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CPUE Standardizations for Yellowfin Tuna Caught by Taiwanese Longline Fishery in the Indian Ocean Using Generalized Linear Model

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1 Introduction

1.1 Historical development of Taiwanese longline fishery in the Indian Ocean

Taiwan began to develop distant water tuna longline fisheries in the mid-60s. Early distant water operations targeted albacore and yellowfin for export to foreign canneries. Until the early 80s, Taiwanese tuna longline fishery expanded the ultra-low freezing technology (ULT) tuna operations. Bigeye and yellowfin are the major species caught by the ULT tuna longliners, while albacore is still a major target species for a large Taiwan fleet in the Indian Ocean longline (Haward & Bergin 2000; Lee & Liu 2000; Hsu et al. 2001)

Yellowfin tuna is among the most primary target species for longline fishing in the open seas operating in the perimeter around Indian Ocean. There was seasonal effort allocated near the Arabian Sea and the Bay of Bengal to target Yellowfin. There was an observable change when Taiwanese longline fishing activities shifted target species from albacore to bigeye. Looking into the history of Yellowfin tuna longline fishing in the Indian Ocean, prior to the late 80s, the average catch recorded at lower than 10,000 mt. However, as a result of a shift of target species from albacore to bigeye, the YFT catch started increasing between 20,000 to 30,000(Chang et al. 2008b) mt. It spiked at an excessive high of 80,000 mt in 1993. However, this number was not maintained; until another significant spike, which was recorded at 60,000 mt 2005 (Fig. 1). In that year, the vessel number of Taiwanese longline fishery is relatively high than other years. Also it is noteworthy that these catches were recorded as coming from fishing activities in the fishing grounds off Pakistan and Oman (Haward & Bergin 2000; Chang et al. 2008b). After 2009, the YFT catch remained around 13,000 mt mainly due to the reduction of fishing effort.

1.2 The yellowfin status in the Indian Ocean

The current status is currently not overfished and overfishing is not occurring. The total stock biomass was above MSY level (290,000-453,000 t) and fishing mortality is just below or near MSY level (0.59 – 0.90). However, estimates of total catches and spawning stock biomass show a marked decrease over the last decade. Annual catches of yellowfin tuna should not exceed the lower range of MSY (300,000 t) in order to ensure the stock is sustainable in the long term (IOTC 2012).

1.3 Summary of the previous CPUE standardizations for Yellowfin Tuna Caught by Taiwanese Longline Fishery in the Indian Ocean

In 2000, Task II data set was used to estimate the standardized CPUE trend for the assumed Western and Eastern yellowfin stocks in the Indian Ocean. Two CPUE series showed similar stable trend since 1980 and suggested maybe the Indian Ocean just have one unit YFT stock (Lee & Liu 2000). In order to understand deeply the similarities and dissimilarities between the two main YFT CPUE series from Taiwan and Japan, Japanese and Taiwanese scientist tried 7 scenarios to consider the effects of oceanography factors and target factor on the YFT CPUE series. The main dissimilarity in the YFT CPUE series is the trend after 1991, Taiwanese case showed significant increasing trend after 1991 and then gradually decline until 2000 to the level of early 1980s while Japanese case showed continuous declining trend after 1991 (Okamoto et al. 2004).

Again, in 2010, comparison with Taiwanese and Japanese CPUE series was made (Nishida & Chang 2010). This study considered the common fishing grounds for Taiwanese and Japanese tuna longline fisheries. The fine spatial resolution logbook data and NHBF information was used in this study. Overall speaking, there were some signals of jumps and bumps only shown in Taiwanese CPUE series.

Consider the issue about the separation of the Taiwanese regular and deep tuna longliners in the Indian Ocean, the criteria of the bigeye tuna catch ratios was developed to fulfill the separation based on the available NHBF information in the logbook data since 1995 (Lee & Nishida 2002; Lee et al. 2005). Other reports used various catch ratio of albacore, yellowfin and bigeye as target proxies in the GLM models (Wang & Wang 2002; Wang et al. 2005; Liu et al. 2007; Chang et al. 2008a; Yeh & Chang 2009; Yeh & Chang 2010). Besides, oceanography factors was included in the GLM model in several reports(Wang et al. 2005; Chang et al. 2008a; Yeh & Chang 2010) .

In the previous studies, a specific rule of data extraction was applied to deal with the violation of the normal distribution shown in the residual of the GLM model. The rule is to exclude the high catch composition with BET>75% and catch of yellowfin recorded as zero or the information is entirely unavailable for YFT or ALB, due to the data coming from specific BET-targeting fishing activities; and yellowfin catch recorded at zero due to incomplete information in the data provided (Chang et al. 2008a; Yeh & Chang 2009).

In order to consider the performance of different analytical methods for CPUE standardization, a sensitivity analysis was carried out to understand the effect of various data sets with various spatial resolution, various data extraction rules, various target proxy based on NHBF information or catch composition and various statistical models on standardized CPUE series (Yeh & Chang 2012). The results showed that the trend was more sensitive to the definition of catch composition as a target proxy more than the interaction factors in the GLM model. And there was a subtle effect of two different proxies on CPUE series except the signal in 2005.

1.4 Purpose of the study

In this study, in order to obtain an updated standardized CPUE series for yellowfin tuna caught by Taiwanese longline fishery, the analytical methods of base case adopted in the previous report were applied on the available updated data set in 2012 (Yeh et al. 2012).

2 Material and Method

2.1 Data set and extraction

In this study, daily set-by-set catch and effort data with 5 degree by 5 degree resolution from the logbooks of Taiwanese longline fishery from 1980-2012 were provided by Overseas Fisheries Development Council (OFDC). In addition, the data on the number of hooks between floats (NHBF) were available since 1995, and the percentage of data with NHBF was about 80% of the total data from 1995 to 2012. To obtain a longer series for yellowfin stock assessment, therefore we use the species composition to be a target proxy to consider the effects of target species shifts issue.

Statistical models of GLM were used to model the logarithm of the nominal CPUE (defined as the number of fish per 1,000 hooks) in this study. The main factors considered in this study are year, season (Jan.-Mar., Apr.-Jun., Jul.-Sep., and Oct.-Dec.), area (Areas 1 to 5), and target. The interactions between the main factors are also included in the model. The information of NHBF or hooks per basket (HPB) is usually used as target proxy in the CPUE standardization models. However, this information was only available from 1995 onwards in the logbooks of Taiwanese longline fishery. Alternative indicators were therefore adopted in the study:

1. Four categories of Bigeye catch composition (catch of Bigeye / catch of Bigeye, Yellowfin and Albacore) defined based on the information of NHBF from observer data (1: <= 25%; 2: 25%-50%; 3: 50%-75% 4: >=75%)

2. Four categories of Albacore catch composition (catch of Albacore / catch of Bigeye, Yellowfin and Albacore) defined based on the information of NHBF from observer data (1: <= 25%; 2: 25%-50%; 3: 50%-75% 4: >=75%).

GLM model: The CPUE is predicted as a linear combination of the explanatory variables. At first, the following form was assumed as a full model.

$$\log(\mathrm{CPUE} + \mathrm{c}) = \quad + \mathrm{Y} + \mathrm{S} + \mathrm{A} + \mathrm{T} + \mathrm{interactions} +$$

,where CPUE is the nominal CPUE of yellowfin tuna,

c is the constant value (10% of the mean of CPUE),

μ is the intercept,

Y is the effect of year,
S is the effect of season,
A is the effect of fishing area,
T is the Target proxy,
Interactions is the interactions between main effects,
is the error term, $\sim \mathrm{N}(0,\ {}^{2})$.

Fishing areas used in this study were redefined by five new areas based on the IOTC statistics areas for yellowfin tuna in the Indian Ocean (Fig. 2):

- Area 1: Arabian Sea;
- Area 2: Western Indian Ocean;
- Area 3: Mozambique Channel;
- Area 4: Southern Indian Ocean and Atlantic-Indian Region;
- Area 5: Bay of Bengal, Eastern Indian, and Java Sea.

2.2 Statistical runs

This study has conducted a set of standardization runs using logbook data, by GLM model. All runs only keep significant factors ($p<0.05$) in the analysis of CPUE by the effective effort. The calculation was done using GLM procedure of SAS (Ver.9. 2). The standardized CPUE were then computed from the least square means (LSMeans) of the estimates of the year effects and quarterly effects.

3 Results and Discussion

Table 1 show the ANOVA tables for the GLM analyses for the whole Indian Ocean and tropical Indian Ocean separately. The model of all runs explained greater than 50% of the variance.

Nominal and standardized CPUEs obtained from GLMs are shown in Fig. 3-6. Before 2007, the annual nominal CPUE was ranged between 2 fish/1000 hooks and 5 fish/1000 hooks in the tropical and whole Indian Ocean. After that, the nominal CPUE continually dropped to the historical lowest CPUE of 1 fish/1000 hooks. And then came back to the level of 2 fish/1000 hooks in 2012. As for the standardized CPUE series, they showed very similar trend with the nominal CPUE except before 1986. There is no updated information for the Area 1 since few fishing activities occurred in this area for 2011 and 2012. Distributions of the standardized residuals for the GLMs are shown in Fig. 7 and Fig. 10. The distributions of the standardized residuals for all cases appear to deviate slightly from normal distribution assumption. The normal probability plots are showed in Fig. 8 and Fig. 11. The qqplots show some extent of divergence for left tail. The residuals against the year effect are shown in Fig. 9 and Fig. 12. There is no obvious signal that the residual variances are heterogeneity.

Table 1. ANOVA table for the annual based CPUE standardization for the whole and tropical Indian Ocean from 1980 to 2012.

Whole Indian Ocean

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	162	561308.3736	3464.8665	5779.62	<.0001
Error	681886	408789.0866	0.5995		
Corrected Total	682048	970097.4601			
	R-Square	Coeff Var	Root MSE	lnbetcpue Mean	
	0.57861	220.6318	0.774272	0.350934	
Source	DF	Type III SS	Mean Square	F-value	P-value
year	32	18807.00729	587.71898	980.35	<.0001
Area	4	5349.00153	1337.25038	2230.62	<.0001
season	3	1126.1623	375.38743	626.17	<.0001
ralb	3	78187.86082	26062.62027	43474.1	<.0001
rbet	3	87194.38047	29064.79349	48481.9	<.0001
year*season	96	8769.46629	91.34861	152.38	<.0001
season*rbet	9	2420.97377	268.99709	448.7	<.0001
Area*rbet	12	2596.84234	216.40353	360.97	<.0001

Tropical Area (Area2 and Area 5)

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	153	277457.994	1813.4509	3318.59	<.0001
Error	463509	253285.6498	0.5465		
Corrected	463662	530743.6438			
	R-Square	Coeff Var	Root MSE	lnbetcpue Mean	
	0.522772	110.7451	0.739224	0.667501	
Source	DF	Type III SS	Mean Square	F-value	P-value
year	32	10767.9595	336.4987	615.79	<.0001
Area	1	858.8493	858.8493	1571.68	<.0001
season	3	479.4707	159.8236	292.47	<.0001
ralb	3	20953.0131	6984.3377	12781.2	<.0001
rbet	3	164744.7933	54914.9311	100494	<.0001
year*season	96	6563.8728	68.3737	125.12	<.0001
Area*season	3	528.3231	176.1077	322.27	<.0001
season*rbet	9	440.0656	48.8962	89.48	<.0001
Area*rbet	3	387.9456	129.3152	236.64	<.0001

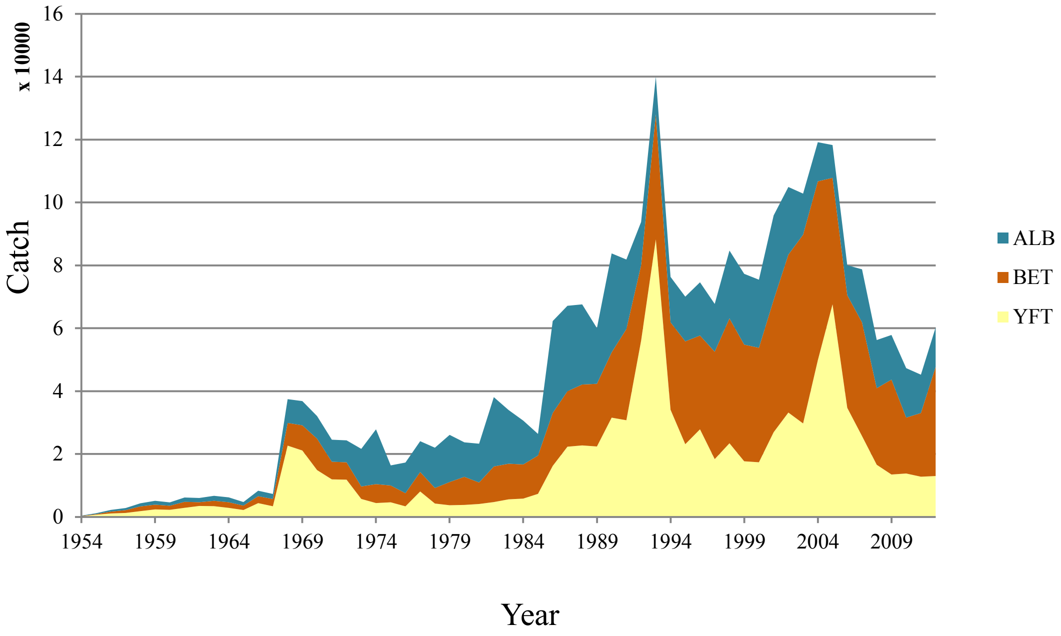

Figure 1. Nominal catches (10,000 mt) of main target species caught by Taiwanese longline fishery in the Indian Ocean over the period 1954 to 2012.

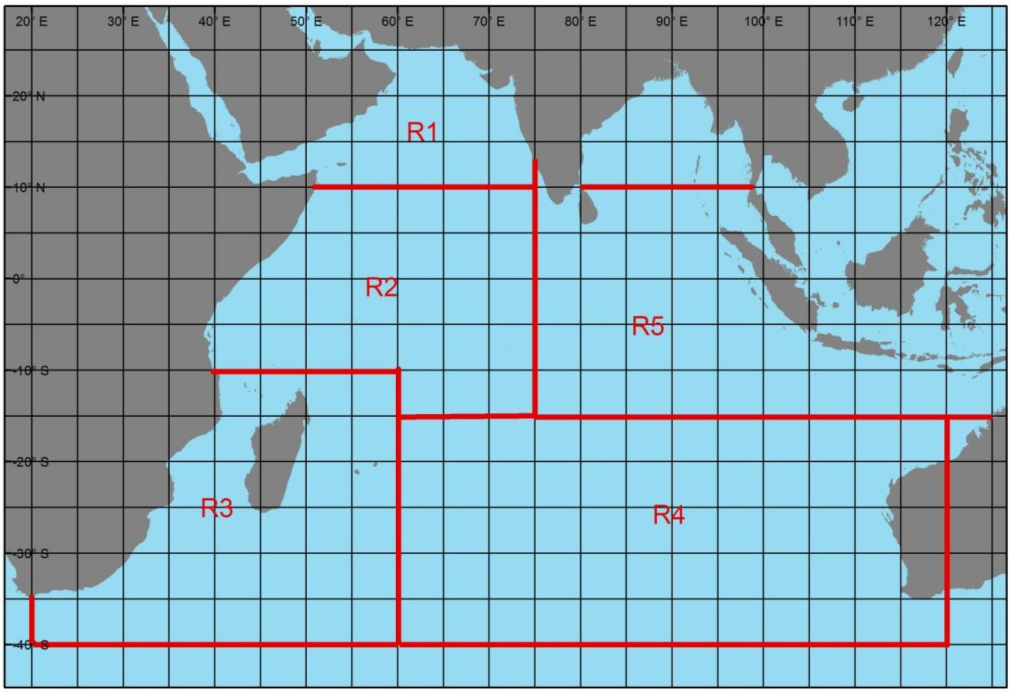

Figure 2. Area stratification used for the standardization of CPUE for yellowfin tuna in the Indian Ocean (Julien provided).

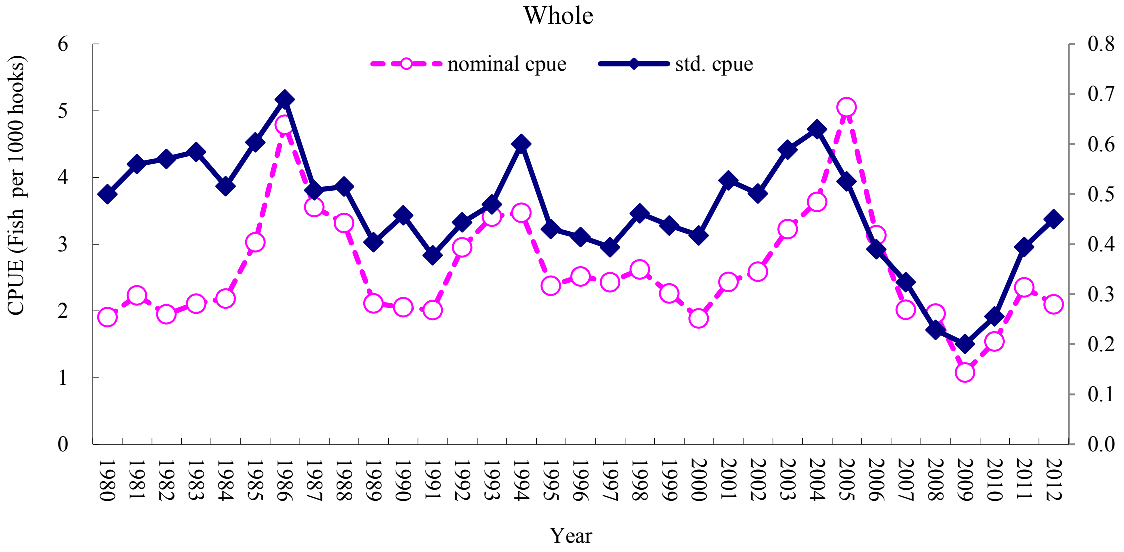

Figure 3. Nominal and Standardized annually CPUE series for Yellowfin in the whole Indian Ocean from 1980 to 2012.

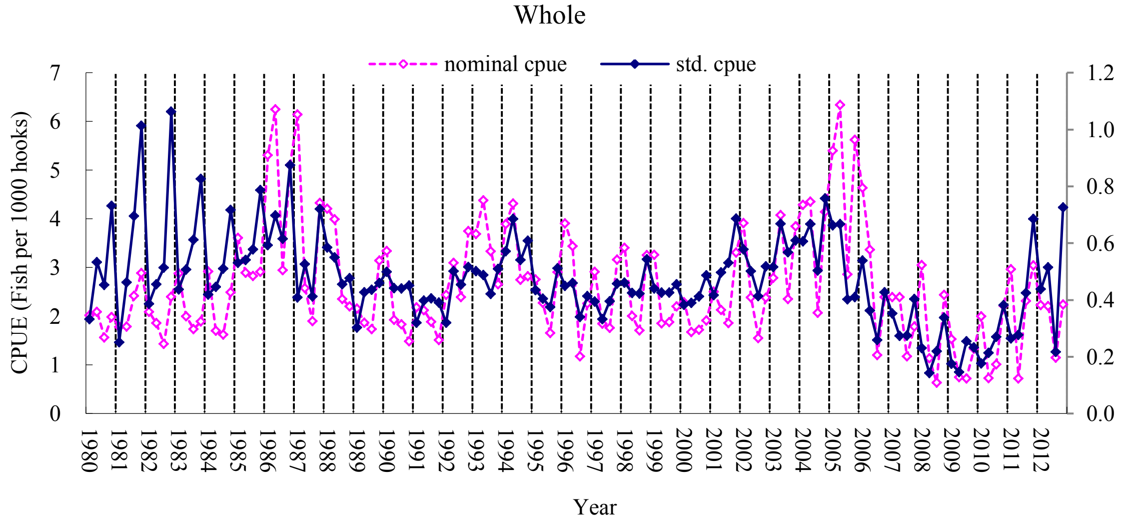

Figure 4. Nominal and Standardized quarterly CPUE series for Yellowfin in the whole Indian Ocean from 1980 to 2012.

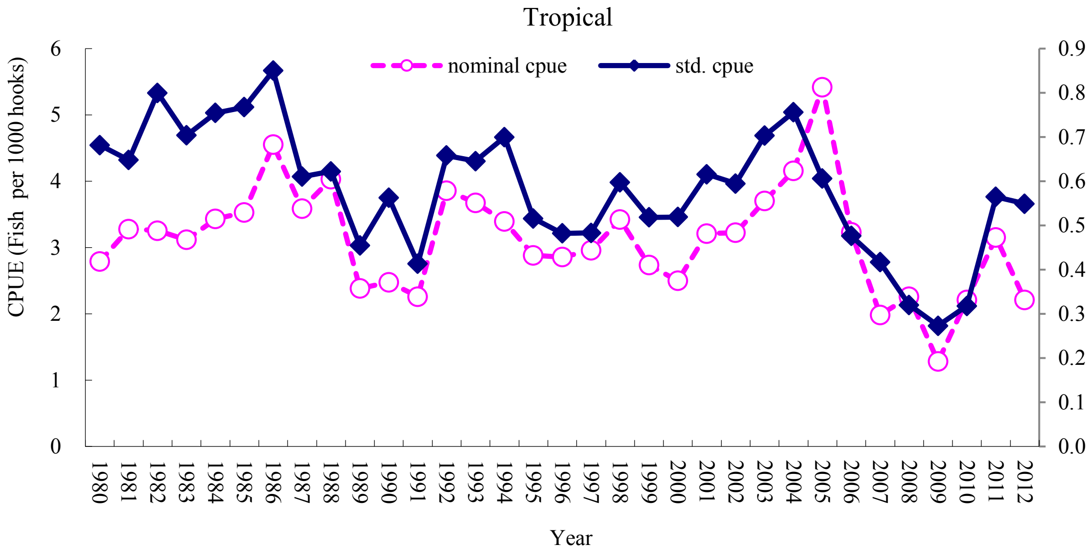

Figure 5. Nominal and Standardized annually CPUE series for Yellowfin in the tropical Indian Ocean from 1980 to 2012.

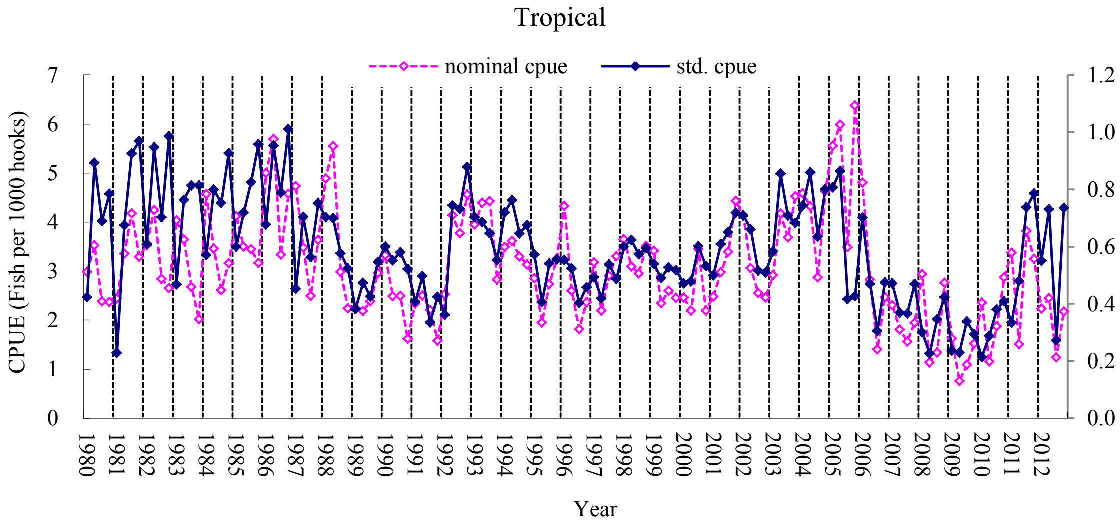

Figure 6. Nominal and Standardized quarterly CPUE series for Yellowfin in the tropical Indian Ocean from 1980 to 2012.

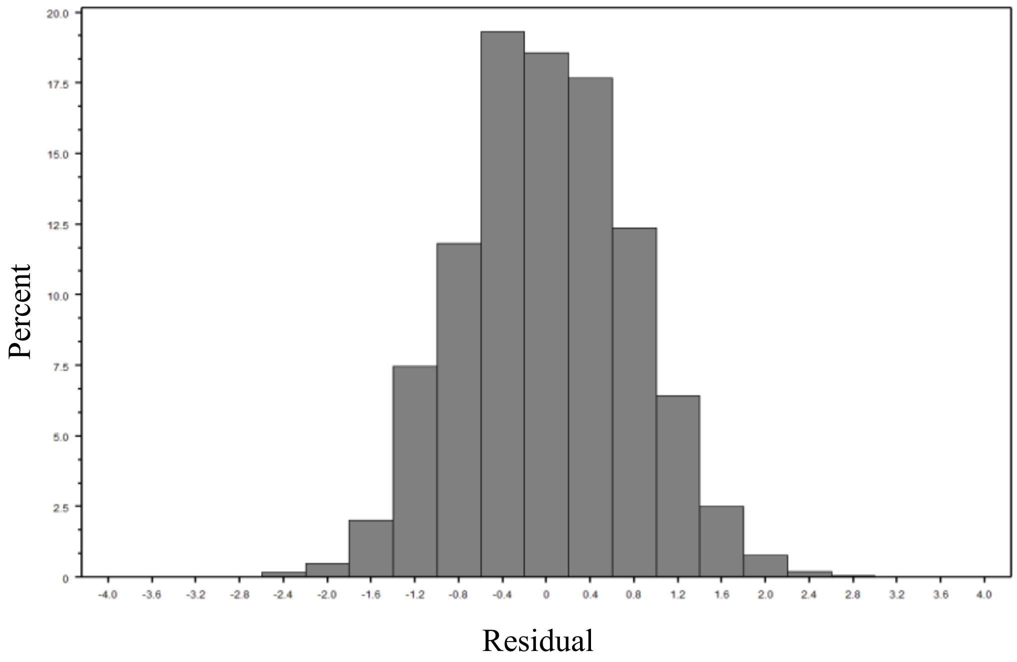

Figure 7. The residuals distribution of annual based CPUE standardization for the whole Indian Ocean from 1980 to 2012.

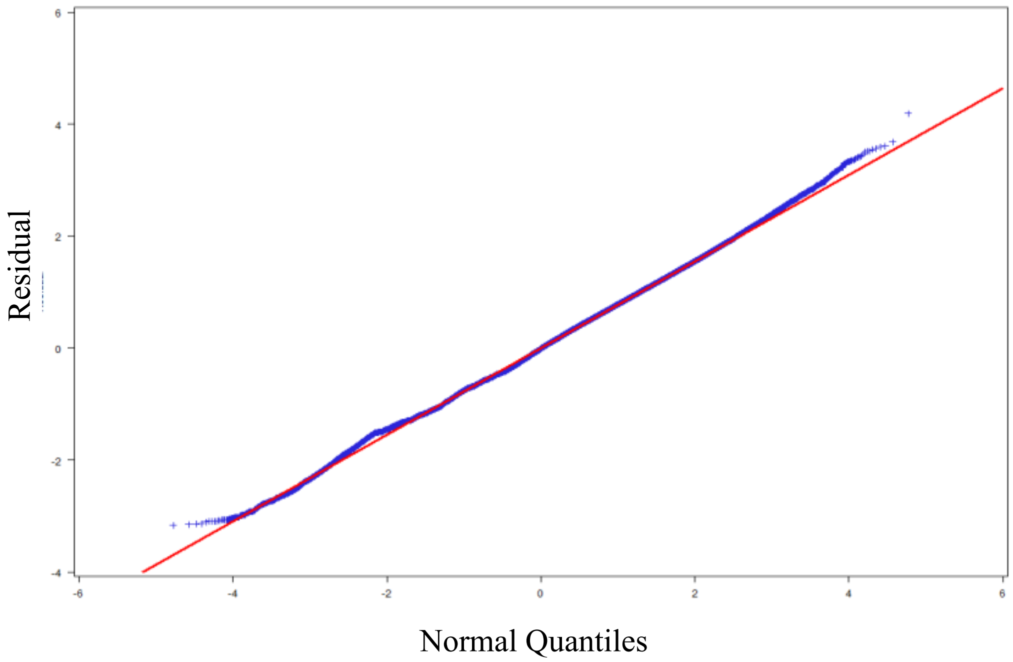

Figure 8. The QQPlot of annual based CPUE standardization for the whole Indian Ocean from 1980 to 2012.

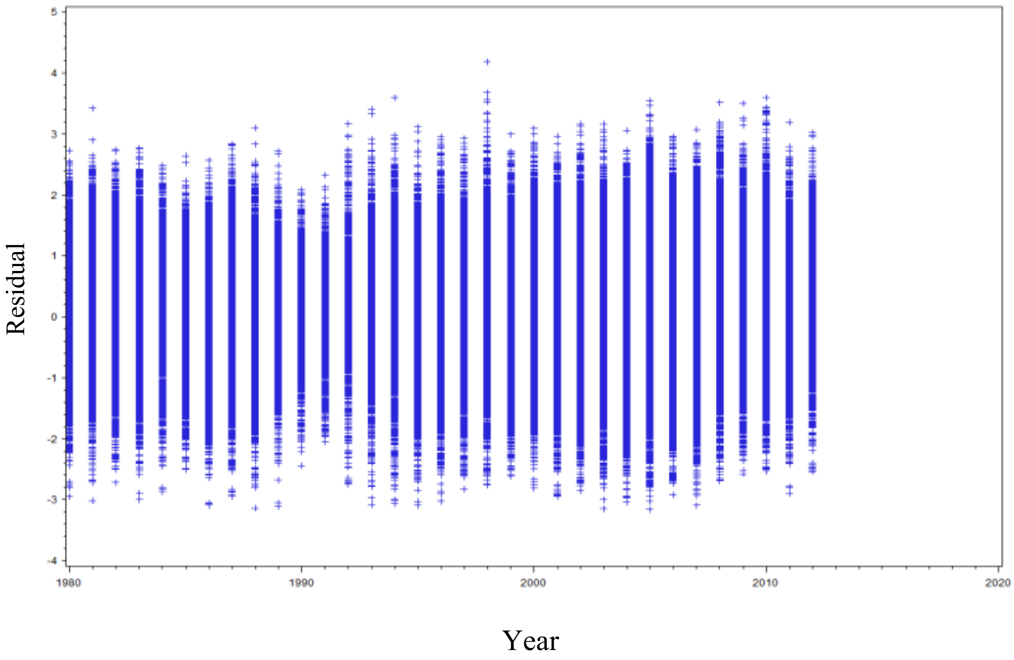

Figure 9. Plot of residuals against the year effect in annual based CPUE standardization for the whole Indian Ocean from 1980 to 2012.

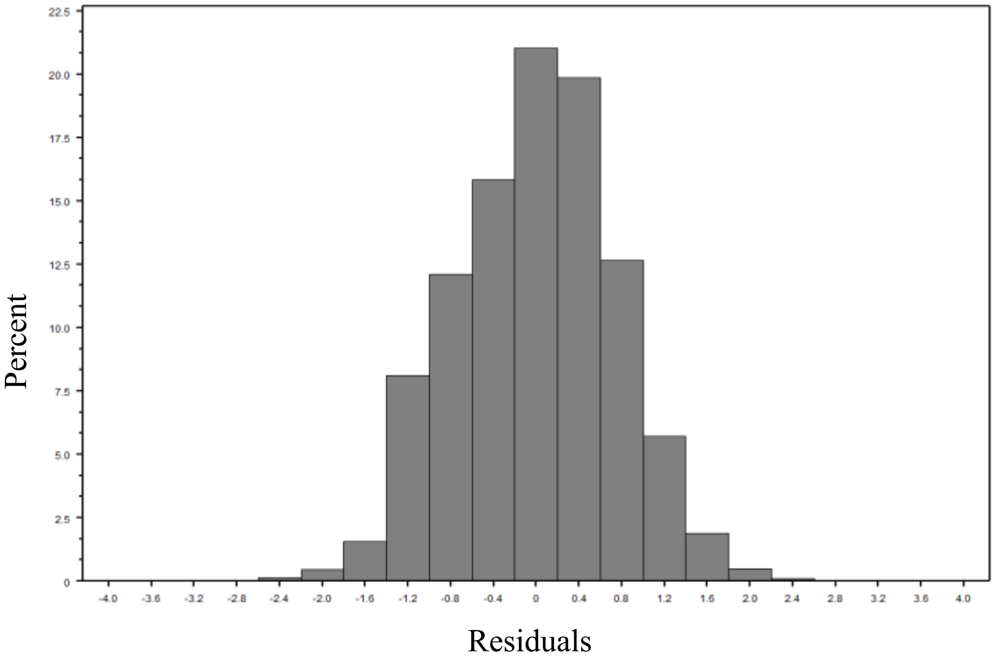

Figure 10. The residuals distribution of annual based CPUE standardization for the tropical Indian Ocean from 1980 to 2012.

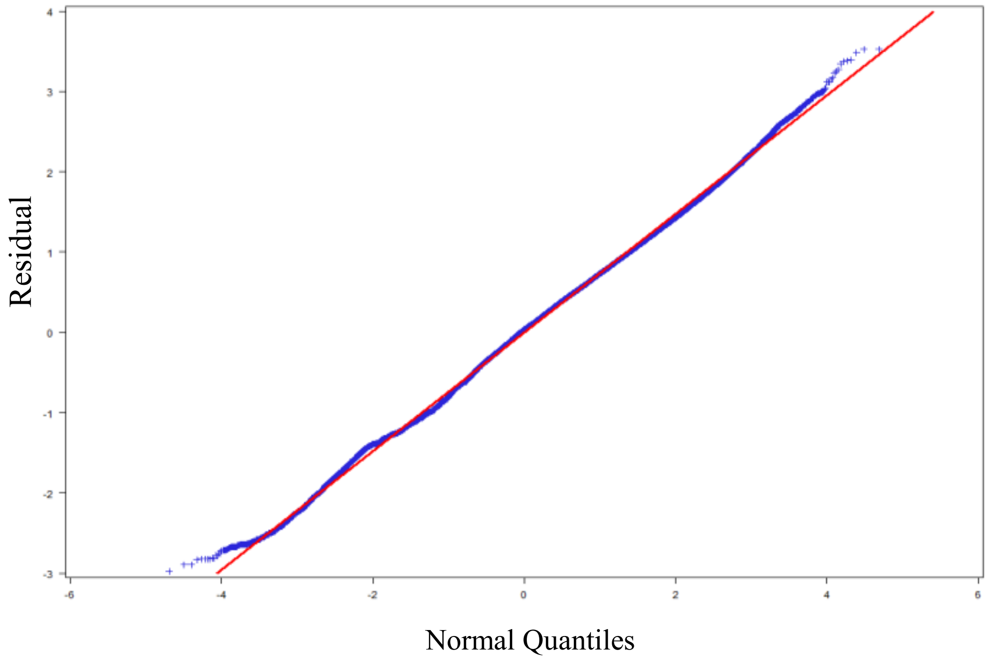

Figure 11. The QQPlot of annual based CPUE standardization for the tropical from 1980 to 2012.

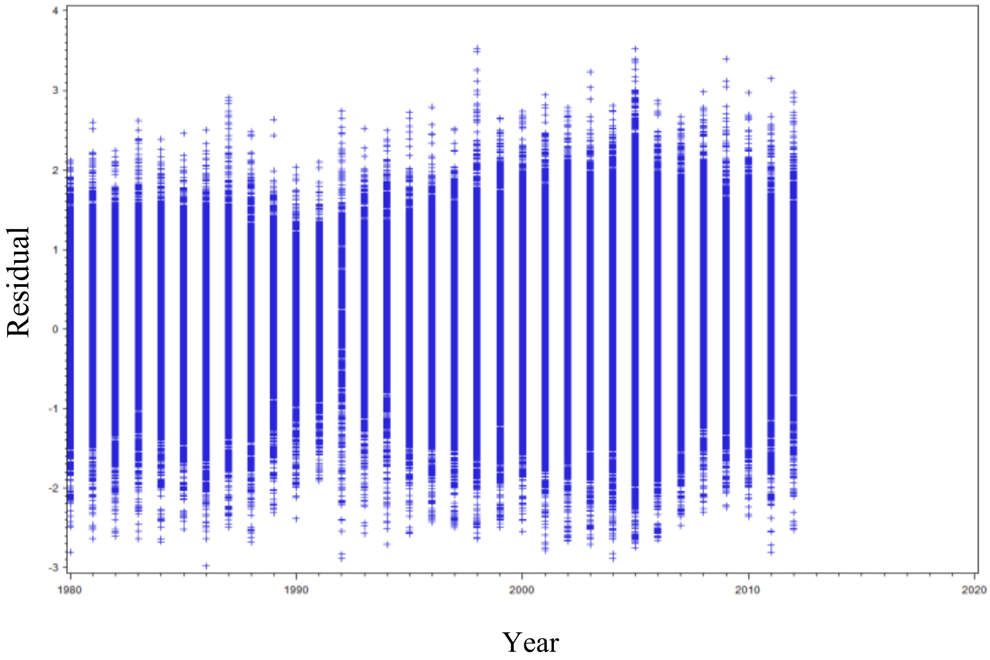

Figure 12. Plot of residuals against the year effect in annual based CPUE standardization for the tropical Indian Ocean from 1980 to 2012.

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