log(effort) (red).

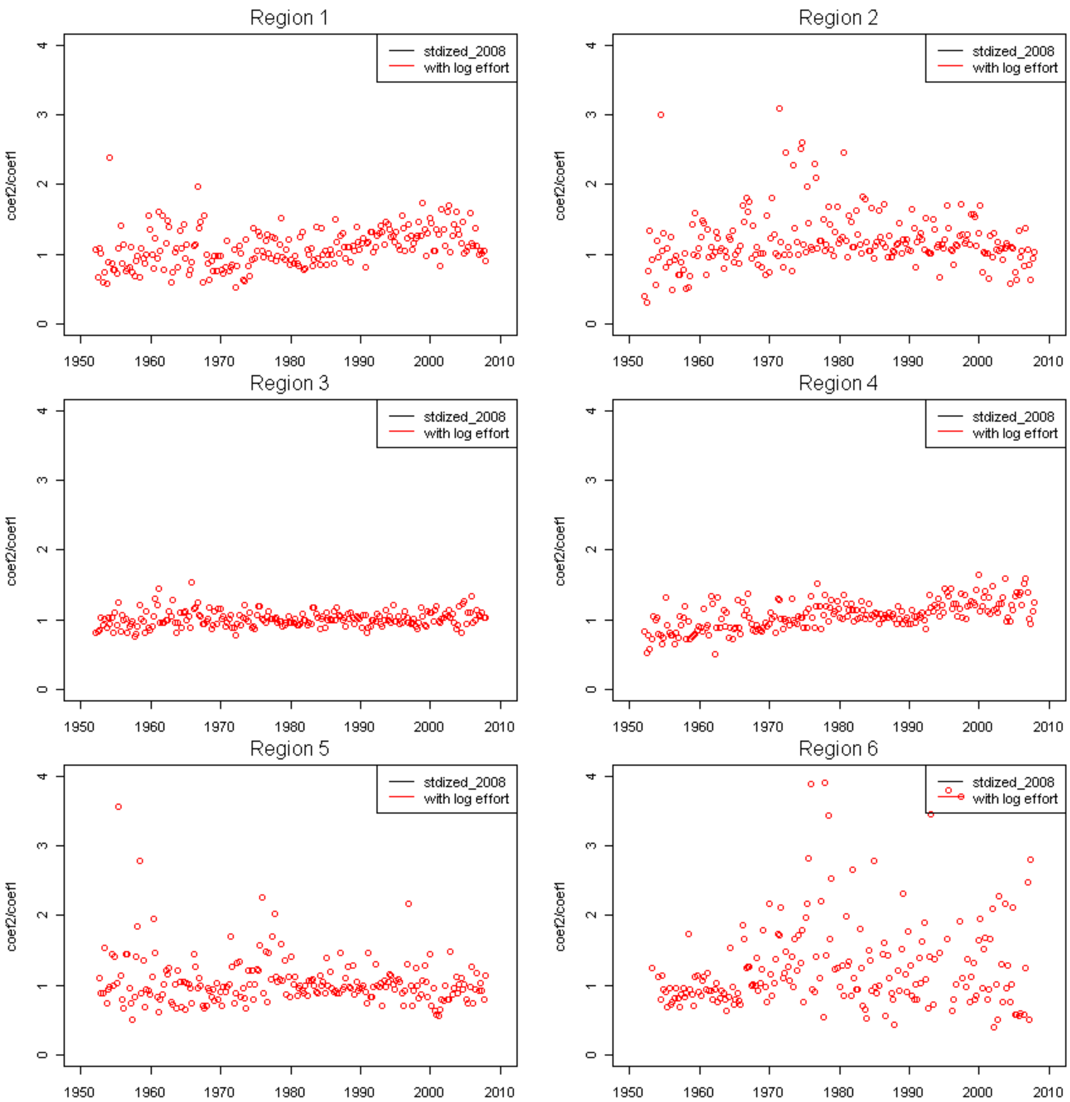


Figure 7: Ratios (2008 approach but with log(effort) vs 2008 approach) of bigeye CPUE indices, by year-quarter and region.

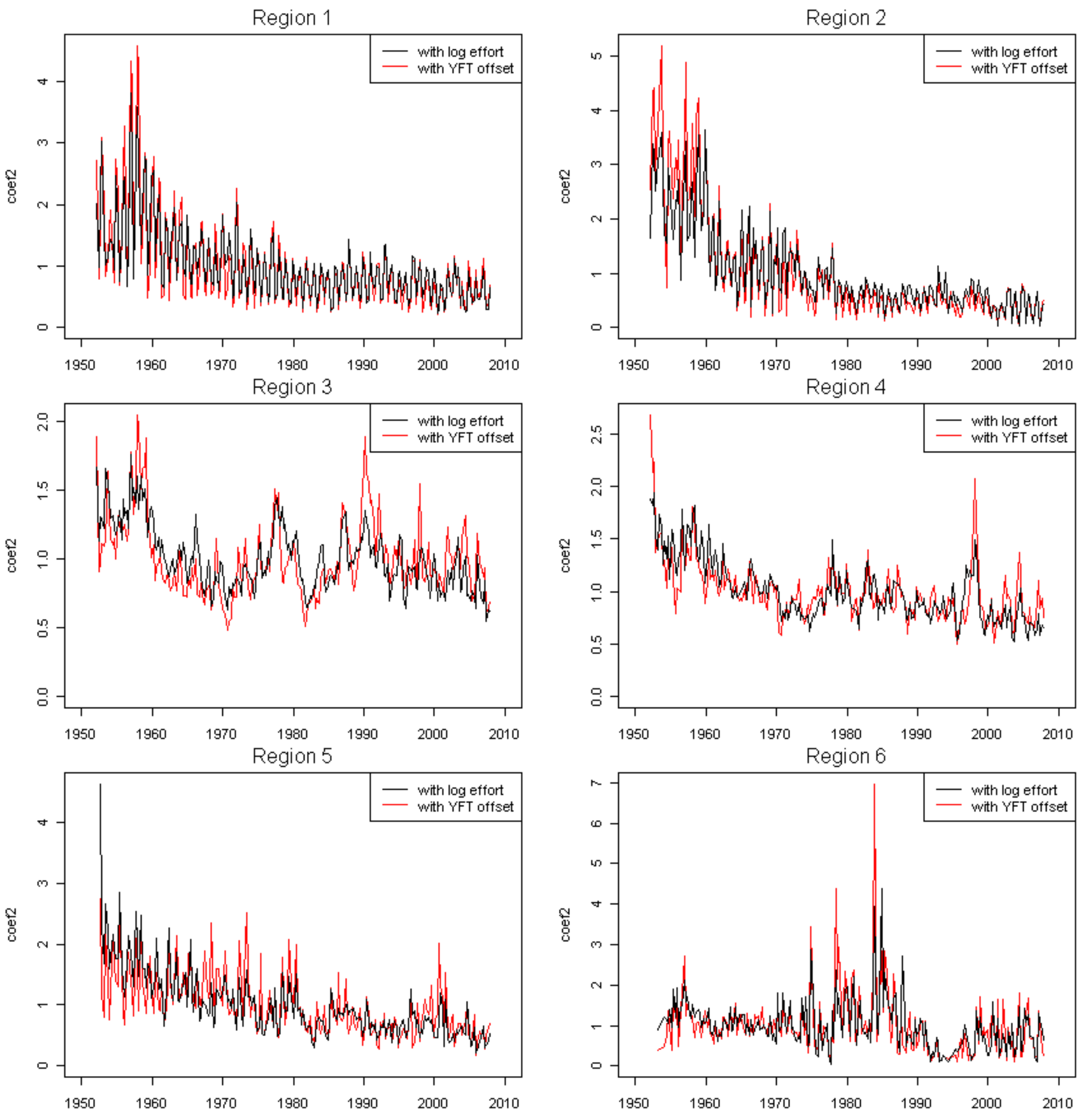


Figure 8: Standardized indices of bigeye CPUE by region, estimated using the 2008 approach changed to use log(effort) (black) and the 2009 approach which used log(effort) and the yellowfin CPUE with the abundance offset (red).

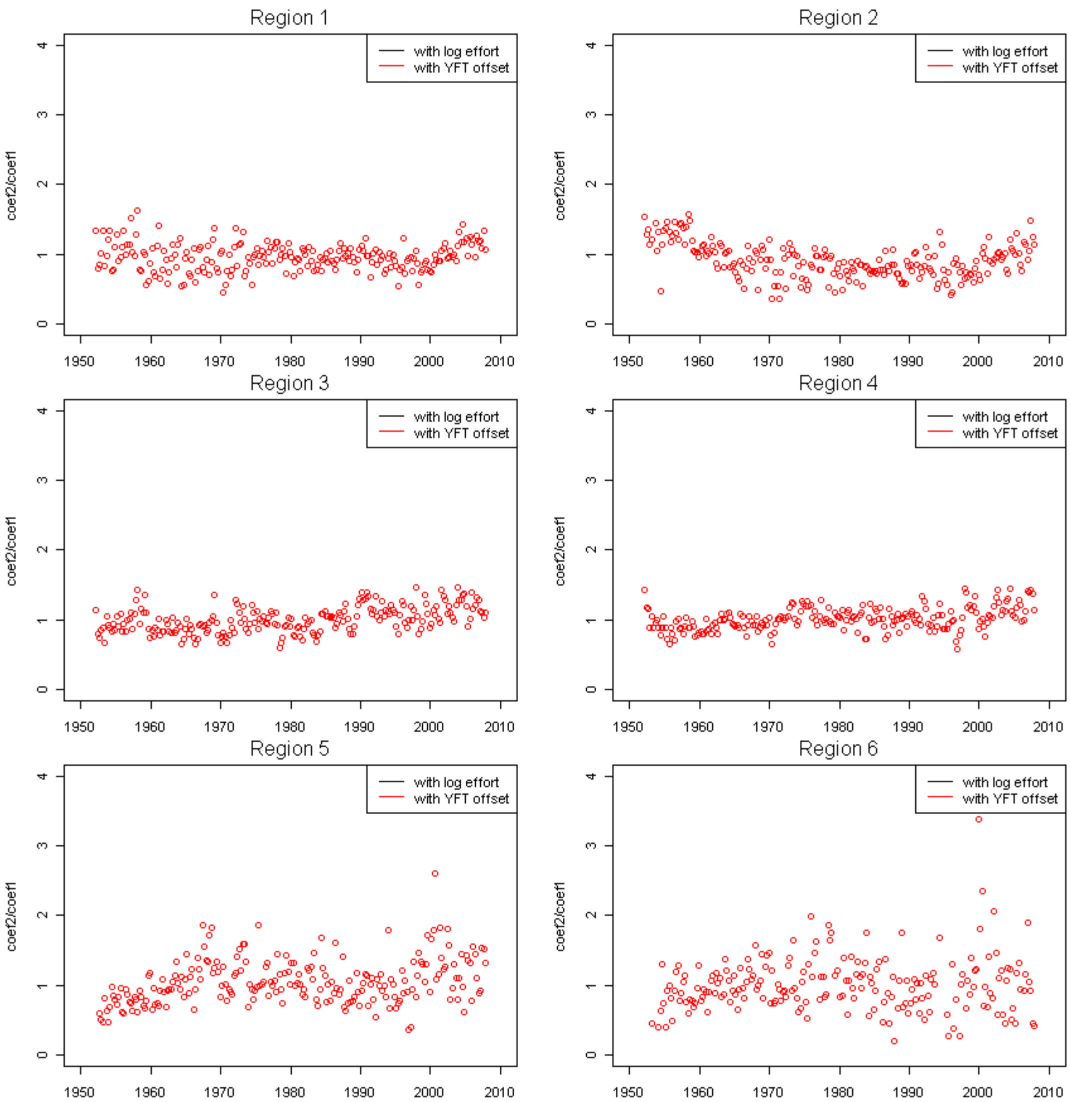


Figure 9: Ratios (2009 approach with yellowfin CPUE offset vs 2008 approach but with log(effort)) of bigeye CPUE indices, by year-quarter and region.

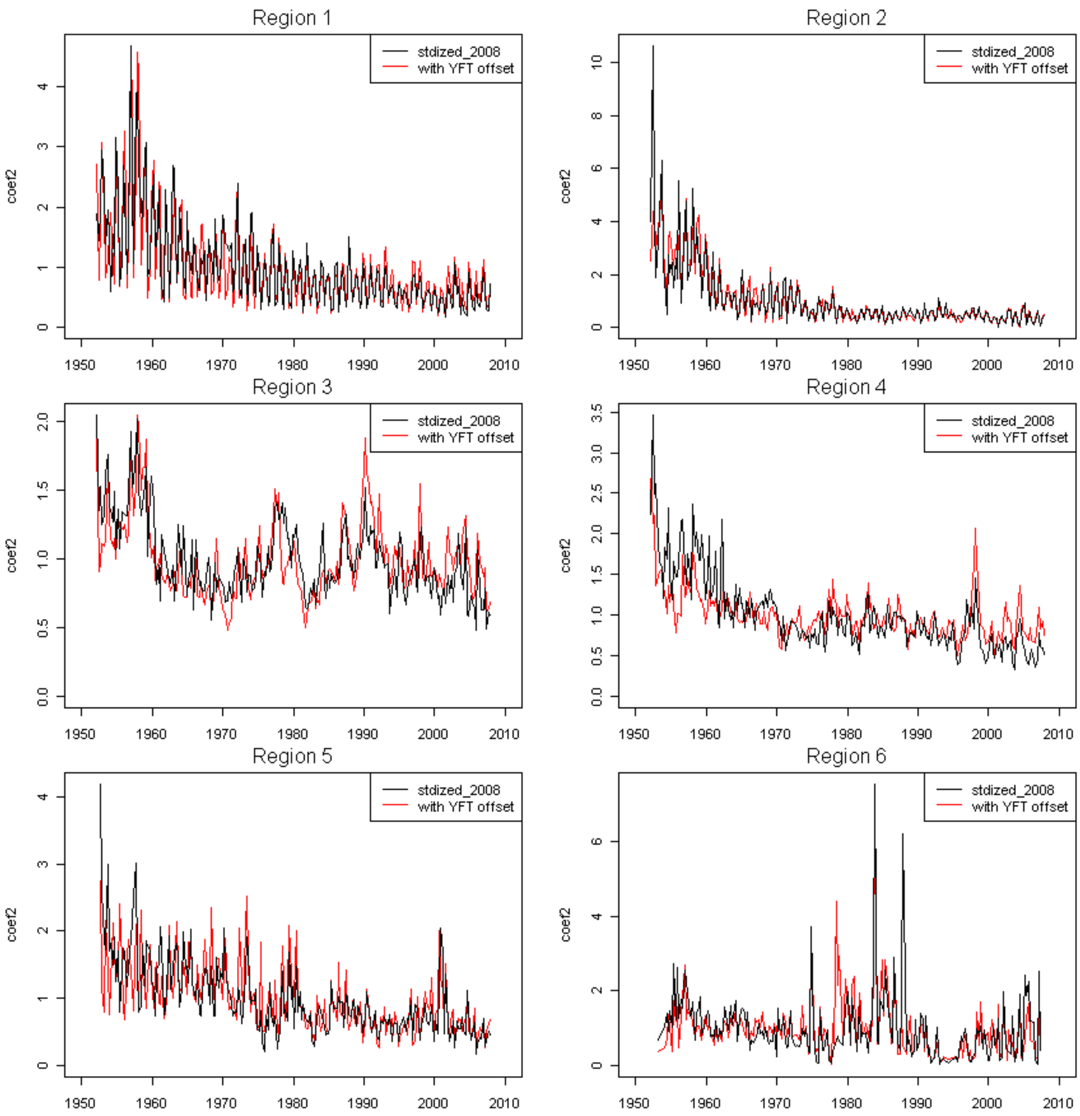


Figure 10: Standardized indices of bigeye CPUE by region, estimated using the 2008 approach (black) and the 2009 approach which used log(effort) and the yellowfin CPUE with the abundance offset (red).

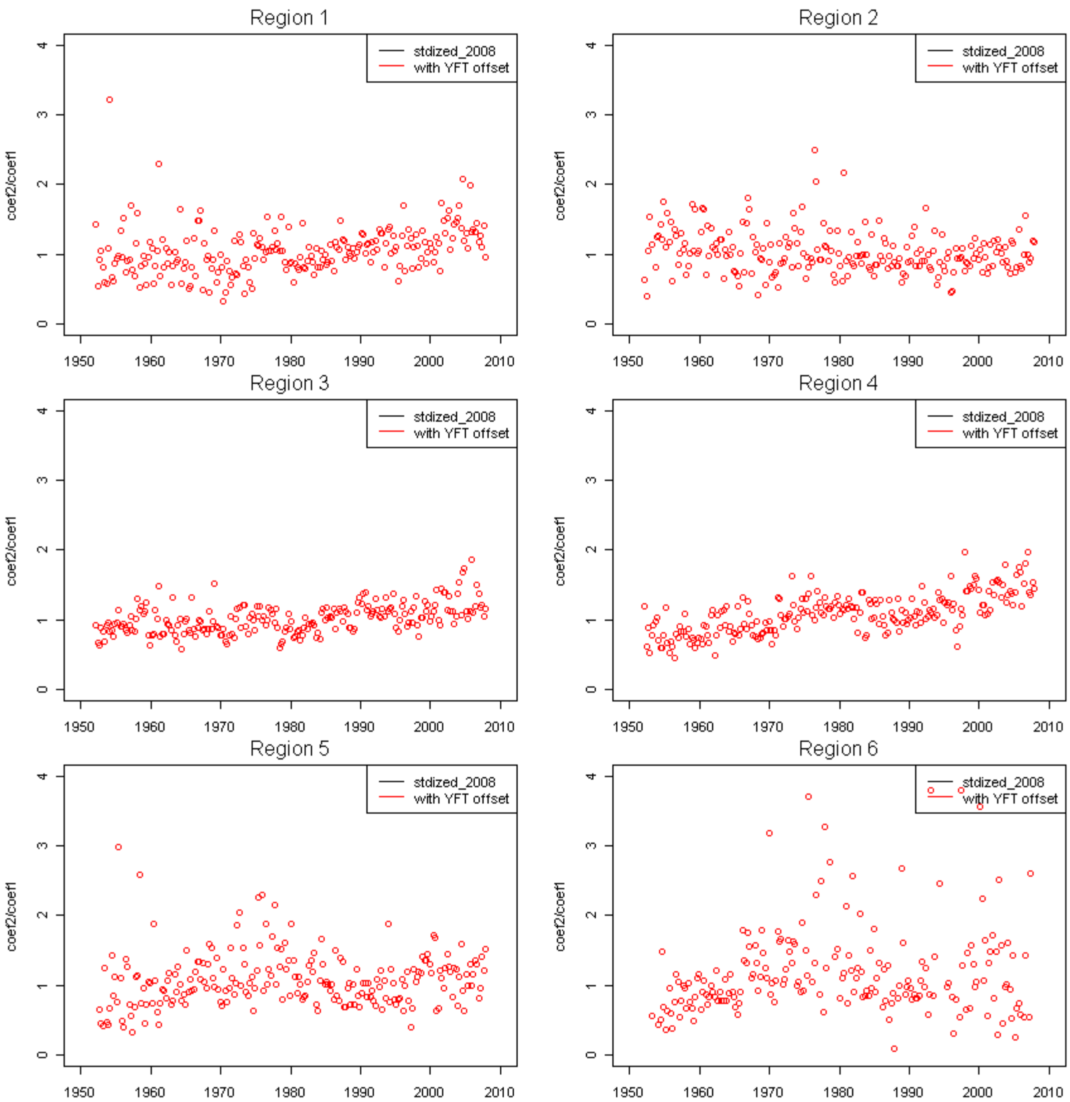


Figure 11: Ratios (2009 approach with yellowfin CPUE offset vs 2008 approach) of bigeye CPUE indices, by year-quarter and region.

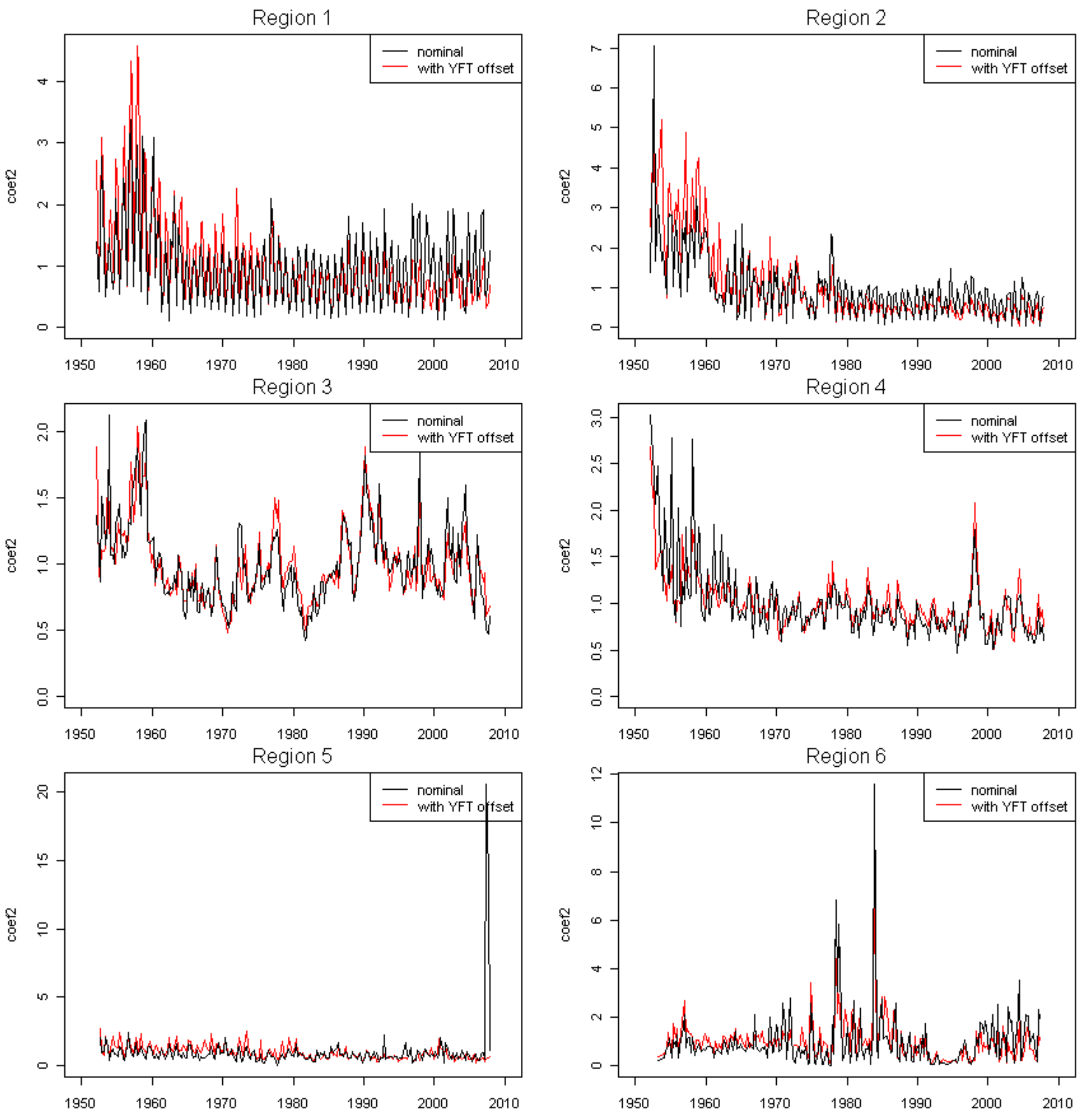


Figure 12: Indices of bigeye CPUE by region, comparing nominal catch vs effort (black) and the 2009 standardized indices which use log(effort) and the yellowfin CPUE with the abundance offset (red).

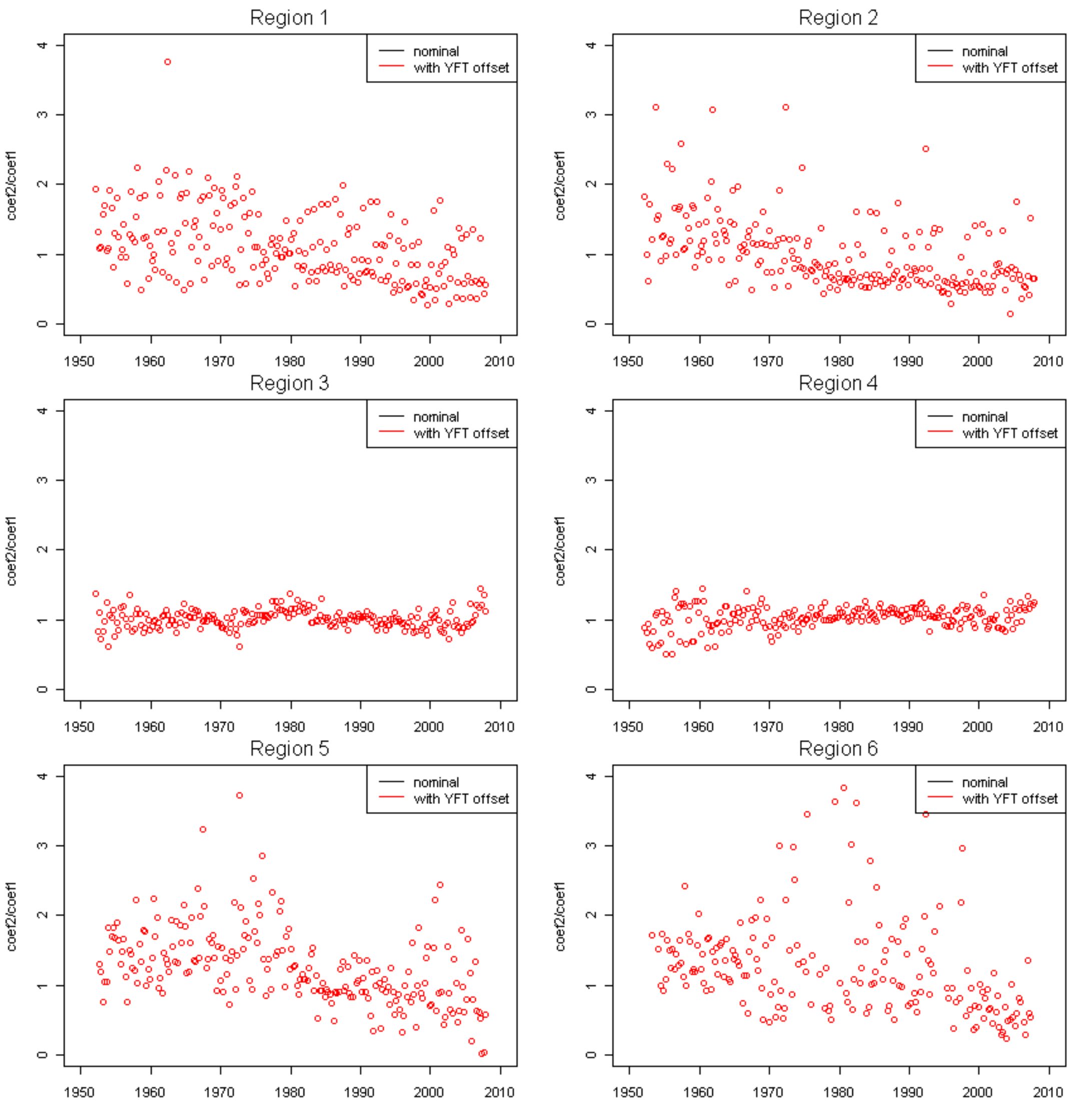


Figure 13: Ratios (2009 approach with yellowfin CPUE offset vs nominal CPUE) of bigeye CPUE indices, by year-quarter and region.

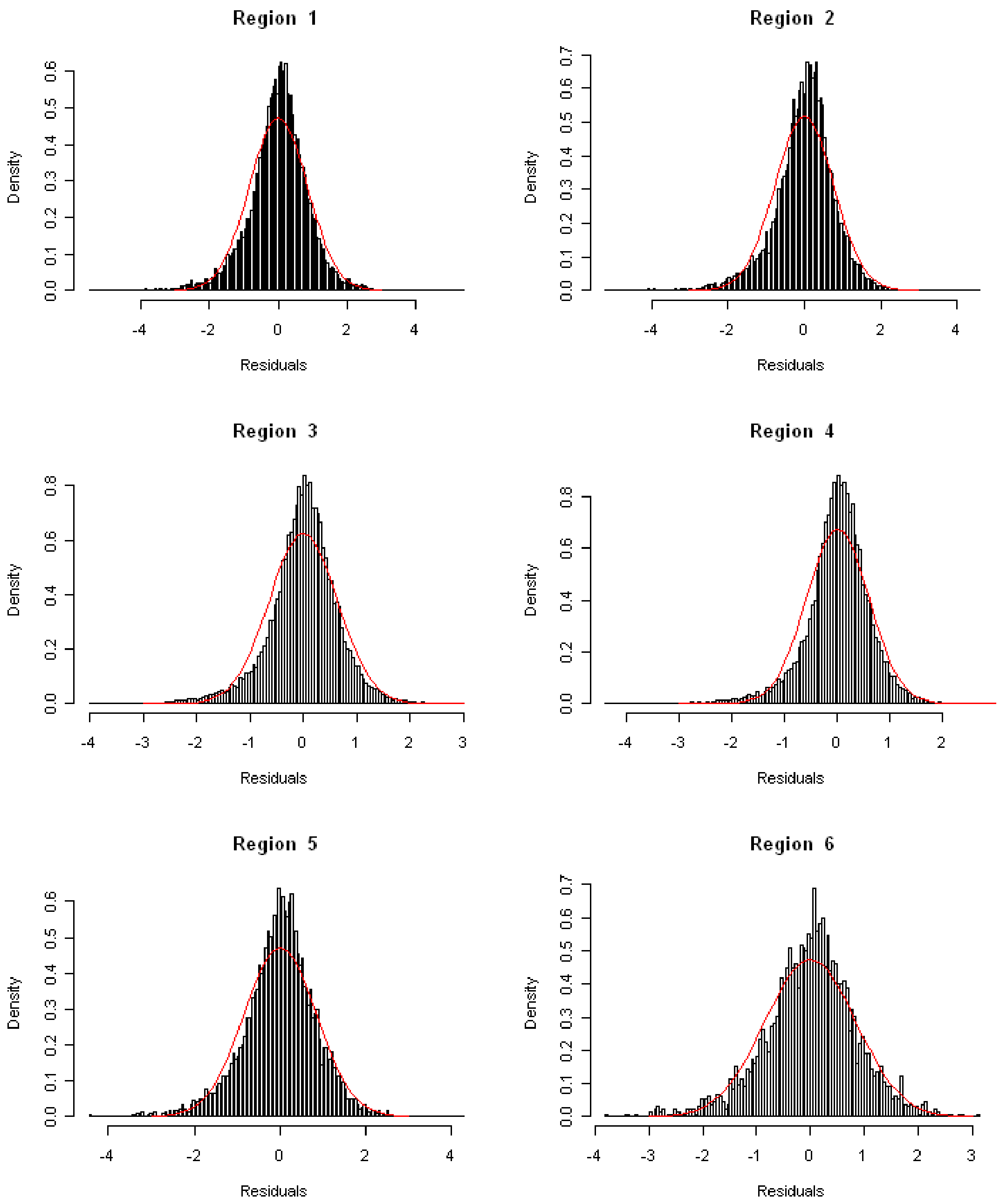


Figure 14: Density histograms of residual sizes by region from the GLMs used to estimate the 2009 bigeye indices (black), compared with a normal distribution with mean zero and the same standard deviation as the residuals. The distribution shows positive kurtosis and negative skewness, with more negative residuals than are assumed by the normal distribution.

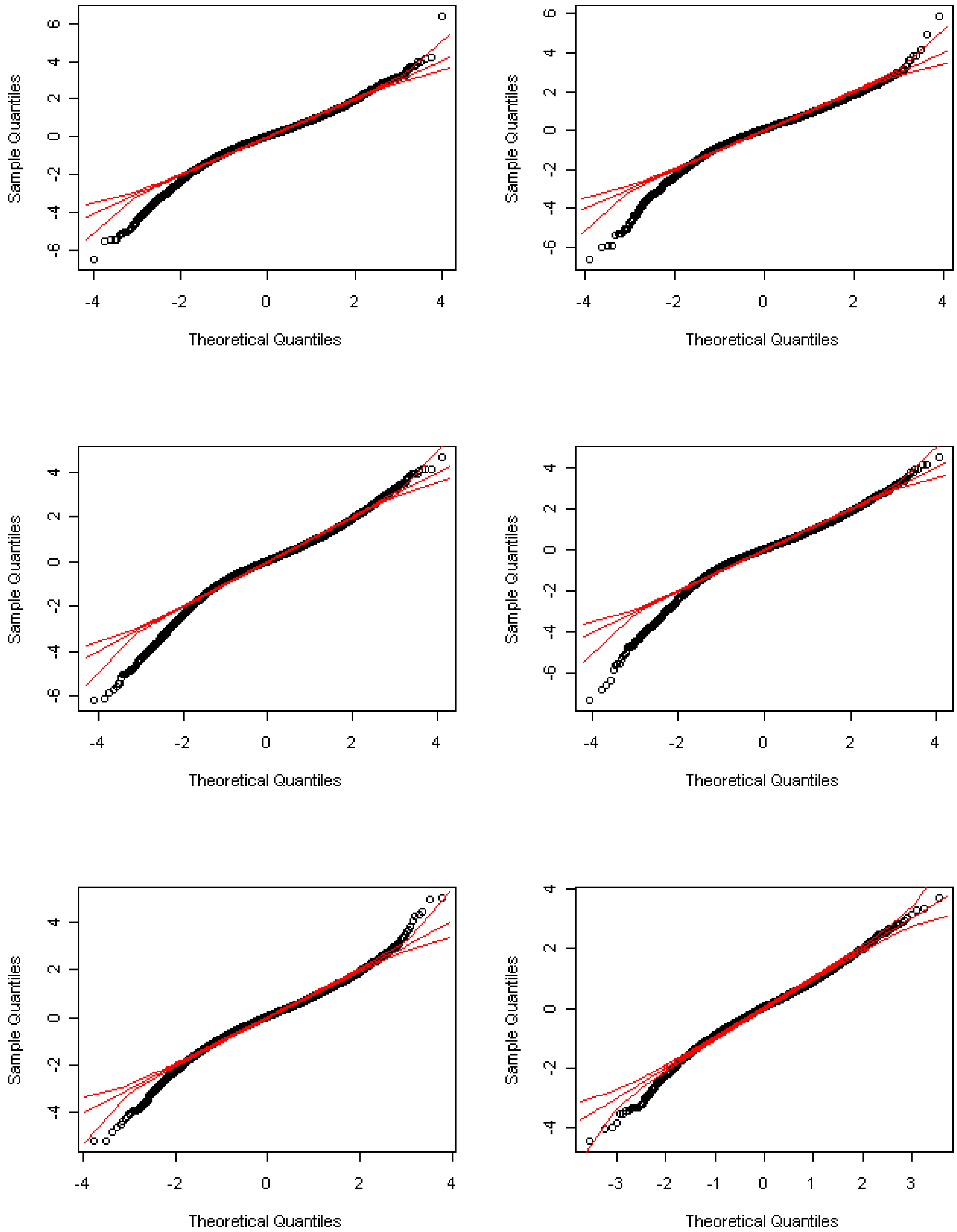


Figure 15: Q-Q plots of residuals by region from the GLMs used to estimate the 2009 bigeye indices (black), compared with the expected distribution assuming normality, with median and ± 2SD's. In each case the negative residuals are more extreme than expected.

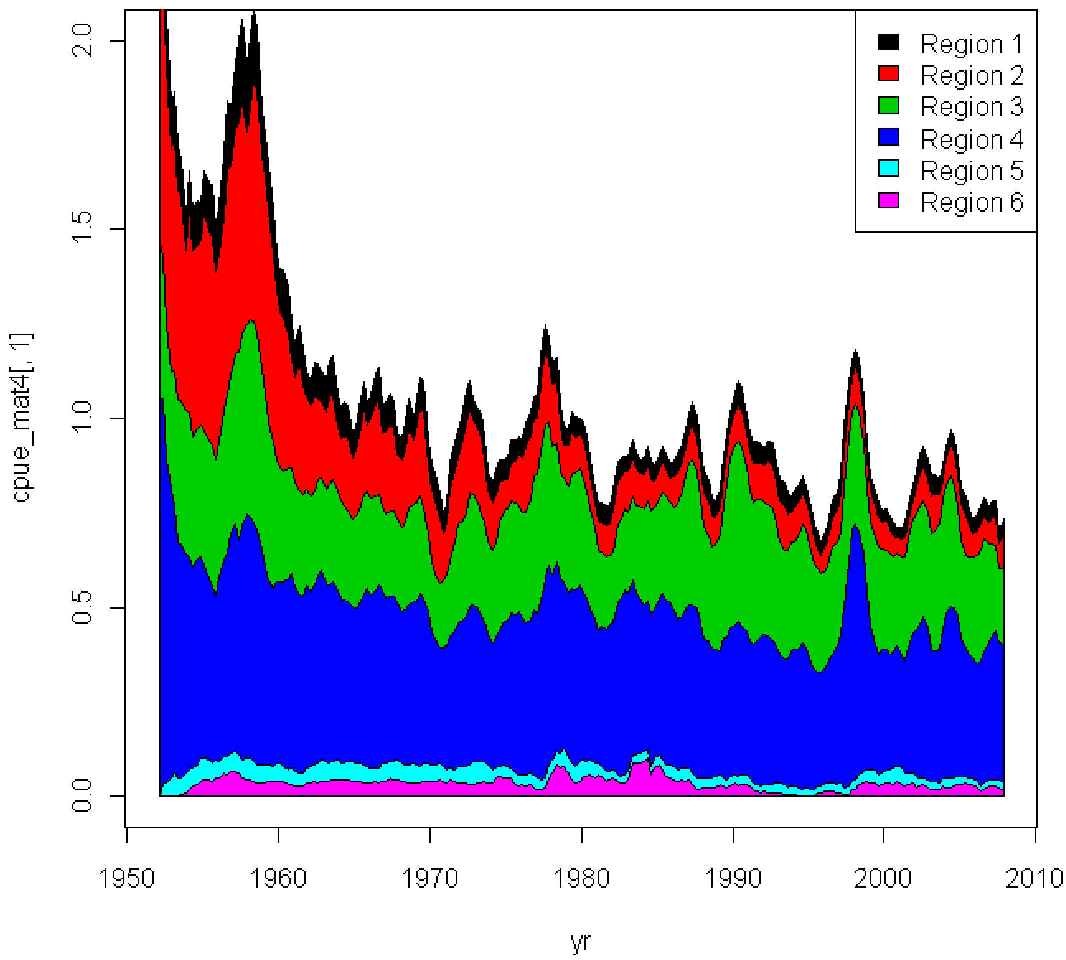


Figure 16: Indices of bigeye abundance through time for all regions, adjusted by regional scaling factors.

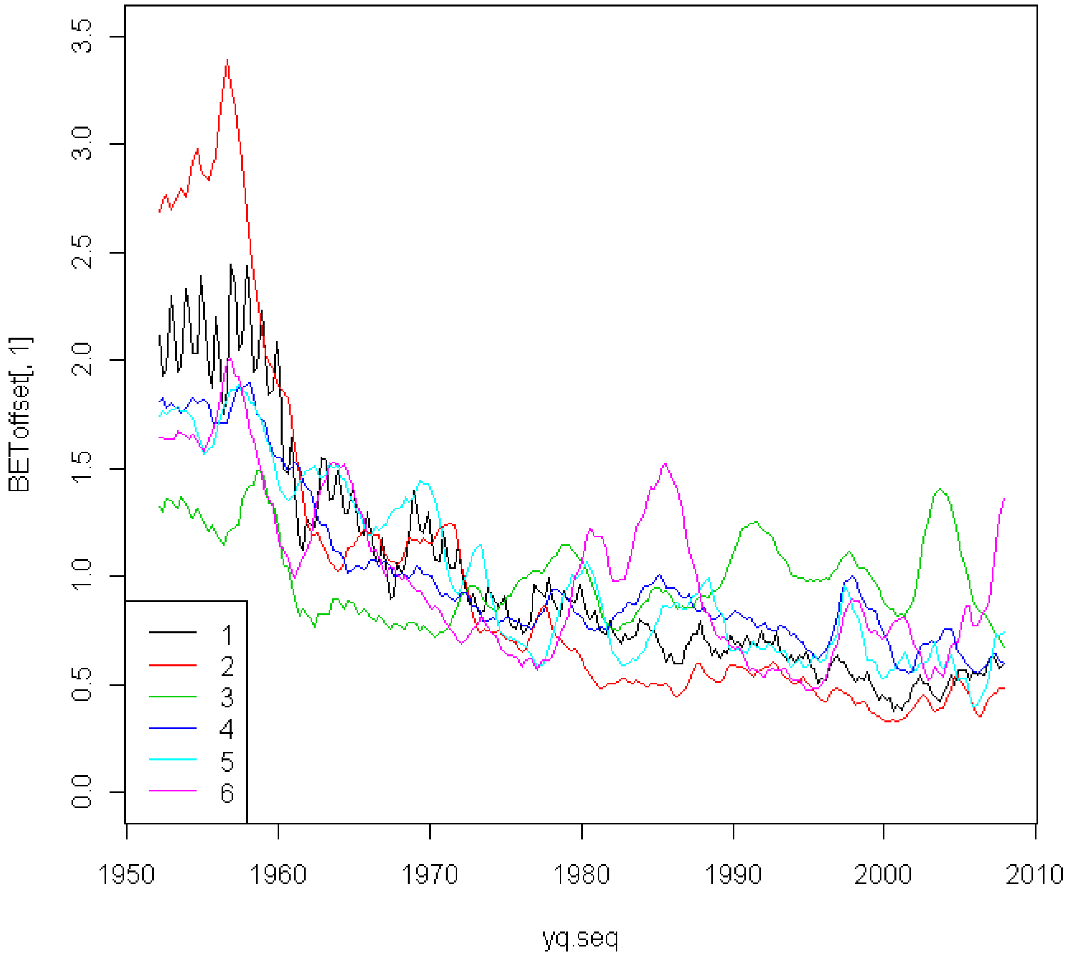


Figure 17: Indices of numbers of bigeye available to the Japanese DW LL fishery through time, by region, from the 2008 stock assessment. These values are used as offsets to the observed bigeye CPUE by time and stratum in the yellowfin standardization GLM.

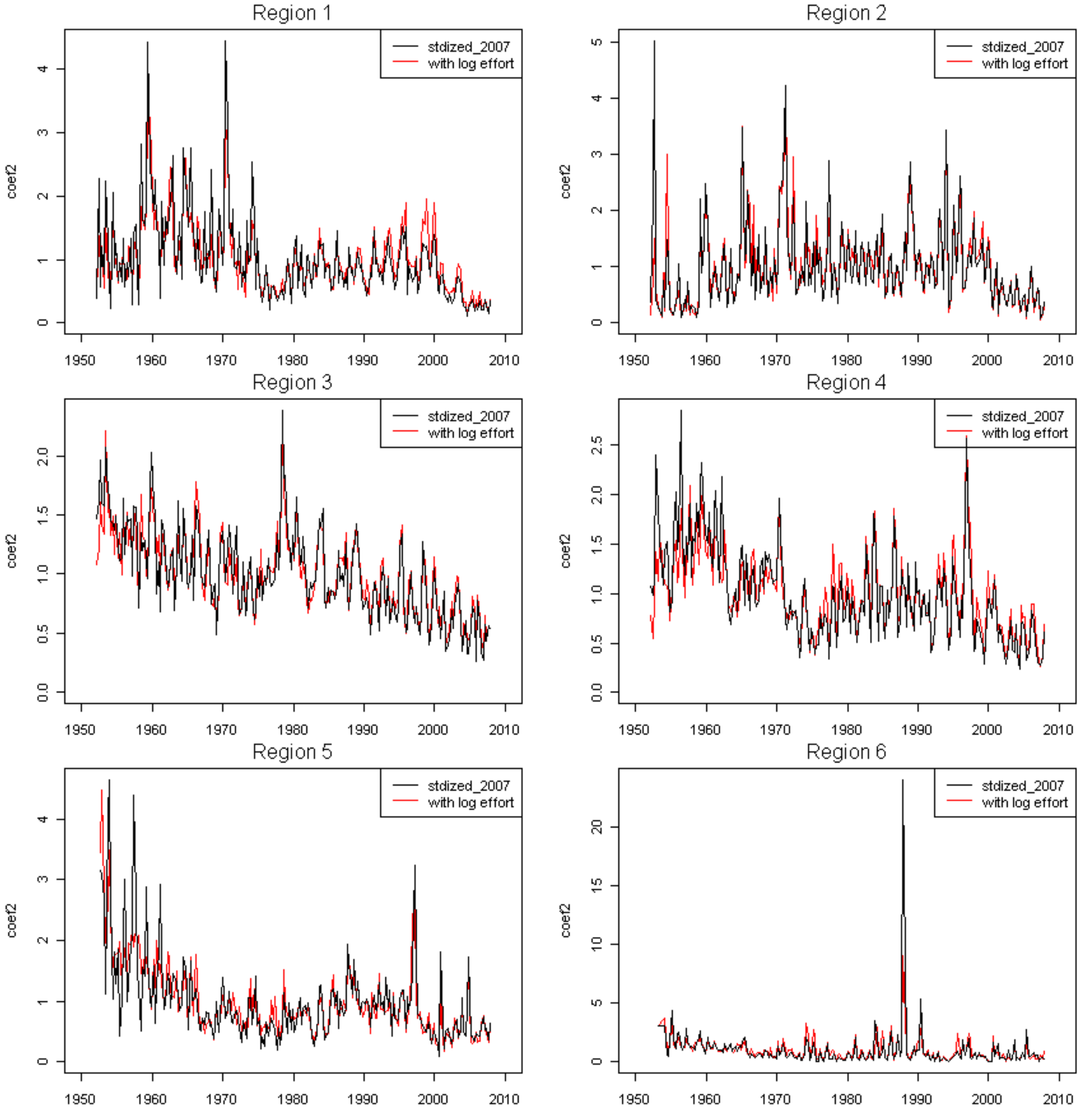


Figure 18: Standardized indices of yellowfin CPUE by region, estimated using the 2007 approach (black) and the 2007 approach changed to use log(effort) (red).

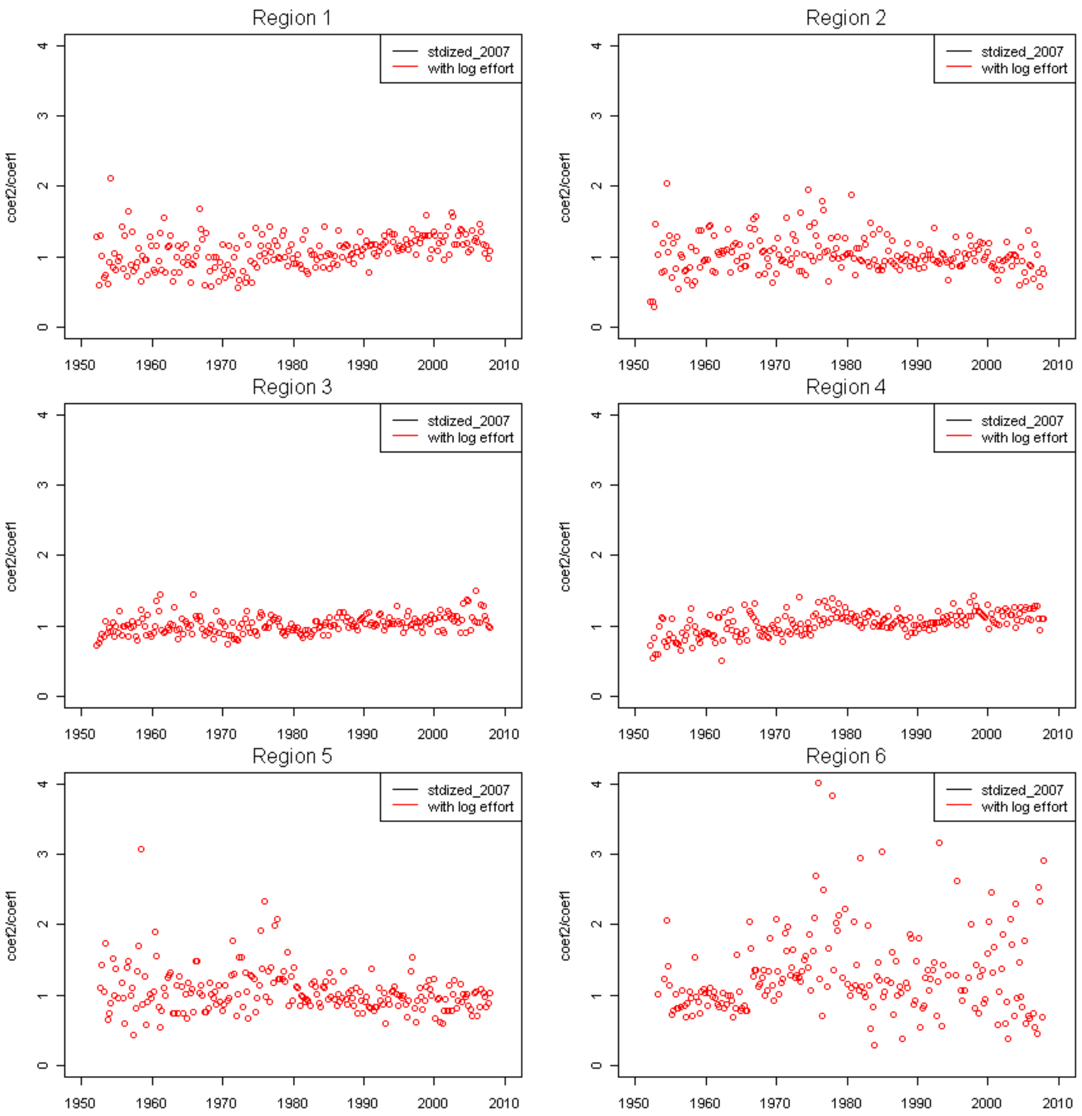


Figure 19: Ratios (2007 approach but with log(effort) vs 2007 approach) of yellowfin CPUE indices, by year-quarter and region.

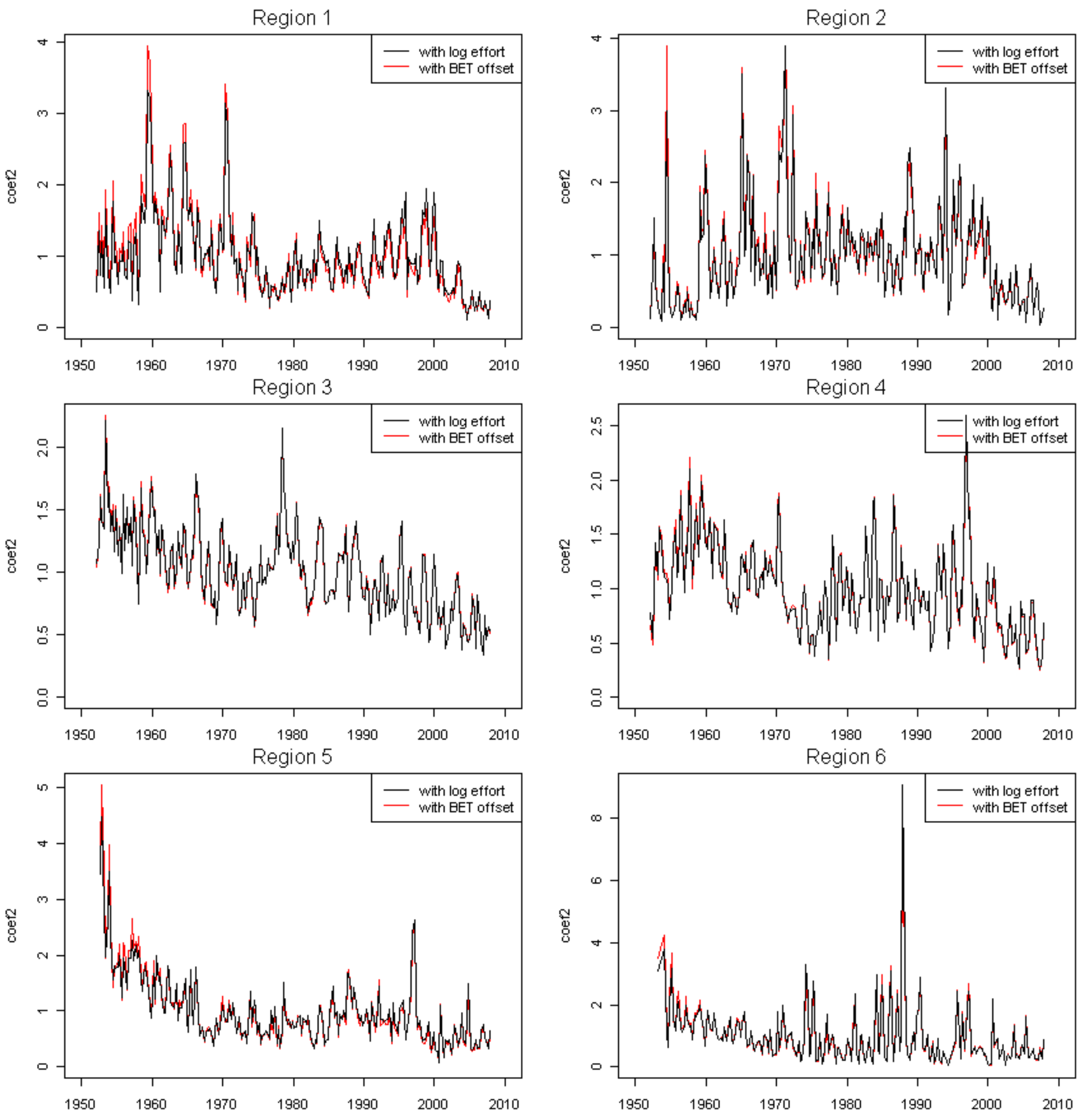


Figure 20: Standardized indices of yellowfin CPUE by region, estimated using the 2007 approach changed to use log(effort) (black) and the 2009 approach which used log(effort) and the bigeye CPUE with the abundance offset (red).

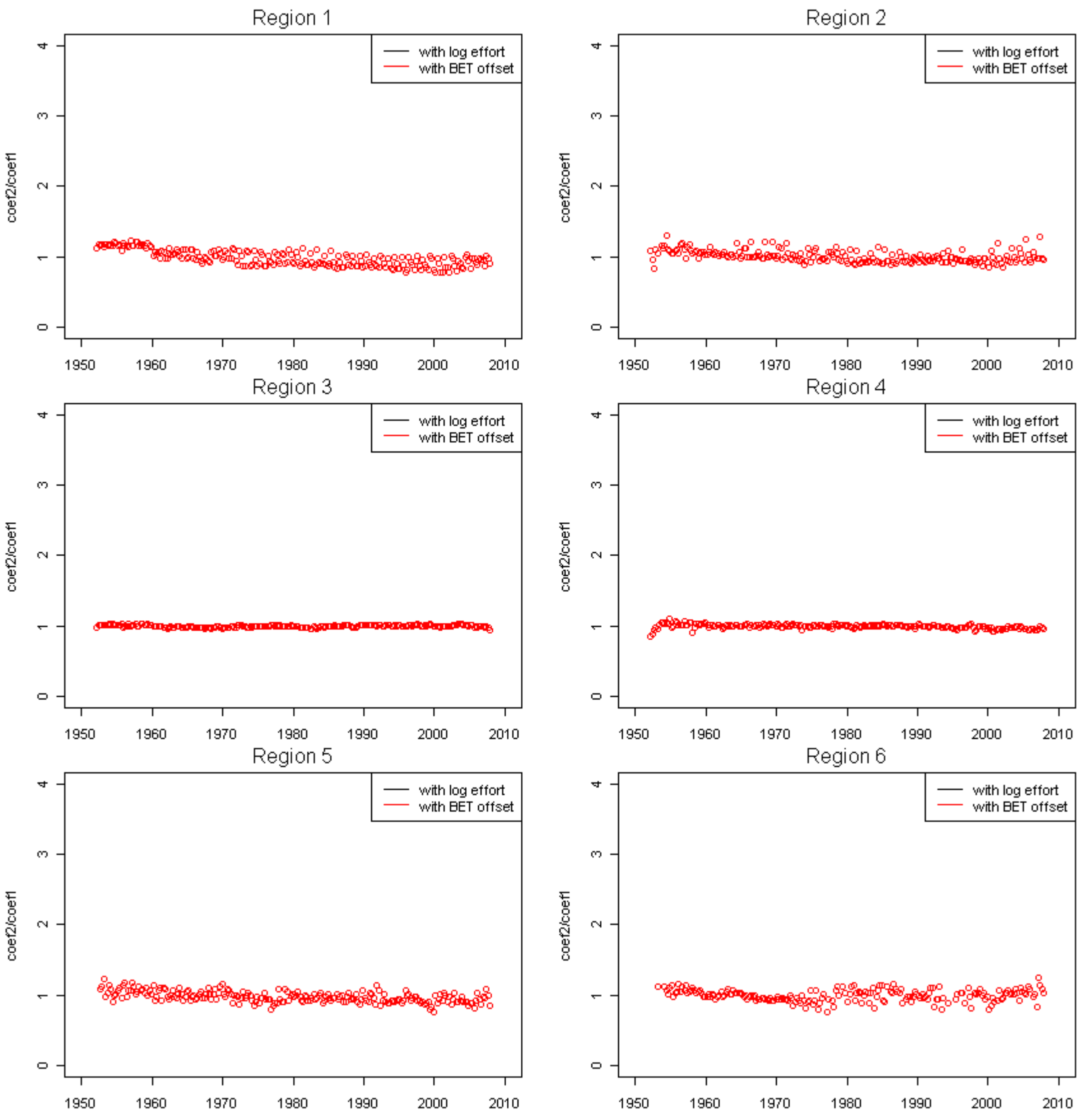


Figure 21: Ratios (2009 approach vs 2007 approach but with log(effort)) of yellowfin CPUE indices, by year-quarter and region.

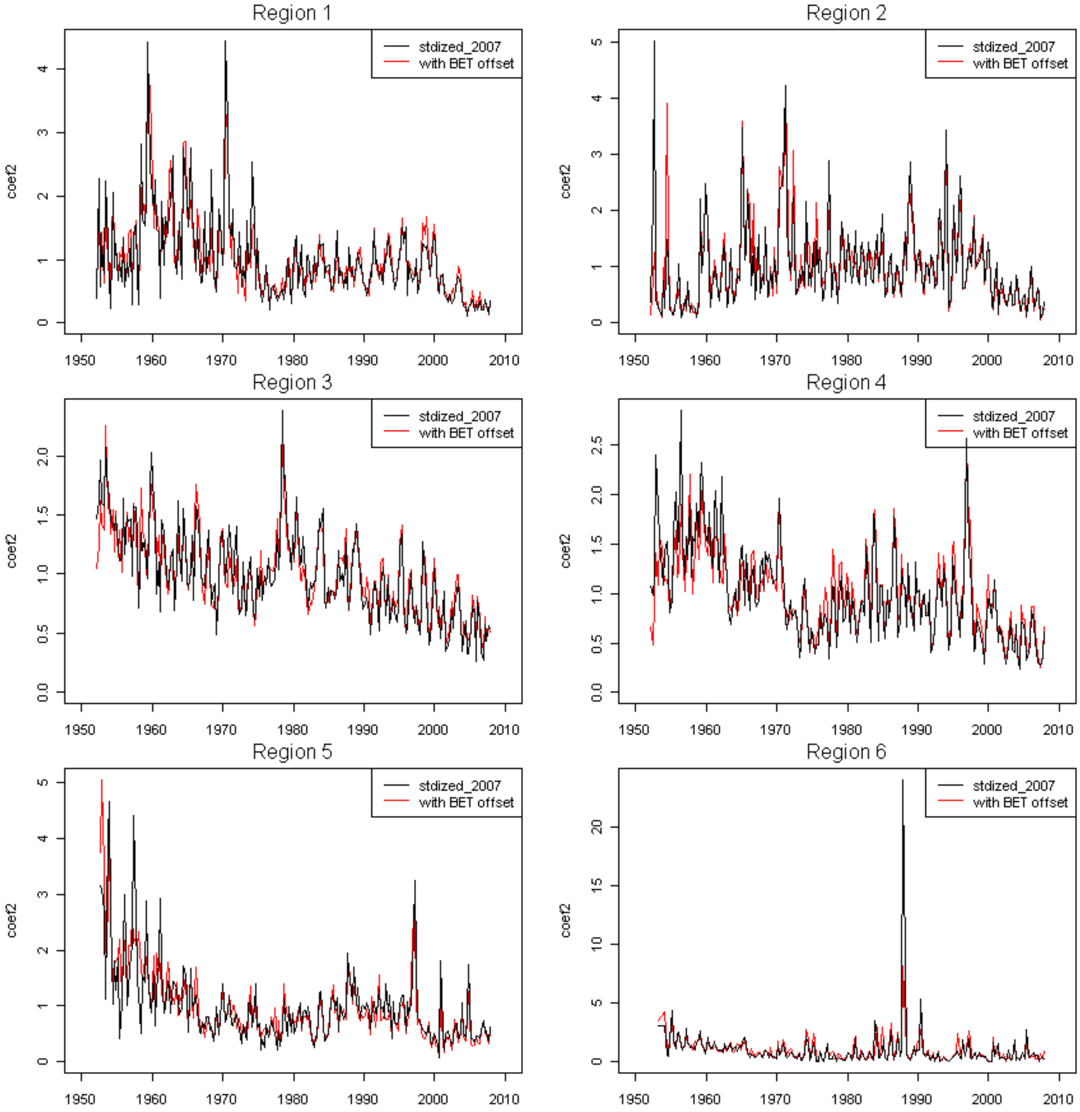


Figure 22: Standardized indices of yellowfin CPUE by region, estimated using the 2007 approach (black) and the 2009 approach which used log(effort) and the bigeye CPUE with the abundance offset (red).

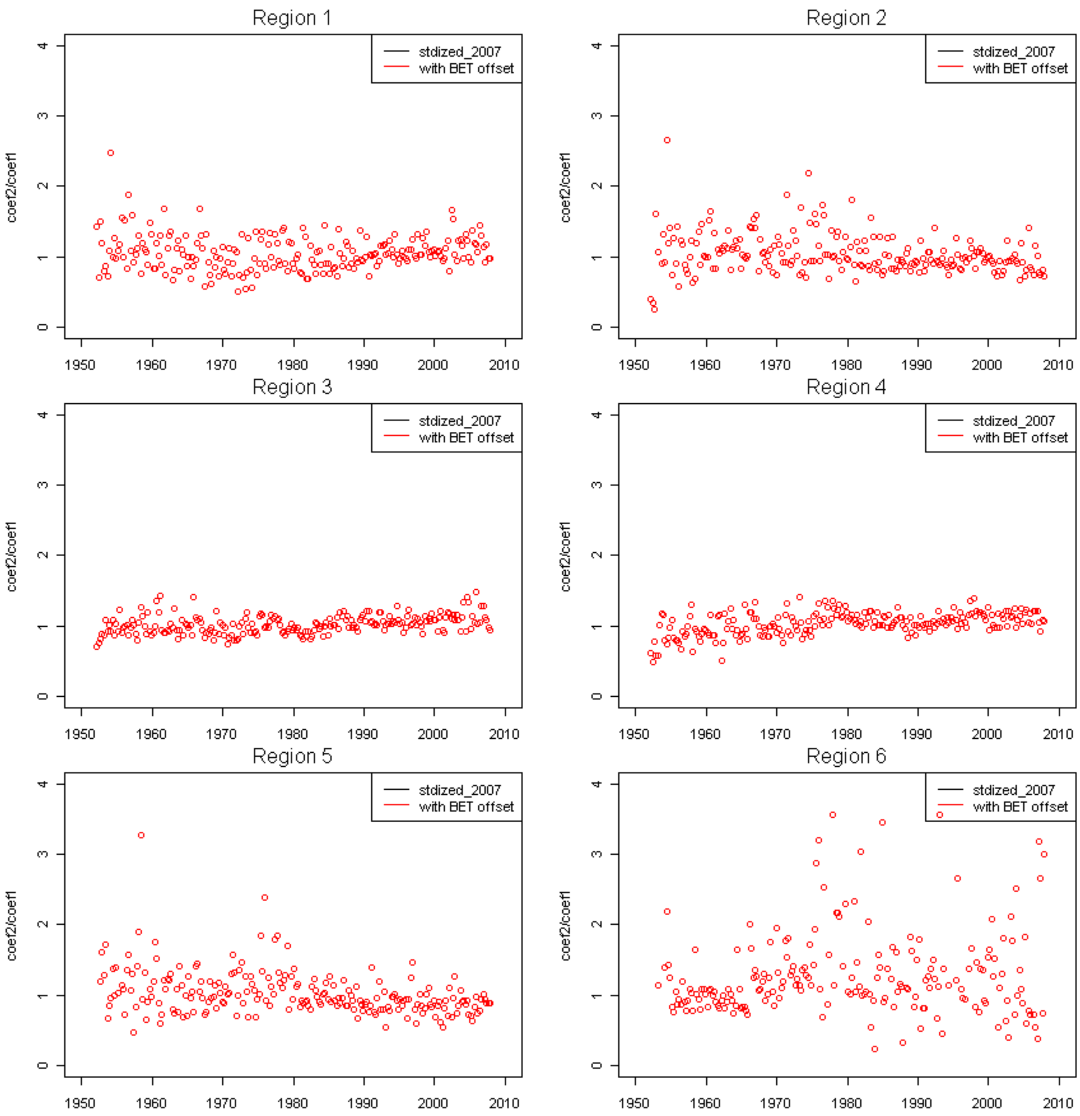


Figure 23: Ratios (2009 approach vs 2007 approach) of yellowfin CPUE indices, by year-quarter and region.

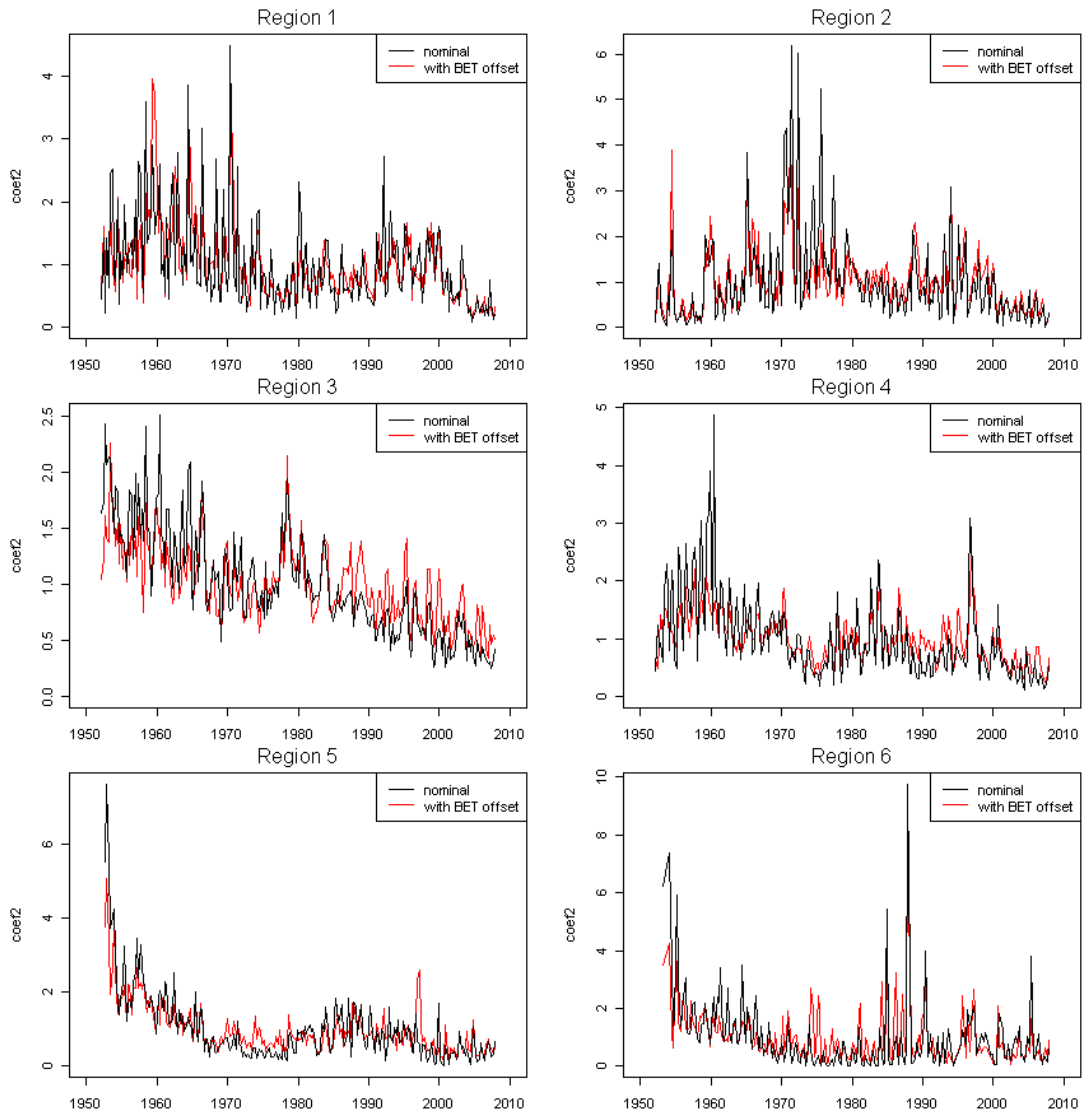


Figure 24: Indices of yellowfin CPUE by region, both nominal (black) and estimated using the 2009 approach which used log(effort) and the bigeye CPUE with the abundance offset (red).

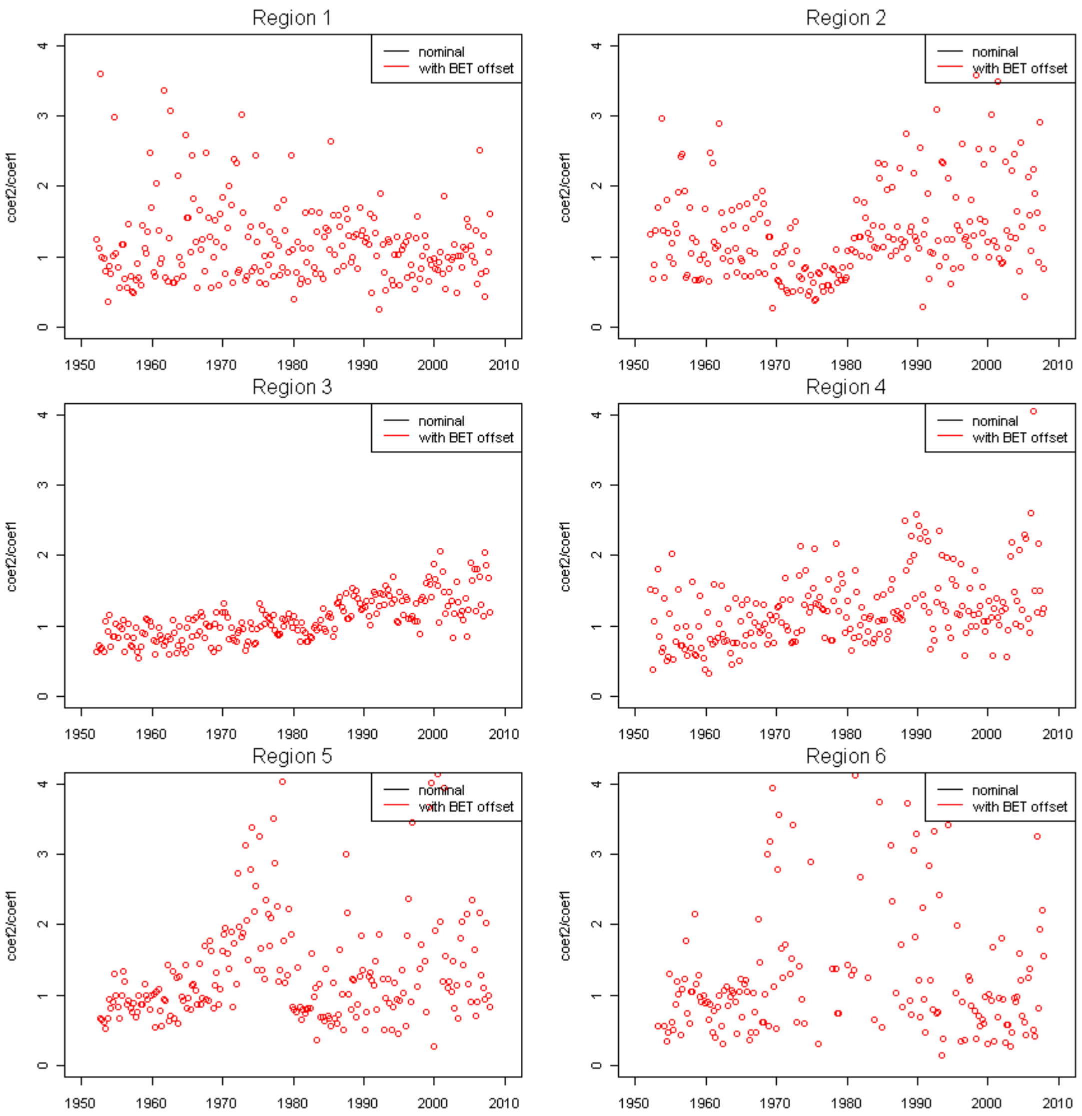


Figure 25: Ratios (2009 approach vs nominal) of yellowfin CPUE indices, by year-quarter and region.

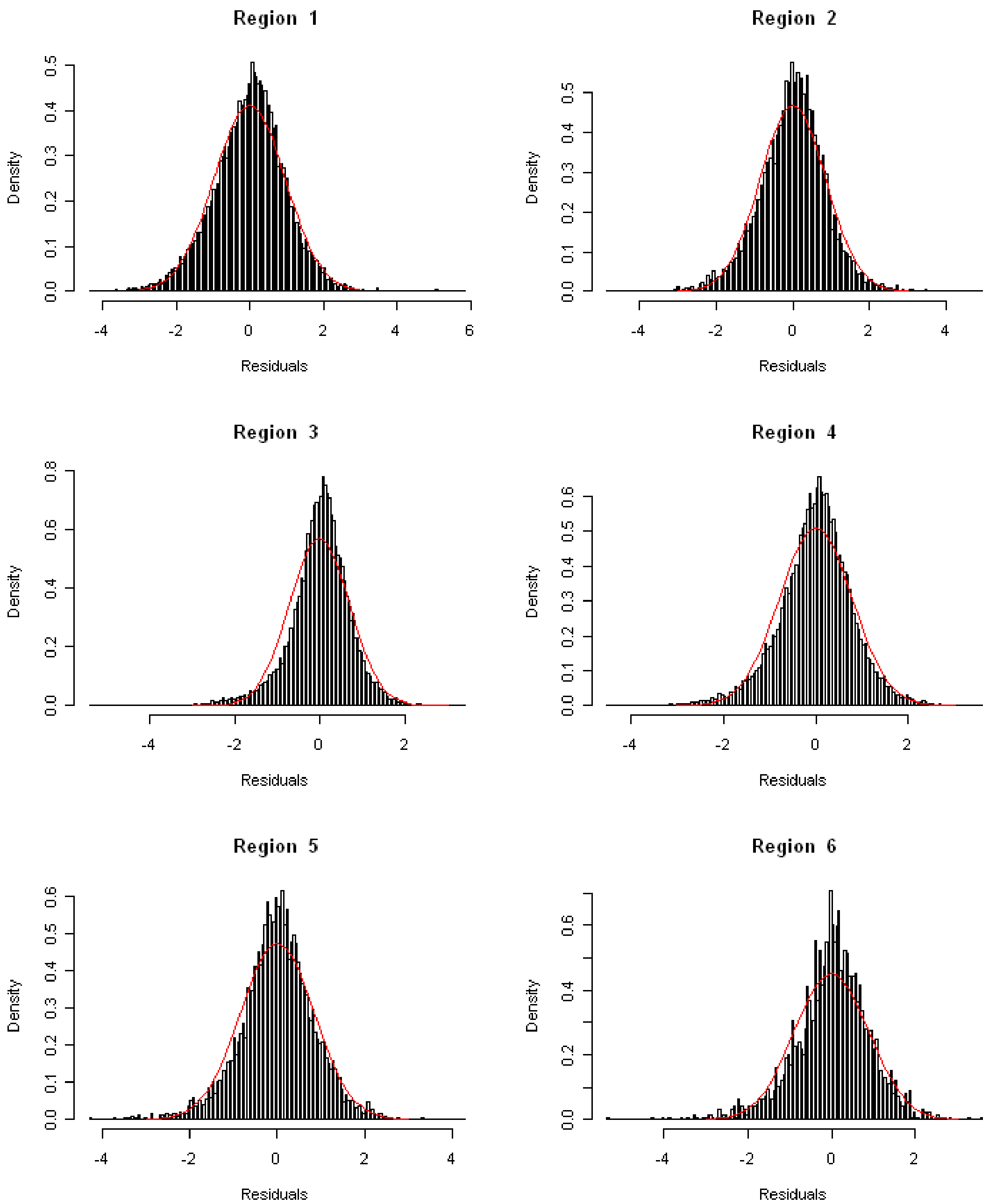


Figure 26: Density histograms of residual sizes by region from the GLMs used to estimate the 2009 yellowfin indices (black), compared with a normal distribution with mean zero and the same standard deviation as the residuals. The distribution shows positive kurtosis and negative skewness, with more negative residuals than are assumed by the normal distribution.

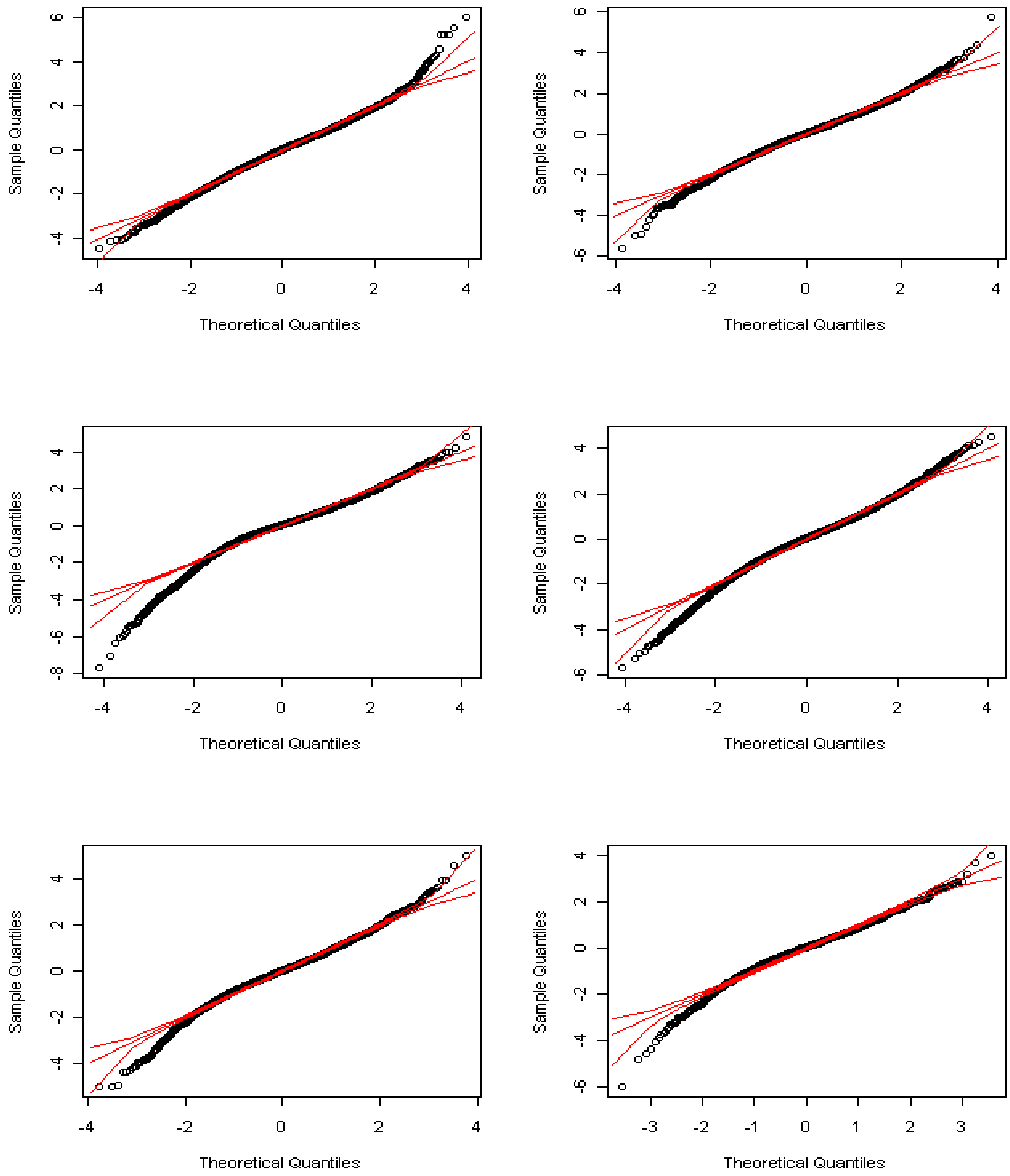


Figure 27: Q-Q plots of residuals by region from the GLMs used to estimate the 2009 yellowfin indices (black), compared with the expected distribution assuming normality, with median and ± 2SD's. In each case the negative residuals are more extreme than expected.

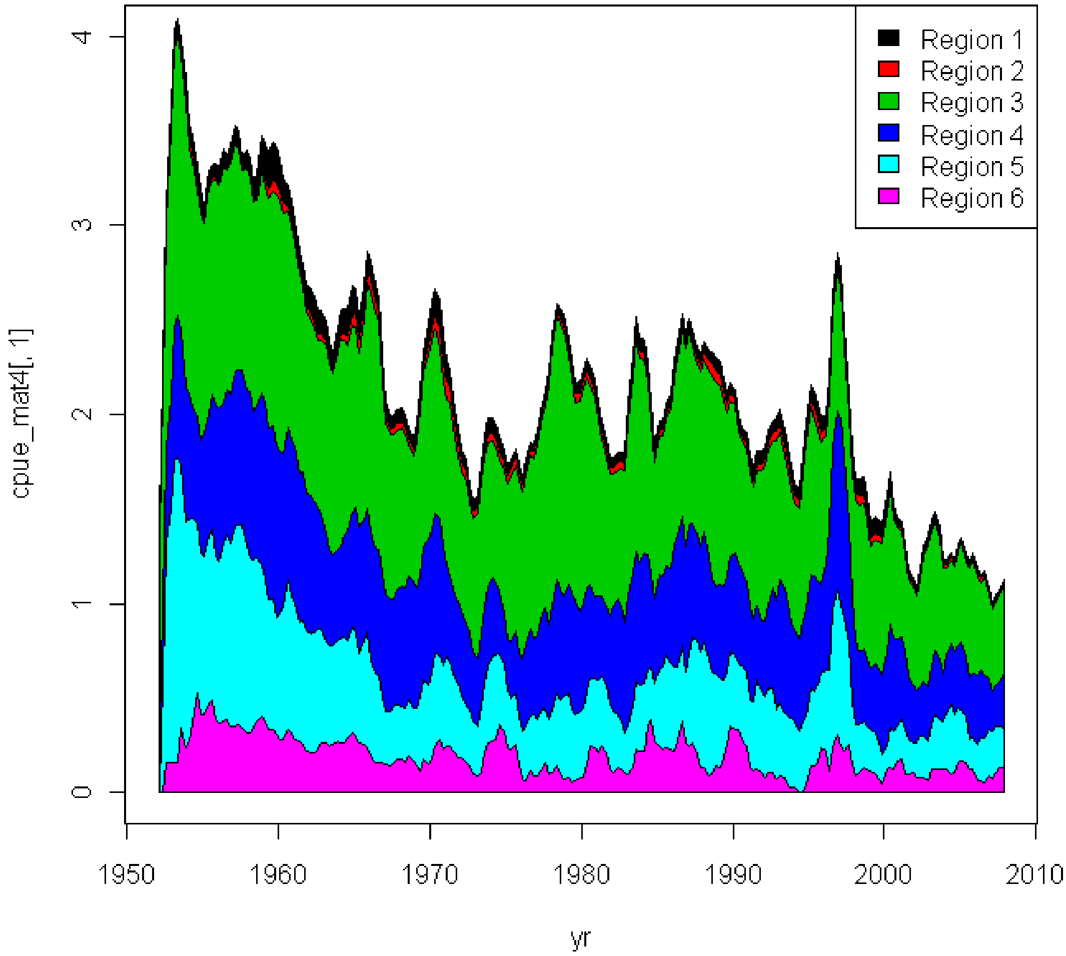


Figure 28: Indices of yellowfin abundance through time for all regions, adjusted by regional scaling factors.

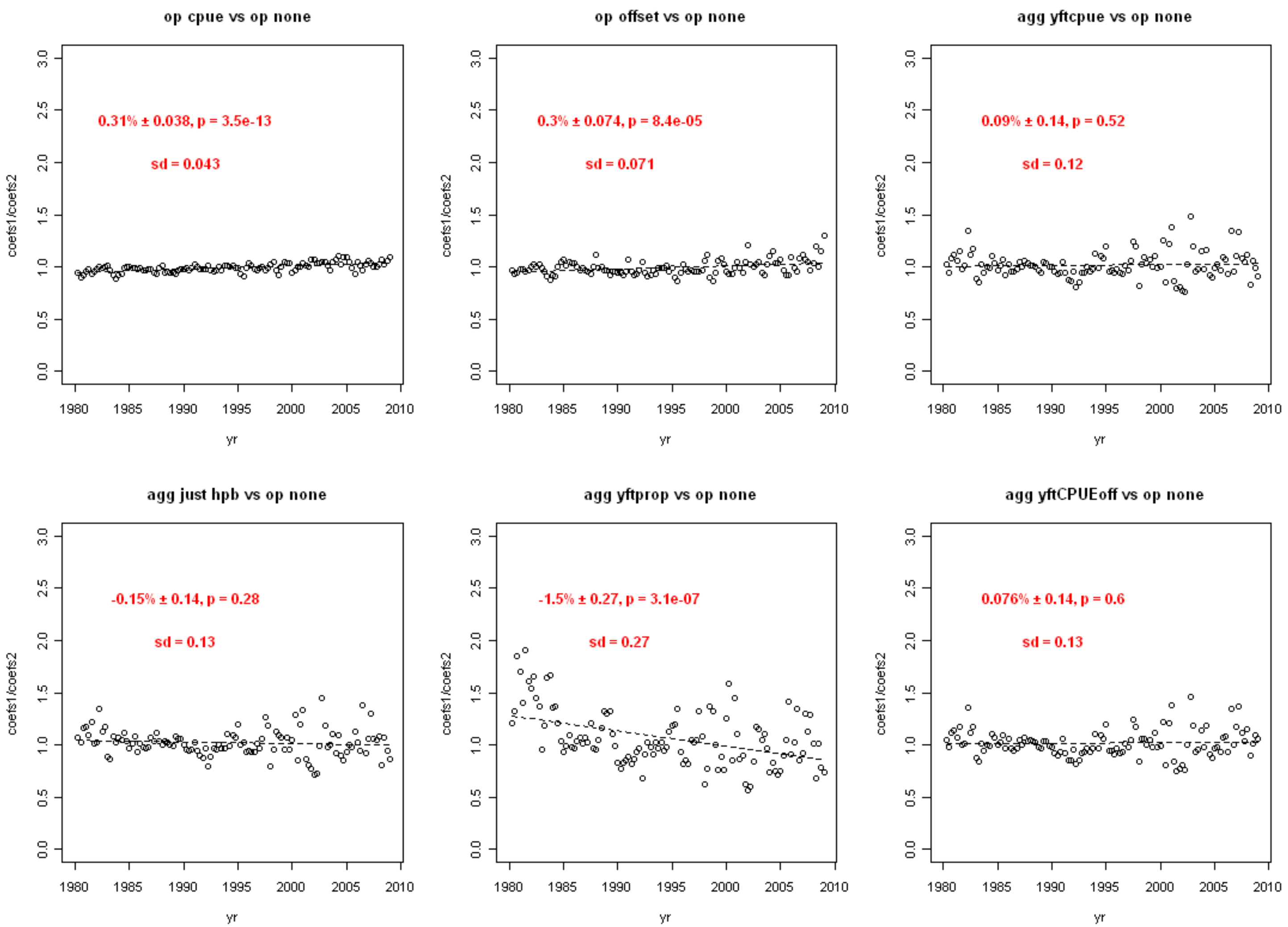


Figure 29: Comparison of bigeye tuna abundance indices using several alternative targeting indicators, based on both aggregated and operational data.

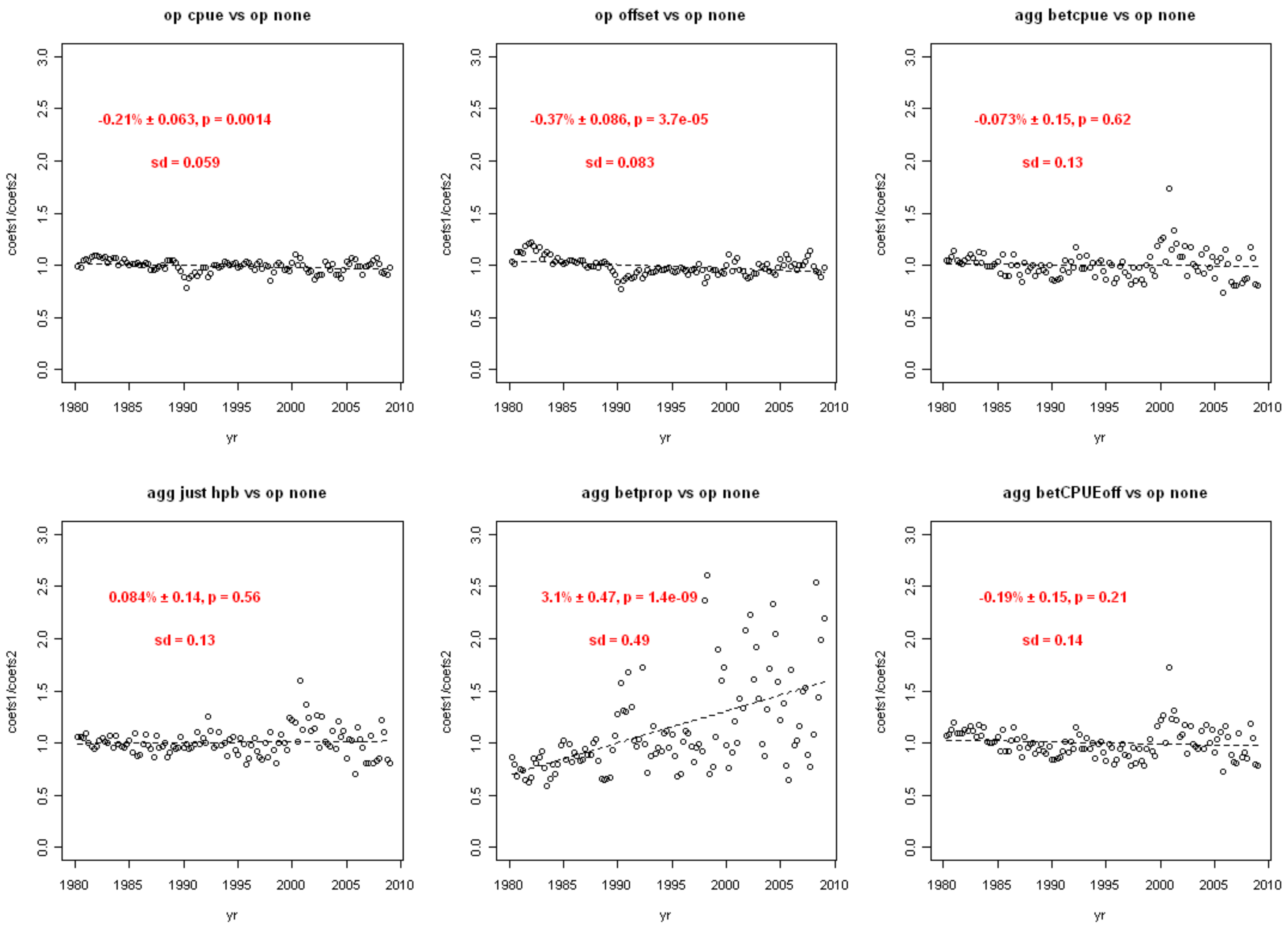


Figure 30: Comparison of yellowfin tuna abundance indices using several alternative targeting indicators, based on both aggregated and operational data.

Figure 31: Proportion of reported sets that record zero catch of bigeye and/or yellowfin by year.

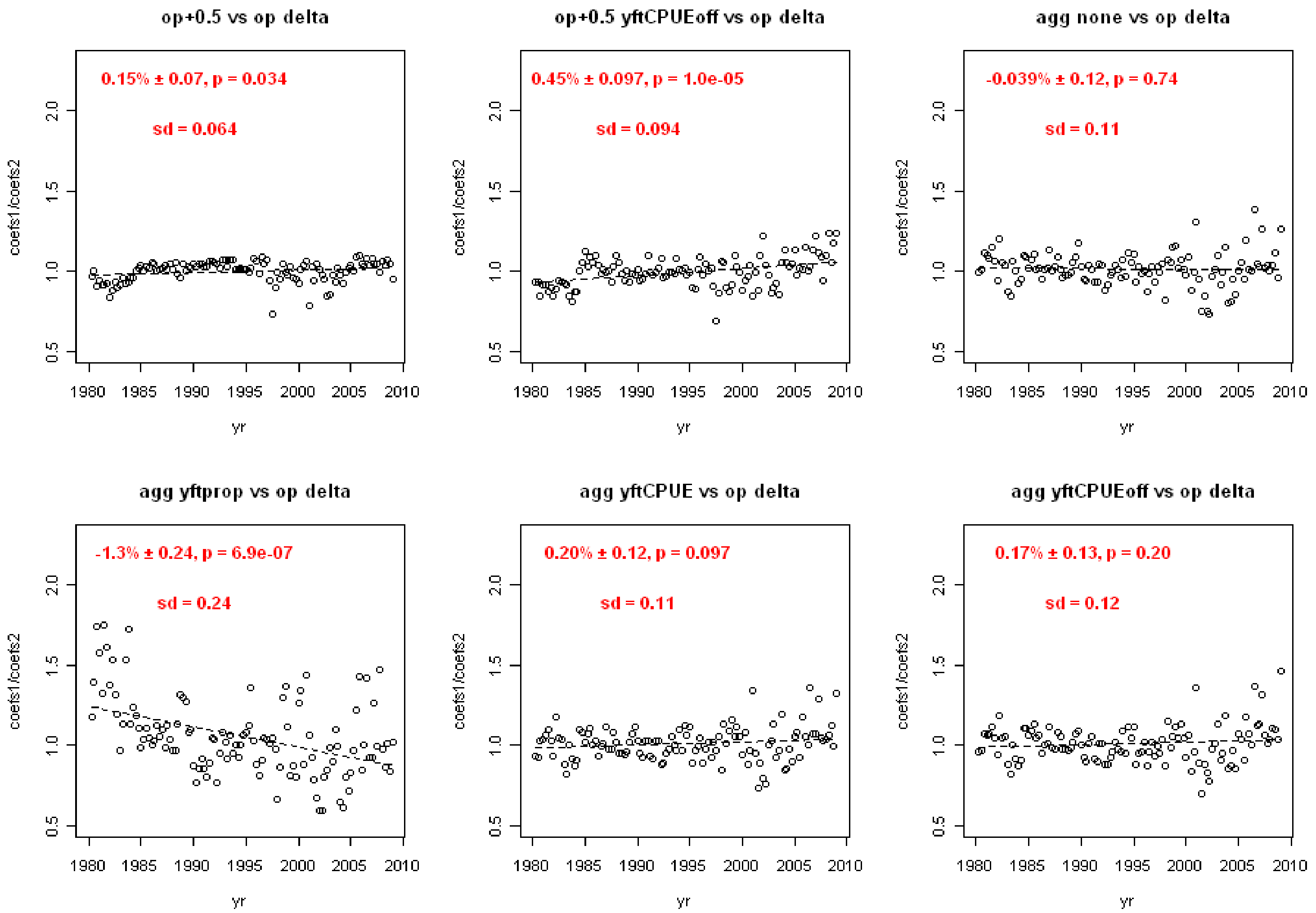


Figure 32: Ratios of bigeye CPUE indices, to compare targeting indicators, and aggregated vs operational data. All options are compared with a delta lognormal GLM on operational data (op delta). Options labelled 'op+0.5' apply a GLM with response variable ((catch+0.5) / effort) to operational data. Options labelled agg use aggregated data.

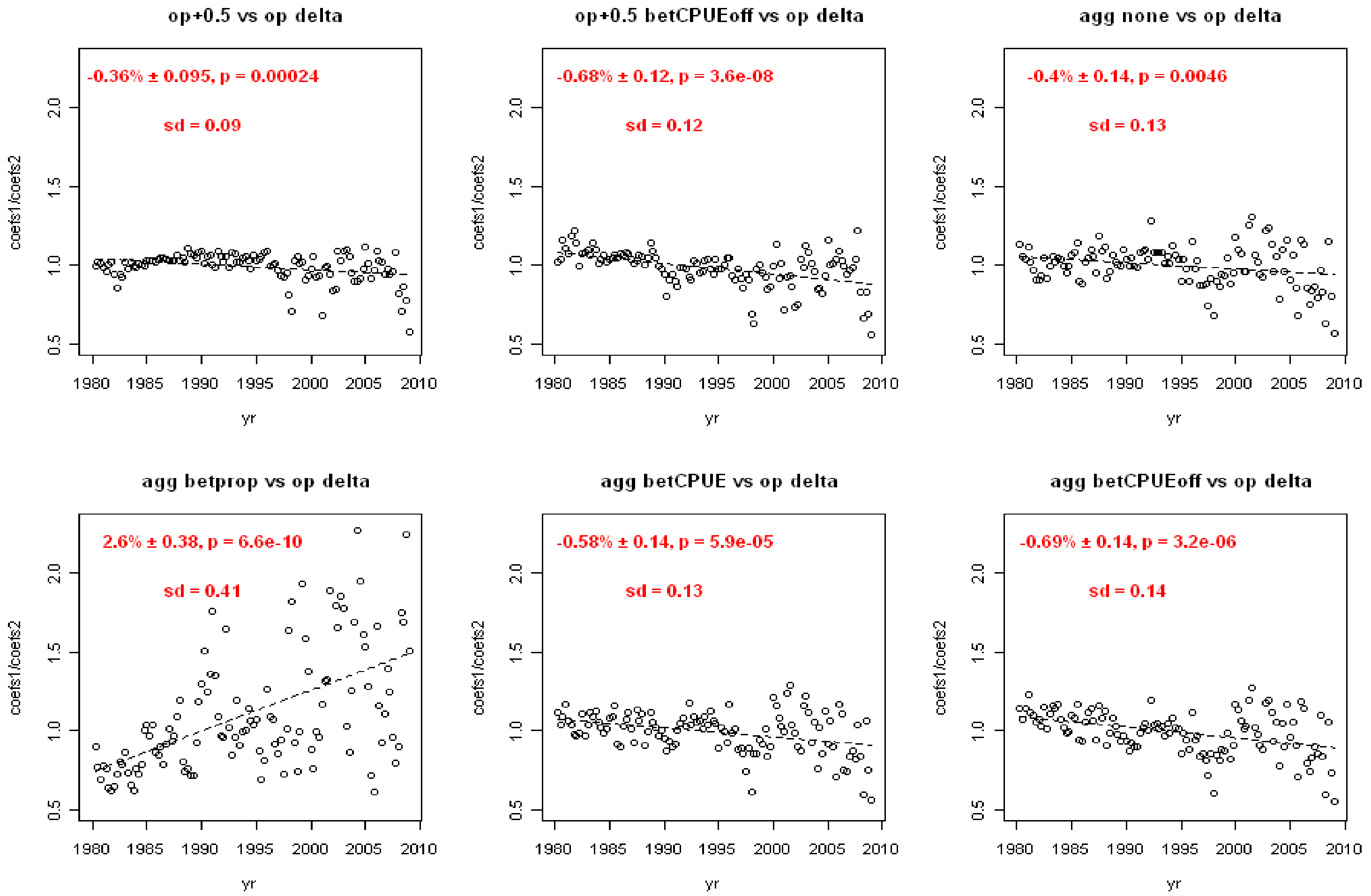
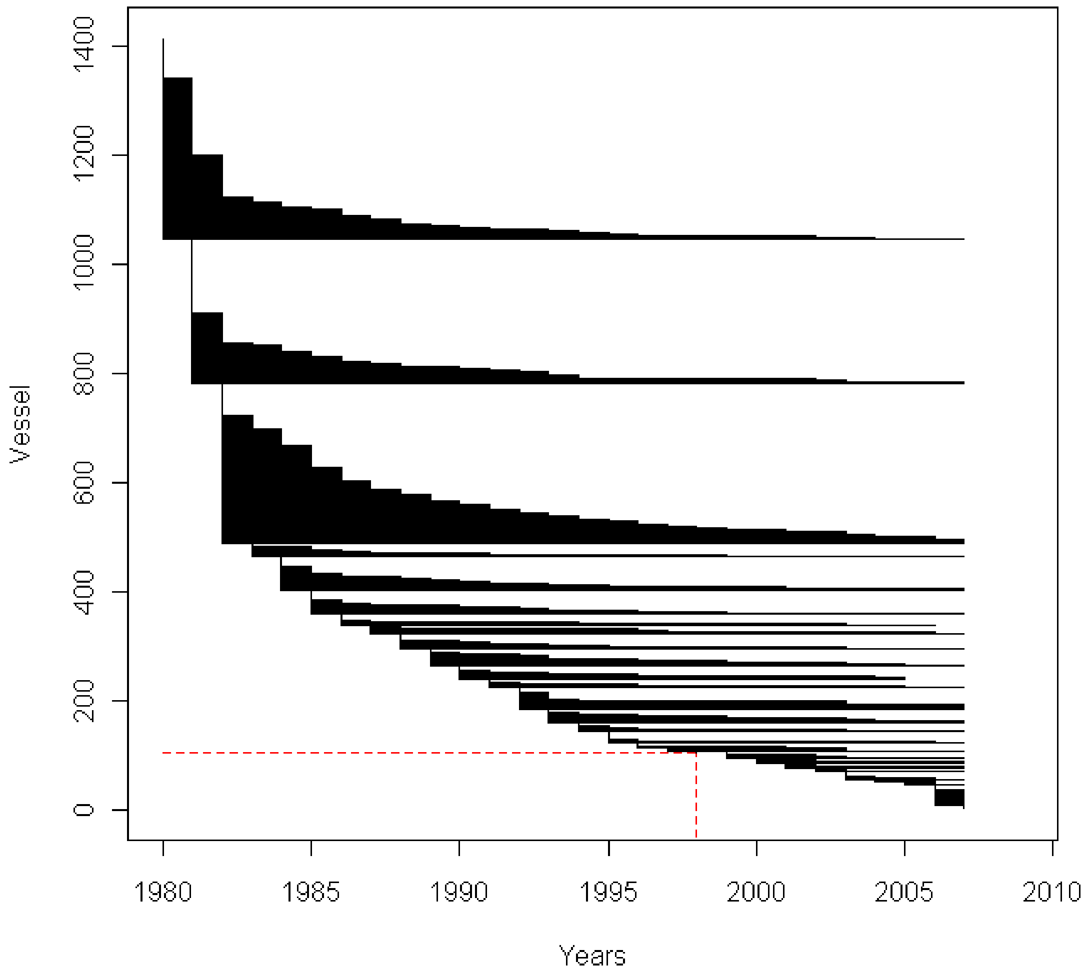


Figure 33: Ratios of yellowfin CPUE indices, to compare targeting indicators, and aggregated vs operational data. All options are compared with a delta lognormal GLM on operational data (op delta). Options labelled 'op+0.5' apply a GLM with response variable ((catch+0.5) / effort) to operational data. Options labelled agg use aggregated data.



Vessel
1400
1200
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
Years

Figure 34: Distribution of first and final years of observed effort by all Japanese DW LL vessels reporting effort in region 3. The red dashed lines mark 1998, the point at which the discontinuity in the changes in the estimated fishing power occurs.

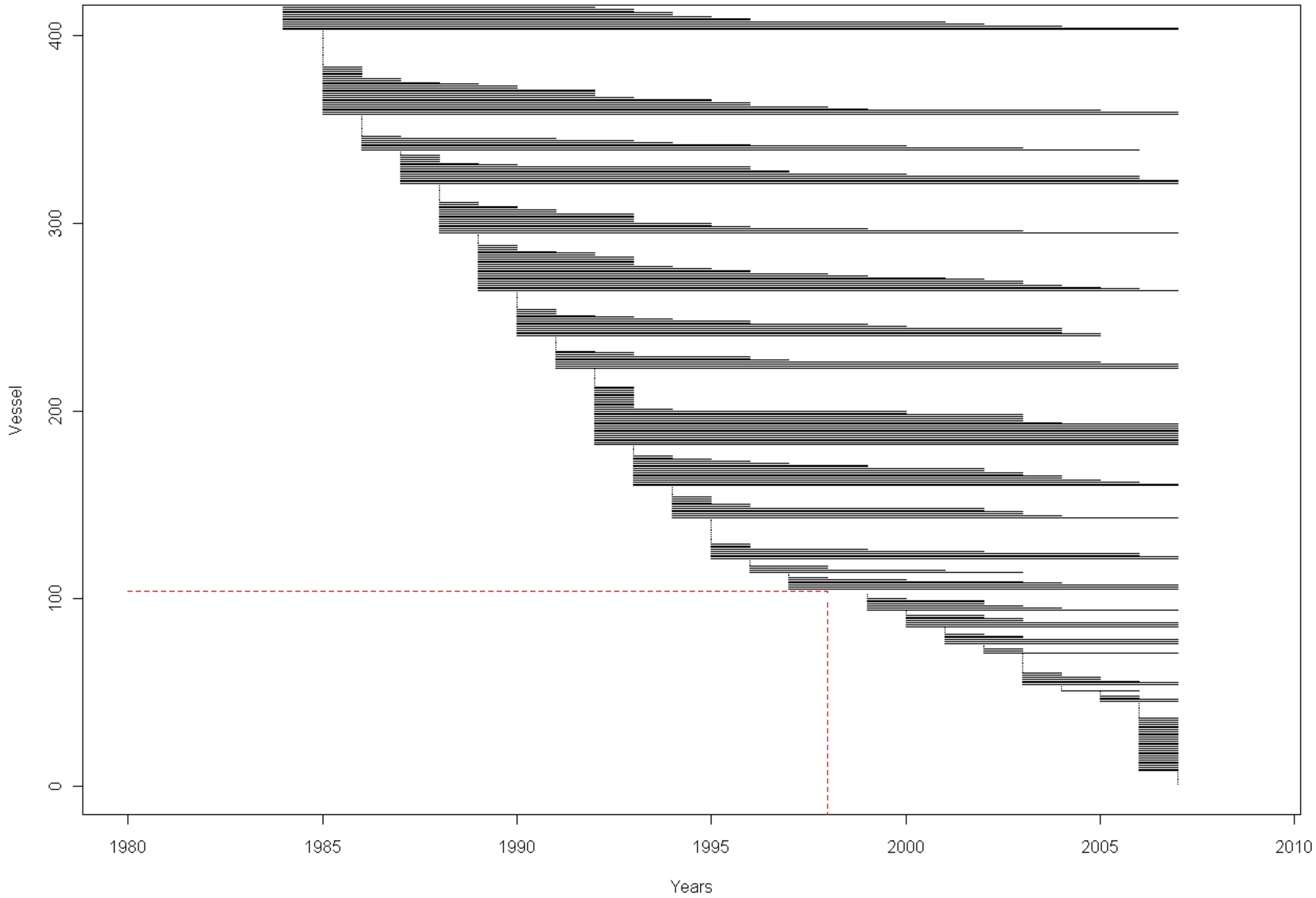


Figure 35: Distribution of first and final years of observed effort by Japanese DW LL vessels reporting effort in region 3, for the 400 vessels that first reported most recently. The red dashed lines mark 1998, the point at which the discontinuity in the changes in the estimated fishing power occurs.

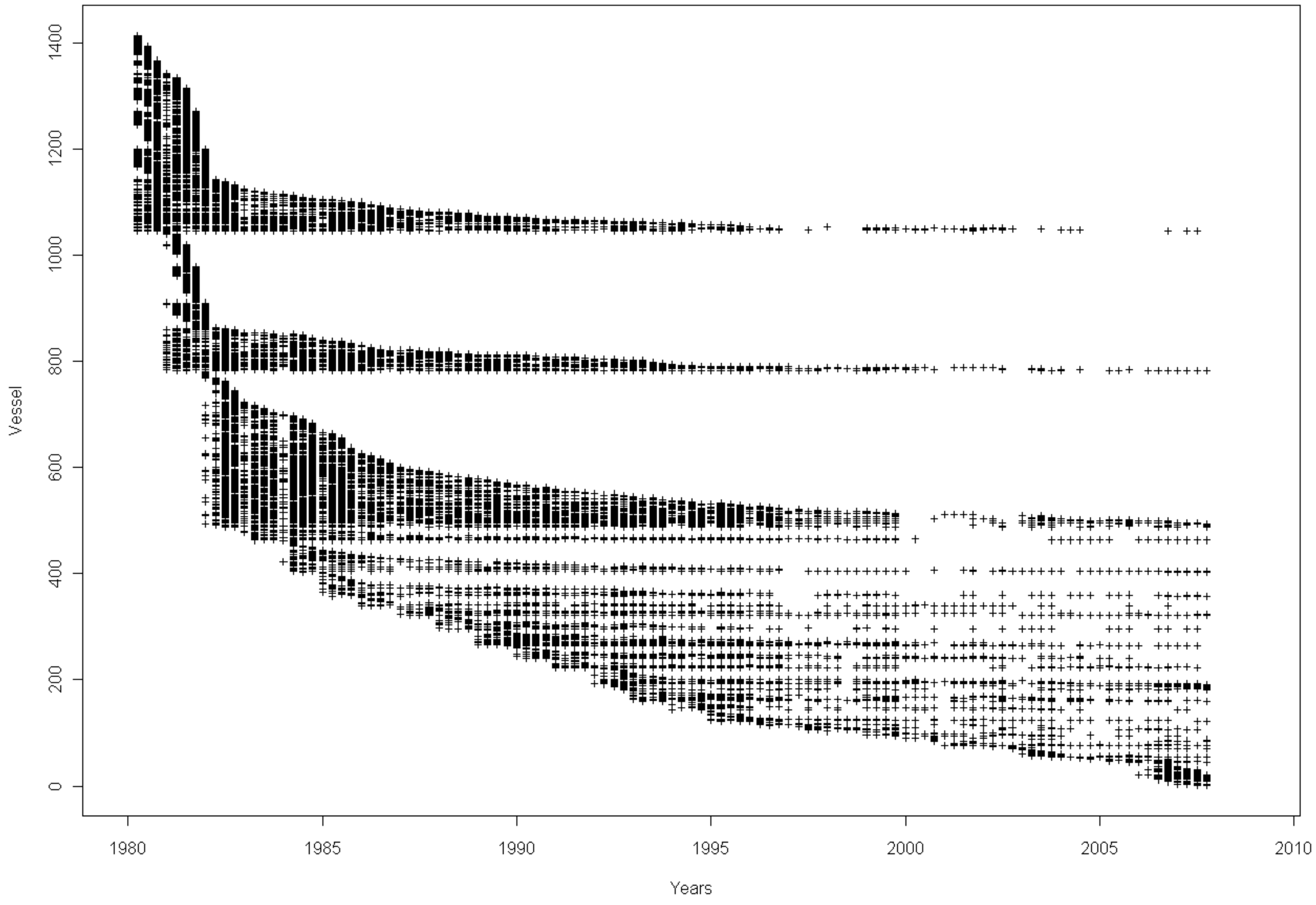
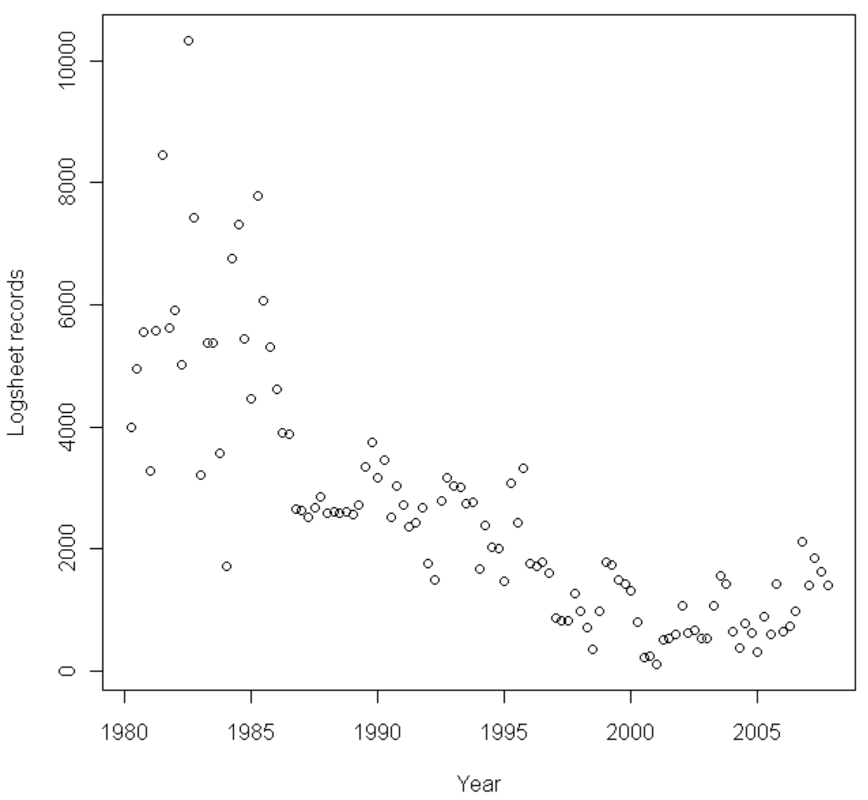


Figure 36: Logbook entry presence and absence by vessel and quarter for vessels included in the full fishing power analysis. Vessels are sorted by (a) year of first logsheet and (b) year of last logsheet.



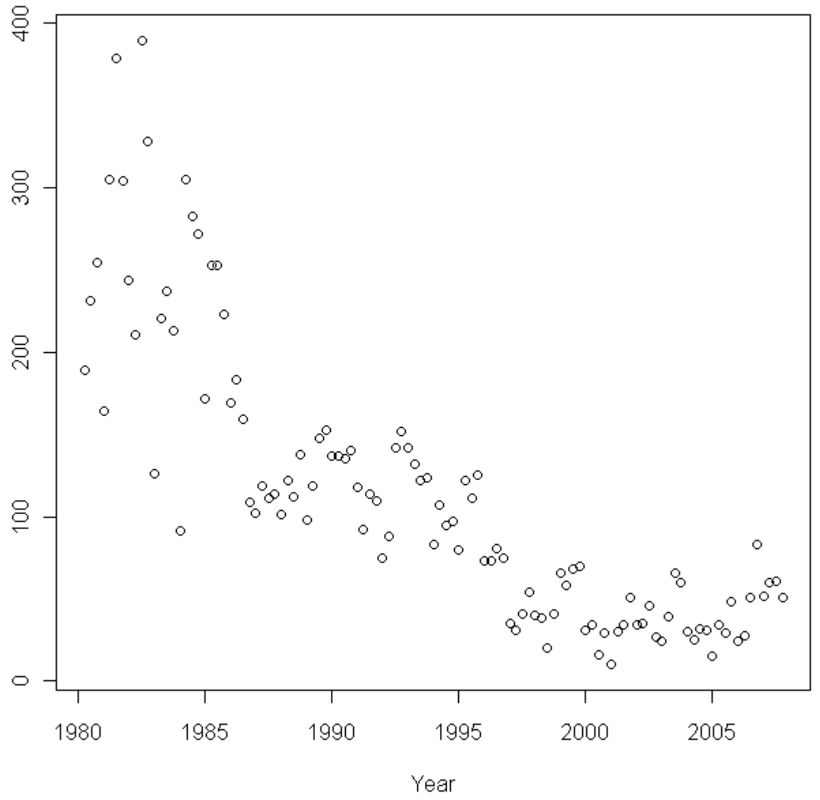


Figure 37: Number of logsheet records (left) and unique vessels (right) by year and quarter, for Japanese DW LL vessels fishing in region 3.

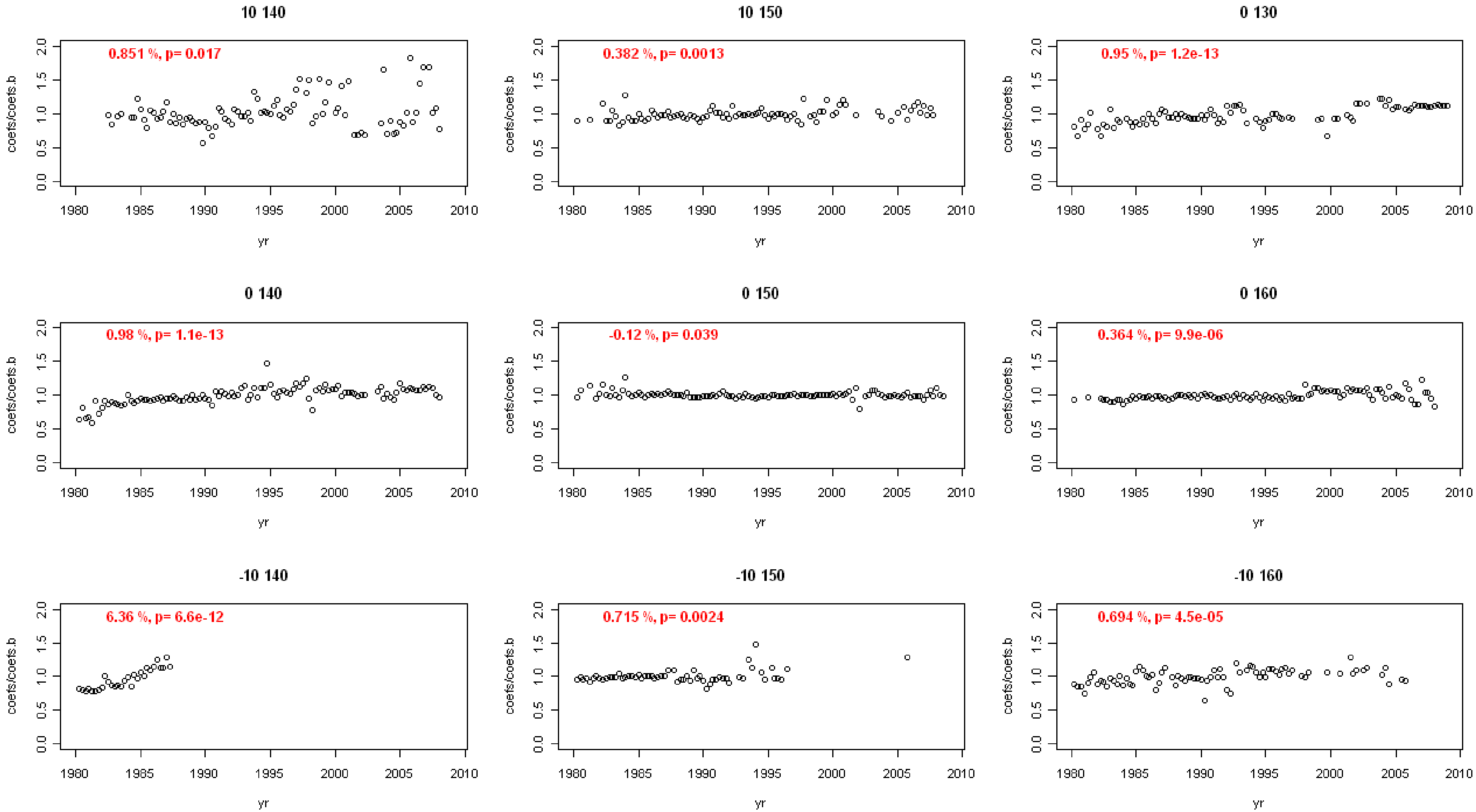


Figure 38: Impact by 10 degree square of increasing fishing power on bigeye CPUE abundance indices, estimated using vessels with at least 25 quarters of effort.

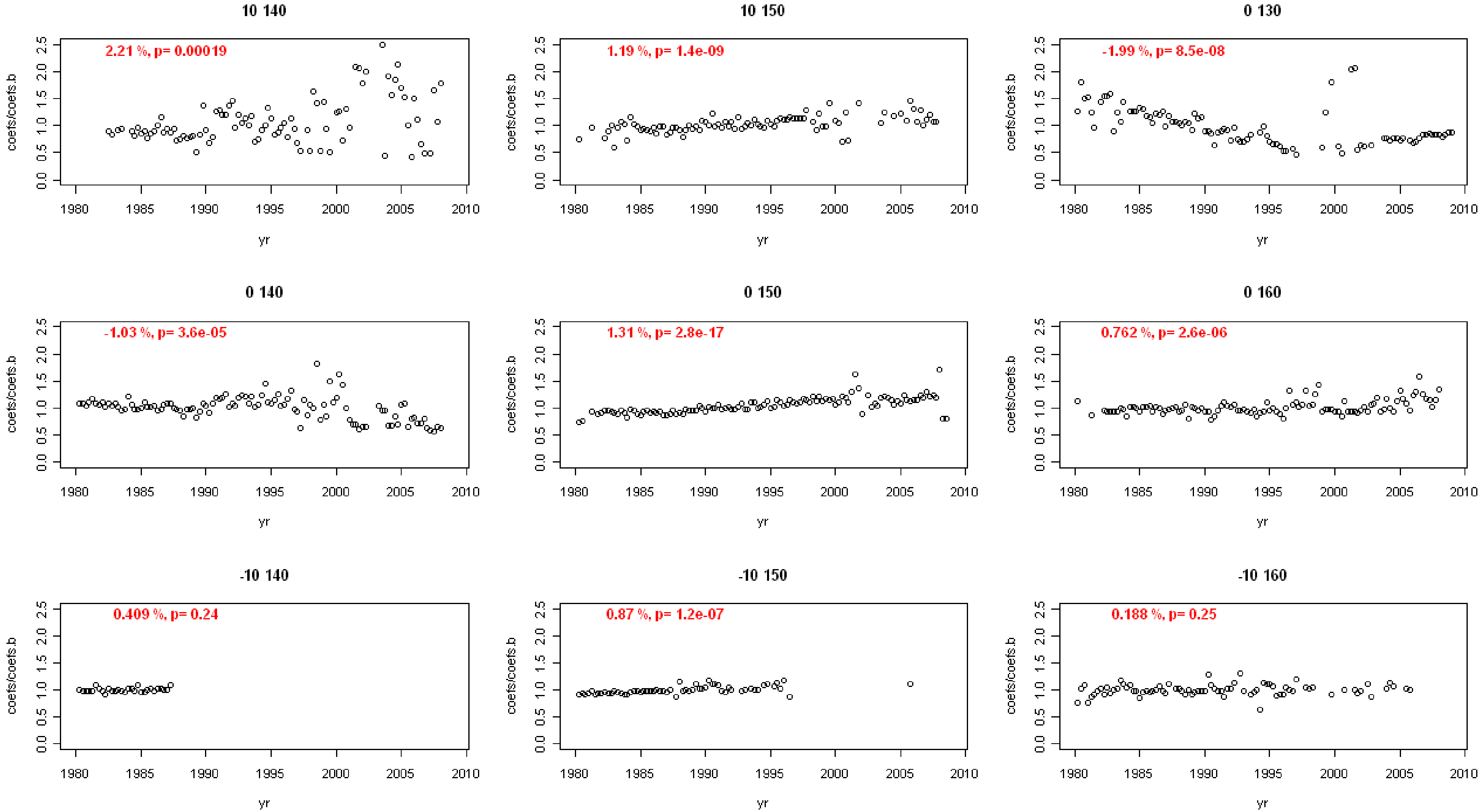


Figure 39: Impact by 10 degree square of increasing fishing power on yellowfin CPUE abundance indices, estimated using vessels with at least 25 quarters of effort.

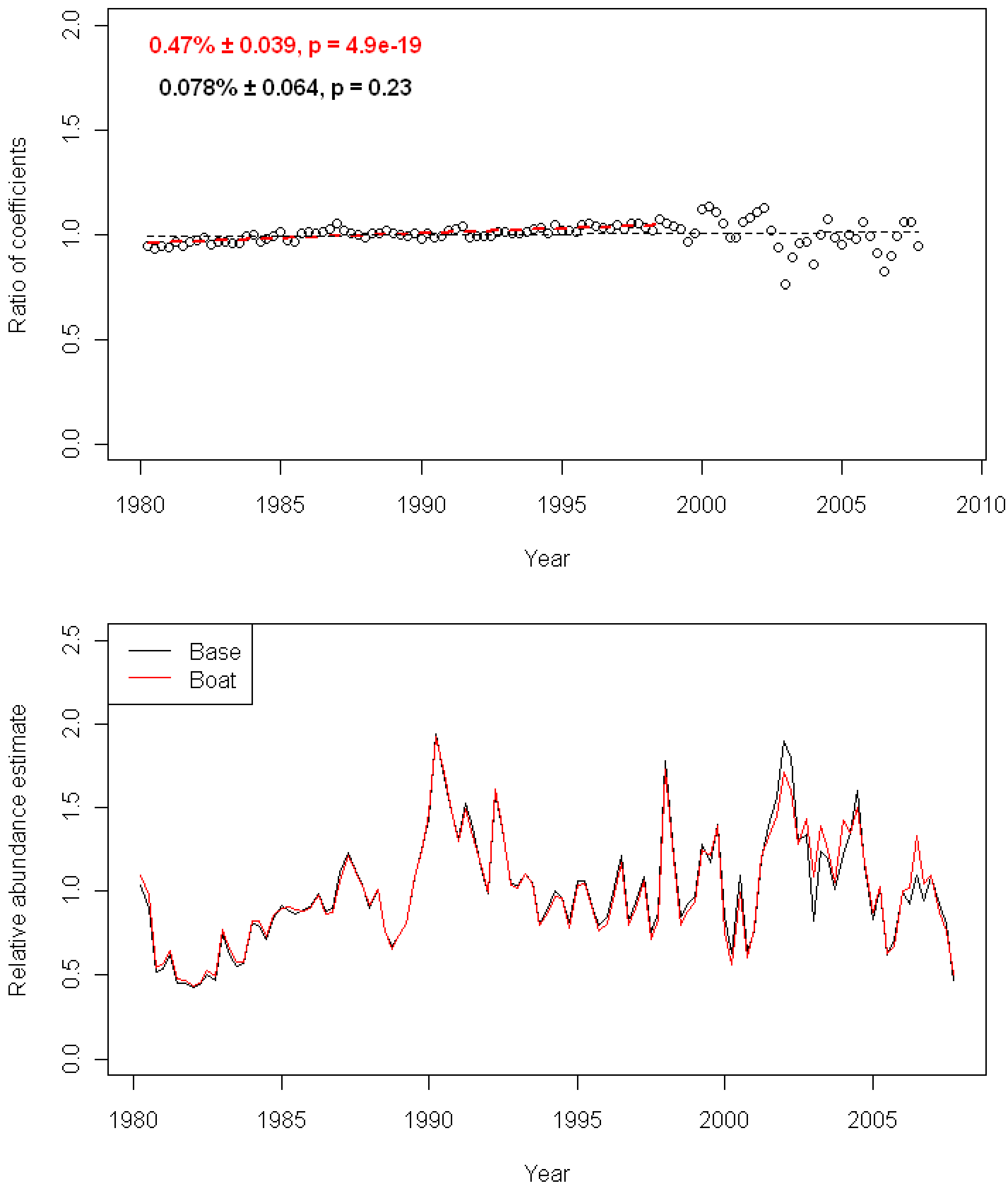


Figure 40: Impact of increasing fishing power on bigeye CPUE abundance indices, estimated using all region 3 data and vessels with at least 10 quarters of effort.

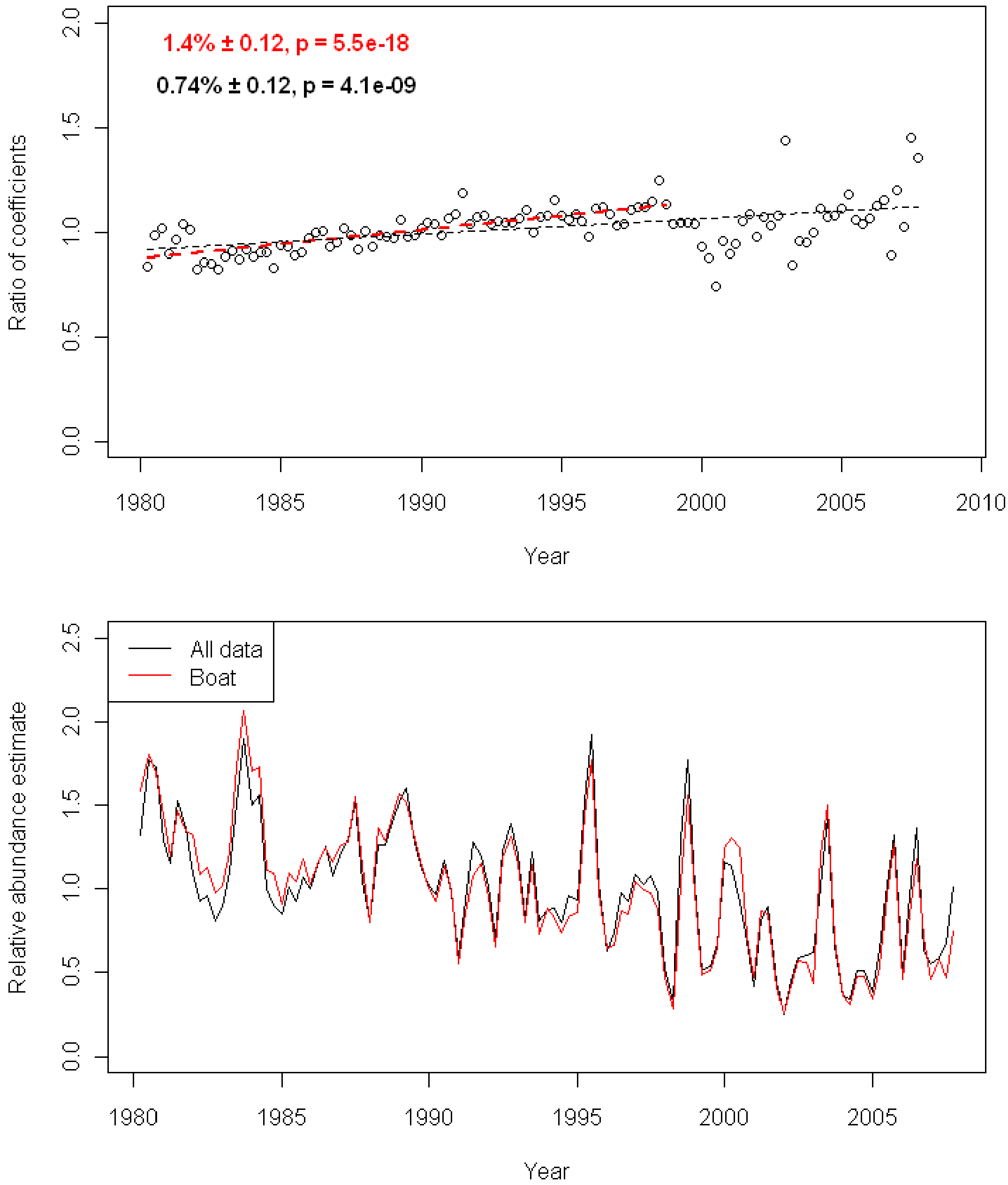


Figure 41: Impact of increasing fishing power on yellowfin CPUE abundance indices, estimated using all region 3 data and vessels with at least 10 quarters of effort.