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SPATIAL DISTRIBUTION MEASURES FOR THE ANALYSIS OF LONGLINE CATCH AND EFFORT DATA

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Examination of various concentration indices of longline catch and effort data in the western Pacific Ocean, 1950–2007

Shelton J Harley

Summary

Several spatial indices were applied to raised aggregate 5x5 degree square and month longline catch and effort data for bigeye, yellowfin, and albacore tunas from the three main distant-water longline fleets: Japan, Korea, and Taiwan, for the period 1950-2007. Indices considered included Gulland's index, which measures the extent to which effort occurs in the regions where highest CPUE was encountered for a species. Interesting patterns were found between regions and fleets that might provide insights into targeting behaviour and the potential for hyperstability (i.e. increasing catchability as abundance declines). Other indices were considered, but not included in the paper due to space limitations and should be considered in future work.

It is recommended that such analyses be undertaken on a regular basis as part of the characterisation of fisheries and to assist in the analysis and interpretation of CPUE data.

1. Introduction

An understanding of spatial distribution patterns in exploited fish populations has long been recognized as important for the interpretation of catch-per-unit-effort (CPUE) indices of abundance (Gulland 1956; Griffiths 1960; Paloheimo and Dickie 1964; Clark 1982). The distribution of both the fish and fishing effort are equally important to determining how CPUE relates to the population being fished.

The aim of this work described here was to apply a range of techniques to catch and effort data from the Japanese, Korean, and Taiwanese longline fisheries operating in the western and central Pacific Ocean (WCPO). The techniques involve summarizing catch and effort data for a single year with a series of indices that reflect either the concentration of catch and effort spatially (Swain and Sinclair 1994; Myers and Cadigan 1995) or the extent to which the majority of the catches of a species were taken from areas of the highest density (Gulland 1956). I will show that these indices provide a useful summary of the data, indicating known events in the history of the fisheries, and provide useful and quantifiable insights into the interpretation of CPUE indices.

When these techniques are applied to survey data, i.e., data collected over the range of a stock using some standardized sampling protocols, such indices can provide useful insights into the important ecological question of density-dependent habitat selection (Fretwell and Lucas 1970; MacCall 1990). Spatial distribution patterns should contain information on habitat preferences and the relative carrying capacity of different areas inhabited by a stock. Unfortunately, fishery-independent survey data are rarely available for large pelagic species such as the tunas and billfishes so we face the challenge of simply attempting to determine trends in relative abundance rather than the other ecologically appealing questions.

This reliance on CPUE data for monitoring large pelagic species has been long recognized and there has been considerable work in the IATTC on the interpretation of CPUE data. Historically, tunas in the EPO were mainly captured by pole and line (baitboat) vessels so it was the CPUE from these fisheries that was the focus of considerable research. Allen and Punsly (1984) provide a good review of the early work of assessment scientists in the eastern Pacific Ocean (EPO). Griffiths (1960) developed an index of concentration to describe the extent to which the catch of a species was taken from areas of high density (high catch rates) and Calkins (1961, 1963) extended this work to include the multi-species aspect of the tuna fisheries operating in the EPO. In this paper I extend some of the work undertaken in the EPO to the WCPO.

This rest of this paper will be as follows: first I will describe the longline data used in the analysis; second, I will define a number of indices that will be calculated from the data; and finally, I will calculate these indices for the catch and effort data along with total catch and CPUE for the key tuna species taken in WCPO longline fisheries.

2. Methods

Data

The data used for this analysis consist of longline catch and effort data for the Japanese, Taiwanese, and Korean longline fleets fishing in the WCPO. Data was only available at 5x5 degree square by month resolution. There is a reasonably good subset of species that have accurately been recorded over time, but for the purposes of this exploratory work I have focussed only on the three key species taken: albacore tuna (*Thunnus alalunga*), bigeye tuna (*Thunnus obesus*), and yellowfin tuna (*Thunnus albacares*). Analyses for the EPO provided considerable insights into changes in billfish targeting practices (SJH, unpublished data), so if this work is continued in the WCPO region, it should be extended to include billfish.

The analyses have been undertaken at the level of the six regions used in the MULTIFAN-CL stock assessments for bigeye and yellowfin tuna (Langley et al. 2007; 2008) which are provided in Figure 1.

Concentration indices

The most common way to display spatial catch and effort data involves 3-dimension plots, i.e., latitude versus longitude with density of catches given using colours or symbols. This approach allows the reader to determine the areas where catches are taken and identify hotspots. What is more difficult is to visualize how “spread-out” the catch or effort is and how this changes over time. It would be useful to reduce the information presented in one of these plots down to a single index that summarizes key features of the data. These indices could be then compared over time on a single plot rather than by attempting to assimilate information from 40 individual plots.

Here I will describe several graphical and statistical measures of spatial distribution patterns. Each index will measure a different aspect of the catch and effort data. The first two relate to how effort and catch is concentrated while the last describes the extent to which the catch of a species is taken from areas of highest density.

Lorenz curve and Gini index

The Lorenz curve is a graphical technique commonly used in econometrics to describe income inequality (Dagum 1985; Karoly 1992), for example, is wealth even distributed among individuals or is the majority of the wealth possessed by a few.

When a Lorenz curve is applied to survey data it involves ranking strata based on their density and then plotting cumulative biomass versus cumulative area (Myers and Cadigan 1995). Consider an area with *n* strata. Let $\bar{C}_i$ be the mean density of fish in stratum i such that $\bar{C}_1 \geq \bar{C}_2 \geq \ldots \geq \bar{C}_n$. Letting $\hat{P}_i = \left(\frac{A_i}{a}\right)\bar{C}_i$ be the swept-area abundance estimate in stratum i, where A_i is the area within stratum i, and a is the area swept by a unit of effort.

The Lorenz curve is the curve relating cumulative catch (*X*) to cumulative area (*Y*). The polygon that is produced joins the points $(X_h/X_n, Y_h/Y_n,), h = (0,1,2,\ldots,n)$ where $Y_0 = 0$ and $Y_h = \sum_{i=1}^{h} P_i$ is the area of h strata with the lowest catch, and $X_0 = 0$ and $X_h = \sum_{i=1}^{h} P_i$ is the catch of h strata with the lowest catch.

It is be possible to use this same approach with the CPUE estimates of strata density, but the number of squares fished changes from year to year so it is unlikely that any measures would provide information on the distribution of the species. Instead, I will focus on the distribution of catch across the WCPO. Here our strata are all of identical size aside (ignoring the small number of squares that contain land and impact of higher latitudes) so we rank squares in descending order of catches (or effort) and then plot cumulative catches (or effort) versus the number of squares that the catches came from.

If the density of fish was the same across all strata, i.e., the fish were uniformly distributed, the Lorenz curve would be a straight line from the origin to (100,100) and would be the identity function (Myers and Cadigan 1995).

The Lorenz curve alone does not provide a reductionist view of the data, rather we still require a single plot for every year. The Gini coefficient (G) is commonly used to summarise the information presented by the Lorenz curve (David 1985; Myers and Cadigan 1995). The Gini coefficient is defines as twice the area between the identity function (the straight line from the origin to (100,100)) and the Lorenz curve. This is expressed using the notation used in the previous section as,

$$G = 1 - \sum_{i=1}^{n}(X_i - X_{i-1})(Y_i + Y_{i-1}),$$

where higher values of g indicate higher concentration of abundance / catches / effort in a small part of the area. The index is dimensionless, i.e., its calculation does not depend on the absolute value of catch.

A value of one indicates that catches (or effort) were uniformly distributed over the area, whereas smaller values indicate that catches were concentrated in a subregions of the overall areas fished.

I will examine trends in the Gini index for catch over time. It is also possible to investigate how this index changes with total catch and effort, but these results and Lorenz curves have not been reported here due to space constraints, but could be included in future work.

D_x indices

A plot such as the Lorenz curve is commonly associated with"90% /10%" statements, e.g., "90% of the catch was taken by 10% of anglers". Swain and Sinclair (1994) used the area inhabited by *x*% of the population as an indicator of population distribution. D_x for any x can be calculated from the Lorenz curve using linear interpolation. Swain and Sinclair (1994) showed that this index could be plotted against total abundance to determine if when abundance increased it occurred uniformly over all areas or higher in so-called preferred areas – uniform versus non-uniform increases in abundance. I have not included these indices in this paper at this stage due to space constraints, but if further work in this area is considered then the approach will be revisited in the future.

Gulland's indices of density and concentration

Gulland (1956) developed two simple density indices and a single concentration index to be applied to catch and effort data, and subsequently Griffiths (1960) applied these to data from tuna fisheries. Gulland's concentration index has a different interpretation than the two indices previously described, rather it describes the ability of the fleet to take catches from the areas of highest density. These indices were later applied by Calkins (1961) and Calkins (1963) to skipjack and yellowfin tuna catches by both purse seiners and pole and line vessels. This approach has received little attention since this early work but will be examined here.

The two indices developed by Gulland were called the weighted and un-weighted indices. The un-weighted index, I_u, was simply the total catch divided by total effort

$$I_u = \sum_{i=1}^{N} y_i / \sum_{i=1}^{N} e_i$$

where $y_i$is the catch in the ith strata (e.g., 5x5 degree square), e_i is the effort in the ith strata, and *N* is the number of exploited strata.

For the weighted index each strata gets equal weight regardless of the effort. The index is the average strata density

$$I_w = \sum_{i=1}^{N} (y_i/e_i)/N \, .$$

From these two indices we can calculate an index of concentration:

$$I_c = I_u / I_w = \left[\sum_{i=1}^{N} y_i \bigg/ \sum_{i=1}^{N} e_i \right] \bigg/ \left[\sum_{i=1}^{N} (y_i/e_i)/N \right]$$

which is a measure of the extent to which the fleet has concentrated fishing effort on higher than average densities of fish (i.e., they expend more effort in areas where they obtain higher catch rates).

When the index is greater than one, more of the fishing <u>in that year</u> occurred in areas of higher than average catch rates. Thus, the index reflects some aspects of targeting <u>within a year</u>, for example, Calkins (1963) used this approach to show that purse-seiners were expending more effort in the areas of high yellowfin density rather than the areas of high skipjack density. The index might also indicate areas of co-occurrence, e.g. other species that are found in high densities in the same area as the target species. As this index only considers CPUE within a year, it does not provide any insights into potential increases in efficiency or effort creep. However, trends over time in the index can provide insights into changes in targeting practices and the potential for hyperstability or hyper-depletion in CPUE (e.g. for changes in CPUE to not be proportional to changes in abundance).

3. Results and discussion

Plots of catch, effort, and CPUE for the three fleets and species are provided in the Appendix.

The Japanese fleet is the longest standing fleet in the region operating from the early 1950s. In all regions, except region 6, there was a rapid increase in the numbers of squares fished and for almost all regions there has been a continual decrease in the number of squares fished over time, consistent with reductions in effort (Figure 2). As the fishery expanded the catch became more concentrated (i.e. the Gini coefficient declined) suggesting that fishing was in an exploratory phase and not all new areas fished yielded good catches. Then as the distribution of effort (number of squares fished) declined over recent years this has been associated with an increase in the Gini coefficient indicating that catches are more evenly distributed over the areas fished. This suggests that the fleet has improved its understanding of the key areas / seasons to fish and has focussed its effort in these areas as time has gone on. Interpretation of the patterns in region 6 are more complex and are probably due to the very important southern bluefin fishery that operated in that area, but for which we do not have the bluefin catch data. The peak number of squares fished were only exploited for a short time up to 1970 which was followed by a large reduction in the numbers of squares fished.

Most of the effort of the Korean fleet occurs in region 4, with much lesser amounts in regions 3 and 6 (Appendix). The number of squares fished in region 4 rapidly increased during the 1970s and has remained at a constant level since this time (Figure 2). Fishing in region three is far more sporadic and the peak fishing effort in region 6 is about 10 years after the peak in number of squares fished by the Japanese fleet.

There has been dramatic increases in Taiwanese effort in recent years (Appendix). Most of the Taiwanese effort occurs in regions 1 and 3, but there is also significant effort in region 4. This rapid expansion of effort is associated with an exponential increase in the numbers of squares. Little else can be interpreted from these plots.

Trajectories of Gulland's index for the Japanese fleet provide some quite interesting results (Figure 3). In the early part of the period albacore seems to have been the main target species in regions 1 and 2 with bigeye tuna replacing albacore as the key target species over time. Not surprisingly albacore does figure highly in regions 3 and 4 and bigeye tuna appears to be the target in region 4, and both bigeye and yellowfin targeted in region 3. This might suggest that the co-occurrence of yellowfin and bigeye tuna is greater in region 3 than region 4. As noted above, interpretation of patterns for regions 5 and 6 are complicated by the presence of a seasonally important southern bluefin tuna fishery. For region 6 this is clearly shown for the 1970s-1980s where effort is not been directed at the areas of highest catches of either of the three tuna species considered. In more recent years there appears to be more of a focus on albacore in region 5 and bigeye and yellowfin in region 6.

For Korea only region 4 has sufficient data to warrant attempts to interpret trends in Gulland's index and this confirms that bigeye tuna is the principle target species in this fishery and in recent years the fishery has moved their effort away from the areas where higher albacore CPUE was encountered (Figure 4).

For Taiwan it is not clear what species was the focus of their early fishing in region 3, but the fishery seems to have increased its targeting for yellowfin and bigeye tuna in recent years (Figure 5). There are no real discernable trends in other regions.

Future work and conclusions

The types of analyses described in this paper appear to be able to provide insights into the behaviour over time of fishing fleets. These analyses will be important for the interpretation of CPUE data and whether the potential for non-linearity between CPUE and abundance (Harley et al. 2001). This work described here is very preliminary in nature and if the WCPFC-SC considers that further work of this type is warranted then the following should be considered:

- Collaborative analyses with national scientists and others who may have experience of the fisheries
- Expanding the list of species included
- Consider grouping species to consider the multi-species nature of the fisheries
- Incorporate economic information of the relative values of the different species
- Expansion of the number and type of indicators used
- Investigating the potential of analysing the data at finer resolution (e.g. 1x1)

With respect to the first point, similar analyses undertaken for the EPO (SJH, unpublished analysis) benefited enormously from the joint IATTC/Japan reviews of the Japanese fishery that have been undertaken since 1965 (e.g. Suda and Schaefer 1965; Nakano and Bayliff 1992; Uosaki and Bayliff 1999). It is strongly recommended that such work be undertaken for the major longline fleets operating in the WCPO.

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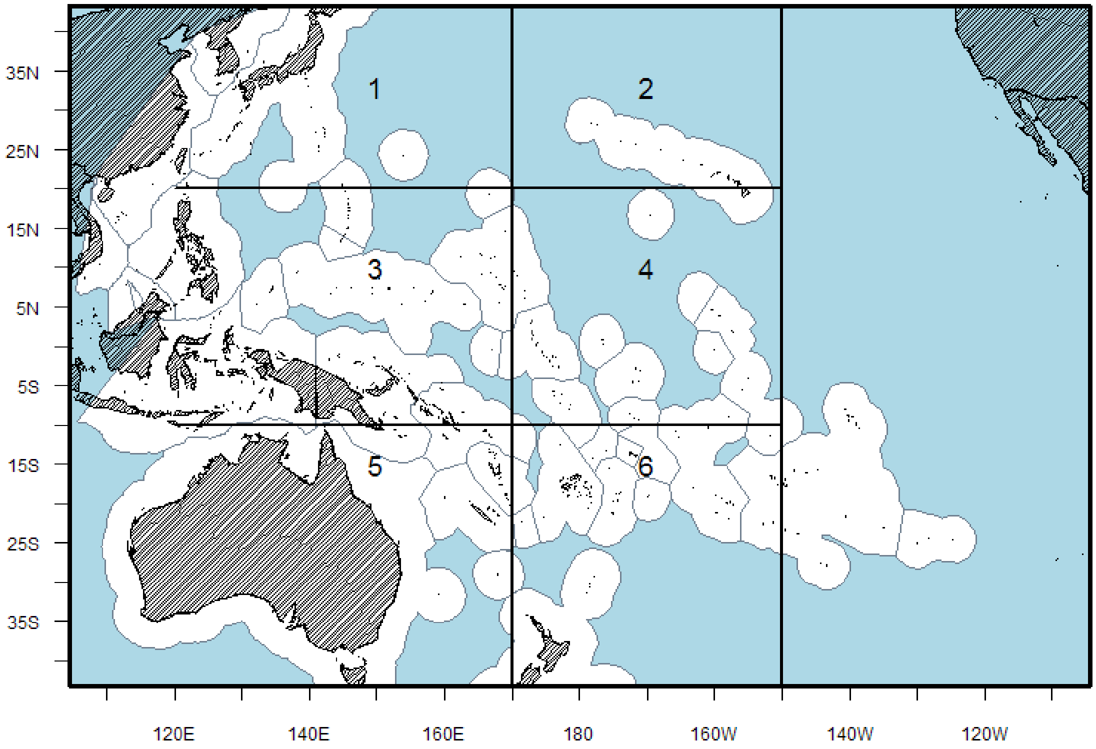


Figure 1: Regions assumed in the analysis. These are the same as those assumed in the current bigeye and yellowfin tuna stock assessments.

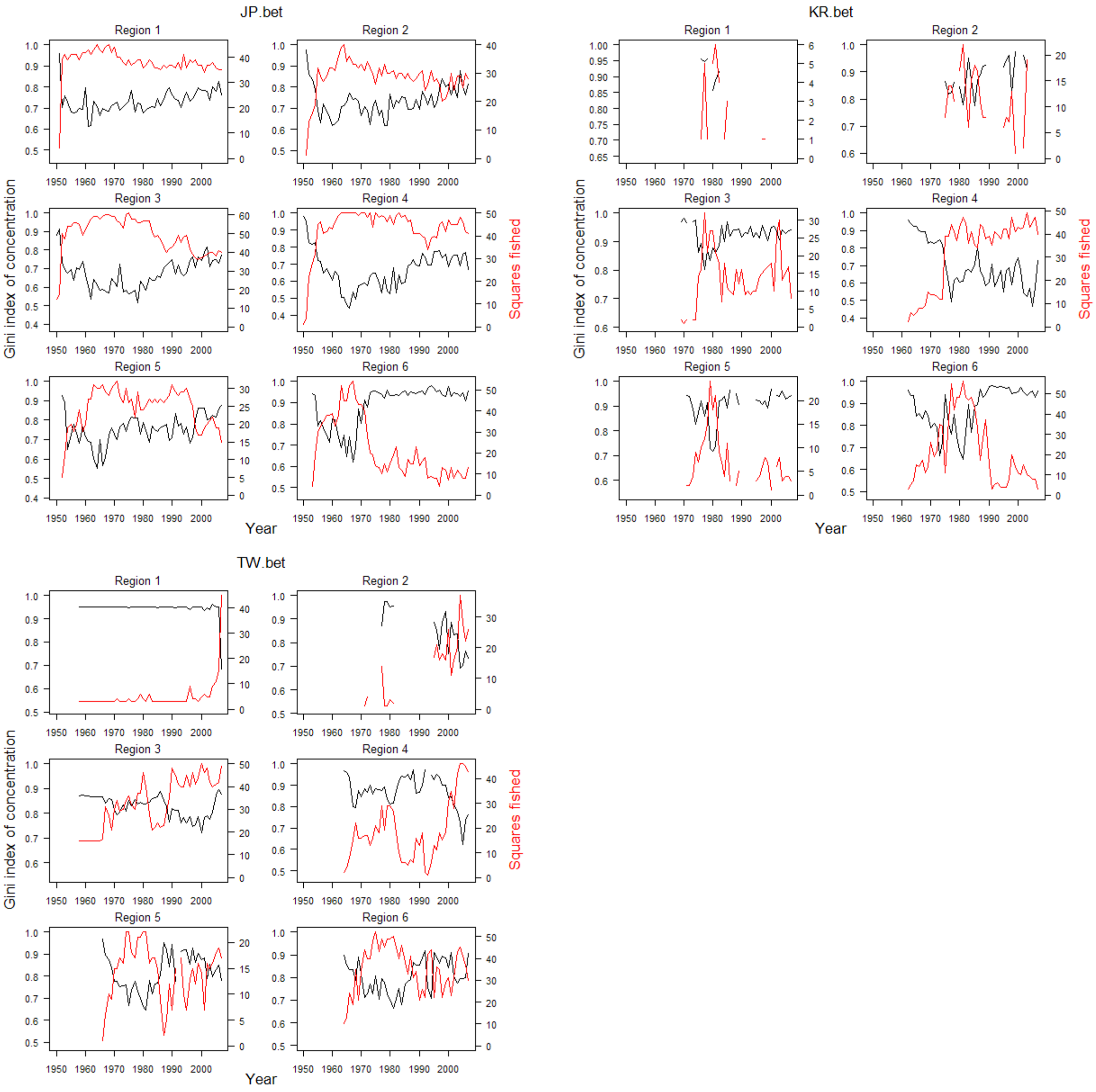


Figure 2: Gini coefficient of concentration for bigeye tuna catch and number of 5x5 degree squares fished by year and region for the Japanese (top left panel), Korean (top right panel), and Taiwanese (lower left panel) distant water longline fleets.

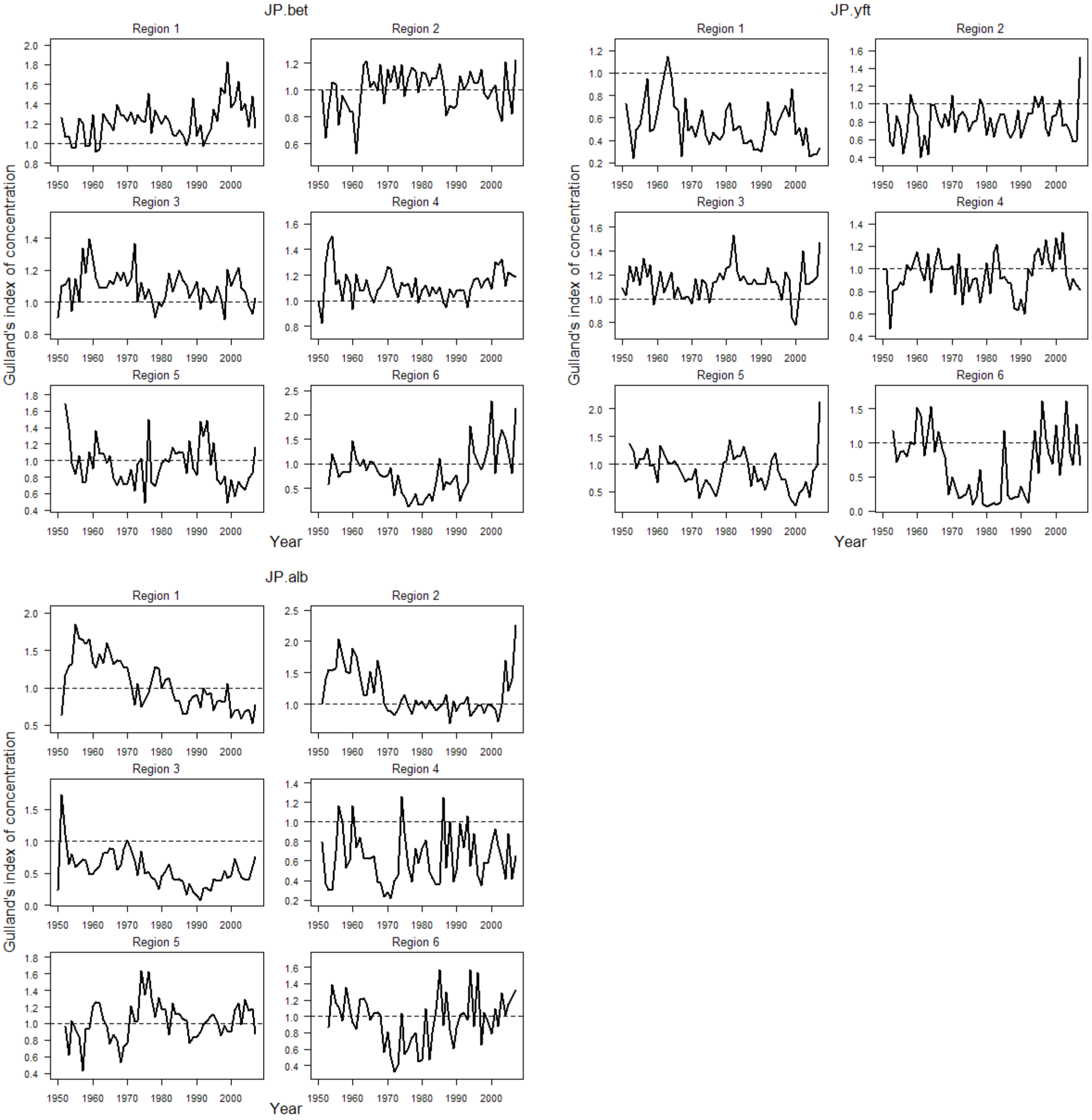


Figure 3: Gulland's index of concentration for the Japanese distant-water longline fleet for bigeye tuna (top left panel), yellowfin tuna (top right panel), and albacore tuna (lower left panel) by region and year.

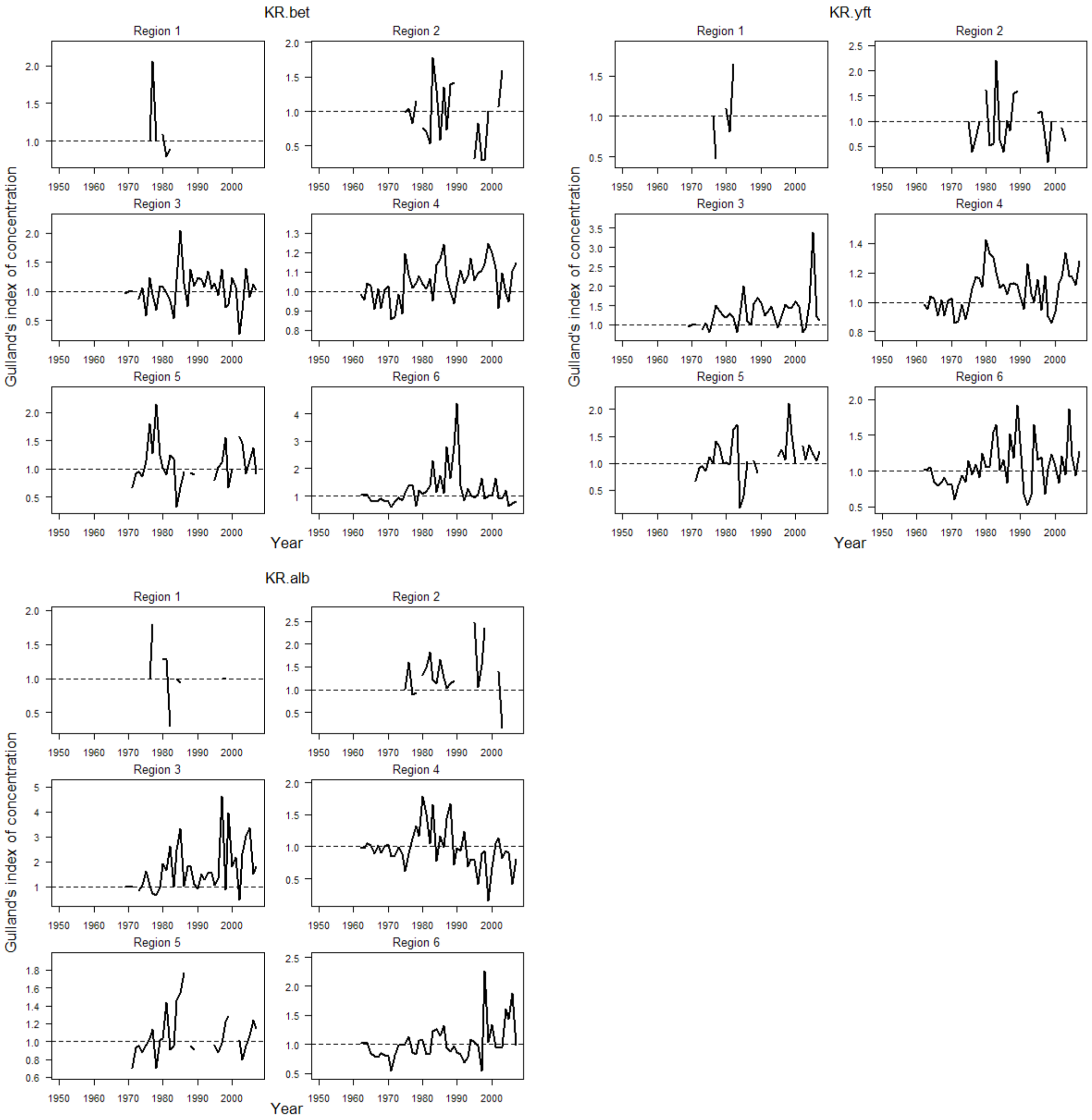


Figure 4: Gulland's index of concentration for the Korean distant-water longline fleet for bigeye tuna (top left panel), yellowfin tuna (top right panel), and albacore tuna (lower left panel) by region and year.

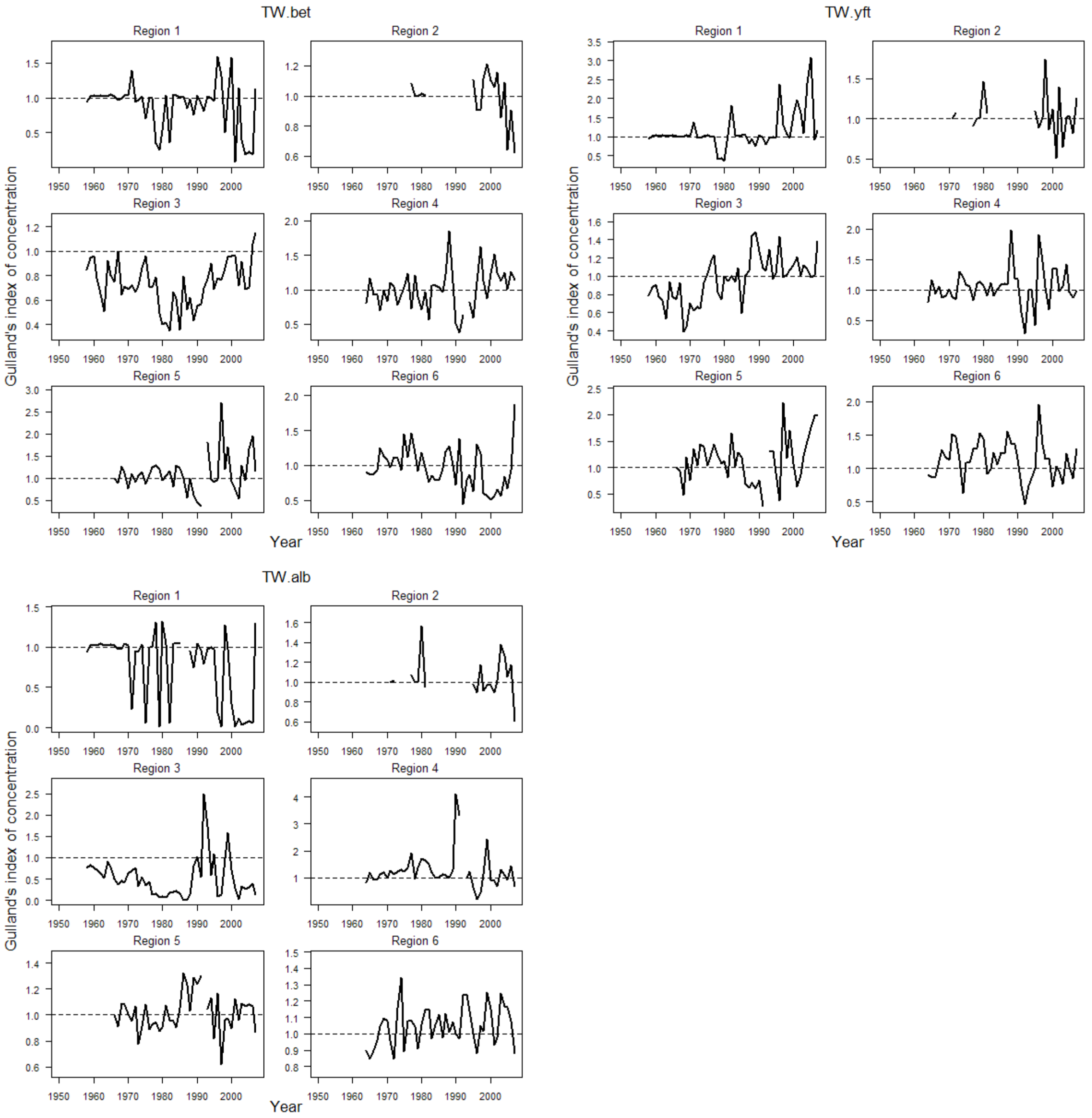
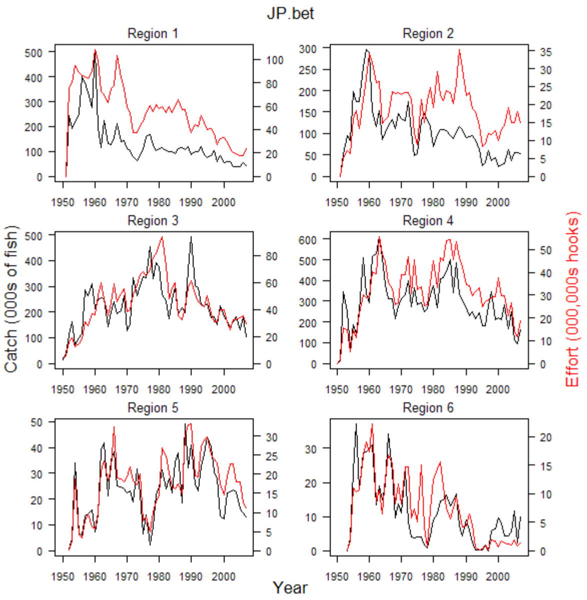
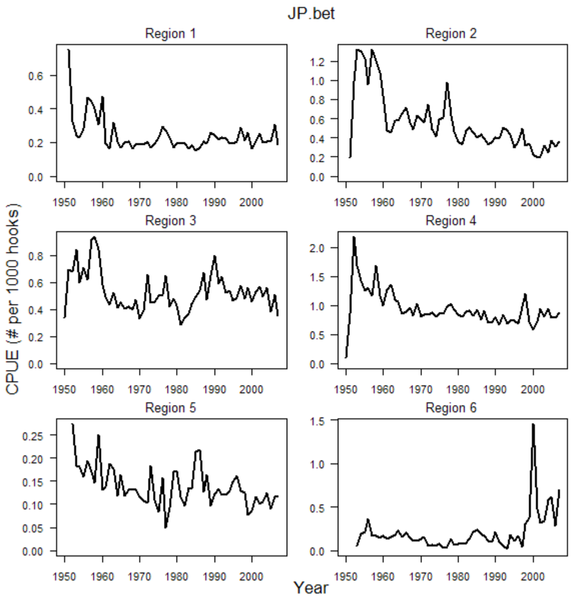


Figure 5: Gulland's index of concentration for the Taiwanese distant-water longline fleet for bigeye tuna (top left panel), yellowfin tuna (top right panel), and albacore tuna (lower left panel) by region and year.

Appendix: catch, effort and CPUE by fleet and region for BET, YFT, and ALB


JP.bet
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
1950 1960 1970 1980 1990 2000
Year


JP.bet
Region 1
Region 2
Region 3
Region 4
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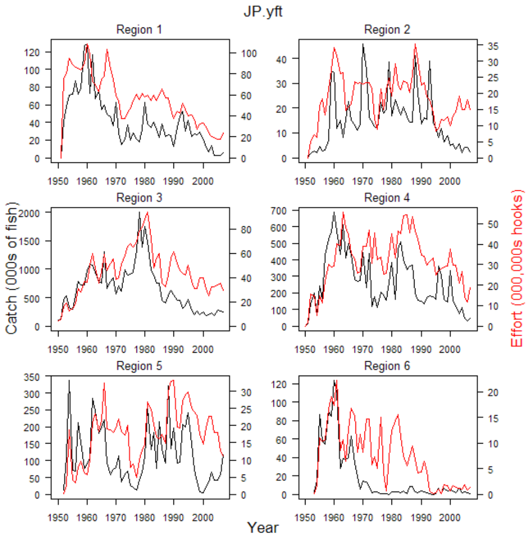
Region 6
CPUE (# per 1000 hooks)
1950 1960 1970 1980 1990 2000
Year


JP.yft
Region 1
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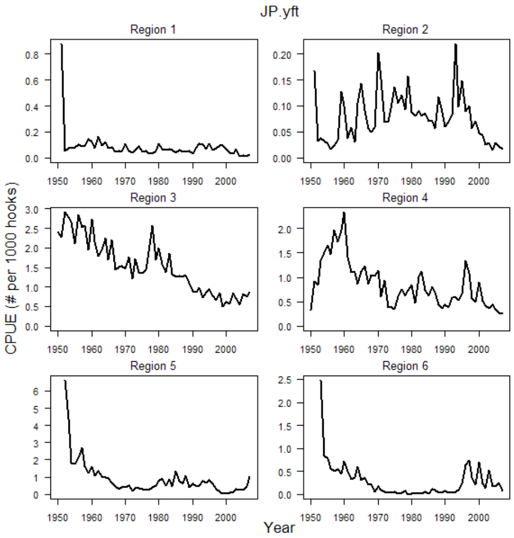
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
1950 1960 1970 1980 1990 2000
Year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CPUE (# per 1000 hooks)
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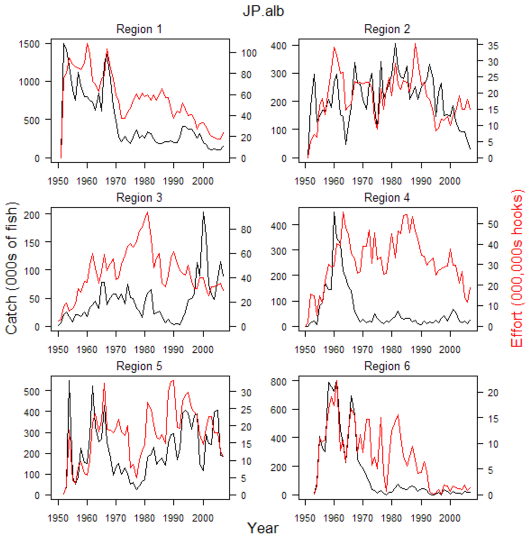
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Catch (000s of fish)
Effort (000,000s hooks)
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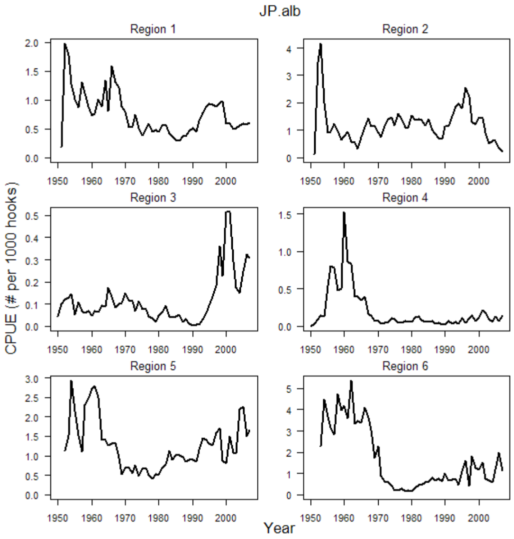
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CPUE (# per 1000 hooks)
1950 1960 1970 1980 1990 2000
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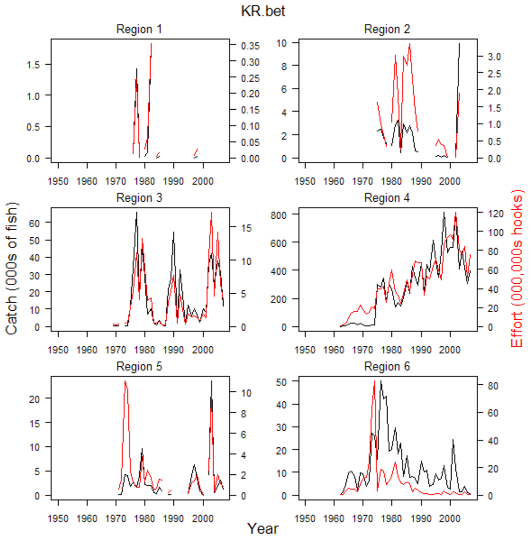
KR.bet
Region 1
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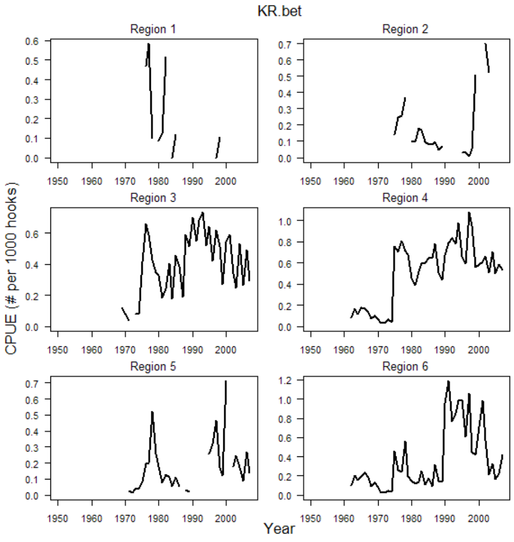
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
1950 1960 1970 1980 1990 2000
Year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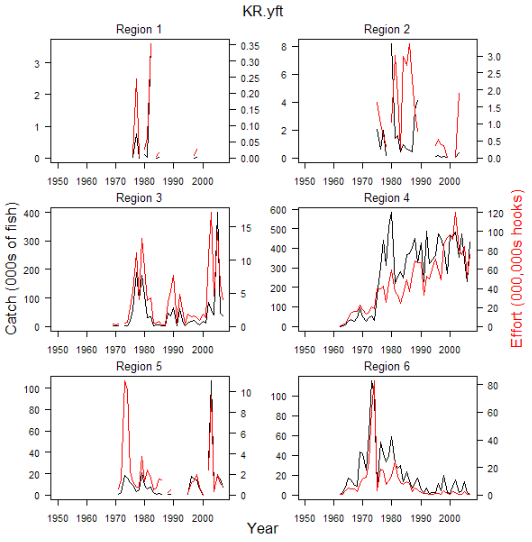
CPUE (# per 1000 hooks)
1950 1960 1970 1980 1990 2000
Year


KR.yft
Region 1
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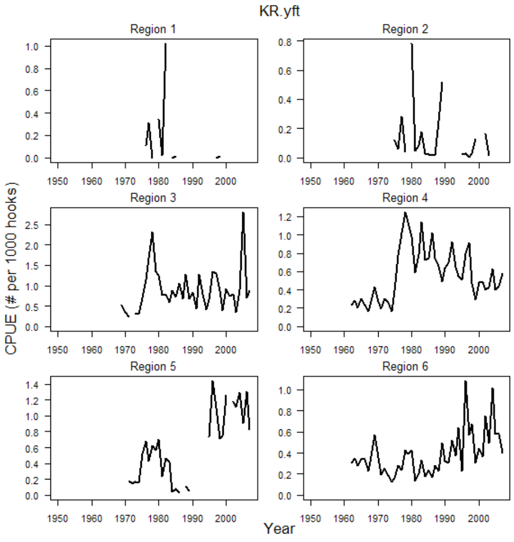
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
1950 1960 1970 1980 1990 2000
Year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Region 1
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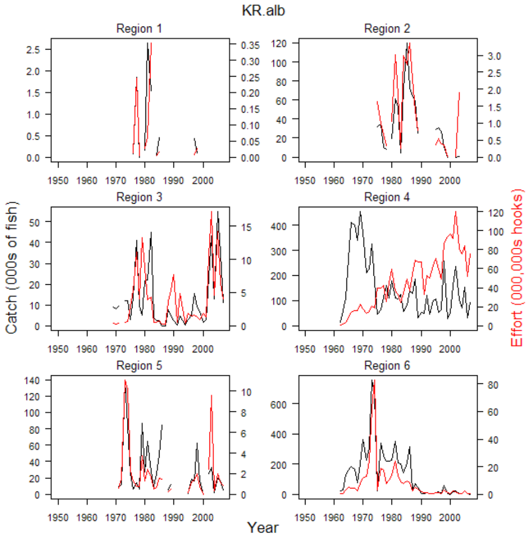
Region 6
CPUE (# per 1000 hooks)
1950 1960 1970 1980 1990 2000
Year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Region 1
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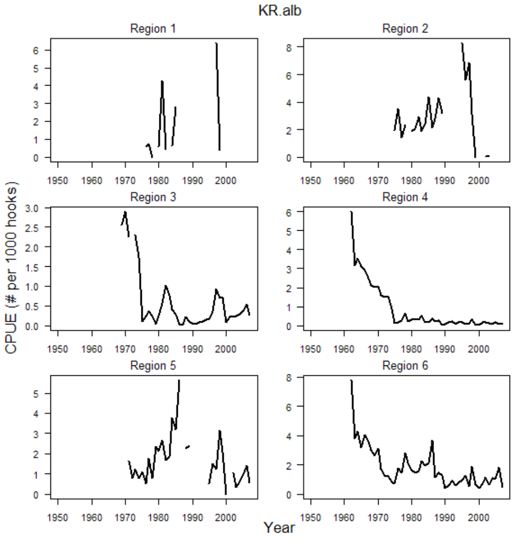
Catch (000s of fish)
Effort (000,000s hooks)
1950 1960 1970 1980 1990 2000
Year


KR.alb
Region 1
Region 2
Region 3
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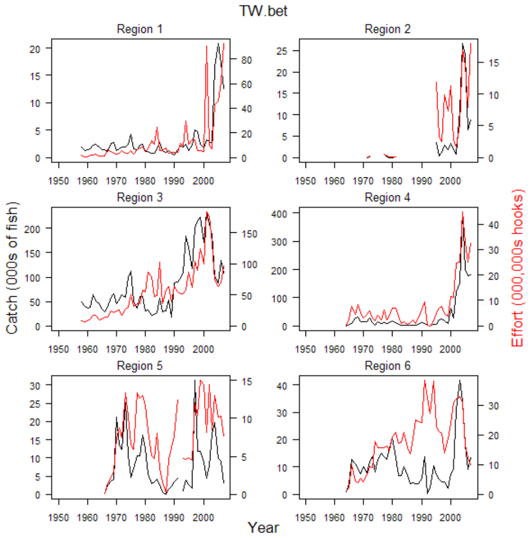
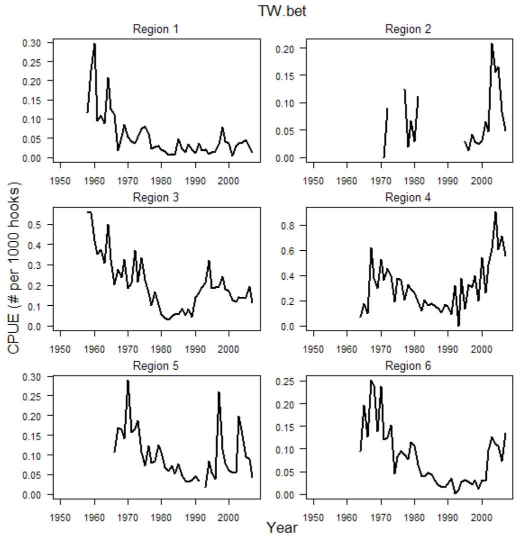
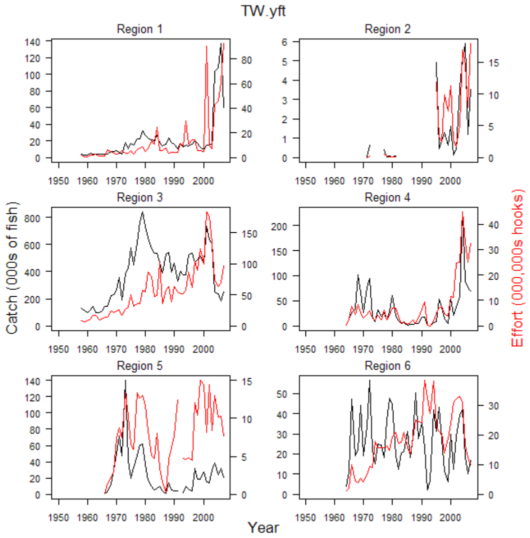
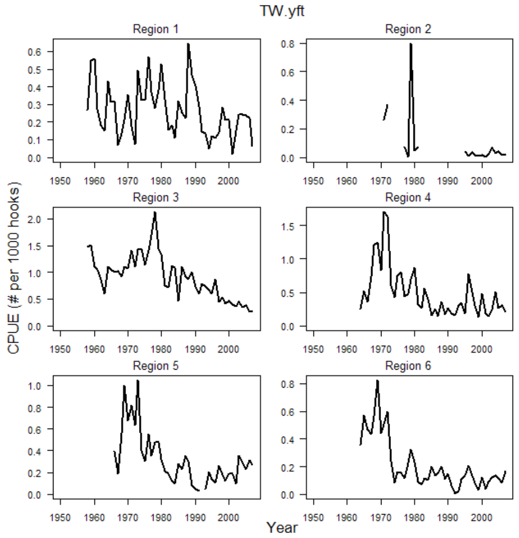
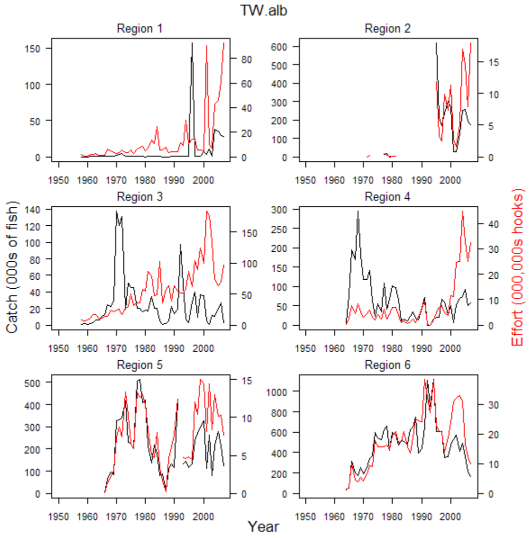
Region 5
Region 6
CPUE (# per 1000 hooks)
1950 1960 1970 1980 1990 2000
Year

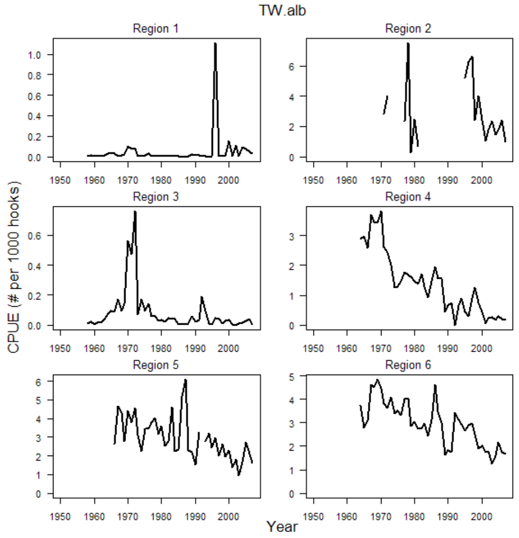

TW.bet
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
Year
1950
1960
1970
1980
1990
2000


TW.bet
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
CPUE (# per 1000 hooks)
Year
1950
1960
1970
1980
1990
2000


TW.yft
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
Year
1950
1960
1970
1980
1990
2000


TW.yft
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
CPUE (# per 1000 hooks)
Year
1950
1960
1970
1980
1990
2000


TW.alb
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Catch (000s of fish)
Effort (000,000s hooks)
Year
1950
1960
1970
1980
1990
2000


TW.alb
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
CPUE (# per 1000 hooks)
Year
1950
1960
1970
1980
1990
2000