Received: 31 October & 15 November 2014
IOTC–2014–WPTT16–27 Rev_1

2014

Spatial considerations in bigeye and yellowfin CPUE from Japanese and Taiwan,China longline fisheries in the Indian Ocean

SIMON HOYLE

Hoyle Consulting Ltd

20 Bisley Ave, Nelson 7011, New Zealand
+64-3-648-5315
simon.hoyle@gmail.com

Spatial considerations in bigeye and yellowfin CPUE from Japanese and Taiwan,China longline fisheries in the Indian Ocean

Simon D. Hoyle[1]

Abstract

Aggregated catch and effort data from the Japanese and Taiwan,China longline fisheries were analyzed in order to investigate spatial patterns in CPUE trend and effort concentration. Analyses were carried out by region and also at finer spatial scales, as well as by fleet and species. The CPUE standardizations used generalized linear models that included temporal effects and 5 degree grid squares, and assumed lognormal error distributions. Gulland's index of effort concentration was extended to include standardized CPUE, which reduced noise and bias in the index, and facilitated comparison with long-term spatial abundance patterns.

Results indicated that the differences in CPUE trend between fleets were maintained when fishing locations were taken into account. They also indicated spatial differences in CPUE trend within fleets and regions, which are likely to be at least partly due to apparent differences in targeting, but may also be affected by differences in abundance trends, and differences in reporting.

To estimate appropriate CPUE indices, and to design fishery and regional structures, a series of analyses is recommended. Operational data should be explored using cluster analysis, principal component analysis, fine scale spatial analyses, and vessel behaviour analyses to investigate the effects of targeting on CPUE trends, and identify methods to prepare CPUE indices that take targeting into account. These analyses will be more effective if they include catches of more species. Next it will be necessary to investigate spatial patterns of CPUE trends and fish sizes once targeting and other effects (e.g. vessel effects) have been taken into account. These analyses can be combined with analyses of tagging data, consideration of genetic evidence, and model sensitivity analyses, to recommend appropriate regional and fishery structures.

1. Introduction

Standardized longline CPUE indices are critically important inputs to stock assessments of bigeye and yellowfin tuna in the Indian Ocean, as they are for a number of other species. These indices provide the relative abundance trends that define the impact of fisheries on the stocks. Deriving CPUE indices is challenging because stocks and habitats are complex, fisheries target various mixtures of species, and fishing technology has changed through time. Despite ongoing progress, there are a number of remaining problems and uncertainties about methods for deriving CPUE indices.

The IOTC CPUE workshop in San Sebastien IOTC CPUE workshop (Anon 2013) recommended further work to understand why Taiwan,China (TW) and Japanese (JP) CPUE series diverge for tropical and temperate tunas in the Indian Ocean, and consequently to identify better approaches for deriving indices of IO tuna abundance. The workshop suggested possible causes of the differences including different data processing methods by different scientists in TW; fundamental differences in the nominal catch; or different analytical approaches.

[1] Hoyle Consulting Ltd, 20 Bisley Ave, Nelson 7011, New Zealand. Simon.hoyle@gmail.com.

One of the strongest recommendations made at the workshop by the participants was the following:

"In areas where CPUE's diverged the CPC's were encouraged to meet inter-sessionally to resolve the differences. In addition, the major CPC's were encouraged to develop a combined CPUE from multiple fleets so it may capture the true abundance better. Approaches to possibly pursue are the following: i) Assess filtering approaches on data and whether they have an effect, ii) examine spatial resolution on fleets operating and whether this is the primary reason for differences, and iii) examine fleet efficiencies by area, iv) use operational data for the standardization, and v) have a meeting amongst all operational level data across all fleets to assess an approach where we may look at catch rates across the broad areas".

Some of the approaches above can be pursued with the aggregated data held by the IOTC, while others require operational data. Some of these steps have already been undertaken by JP and TW scientists, while other tasks remain. For example, Okamoto (2014b) and Yeh (in preparation) have examined trends of the two fleets in shared (core) areas, so those analyses have not been repeated here.

In this paper I examine spatial variation in CPUE trends and temporal variation in effort concentration, comparatively across both fleets. These issues are related to both targeting and potential bias in CPUE, are fundamental to development of abundance indices for stock assessments, and can be investigated using aggregated data. Spatial variation can also be informative about stock structure.

These issues of spatial patterns in CPUE are also significant for regional and fishery definitions. There is currently uncertainty about the appropriate spatial scales for modelling and managing Indian Ocean tuna populations (e.g. Kolody *et al.* 2013; Langley 2012). The 2012 yellowfin assessments with separate regions (Langley *et al.* 2012; Nishida *et al.* 2012) included 5 regions, with the area around Madagascar included in a south-western region. The 2013 SS3 bigeye assessment (Langley *et al.* 2013) included 3 regions, with the latitudinal boundary at 20S west of Madagascar, and 15S east of Madagascar. In stock assessments, regions are generally designed so that they represent a single stock component, with a consistent abundance trend throughout. When this is not the case, projections are less reliable and it may be difficult to estimate the cumulative abundance trend. For spatial definitions of fisheries, CPUE trend variation may necessitate time-area interactions in the analyses, which can be problematic. Fisheries may cover all or part of a region, but assumptions of constant selectivity require that each fishery takes fish of the same size throughout its range.

2. Methods

I examined spatial variation in CPUE trends and temporal variation in effort concentration, comparatively across both fleets, using a dataset of aggregated catch and effort data focused on the core areas of the bigeye and yellowfin fisheries between 10N and 15S (Figure 1). All analyses were carried out in R version 3.1.1 (R Core Team 2014).

Data were analysed either in 5 by 5 blocks, in 10 (latitude) by 20 (longitude) blocks, or separately in 3 'regions' similar but not identical to the 2013 bigeye assessment regions. The equatorial regions were defined between 15 degrees south and 10 degrees north. Region 1 (core west) reached from the coast of Africa to 80 degrees east, and region 2 (core east) from 80 degrees east to the coasts of Indonesia and Australia. Region 3 (south) spanned from Africa in the west to Australia in the east, between 35 and 15 degrees south. Data south of 35S were omitted because that area included a great deal of effort targeted at southern bluefin tuna. Where data were analysed in 10 by 20 blocks, the northwest corner was at 5-15N and 40-60E, and the southeast corner at 35-25S and 100-120E.

Initially, patterns in the effort distribution in time and space for each fleet were mapped, showing average annual effort over 12 years in thousands of hooks. Given the large spatial variation in effort, contours were placed on the map on a $\log_{10}$ scale.

Catch and effort data were standardized by region for both species and fleets, using generalized linear models with lognormal error distribution, and the following model:

$$\log(CPUE + const) = \mu + year + qtr + latlong5 + \epsilon$$

The term *const* was 10% of the overall mean CPUE, μ was the intercept, *year* and *qtr* were time effects, and *latlong5* was an effect for 5 by 5 degree grid squares.

After fitting the model, the predicted CPUEs were generated by back-transforming: CPUE = ($e^{response}$) – const, with responses generated using the predict() function in R for all values of the parameter of interest, with other parameter values held constant. The predicted CPUEs were plotted by year, relative to the average CPUE across all years. The predicted CPUEs for each 5 degree square were mapped for the standard period of the 2nd quarter of 2001.

Indices of fishing effort concentration were also calculated, including the Gini coefficient (Gini 1912), Gulland’s index of concentration (Gulland 1956), and alternative versions of Gulland’s index. Gini indices have previously been applied to tuna populations by Harley (2009) and McKechnie (McKechnie *et al.* 2013), and Gulland’s indices by Griffiths (1960), Calkins (1961, 1963), Harley (2009), and McKechnie *et al.* (2013).

The Gini coefficient, best known as an indicator of wealth concentration, can be used to measure the degree of aggregation of any quantity. In this case we use it to estimate the spatial aggregation of the catch of each species, and effort, for each flag. A higher Gini index indicates that more of the catch (or effort) is being taken from fewer spatial cells. We estimated it as follows for each year, where the values y_i are catches or effort per 5 by 5 degree cell, ranked from lowest to highest, and including zeroes for unfished cells.

$$Gini = \frac{2\sum_{i=1}^{n} i y_i}{n\sum_{i=1}^{n} y_i} - \frac{n+1}{n}$$

Gulland’s index of concentration measures the extent to which a fleet has concentrated its fishing effort in areas with higher than average catch rates (Harley 2009). It is calculated as follows, where y_i is the catch in the *i*th stratum, e_i is the effort in the *i*th stratum, and N is the number of exploited strata.

$$Gulland = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} e_i} . \frac{1}{\sum_{i=1}^{N} \frac{y_i}{e_i N}}$$

This index varies from year to year depending on both the distribution of the effort, and the distribution of the catch rates. If effort is evenly distributed with respect to catch rate then the index will average 1, whereas it will be higher than 1 if effort is preferentially targeted to areas with higher than average catch rate.

However, the standard Gulland’s index only takes into account the catch rate in areas with fishing effort, and may therefore decline in a counterintuitive way with increasing effort concentration, if vessels stop fishing in an area with low catch rates. Two further concerns are that a) catch rates in areas with low effort can be very variable, adding noise to the index, and b) unstandardized catch rates are not necessarily good indicators of fish density, since they are affected by factors such as vessel fishing power. One way to address these problems is to use standardized catch rates estimated over longer periods, based on the assumption that spatial effects are important in determining catch rates and persist long-term. This assumption is well-established for longline fisheries, based on the contribution of spatial effects to standardized catch rates. It is also reasonable to assume that fleets base their decisions about where to fish, at least to some extent, on long-term catch rates.

I therefore developed two alternative versions of the Gulland's index which used standardized catch rates to define the relative catch rate in each 5 by 5 degree cell. The first approach (long-term Gulland's index) used standardized catch rates over the entire period of the fishery, and the second approach (five-year Gulland's index) used standardized catch rates for the five years up to and including the year of interest. For the five-year Gulland's index, spatial catch rates for the first four years were based on the first 5 years of data. In both cases the indices were calculated as follows for each year, where e_i is effort in cell i, and $CPUE_i$ is the estimated catch rate in cell i:

$$Alternative\ Gulland = \frac{1}{\sum_{i=1}^{N} CPUE_i \sum_{i=1}^{N} e_i} \sum_{i=1}^{N} e_i CPUE_i$$

3. Results and Discussion

There is considerable variation between fleets in the spatial distribution of their fishing effort, and these distributions change through time (Figure 2). Japanese effort was greater in the west than in the eastern Indian Ocean, with a peak area of effort between the equator and 10 N. However, effort has moved further south since the year 2000. Since the 1990s there has also been considerable Japanese fishing effort at about 30 degrees S. Taiwan,China longline fishing effort has had a similar spatial distribution throughout the period since 1967, initially at similar levels in both the eastern and western tropical areas of the Indian Ocean. There has been a moderate transfer of effort towards the western area since 1990.

CPUE standardization

Standardized catch rates for the Japanese and Taiwanese fleets were similar to those estimated by Okamoto (2014a) using aggregated data (Figure 3). Yellowfin CPUE declines quite steeply through the time series in the tropical regions, while bigeye CPUE is relatively stable.

There is considerable spatial variation in catch rate (Figure 4), with very different patterns between the two species. For bigeye the Japanese catch rates tend to be higher in the east, with a minimum at about the latitude 20 degrees S. Taiwanese vessels show a similar minimum CPUE at about 20S, with higher catch rates to both the north and south. For both Japanese and Taiwanese longline fisheries the yellowfin catch rates are considerably higher in the west than in the east, with highest catch rates near the African coast, between the equator and 20S. This may reflect the relative distributions of the two species. Similarly, in the Western Pacific the catch rates of bigeye increase further east, while yellowfin catch rates are higher in the west (Hoyle and Okamoto 2011; Hoyle and Okamoto 2013). The large peak in yellowfin CPUE in the west is split into two regions by the regional structure current used in yellowfin stock assessments (Langley *et al.* 2012). For both bigeye and yellowfin, Taiwanese catch rates decline more further south than do the Japanese catch rates, reflecting the dominance of albacore targeted effort in the Taiwanese fishery south of 20S. The general patterns of spatial distribution of catch rates are consistent through time, although there are some significant changes (Figure 5 and Figure 6). For example, the high Japanese bigeye catch rate south of 25S prior to 1975 is no longer apparent by the mid-1980s, which may reflect a change in targeting in that area towards southern bluefin tuna.

The strong spatial variation in catch rates of both bigeye and yellowfin fisheries, even over relatively small distances, indicates the importance of including spatial effects at relatively fine scales such as 5 degree squares in CPUE standardizations. Standardizing the data with coarser resolution cells will introduce bias, if effort distribution moves within cells.

Given that the large spatial differences in catch rates may reflect differences in relative abundance, it is important to consider possible differences in abundance trend and population structure at the same scale. I analysed the CPUE data in blocks of 10 degrees of latitude and 20 degrees longitude. Spatial patterns for bigeye CPUE taken by the Japanese fleet were very similar across the equatorial areas from 15S to 5N, but much more variable from 5N to 15N, and south of 15S (Figure 7). Bigeye CPUE for the Taiwan,China fleet was somewhat similar in showing more variability north of 5N and south of 15S, but in general its CPUE was more variable both between areas and through time than the Japanese CPUE. Yellowfin CPUE for Japan similarly declined strongly across all equatorial areas, but interestingly there was a clear spatial pattern in the trend, with less decline in the western areas of higher catch rate than in the east (Figure 8). However, this spatial difference in trends was less apparent in the Taiwanese data. Otherwise, trends for Taiwan and Japan were quite similar for yellowfin. Areas to the north of 5N and south of 15S showed different and quite variable trends, possibly reflecting differences in targeting practices between areas, fleets, and time periods, or possibly spatially varying abundance trends.

Analyses of population size structure (Geehan and Hoyle 2013) did not show strong spatial size patterns, although there were some potentially anomalous differences between the evidence from catch data and size sampling data. Given the problematic temporal changes in the Taiwanese size sampling data, further investigation may help to identify spatial patterns in size distributions that relate to population structure.

Mapping the long term CPUE trends by species and fleet at a 5 degree resolution similarly showed more decline in yellowfin than in bigeye CPUE, and with Japanese yellowfin CPUE showing more decline in the east than in the west (Figure 9). For both fleets the yellowfin CPUE declines are greater in the equatorial area than further south. Trends from 1990-2012 were highly spatially variable (Figure 10), reflecting the noisy data and possibly changing fleet distributions and targeting practices.

The variation in spatial catch rate patterns and trends between the Taiwan,China and Japanese fleets suggests that fishing strategies have affected catch rates. This is supported by the results in Okamoto (2014a), which indicate a strong effect of HBF on catch rate. For example, the yellowfin tuna CPUE trend is different east and west for Japan but not for Taiwan,China, which may reflect different trends in fishing strategy for the two fleets. There may also be different trends in abundance spatially. Untangling the various factors affecting catch rate and identifying the underlying abundance trend will require closer investigation of the fishing data.

Vessels use different targeting strategies to target particular species. Some aspects of fishing strategy such as hooks between floats (HBF) are recorded in logbooks, but any others that may also affect catch rate are not reported consistently, or at all (gear, bait, and setting strategies). However, there are methods available that can be used to investigate targeting, but do not require information on the specific components of fishing strategy that affect catch rates. Classifying effort into groups with consistent targeting strategies can be an effective way to deal with target change. Methods for classifying effort in this way can use cluster analysis (Bigelow and Hoyle 2008; He *et al.* 1997) or some new methods using principal component analysis (Winker *et al.* 2013; Winker *et al.* 2014). Analyses of trends in species composition and vessel movement behaviour (Hoyle and Okamoto 2013) can also be informative about targeting strategies.

Effort concentration

Changes in effort concentration can be indicative of changes in fishing strategy, which may reflect target change. Changes in Gini coefficients through time (Figure 11) provide a starting point for understanding how and why effort patterns have changed. Gini coefficients showed similar patterns for both Japanese and Taiwanese effort in the equatorial areas. Patterns were broadly similar for bigeye, yellowfin and fishing effort, but there were some differences. In region 1 the Japanese catches and effort were more concentrated than the Taiwanese after about 1990. In region 2 however, the Taiwanese catches were more concentrated than the Japanese, while the concentration of effort was similar. In the southern region 3, Japanese catch and effort was much more concentrated than the Taiwanese, apart from a short period before 1970. Concentration in region 1 peaked in the early 1980s and then declined until the mid-2000s, after which it climbed again steeply. The latter increase may reflect the effects on effort distribution of piracy near Somalia. In region 2, concentration has increased fairly steadily throughout the time period.

The three approaches (Figure 12, Figure 13, and Figure 14) for analysing effort concentration with respect to CPUE gave results that were significantly different in many respects. The longer term indices were much less variable which made it easier to see patterns. This indicates that much of the variability in the standard indices is due to short-term changes in CPUE. In some cases (e.g. Taiwanese BET R1) the standard Gulland’s index changed in a qualitatively different way from the longer term indices, due to lack of fishing in part of the distribution. However in the example given the change was due to loss of the CPUE component rather than the effort component.

The long term Gulland’s indices (Figure 14) show that Japanese fishing effort in region 1 was focused on areas with higher bigeye catch rates and lower yellowfin catch rates until the mid-1990’s, since when there has been a progressive and strong shift towards areas with higher yellowfin and lower bigeye catch rates. In contrast, western equatorial Taiwanese effort has remained relatively consistently in areas with higher than average bigeye catch rates, but average yellowfin catch rates. In eastern equatorial region 2, both Taiwanese and Japanese effort distribution have been relatively consistent, with Taiwanese effort in areas where both yellowfin and bigeye catch rates are higher than average, and Japanese effort in areas with slightly above average bigeye CPUE and average yellowfin CPUE. Note, however, that the Japanese and Taiwanese spatial CPUE effects were different and may reflect reporting differences to some extent, rather than differences in targeting or effort. In the southern region 3, Japanese fishing occurred in areas with average bigeye catch rates and considerably above average yellowfin catch rates, moving towards lower bigeye catch rate areas from the mid-1990s. In contrast, bigeye CPUE for Taiwanese fishing effort was average until the mid-1980s and then increased, while yellowfin CPUE was average and then declined.

4. Conclusions and Recommendations

The results presented here indicate that the significant differences in CPUE trend between the fleets are maintained when the location of fishing is taken into account. They also indicate spatial differences in CPUE trend within fleets and regions. Changes in effort concentration through time suggest that targeting patterns within fleets have changed in different ways. The different CPUE trends for the two fleets are therefore likely to be at least partly due to differences in targeting, but may also be affected by differences in reporting.

The following work suggested in order to estimate CPUE trends that are representative of tuna abundance, and to design fisheries and regions that are appropriate for assessing these stocks.

- Analyze operational data using cluster analysis and principal component analysis to investigate the effects of targeting on CPUE trends. These analyses will be more effective if they include catches of more species, including bycatch species. Explore fine-scale spatial patterns in species composition and patterns of vessel behaviour. Identify methods to prepare CPUE indices that take targeting into account.
- Investigate spatial patterns of CPUE trends and fish sizes once targeting and other effects (e.g. vessel effects) have been taken into account. Use these analyses, in combination with analyses of tagging data, consideration of genetic evidence, and model sensitivity analyses, to recommend appropriate regional and fishery structures.

5. Acknowledgments

I am grateful to the International Seafood Sustainability Foundation for funding this study, and the Indian Ocean Tuna Commission for their support. Thanks also to Dr Hiroaki Okamoto of the Japanese National Research Institute for Far Seas Fisheries, and Dr Yu-Min Yeh of Nanhua University, Taiwan.

6. References

Anon. Report of the IOTC CPUE Workshop, San Sebastian, Spain, 21–22 October, 2013. Indian Ocean Tuna Commission; 2013

Bigelow, K.A.; Hoyle, S.D. Standardized CPUE for distant-water fleets targeting south Pacific albacore. WCPFC Scientific Committee. Nouméa, New Caledonia; 2008

Calkins, T.P. Measures of population density and concentration of fishing effort for yellowfin and skipjack tuna in the eastern Tropical Pacific Ocean 1951-1959. Inter-American Tropical Tuna Commission Bulletin. 6:69-152; 1961

Calkins, T.P. An examination of fluctuations in the "concentration index" of purse seiners and baitboats in the fishery for tropical tunas in the Eastern Pacific, 1951-1961. Inter-American Tropical Tuna Commission Bulletin. 8:255-316; 1963

Geehan, J.; Hoyle, S. Review of length frequency data of the Taiwan,China distant water longline fleet, IOTC-2013-WPTT15-41 Rev_1. Indian Ocean Tuna Commission Working Party on Tropical Tunas, San Sebastian, Spain, 23–28 October, 2013; 2013

Gini, C. Variabilità e mutabilità. Reprinted in Memorie di metodologica statistica (Ed Pizetti E, Salvemini, T) Rome: Libreria Eredi Virgilio Veschi. 1; 1912

Griffiths, R.C. A study of measures of population density and of concentration of fishing effort in the fishery for yellowfin tuna, Neothunnus macropterus, in the Eastern Tropical Pacific Ocean, from 1951 to 1956. Inter-American Tropical Tuna Commission Bulletin. 4:39-136; 1960

Gulland, J.A. On the fishing effort in English demersal fisheries. Fisheries Investigations Series II. 20:41 pp; 1956

Harley, S. Spatial distribution measures for the analysis of longline catch and effort data. 2009

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

Hoyle, S.D.; Okamoto, H. Analyses of Japanese longline operational catch and effort for bigeye and yellowfin tuna in the WCPO. Pohnpei, Federated States of Micronesia; 2011

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

Kolody, D.; Grewe, P.; Davies, C.; Proctor, C. Are Indian Ocean tuna populations assessed and managed at the appropriate spatial scale? A brief review of the evidence and implications. 15th Working Party on Tropical Tuna: Indian Ocean Tuna Commission; 2013

Langley, A. An investigation of the sensitivity of the Indian Ocean MFCL yellowfin tuna stock assessment to key model assumptions. IOTC-2012-WPTT-14-37; 2012

Langley, A.; Herrera, M.; Million, J. Stock assessment of yellowfin tuna in the Indian Ocean using MULTIFAN-CL. Working Party on Tropical Tuna: Indian Ocean Tuna Commission; 2012

Langley, A.; Herrera, M.; Sharma, R. Stock assessment of bigeye tuna in the Indian Ocean for 2012. IOTC Working Party Document; 2013

McKechnie, S.; Hoyle, S.; Harley, S. Longline CPUE series that account for changes in the spatial extent of fisheries. 2013

Nishida, T.; Rademeyer, R.; Ijima, H.; Sato, K.; Matsumoto, T.; Kitakato, T.; Fonteneau, A. Stock and risk assessment on yellowfin tuna (Thunnus albacares) in the Indian Ocean by AD Model Builder implemented Age-Structured Production Model (ASPM) and Kobe I+ II software–Preliminary results on the base case. IOTC-2012-WPTT14-40 Rev_1; 2012

Okamoto, H. CPUE of bigeye and yellowfin tuna caught by Japanese longliner in the Indian Ocean standardized by GLM considering several aspects of area, catchability and data resolution. IOTC 16th Working Party on Tropical Tunas (WPTT); 2014a

Okamoto, H. Provisional study on comparison of CPUE trend of bigeye and yellowfin tuna between Japanese and Taiwan-China longline fisheries based on whole and shared strata in the Indian Ocean. IOTC 16th Working Party on Tropical Tunas (WPTT); 2014b

R Core Team. R: A Language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2014

Winker, H.; Kerwath, S.E.; Attwood, C.G. Comparison of two approaches to standardize catch-per-unit-effort for targeting behaviour in a multispecies hand-line fishery. Fisheries Research. 139:118-131; 2013

Winker, H.; Kerwath, S.E.; Attwood, C.G. Proof of concept for a novel procedure to standardize multispecies catch and effort data. Fisheries Research. 155:149-159; 2014

7. Figures

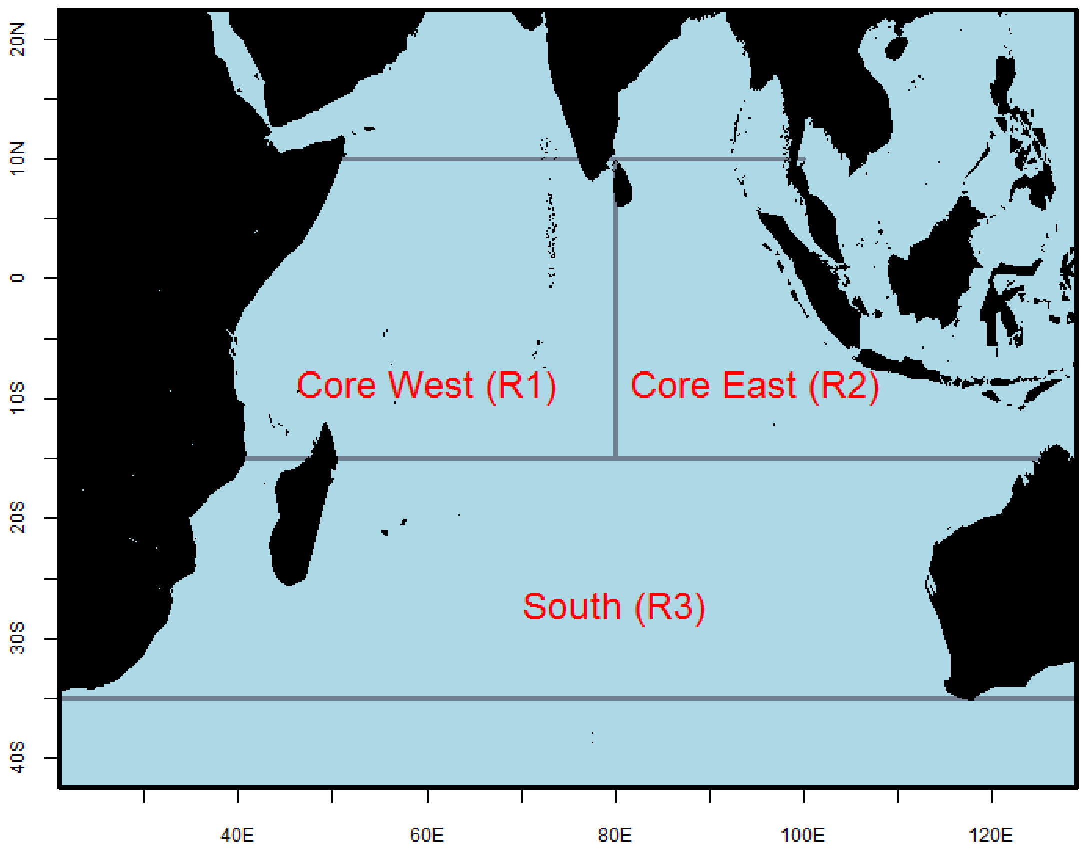

Figure 1: Indian Ocean, showing the spatial definitions of core areas used in this paper.

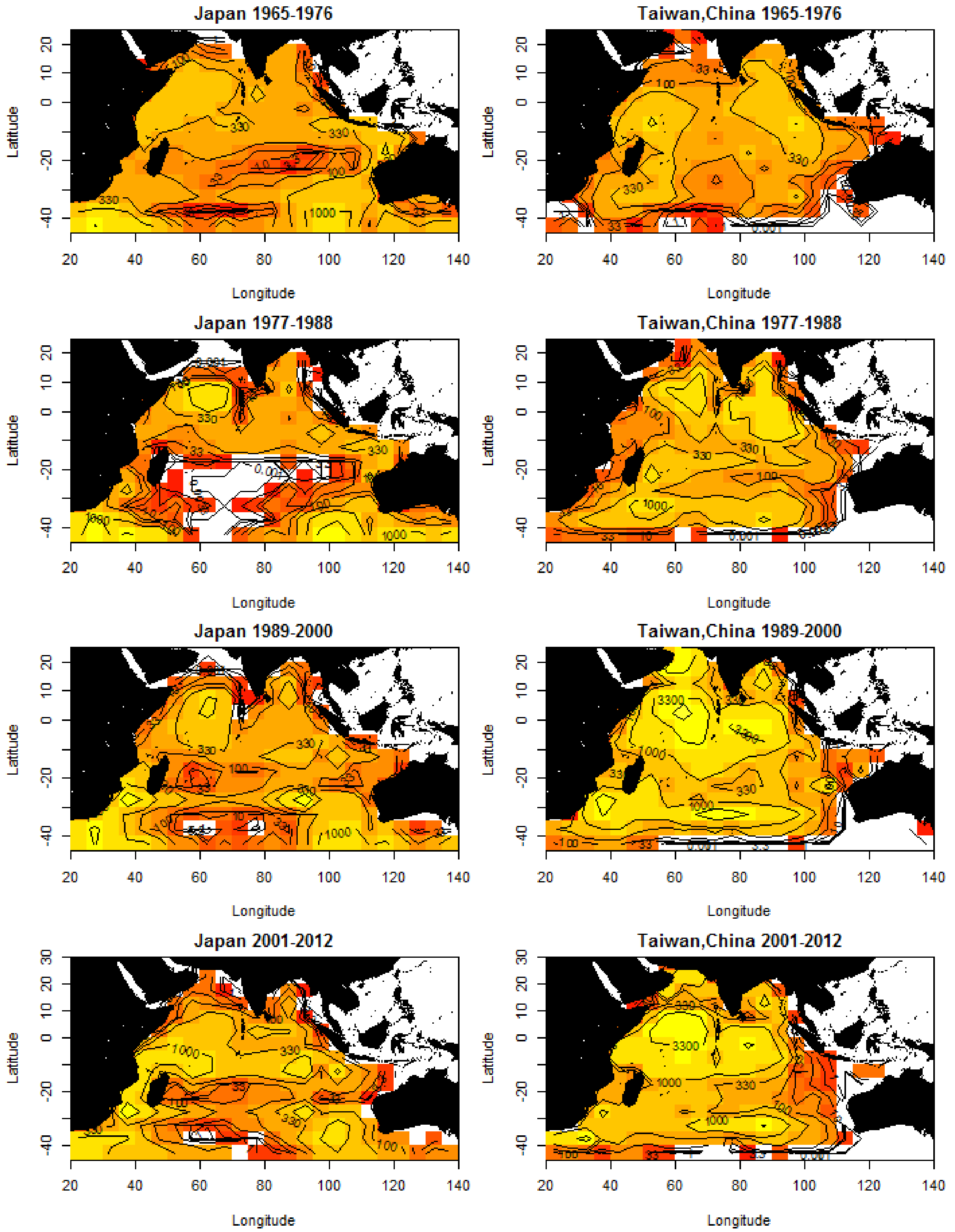

Figure 2: Average effort (1000s of hooks) per year by 5 degree square, for Japanese (left) and Taiwan,China (right) longline fishing, grouped into four 12-yeqr periods. Yellower colour indicates more fishing effort.

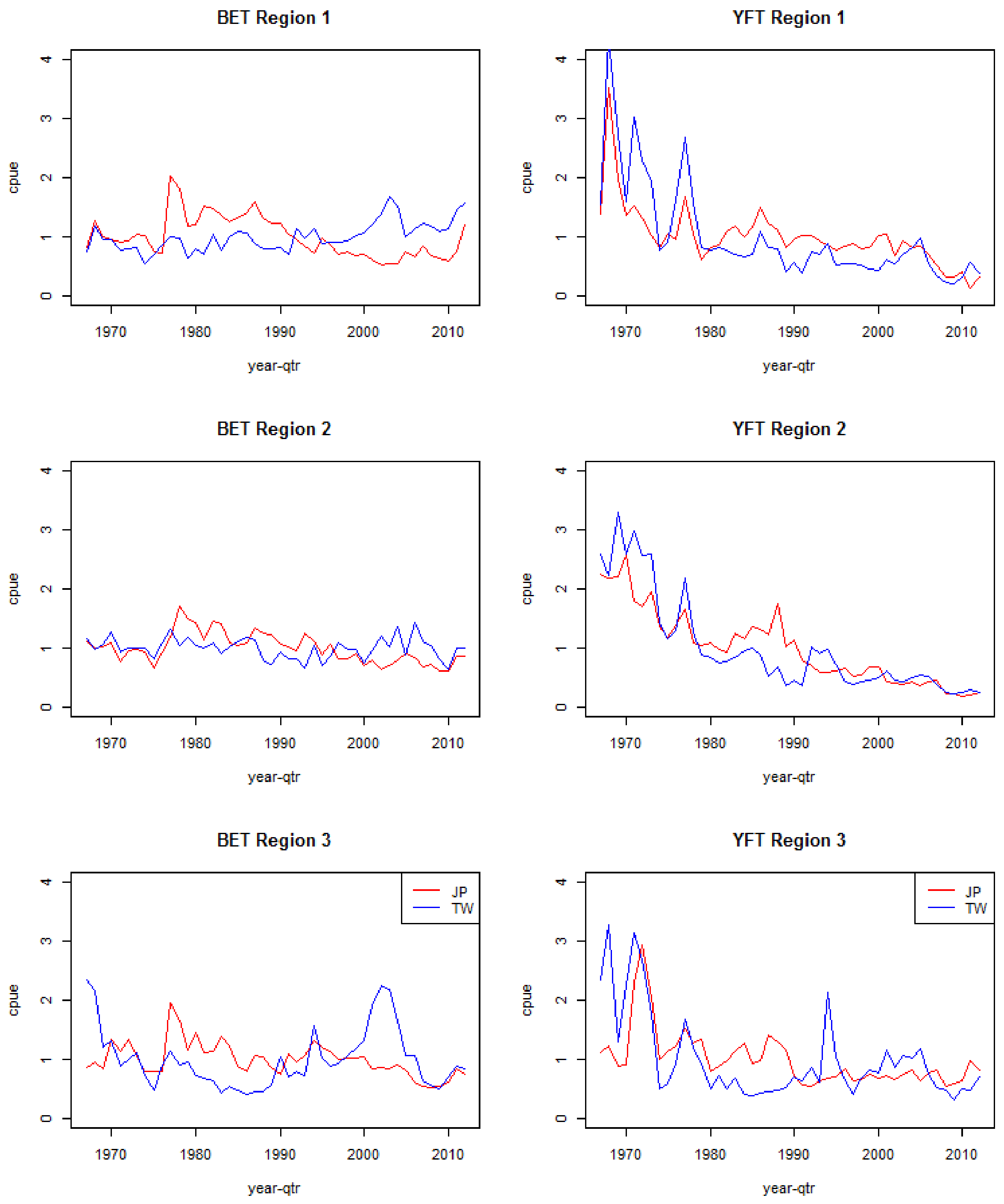

Figure 3: Estimated trends of standardized CPUE 1967-2012 by region for Japan (red) and Taiwan,China (blue), for bigeye (left) and yellowfin (right).

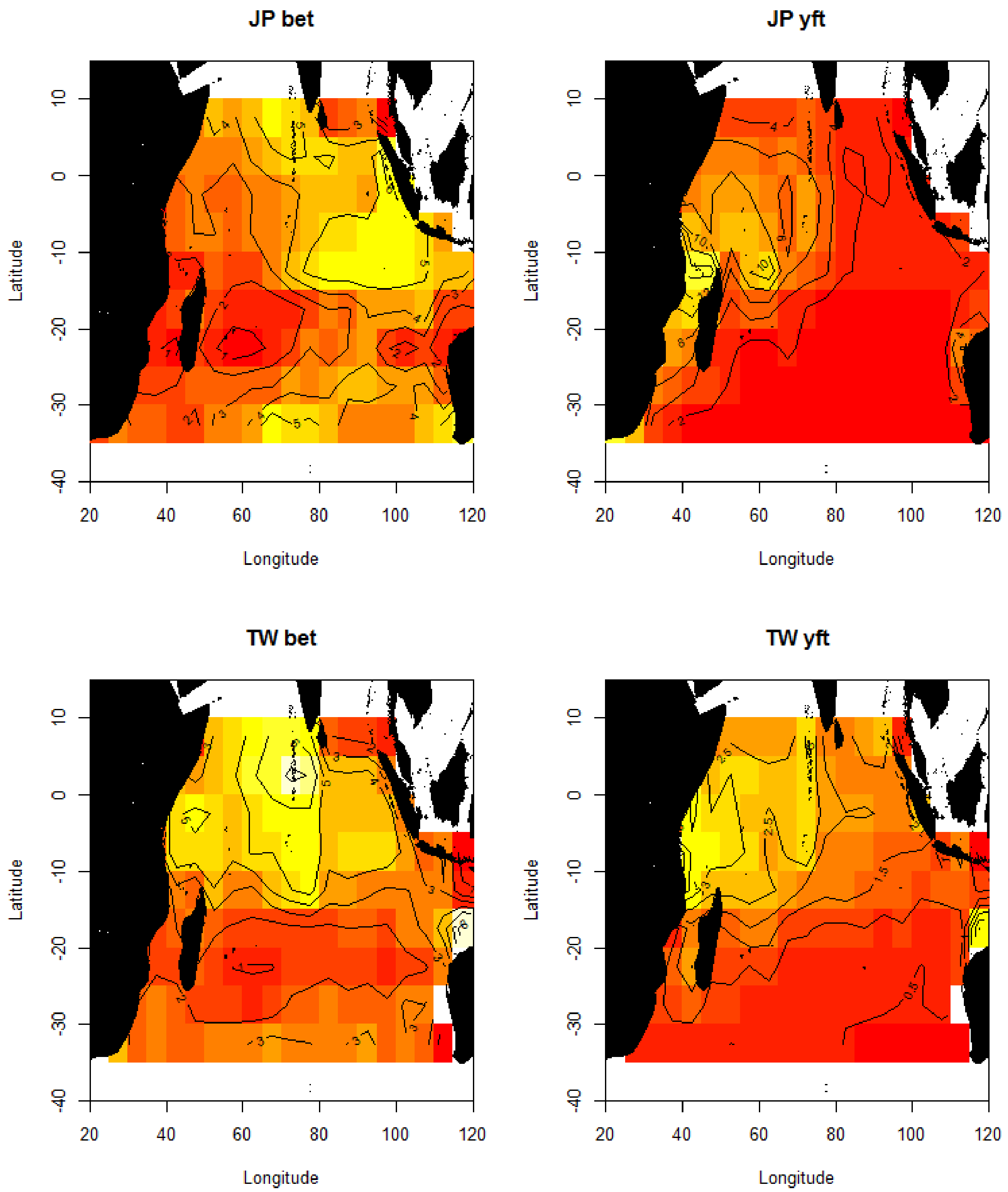

Figure 4: Standardized CPUE by 5 degree square for bigeye (left) and yellowfin (right, estimated from Japanese (top) and Taiwan,China (bottom) longline data. Yellower colour indicates higher CPUE.

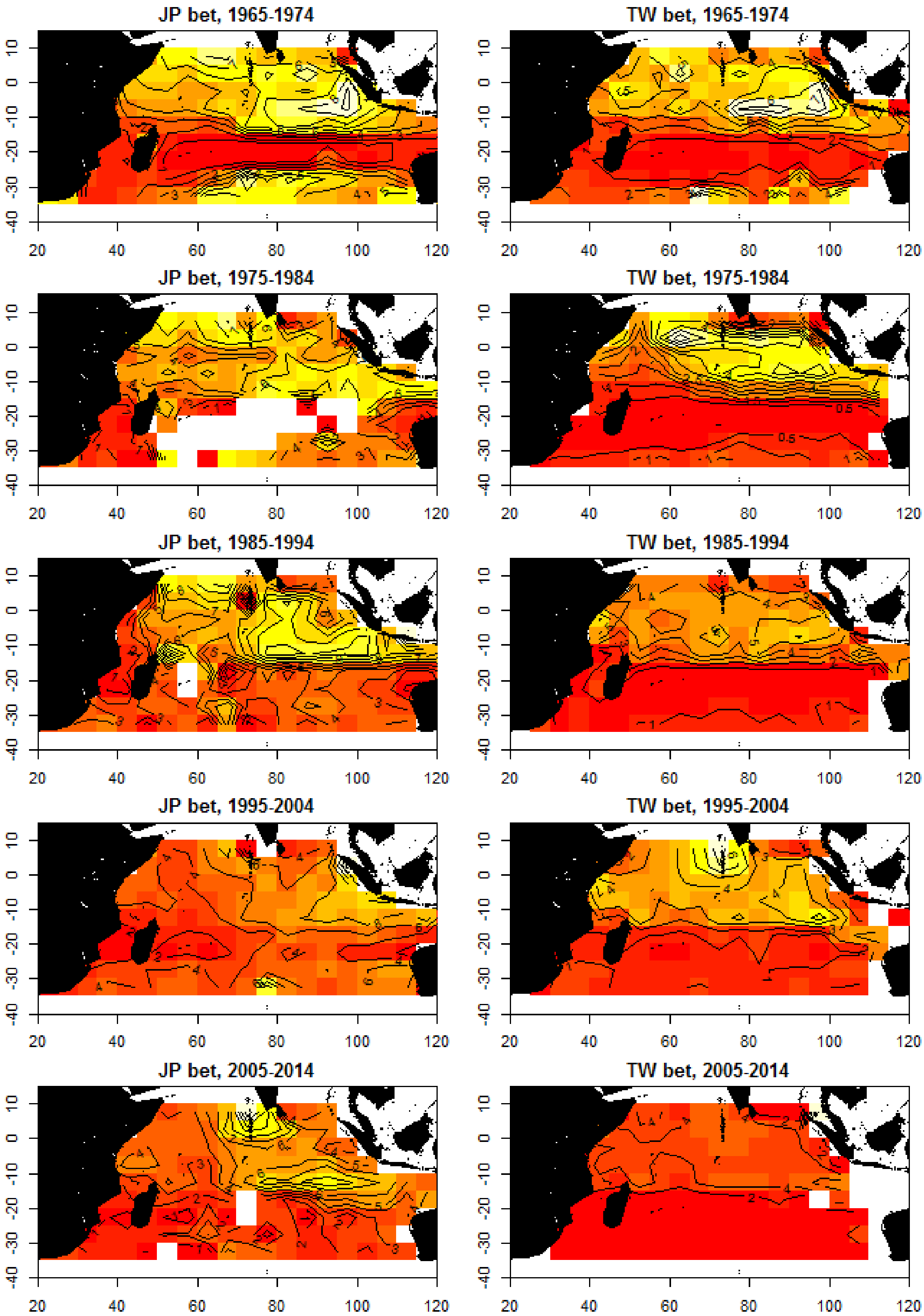

Figure 5: Standardized CPUE by 5 degree square for bigeye tuna by decade, estimated from Japanese (left) and Taiwan,China (right) longline data. Yellower colour indicates higher CPUE.

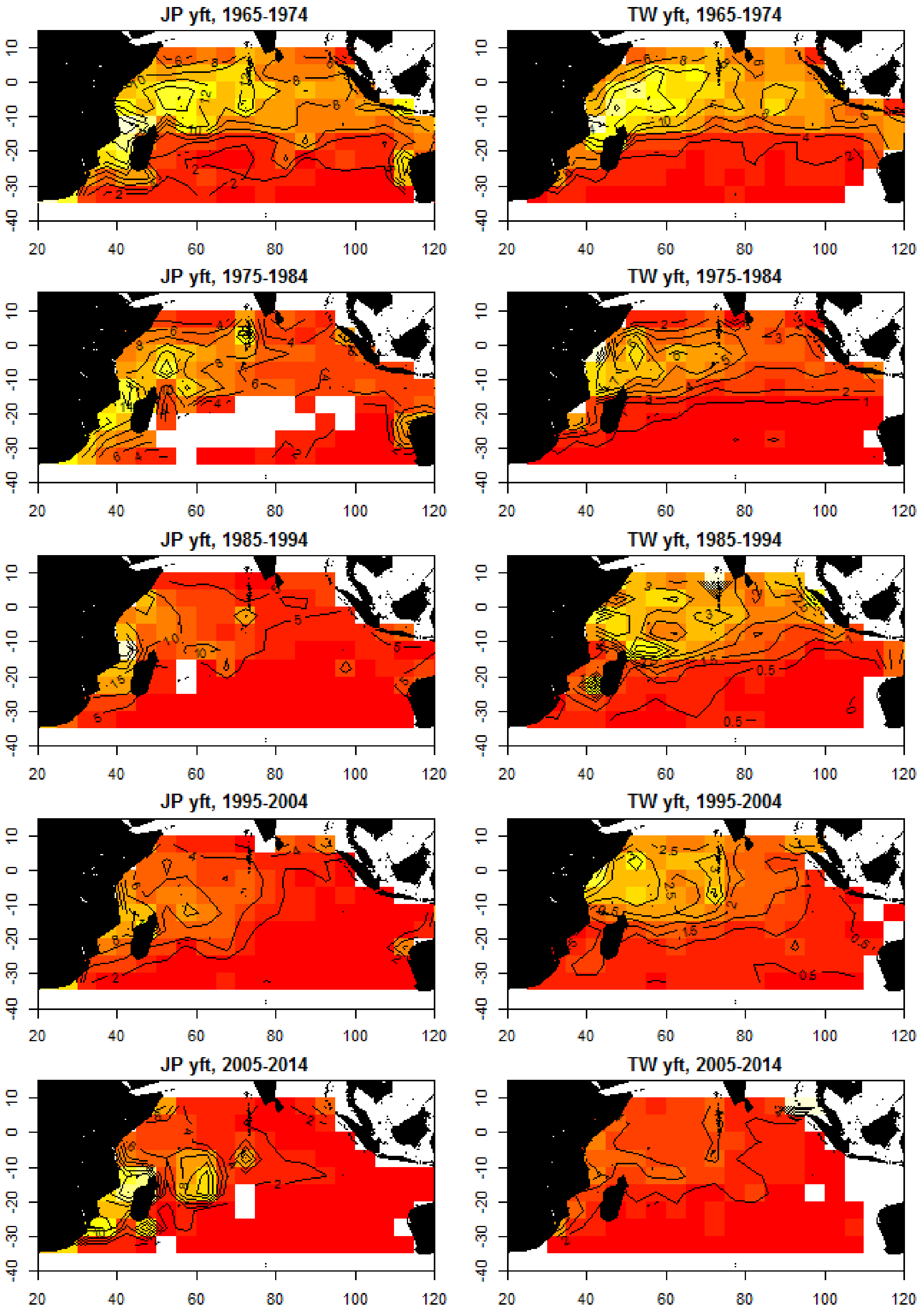

Figure 6: Standardized CPUE by 5 degree square for yellowfin tuna by decade, estimated from Japanese (left) and Taiwan,China (right) longline data. Yellower colour indicates higher CPUE.

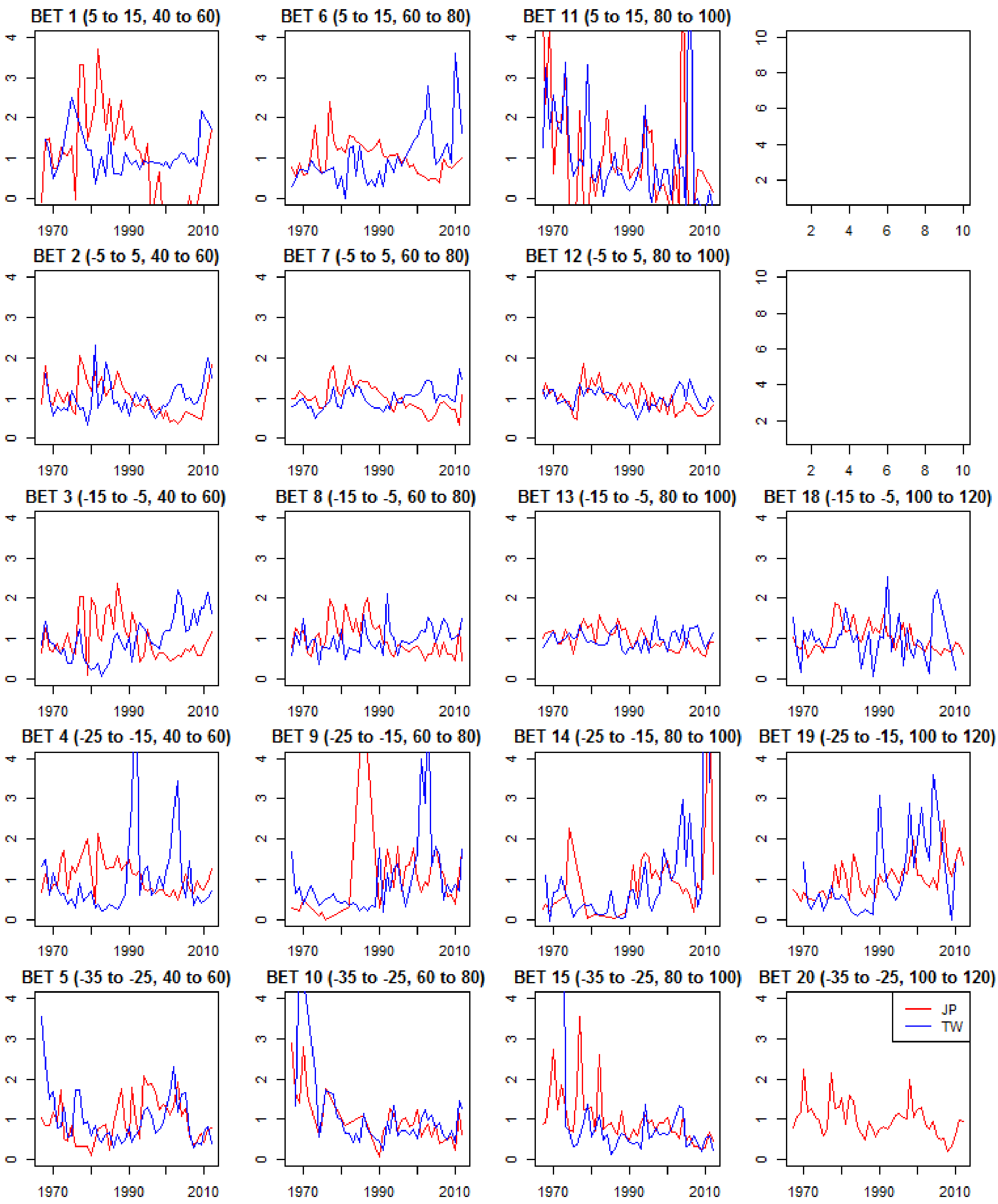

Figure 7: Estimated trends of standardized CPUE 1967-2012 in 10 x 10 degree sub-regions for Japan (red) and Taiwan,China (blue), for bigeye tuna.

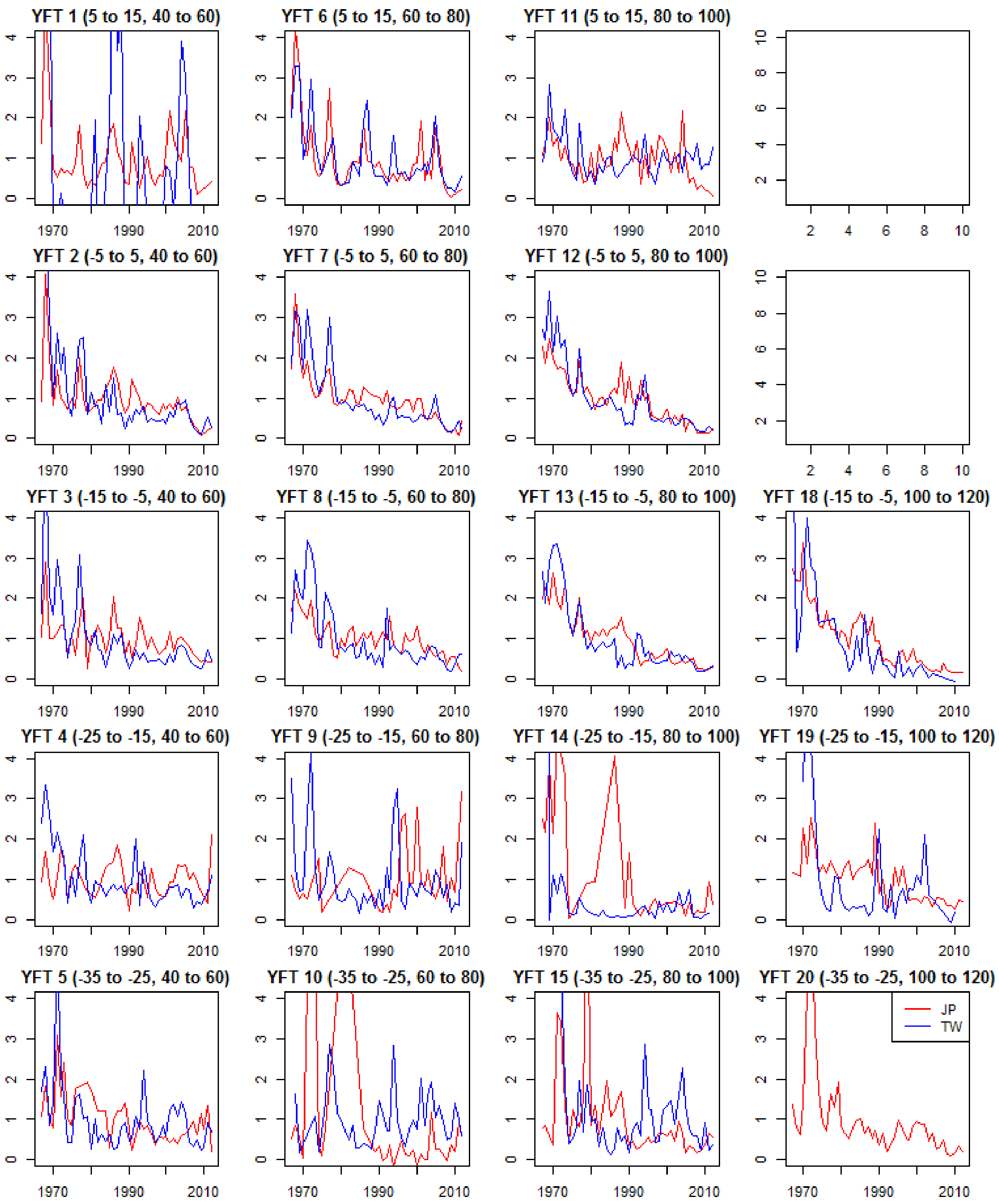

Figure 8: Estimated trends of standardized CPUE 1967-2012 in 10 x 10 degree sub-regions for Japan (red) and Taiwan,China (blue), for yellowfin tuna.

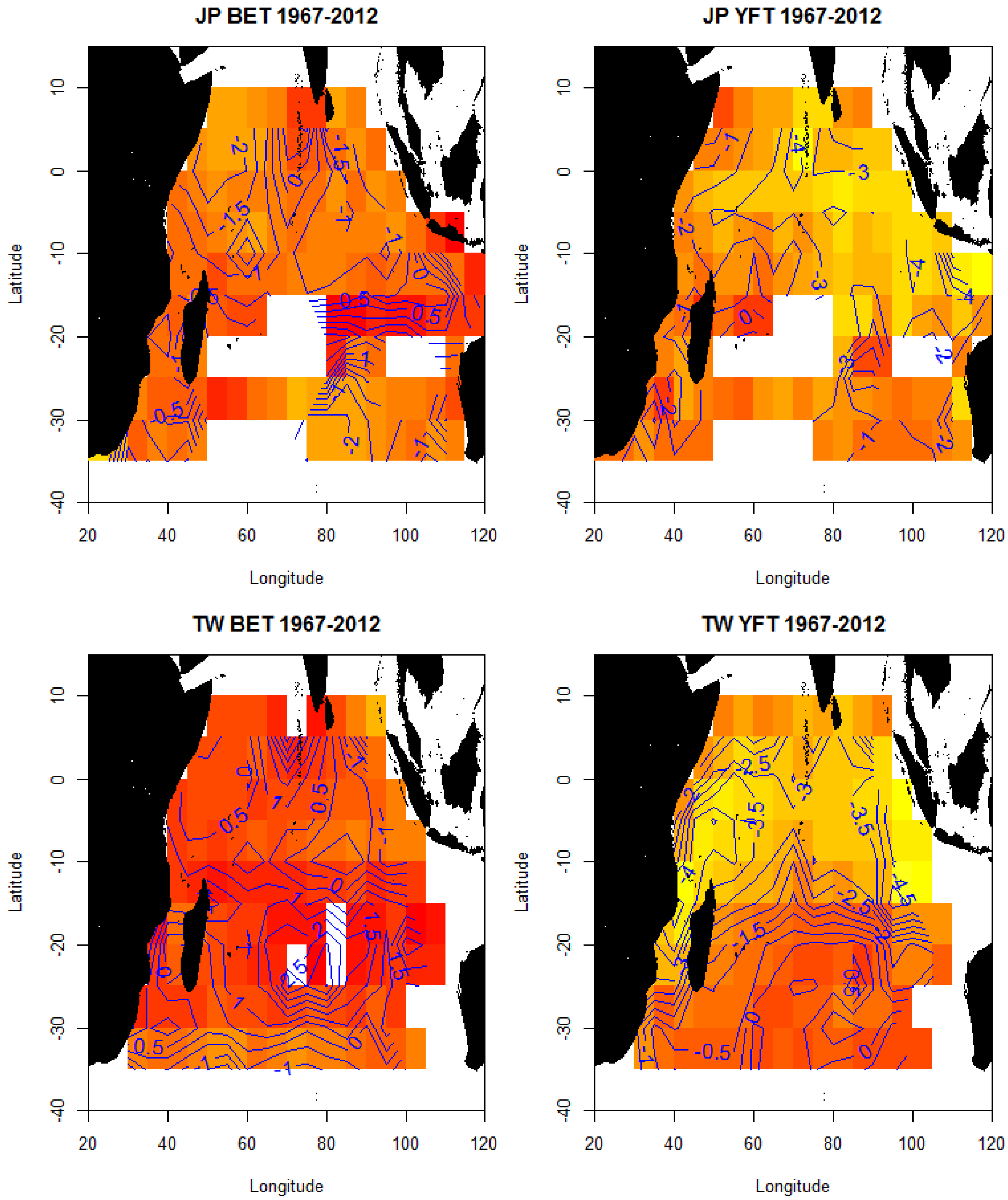

Figure 9: Maps of linear CPUE trend 1967-2012 per 5 degree square, for bigeye (left) and yellowfin (right), from Japanese (top) and Taiwan,China (bottom) longline data. Yellower colour indicates steeper decline.

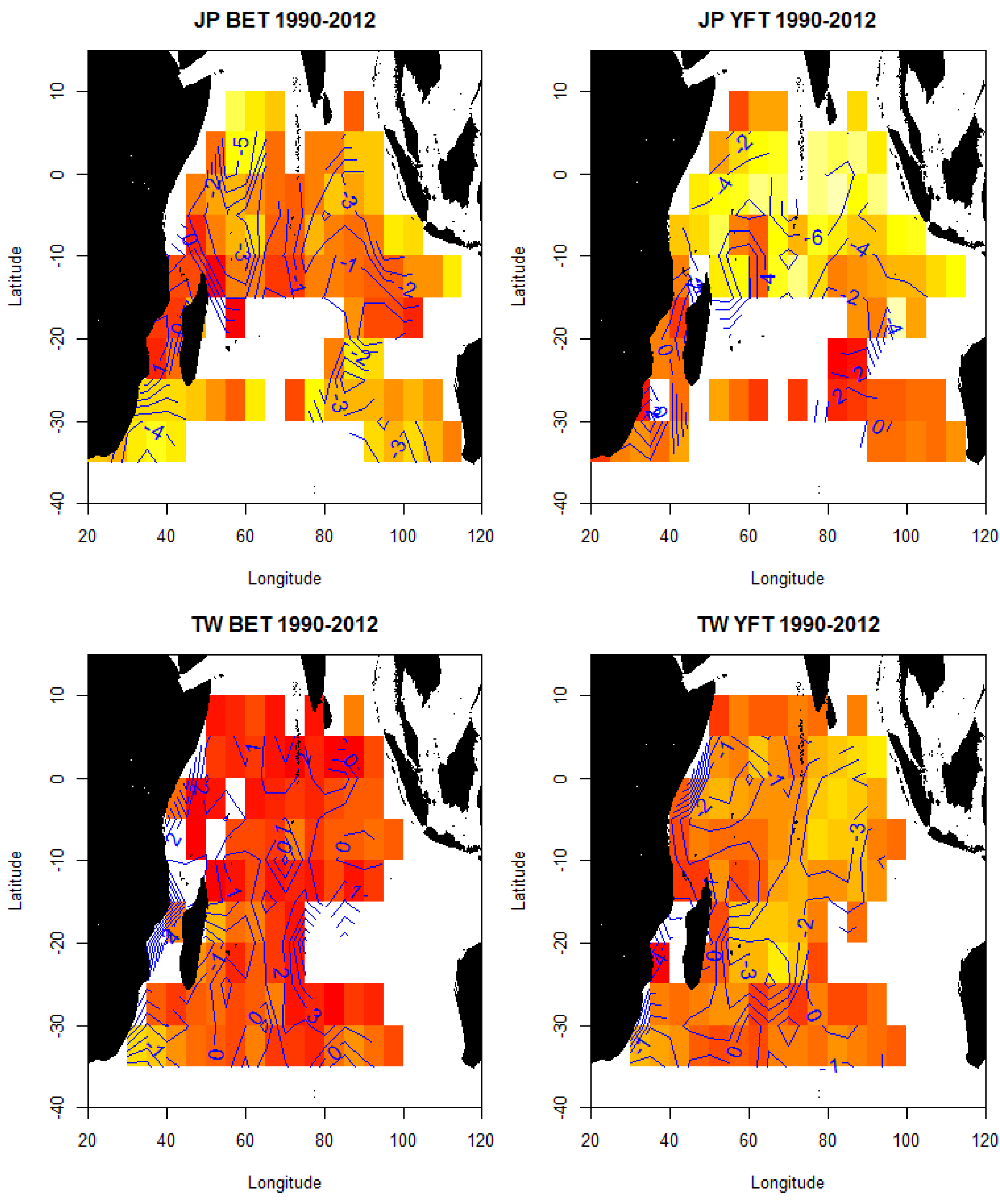

Figure 10: Maps of linear CPUE trend 1990-2012 per 5 degree square, for bigeye (left) and yellowfin (right), from Japanese (top) and Taiwan,China (bottom) longline data. Yellower colour indicates steeper decline.

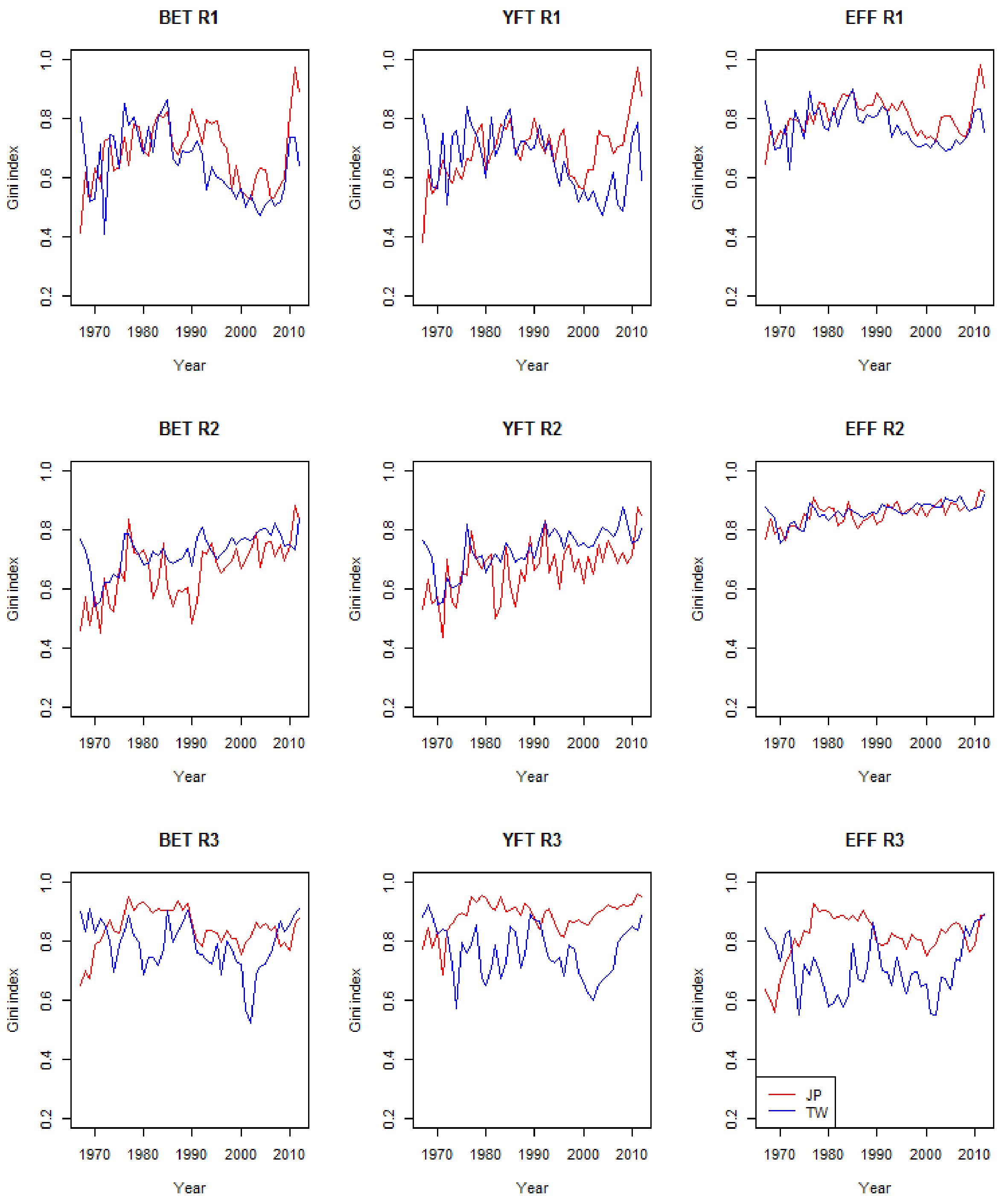

Figure 11: Gini indices of concentration by region for bigeye catch (left), yellowfin catch (middle) and fishing effort (right) for both Japanese (red) and Taiwan,China (blue) longline fishing.

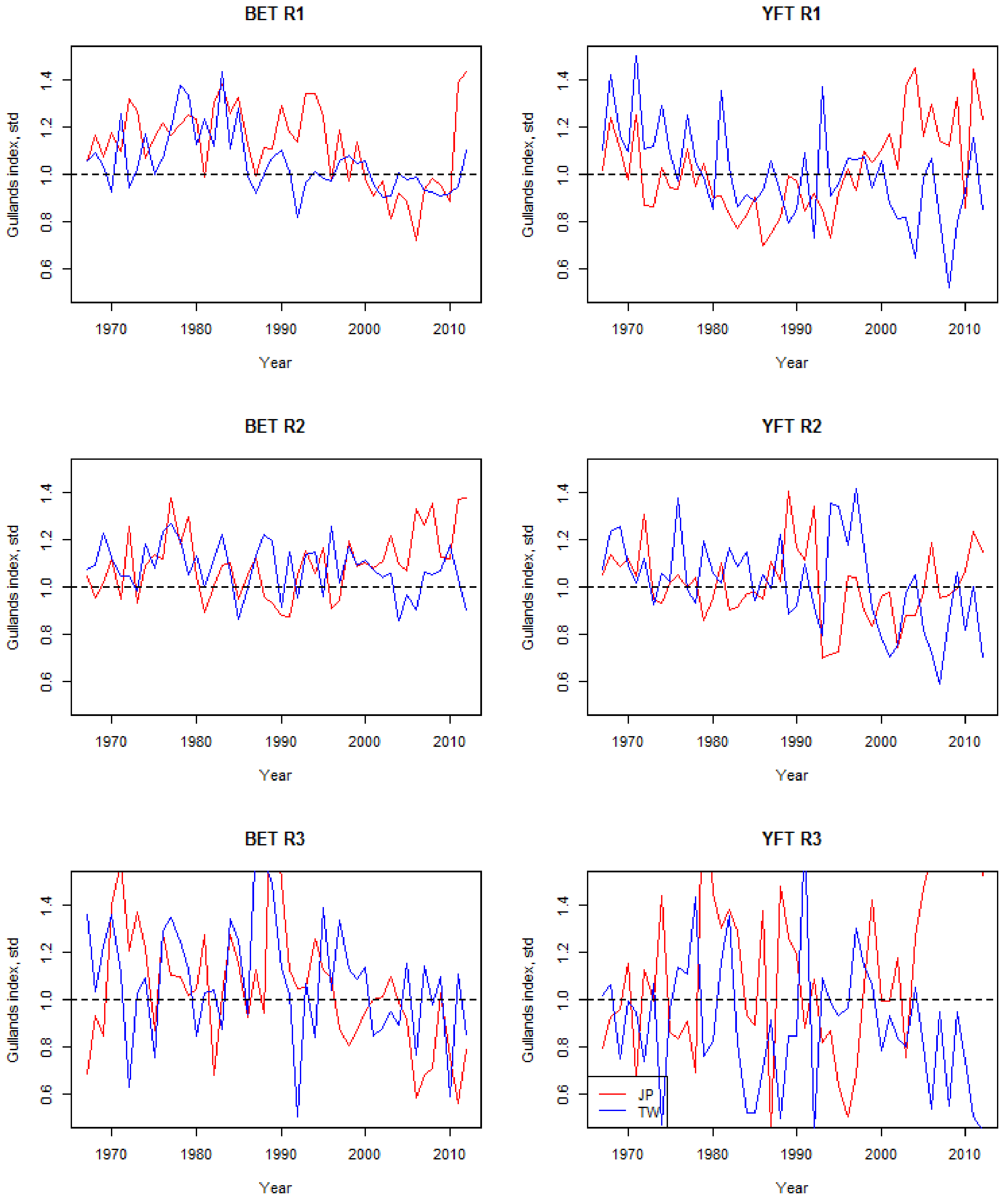

Figure 12: Standard Gulland's index of effort distribution by region for bigeye (left) and yellowfin (right) for Japanese (red) and Taiwanese (blue) fishing effort.

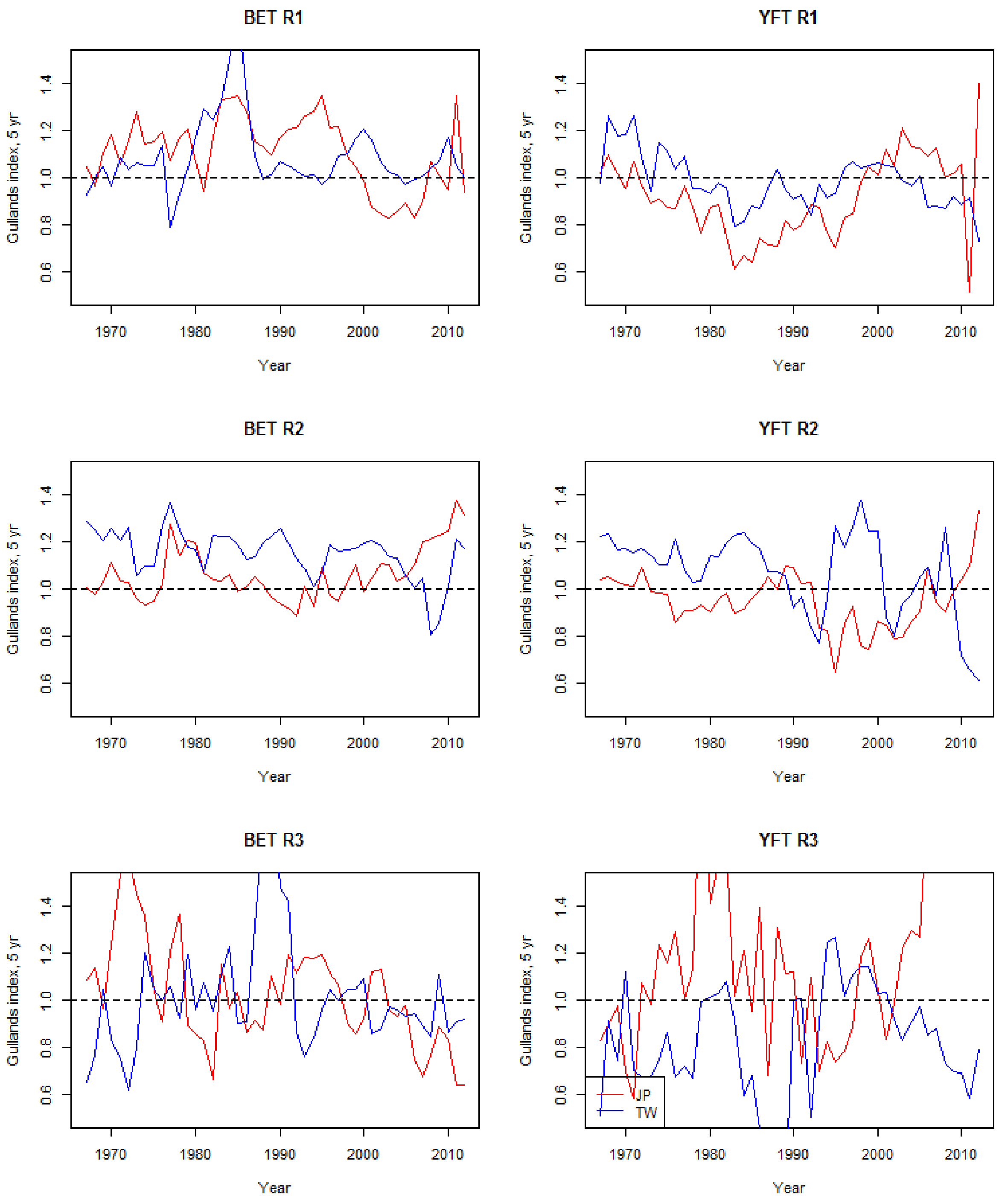

Figure 13: Five-year Gulland's index of effort distribution by region for bigeye (left) and yellowfin (right) for Japanese (red) and Taiwanese (blue) fishing effort.

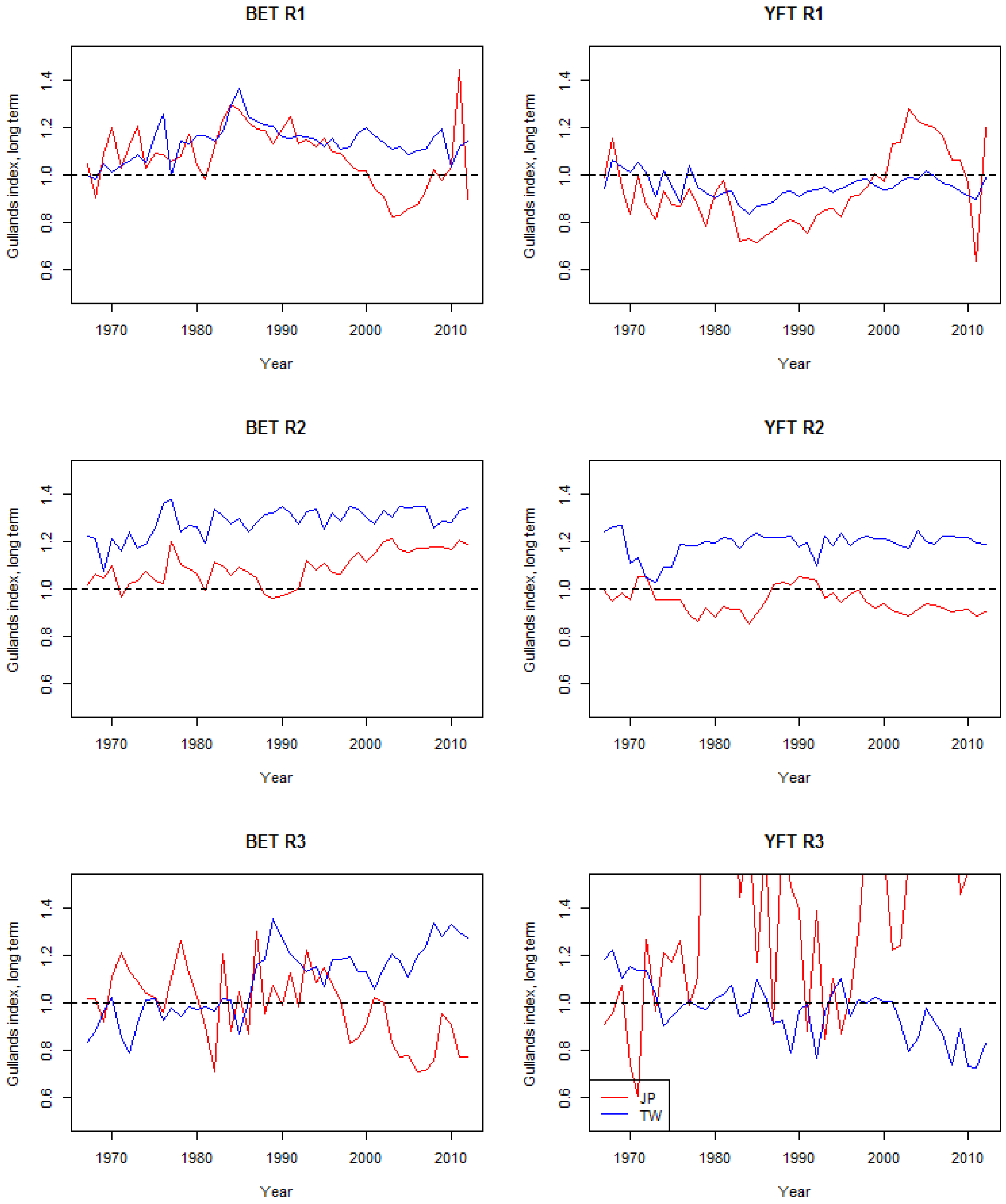

Figure 14: Long-term Gulland's index of effort distribution by region for bigeye (left) and yellowfin (right) for Japanese (red) and Taiwanese (blue) fishing effort.