Collaborative study of yellowfin tuna CPUE from multiple Indian Ocean longline fleets in 2018.

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Executive Summary

In May and June 2018 a collaborative study was conducted between national scientists with expertise in Japanese, Korean, Seychelles, and Taiwanese longline fleets, an independent scientist, and an IOTC scientist. The meetings addressed Terms of Reference covering several important issues related to yellowfin and albacore tuna CPUE indices in the Indian Ocean. The study was funded by the Indian Ocean Tuna Commission (IOTC).

Terms of Reference

1. Validate and improve current methods for developing indices of abundance for the main IOTC species.
2. Provide indices of abundance for selected IOTC species to be presented at the IOTC Working Parties in 2018.
3. Provide support and training to national scientists in their analyses of catch and effort data.
4. The analyses will consider data to be provided by key industrial fisheries operating in the Indian Ocean, including data from the Japanese, Taiwanese, and Korean longline fleets.
5. Analyses will be carried out in a series of meetings scheduled during 2018. After preliminary discussions/meetings between the consultant and participating data providers, preparations will be carried out for each dataset and methods for CPUE standardization developed (or further elaborated upon), which will be followed by a joint CPUE meeting between all participating countries and the consultant.

Tasks will include the following, to the extent possible in the available time:

6. Work with the IOTC Stock Assessment Officer to coordinate meetings between data holders and the consultant.
7. Load, prepare, and check each dataset, given that data formats and pre-processing often change between years and data extracts, and important changes to fleets and reporting sometimes occur in new data.
8. Conduct the following analyses to improve CPUE methods and prepare indices:
    - Apply cluster analyses or alternative methods for identifying targeting. Develop CPUE standardizations for main IOTC species using reliable data from each CPC, with priorities given to yellowfin tuna and albacore in 2018. Prepare separate indices for each fleet, and joint indices. Thoroughly check all code and results in order to validate the final standardized indices series.
    - Explore alternative modelling and data transformation methods in order to normalise residuals and to accommodate strata with no zero catches.
    - Explore residual patterns spatially and among clusters, fleets and vessels through time, and change models where necessary to address any problems identified.
    - Apply methods for estimating relative regional weights, so as to apportion relative abundance among regions.
    - Explore other distributions to improve model fit.
9. Document the analyses in accordance with the IOTC Guidelines for the presentation of CPUE standardisations and stock assessment models, adopted by the IOTC Scientific Committee in 2014;

and to provide draft reports to the IOTC Secretariat no later than 60 days prior to the relevant IOTC Working Party meeting.

10. Undertake any additional analyses deemed relevant by the IOTC Working Parties, Scientific Committee, or IOTC Secretariat.

All work is subject to the agreement of the respective fisheries agencies to make the data available.

As in 2017, this document covers only the joint indices of abundance, describing their development for yellowfin and albacore tunas. Results are reported only for yellowfin tuna, with albacore tuna results presented in a separate document to the Working Party on Temperate Tunas.

Other issues are covered in related papers that describe the data preparation, cluster analyses, and individual indices for each fleet.

Data for the four fleets were standardized for each region to estimate indices of abundance. Indices were estimated using two approaches, delta lognormal and lognormal + constant, but the main approach was the delta lognormal. All models included the explanatory variables year-quarter and 5° cell as categorical variables, and a cubic spline on hooks as a covariate. Models for tropical regions included a cubic spline fitted to hooks between floats, while models for temperate areas included a categorical variable for cluster. Some models included vessel identity as a categorical variable. Models were run for the period 1952-1979 without vessel identity, for the later period 1979-2017 with vessel identity (including the four quarters of 1979 in both analyses), and for the whole period 1952-2017 both with and without vessel identity.

Figures and tables are provided for each set of indices, including both quarterly and annual indices. Diagnostic plots are also presented.

Introduction

In May and June 2018 a collaborative study of longline data and CPUE standardization for albacore and yellowfin tunas was conducted between scientists with expertise in Japanese, Taiwanese, Korean, and Seychelles fleets, an independent scientist, and an IOTC scientist. The study was funded by the Indian Ocean Tuna Commission (IOTC). The study addressed the Terms of Reference outlined below, which cover the most important issues that had previously been highlighted by different working parties. Work was carried out, for those factors relevant to them, for the following:

- Area: Indian Ocean
- Fleets: Japanese longline; Taiwanese longline, Korean longline, Seychelles longline
- Stocks: yellowfin tuna, albacore tuna.

As in 2017, this document covers only the joint indices of abundance, describing their development for yellowfin and albacore tunas. Results are reported only for yellowfin tuna, with albacore tuna results presented in a separate document to the Working Party on Temperate Tunas.

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  - o Explore alternative modelling and data transformation methods in order to normalise residuals and to accommodate strata with no zero catches.
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  - o Apply methods for estimating relative regional weights, so as to apportion relative abundance among regions.
  - o Explore other distributions to improve model fit.

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10. Undertake any additional analyses deemed relevant by the IOTC Working Parties, Scientific Committee, or IOTC Secretariat.

All work is subject to the agreement of the respective fisheries agencies to make the data available.

Methods

Data cleaning and preparation

The four datasets had many similarities but also significant differences. The variables differed somewhat among datasets, as did other aspects such as the sample sizes, the data coverage and the natures of the fleets.

Data preparation and analyses were carried out by each participant, using a standard set of scripts developed for this purpose in R version 3.3.0 (R Core Team 2016). The approaches used are described by Hoyle et al. (2015b) and Hoyle et al. (2016). The datasets and the analyses are described in working papers by each participant and will not be further reported here. The Japanese data for 2017 are preliminary.

For more detail about the Japanese, Korean, and Taiwanese fleets, see the descriptive figures in the following WPTT information papers (Hoyle et al. 2015a, Hoyle and Okamoto 2015, Hoyle et al. 2015c). For detail about the Seychelles fleet, see the WPTT working paper provided by the Seychelles (ref).

Plotting and data selection

We pooled data from multiple fleets into a single dataset for years 1952-2017. The pooled dataset included all data from the Japanese (1952-2017) and Korean (1971-2017) fleets. For the Taiwanese fleet data from 2005-2017 were included. For the Seychelles fleet all data (2000-2017) were included, except in analyses that included hooks between floats.

Joint analyses included prepared and clustered data from each of the fleets. In some analyses clusters that caught very few of the species of interest were omitted, because they provide little relevant information and may cause analysis problems due to large numbers of zeroes, and memory problems due to large sample sizes. Cluster selection was based on review and discussion of the plots of covariates and species compositions by cluster.

For standardization of each regional structure and region, data were included in the analysis if they met a set of selection criteria (Table 2). Selection criteria were based on the minimum number of sets or substrata per stratum. Vessels needed to have fished for at least N1 quarters in the region. Vessels were included if they had made at least N2 sets. Each 5° cell was included if it contained at least N3 sets. A year-quarter was included if there were at least N4 sets. An option has been added to include each year-quarter by 5° cell stratum only if there were at least N5 sets, but the feature was not operational during these analyses.

For datasets with more than 60,000 sets the number of sets in each stratum (5° square * year-quarter) was limited by randomly selecting 30 sets without replacement from strata with more than this number of sets. Testing suggested that this approach did not cause bias, and the effects on random variation were reduced to very low levels at 30 sets per stratum (Hoyle and Okamoto 2011).

CPUE standardization

CPUE standardization methods generally followed the approaches used by Hoyle and Okamoto (2011) with some modifications. The operational data were standardized using generalized linear models in R. Indices were prepared for each species and region using several approaches, summarised in Table 1 and further described below.

Table 1: Species, regions, distributions and variables used in CPUE analyses. The distributions used are logC (lognormal constant), bin (binomial), and logN (lognormal).

Species	**Regions**	**Fleets**	**Target variable**	**Vessel ID**	**Period**	**Distribution**
YFT	2, 3, 4, 5, 2n, 2s	All	Cluster	Y, N	1952-2017	logC, bin, logN
				N	1952-1979	
				Y	1979-2017	
		All except SY	HBF	Y, N	1952-2017	
				N	1952-1979	
				Y	1979-2017	
ALB	1, 2, 3, 4	All	Cluster	Y, N	1952-2017	
				N	1952-1979	
				Y	1979-2017	
		All except SY	HBF	Y, N	1952-2017	
				N	1952-1979	
				Y	1979-2017	

Distributions

CPUE was defined at the set level as catch in number divided by hooks set. Two different approaches were used: lognormal constant and delta lognormal.

Lognormal constant analyses were carried out using generalized linear models that assumed a lognormal distribution. In this approach the response variable $\log(CPUE + k)$ was used, and a Normal distribution assumed. The constant *k*, added to allow for modelling sets with zero catches of the species of interest, was 10% of the mean CPUE across all sets.

Two alternative models were used, including either cluster or hooks between floats.

ln$(CPUE+k)$~ $yrqtr+vessid+latlong5+cluster+\phi(hooks)+\epsilon$, or

ln$(CPUE+k)$~ $yrqtr+vessid+latlong5+\varphi(hbf)+\phi(hooks)+\epsilon$

The covariates were year-quarter (*yrqtr*), and 5° cell (*latlong5*) fitted as categorical variables, and a cubic spline function ϕ with 10 degrees of freedom applied to the continuous variable *hooks*. Analyses including the vessel identifier (*vessid*) fitted it as a categorical variable. Analyses including hooks between floats (*hbf*) fitted it as a continuous variable using a cubic spline φ with 3 degrees of freedom, while those including cluster (*cl*) fitted it as a categorical variable.

Delta lognormal analyses (Lo et al. 1992, Maunder and Punt 2004) used the same covariates as the lognormal constant model. They employed a binomial distribution for the probability *w* of catch rate being zero and a probability distribution *f(y)* , where y was log(catch/hooks set), for non-zero (positive) catch rates. The index estimated for each year-quarter was the product of the year effects for the two model components, $(1-w).E(y|y \neq 0)$.

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

$\mathrm{g}(w) = (CPUE = 0) \sim covariates + \epsilon$, where *g* is the logistic function.

$\mathrm{f}(y) = CPUE \sim covariates + \epsilon$, for nonzero sets

Data in all models except the binomial model were 'area-weighted', with the weights of the sets adjusted so that the total weight per year-quarter in each 5° square would sum to 1. This method was based on the approach identified using simulation by Punsly (1987) and Campbell (2004), that for set *j* in area *i* and year-quarter *t*, the weighting function that gave the least average bias was: $w_{ijt} = \frac{log(h_{ijt}+1)}{\sum_{j=1}^{n}\log(h_{ijt}+1)}$. Given the relatively low variation in number of hooks between sets in a stratum, we simplified this to $w_{ijt} = \frac{h_{ijt}}{\sum_{j=1}^{n} h_{ijt}}$.

Data periods

Vessel identity information for Japan was only available from 1979, and most of the data before 1979 was Japanese. The Korean dataset started in 1971 and had vessel ids throughout, but covered a limited area with relatively low effort, so its influence was small in some analyses. The full Taiwanese dataset started in 1979, and in any case Taiwanese data before 2005 were omitted.

Overlap between vessels with the same id across years is required to avoid confounding between year effects and vessel ids. Thus we could not apply a consistent approach across all years when including vessel ids in the model.

The discontinuity in vessel 1979 could be addressed in several different ways. We therefore analysed the data in several ways so as to provide the assessment scientists with appropriate data.

First, we standardized the full dataset from 1952 to the present without including vessel effects.

Next we standardized the full dataset with vessel effects, assigning an identical dummy vessel ID to all sets that lacked vessel identity information. However, using a dummy value introduces several problems. First, most Japanese vessels begin to report their callsign in 1979, but a few do not, and these are presumably self-selected and not randomly selected from the vessel population. We therefore omitted all sets without vessels ids starting in 1979. This mostly restricted the overlap between dummy and real vessel IDs to one year – 1979. However, there was a little overlap between the pre and post-1979 periods in some cases due to Korean vessel ids, which start in 1971. The limited overlap resulted in some indices showing a discontinuity in 1979. A second problem was that residuals may be more variable before 1979, without a true vessel ID in the model, which can introduce bias into the standardization.

The solution was to estimate two time series: 1952-1979 without vessel effects, and a second time series 1979-2017 with vessel effects (omitting all sets without vessel IDs). Subsequently the analyst may use the two time series as desired, either as separate indices in the assessment, or the recommended approach of concatenating them after adjusting the averages so that the estimates for 1979 are the same. This approach also has the advantage that it allows covariate estimates such as spatial effects to differ by time period.

Covariate effects

The effects of covariates were examined by plotting the predicted effects, with 95% confidence limits, of each parameter at observed values of the explanatory variables. Spatial effects with 95% confidence intervals were plotted by latitude. The cumulative vessel effects through time were examined by plotting each vessel's effect at every time that vessel made a set. An average vessel effect over time was examined by calculating the mean of the vessel effects for all sets made by the fleet during each time period, and this was also plotted. There is insufficient space to include all plots in the report, but these are available on request.

Changes in catchability through time were investigated by fitting to the operational data both with and without a term for individual vessel. The two models were designated respectively the 'base model' and the 'vessel-effects model'. Abundance indices were calculated for each model, and normalized to average 1.

For all model comparisons, the indices estimated for each year-quarter were compared by dividing the base model by the vessel effects model, plotting the time series of ratios, and fitting a log-linear regression. The slope of the regression represented the average annual compounding rate of change in fishing power attributable to changes in the vessel identities; i.e. the introduction of new vessels and retirement of old vessels. Gradients are shown on the figures, together with confidence intervals.

Model diagnostics

Residual distributions and Q-Q plots were produced for all but the binomial analyses. For the lognormal positive analyses that included cluster in the model, median residuals were plotted by cluster. For all lognormal positive analyses, residuals by year-quarter were plotted by flag; median residuals by year-quarter were plotted by flag; and median residuals by 5° cell were mapped onto a contour plot for each flag.

The effects of covariates were examined using influence plots, using the R package influ (Bentley et al. 2011).

Indices of abundance

Indices of abundance were obtained by applying the R function predict.glm to model objects. The datasets used for prediction included all year-quarter values, with all other variables fixed at either the median for continuous variables, or the mode for categorical variables. Binomial time effects were obtained by a) generating logit time effects from the glm, and b) adding a constant to these logit time effects so that the mean of the back-transformed proportions was equal to the proportion of positive sets across the whole dataset. The main aim with this approach is to obtain a CPUE that varies appropriately, since variability for a binomial is greater when the mean is at 0.5 than at 0.02 or 0.98, and the multiplicative effect of the variability is greater when the mean is lower. The outcomes were normalised and reported as relative CPUE with mean of 1.

Uncertainty estimates were provided by applying the R function predict.glm with type = ”terms” and se.fit=TRUE, and taking the standard error of the year-quarter effect. For the delta lognormal models we used only the uncertainty in the positive component. Uncertainty estimates from standardizing commercial logbook data are in general biased low and often ignored by assessment scientists, since they assume independence and ignore autocorrelation associated with (for example) consecutive sets by the same vessels in the same areas. There may be a very large mismatch between the observation error in CPUE indices and the process error in the indices that is estimated in the assessment. This is particularly true for distant water longline CPUE, where very large sample sizes generate small observation errors.

Annualized indices were developed from the year-quarter indices. For each time series, the year-quarter estimates were modelled with a linear regression with normally distributed residuals, fitting year-quarter as a function of year + quarter. The year effects were then predicted in the second quarter of the year, and normalized to average 1. The second quarter was chosen because there were fewer missing values than other quarters.

Time-area interactions

We did not explicitly model time-area interactions, but explored the potential for them to occur in the 1979-2017 analyses for each region. We modelled the long term trends in median residuals for each 5° cell year-quarter stratum. We determined the median residual for each 5° cell year-quarter, and then fitted a regression of median residuals versus year-quarter for each 5° cell. We extracted the slope of each regression and plotted them on a map, with darker red representing decline and lighter yellow representing increase relative to the average model trend.

Results

We estimated delta lognormal indices for all regions of yellowfin regional structure Y (Figures 2-7) and for the split north-western region 2 (regional structure Y2, Figures 3 and 4). We also estimated annualized indices (Figures 8-13). Diagnostics for the lognormal positive distribution indicated some negative skewness in the distributions of residuals (Figures 14- 15), with better fits for the indices that included vessel effects.

We estimated a number of other indices, but here present figures for only the indices likely to be used in assessments, so as to conserve space. In tropical areas (yellowfin regions 2 and 5) we selected figures from the analysis that omits low-target clusters from the dataset, and includes HBF but not cluster in the model. In temperate areas (yellowfin regions 3 and 4) we selected figures from the analysis that omits low-target clusters from the dataset, and conversely includes cluster but not HBF in the model. This is because in southern regions there are known differences in fishing behaviour among vessels targeting different species, and these differences are reflected in the species composition, making it appropriate to use cluster in the standardization model. For example, the Japanese southern bluefin tuna fishery takes largely SBT, with some catch of albacore. The Taiwanese oilfish fishery is also a clear example, with a very high representation of species 'other'.

In tropical areas however, although there have been changes in targeting through time, vessels are believed to target bigeye and yellowfin at the same time and using similar methods, but to different extents by area and season, and with changes through time. In this complex situation clustering may be useful to remove data from clearly separate fisheries (such as the southern bluefin tuna fishery that occurred in eastern areas near Indonesia in the 1960s and 70s). However including cluster in the model may be problematic due to the confounding of clusters with abundance change. We have therefore used hooks between floats in the models for tropical areas, as was done in previous years' analyses. However, unlike previous analyses, we excluded clusters with minimal catch of the species of interest for reasons described above.

In reporting results we focus mainly on the two shorter sets of indices in the lower half of each set of figures. These cover the 1952 – 1979 period without vessel effects, and the 1979 – 2017 period with vessel effects.

For yellowfin tuna, indices in the tropical areas were characterized by very steep declines in standardized CPUE prior to 1965. Declines continued at a slower rate until 1980. From 1980 the western tropical region 2 CPUE (Figure 2) increased until about 1986-87, then declined until around 1995, increased again until 2005, and then decreased again. Since about 2011 it has remained relatively stable, a little above the lowest level which was observed in the late 2000's. The eastern tropical region 5 followed a similar pattern until 1990 but then declined steadily, and in 2017 was close to the lowest level in the time series (Figure 7).

The western tropical region was split into two subregions in the regY2 structure. The south-western tropical region 2s (regY2_R2, Figure 3) and the north-western tropical region 2n (regY2_R7, Figure 4) followed similar trends before 1965, declining steeply. Estimated catch rates were highly variable, partly due to sparse data. After 1980 CPUE increased somewhat in both subregions and then declined with medium-term variability until 2010. Catch rates increased somewhat in both subregions after 2010.

Yellowfin in western temperate region 3 followed a similar pattern to the western tropical indices, with a decline until about 1965 followed by an increase from 1980 until the late 1980s, and subsequently a relatively stable pattern but with significant variability, both in the medium term and seasonally (Figure 5). In eastern temperate region 4 the pattern was similar to the western temperate area before 1965 (Figure 6). After 1979 catch rates increased slightly overall until the mid-2000's, but then declined rapidly and reached their lowest observed levels by 2017.

Residuals for these analyses were reasonably normally distributed (Figures 14 to 15), with the residuals for the tropical indices tending to be more left skewed.

The effects of the standardization process on the indices are shown in Figures 16 to 20. Most indices saw substantial reduction in variability, due to standardization of the effects of spatial movements of the fleets, and changes in targeting. The indices post-1979 showed larger changes in trend, partly because the relatively large vessel effects could be accounted for, but also due to large changes in both targeting and fleets.

Median residuals were also reported by year-quarter (Figures 21 to 23) and by 5° cell (Figures 24 to 26), with additional grouping by flag in the tropical areas, where the selected models did not include cluster variables, and by cluster in the temperate areas.

Patterns by year are affected by the introduction of different fleets and changes in the number of vessels, which affect the variability of the medians by fleet and by cluster. Changes in the trends of the medians, however, may indicate problems in the modelling such as changes in fishing power by part of the fleet that are not explained by the available data.

In the median residuals by year-quarter for 1979-2017 (Figures 21 to 23) the Japanese residuals become more variable after 2005 when the Taiwanese data are introduced, and a similar pattern occurs after the arrival of Korean vessels in 1975. In region 5 the Japanese residuals trend negative after about 2000.

There are no clear spatial residual patterns in the split north-western regions for yellowfin tuna, perhaps because the regions are too small for much spatial differentiation (Figures 24 and 25). In the eastern tropical region the Taiwanese residuals are negative in the north after 1979, and positive in the southeast (Figure 26).

The influence plots for western tropical areas (Regions 2N and 2S, regY2_R2 and regY2_R7, Figures 27 and 28) show relatively little influence from most variables, with spatial patterns having the strongest effects. In the northern tropical area yellowfin CPUE declined due to changing spatial effects in the 1952-1965 period. During the post-1979 period vessel ids were available, and there were some large changes in yellowfin catch rates 1995-2000 associated with increase in Japanese vessels with higher catch rates than the Korean vessels they replaced. After 2005 there were fewer Japanese vessels and more Taiwanese vessels with lower yellowfin catch rates.

In the western temperate area (region 3, regY_R3, Figure 29) spatial effects were influential, showing the expected greater seasonality further south. Here there was no evidence of movement to areas with lower yellowfin catch rates in the period up to 1965. Cluster effects also showed seasonality, associated with seasonal targeting behaviour. Post-1979 clustering effects indicated a shift away from effort types associated with yellowfin targeting after 1990 , but an increase again from 2005 with the Taiwanese fleet. Vessel effects for the Japanese fleet were generally higher than the other fleets, and including vessel effects after 1979 was influential. There was an early increase in mean fishing power associated with vessel ids, but then a decline post-2005 with the introduction of the Taiwanese fleet to the analysis, and the reduced effort of the Japanese fleet.

In the eastern temperate region 4 (regY_R4, Figure 30) there was a substantial move of effort to areas with lower yellowfin catch rates 1952-1970. After 1979 catch rates varied with targeting clusters until about 1990, but after this time the Japanese cluster with higher yellowfin catch rates substantially reduced its effort. This change is also apparent in the spatial influence plot, with reduced variability after 1990, since the JP YFT cluster fished in the north of region 4.

In the eastern tropical region 5 (regY_R5, Figure 31), there is a decline in catch rates after 1975 associated with a change in the numbers of hooks per set. After 1979 there appears to be a shift towards areas with higher yellowfin catch rates after 2005, possibly due to the introduction of the Taiwanese fleet. Hooks between floats and hooks per set have contrasting influence on CPUE, with HBF associated with a decline and hooks an increase in catch rates from 1995 to 2000. From 1979 to 1990 there is a shift to vessels with higher yellowfin catch rates. This declines again in the 1990s, but increases from about 2000 as the Seychelles and Taiwanese fleets arrive. These fleets may target yellowfin in region 5 more than the Japanese fleet does.

Trends through time in temporal residuals from the 1979-2017 models in equatorial regions 2 and 5 show more catch rate decline than elsewhere in the tropical areas between 5°N and 5°S, corresponding to areas with more purse seine effort (Figure 32). In the western temperate area region 3 there is no clear pattern (Figure 33). In eastern temperate region 4 there is more catch rate decline in northern than southern areas.

Discussion

The CPUE indices presented in this paper are derived from joint analysis of Japanese, Korean, Seychelles, and Taiwanese data. In 2015 and 2016 this joint paper included analyses of data from individual fleets, but in 2017 and this year the methods and results for the individual fleets, including cluster analyses, are provided in separate papers.

The general approach was to run separate models for different areas, so that parameter estimates and uncertainty distributions could differ among areas (Chang et al. 2011). The models used 5° cell area effects, as recommended by the 2013 IOTC CPUE workshop (Anon 2013) to account for changes in effort distribution, and adjusted statistical weights to allow for changing effort concentration (Punsly 1987, Campbell 2004). The models included vessel effects where available, to account for some effects of changing fishing power and targeting within the fleet (Hoyle and Okamoto 2011). They also used cluster analysis based on species composition in order to identify target change, and to separate out effort using different fishing strategies (He et al. 1997). Cluster was used as a variable in the standardization models in temperate areas, but not in tropical areas due to concerns about confounding with abundance changes in the species of interest.

As in the 2017 analyses, we included data from the Seychelles. These data were first made available in 2017 and have only been included in the indices that used clustering. Most of the Seychelles time series does not report the hooks between floats variable, which is required for the tropical indices. This was unfortunate because most of the Seychelles effort is in the western tropical area. In future this dataset should be included in tropical indices, but we will need to find a way to address the lack of HBF, perhaps using a proxy variable based on understanding of how HBF and other setting methods are used for targeting.

The western tropical area have been split into northern and southern sub-regions. The region was split in the 2016 bigeye stock assessment to improve tag mixing (Langley 2016). Trends appeared to differ between the sub-regions to some extent so we have also applied the approach to the yellowfin indices.

Temporal trends appear to vary within regions, with greater decline in residuals indicating greater decline in CPUE in tropical areas close to the equator. Similar spatial patterns have been observed in Atlantic fisheries (Hoyle et al. 2018), with larger declines in catch rates in tropical areas. Tropical areas receive more purse seine effort, and this trend may be associated with greater depletion of areas subject to more purse seine fishing. There may be other explanations such as reduced efficiency or targeting ability in areas with more purse seine fishing. Further exploration is required to identify the timing of the changes, and whether other factors, such as target change, gear change, or fleet composition, are contributing to or causing these trends. If trends do vary spatially and non-randomly, then time-area interactions at appropriate scales should be included in future models.

The joint data were only available for one week, and this time was also occupied by training, presentations, and discussions during the joint CPUE workshop. This limited data access was a constraint on testing and development.

The analyses presented here used an R package 'cpue.rfmo', which the first author of this report is developing for the standardization of pelagic longline data used by tuna RFMOs.

CPUE indices are very influential components of stock assessment models, and further work to improve and validate indices is a high priority. We suggest the following priorities for further work:

1) Explore options for extending the Japanese time series of vessel effects into the pre-1979 period.
2) Increase understanding of the fisheries that provide the CPUE by a) further exploring the size data associated with each fleet, if possible with size data at the vessel set level; and b) exploring vessel movement patterns through time.
3) Explore alternative modelling and data transformation methods in order to normalise residuals and to accommodate strata with no zero catches.
4) Explore alternative subarea-time interactions to the standardization models, to address differences in trends among areas. Continue to explore residual patterns spatially and among clusters, fleets and vessels through time, and change models where necessary to address any problems identified. Develop additional residual and exploratory plots to explore possible confounding effects, such as maps of residuals by season to explore seasonal catchability changes.
5) Test alternative methods for identifying and accounting for targeting.

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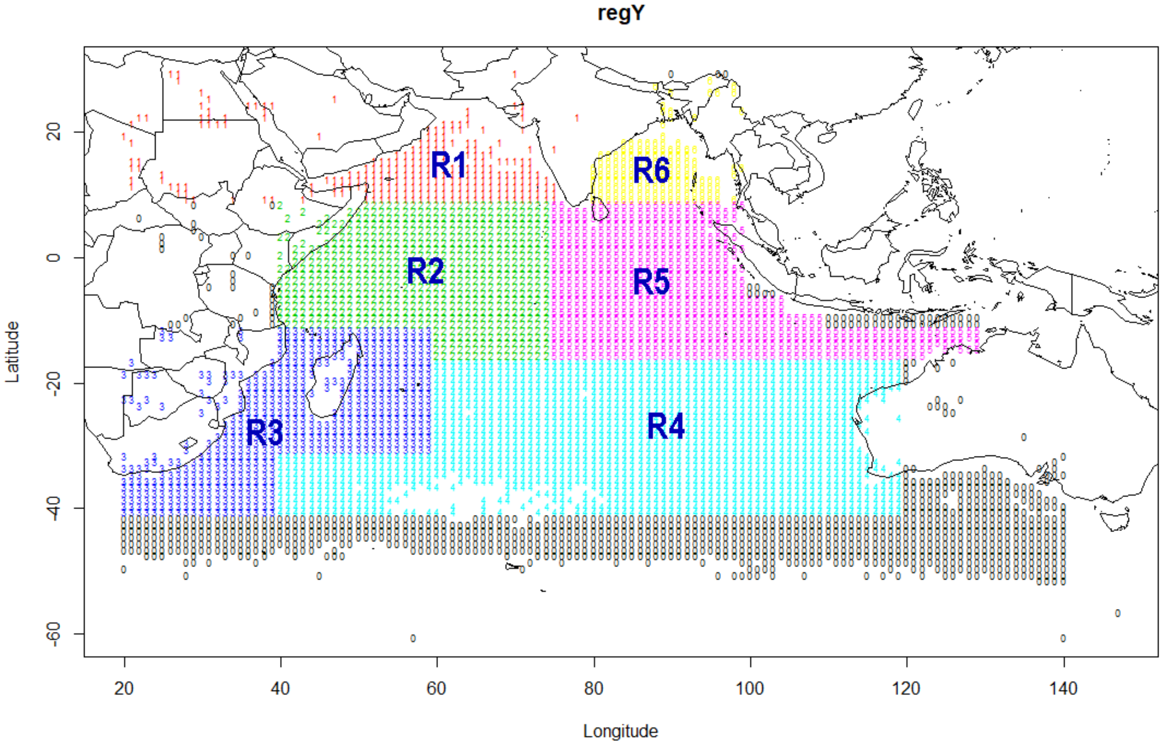
Tables

Table 2: Criteria defining the minimum numbers of strata by region and regional structure, for 5 different types of strata.

Regional structure	Number of regions	Min vessel quarters (N1)	Min vessel sets (N2)	Min latlong sets (N3)	Min yr-qtr sets (N4)	Min yq latlong sets (N5)
Y	6	2, 5, 5, 2, 5, 2	40, 100, 100, 40, 100, 40	20, 50, 50, 20, 50, 20	20, 50, 50, 20, 50, 20	3, 5, 5, 3, 5, 3
Y2	7	2, 5, 5, 2, 5, 2, 5	40, 100, 100, 40, 100, 40, 100	20, 50, 50, 20, 50, 20, 50	20, 50, 50, 20, 50, 20, 50	3, 5, 5, 3, 5, 3, 5
A4	4	3, 2, 5, 5	60, 40, 100, 100	30, 20, 50, 50	30, 20, 50, 50	3, 3, 5, 5
A5	1	5	100	50	50	5

Figures



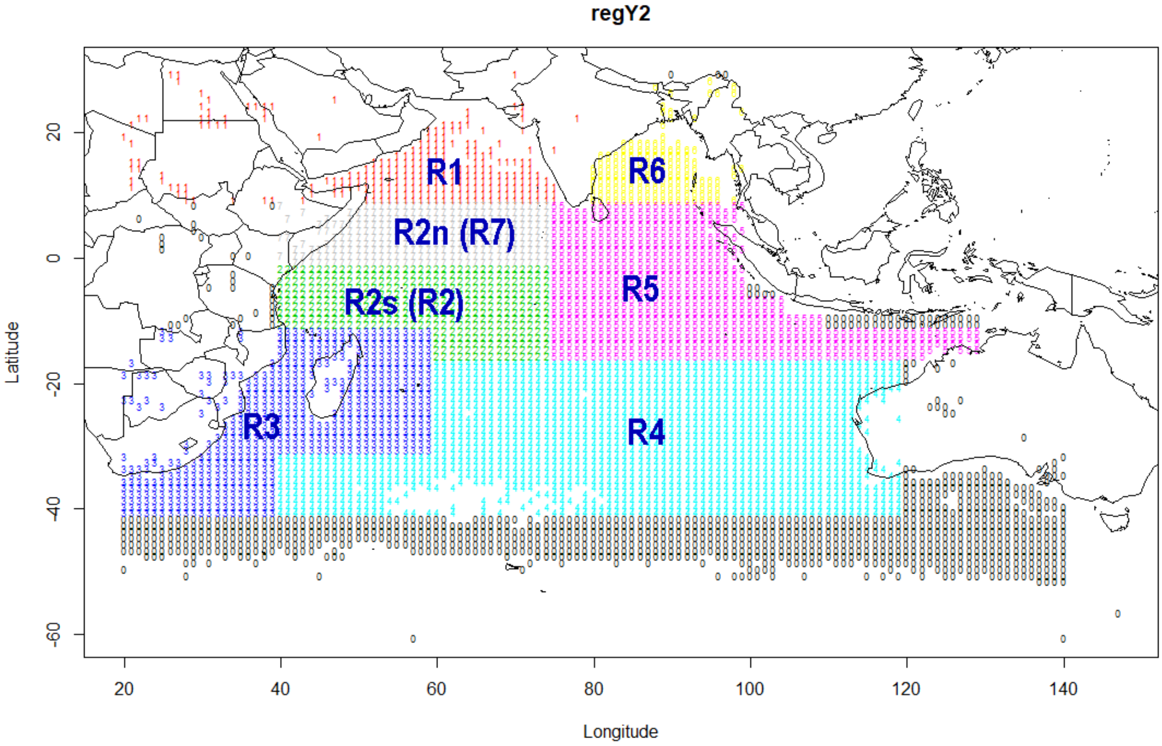


Figure 1: Maps of the regional structures used to estimate yellowfin CPUE indices for the versions in which the western tropical region is contiguous (Y, above) and split (Y2, below).

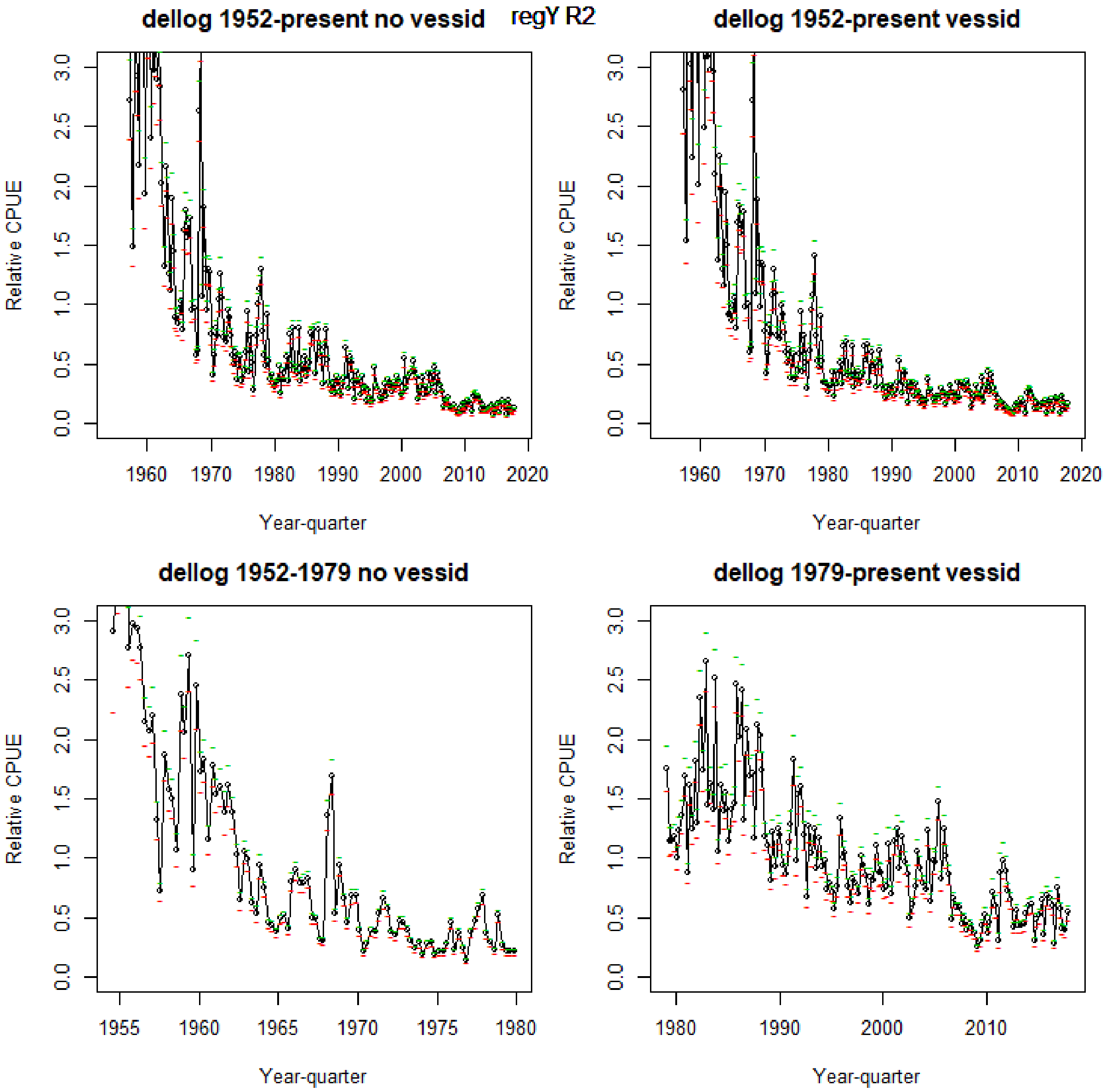


Figure 2: Quarterly CPUE series for yellowfin region 2 (western tropical, regY_R2), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

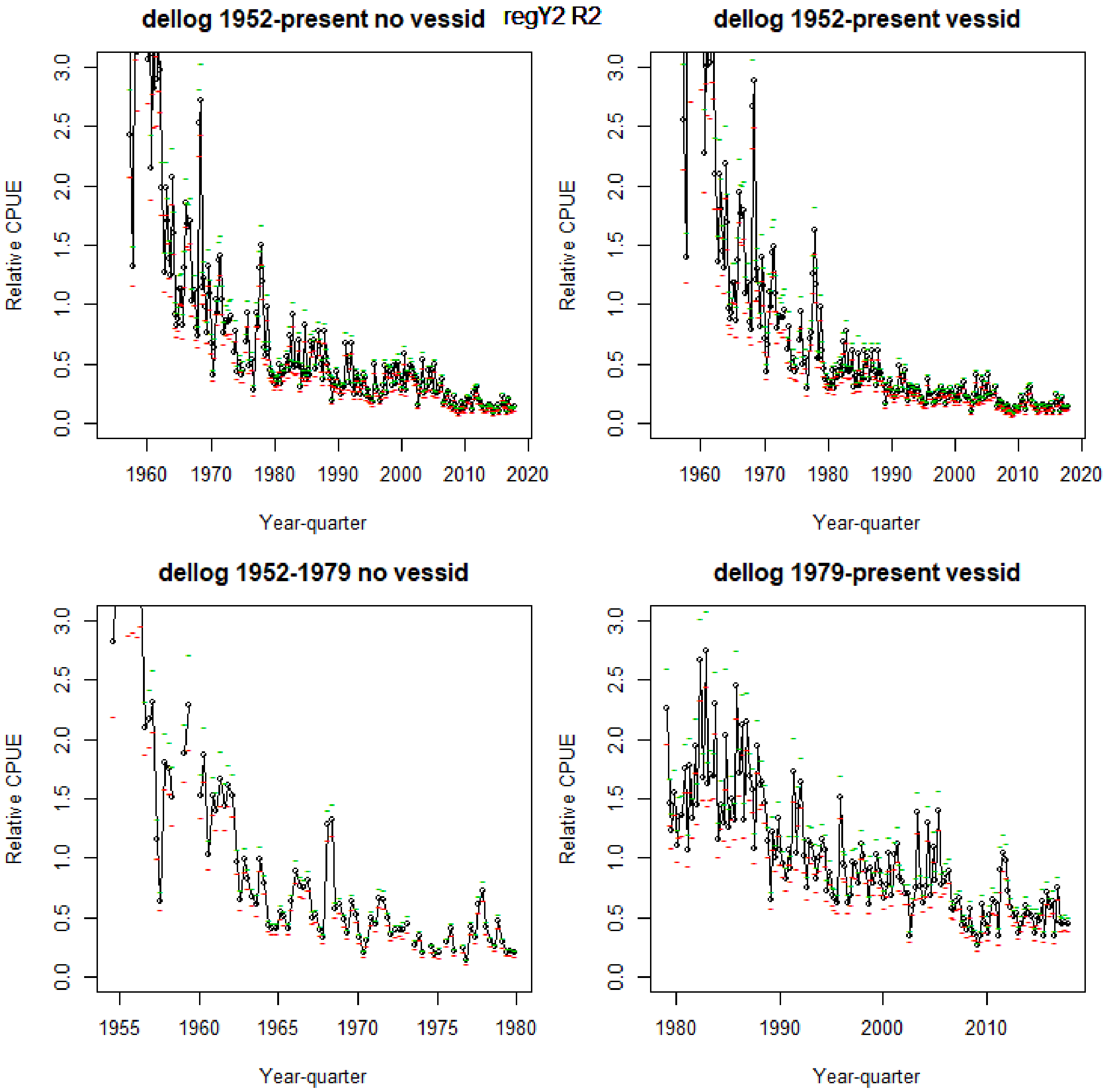


Figure 3: Quarterly CPUE series for yellowfin region 2s (south-western tropical, regY2_R2) in regional structure Y2, which is the southern part of the western tropical region. The plots include time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

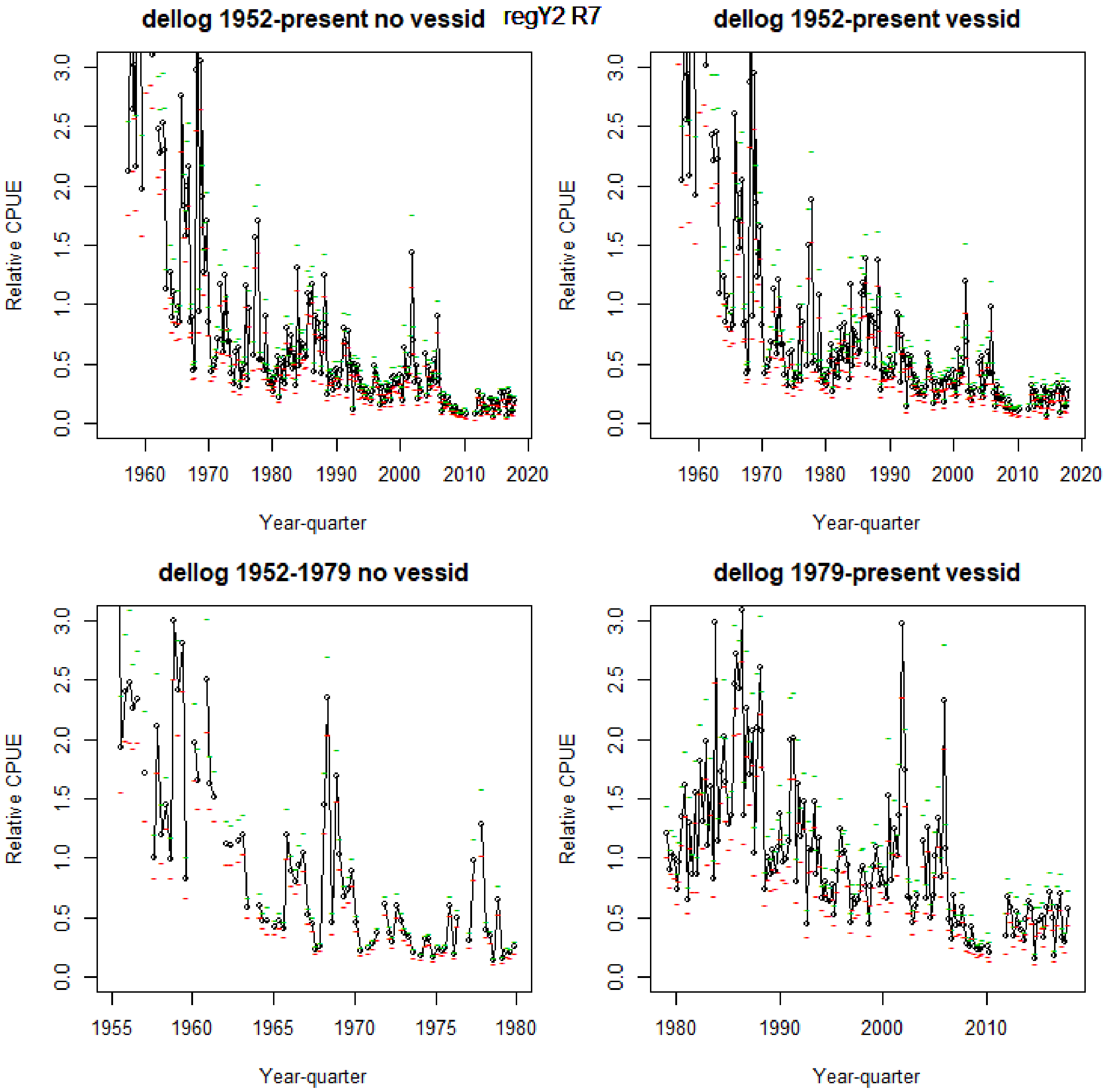


Figure 4: Quarterly CPUE series for yellowfin region 2n (north-western tropical, regY2_R7) in regional structure Y2, which is the northern part of the western tropical region. The plots include time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

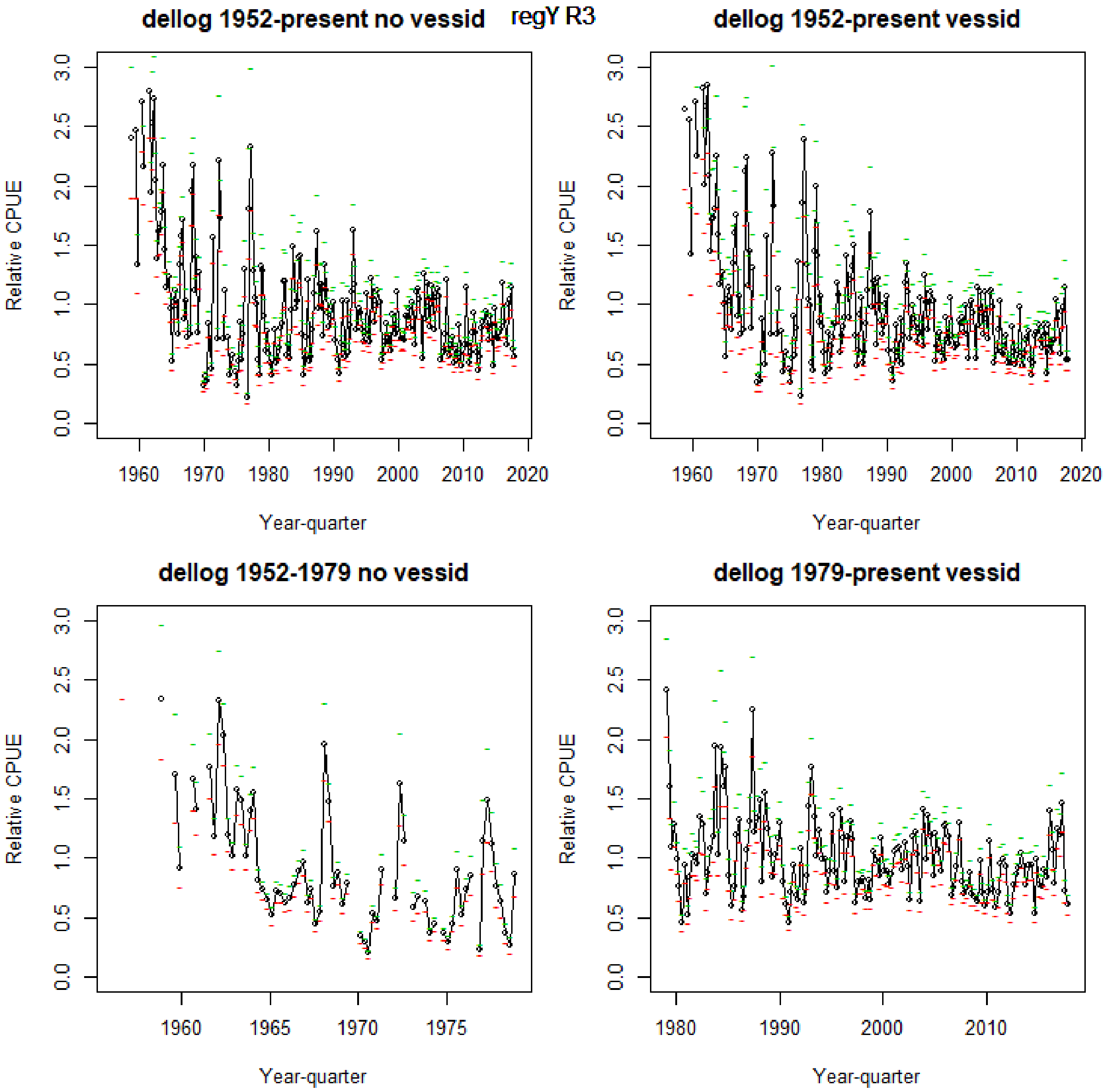


Figure 5: Quarterly CPUE series for yellowfin region 3 (western temperate, regY_R3), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

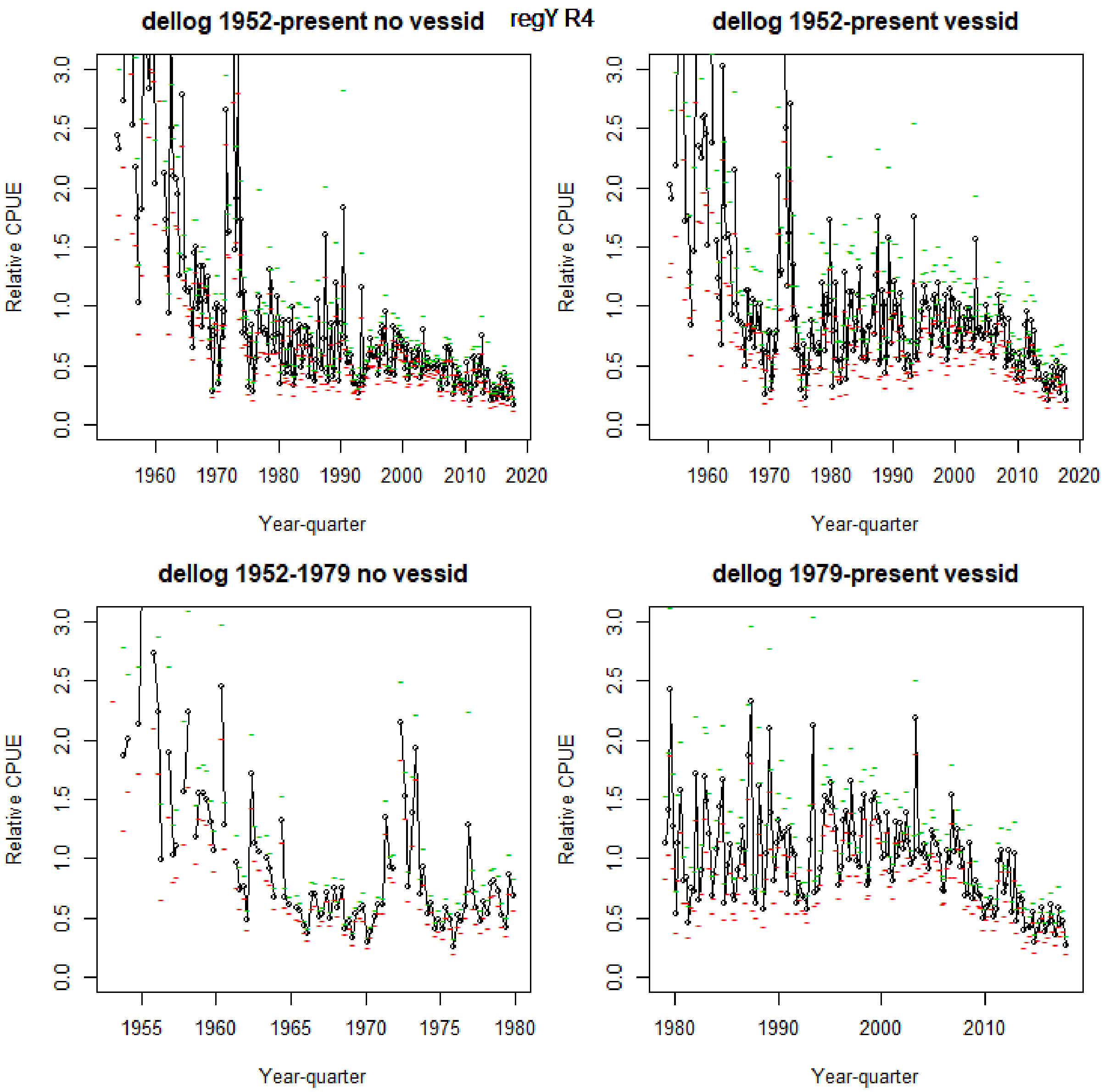


Figure 6: Quarterly CPUE series for yellowfin region 4 (eastern temperate, regY_R4), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

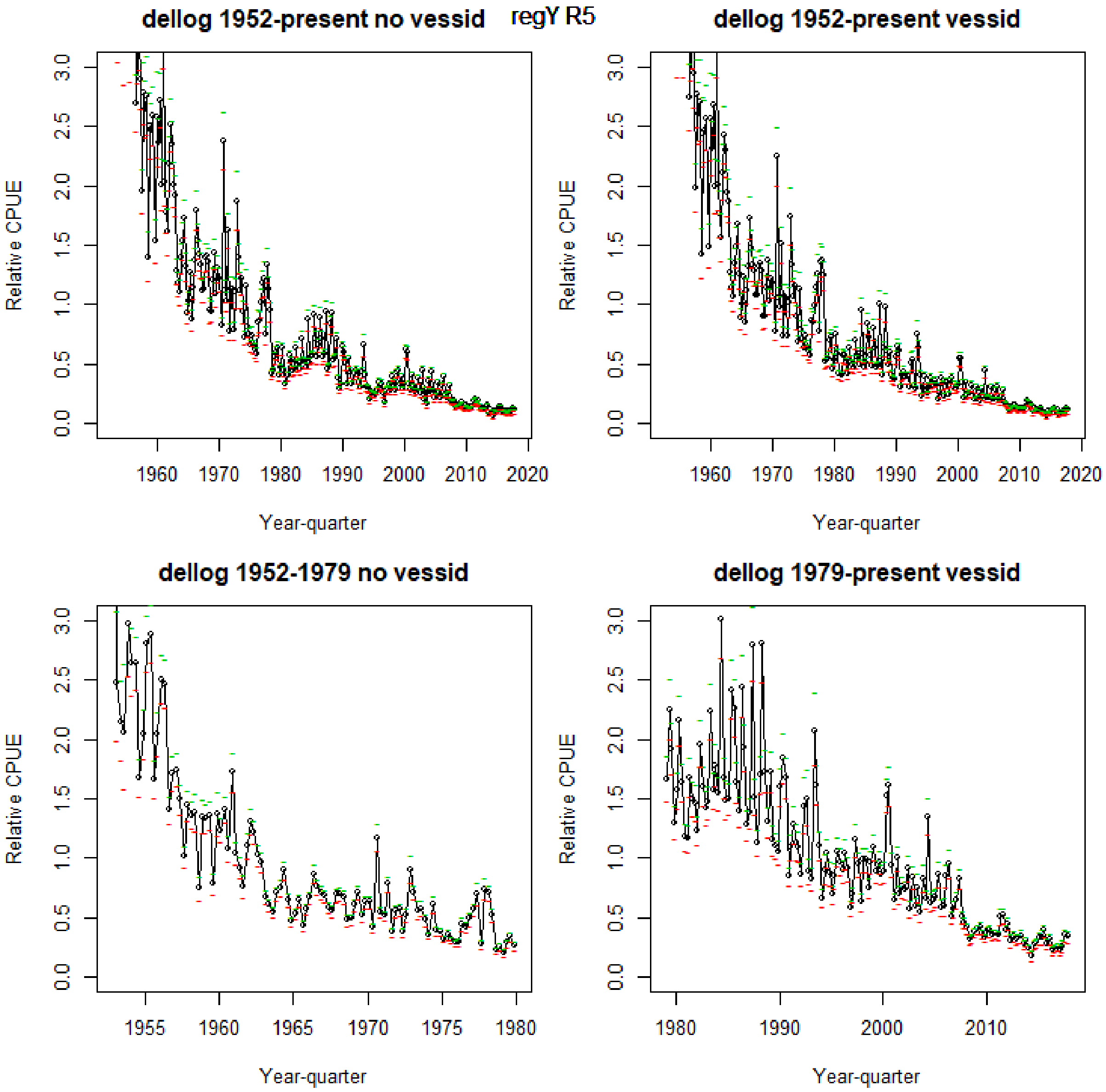


Figure 7: Quarterly CPUE series for yellowfin region 5 (eastern tropical, regY_R5), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

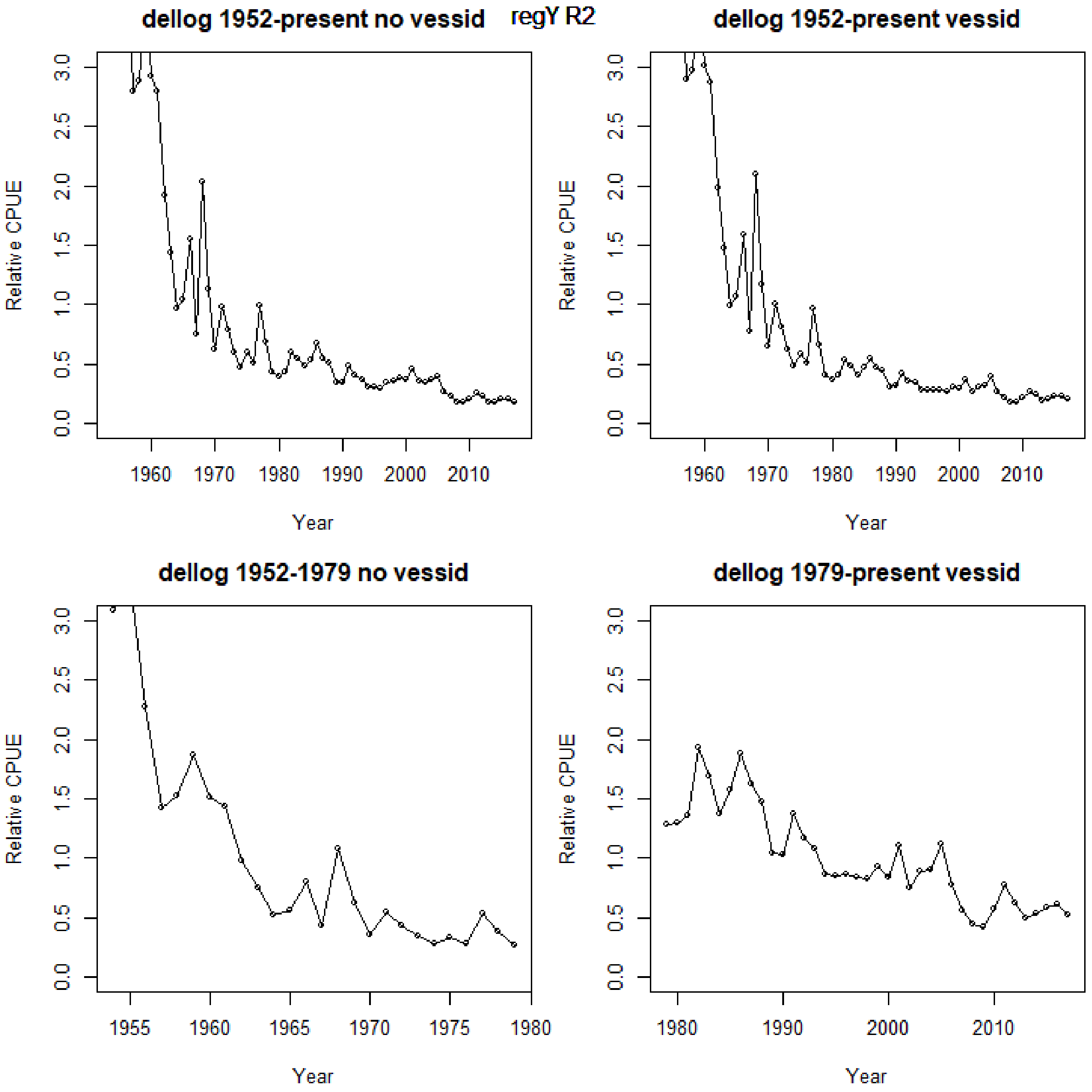


Figure 8: Annual CPUE series for yellowfin region 2 (western tropical, regY_R2), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

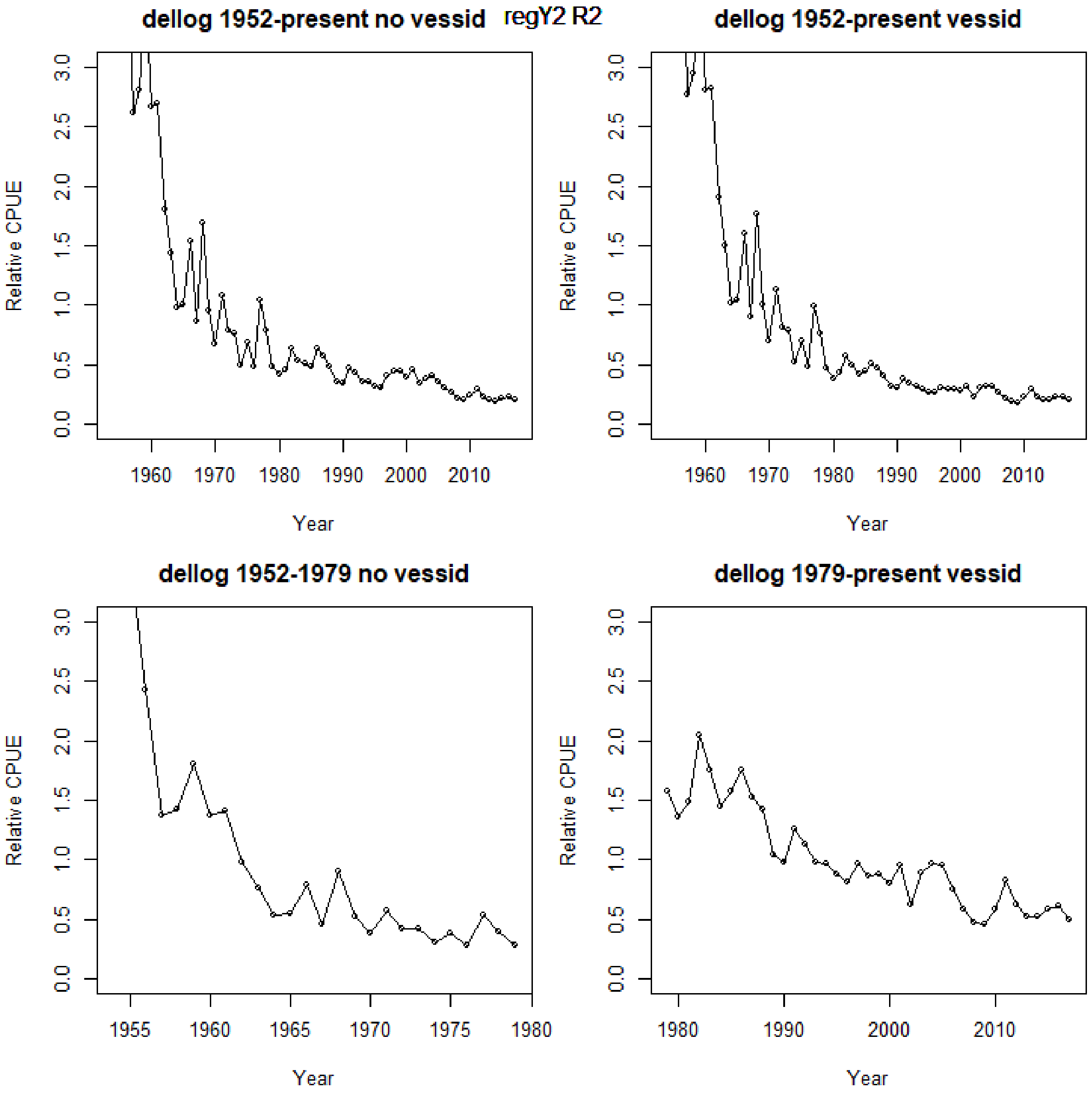


Figure 9: Annual CPUE series for yellowfin region 2S (south-western tropical, regY2_R2), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

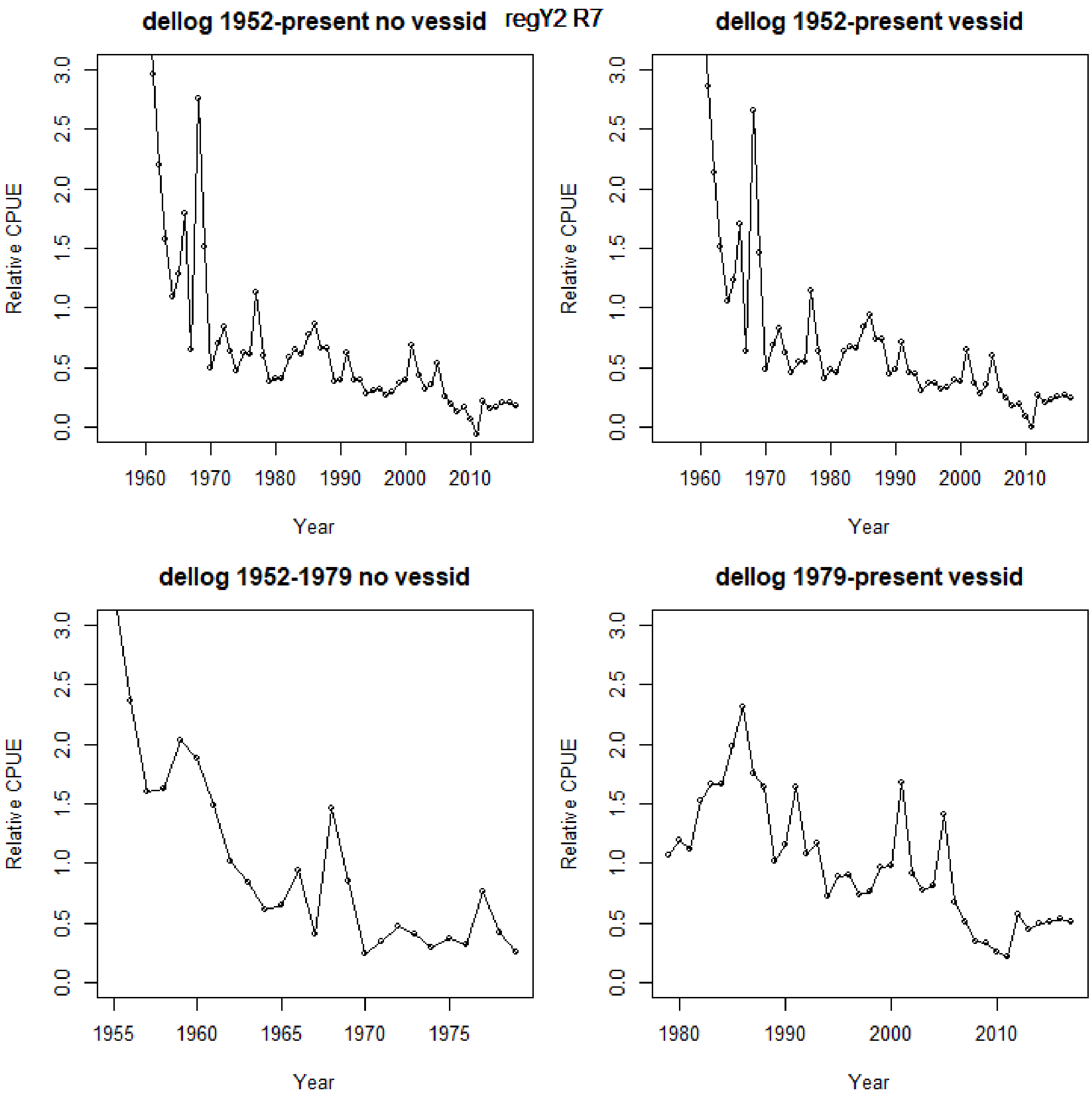


Figure 10: Annual CPUE series for yellowfin region 2N (north-western tropical, regY2_R7), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

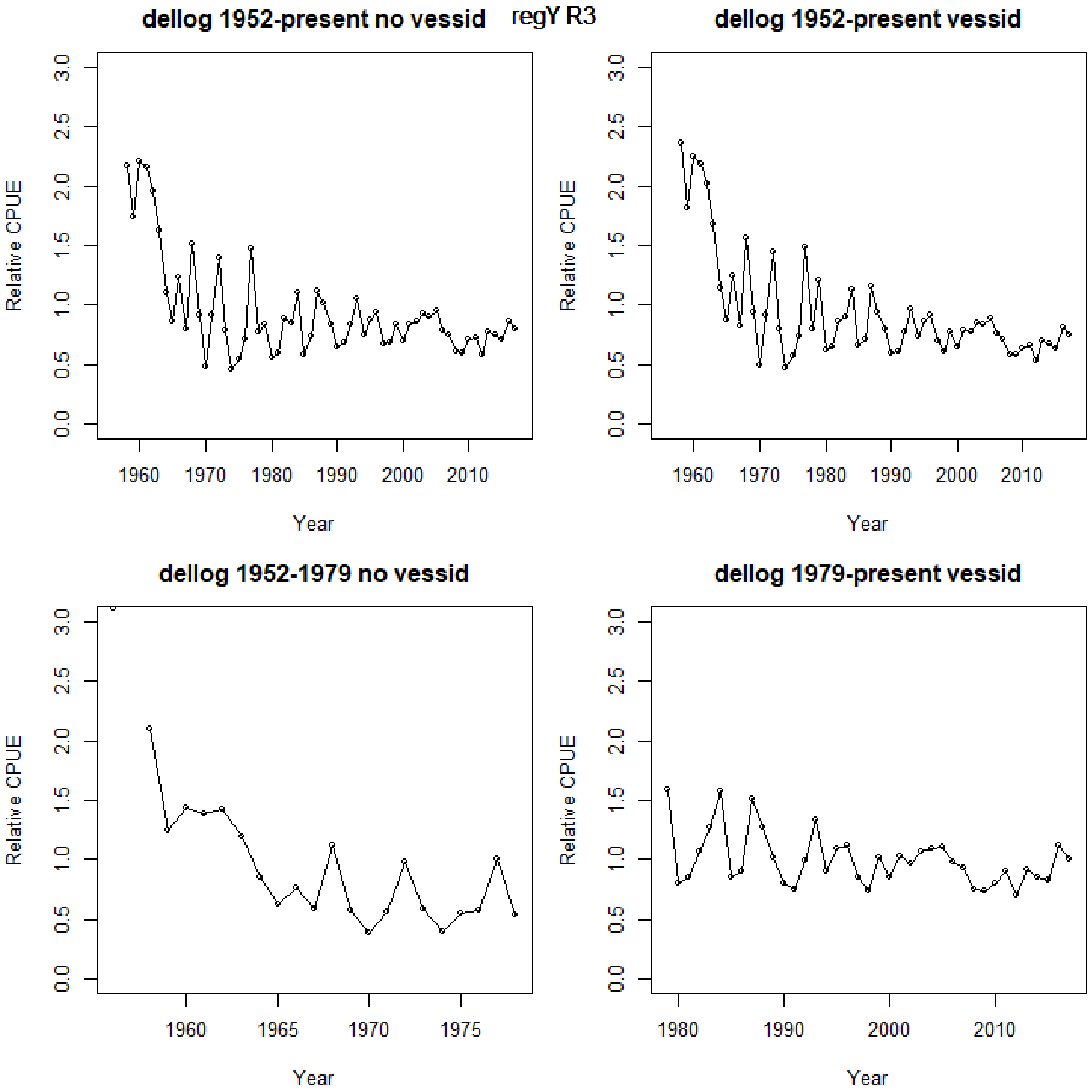


Figure 11: Annual CPUE series for yellowfin region 3 (western temperate, regY_R3), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

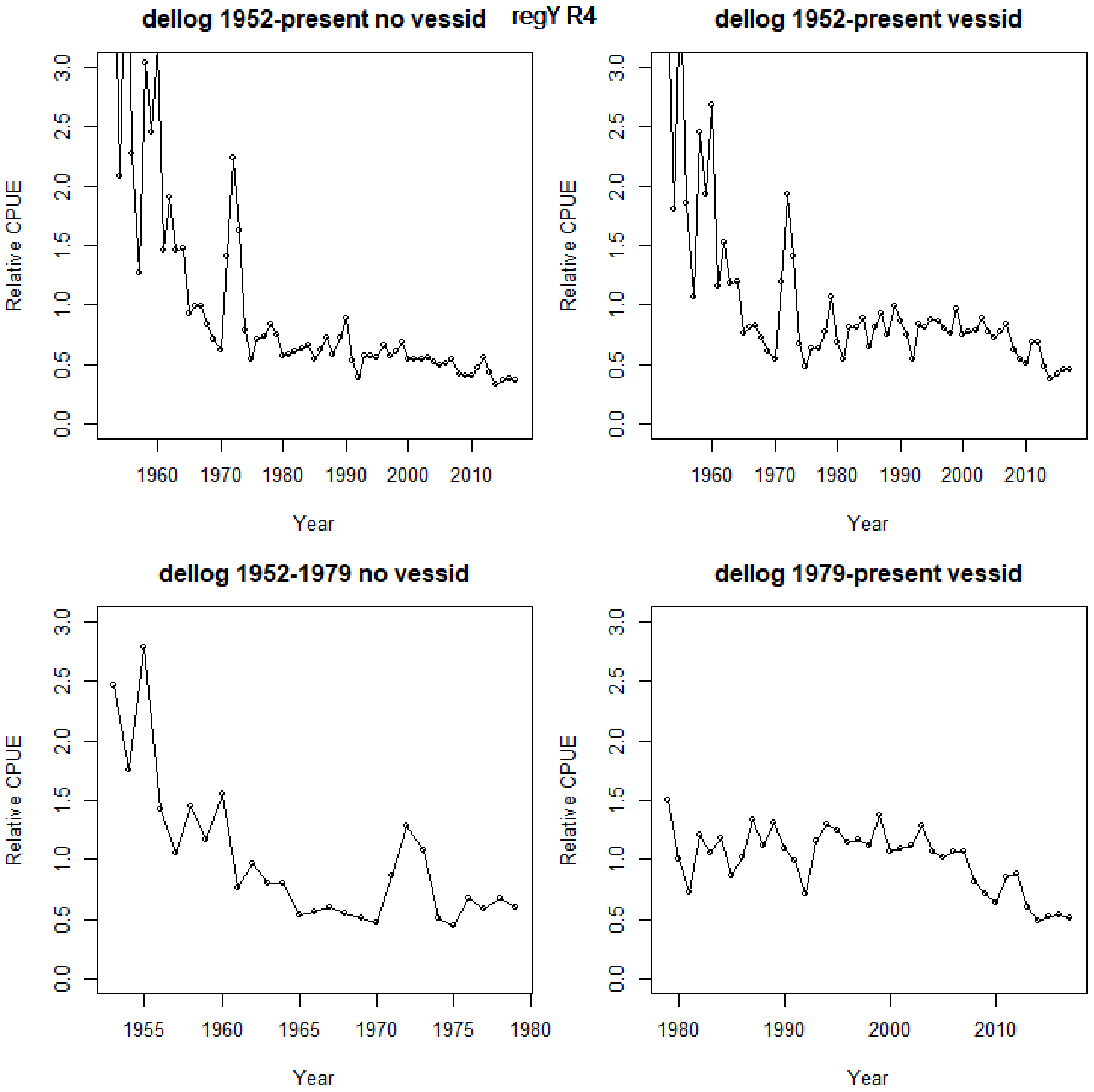


Figure 12: Annual CPUE series for yellowfin region 4 (eastern temperate, regY_R4), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

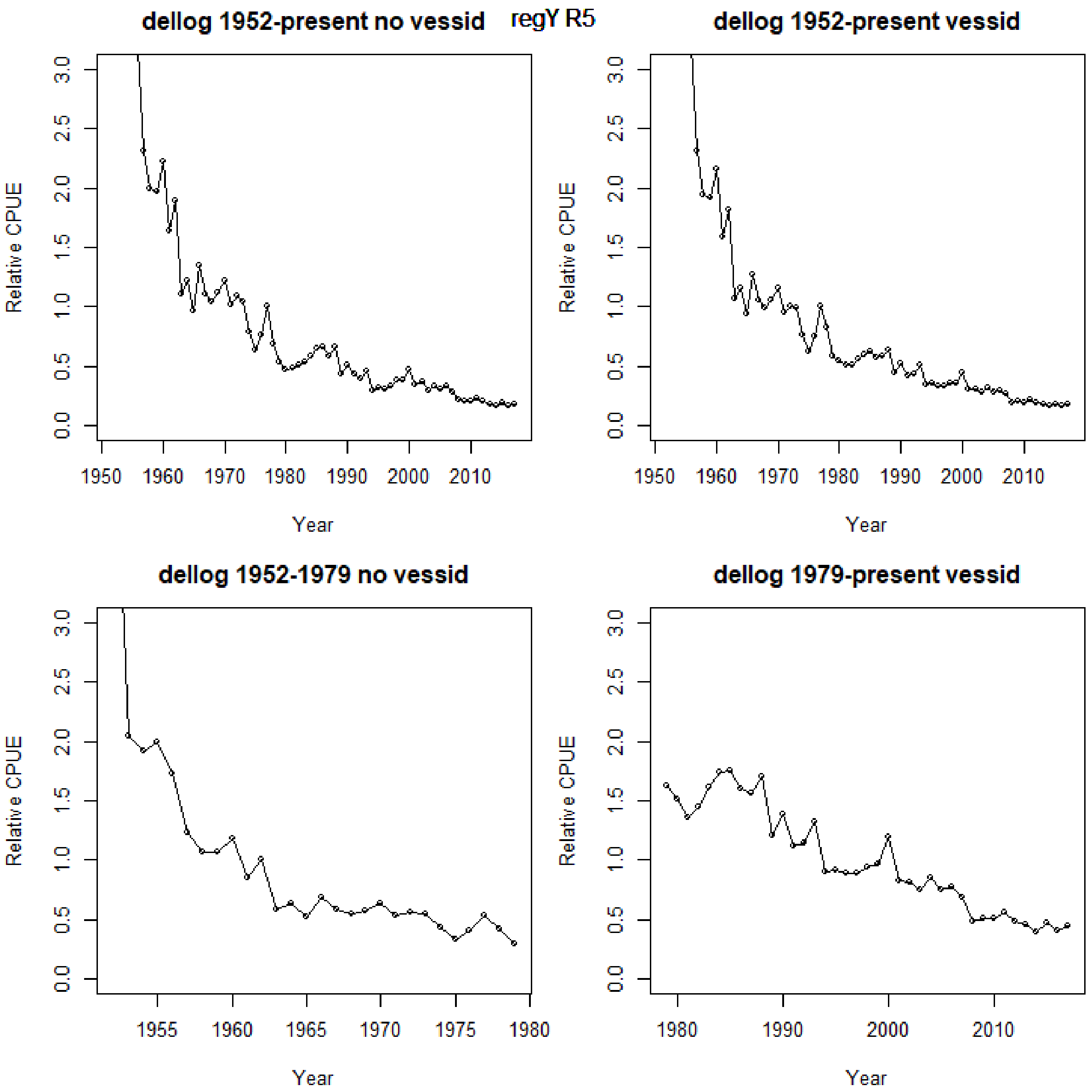


Figure 13: Annual CPUE series for yellowfin region 5 (eastern tropical, regY_R5), including time series for all years (top) both with (right) and without (left) vessel effects, and time series for 1952-79 without vessel effects, and 1979-2017 with vessel effects.

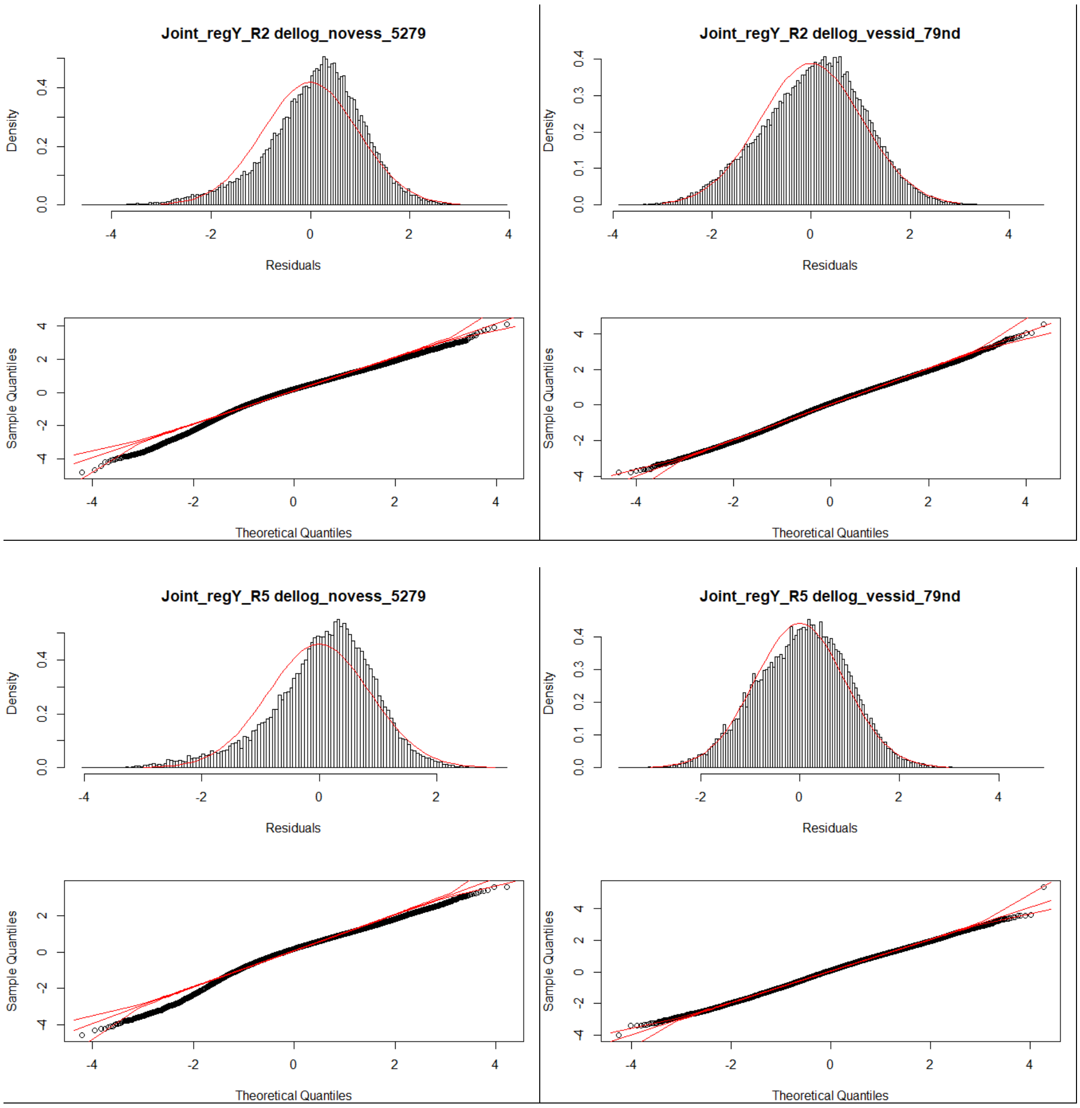


Figure 14: Diagnostic plots for yellowfin lognormal positive models in tropical regions 2 and 5 (regY_R2 and regY_R5), for 1952-79 without vessel effects (left) and for 1979-2017 with vessel effects (right).

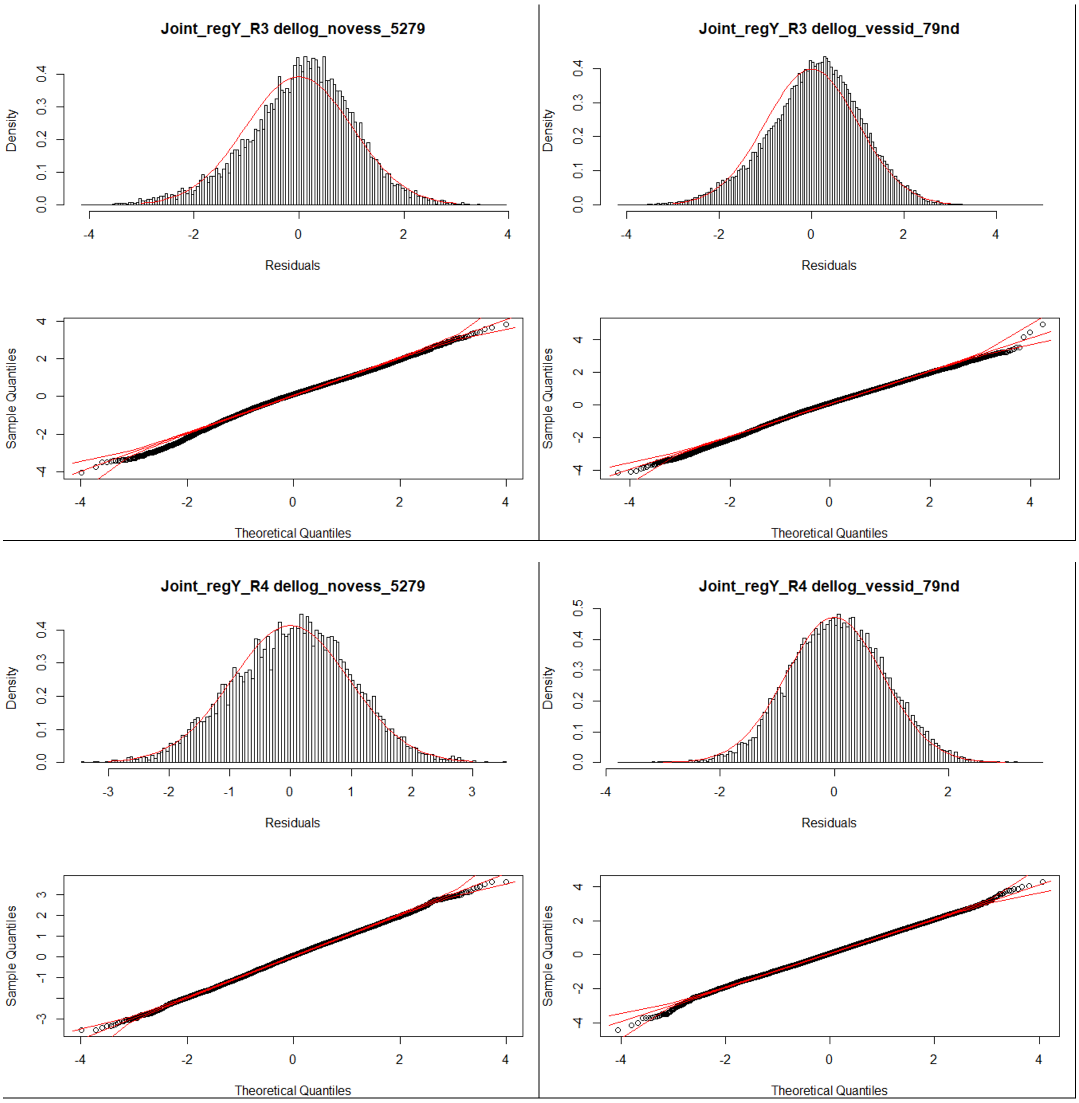


Figure 15: Diagnostic plots for yellowfin lognormal positive models in temperate regions 3 and 4 (regY_R3 and regY_R4), for1952-79 without vessel effects (left) and for 1979-2017 with vessel effects (right).

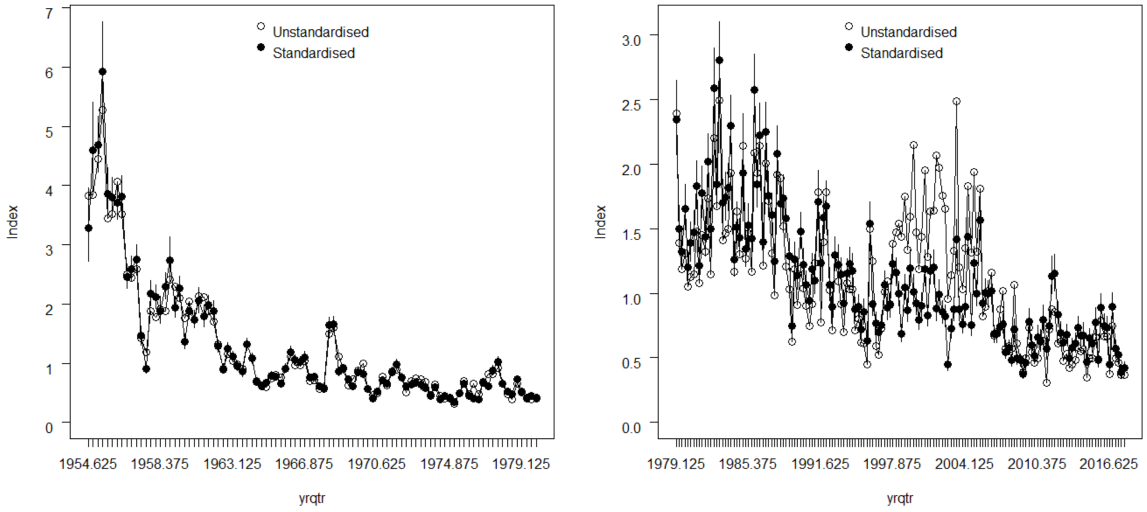


Figure 16: Comparison plot of unstandardised and standardised indices for yellowfin tuna in region 2S (south-western tropical, regY2_R2) in the periods 1952-1979 (left) and 1979-2017 (right).

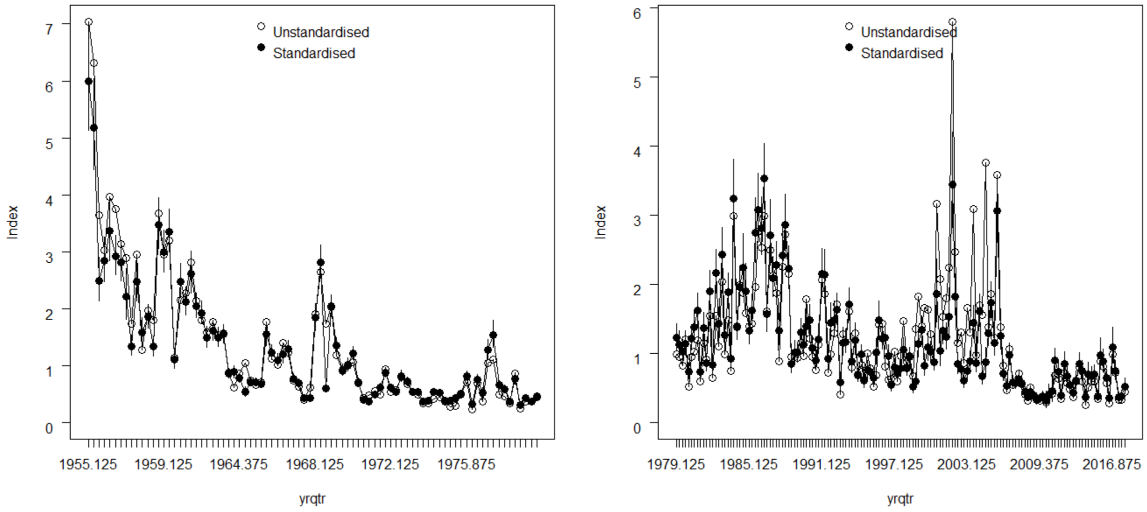


Figure 17: Comparison plot of unstandardised and standardised indices for yellowfin tuna in region 2N (north-western tropical, regY2_R7) in the periods 1952-1979 (left) and 1979-2017 (right).

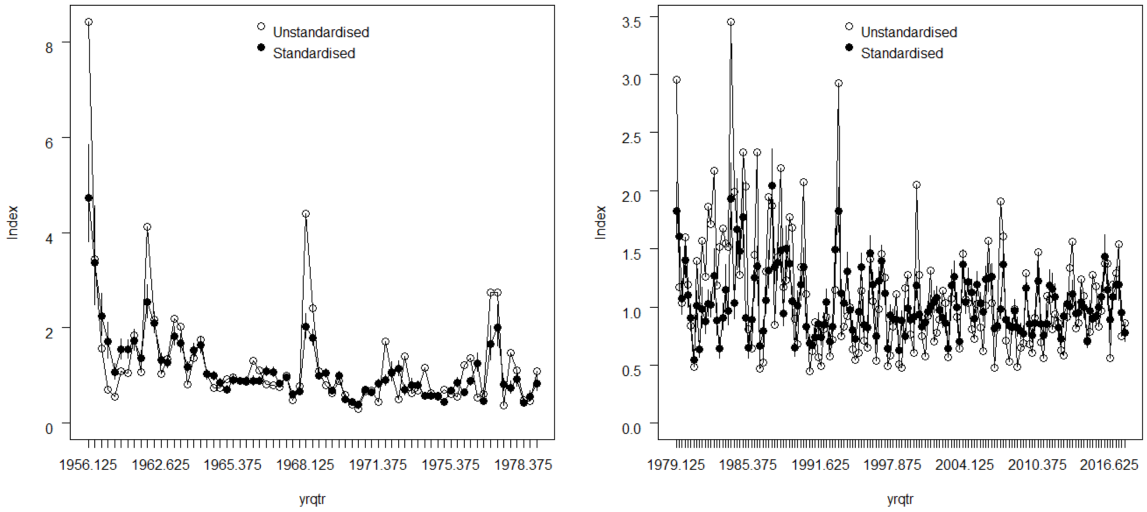


Figure 18: Comparison plot of unstandardised and standardised indices for yellowfin tuna in region 3 (western temperate, regY_R3) in the periods 1952-1979 (left) and 1979-2017 (right).

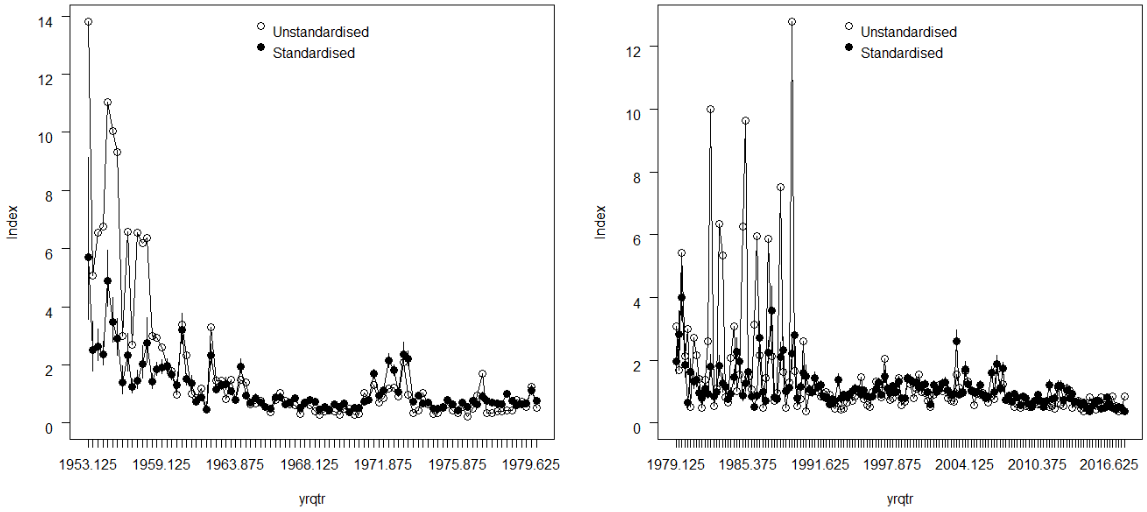


Figure 19: Comparison plot of unstandardised and standardised indices for yellowfin tuna in region 4 (eastern temperate, regY_R4) in the periods 1952-1979 (left) and 1979-2017 (right).

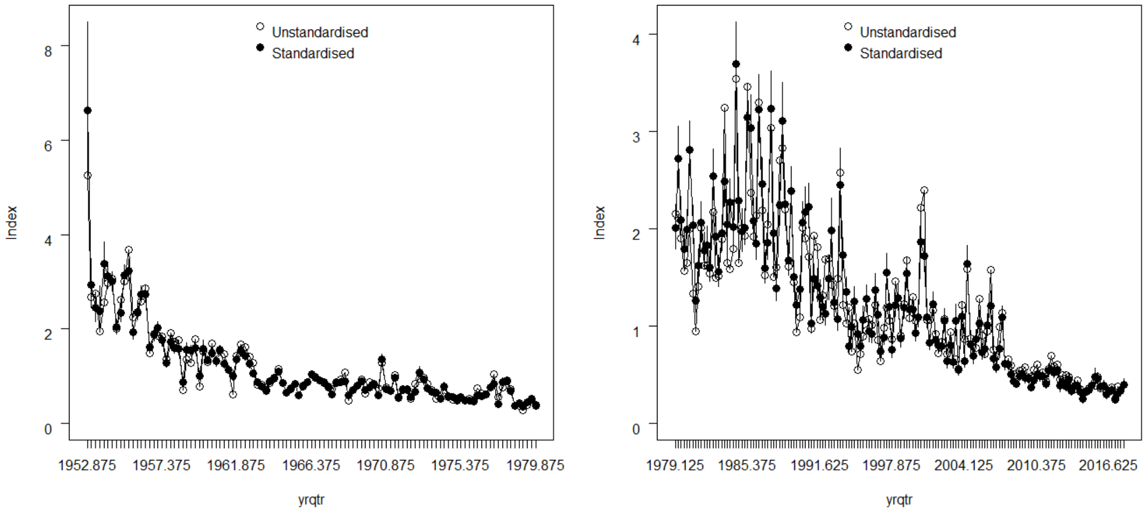


Figure 20: Comparison plot of unstandardised and standardised indices for yellowfin tuna in region 5 (eastern tropical, regY_R5) in the periods 1952-1979 (left) and 1979-2017 (right).

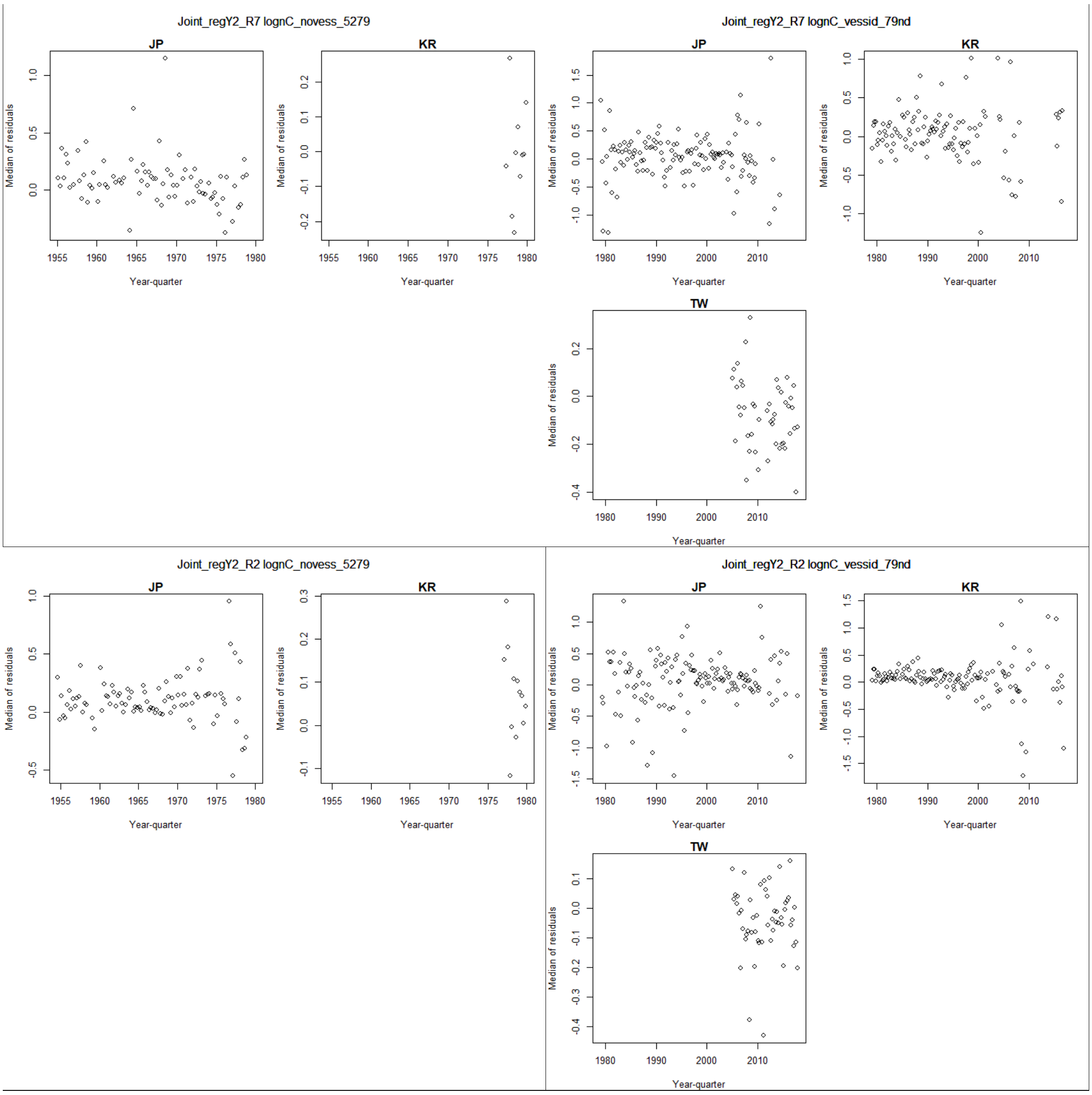


Figure 21: Median residuals from the lognormal constant model per year-quarter (x-axis), by flag (subplots), for yellowfin in region 2n (north-western tropics, regY2_R7, above), and 2s (south-western tropics, regY2_R2, below). Residuals are shown for 2 models: 1952-2017 without vessel effects (left), and 1979-2017 with vessel effects (right).

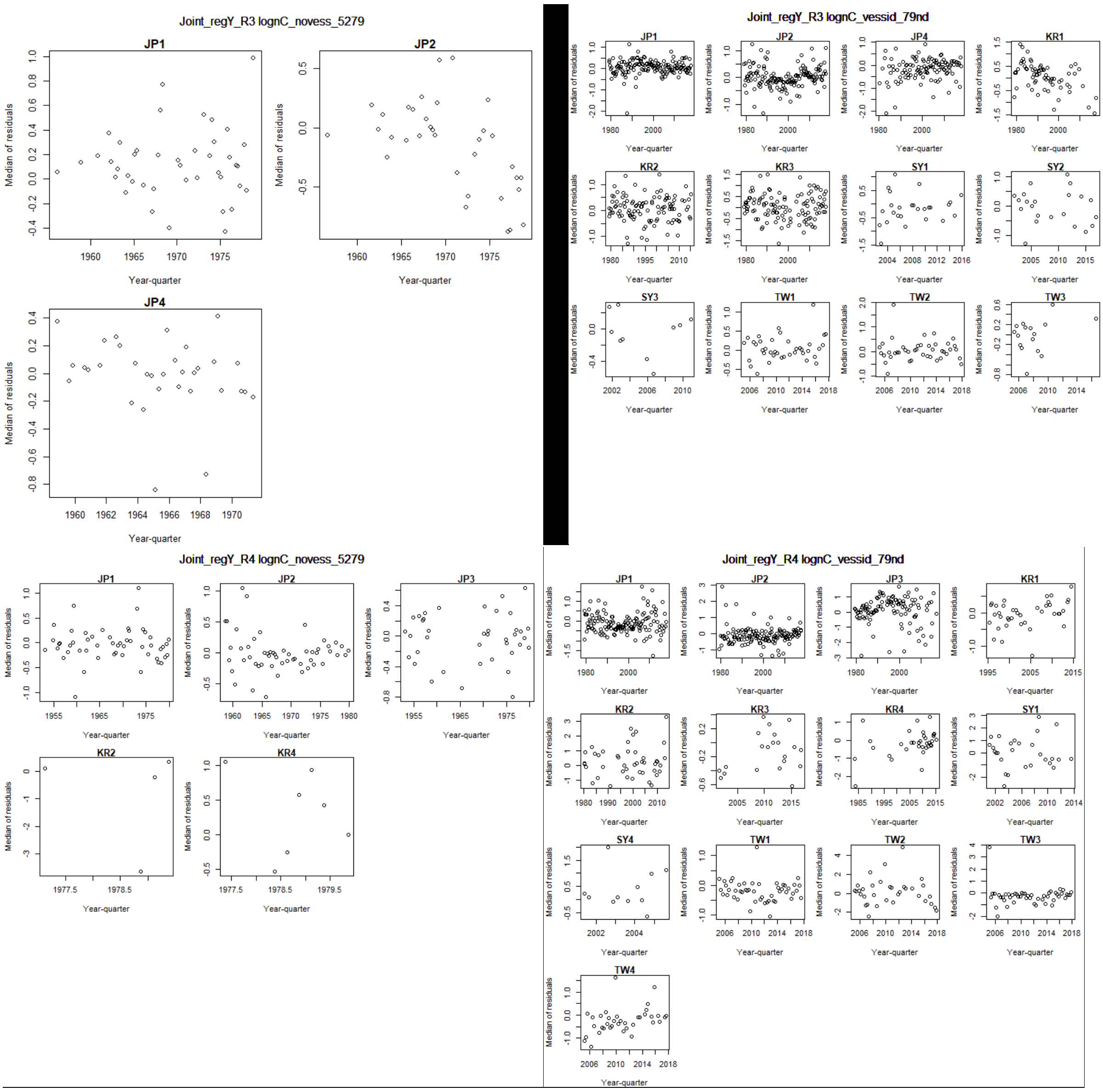


Figure 22: Median residuals from the lognormal constant model per year-quarter (x-axis), by cluster (subplots), for yellowfin in regions 3 (western temperate, regY_R3, above) and 4 (eastern temperate, regY_R4, below). Residuals are shown for 2 models: 1952-1979 without vessel effects (left), and 1979-2017 with vessel effects (right).

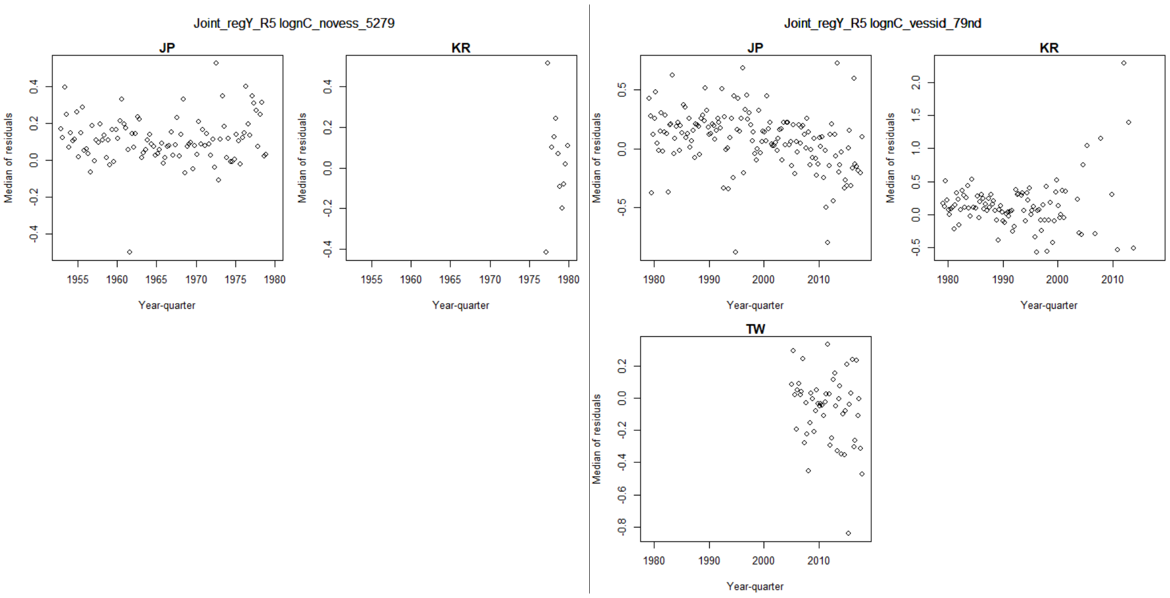


Figure 23: Median residuals from the lognormal constant model per year-quarter (x-axis), by flag (subplots), for yellowfin in region 5 (eastern tropics, regY_R5). Residuals are shown for 2 models: 1952-1979 without vessel effects (left), and 1979-2017 with vessel effects (right).

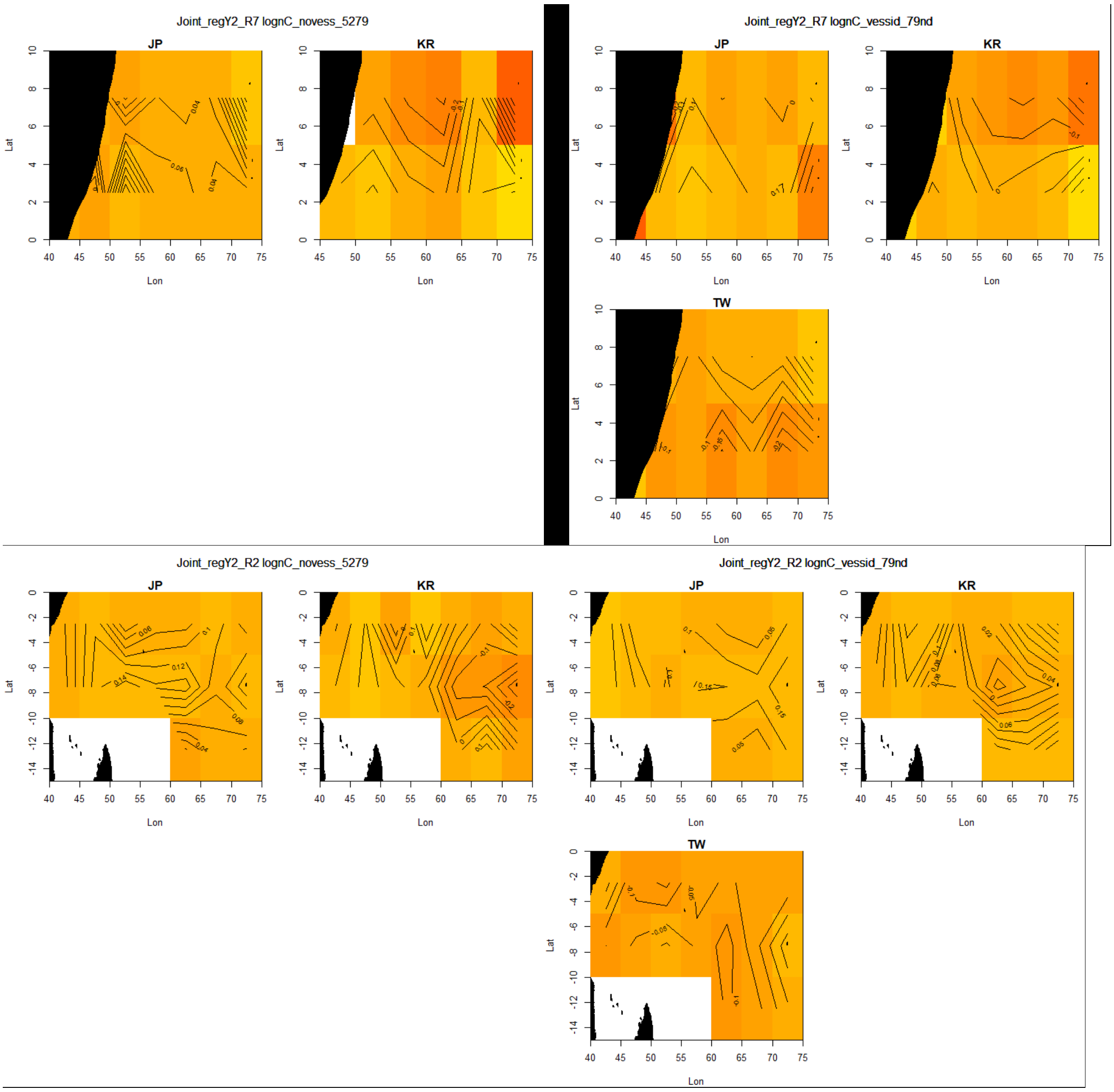


Figure 24: Yellowfin residuals for western tropical regions 2n (regY2_R7, above) and 2s (regY2_R2, below), by flag. Median residuals are mapped by 5° cell for the periods 1952-1979 without vessel effects (left), and 1979-2017 with vessel effects (right).

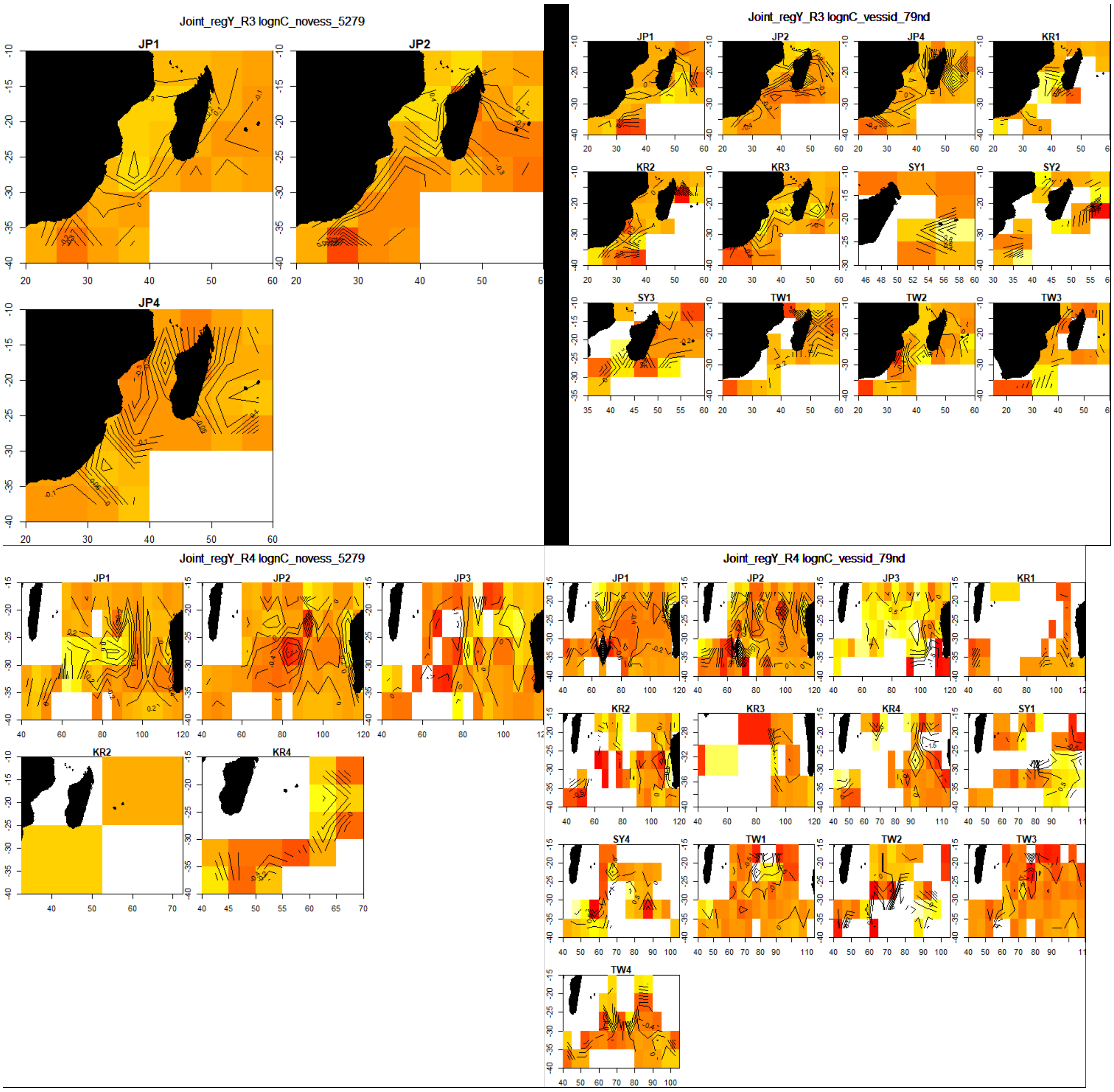


Figure 25: Yellowfin residuals for temperate regions 3 (regY_R3, above) and 4 (regY_R4, below), by cluster. Median residuals are mapped by 5° cell for the periods 1952-1979 without vessel effects (left), and 1979-2017 with vessel effects (right).

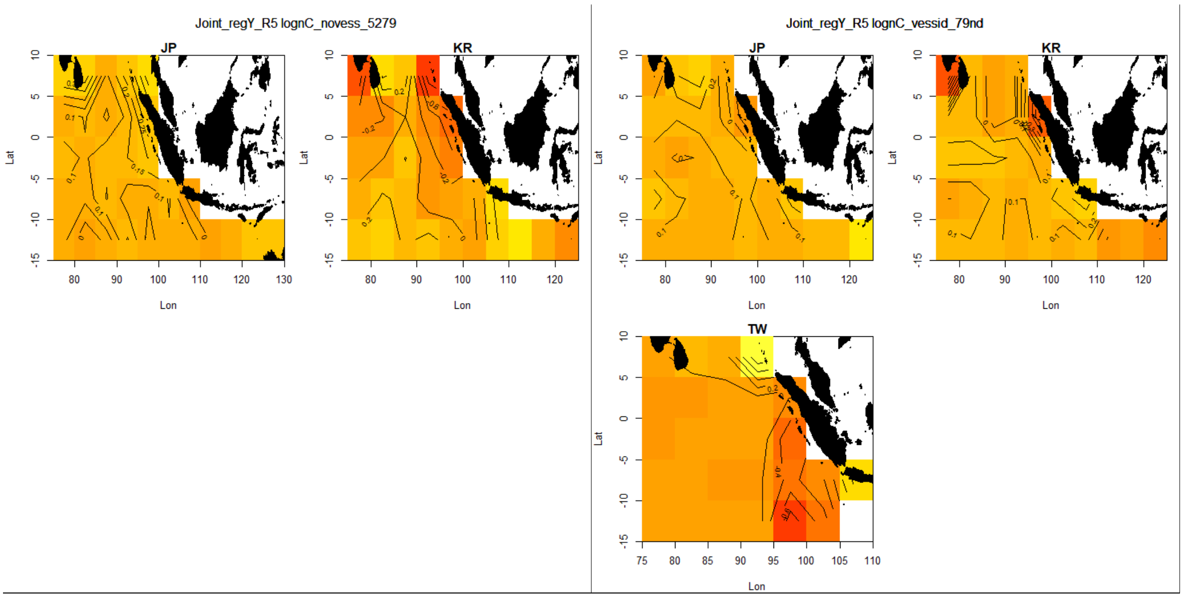


Figure 26: Yellowfin residuals for eastern tropical region 5 (regY_R5), by flag. Median residuals are mapped by 5° cell for the periods 1952-1979 without vessel effects (left), and 1979-2017 with vessel effects (right).

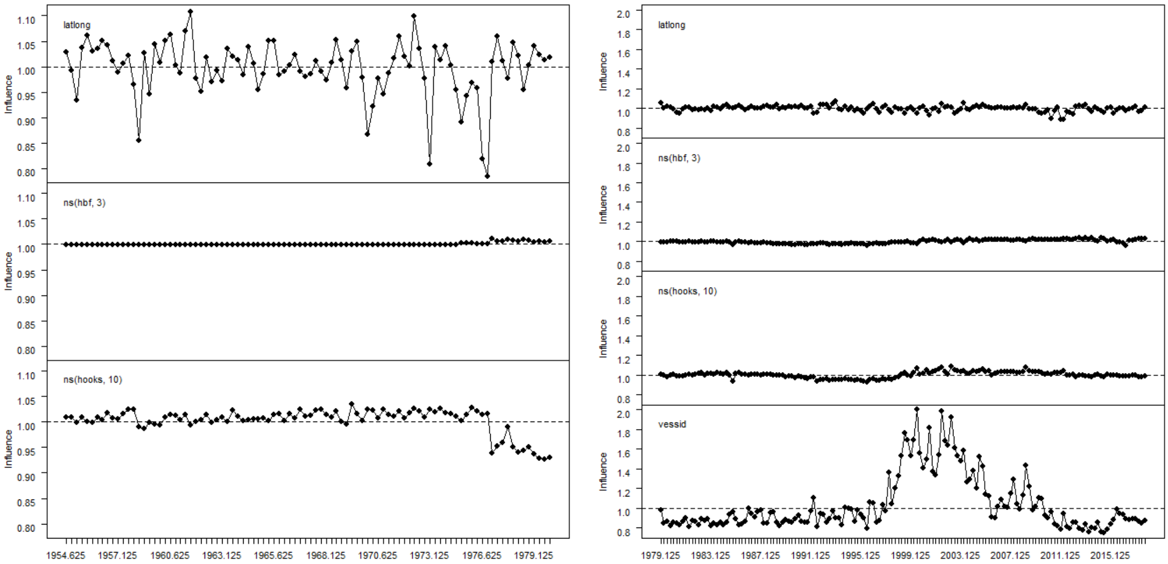


Figure 27: Influence plot for yellowfin region 2S (south-western tropical, regY2_R2) in the periods 1952-1979 (left) and 1979-2017 (right), showing the multiplicative effect (y axis) of each variable on the standardized index.

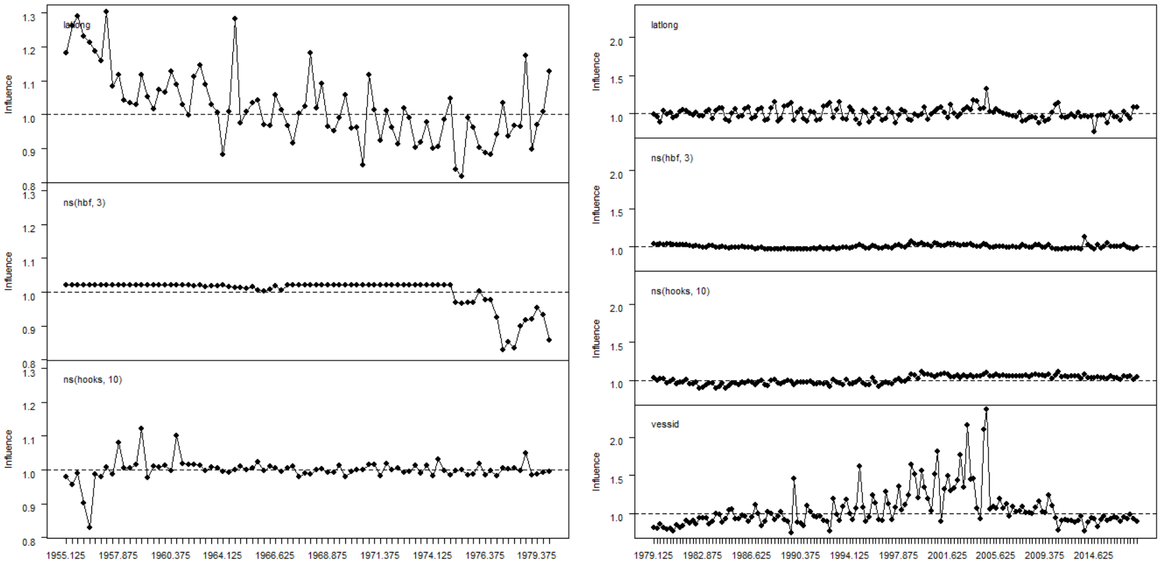


Figure 28: Influence plot for yellowfin region 2N (north-western tropical, regY2_R7) in the periods 1952-1979 (left) and 1979-2017 (right), showing the multiplicative effect (y axis) of each variable on the standardized index.

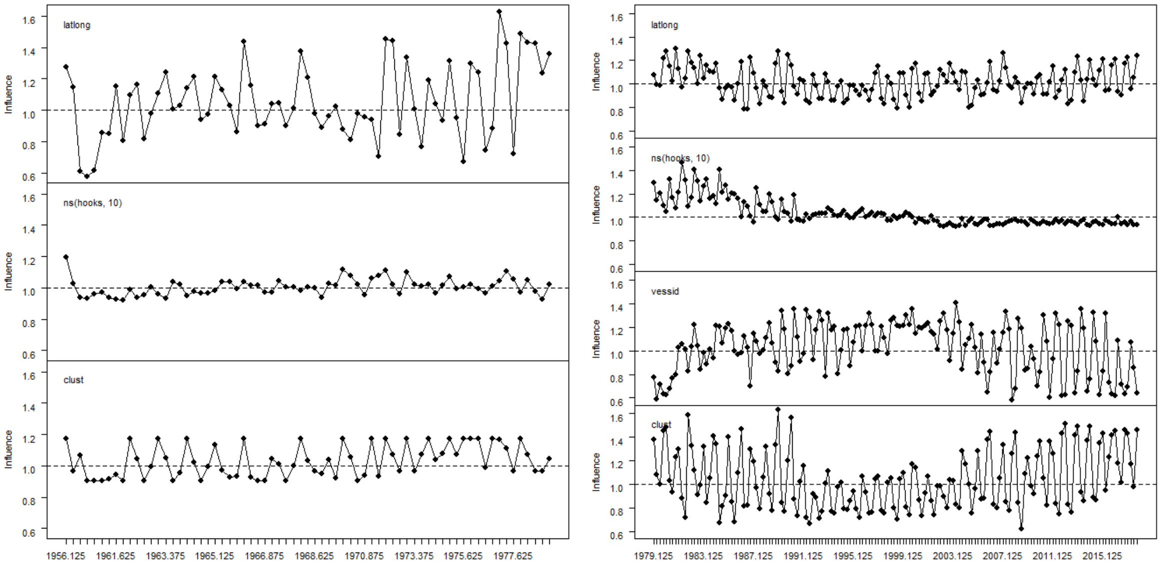


Figure 29: Influence plot for yellowfin region 3 (western temperate, regY_R3) in the periods 1952-1979 (left) and 1979-2017 (right), showing the multiplicative effect (y axis) of each variable on the standardized index.

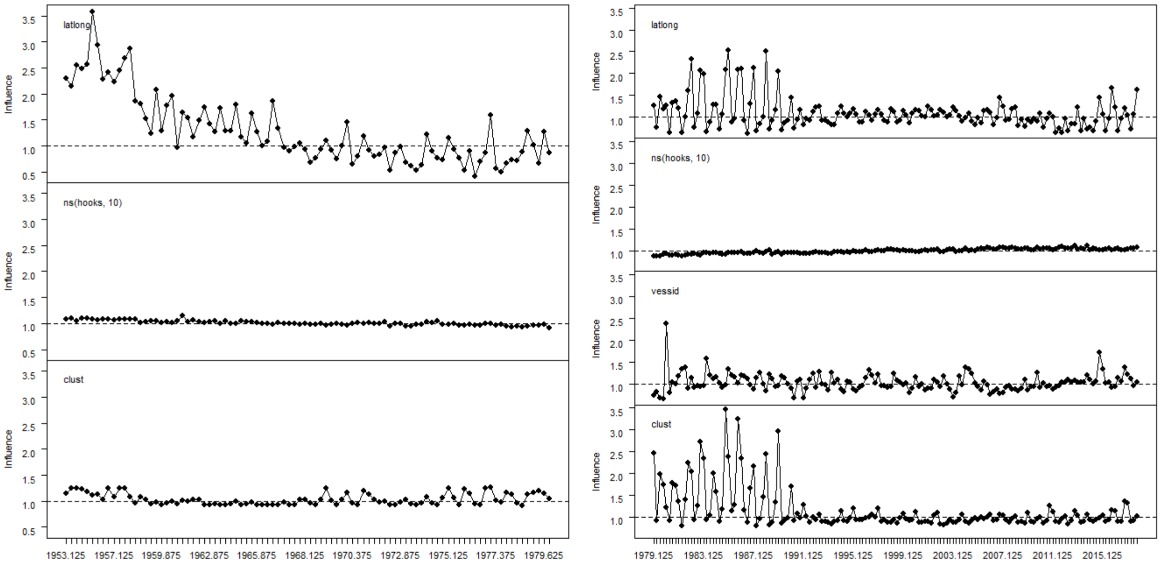


Figure 30: Influence plot for yellowfin region 4 (eastern temperate, regY_R4) in the periods 1952-1979 (left) and 1979-2017 (right), showing the multiplicative effect (y axis) of each variable on the standardized index.

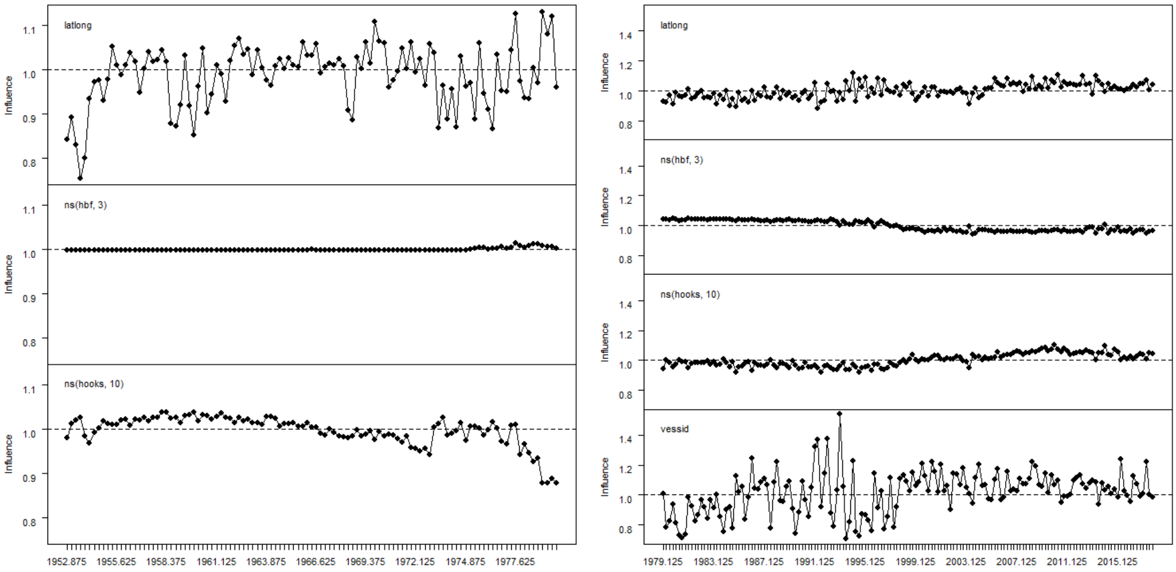


Figure 31: Influence plot for yellowfin region 5 (eastern tropical, regY_R5) in the periods 1952-1979 (left) and 1979-2017 (right), showing the multiplicative effect (y axis) of each variable on the standardized index.

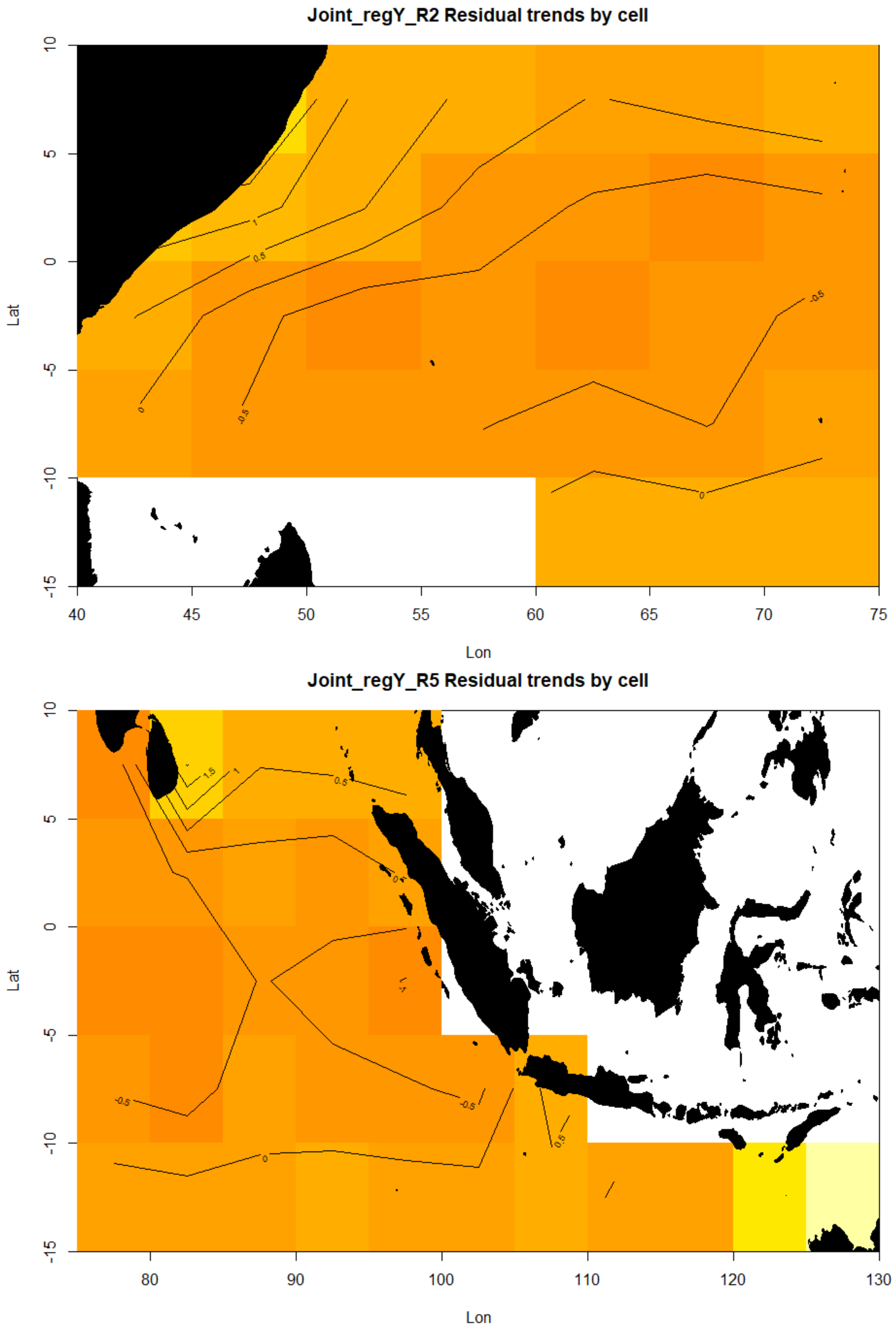


Figure 32: Trends in temporal residuals by grid cell for tropical yellowfin regions 2 (western, regY_R2) and 5 (eastern, regY_R5) from the model for 1979 to 2017 with vessel effects. The trends in each cell are estimated by regressing the residuals against year-quarter. Darker red represents decline and lighter yellow represents increase relative to the model average.

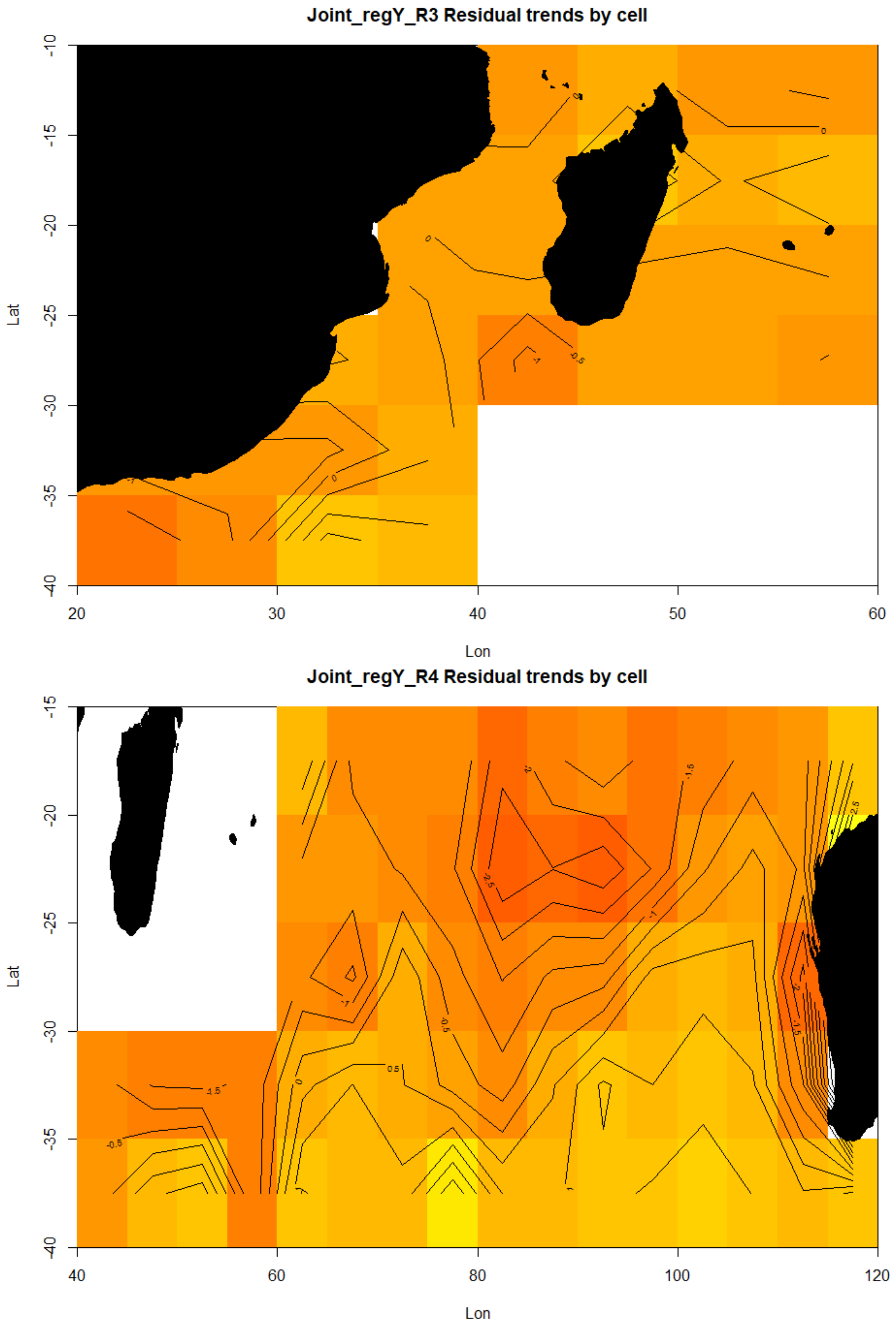


Figure 33: Trends in temporal residuals by grid cell for temperate yellowfin regions 3 (western, regY_R3) and 4 (eastern, regY_R4) from the model for 1979 to 2017 with vessel effects. The trends in each cell are estimated by regressing the residuals against year-quarter. Darker red represents decline and lighter yellow represents increase relative to the model average.