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Yellowfin CPUE Standardization for Taiwanese Distant Water Longline Fishery in the WCPO – with Emphasis on Target Change

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Introduction

Taiwanese tuna fisheries have a long history of fishing in the Western and Central Pacific Ocean (WCPO). Currently they employ two main gear types to fish for tuna and tuna-like species in the region, the longline and the purse seine. Records of longline fisheries are available as far back as the 1960s. As the longline fisheries developed, some vessels began to fish in the waters of coastal states of the WCPO in accordance with fishing access agreements. These vessels were termed the ‘offshore longline fishery’ and the rest, which constituted the majority of the effort, was termed the ‘distant-water longline fishery’ (DWLL). The DWLL provides about 45 years of fishing records since 1964.

Albacore, yellowfin and bigeye tunas have been the main species caught, but the approach to targeting has varied through time, as well as spatially. Each species has its main fishing ground: temperate waters in the north and the south Pacific were the major fishing ground for albacore; and tropical waters in the central Pacific have been the major fishing ground for bigeye and yellowfin tunas. In the course of target change, the geographical distribution of efforts and catches of the DWLL changed (Fig. 1).

Historically, DWLL vessels have continuously fishing for southern albacore (Fig. 1), but this is not the case for northern albacore. The southern albacore-targeting vessels (the ALB vessels) also fished for yellowfin in the early stage of the history, and so are more relevant than are the northern albacore vessels to the stock assessment of the WCPO yellowfin resource. Albacore has consistently been the major target species of the DWLL; the annual catch has fluctuated between 15,000 – 25,000 tons (Fig. 2). However, recently targeting of albacore has declined, with a reduction in the number of ALB vessels and shifting of target species to tropical tunas, which currently have higher commercial value.

Yellowfin tuna was a target of the longline fishery in the mid-1960s to mid-1970s for canning. However this targeting decreased because of the canneries' preference for white-meat species such as albacore. Following the development of the bigeye fishery in the tropical areas of the WCPO since 2002, the catch of yellowfin has increased again. However, this increase was mainly due to the increase of fishing activities by bigeye-targeting vessels (BET vessels), not necessary the increase of yellowfin fishing activities. On the other hand, bigeye tuna was mainly a bycatch when yellowfin was a target in the early stage of the longline history. The catch was low until the development of bigeye fishery in WCPO around 2002.

This target change was accompanied by many adaptations in the fishery, such as changes of fishing ground/season and fishing gear (e.g., number of hooks per basket). As may be expected, these changes affected the CPUE (catch per unit effort), and must be taken into account when using CPUE to develop an abundance index. A simple example is that the increase of targeting activities on bigeye increased the bigeye CPUE after 2002, but it should not be inferred that the bigeye stock became abundant.

The effects of target changes on CPUE need to be properly addressed in the CPUE standardization procedure, but it can be difficult to deal with. In the case of WCPO bigeye, many models and assumptions have been applied to standardize the CPUE (such as Su *et al*. 2008), but it has been difficult to fully remove the effects of targeting changes. In the aforementioned example, most of the effect of the targeting change was removed from the index, however the resulted CPUE still increased significantly after 2002, in contrast with the CPUE from the Japanese fleet fishing in the same areas but with more consistent targeting behavior (Langley *et al.* 2008; Hoyle 2009).

In this paper we standardize the WCPO yellowfin tuna CPUE, with emphasis on the treatment of targeting factors. Discussions on inclusion of some other factors are also provided.

Material and methods

The data

Set by set logbook data of Taiwanese DWLL of 1964-2008 were obtained from the Overseas Fisheries Development Council of the ROC, which since 1996 has been commissioned by the Fisheries Agency of Taiwan to process and compile tuna fisheries statistics. These logbook data include vessel identity, fishing position (noon time position at 5°×5° longitude×latitude square level), fishing date, total hooks deployed, catches (in number) of major tunas and billfishes, and information of number of hooks per basket (starting from 1995 when it becomes available). The catch data has undergone a crosscheck process with commercial trading data on a trip-by-trip basis, since the detail commercial trading data became available in 1997. The fishing location information has undergone a similar verification process with VMS data, since 2005 when VMS data became reasonably complete. CPUE was calculated as catch in number per 1,000 hooks. The data of 2007-08 are still preliminary.

This study also references the observer data, which have been collected on DWLL in the Pacific Ocean since 2002, when the program was implemented by the Taiwan Fisheries Agency. Accumulated and average catch composition for ALB vessels and BET vessels were calculated from 49 observation trips from 2002-2008.

The covariates and standardization cases design

Covariates were defined according to the factors that might affect yellowfin CPUE. Catch rate fluctuates in different spatiotemporal strata and so covariates relating to fishing time/area are fundamental to the standardization procedure. Basic covariates defined for this study include year, quarter (Jan.-Mar., Apr.-Jun., Jul.-Sep., and Oct.-Dec.) and statistical region stratification. The 'region stratification' was referred as 'Region' in this study (Fig. 3) and matches the configuration used in the WCPO yellowfin stock assessment (Langley et al 2007, 2009). In principle, R1 and R2 are the north Pacific albacore fishing ground, R3 and R4 are the tropical tuna (bigeye and yellowfin tunas) fishing ground, and R5 and R6 are the south Pacific albacore fishing ground.

This study also performed many exploratory examinations on effects of additional covariates. Altogether the study performed 8 cases of CPUE standardization runs; the covariates included in the models are listed in Table 1. The following remarks describe the additional covariates and relative case runs.

Considering the complexity of the Taiwanese DWLL fleet, target species is the most important factor to be addressed. This factor was addressed from two perspectives: separating the data at the vessel-year level by presumed target, and including a target indicator in the model. For the first aspect, the study used *ad hoc* criteria developed from observer data to separate the data on a vessel*year basis into three 'fleet types'. These fleet types were either included in the model as a covariate (Case-2 to -6, a pair of comparison tests in Case-1 against Case-2), or different types of data were standardized separately (Case-7 and -8).

For the second aspect, four types of target indicators were defined and tested individually within a standardization run (Case-3). The four indicator types were (1) ALB & BET - albacore catch and bigeye catch were included in the model as two categorical variables, after transforming the continuous catch values by comparing them to quantile of the catch of the same year; (2) ALB% & BET% - same as (1) but using of the proportion of the species in the catch, rather than the catch itself; (3) as for (1), but using catch composition of yellowfin tuna; (4) NHPB - treating number of hooks per basket as a covariate in the model. These indictor types have been applied or discussed in the CPUE standardization works for other stocks in the past (Ortiz et al., 2000; Takeuchi and Yokawa, 2000; Mejuto et al., 2001; Hoey et al., 2003; Chang and Wang, 2004; Wang et al., 2005; Wang et al., 2006; Chang et al., 2007; Liu et al., 2007; Chang et al., 2008; Hsu, 2008; Mejuto et al., 2008; Su et al., 2008)

It is common in the scientific meetings of tuna RFMOs of the Atlantic and Indian Oceans (i.e., ICCAT and IOTC) and many other research works (Yokawa et al., 2001; Chang, 2003; Chang and Wang, 2004; Ortiz and Arocha, 2004; Wang et al., 2006; Chang et al., 2007; Liu et al., 2007; Chang et al., 2008; Mejuto et al., 2008; Okamoto, 2008) that, although the distribution of a fish stock could be separated into different regions (subareas, such as Fig. 3) according to CPUE or fish size distribution patterns, the ‘region’ factor was included in the model and performed a single standardization analysis. However, in the tuna RFMOs of the Pacific Ocean (i.e., IATTC and WCPFC), standardizations are usually performed separately for each region (therefore no ‘region’ factor in the model) (e.g. Langley et al 2005, Hoyle and Maunder 2005, Hoyle 2009). The effect of single analysis and separate analyses was tested in the study in Case-3 vs. Case-5 and Case-4 vs. Case-6.

It is also common that when regions are defined (a region composed of many 5°×5° longitude×latitude squares, or 5-degree squares), the ‘region’ is treated as a factor in the model, without considering the effect from 5-degree grid position in terms of longitude and latitude (termed as grid effect). However, this grid effect is considered in most of the CPUE standardizations of the Pacific tuna species (e.g. Langley et al, 2005; Hoyle and Maunder, 2005; Hoyle, 2009). This effect was tested in the study in Case-2 vs. Case-4 and Case-5 vs. Case-6.

The basic analytical model used was a generalized linear model (GLM, Kimura, 1981; Maunder and Punt, 2004; Venables and Dichmont, 2004) with a lognormal error assumption which is commonly used to standardize catch and effort data (Maunder and Punt, 2004). Zero catches are usually adjusted by adding a positive constant, while maintaining or achieving normality of the transformed data (Berry, 1987). In this study, 10% of the mean catch rate was added to all nominal CPUEs (Ortiz et al., 2000; Ortiz and Arocha, 2004). However, when dealing with data for bycatch species in which many sets have zero catch, a GLM approach assuming a delta-lognormal model distribution will fit the data better. With this two-step approach, the proportion of positive sets is modeled assuming a binomial error distribution, and the catch rate of the non-zero catch sets is modeled assuming a lognormal error distribution (Lo et al., 1992; Stefánsson, 1996; Rodríguez-Marín et al., 2003; Maunder and Punt, 2004; Ortiz and Arocha, 2004). The standardized index is the product of these model-estimated components. The results from common lognormal assumption and delta-lognormal assumption were examined in Case-7 vs. Case-8.

In the model runs, two-way interactions among the main factors were examined. Normally a step-wise regression procedure is used to determine the set of main factors and interactions that significantly explain the observed variability and then define the final model. This procedure was not performed however, because the study has purposely conducted case comparisons by including specific factor(s) into the model. Therefore, the study determine the factors and interactions based primarily on whether they could explain the variability significantly ($p<0.001$).

Results and Discussion

The significant factors ($p<0.001$) in the final model are shown in Table 1 for the 8 case runs, together with their R^2 and residual distributions. The table also provides percentage of Mean Square (MS) of a factor to overall MS in model for the first two factors. Explanations of the results, comparisons and discussions follow for each case.

Case-1

This is a simple GLM run that forms a basis for later comparisons. The factors included in this model (i.e., year, quarter, region, target and interaction terms) were those commonly used for standardizing Taiwanese distant water CPUE in the other Oceans (Chang et al., 2007; Liu et al., 2007; Chang et al., 2008). Target indicator was catch ratios of bigeye (BET%) and albacore (ALB%), assuming that fishing vessels will make all necessary adjustments to increase the catch composition of their target species. So, for example, for an albacore targeting vessel the albacore catch would normally be higher against the vessel’s overall catch. The continuous catch ratios were grouped into four categories based on quantile of the annual catch ratios by species. From Table 1, the two target factors have explained over 90% of the mean squares, emphasizing the importance of target factor in the model.

The GLM assumes a log-normal error distribution. However, the diagnostic residual plot in Table 1 shows the error distribution did not conform to log-normal assumption and the residuals could be split into two groups. Fig. 4 shows species compositions of the source data that resulted in the two groups of residuals, indicating that the features of the two groups' data are different in species composition. The group-B data has higher albacore composition (95% in average) in the catch, indicating that it comes from the ALB fleet; and the group-A might come from the BET fleet. This suggests that the different features of the two groups' data need to be properly addressed in the model.

Case-2

This case includes fleet type information to address the above concern. The Fisheries Agency has been implementing an observer program in the Pacific Ocean since 2002. From the 49 trips of observer data during 2002-08, it was noted that ALB-targeting vessels fished mainly in the ALB fishing ground (Regions 5 and 6), but sometimes fished in BET fishing ground (Regions 3 and 4) and the proportion of albacore in the catch (ALB%) was different in the two fishing grounds. The observer data showed that the average ALB% of an albacore vessel was 94% in southern albacore fishing ground and 63% in bigeye fishing ground (Fig. 5). On the other hand, for a BET-targeting vessel, the ALB% was less than 20% in the bigeye fishing ground. Based on this information, ad hoc criteria were set to assign each vessel*year a fleet type: fleet type A – annual ALB% of that vessel >95% in albacore fishing ground; fleet type B – annual ALB%>70% in bigeye fishing ground; and, fleet type C – the rest.

The target indicator normally used (ALB%&BET%) has a statistical defect that will be discussed in the following case. For the convenience of comparisons with the remaining cases, the target indicator used in this case was catches of ALB and BET (ALB&BET).

The residual distribution of the Case-2 run, which adds fleet type factor to the Case-1 model, is significantly better than that of Case-1. Fleet type factor has explained 75% of the overall MS.

Case-3

This case is a test of the effect of different target indicators. Albacore and bigeye occupy different depths of the sea. If NHPB can be assumed to represent the depth of the hooks, e.g., larger NHPB indicating hooks set deeper to target bigeye, then NHPB would be a good indicator for target factor. Although this assumption is not always valid, since the depth of hooks is affected by strength of current, weight of line material and many other environmental or technical factors, NHPB has been used for many CPUE standardizations as a target indicator.

The NHPB information of the Taiwanese DWLL is available only since 1995 and the coverage was low in the beginning. For comparing the effects of different target indicators, only the data with NHPB information were used in this case. Table 1 shows that when using catches of ALB and BET (ALB&BET) as an indicator, the residual distribution was more in conformity with the assumed log-normal distribution. However the resulting relative CPUEs did not show differ much among the four indicators (Fig. 6). Although it seems ALB&BET produced flatter trend than that using ALB%&BET% in Fig. 6, the long term trend (using full set of data) shown a different image (Fig. 7).

The response variable in the GLM is natural logarithm transformed CPUE of yellowfin. From a statistical point of view, if the explanatory variable also utilized the information of yellowfin, then the model violates the requirement that the explanatory and response variables should be independent. In this case, ALB%&BET% and YFT% are not appropriate to be target indicators although the results are obviously similar to that of using NHPB in the short time of 1995-2008.

Case-4

This case, comparing to Case-2, includes 5-degree grid factor in the model. In this case, the region factor could not be included, or no standardized year effect could be obtained. The grid factor is confounded with the region factor (region is made up of many grid squares). From Table 1, there was not much improvement by including grid factor in terms of residual distribution and R^2. The standardized relative CPUEs also appeared similar between the two series, except for the early two years (Fig. 8).

The consideration for including this grid factor was that, it is very likely that there is a lot of local (i.e. within region) spatial variation in catch rate, so including this factor helps to account for catch rate changes when fishing effort moves within the region. For example, this factor may be important when hyperstability or hyperdepletion are possible. The underlying concept is that locations have relatively permanent features (bathymetry, oceanography) that affect the local numbers or catch rates of tuna. Interacting the grid effect with time is generally not feasible, since there is rarely enough data to estimate each grid*time parameter. In any case, the stock assessment model assumes a uniform biomass trend within each region, so a single temporal abundance index for each region is an appropriate output from the CPUE standardization.

Including grid factor did not make much difference to the results in this case, in comparison with Case-2, but similar comparisons were also conducted in Case-5 and -6 (discussed later) and the results did show improvements. Therefore, this study recommended including grid factor in the CPUE standardization for wide-range distributed species.

Case-5

All 6 regions were combined as a single run with region factor in previous cases. Starting from this case, the GLM run was performed separately for each region. To make the study concise, only regions 4-6 where most fishing effort is concentrated were considered in this and the following cases.

This case basically is the same as Case-2 except of separate GLM runs for each region. The residual distributions in Table 1 demonstrated that the apparent normal distribution pattern in Case-2 (all regions combined) was not maintained when the regions were separated, particularly for Regions 4 and 6. This result suggested that the combined model may have disguised a mixture of distributions. Comparisons of the CPUE series by region derived from the combined model in Case-2 and from the separate model in this case (not shown here) also shown improvements in that all the outliers in Regions 4-6 (large increases in several years) in Case-2 disappeared in this case. It is very likely that the relationship between response variable (transformed catch rate) and explanatory variables (covariates) are not constant over the entire study regions, which may bias the year effects. Therefore, conducting separate model runs for each region is recommended.

Case-6

This case examines the effect of including the grid factor in separate model runs for each region. Apart from including the grid factor, it is the same as Case-5. Including the grid factor improved the residual distributions and R^2. As expected for region 6 where spatial variation of yellowfin CPUE is high, grid factor has explained 38% of the total variance (13% of the overall MS in Table 1). It further demonstrated that if effort shifts from low catch rate areas to high catch rate areas, then a model without grid factor included will be biased.

Case-7

This case deals with target effect by further separating the data by fleet type and performing independent GLM runs. Although Case-3 shows that using ALB&BET as indicator might be statistically more reasonable and has better performance in the resulting residual distribution, this indicator may be affected by the abundance change of albacore and bigeye tuna through time, which may itself cause bias. The continuous catch values of each species were generally transformed to categories (4 categories) by splitting them at their 'quantiles' (Liu et al., 2007; Chang et al., 2008; Hsu, 2008; Su et al., 2008). There are usually two types of 'quantiles': first, quantiles of the whole series of data, and second, quantiles of the yearly data. Taking bigeye as an example, the first type of quantiles will clearly be affected by the bigeye abundance if the abundance has substantially changed through long time series, i.e., the category will be different in low abundant years and high abundant years even though the vessel is still targeting bigeye. The second type of quantiles may be biased if the proportions of sets targeting each species change. When more vessels are targeting bigeye, more sets that were actually targeting bigeye will be allocated to a non-bigeye-targeting category, and vice versa.

Such proportional catch approaches may also be confounded with changes in the spatial and seasonal distribution of fishing effort. In general, there will be areas with high bigeye catch and low yellowfin catch, and vice versa (negative correlation). On the other hand, there may also be areas with low bigeye and yellowfin catches, and other productive areas with high abundances of both species (positive correlation). Effects in one direction may be more important than effects in the other. Here we are only interested in the yellowfin catch rate, and if vessels use different fishing methods to target one species or another. If vessels are consistently targeting bigeye then including ALB&BET may simply introduce a new source of confounding.

Since the fleet type has been defined and the different targeting fleets separated (and thus target factor has been addressed), this case then performed separate GLM runs for different fleet type x region combinations, without including any additional target factor. Altogether 6 runs were conducted. The residual distributions (Table 1) indicated that the lognormal model distribution assumption was not appropriate for these standardizations, with two modes apparent in residual distributions from the runs for fleet type A data in southern albacore area (Regions 5 and 6). Detailed examination revealed that the left mode consisted of data with zero yellowfin catch, indicating an alternative model should be considered to address this sort of data.

Case-8

This case used delta-lognormal assumption in the model to deal with zero catch data and positive catch data separately. This process successfully addressed the zero catch issue and has improved the residual distribution significantly. In most cases year factor alone or together with grid factors together explained more than 50% of the MS.

Fig. 9 shows the relative CPUE series for each fleet type x region combination. Most fishing efforts have been deployed in Regions 4 and 6 (Figs. 1 and 3) and thus these two regions may provide more information about the stock. Fleet A is the ALB fleet in the southern albacore area. Yellowfin tuna was a bycatch to this fleet, and the CPUE from this fleet data may not be substantially affected by the bigeye or yellowfin targeting effect (a complex of changing gear materials, fishing techniques, skills and so on). Therefore the CPUE of fleet A in Region 6 (panel A, R6 of Fig. 9) was considered more suitable to be used as abundance index.

Fleet type C represents the BET fleet fishing for bigeye or yellowfin tunas. The standardized yellowfin CPUE of fleet C may be informative but, as previous explained, this fleet might be easily affected by the target effect if this effect has not been perfectly addressed. It could be noted in Fig. 9 (panel C, R6) that there is a mode in the last few years for relative CPUE of fleet C in Region 6; and, this mode coincides with the mode in bigeye and yellowfin catch (Fig. 2) implying the possibility of influence by bigeye targeting (which may occur in the northern part of Region 6, Fig. 3).

The CPUE of fleet A in Region 6 could be considered as index of bycatch fleet and the CPUE of fleet type C in Region 4 (panel C, R4) could be considered as index of target fleet. Fluctuations of the two series were not in accord but the long-term trends were almost the same which may suggest the long-term status of the stock is declining.

Fig. 10 provides comparisons of CPUE series from Case-7 (lognormal assumption) and Case-8 (delta lognormal assumption), for the fleet types A and C in Region 6. The trends differ, particularly for fleet type C. The slope of the CPUE trend is a very influential factor in stock assessments. This indicates the importance of using the appropriate distributional assumption.

The standardized TW series estimated for region 6 from the ALB fleet data were substituted into the yellowfin stock assessment, replacing the time series for the

Japanese fleet in region 6. The recruitment and biomass trends (figures 11 and 12) in region 6 are particularly affected, which indicates the significance of the CPUE trends for model results. Trends in other regions are not affected substantially. Movement rates into region 6 drop, and movement rate out of region 6 increase. It is not possible to draw many strong conclusions about the results since the CPUE series was applied to a fishery which tends to select slightly smaller fish than the Taiwanese fishery. Further work should be carried out to separate the Japanese and Taiwanese fleets in the model.

This report provided several examinations and discussions of inclusions of additional covariates. The results indicated that 5-degree grid effect should be considered, and that GLM runs should preferably be conducted separately by region, rather than in a combined model. The most important factor to take into account was targeting, especially for a fishery with complex target species. The study demonstrated the effects of considering different sorts of target indicators but suggested that the best approach is to separate the data by different targeting fleet. The separation approach applied here was based on aggregated information from 49 observer trips data (to avoid influence from singe vessel) from which simple "catch ratio x region" criteria were developed. This approach provided a simple base for separation. However, the separation could be done in a more precise manner in future by using statistical clustering techniques, taking advantage of detailed information from logbook and observer data.

The 6 regions defined here were adopted from WCPFC, based on spatial analyses of yellowfin catch size distributions and catch rate trends (Langley 2006a, 2006b). This regional definition is used in WCPFC stock assessment models, and indices of abundance used in these models must use matching regions. However, this definition was not entirely suitable for standardization of Taiwanese DWLL since it did not split the catch distribution of different species correctly, i.e., the Region 4 should extended at least 5° south to cover all bigeye targeting efforts (Fig. 3). Further examination of the regional definitions may be useful, based on (for example) catches, catch composition, and fish sizes. The effect on standardizations and the stock assessment of different regional definitions may also be examined.

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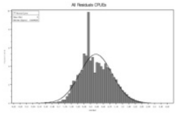
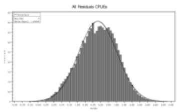
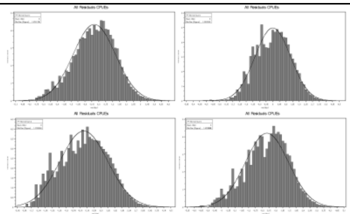
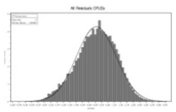
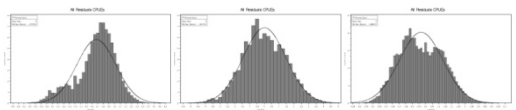
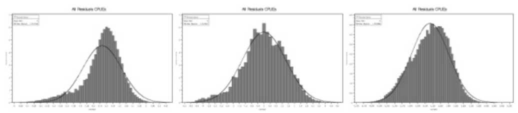
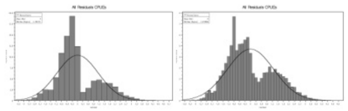
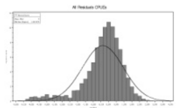
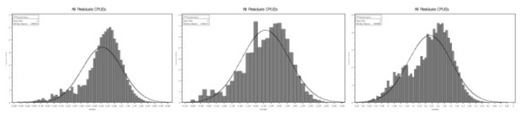
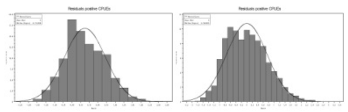
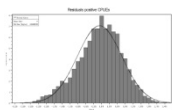
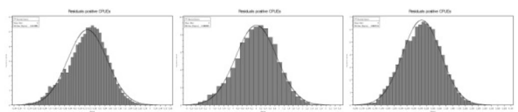
Table 1. Summary of significant factors (p<0.001) in the final GLM (cases 1-7) or GLMM (case 8) models, R^2, and residual plot, by Cases. "(x)" in the table indicates that the factor was not included in the case. The capital word of the factor was used as abbreviation in the 'Interactions'. The percentage of Mean Square of a factor contributed to the whole model was shows in parenthesis for the most important two factors.

	Year	Quarter	Fleet type	Grid[*1]	Region[*2]	Target	Interactions	R^2	Residual distribution (in order of left to right and top to down)
Case-1	Y	Q	(x)	(x)	R1-R6 comb.	ALB%(10%), BET%(84%)	Y*Q, Y*A%, Q*R, Q*A%, Q*B%, R*A%	0.563	
Case-2	Y	Q (6%)	F (75%)	(x)	R1-R6 comb.	ALB, BET	Y*Q, Y*R, Q*A%, Q*B%, R*A%, R*B%	0.404	
Case-3	Y	Q	F	(x)	R1-R6 comb.	ALB&BET, ALB%&BET%, YFT%, NHPB	Y*Q	0.430, 0.564, 0.545, 0.390	
Case-4	Y	Q	F	G	R1-R6 comb. 'Region' not a covariate	ALB, BET	Y*Q, Q*A, Q*B	0.452	
Case-5	Y	Q	F(R4-19%, R5-51%, R6-53%)	(x)	R4, R5, R6 sep.	ALB, BET(R4-45%, R5-27%, R6-32%)	Y*Q, Q*A, Q*B	0.298, 0.431, 0.281	

*1 Grid, 5 degree latitude x longitude factor

*2 'Region' was a factor in the model when R1-R6 were combined (comb.) and was not when regions were separated (sep.).

Table 1. (continued)

	Year	Quarter	Fleet type	Grid*1	Region*2	Target	Interactions	R^2	Residual distribution (in order of left to right and top to down)
Case-6	Y (R4-27%)	Q	F(R4-35%, R5-61%, R6-53%)	G (R5-19%, R6-13%)	R4, R5, R6 sep.	Alb, Bet	Y*Q, Q*A, Q*B, G*A, G*B	0.427, 0.514, 0.425	
Case-7	Y	Q (R6-27%)	F=A	G (R5-33%, R6-36%)	R5, R6 sep.		Y*Q (R5-27%)	0.292, 0.241	
	Y(56%)	Q(22%)	F=B	G	R4		Y*Q	0.366	
	Y (R4-58%, R5-14%)	Q (R6-23%)	F=C	G (R5-69%, R6-53%)	R4, R5, R6 sep.		Y*Q (R4-16%)	0.388, 0.433 0.352	
Case-8	Y (R5-46%, R6-48%)	Q	F=A	G (R5-23%, R6-20%)	R5, R6 sep.		Y*Q	0.431, 0.293	
	Y(47%)	Q(22%)	F=B	G	R4		Y*Q	0.283	
	Y (R4-67%, R5-19%)	Q (R6-42%)	F=C	G (R5-61%, R6-32%)	R4, R5, R6 sep.		Y*Q (R4-14%)	0.442, 0.418, 0.397	

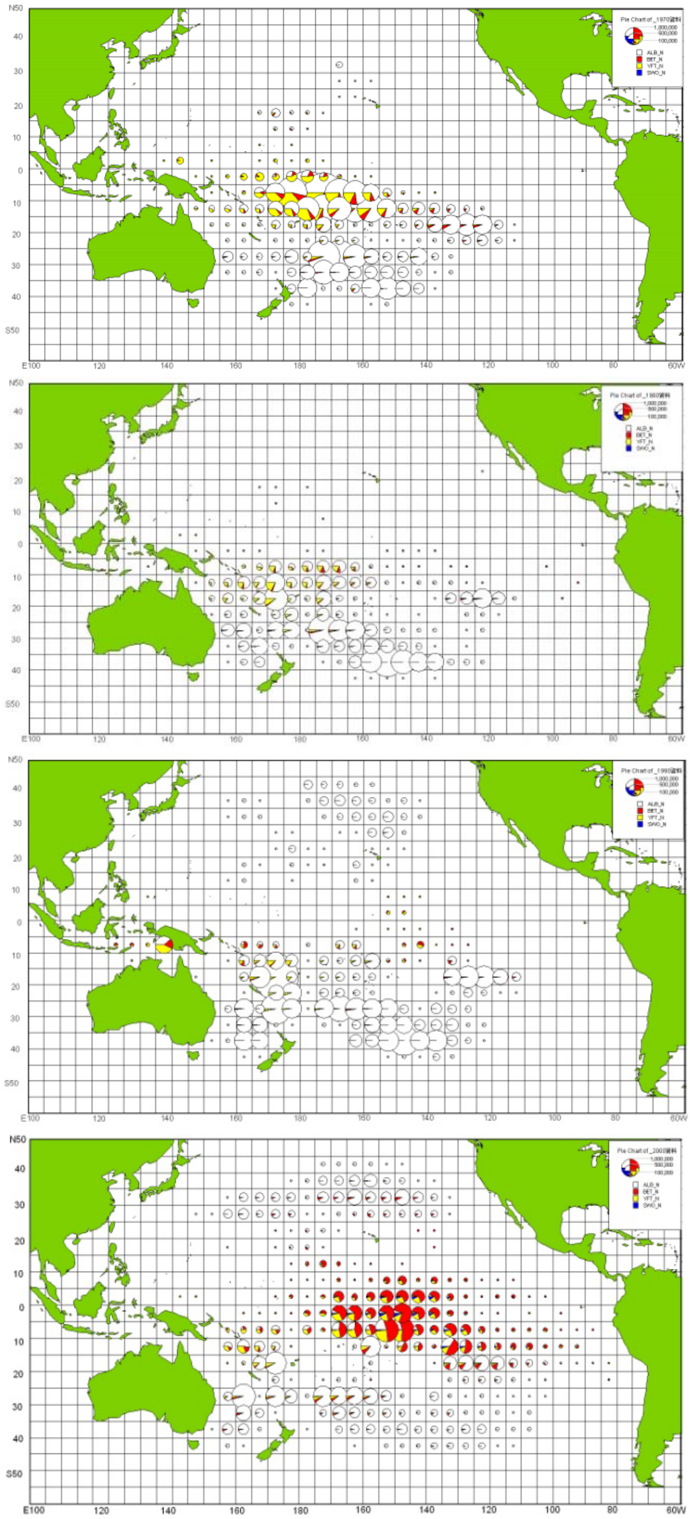


Fig. 1. Distributions of average catch composition of albacore (white color), bigeye (red color), yellowfin (yellow color) tunas and swordfish (blue color), by decades. From top to bottom: 1970s, 1980s, 1990s and 2000-2008. 2008 data is still preliminary.

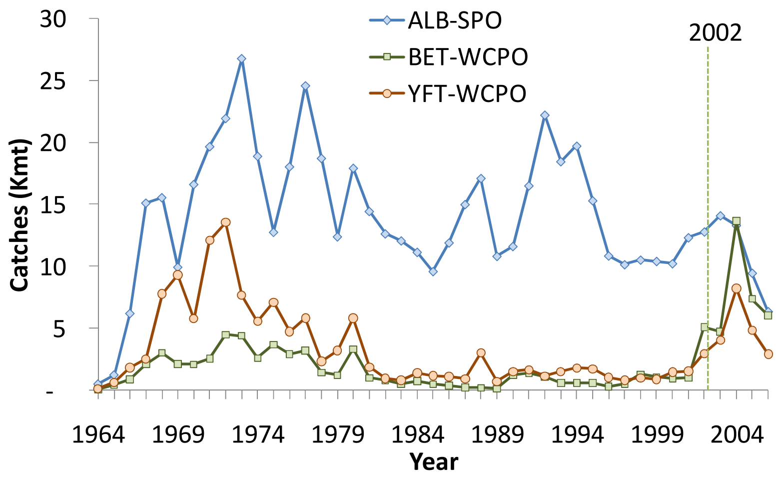


Fig. 2. Annual catch trends of the three major species of Taiwanese distant-water longline fishery in the Western Central Pacific Ocean (WCPO), from 1964 to 2006. ALB-SPO: albacore in the south Pacific Ocean (mainly within the range of WCPO); BET-WCPO, YFT-WCPO: bigeye and yellowfin tunas in the WCPO.

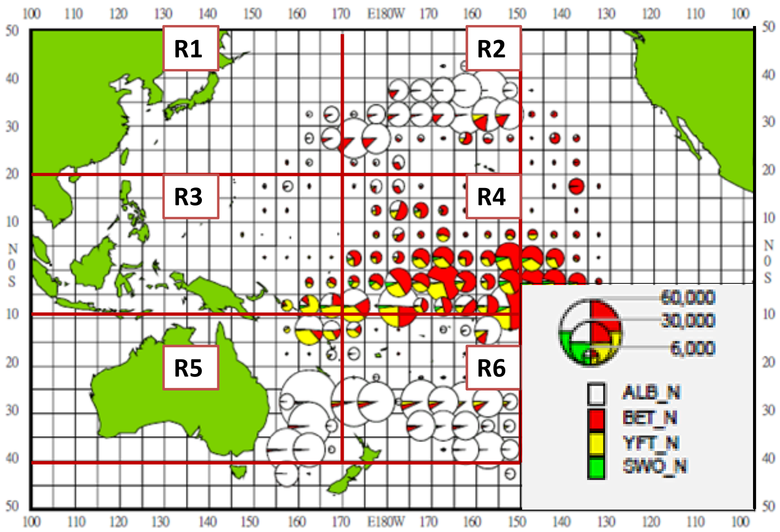


Fig. 3. Region stratification used in the study. The background is catch composition of Taiwanese DWLL in 2005 by the four major species: albacore (ALB), bigeye (BET), yellowfin (YFT) and swordfish (SWO), in terms of catch in number.

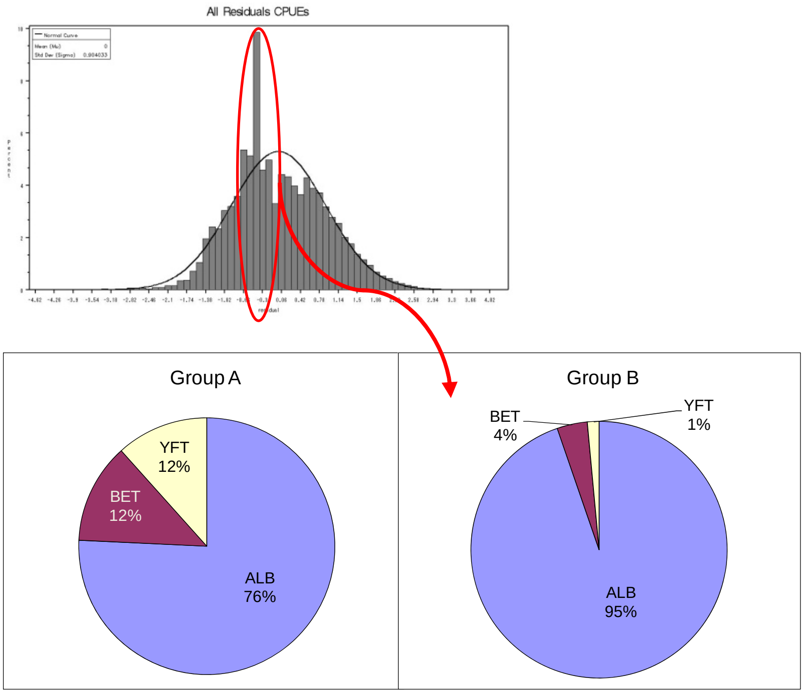


Fig. 4. Residual distribution of the case-1 model (top) and the species composition of the source logbook data that resulted in the two groups residuals (bottom). The circled area of the residual distribution is termed as Group-B and the catch composition of this group data is shown in the right bottom panel.

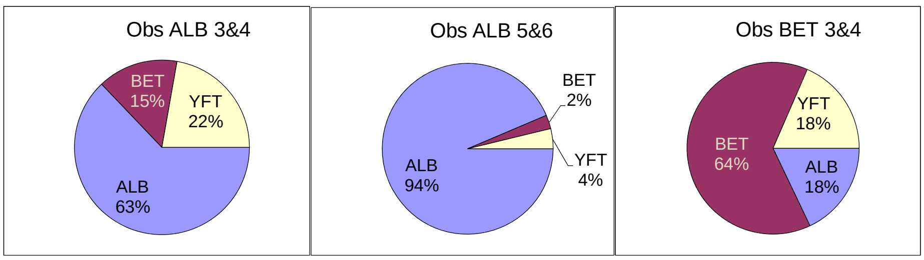


Fig. 5. Catch ratios of albacore (ALB), bigeye (BET), yellowfin (YFT) tunas of albacore targeting vessels in regions 3 and 4 (left), regions 5 and 6 (middle) and bigeye targeting vessels in regions 3 and 4 (right), based on observer data from 2002-2007.

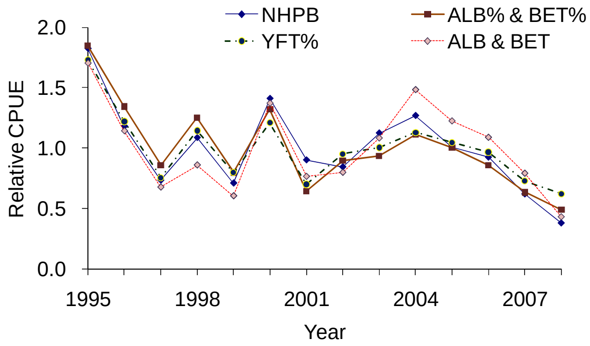


Fig. 6. Relative CPUE series for using different target indicators in the Case-3 run, for period of 1995-2008.

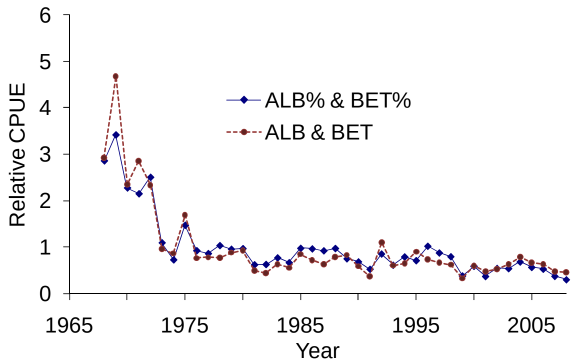


Fig. 7. Relative CPUE series for using catch compositions (ALB%&BET%) and catches (ALB&BET) of albacore and bigeye tuna as indicators, for period of 1968-2008.

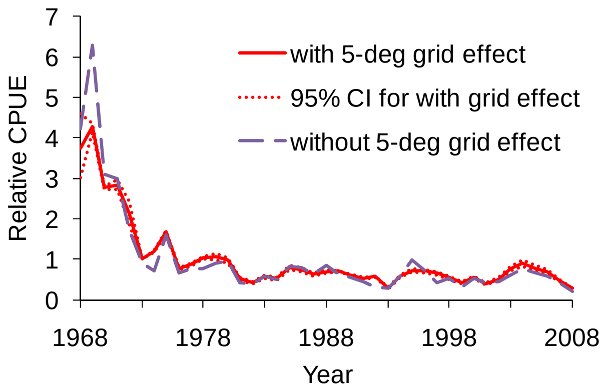


Fig. 8. Relative CPUE series for comparison of the standardization results with and without 5-degree grid factor included for Case-2 and -4.

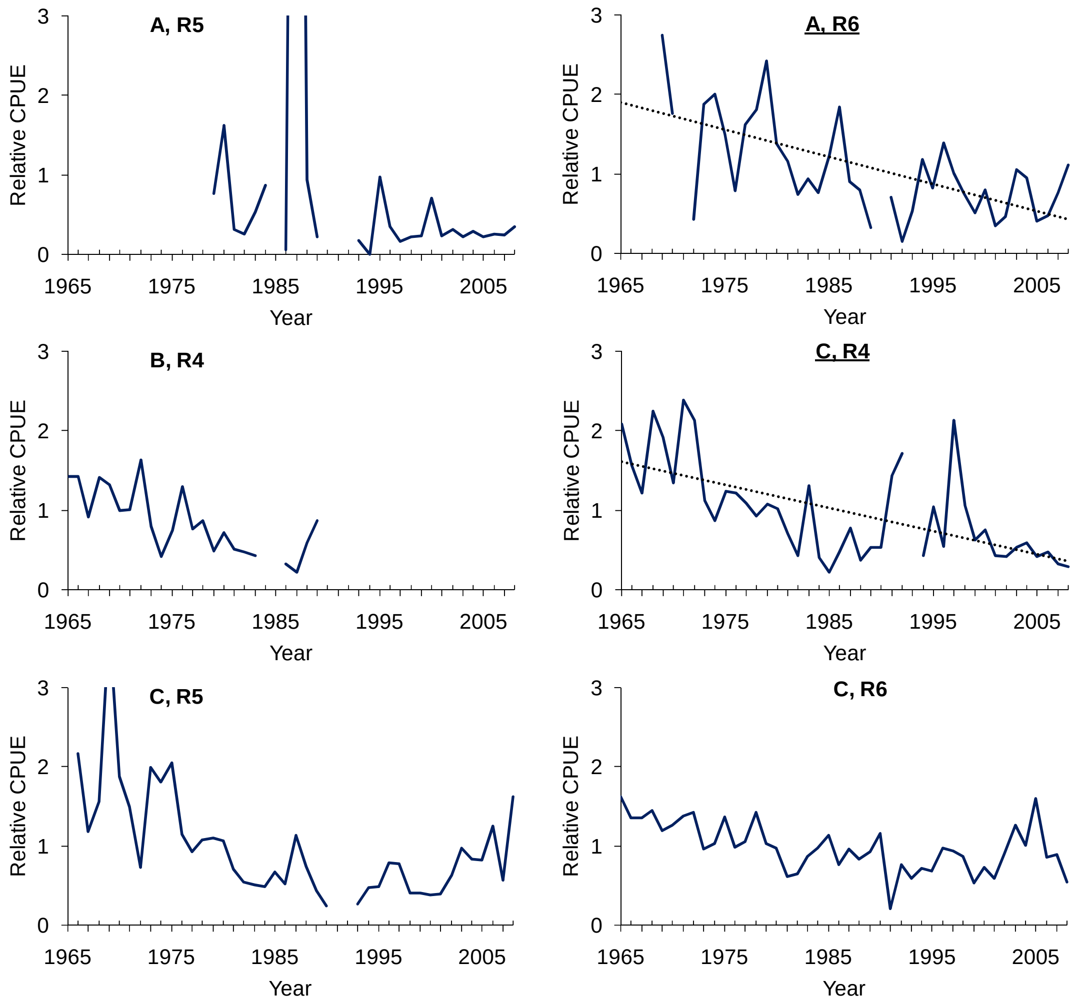


Fig. 9. Relative CPUE series obtained from GLM runs with delta-lognormal model assumption, by region (R4-R6) and by fleet type (A-C), for Case-8. The dashed lines are linear trends of the series.

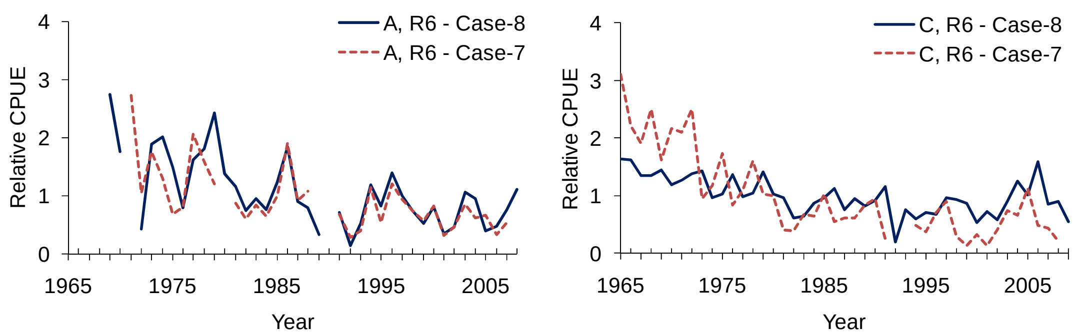


Fig. 10. Comparisons of CPUE series from Case-7 (lognormal assumption) and Case-8 (delta lognormal assumption), for the fleet types A and C in Region 6. (Note: no 2008 estimations are available from Case-7 for both fleet types.)

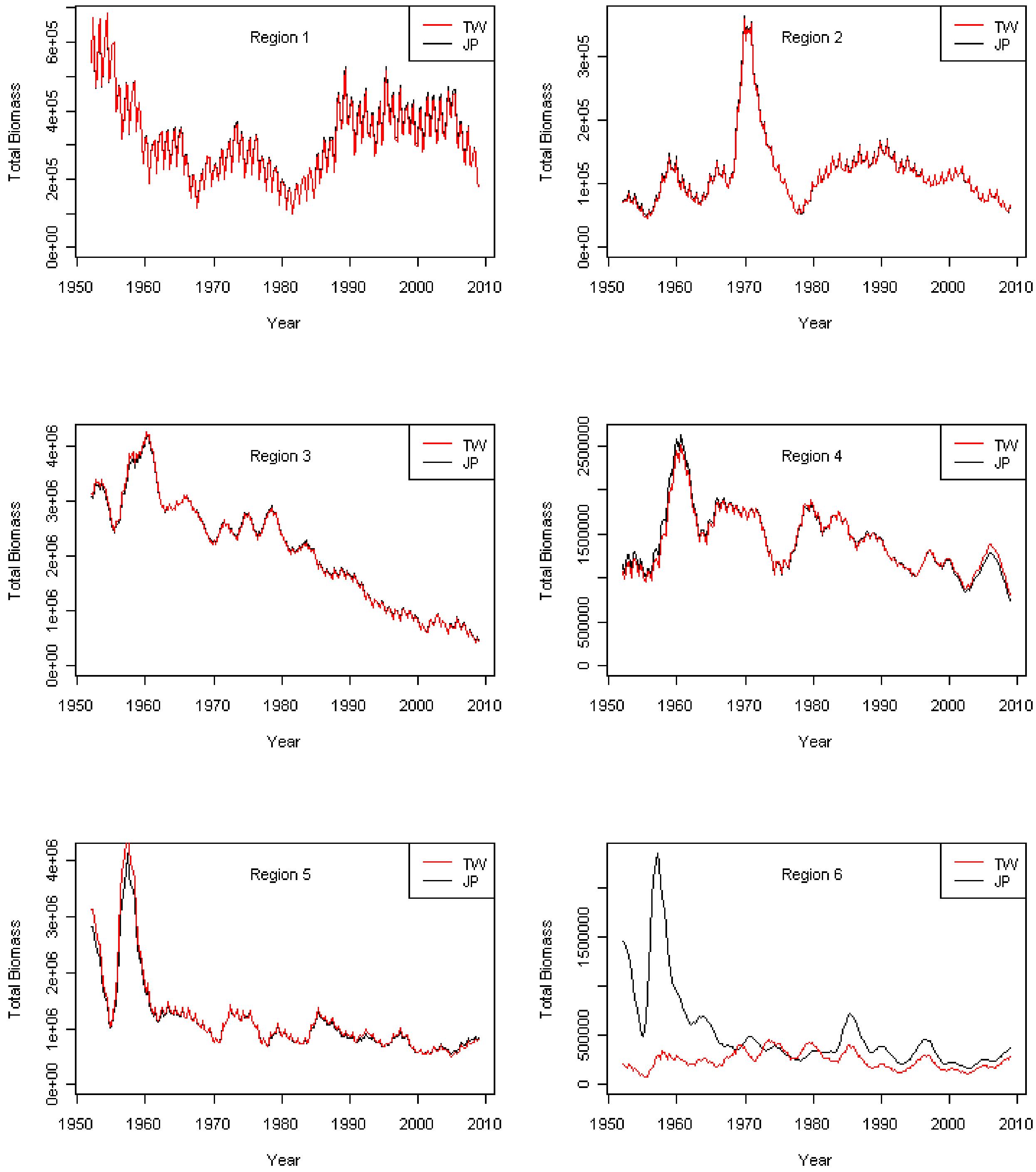


Fig. 11. Estimated total biomass (mt) for the standard stock assessment (CPUE low, sample size high, Qincr) stock assessment model (black) and a version replacing the longline index for region 6 with Taiwanese longline CPUE (red).

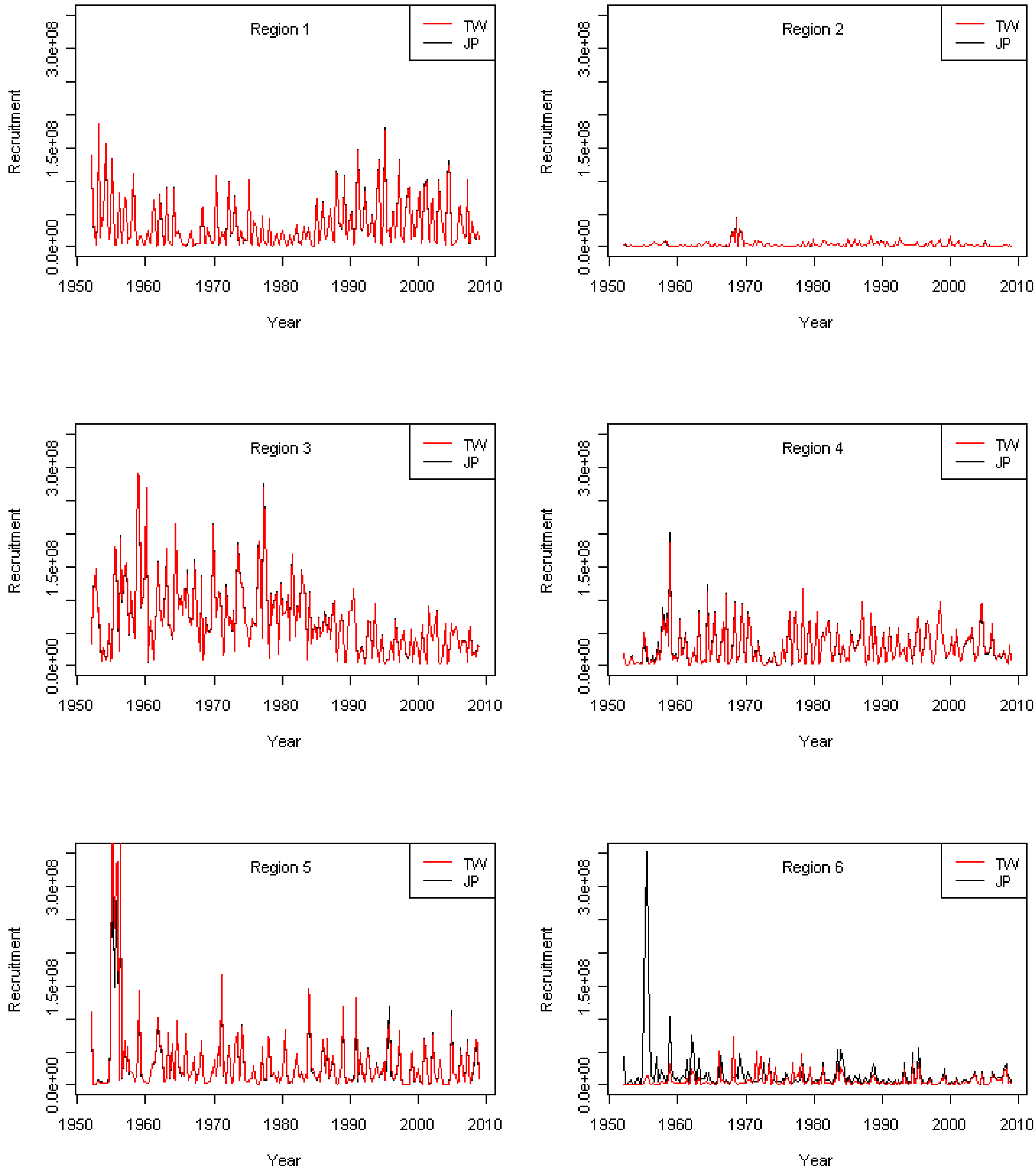


Fig. 12. Estimated quarterly recruitment for the standard stock assessment (CPUE low, sample size high, Qincr) stock assessment model (black) and a version replacing the longline index for region 6 with Taiwanese longline CPUE (red).