SCIENTIFIC COMMITTEE
TENTH REGULAR SESSION

Majuro, Republic of the Marshall Islands
6-14 August 2014

Analyses of longline catch per unit effort data for bigeye and yellowfin tunas

WCPFC-SC10-2014/SA-IP-03

McKechnie, S.[1], Harley, S.[1], Chang, S-K.[2], Liu, H-I.[3], Yuan, T-L.[2]

[1]Oceanic Fisheries Programme (OFP), Secretariat of the Pacific Community, Noumea, New Caledonia

[2]National Sun Yat-sen University, Kaohsiung, Taiwan

[3]Overseas Fisheries Development Council of the ROC, Taipei, Taiwan

1. Executive Summary

Standardised catch-per-unit-effort (CPUE) indices extending until the last quarter of 2012 are needed for the 2014 assessments of Bigeye (BET) and Yellowfin (YFT) tuna. Unfortunately, the operational data for the Japanese longline fleet (JPLL) that were used to estimate the CPUE indices for the 2011 assessments were unavailable and thus these indices could not easily be updated. This paper presents the methods used to produce indices for the 2014 assessments.

The first technique "splices" together the JPLL operational indices of Hoyle and Okamoto (2011) that are available until quarter 4 2010 with JPLL aggregate indices (aggregate data is held by SPC) that extend until quarter 4 2012. The second technique analyses SPC-held operational-level longline (LL) data for all available fleets in each assessment region, including extra data for the Chinese-Taipei (TW) fleet (not held by SPC) in regions 4 and 6 which were analyzed during a collaboration exercise.

A vessel variable is used within a Generalized linear model (GLM) framework to try to account for changes in the fishing efficiency within and between fleets over time, and clustering analyses are used to partition fishing effort into discrete groups that represent different modes of operation with respect to species targeting. The all fleets standardisation therefore attempts to meet two of the major recommendations of the independent review of the 2011 BET stock assessment, namely; produce indices that are not biased by the spatial contraction of effort of the JPLL fleet, and produce indices that account for changes in species targeting over the stock assessment period.

The resulting spliced JPLL and all fleets indices had largely similar dynamics in most regions where they are both available. The exceptions were a much higher estimated abundance for the all fleets indices for both species before about 1970 in Region 4, and a similar phenomenon for BET in Region 6. In some cases the clustering analyses led to indices with higher or lower trends in CPUE than the nominal and JPLL indices due to shifts in the prevalence of different clusters over time.

The all fleets indices are available for new regions 7 and 8 for where operational JPLL indices do not exist, and have far more complete indices for region 6 where the JPLL indices have very few data after the early 1970s. It is recommended that the all fleets indices are used for the assessment models for the regions where they are available and the spliced JPLL indices are used for the other regions and region 4 for BET where the index severely conflicted with other data sources in the stock assessment model.

2. Introduction

Standardised CPUE indices are a vital input for all stock assessments of tuna carried out by the Secretariat of the Pacific Community (SPC) using Multifan-CL (MFCL). As stock assessments have developed over a number of years, large changes in the standardisation process have occurred including a shift from aggregated to operational-level data (Hoyle 2011). Despite placing a heavy emphasis on developing robust indices, the reliance on data obtained from commercial fishing vessels will always prove challenging for producing indices that are proportional to abundance of the stock. In the case of BET and YFT there has been evidence of conflict between the CPUE series and other datasets (e.g. catch, size frequencies, tagging data) in previous assessments (Davies *et al.* 2011, Langley *et al.* 2011). This problem was highlighted in the independent review of the 2011 Bigeye tuna assessment

(BET review; Ianelli *et al.* 2012) and the review panel made several recommendations with respect to either improving standardizations or assessing the assumptions of the currently-used methods.

Previous BET/YFT assessments carried out by SPC in MFCL (Fournier *et al.* 1998) have relied on standardised indices estimated using operational data for the JPLL fleet (Hoyle and Okamoto 2011). There are several concerns with this approach; 1) The effort expended by the JPLL fleet has declined over the last several decades and has contracted spatially, potentially affecting CPUE indices if the contraction has been towards cells with higher or lower catch rates and different trends in catch rates, 2) The operational JPLL data has been identified as the preferred dataset for standardisations, however it is not freely available to SPC and requires travel to Japan to estimate/update indices, 3) There is conflict between the CPUE data and other data sources (e.g. catch) in the stock assessment model that suggest that one or more may be substantially biased.

The BET review identified several avenues of potential research with respect to the CPUE standardisations, including investigating changes in targeting and the spatial contraction of the JPLL fleet (Ianelli *et al.* 2012). Targeting issues have recently been explored for the JPLL operational-level data in Regions 3 and 4 (Hoyle and Okamoto 2013) but have not been incorporated into CPUE standardisations, and changes in targeting in other regions have not been investigated. Furthermore, the implications of spatial contraction of fishing effort remain outstanding despite a preliminary investigation that was presented at SC9 (McKechnie *et al.* 2013) for the JPLL operational-level data in Region 3.

While the effort of the JPLL fleet has contracted over time, the effort and spatial distribution of other fishing nations has expanded. An approach that simultaneously analyses operational-level data for multiple fleets has the potential to overcome some of the issues of spatial contraction of individual fleets (in this case JP). This approach generally proceeds by modelling data using a vessel variable (rather than a fleet variable), under the assumption that CPUE is generally more affected by the characteristics of the individual vessel, including the skipper and crew, rather than the fleet it belongs to. A similar approach has been used to calculate the CPUE indices for South Pacific albacore (Bigelow and Hoyle 2012) and those indices were the basis of the most recent stock assessment of that species (Hoyle *et al.* 2012). This paper presents the methods used to estimate new CPUE indices for BET/YFT based on these datasets.

Consequently, there are now multiple methods available for calculating BET/YFT indices for each assessment region and on different datasets (JPLL operational vs all fleets operational). Choices need to be made about the most suitable indices to use in the 2014 assessment, and if/which indices should be included in sensitivity analyses. The aims of this paper are therefore manifold:

- As an alternative to relying on JPLL data that is not openly available to SPC, develop CPUE indices from operational-level data that is available and does not display the same spatial contraction of effort as JPLL data.
- Investigate clustering analyses that can partition fishing activity into different groups based on targeting practices, and use the resulting cluster variables to help account for the effects of changing targeting over time on CPUE.
- Refine methods to standardise this diverse dataset.
- Update the JPLL aggregate CPUE indices and investigate the potential to combine the JPLL aggregate with the JPLL operational indices such that the latter (which are

preferred on scientific merit) can be used for most of the assessment period with the indices for the time period since the analysis of Hoyle and Okamoto (2011) estimated from the former.

- Present all CPUE indices available for each region in the new assessment regional structure (McKechnie *et al.* 2014) and highlight their strengths and weaknesses.
- Identify which indices are most suitable for use in reference case assessment models and which might be suitable for use in sensitivity runs.

3. Methods

3.1. Data preparation

3.1.1. SPC-held operational-level data

All available (to SPC) operational-level LL data for all fleets operating in the WCPO were extracted from the SPC database. All sets were assigned to the BET/YFT WCPFC stock assessment regions (Figure 1; and see McKechnie *et al.* 2014 for further details) and those outside of those regions were discarded. The time-step for the BET/YFT assessment models is the year-quarter scale and so this was the focus of the CPUE indices produced here.

The operational data available in each region comes from a variety of fleets including both distant water fishing nations and Pacific Island Countries and Territories (PICTs), with the relative amounts for different fleets related to the EEZs present in the regions and provision of data for those regions by Distant Water Fishing Nations (DWFNs). For example, there is extremely limited data available for Regions 1 and 2 as they are dominated by high seas and data provision by DWFNs is low, while Region 6 has more extensive EEZ coverage and additional logsheet data is available from the cannery in Pago Pago.

Coverage of the operational data for the DWFNs outside PICT EEZs is very poor which results in spatial gaps in data for some regions, especially in high seas areas. This is obviously far from ideal for constructing indices of abundance for whole regions.

In February 2014 personnel from the National Sun Yat-sen University and the Overseas Fisheries Development Council of the ROC travelled to SPC with the full TW operational LL dataset to resolve issues related to resolving differences in the holdings of TW data between SPC and TW and to allow SPC to undertake CPUE standardisation on the full operational datasets. This data could not be retained by SPC and so in the limited time available, this initial collaboration between TW and SPC focused on the most important regions for CPUE standardisation and within these, a more restricted set of analyses had to be conducted compared to other regions. For example, the full step plots could not be produced (run-time for the full set of models would have been prohibitive) and some diagnostics are unavailable as R model objects could not be retained if confidentiality of data was to be ensured. Regions 4 and 6 were chosen as TW is a very important fleet there and the data that could be added to that held by SPC had the potential to significantly increase the spatial coverage of the data, and consequently improve the quality of the CPUE indices in these regions.

3.1.2. Data cleaning and clustering

The full dataset was split into individual datasets for each region and analyses were conducted separately on each. These datasets contains records from a variety of fleets and individual vessels targeting different species, with the target perhaps changing at a variety of time-scales. Clustering techniques are often used in these situations in an attempt to reduce the effects of changes in targeting through time on CPUE of the focal species (He *et al.* 1997, Hoyle and Okamoto 2013). Clustering methods used here closely follow those of Bigelow and Hoyle (2012). Sets were pooled over trips to reduce the effects of random variation when calculating the catch composition of tuna. Proportions of individual species were calculated by dividing their catch in numbers by the sum of the total number of BET, YFT and albacore (ALB) caught on the trip. Prior to applying clustering analyses, the dataset in each region was reduced by removing records that were considered to have the potential to bias calculation of standardised CPUE for example vessels that only fished for a very small number of quarters

Geographical position of individual sets was available at different scales for different fleets and so they were assigned to the coarsest scale in the dataset, which was to 5×5° spatial cells. Sets were only retained for year-quarters and 5×5° spatial cells where the number of sets was considered sufficient for fitting Generalized Linear Models (GLMs). The time-period modelled was region-specific and dependent on the fleets operating in the region as data availability depends not only on the timing of the establishment of the fishery but also the time-period over which logsheet data was provided to SPC. Data for vessels fishing in less than a certain number of quarters within the region were discarded to minimise non-representative fishing effort from influencing CPUE indices. The cut-off was region-specific owing to the need to prevent loss of too much data while allowing robust vessel coefficients to be estimated and clustering algorithms to be undertaken with available computing resources. Vessels had to fish for 10 or more quarters for most regions with the exceptions being Regions 7 and 8 (5 quarters; many fewer data were available here and so the cut-off was less strict), Region 6 (12 quarters; maximum amount of data that could be analysed on the computer provided by TW) and Region 3 (15 quarters; maximum amount of data that could be analysed on the SPC computers).

The process of reducing the data to a set suitable for fitting models was consequently: remove data for year-quarters with insufficient sets, remove data for vessels fishing less than the limit of number of quarters fished, remove data for trips where no focal tuna (ALB, BET, YFT) were captured (trips where other species such as Southern Bluefin tuna were targeted for example) or less than five sets were fished, and finally again remove data for vessels fishing less than the required number of quarters. This last step was introduced to prevent the case where data for certain vessels was very sparse after the year-quarter/spatial cell and no tuna reductions were applied, and so ensuring the robust estimation of the vessel coefficients. The consequences of these data-cleaning decisions with respect to catch and effort of the focal species in each region are displayed in Table 1.

Initial standardisations in Region 5 indicated unusual behaviour in the fleets during the mid-1990s which, during the pre-assessment workshop (April 2014; OFP 2014), was hypothesised to be related to the rapid expansion of swordfish (SWO) targeting by many vessels in the AU LL fleet. The workshop suggested including SWO in cluster analyses for this region only and these are the datasets and analyses presented in this paper for Region 5.

For the cleaned datasets, Ward's minimum variance method of hierarchical cluster analysis (Ward 1963) was utilised to partition fishing trips into clusters. Squared Euclidean distances were calculated for the full dataset of fishing trips across the whole time period and the hierarchical clustering was conducted using R function `hclust`. The number of clusters appropriate for the dataset was assessed in a pragmatic manner by considering the dendrogram and investigating the properties of the individual clusters. For example, the clusters will become less likely to reflect different targeting practices beyond a certain level of complexity of clustering. The consequences of differences in the choice of the number of clusters with respect to standardised indices were investigated using sensitivity analyses (see section **Error! Reference source not found.**).

3.2. Operational standardisation

3.2.1. Reference models

Delta-log-normal (DLN) standardisation models were developed for the operational data using GLM-based methods and were similar to those previously used for operational JPLL analyses (e.g. Hoyle and Okamoto 2011). The proportion of positive catches of the focal species (BET or YFT) at the set level were modelled using binomial GLMs with a binary response variable (y_i ; 1 = ≥ 1 fish of the focal species caught, or a 0 = zero fish of the focal species caught in set *i*)

$$y_i \sim \mathrm{Bernoulli}(p_i)$$

a logit link function, and the linear predictor

$$log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_{year-qtr[i]} + \beta_{cell[i]} + \beta_{vessel[i]} + \beta_{cluster[i]} + \beta_{hook} \times hooks_i$$

where the $\beta_{year-qtr[i]}$, $\beta_{cell[i]}$, $\beta_{vessel[i]}$ and $\beta_{cluster[i]}$ are year-quarter (manually constructed by concatenating year and quarter), 5×5° spatial cell, individual vessel and targeting-cluster coefficients for the factor levels of each variable observed for set *i*. Parameter β_{hook} is the coefficient for the continuous variable of hundreds of hooks for set *i*, $hooks_i$.

The log-normal component had a very similar linear predictor and the full GLM is given by

$$logy_i \sim \mathrm{Normal}(\log \mu_i\,, \sigma^2)$$

$$log\mu_i = \beta_0 + \beta_{year-qtr[i]} + \beta_{cell[i]} + \beta_{vessel[i]} + \beta_{cluster[i]}$$

Where $logy_i$ is the log CPUE (catch-in-numbers divided by hundreds of hooks), $\log \mu_i$ is the expected log CPUE, and the coefficients in the linear predictor have the same interpretation as for the binomial component. Weightings were given to each set being modelled to prevent changes in the spatial distribution of effort from biasing CPUE indices, as highlighted by Punsly (1987) and Campbell (2004). The weightings were calculated so that the weightings of all sets within each year-quarter-5×5° cell combination summed to one.

Note that the linear predictors for both components are relatively simple as other variables that are often used in standardisations (such as hooks-between-floats (HBF) and bait-type) were not available for all fleets. However, due to the inclusion of HBF in operational and aggregate JPLL CPUE standardisations, the consequences of excluding this variable were assessed by plotting model residuals versus HBF.

Backwards stepwise model selection using AIC (R function `stepAIC`) was used to check whether any reduced models were more parsimonious than the full model above. This method selected the full model for each region.

Indices for the individual components (binomial and log-normal) were estimated using the `predict` function using the most common level for each categorical variable and the mean value across all sets for continuous variables. The two components were then combined by multiplying them on the appropriate scale to produce the DLN index (Maunder and Punt 2004). Approximate time-varying coefficients of variation (CVs) were calculated using estimates of variation from the log-normal GLM component, as was decided during the pre-assessment workshop 2013 (OFP 2013). The CV for each year-quarter was the standard error of the year-quarter effect on the log-scale calculated using Francis (1999)'s canonical method. Note that these CVs are rescaled before use in the stock assessments as they are acknowledged to substantially underestimate the variance needed for the assessment model.

CPUE indices were transformed by dividing by their mean across the time period they were calculated to make different indices directly comparable on the same scale. Where indices are directly compared in figures the mean CPUE used in the normalization of both indices is calculated over a common set of year-quarters (the set available for the shorter index).

3.2.2. Sensitivity analyses and step plots

Several alternative models were fitted in addition to the "best" or "reference" model which differed in the variables permitted in the linear predictor. A major source of uncertainty is whether the clusters identified and modelled are a reliable index of targeting. The effect of erroneous choice of the number of clusters was tested by fitting models with the clustering variable having one more, or one less cluster than was chosen for the reference model. To test the consequences of the cluster variable being a poor representation of actual targeting of fishing, the reference model was refitted with the cluster variable excluded.

Step plots were used to understand the influence of individual variables on the resulting standardised indices. This involved fitting a sequence of models from the reference model (with the full set of predictor variables) to the most simple one-variable model, with a single variable being removed at each step. The order of removal in each region, for each species was *cluster*, *vessel* then *spatial cell*, with the simplest model containing only the variable *year-quarter*.

For all alternative models (sensitivities and step models), the changes to the linear predictors were made to both the binomial and log-normal components and the standardised DLN indices were calculated and compared to the reference model.

GLMs with alternative distributional assumptions were also considered, for example the negative binomial GLM with catch in numbers as the response and number of hooks in the set as an offset. These models had difficulty (as assessed by simulating data from the fitted model and comparing it to the observed data) in fitting both the number of zeros observed and the upper tail of the number caught, This was especially true in equatorial regions where catch appears to be more of a mixture of distributions, which are better fitted using the DLN approach. Zero-inflated models (e.g. ZINB) were also considered but were unstable and impractical owing to the computational demands with the extremely large datasets.

3.3. JPLL indices

Methods for standardising the aggregated JPLL data were identical to the last occasion that these indices were calculated (Hoyle and Okamoto 2011). An extra 8 quarters of data were extracted from databases to extend the time series to the 4th quarter of 2012. The models were constructed by discarding records with zero catches for the focal species and fitting a Gaussian GLM to the log counts (C_i) of the species in focus (BET or YFT) e.g.

$$\log C_i \sim \mathrm{N}(\log \mu_i, \sigma 2)$$

where the linear predictor is specified

$$log\mu_i \; = \; \beta_0 + \beta_{year-qtr[i]} + \beta_{cell[i]} + f(hbf[i]) + g(\log hooks[i])$$

where $\beta_{year-qtr[i]}$ and $\beta_{cell[i]}$ are factors for the year-quarter and 5° spatial cell for record *i*, $f(hbf[i])$ denotes a 7th-order polynomial relationship for the HBF covariate and $g(\log hooks[i])$ denotes a cubic spline with 10 degrees of freedom for the relationship with the log of the number of hooks for record *i* .

The standardised estimate of abundance (and its standard error) in each year-quarter were estimated using the `predict` function in R. This index of abundance for the aggregated data was combined with the standardised indices for operational data given by Hoyle and Okamoto (2011) using the following methods. If a_t and o_t are the estimated abundances for the aggregate and operational datasets in year-quarter t, then the weighted mean of their ratio over the 5-year period (20 quarters) from 2005 quarter 1 (n_1) to 2009 quarter 4 (n_2) was

$$\mu_r = \frac{\sum_{t=n_1}^{n_2} w_t \times \frac{o_t}{a_t}}{\sum_{t=n_1}^{n_2} w_t}$$

where the w_t are the weights calculated as the inverse of the variance estimate of o_t. The index of abundance for the period 1952-2009 was taken to be o_t. Note that Hoyle and Okamoto (2011) estimated an index for the four quarters in 2010 but for some regions these estimates were extreme and appear to be related to low sample sizes, possibly due to incomplete data (at the time of the analyses) for that year. For this reason the operational index was truncated at 2009. The index of abundance for the 12 quarters 2010-2012 was then the index for the aggregated data adjusted for the weighted mean ratio, e.g. $\mu_r \times a_t$.

3.4. Standardisation of aggregate data with spatial splines

A spatial spline approach was used to calculate regional weighting factors for the BET/YFT assessments (McKechnie *et al.* 2014) and the same models can be used to produce CPUE indices. These indices were not used in the 2014 assessments but are presented here for reference. Aggregate catch and effort data at the 5×5° scale for the LL fleets from JP, Chinese Taipei and Korea was extracted for the entire Pacific Ocean. The data was separated into individual year-quarters for analyses and CPUE was calculated for both species. A Generalized Additive Model (GAM) was fitted to each year-quarter separately and was of the form

$$logy_i \sim \mathrm{Normal}(\log \mu_i \, , \sigma^2)$$

$$log\mu_i \; = \; \beta_0 + f(long_i, lat_i) + \; \beta_{flag[i]}$$

where $logy_i$ is the log of CPUE (numbers of fish caught per 100 hooks, with a constant of 0.01 added to prevent taking the log of zero), $log\mu_i$ is the expected log CPUE and

$long_i$, lat_i, and $flag_{[i]}$ are the longitude, latitude (both at the midpoint of the 5×5° cell they represent) and flag, all of the *i*th record. Function f is an isotropic smooth function of latitude and longitude and so predictions from the model can be made that give a two-dimensional surface of CPUE over the geographical model area for each year-quarter. Because the splines are continuous over the area, predictions can be made for both cells with observations (fitted values) and cell without observations (imputed values). The standardised index for a given assessment region in a year-quarter were the sum of the predicted CPUE values for each 5×5° cell within that region in that year-quarter.

4. Results

4.1. All fleets operational standardisations

4.1.1. Region 3

A large amount of data was available for Region 3 (Table 1), starting from around 1979 (Figure 2). The catch composition is dominated by BET and YFT with the proportion of total catch in numbers of the former steadily increasing over the time period of the data. The rules for cleaning the data resulted in a dataset of about 400,000 sets available for modelling (Table 1).

The clustering analysis first split the trips into two clusters, one with a very high proportion of BET and the other with high YFT (Table 2 and Figure 3). The later cluster was then split into a very high YFT cluster and a cluster with more even numbers of BET and YFT. Three clusters were chosen as the reference case for Region 3, with two, four and no clusters investigated in sensitivity analyses. Figure 4 shows the spatial distribution of the three clusters in the reference model and displays a tendency for effort in clusters with high YFT catch to be well spread across the parts if the region where data is available, while the cluster with high BET catch is more restricted to the more northern part of the region and away from the archipelagic waters of Papua New Guinea (PG) and the Solomon Islands (SB).

Figure 5 shows the composition of the dataset by fleet and cluster and shows a shift in the relative proportion of sets in clusters from the high YFT cluster (cluster 2: green) in the early period to the high BET (cluster 3: blue) and moderate BET and YFT cluster (cluster 1: red). This is most noticeable for the JP fleet for which effort declines over the time period with the importance of other fleets (e.g. China (CN), Federated States of Micronesia (FM), TW) increasing in later years.

Standardised CPUE indices for the all fleets data for BET and YFT in Region 3 are relatively similar to the JPLL indices calculated for the old Region 3 (new Regions 3, 7 and 8 combined) and the standardisation resulted in an increased and decreased negative trend in CPUE of BET and YFT, in comparison to their respective nominal indices (Figure 6). The step plots (Figure 7) show that much of the differences from the nominal can be attributed to the cluster variable, and to a lesser extent, the vessel variable. The sensitivity analyses indicated that there were few differences between standardised indices produced assuming 2, 3 or 4 targeting clusters (Figure 7).

4.1.2. Region 4

Operational data in Region 4 was available from the mid-1960s and the dynamics of the catch composition was more complicated than in Region 3 (Figure 2). The proportion of ALB in the catch decreased rapidly over the 1970s and 1980s, the proportion of YFT increased over the same period before declining moderately until the present, while the proportion of BET increased steadily over the whole time-series to become the numerically dominant species in the catch.

The reference standardisation model for Region 4 was selected to have three clusters identified by the clustering; a cluster with a very high proportion of BET (cluster 1), a cluster with a very high proportion of ALB (cluster 2) and a cluster with a moderate proportion of BET and YFT and less ALB (cluster 3; Table 2). Cluster 3 includes effort across most of the distribution for which data is available, as does cluster 1, although for the latter there is a significant concentration of effort in the area immediately southwest of Hawaii (Figure 4). The albacore cluster (2) is largely restricted to the southern area of Region 4 below about 5S.

Most of the effort in the dataset for Region 4 is attributable to the DWFNs with KR becoming dominant after about 1990 and a significant amount of data available for TW in the early and late parts of the time-series. There is a strong shift from the ALB cluster to the cluster with moderate proportions of BET/YFT (cluster 3) and especially to the high BET cluster (cluster 1).

The reference standardised indices for both BET and YFT exhibit strong declines in abundance over the whole time-period (Figure 6), and the rate of this decline was higher than that of both the JPLL and nominal indices for both species. There is some sensitivity to the choice of number of clusters in Region 4, with the two cluster standardisation producing indices more similar to the nominal indices than the reference standardised indices, while the four cluster indices are virtually indistinguishable from the reference indices (Figure 7). This is because the two cluster model includes albacore targeting in a cluster with moderate proportions of BET and YFT and this cluster is prevalent over the time-series. Models with three or more clusters separate out the targeting of ALB and, because this cluster has low CPUE of BET and YFT and is only prevalent in early years standardisation, increases CPUE above the nominal rate over that period.

4.1.3. Region 5

Operational data was available from 1979 in Region 5 and the species composition of the data is shown in Figure 2. YFT and ALB dominate the species composition with a general decrease, and increase in their proportions, respectively. Proportions of BET and SWO were generally low over the whole time period although during the late 1990s and early 2000s when both species became more prominent in the catch.

A standardisation model with four clusters was chosen as the reference model with the following clusters; 1) moderate catches of all four species, 2) a very high YFT cluster, 3) a cluster of moderately high YFT and ALB catches and very low BET/SWO catches, and 4) a very high ALB cluster. Each cluster was relatively well dispersed across the region although clusters with high YFT tended to be more restricted to the Australian (AU) east coast and the very northern part of the region.

There was a strong shift in the fleet composition of the data from a JP dominated fishery with a strong seasonal component in early years to AU dominance from the mid-1990s and increasing importance of TW and several PICT fleets from about 2000 onward. The relative proportion of the clusters remained relatively consistent over most of the time period, with the high ALB cluster becoming more prevalent in the last decade with the expansion of TW and the PICTs.

Standardised all fleets indices for both species were relatively similar to the JPLL and nominal indices (Figure 6), the cluster variable had a minimal effect on the resulting index for BET and a small effect for YFT, and the indices were very insensitive to whether 3, 4 or 5 clusters were chosen (Figure 7).

4.1.4. Region 6

Operational data in Region 6 was available from the early 1960s and over the whole time-period species composition is dominated by ALB catch with low catches of both BET and YFT. Three clusters were chosen for the reference standardisation model with the first two dominated by ALB catch (0.9 and 0.7 of catch in numbers) and the third had moderate proportions of ALB, YFT and to a lesser degree BET (Table 2). The clusters with higher proportions of YFT and BET displayed more effort in the northern parts of the region than the cluster with extremely high ALB for which effort was spread over the entire region (Figure 4).

TW and to a lesser degree South Korea (KR) were the numerically dominant fleets early in the time-series with PICT fleets, most notably Fiji (FJ) contributing significant effort from the late 1990s onwards. The cluster with an extremely high proportion of ALB (cluster 1) was the overwhelmingly dominant cluster over the whole period.

The standardised indices of both species exhibited strong declines in abundance with the rate of decline higher than either the JPLL or nominal indices. Seasonal variation in YFT CPUE evident in the nominal index was reduced in the standardised index. The cluster variable increased the rate of decline of CPUE indices for both species and the differences in standardised indices between models with 3, 4 or 5 clusters were relatively minor (Figure 7).

4.1.5. Region 7

Region 7 had very similar dynamics to Region 3 which can be summarised very briefly; the three cluster model had a high BET, a high YFT and a moderate of both clusters, there was a shift from clusters with higher YFT to clusters with higher BET, the standardised indices are similar to the JPLL indices in old Region 3 with an apparently stable index for BET and a declining index for YFT, there were moderate differences between the 2 and 3 cluster models but similar overall trends in CPUE while the 3 and 4 cluster indices were very similar. It is notable that the data available in Region 7 comes from a very restricted area of the entire region - the eastern equatorial zone and to a lesser extent the waters of the Philippines archipelago (PH).

4.1.6. Region 8

Much less data (76,000 sets) was available for Region 8, partly because of its smaller size. Three clusters were again chosen for the reference model; 1) very high YFT where effort is spread across the region, 2) moderate proportions of BET and YFT and low ALB, and 3) moderate proportions of YFT and ALB and low BET, with the later two clusters more prevalent in the southern and eastern parts of the region. Most data available is for the JP fleet and towards the end of the time-series, the PG fleets. The very high YFT cluster (1) is the numerically dominant cluster throughout. The standardised indices have several periods of missing data but the general trends appear to be a moderate decline and no obvious trend for BET and YFT respectively.

4.2. Alternative CPUE indices

The JPLL operational indices that were updated with aggregate indices spliced onto the end for the last 12 quarters did not display any profound changes in abundance over this period (Figure 8, Figure 9). The aggregate and operational JPLL indices for Regions 1 and 2 appear relatively stable over the last five years with substantial seasonal variation, and there are no alternative indices to which they could be compared. The most significant differences between the JPLL and all fleets indices occurred in Regions 4 and 6 where abundance declined at a higher rate for both species.

The GAM indices were estimated using the aggregate DWFN data and so show many similarities to the aggregate JPLL indices which use much of the same data. Consequently, the GAM indices show many of the same differences when compared to the all fleets indices (Figure 10, Figure 11), most notably the GAM indices decline at a slower rate in Regions 4 and 6 for both species, and in Region 8 for YFT.

5. Discussion

5.1. Standardised all fleets operational indices

This paper presents the development of a new set of CPUE indices for BET/YFT for Regions 3-8 and provides a comparison of all the LL CPUE indices available for use in the 2014 stock assessments. In general the estimation of indices for the all fleets operational data appears to have been successful, with the addition of the extra TW data during the collaboration of TW/SPC and the increasing provision of operational data by a large number of PICT fleets resulting in no spatial contraction of effort for these datasets, in contrast to that observed in the JPLL dataset. The delta log-normal models appear to provide an adequate fit to the data with some lack of fit to certain data points. This issue will probably always occur with a dataset such as this where an extremely diverse range of vessels is fishing for a variety of target species and there is limited availability of explanatory variables that may help to describe variation in CPUE. The recent papers by Hoyle *et al.* (2014a, b) provide timely advice on methods of diagnosing problems in standardisation procedures and will be a guide for further refinement of the all fleets indices in the future.

Clustering was used to account for changing targeting practices in the all fleets data and in some regions had a substantial influence on the estimated CPUE indices. It is therefore important to note that a major assumption of these models that include cluster variables is that the clusters accurately reflect discreet groups of fishing events with similar targeting operations. This is unlikely to entirely be the case given the extremely diverse (with respect to operational characteristics and targeting strategies) range of vessels fishing in each region. Furthermore, some vessels are likely to change target species within trips or vessels may be targeting species not available in the species composition statistics. The hope is that the broad targeting strategies are identified, that these are the most important strategies with respect to CPUE of the focal species at the region level, and that they produce less biased indices than those that ignore the possibility of changing targeting (such as the JPLL operational indices).

Similarly, there is the assumption that changes in the relative proportions of effort among the clusters is reflective of actual shifts in targeting rather than simply being the result of different trends in the abundance of the different species. For example, does the shift in effort from YFT dominated clusters to BET dominated clusters in Region 3 reflect a genuine change in operational characteristics, or is it a consequence of declining YFT abundance? The actual situation is possibly some way between the two approaches (clustering versus assuming constant targeting strategies), and so it seems reasonable to consider several indices (with alternative assumptions) when formulating sensitivity analyses for the stock assessment models.

5.2. Selection of indices for stock assessment models

The provision of an extra set of CPUE indices for most regions means that decisions must be made about which are the most suitable to be used in the 2014 assessments. In the 2011 assessments, the standardised indices were attributed to the “all flag” LL fisheries which included the JP fleet whose data the indices were calculated from. In 2014, the indices are calculated for multiple fleets, some of which may be from different fisheries. This is the case for all Regions except 6 and 8, where only a single LL fishery is present (McKechnie *et al.* 2014).

Different LL fisheries may have different selectivity and it is possible that their catch and effort may relate to a different vulnerable biomass with the possibility that the different parts of the population being indexed have different temporal dynamics. By recommending the all fleets indices we are assuming that the risk of these potential problems are outweighed by the greater temporal and spatial distribution of operational data resulting from including all fleets irrespective of the fisheries they belong to. It should be noted that in most cases differences in selectivity between these fisheries are minor and the majority of data for a region comes from fleets within the fishery to which the index is attributed. Furthermore, the JPLL operational indices used in the 2011 assessments did not account for any changes in targeting. Finally, we note that any changes to methodology, diagnostics or updating indices as extra data become available cannot be undertaken without expensive travel to Japan to analyse the raw data.

Based on these considerations our recommendations for the 2014 assessment are:

Regions 1, 2: Use the JPLL operational indices and attribute them to fisheries 1 and 2 in region 1 and 2 respectively (McKechnie *et al.* 2014).

Regions 3, 5, 6: Use the all fleets indices and attribute them to fisheries 4, 12 and 13 for regions 3, 5, and 6 respectively (McKechnie *et al.* 2014). Use the JPLL operational indices for these regions and the all fleets indices in sensitivity analyses.

Region 4: Use the JPLL operational indices for BET and attribute them to fishery 9 (McKechnie *et al.* 2014).

Regions 7, 8: Use the all fleets indices and attribute them to fisheries 7, and 8 for Regions 7 and 8 respectively (McKechnie *et al.* 2014). Use the JPLL operational indices calculated for region 3 in the sensitivity analyses.

Region 9: Data is too sparse to calculate standardised indices so it is recommended that the raw catch and effort data are used for these LL fisheries.

5.3. Spatial coverage of all fleets operational data

Due to the different standards of provision of operational data by different fleets and the uneven distribution of fleets across assessment regions, there are parts of several regions that have very little data, particularly in some areas of high seas. By applying indices to fisheries that also fish in these under represented areas we are assuming that the changes in abundance in those areas are consistent with those in the data rich areas. Examples of this issue are the lack of data available in the Northern area of region 3 (above about 10N) and in Region 7 outside of the box covering 0-10N and 130E-140E. In the case of Region 7 it is fortunate that the areas where significant amounts of data are available are also the areas where much of the effort of the LL fisheries occurs (Fisheries 6 and 7; see McKechnie *et al.* 2014 for details of these fisheries).

In Region 3 much of the Northern band is high seas and the lack of data is related to low coverage of operational data rather than the absence of LL fishing. While Hoyle and Okamoto (2011) excluded data north of 5N in their standardisations due to changes in the prevalence of ALB targeting there, future analyses will ideally include this operational JPLL data and attempts could be made to address targeting and thus model CPUE of BET/YFT in this part of the region as well. An example of the value of adding data not held by SPC comes from Region 4 where preliminary analyses conducted on only the SPC-held data resulted in clustering with undesirable attributes such as a changing species composition within clusters over time. Once the TW data were added more BET targeting trips were available for analyses and the misbehaving data for other fleets (mostly KR) were reassigned to different clusters that were more temporally consistent and produced more sensible CPUE indices.

This does however highlight the situation where data exists but is not readily available to the science provider to the WCPFC, and in this regard, the collaboration with TW scientists and industry without having to travel to Taiwan is a highly valuable step towards closer collaboration of SPC and all DWFN with respect to analyses of operational data. Improvements to standardisation procedures will occur through the exchange of ideas between institutes and the provision of more extensive data will lead to more robust CPUE indices being available for stock assessments.

6. References

Bigelow, K. A., Hoyle, S. D. (2012). Standardized CPUE for South Pacific albacore. WCPFC-SC8-2012/SA-IP-14.

Campbell, R. A. (2004). CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fisheries Research 70: 209-227.

Davies, N., Hoyle, S., Harley, S., Langley, A., Kleiber, P., Hampton, J. (2011). Stock assessment of bigeye tuna in the western and central Pacific Ocean. WCPFC-SC7-2011/SA-WP-02.

Fournier, D.A., Hampton, J., and Sibert, J.R. (1998).MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, Thunnus alalunga. Can. J. Fish. and Aquat. Sci. 55, 2105-2116.

Francis, R. I. C. C. (1999). The impact of correlations in standardised CPUE indices. New Zealand Fisheries Assessment Research Document 99/42. 30p.

He, X., Bigelow, K. A., Boggs, C. H. (1997). Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. Fisheries Research 31: 147-158.

Hoyle, S. D. (2011). Research outline for longline catch per unit effort data. WCPFC-SC7-2011/SA-IP-07.

Hoyle, S., Hampton, J., Davies, N. (2012). Stock assessment of Albacore Tuna in the South Pacific Ocean. WCPFC-SC8-2012/SA-WP-04-REV1.

Hoyle, S. D., Okamoto, H. (2011). Analyses of Japanese longline operational catch and effort for Bigeye and Yellowfin Tuna in the WCPO. WCPFC-SC7-2011/SA-IP-01.

Hoyle, S. D., Okamoto, H. (2013). Target changes in the tropical WCPO Japanese longline fishery, and their effects on species composition. WCPFC-SC9-2013/SA-IP-04.

Hoyle, S. D., Langley, A. D., Campbell, R. A. (2014a). Recommended approaches for standardizing CPUE data from pelagic fisheries. WCPFC-SC10-2014/SA-IP-10.

Hoyle, S. D., Langley, A. D., Campbell, R. A. (2014b). Guidelines for presenting CPUE indices of abundance for WCPFC stock assessments. WCPFC-SC10-2014/SA-IP-11.

Ianelli, J., Maunder, M., Punt, A. (2012). Independent review of 2011 WCPO Bigeye Tuna assessment. WCPFC-SC8-2012/SA-WP-01.

Langley, A., Hoyle, S., Hampton, J. (2011). Stock assessment of yellowfin tuna in the western and central pacific ocean. WCPFC-SC7-2011/SA-WP-02.

Maunder, M. N., Punt, A. E. (2004). Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70: 141-159.

McKechnie, S., Hoyle, S., Harley, S. (2013). Longline CPUE series that account for changes in the spatial extent of fisheries. WCPFC-SC9-2013/SA-IP-05.

McKechnie, S., Harley, S., Davies, N., Rice, J., Hampton, J., Berger, A. (2014). Basis for regional structures used in the 2014 tropical tuna assessments, including regional weights. WCPFC-SC10-2014/SA-IP-02.

OFP (2013). Report from the SPC pre-assessment workshop, Noumea, April 2013. WCPFC-SC9-2013/SA-IP-01.

OFP (2014). Report from the SPC pre-assessment workshop, Noumea, April 2014. WCPFC-SC10-2014/SA-IP-07.

Punsly, R. (1987) Estimation of the relative annual abundance of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean during 1970-1985. IATTC, LA JOLLA, CA.

Ward, J. H., Jr. (1963) Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association 58: 236–244.

7. Tables

Table 1: Consequences of rules for removing data on the number of sets (× 1000), effort (× 1 million hooks) and catch in numbers of BET and YFT (× 1000) remaining in the dataset for the regions analysed.

Region 3	Sets	Hooks set	BET catch	YFT catch
Uncleaned	788.2	1475.7	6282.2	12853.6
Remove yrqtrs	773.5	1440.7	6173.1	12439.5
Remove vessels	428.0	870.0	4133.4	7505.5
No tuna	420.3	858.1	4086.7	7433.8
Remove vessels	411.3	842.6	4023.9	7334.4

Region 4	Sets	Hooks set	BET catch	YFT catch
Uncleaned	645.3	1523.8	8314.0	8604.9
Remove yrqtrs	640.8	1510.3	8288.7	8576.5
Remove vessels	462.4	1117.3	6330.3	6244.7
No tuna	456.6	1105.8	6290.7	6205.0
Remove vessels	442.8	1075.8	6164.8	6018.8

Region 5	Sets	Hooks set	BET catch	YFT catch
Uncleaned	460.5	957.3	1338.1	6280.0
Remove yrqtrs	433.5	887.0	1286.6	6064.7
Remove vessels	319.2	610.7	943.5	4184.0
No tuna	304.2	591.1	916.8	4036.3
Remove vessels	294.6	571.8	890.1	3851.4

Region 6	Sets	Hooks set	BET catch	YFT catch
Uncleaned	671.6	1490.6	1474.6	3291.8
Remove yrqtrs	668.9	1482.9	1471.1	3276.5
Remove vessels	509.5	1146.0	1060.6	2594.5
No tuna	472.1	1100.9	1011.2	2470.7
Remove vessels	449.4	1062.2	949.4	2372.7

Region 7	Sets	Hooks set	BET catch	YFT catch
Uncleaned	263.0	318.6	1002.8	1413.3
Remove yrqtrs	209.7	262.4	835.8	1126.1
Remove vessels	204.3	254.8	810.9	1105.1
No tuna	184.2	231.2	736.0	1018.3
Remove vessels	178.4	223.7	708.9	979.0

Region 8	Sets	Hooks set	BET catch	YFT catch
Uncleaned	94.8	198.8	591.3	3196.7
Remove yrqtrs	83.0	172.1	522.4	2837.1
Remove vessels	81.7	168.5	515.7	2801.3
No tuna	78.1	162.8	501.0	2743.6
Remove vessels	76.3	158.6	492.9	2680.3

Table 2: Species compositions and the number of trips fished for individual clusters used when standardising CPUE indices. Values are the catch in numbers of BET, YFT and ALB (and SWO in region five) as a proportion of the total catch in numbers of the three (or four) species in that cluster over the whole time period.

Region 3				
Cluster	P(BET)	P(YFT)	P(ALB)	No. Trips
1	0.41	0.56	0.03	10587
2	0.17	0.82	0.01	6557
3	0.72	0.27	0.01	9838

Region 4				
Cluster	P(BET)	P(YFT)	P(ALB)	No. Trips
1	0.72	0.23	0.05	6362
2	0.12	0.15	0.72	2180
3	0.30	0.53	0.17	4606

Region 5					
Cluster	P(BET)	P(YFT)	P(ALB)	P(SWO)	No. Trips
1	0.22	0.24	0.21	0.33	5640
2	0.09	0.77	0.09	0.05	4883
3	0.06	0.45	0.46	0.03	3552
4	0.04	0.13	0.81	0.02	8094

Region 6				
Cluster	P(BET)	P(YFT)	P(ALB)	No. Trips
1	0.04	0.06	0.91	17908
2	0.09	0.18	0.73	5726
3	0.15	0.43	0.42	6173

Region 7				
Cluster	P(BET)	P(YFT)	P(ALB)	No. Trips
1	0.11	0.89	0.00	4163
2	0.44	0.56	0.00	8597
3	0.76	0.22	0.02	7461

Region 8				
Cluster	P(BET)	P(YFT)	P(ALB)	No. Trips
1	0.10	0.88	0.01	2836
2	0.46	0.49	0.05	744
3	0.07	0.59	0.34	643

8. Figures

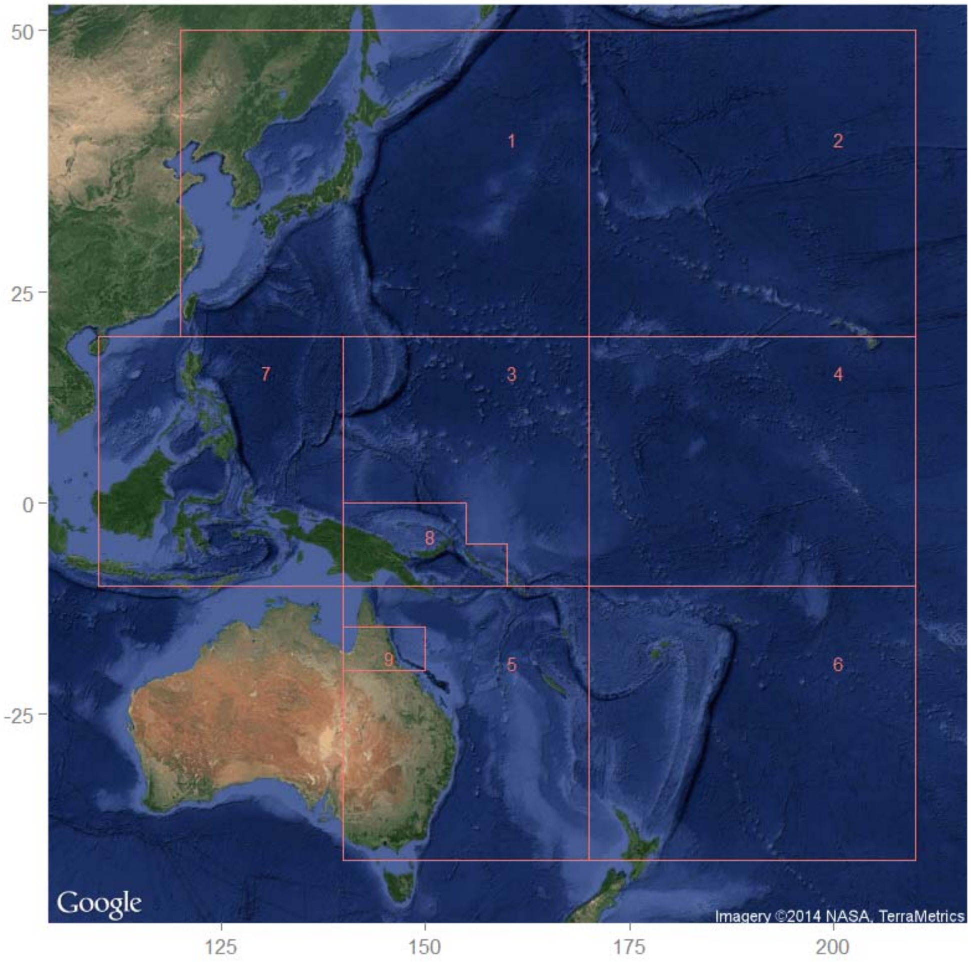
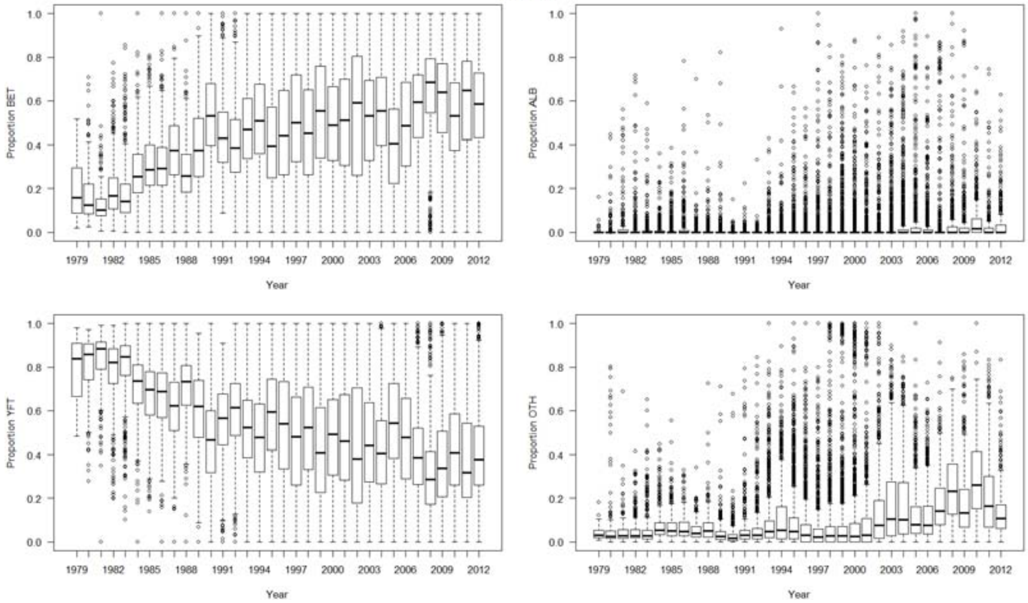


Figure 1: Map displaying the nine regions making up the new regional structure of the 2014 BET/YFT stock assessments.

Region 3



Region 4

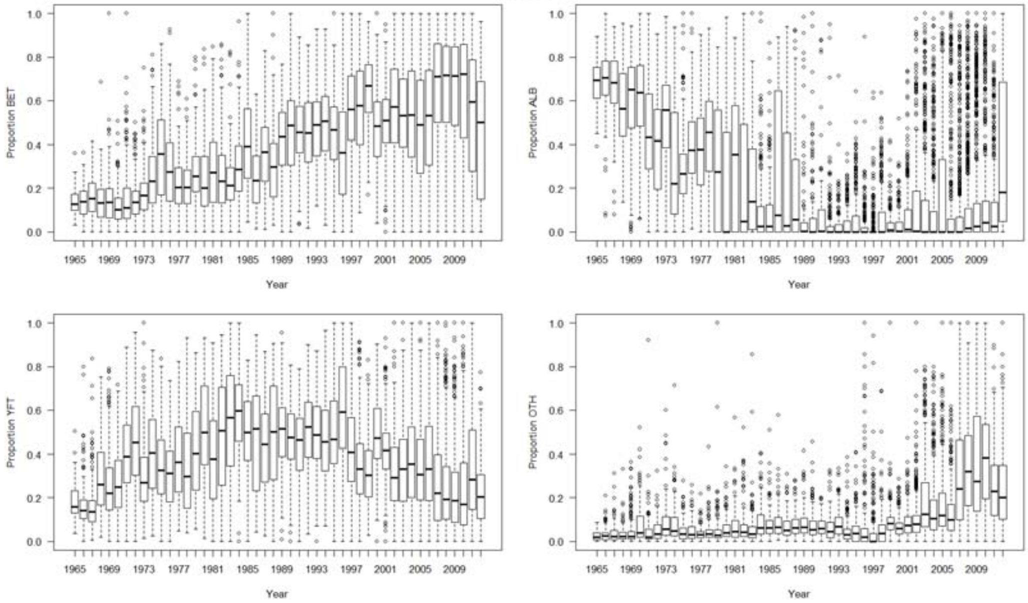
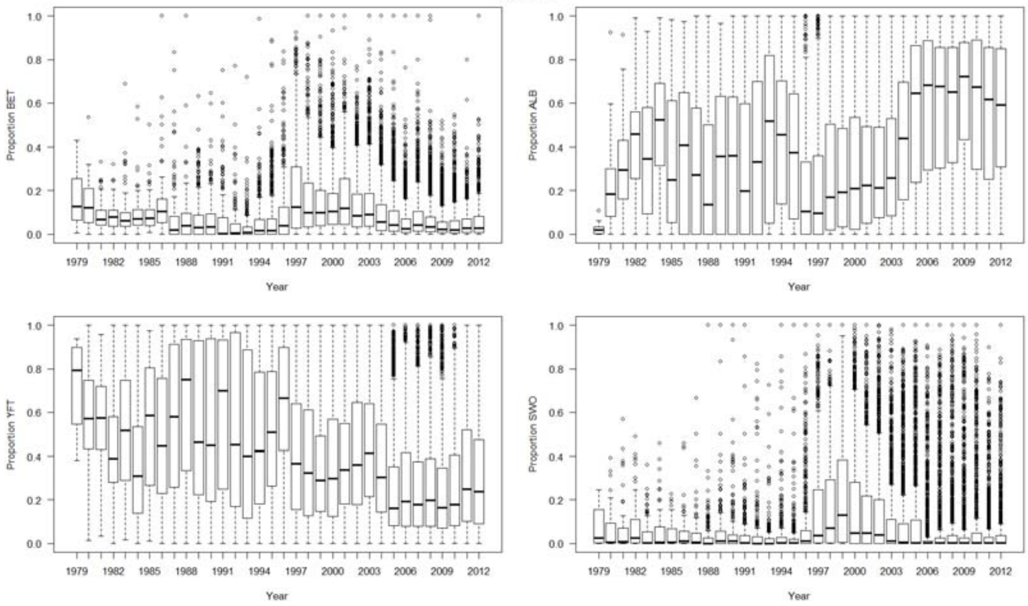


Figure 2: Box plots of the catch composition of the three focal tuna species and "other" species by year for regions 3 and 4.

Region 5



Region 6

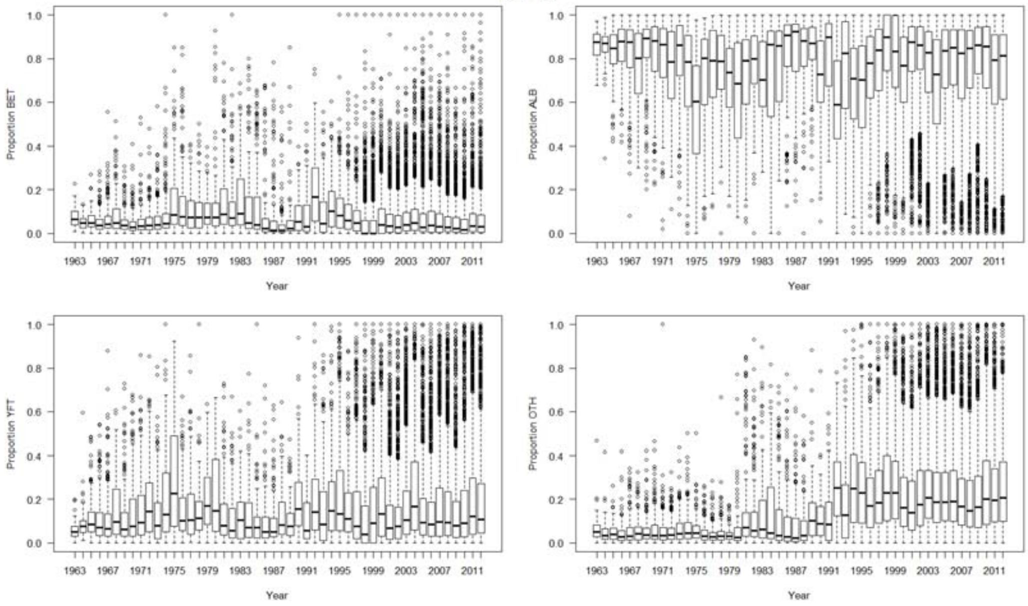
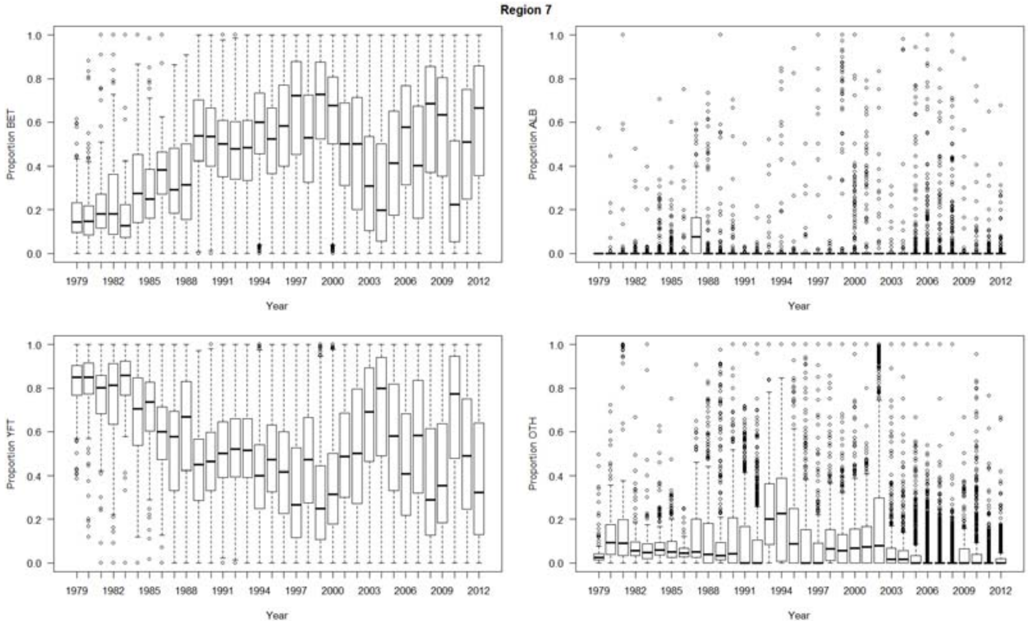


Figure 2 continued: Regions 5 and 6.



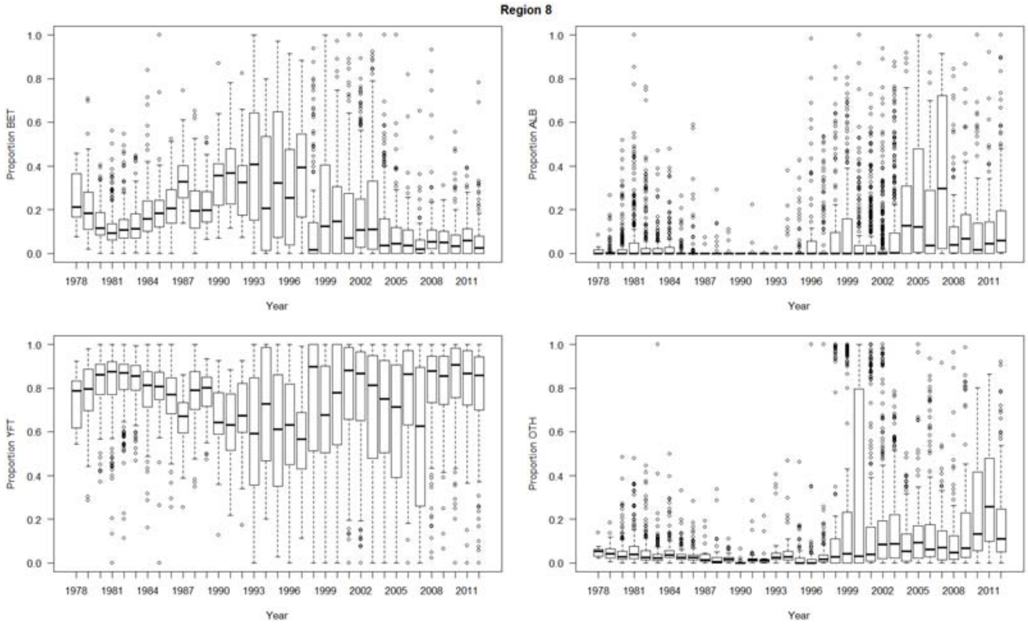


Figure 2 continued: Regions 7 and 8.

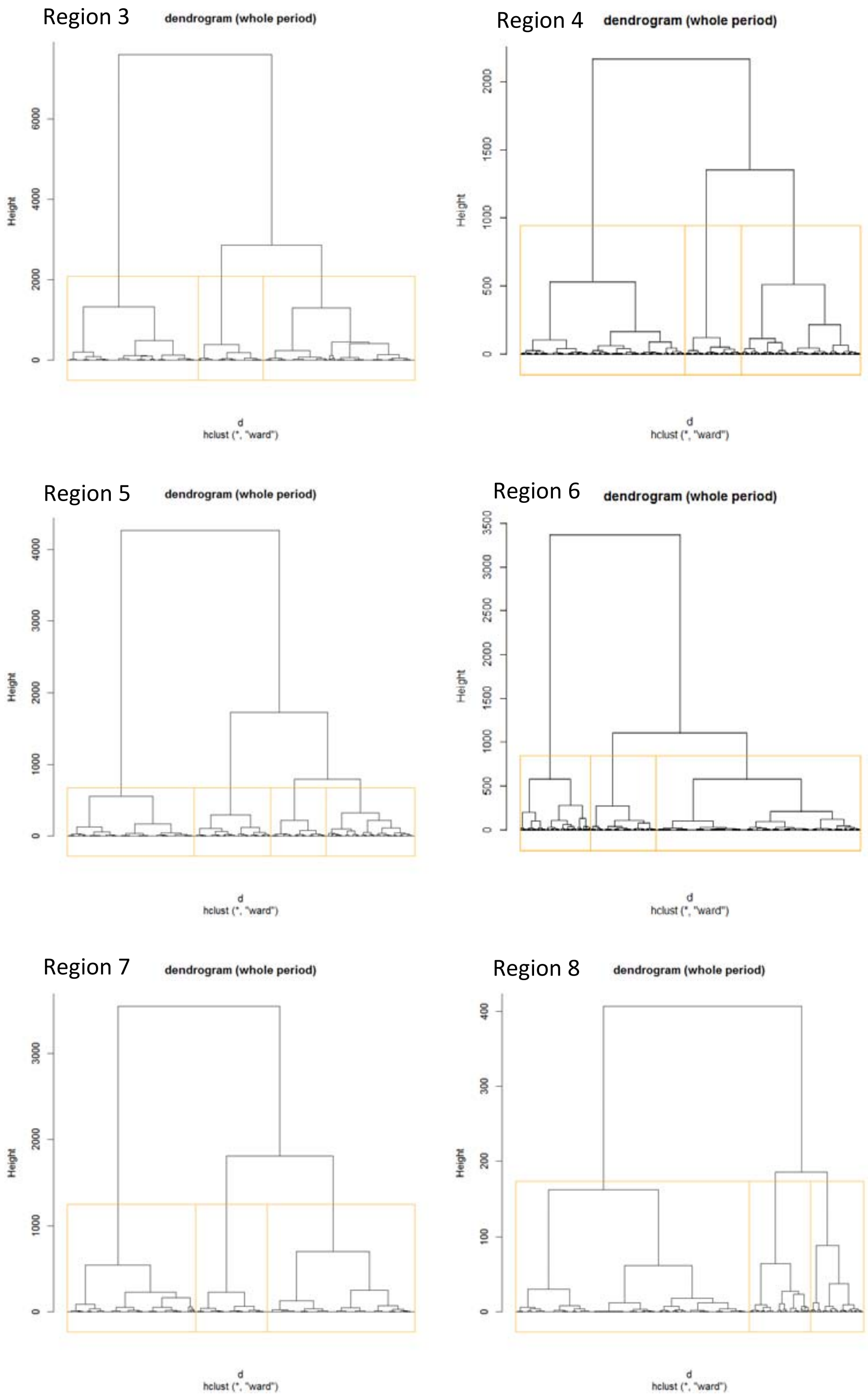
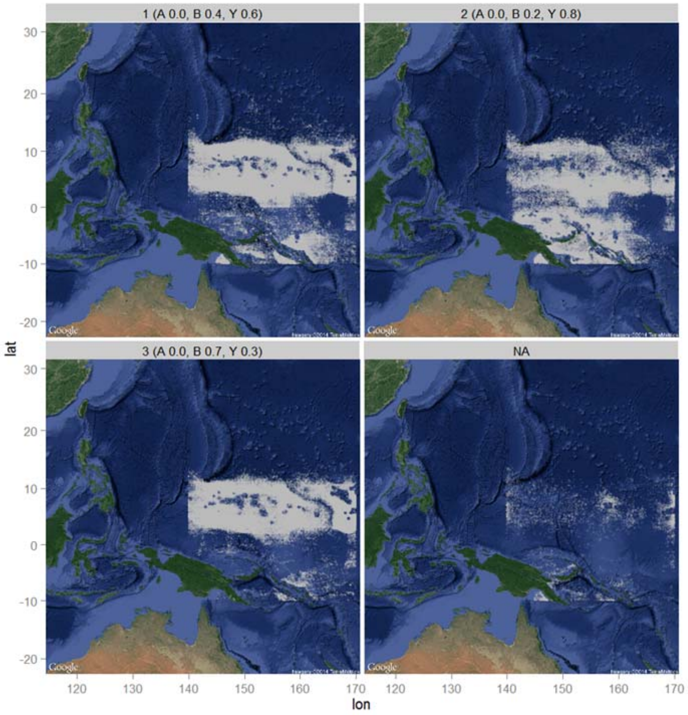


Figure 3: Dendrograms displaying the clustering of trips by their tuna species catch composition for the different regions analysed.

Region 3



Region 4

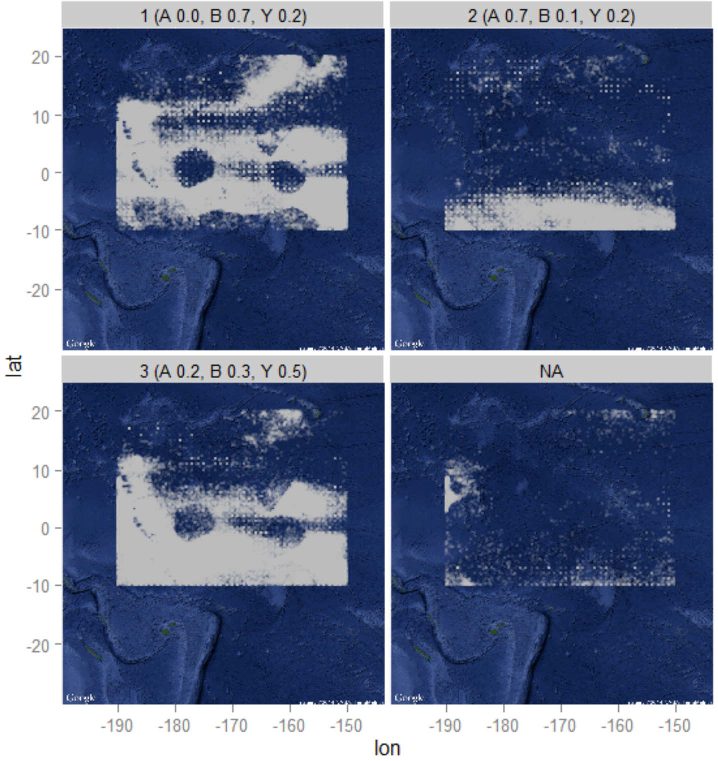
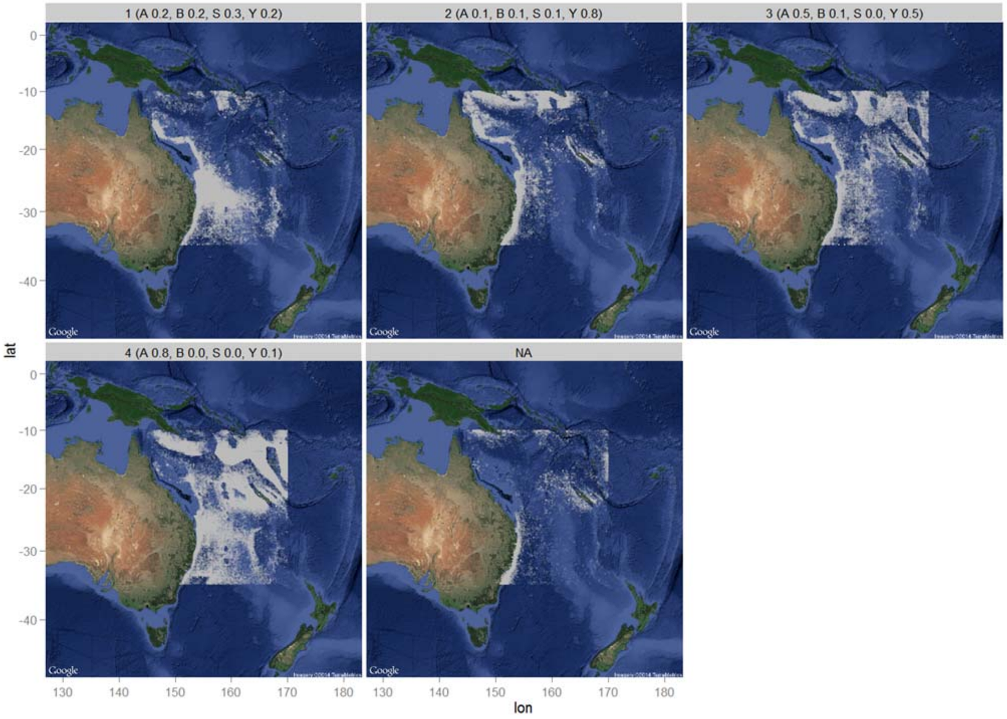


Figure 4: Maps of the location of fishing effort for the different clusters (numbered in the panel headers – species catch composition (catch in numbers) for the cluster is given in the brackets) in regions 3 and 4. Each grey dot represents one set and the panel NA shows sets where either no tuna were caught or sets for trips where less than five sets were fished.

Region 5



Region 6

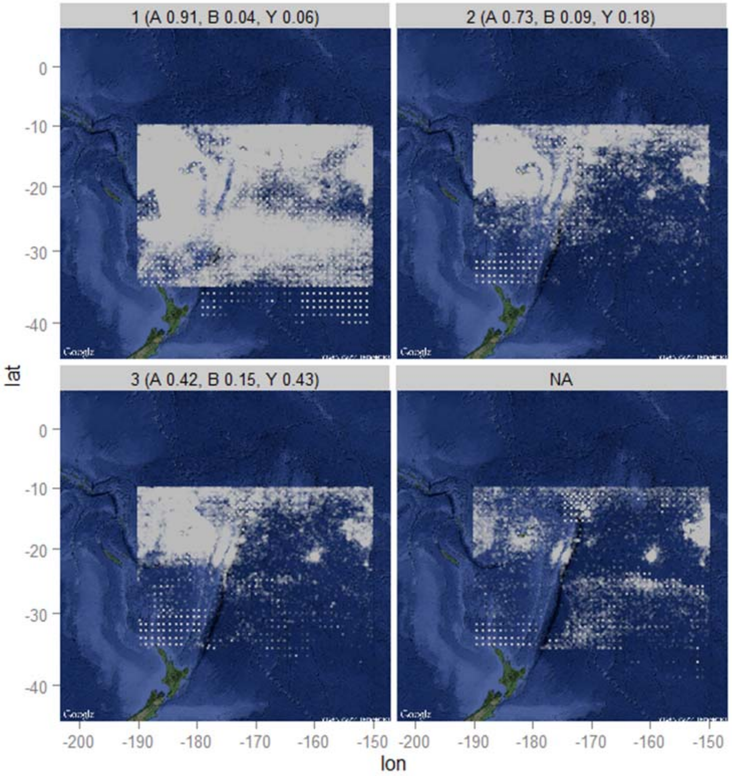
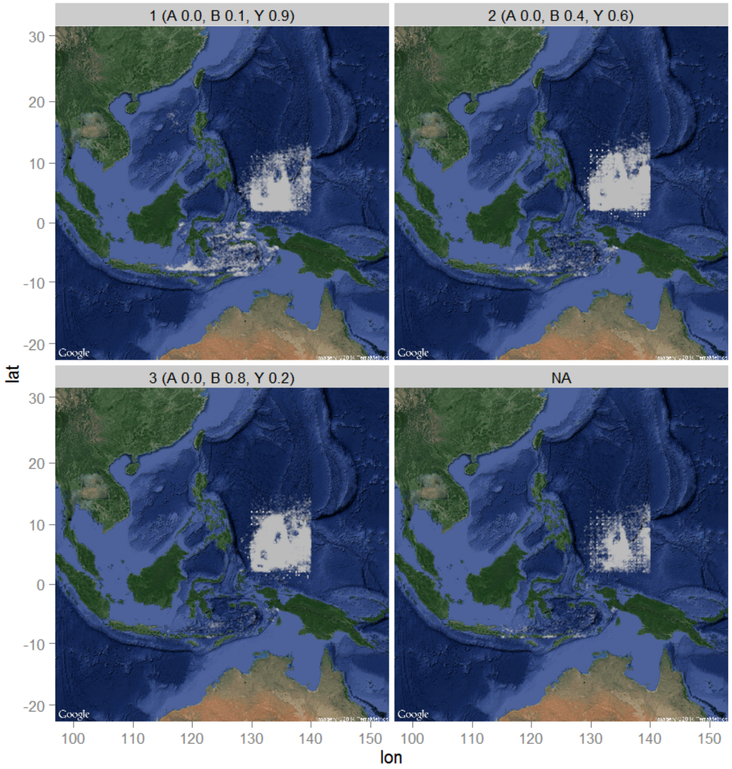


Figure 4 continued: Maps of sets for regions 5 and 6.

Region 7



Region 8

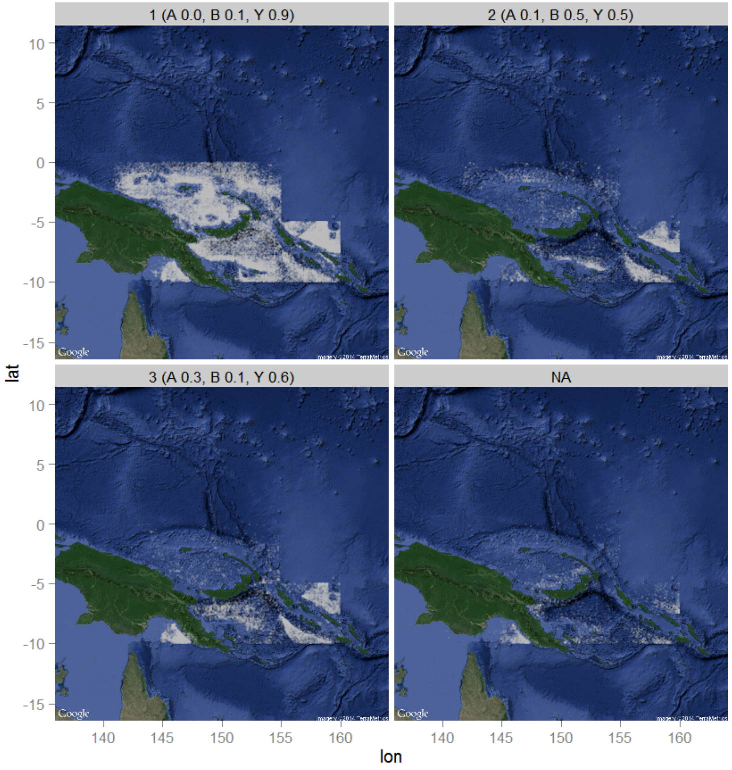
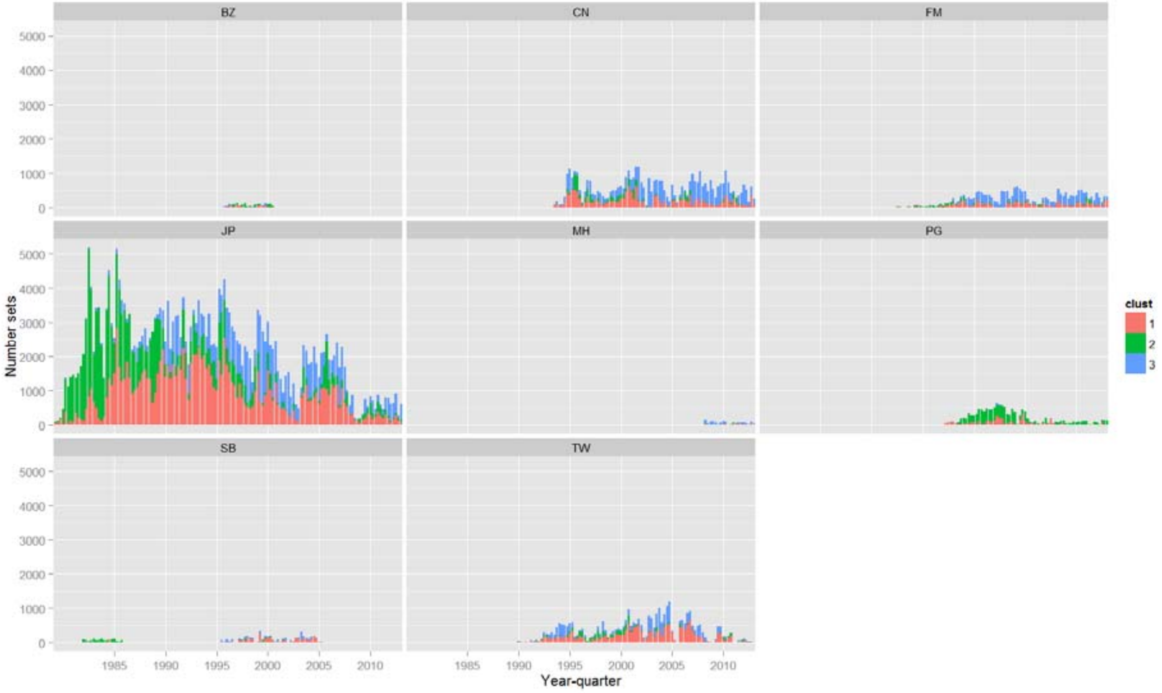


Figure 4 continued: Maps of sets for regions 7 and 8.

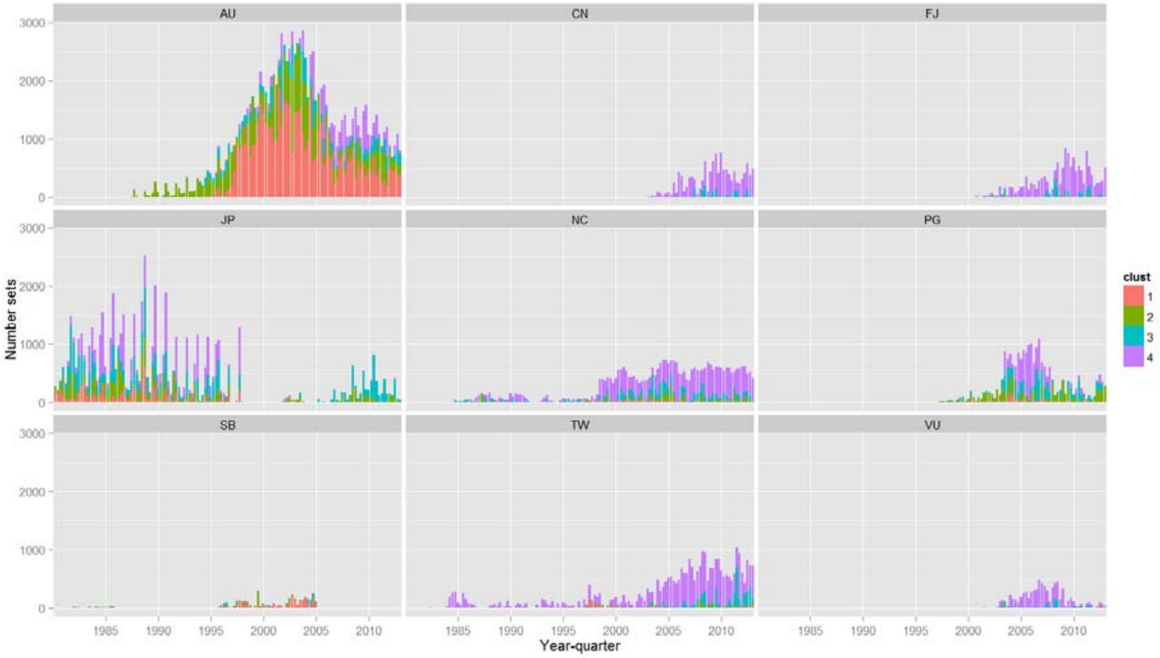
Region 3



Region 4

Figure 5: Plot showing the number of sets contributed by different fleets (two letter abbreviations shown in the panel headers) to the dataset used for modelling CPUE for regions 3 and 4. The different colours indicate the targeting cluster that the sets have been attributed to and the catch composition of each cluster can be checked against the proportions for the cluster of the same number shown for each region in Table 2.

Region 5



Region 6

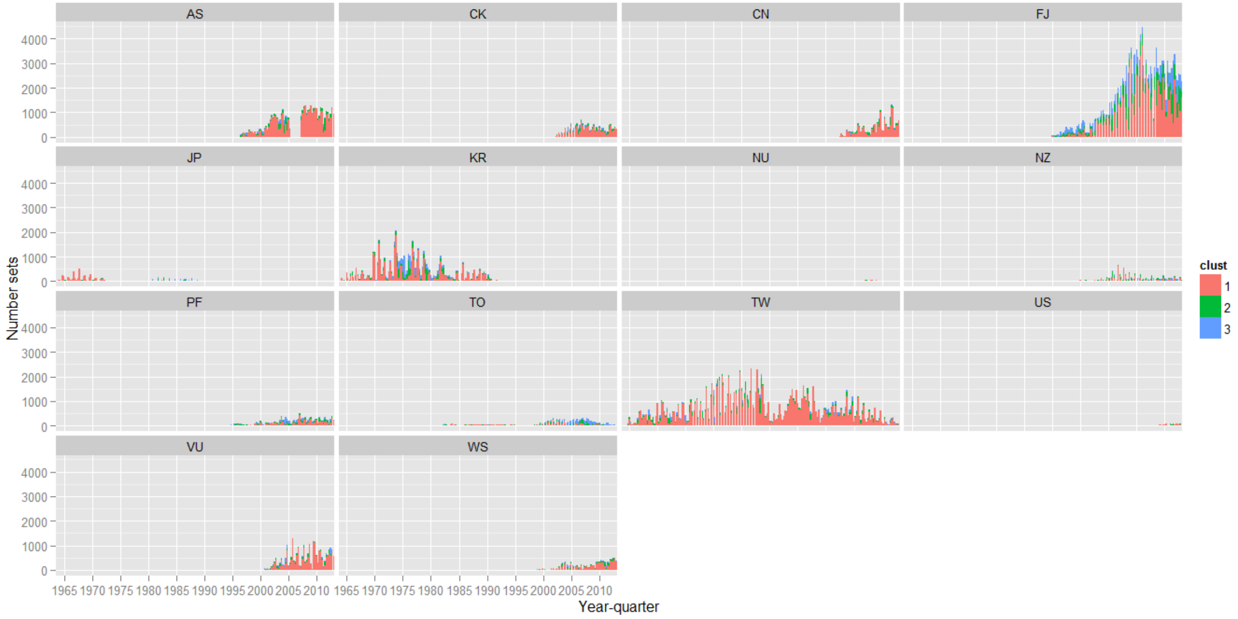
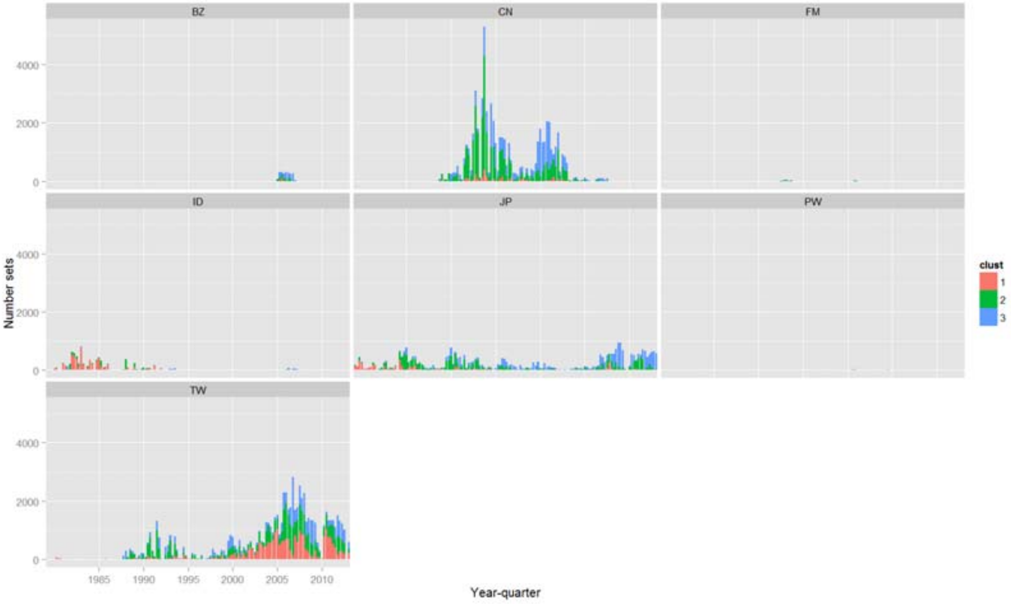


Figure 5 continued: Fleet and cluster composition for regions 5 and 6.

Region 7



Region 8

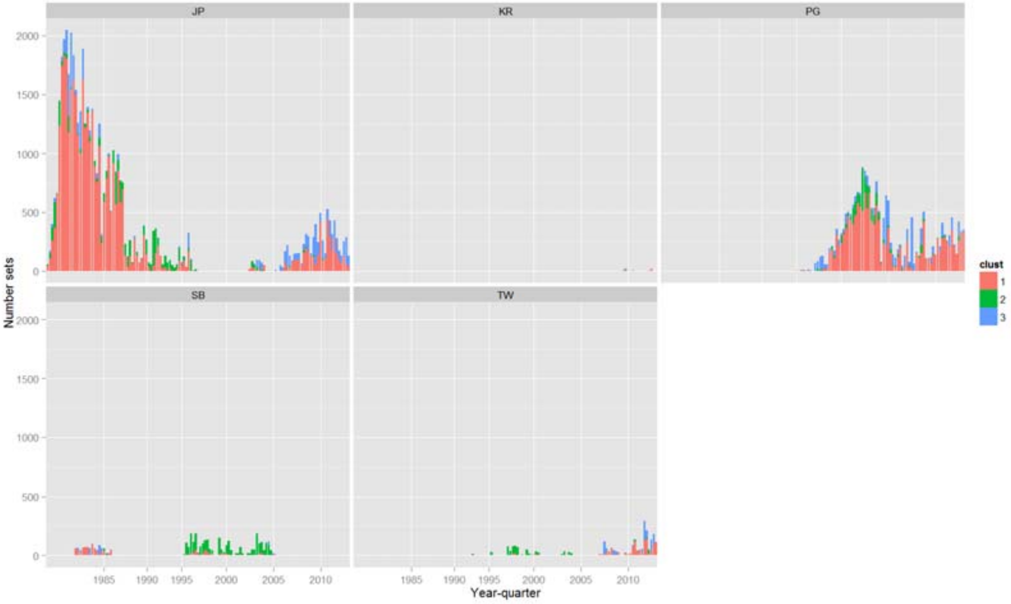
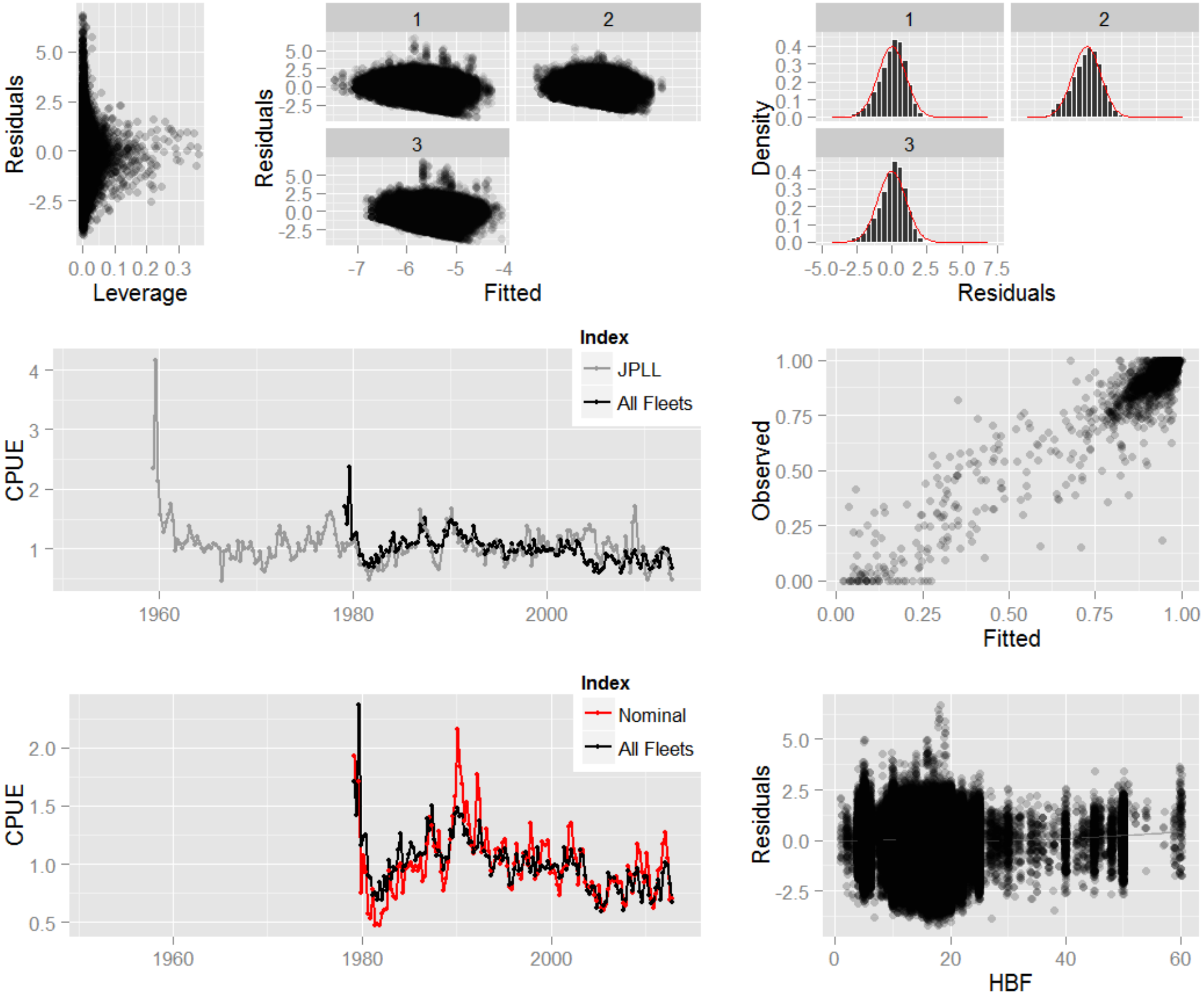


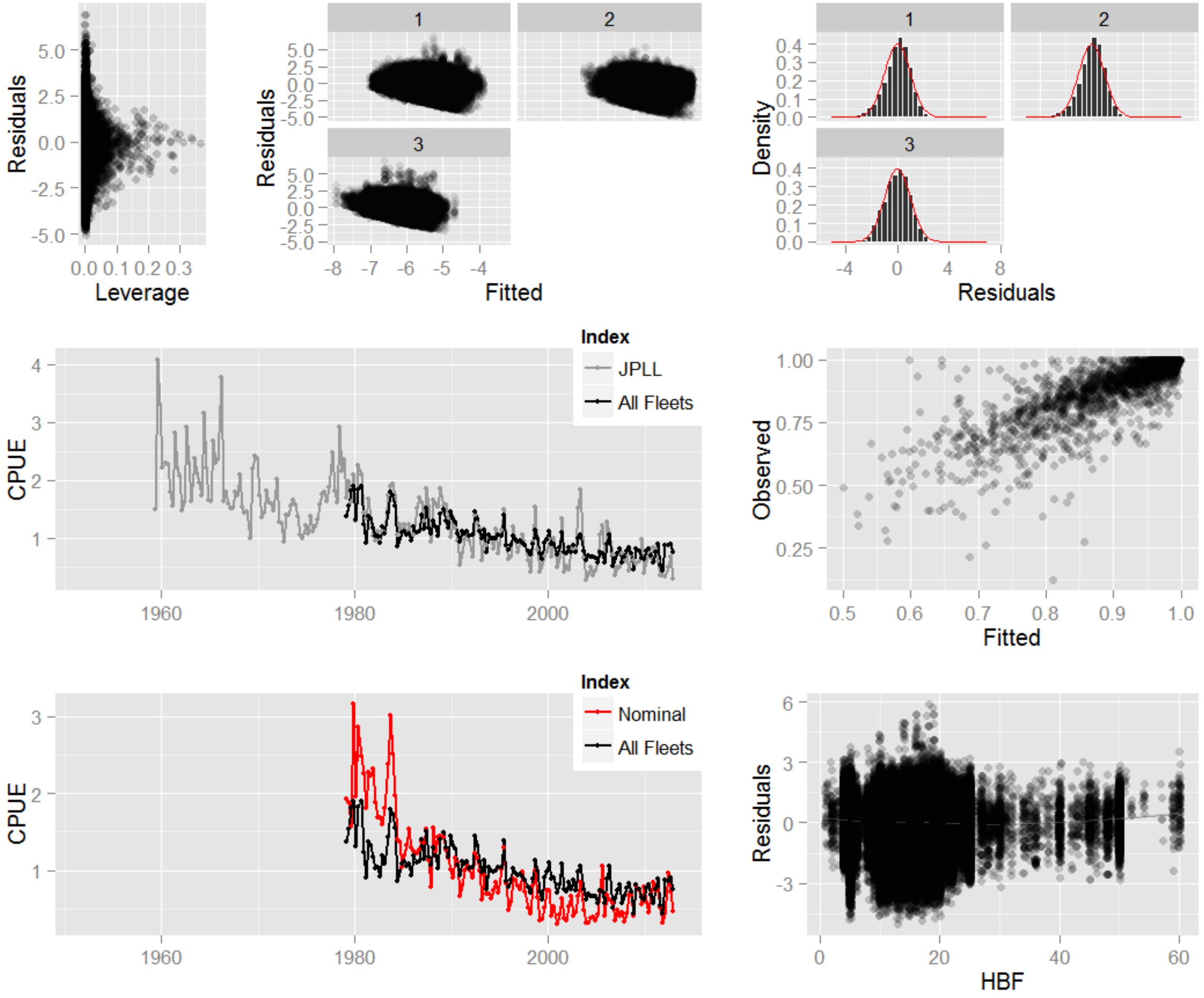
Figure 5 continued: Fleet and cluster composition for regions 7 and 8.

Figure 6 (following pages): Standardised CPUE indices and their diagnostics for each of regions 3 to 8. The three plots on the top row show residual diagnostics (leverage vs residuals, fitted values vs residuals and histograms of residuals) for the lognormal component of the DLN. The fitted vs observed plot (far-right of 2nd row) shows the model-predicted and observed proportion sets with zero catches at the year-quarter-spatial cell scale. The scatter plot shows the relationship between residuals and hooks-between-floats (HBF) for sets where there is information on the later. Line plots compare the standardised all fleets CPUE indices (black lines) with the nominal all fleets indices (red lines) and the updated operational JPLL indices (grey lines). Residuals throughout are raw residuals not the more widely used deviance residuals as the weightings make the later difficult to interpret. Note that the residuals for regions 4 and 6 are from GLMs fitted to data without the extra TW data added as their calculation was not possible from the R objects that were able to be stored by SPC (the summary objects could not be stored for confidentiality reasons).

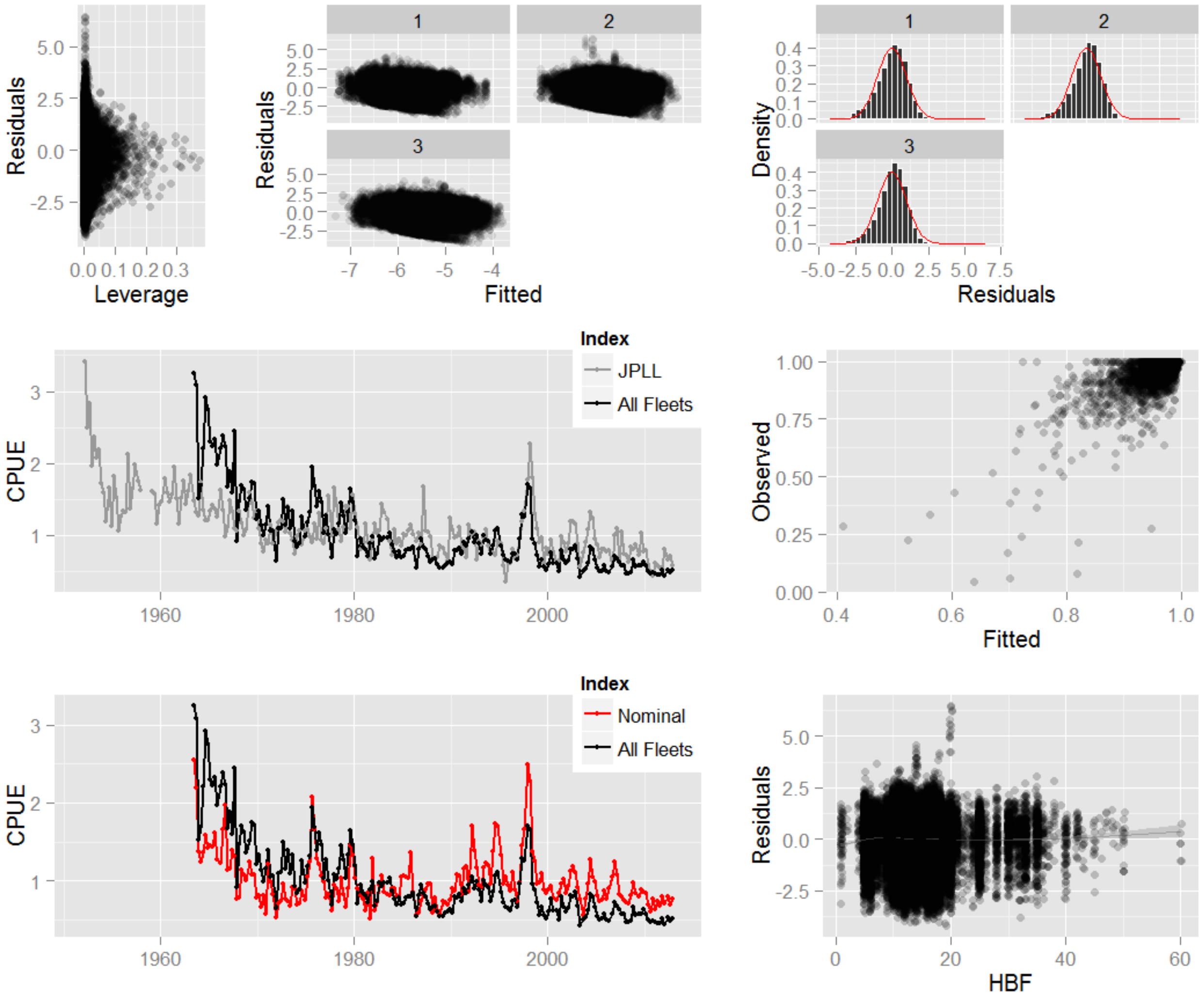
Region 3 BET delta-log-normal analysis



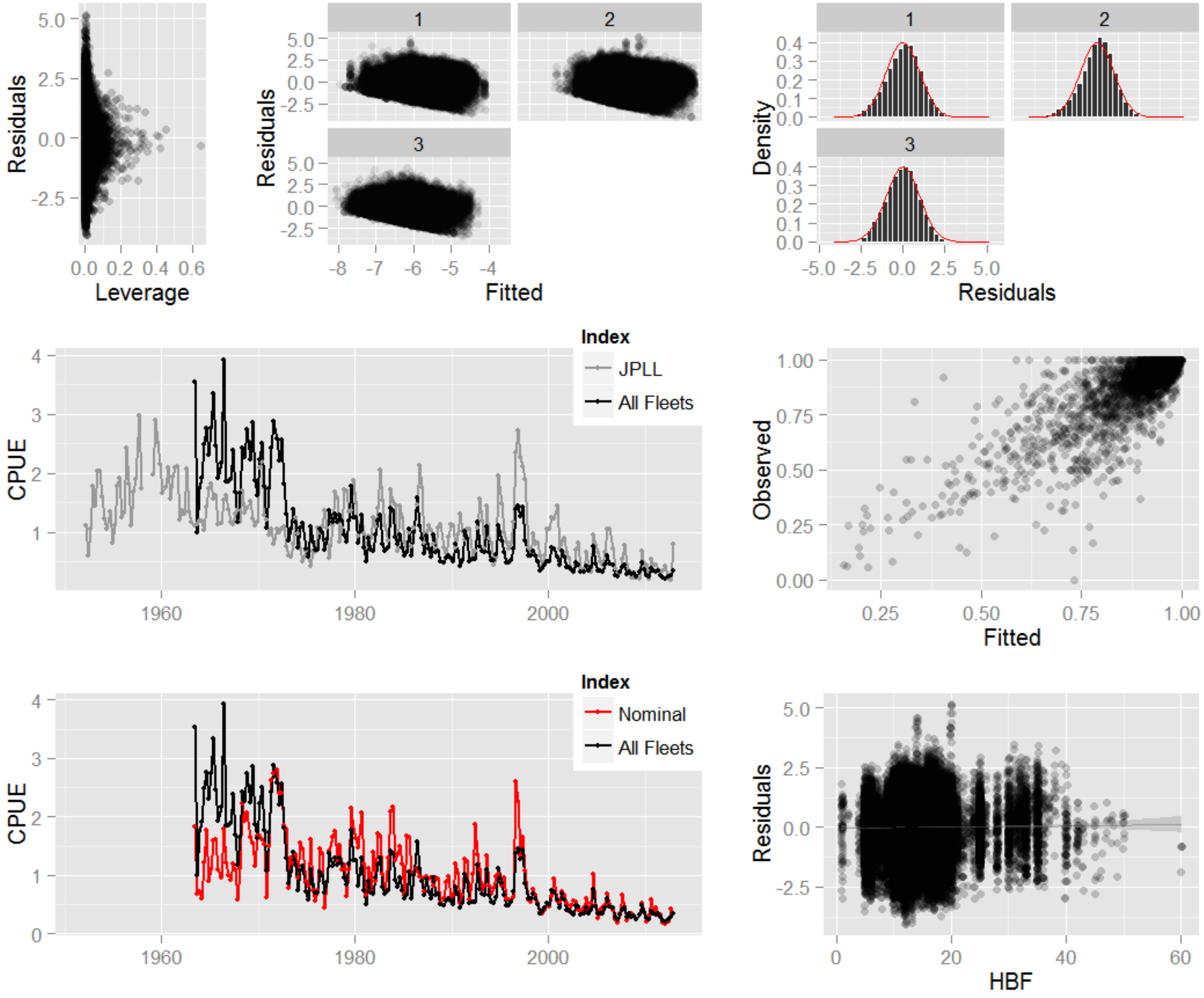
Region 3 YFT delta-log-normal analysis



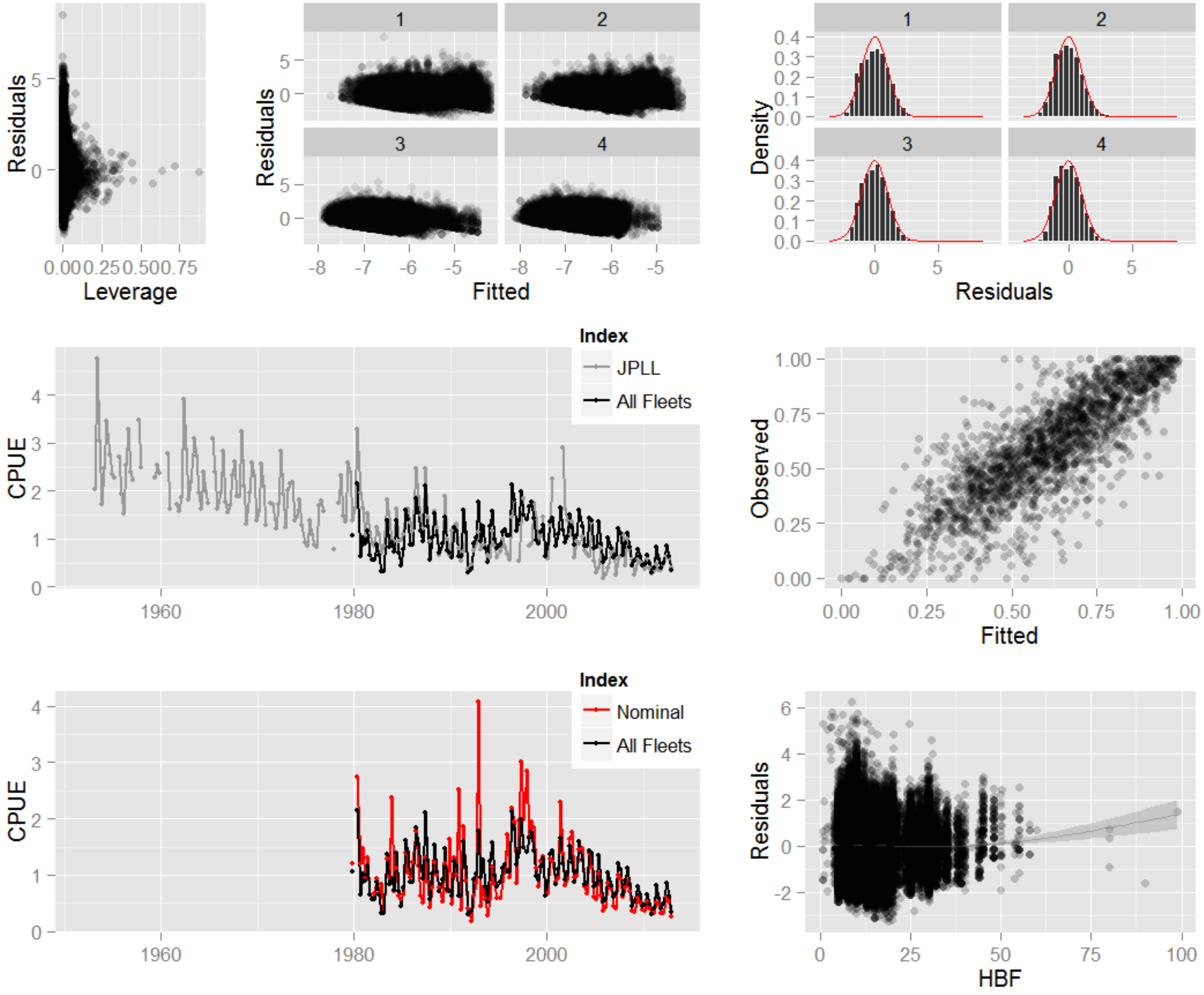
Region 4 BET delta-log-normal analysis



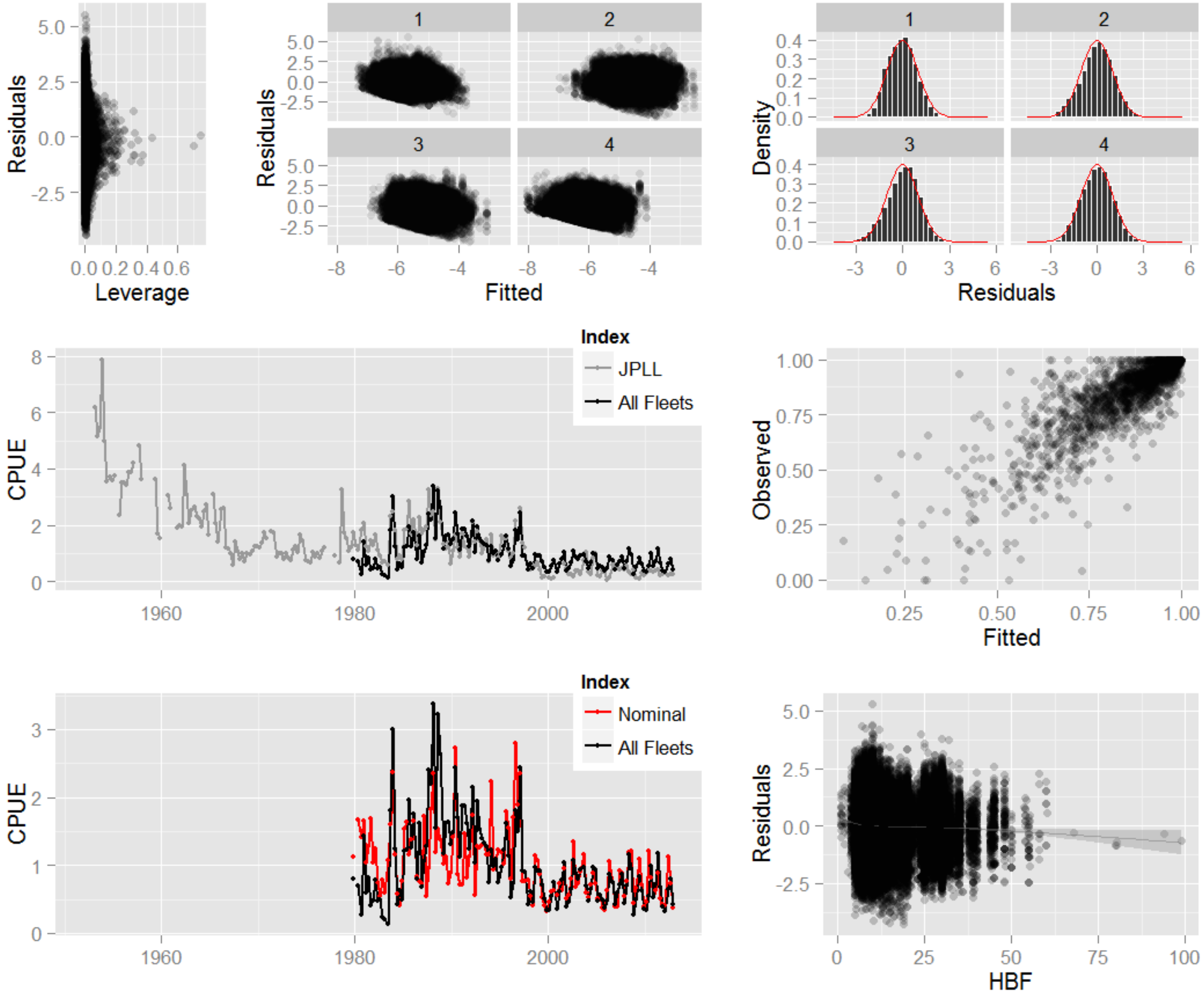
Region 4 YFT delta-log-normal analysis



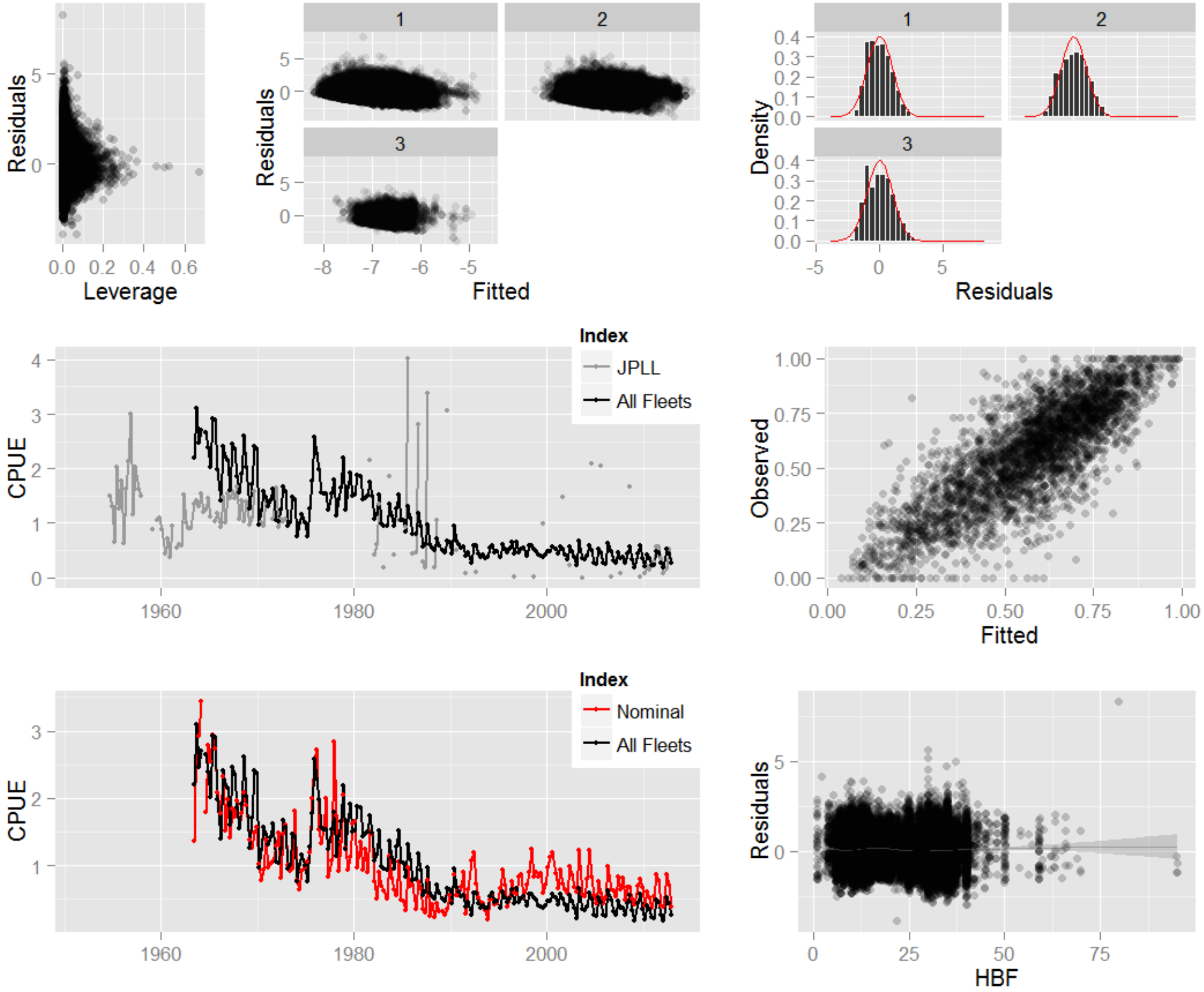
Region 5 BET delta-log-normal analysis



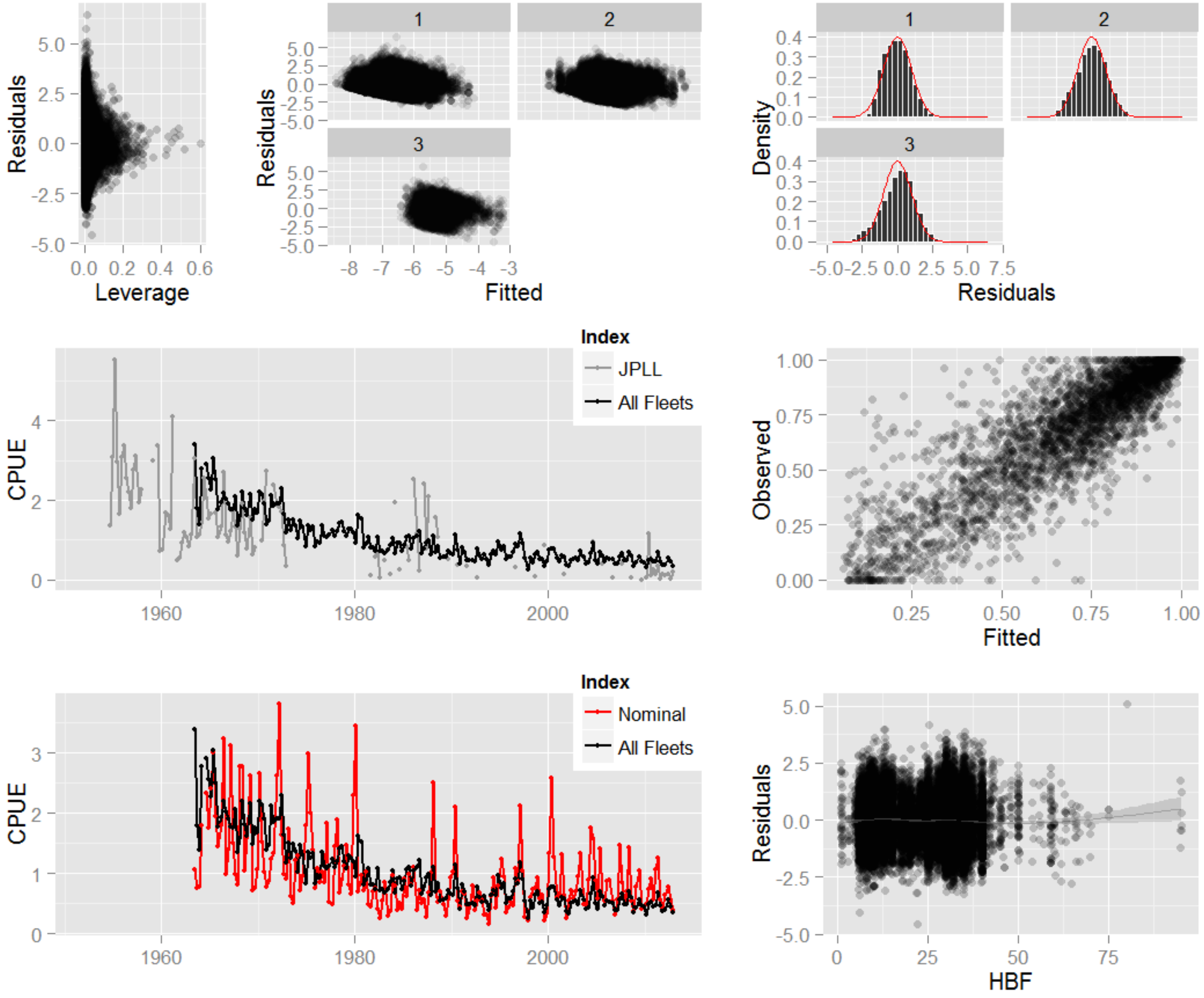
Region 5 YFT delta-log-normal analysis



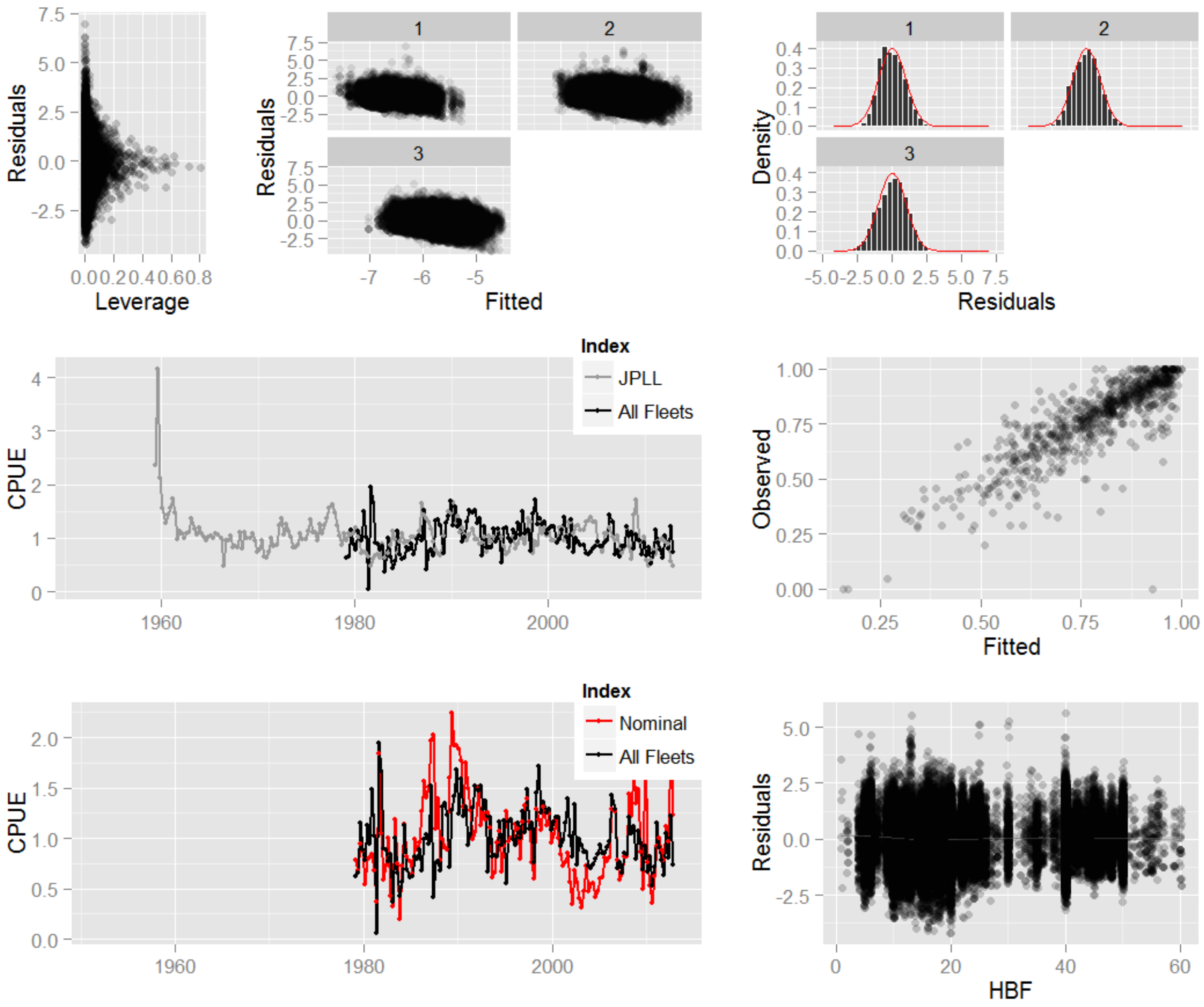
Region 6 BET delta-log-normal analysis



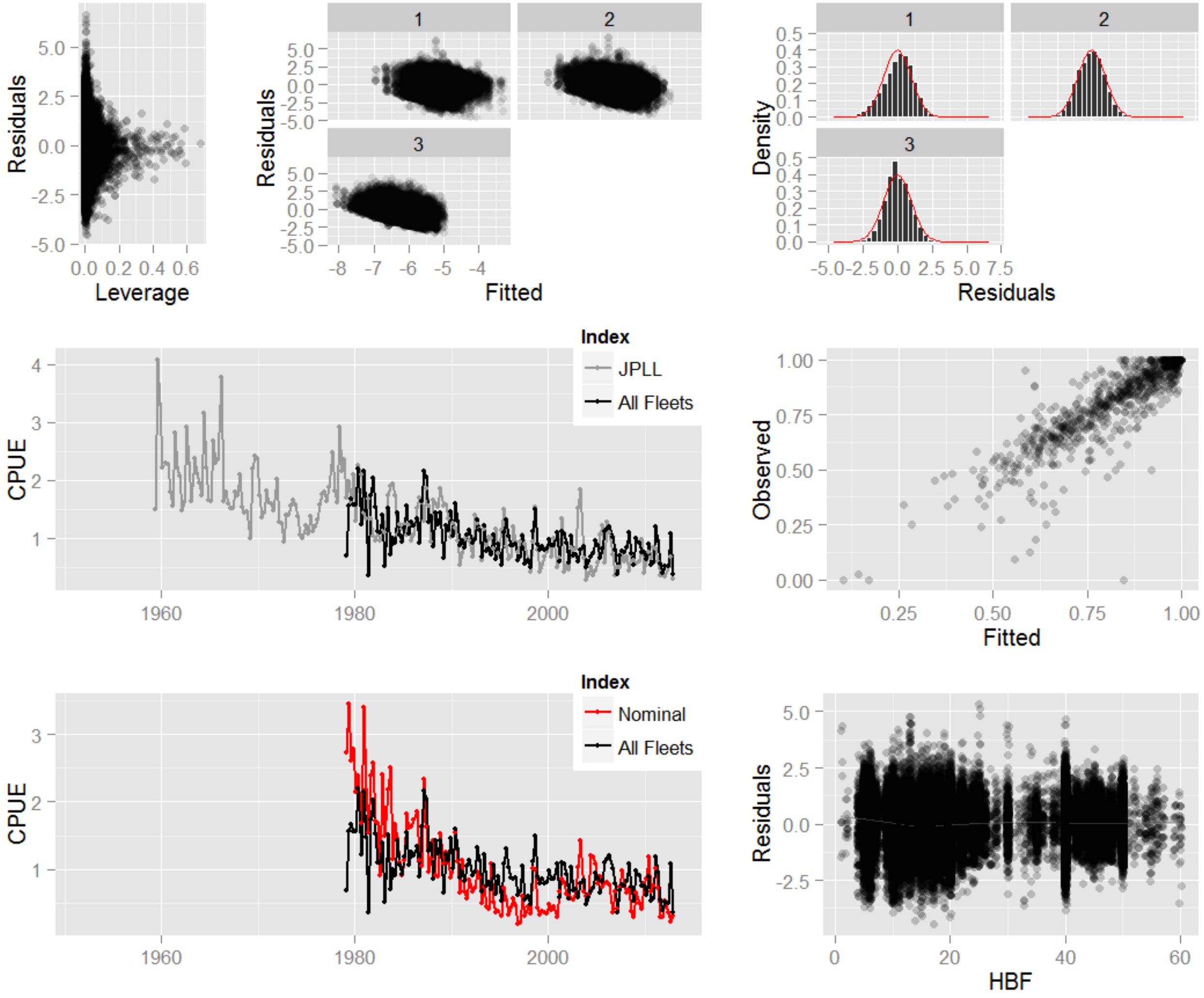
Region 6 YFT delta-log-normal analysis



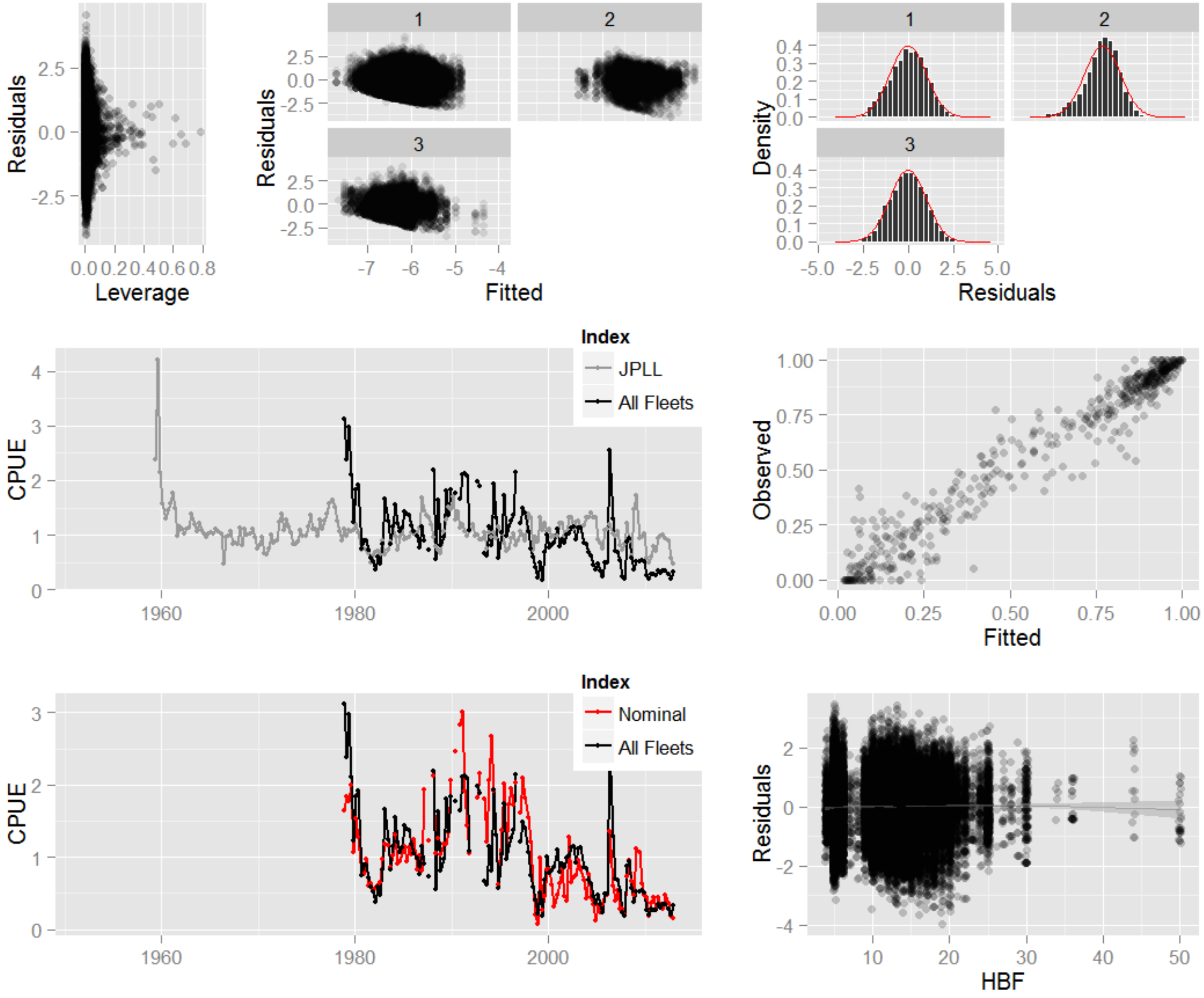
Region 7 BET delta-log-normal analysis



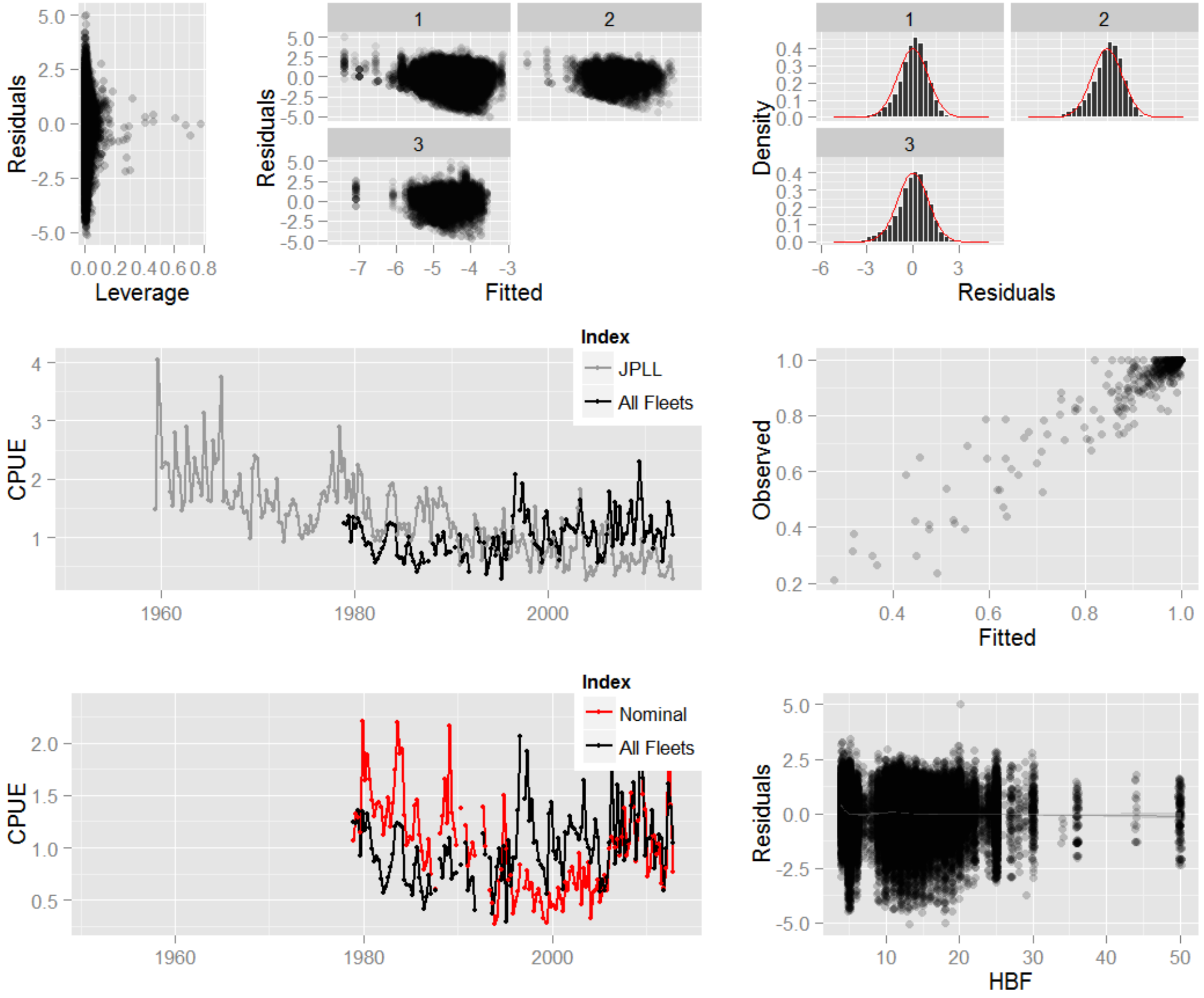
Region 7 YFT delta-log-normal analysis



Region 8 BET delta-log-normal analysis



Region 8 YFT delta-log-normal analysis



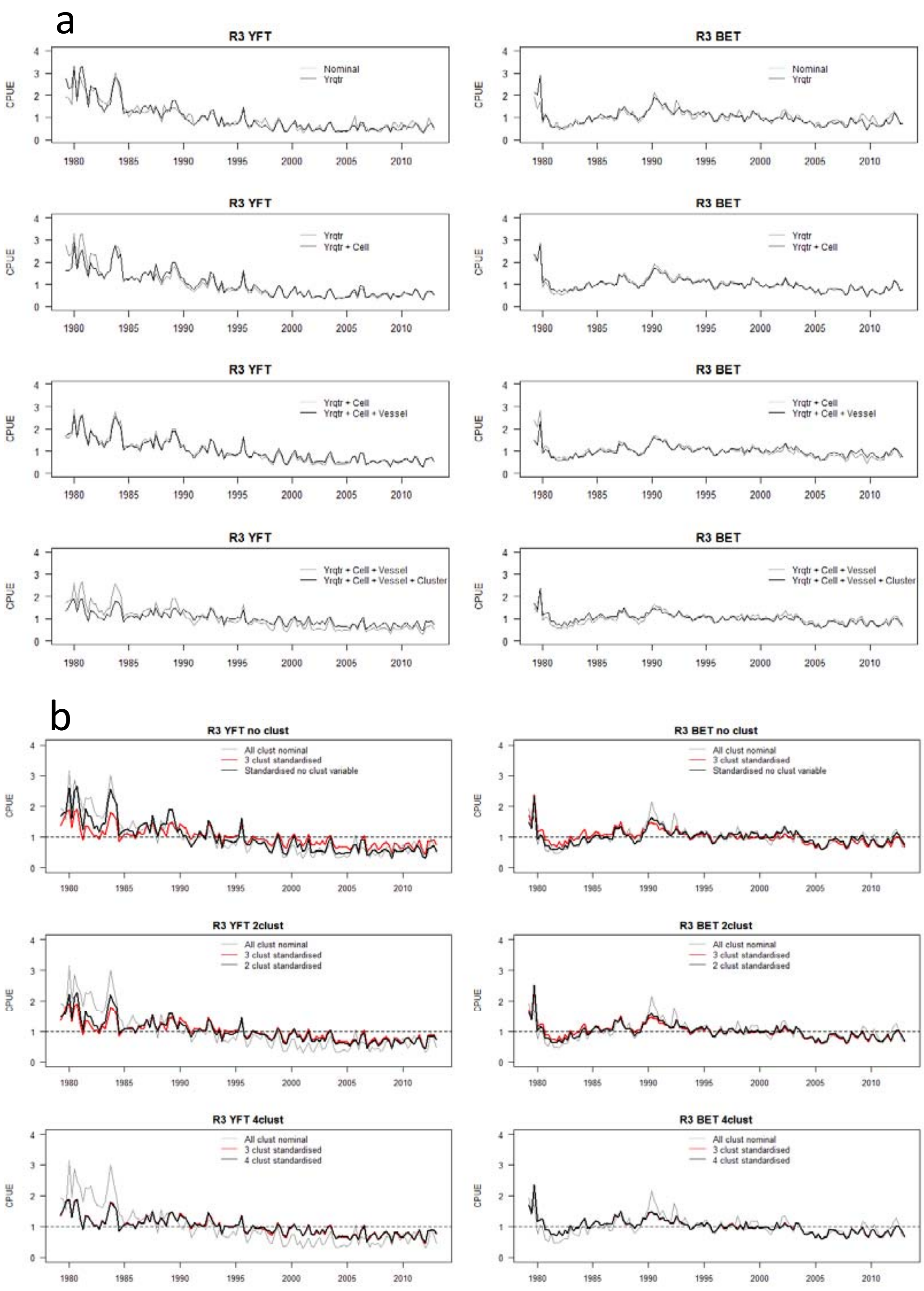


Figure 7: Step plots (a) and indices estimated with models with different numbers of targeting clusters (b) for region 3. Each row of (a) shows the change in the standardised index with an extra variable added. In (b) the nominal index is always grey, the reference model standardised index is always red and the alternative index being compared is black.

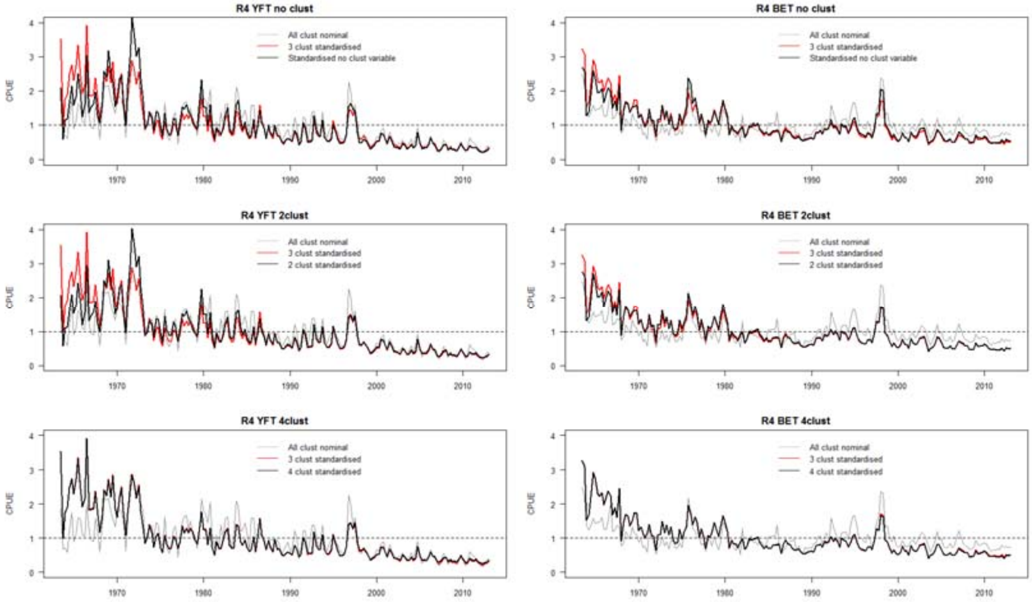


Figure 7 continued: Sensitivity plots for region 4.

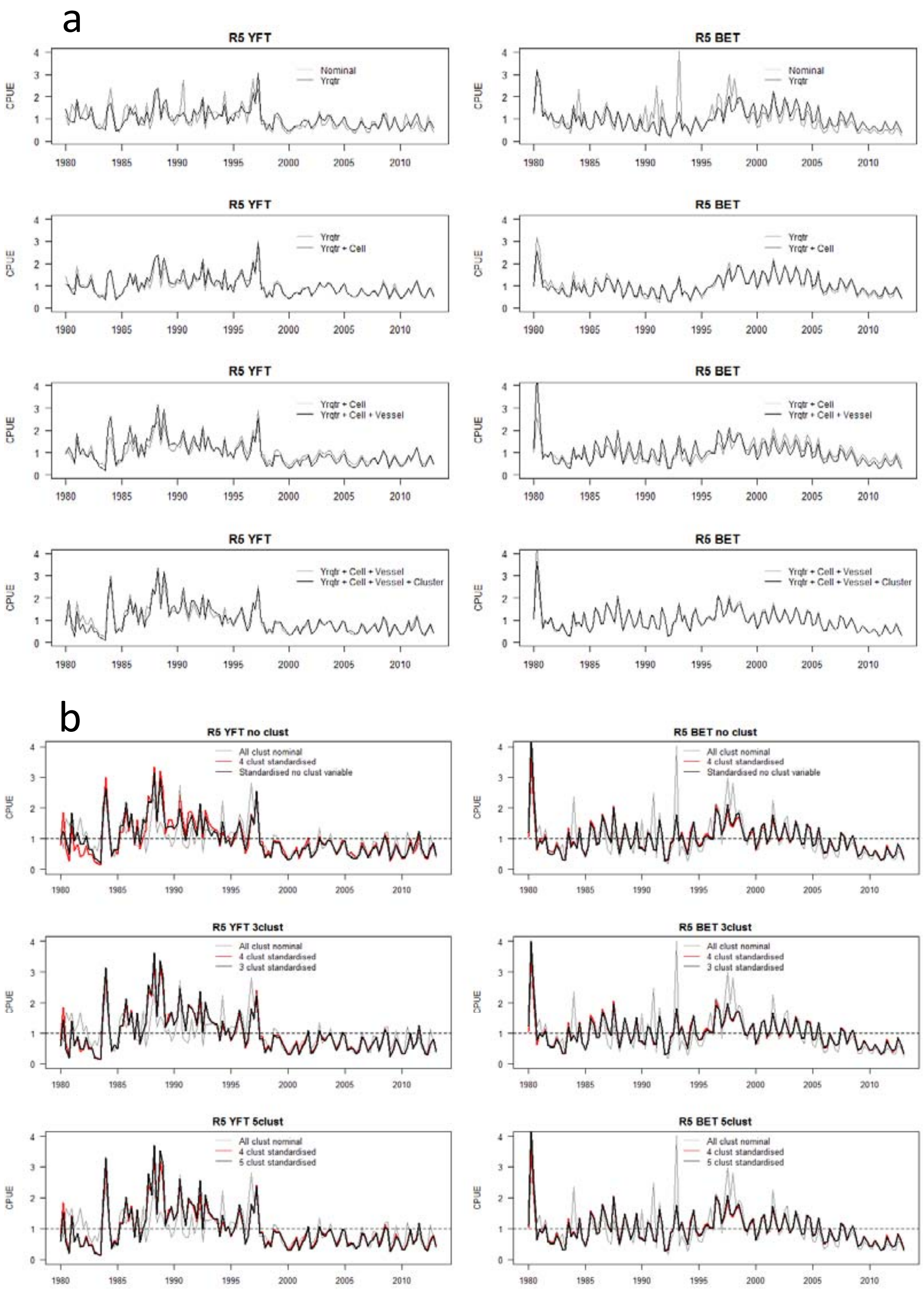


Figure 7 continued: Step plots (a) and sensitivity plots for region 5.

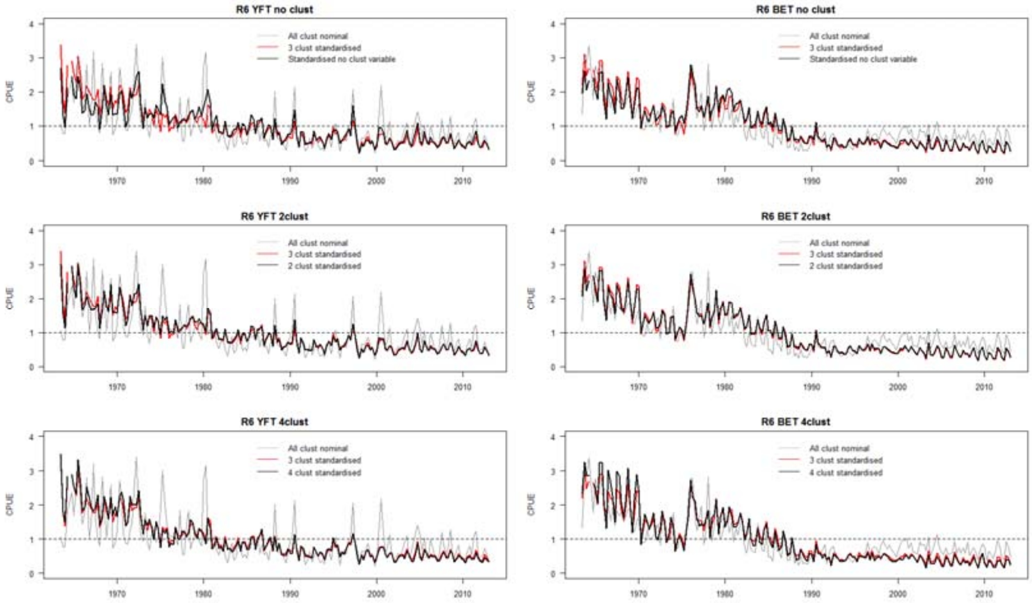


Figure 7 continued: Step plots (a) and sensitivity plots for region 6.

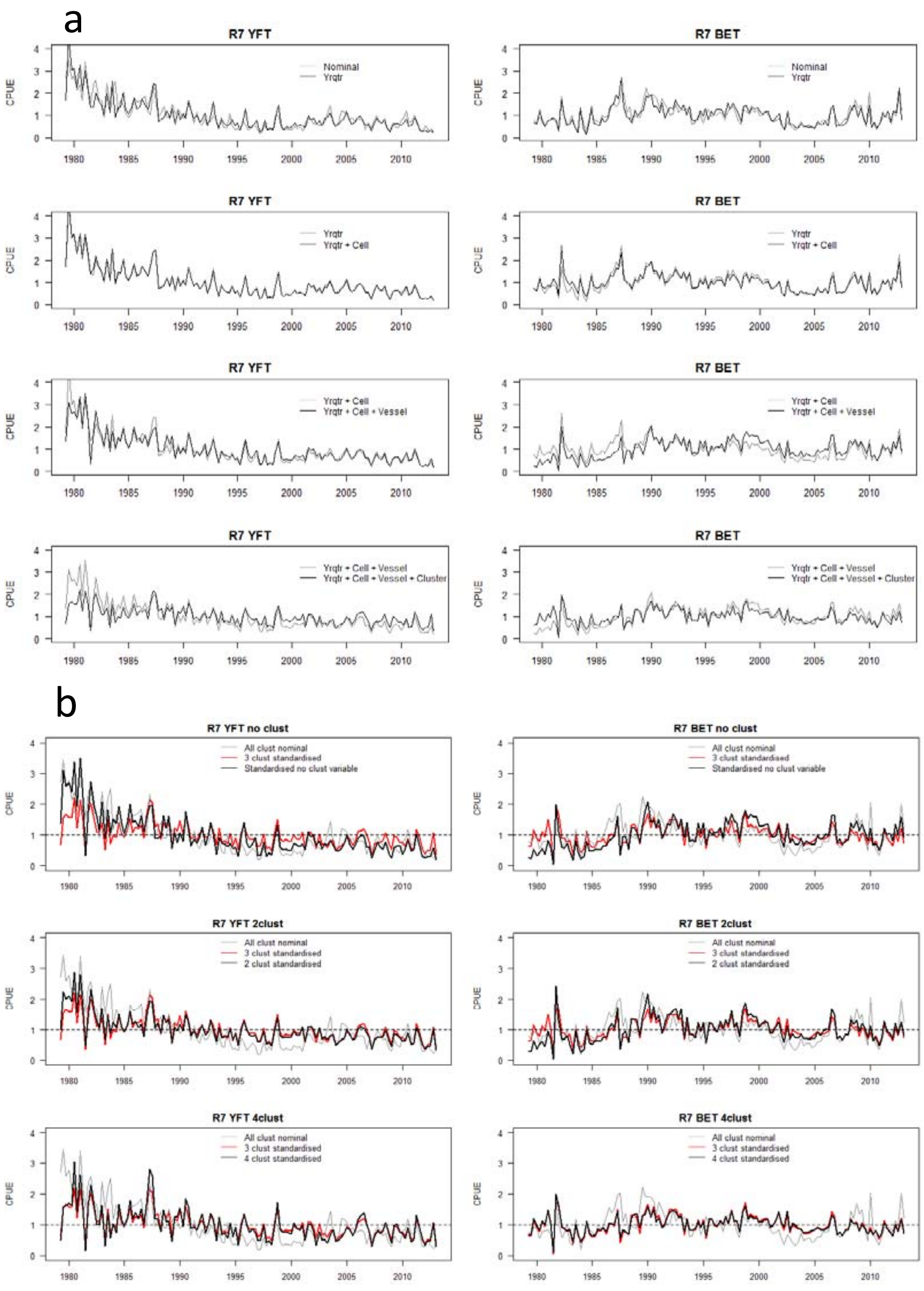


Figure 7 continued: Step plots (a) and sensitivity plots for region 7.

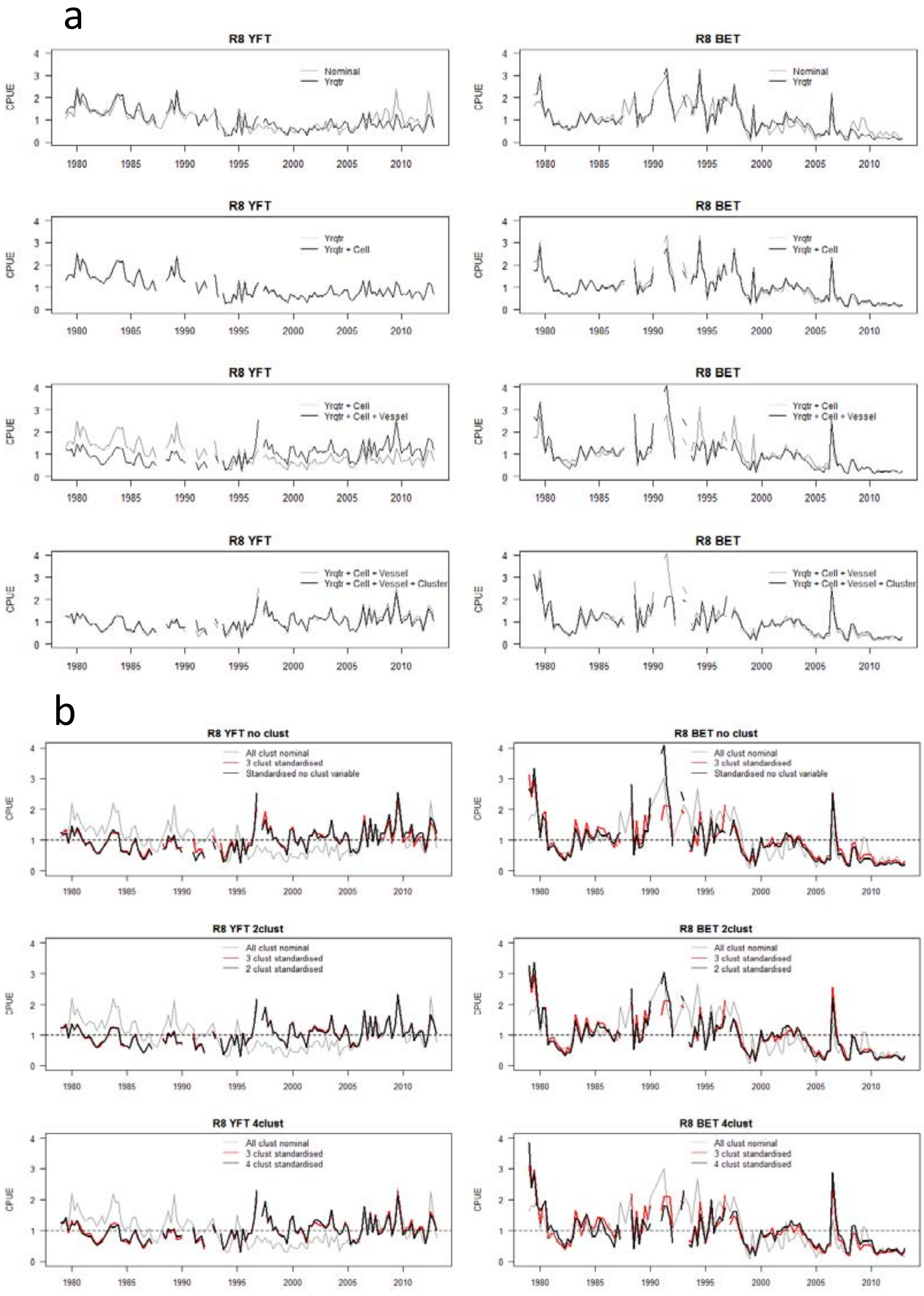


Figure 7 continued: Step plots (a) and sensitivity plots for region 8.

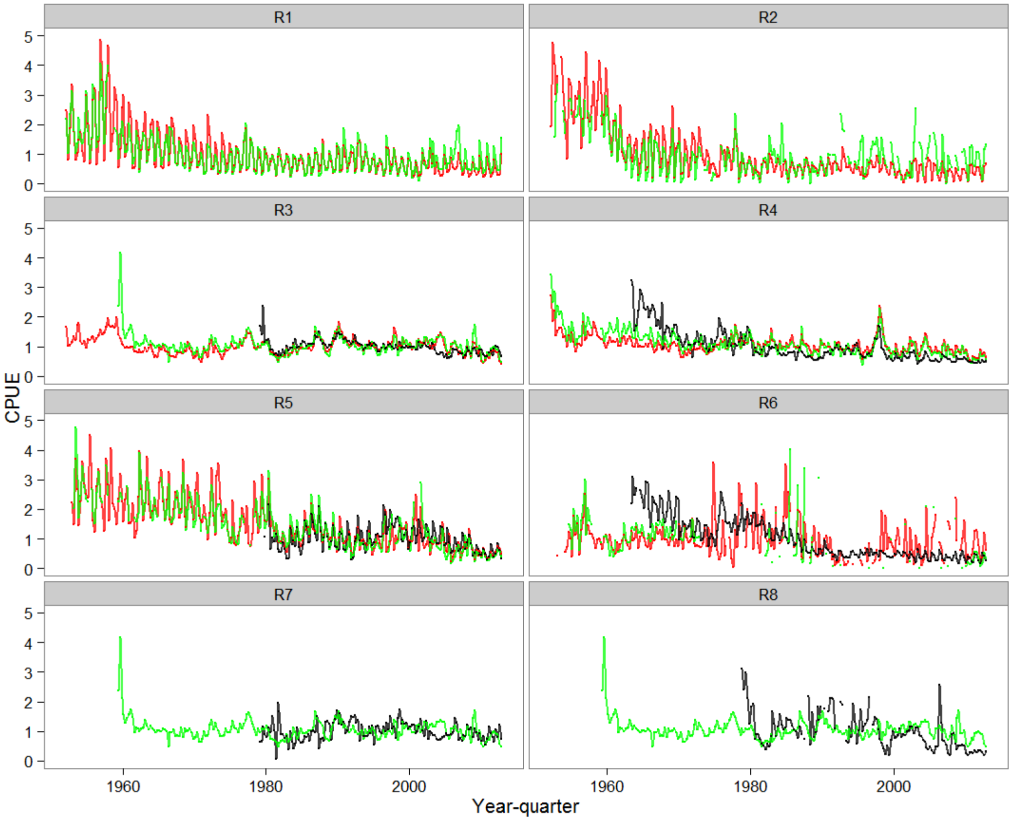


Figure 8: Comparison of standardised CPUE indices for BET in the different assessment regions. Indices are JPLL aggregate (red), JPLL operational (green) and all fleets operational (black). Note that the JPLL operational indices displayed in regions 3, 7 and 8 are the same and relate to the old region 3 (new regions 3, 7 and 8 combined) as they could not be recalculated for the new regional structure.

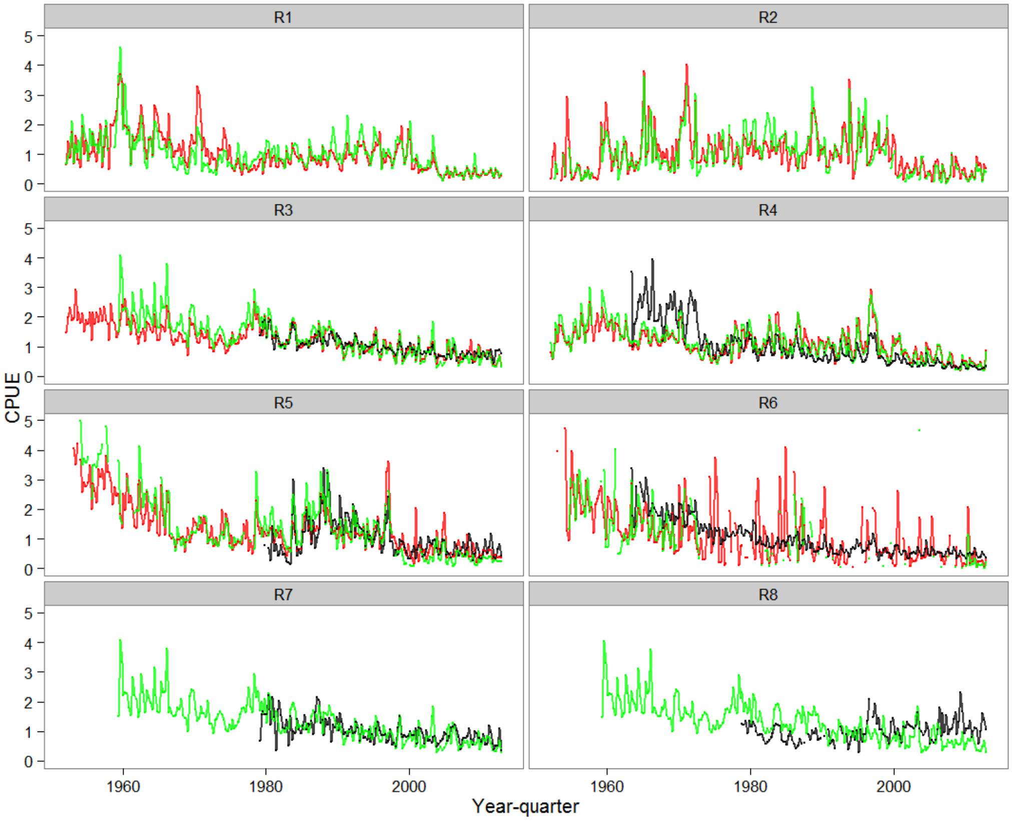


Figure 9: Comparison of standardised CPUE indices for YFT in the different assessment regions. Indices are JPLL aggregate (red), JPLL operational (green) and all fleets operational (black). Note that the JPLL operational indices displayed in regions 3, 7 and 8 are the same and relate to the old region 3 (new regions 3, 7 and 8 combined) as they could not be recalculated for the new regional structure.

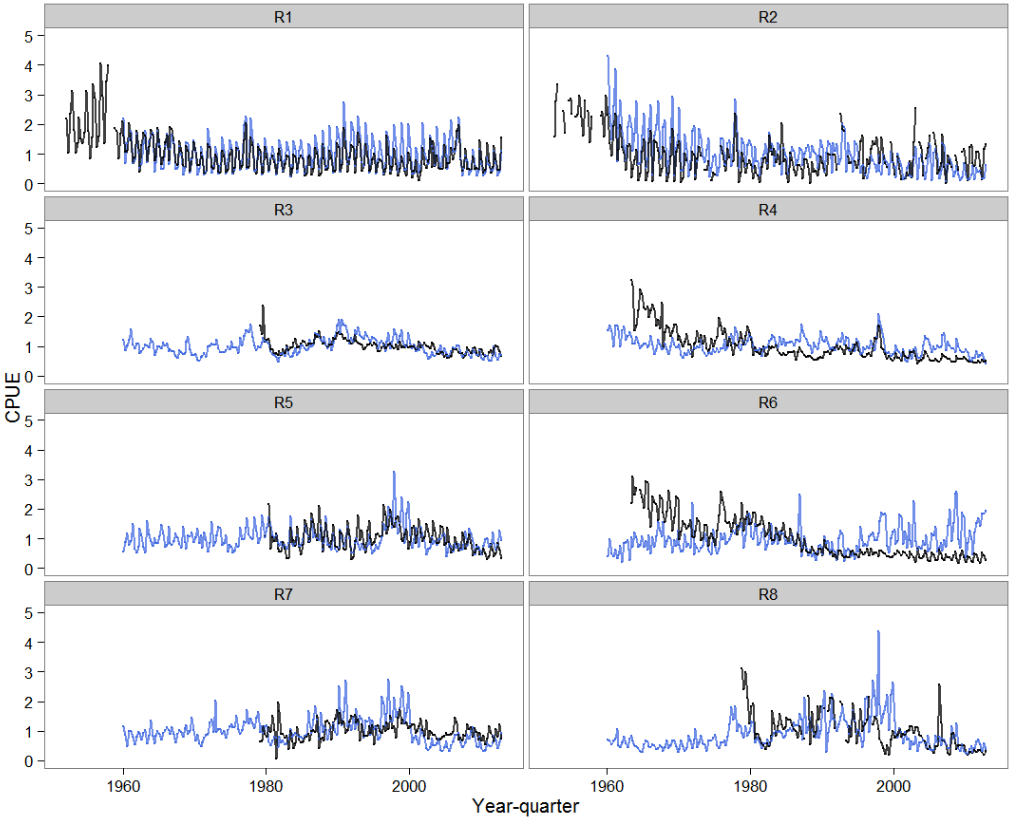


Figure 10: Comparison of standardised operational CPUE indices to be used in the reference case assessment model (black) and spatial GAM CPUE indices for BET in the different assessment regions. Note that the black lines in regions 3 to 8 are for all fleets operational data, while for regions 1 and 2 they are the JPLL operational indices as all fleets indices are not available for those regions.

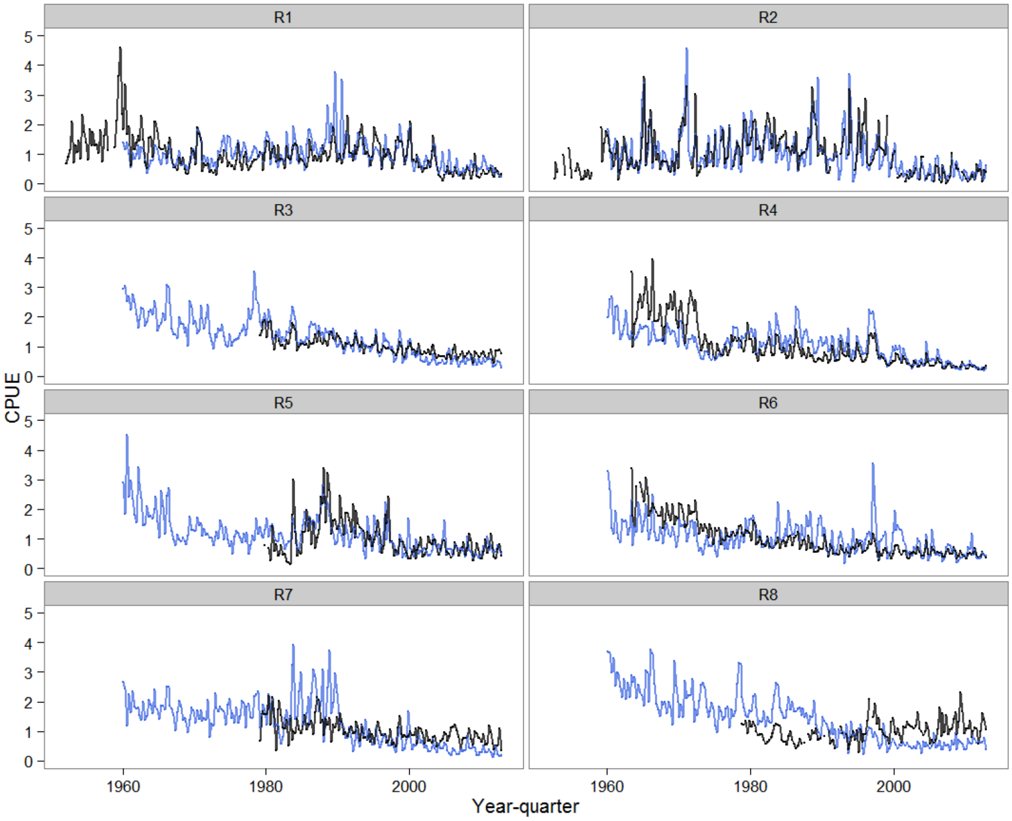


Figure 11: Comparison of standardised operational CPUE indices to be used in the reference case assessment model (black) and spatial GAM CPUE indices for BET in the different assessment regions. Note that the black lines in regions 3 to 8 are for all fleets operational data, while for regions 1 and 2 they are the JPLL operational indices as all fleets indices are not available for those regions.