Received: 14 October 2013

CPUE Standardizations for Bigeye 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; Hsu et al. 2001).

Bigeye tuna, *Thunnus obesus*, is the most valuable and cosmopolitan scombridae, distributing in the tropical and temperate waters (Collette & Nauen 1983). In the Indian Ocean, Taiwanese tuna longline fishery targeting bigeye tuna mainly distributes in the tropical regions, between15°N and 15°S. The production of the entire Indian bigeye tuna stock has exceeded 100,000 mt since 1993, has reached the highest catch 162,556 mt at 1999, then decreased gradually to 87,235 mt in 2010. Recent two years, the production has increased to 115,794 mt in 2012, similar with the level in 2009. Taiwanese catches have been accounted to around 20%-40% since 1979.

There was an observable change when Taiwanese longline fishing activities shifted target species from albacore to bigeye. Looking into the history of bigeye tuna longline fishing in the Indian Ocean, prior to the late 80s, the average catch recorded around 6,000 mt. As a result of a shift of target species from albacore to bigeye, the bigeye catch started increasing to the highest level, 60,000 mt in 2003. However, this number was not maintained. After 2003, total annual bigeye tuna catches by Taiwanese longline fishery has been gradually decreased to 17,700 t in 2010. There was an increasing trend shown in recent two years, the catch reached 34,700 t in 2012 (Figure 1). During 2009-2010, the fishery has been moving off the coast of Somalia due to active piracy in the area. It turned out that the bigeye catch being taken in western Indian Ocean form a smaller percentage of the total catch in 2010 (50%) than the previous years (74% for 2008-2009 and 81% for 2000-2007). However, the proportion has risen to 92% in 2012 since the fleet has been moving back to the coast of

Somalia.

1.2 The bigeye tuna status in the Indian Ocean

The mean bigeye tuna catch over the 2007-2011 period of 101,639 t is below the MSY level (103,000-114,000 t). According to the results of stock assessment held in the previous IOTC workshop (IOTC 2011; IOTC 2012), the stock is probably not overfished, and overfishing is probably not occurring. However, the bigeye catches should be kept at or lower than the 2009 level to on the basis of the estimated uncertainty and the continuing observed decline in CPUE.

1.3 Summary of the previous CPUE standardizations for bigeye tuna caught by Taiwanese longline fishery in the Indian Ocean

For stock assessment purposes, in 2001, based on the available number of hooks per basket (NHBF) information, the logbook data was divided into 3 fishing type (Deep, regular and mixed). And the factor of fishing types was included in the GLM model as a target proxy (Hsu et al. 2001). In the following, the standardizations of CPUE for bigeye tuna caught by Taiwanese longline fishery in the Indian Ocean were conducted by generalized linear mixed model (GLMM) based on aggregated monthly catch and effort data with 5 degree by 5 degree resolution from 1968 to 2004 and daily set by set catch and effort data (logbook data set) with 5 degree by 5 degree resolution from 1979 to 2004 (Hsu 2006). Data manipulation was included in this previous study to screen the logbook data set. The adjustment was adopted to deal with some records with unreasonable large number of hooks.

For understanding the environmental influence on CPUE variations, the standardizations of CPUE for bigeye were carried out based on daily set-by-set catch and effort data with 1 degree by 1 degree resolution from 1995 to 2008 (Chang & Yeh 2009). The environmental data were provided Japanese scientist. The environmental data includes the moon phase by day, Shear current and its amplitude, thermo-cline depth, temperature and salinity at depth of 205 m (205 m is the representative depth where bigeye are caught by LL), IOI, SOI and Di pole index (DPI). The significant environment factors were IOI, thermo-cline depth, temperature at depth of 205 m and amplitude of the shear current (Chang & Yeh 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 CPUE trend was not sensitive to the definition of catch composition as a target proxy as well as the interaction factors in the GLM model. There was a minor effect of two different proxies on CPUE series except the signal in 1995, 1998, and 2005.

1.4 Purpose of the study

In this study, in order to obtain an updated standardized CPUE series for bigeye 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 & Chang 2012).

2 Material and Method

2.1 Data set

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). The data on the NHBF was available since 1995, and the percentage of data with NHBF was about 80% of the total data from 1995 to 2012. However, to obtain a longer series for bigeye stock assessment, therefore we use the species composition to be a target proxy to consider the effects of target species shifts issue.

2.2 Statistical models

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, month, area (Areas 1 to 7, defined in Figure 2), and target species. The interactions between the main factors are also included in the model. The information of NHBF was only available from 1995 onwards in the logbooks of Taiwanese longline fishery. Therefore, the information of NHBF was used to determine the target proxy in the CPUE standardization models. According to the analysis of the relationship between the NHBF and catch composition, the target proxy is defined as follows:

1. Three categories of Albacore catch composition (catch of Albacore / catch of Bigeye, Yellowfin and Albacore) are defined as, 1: <=13%; 2:13%-39%; 3: >39%.

2. Three categories of Yellowfin tuna catch composition (catch of Yellowfin / catch of Bigeye, Yellowfin and Albacore) are defined as, 1: <=20%; 2:20%-35%; 3: >35%.

We used six GLM models for six nominal CPUE series: annually and quarterly data in 5x5 grid resolution for the whole Indian Ocean (Area1 – Area 7), tropical Indian Ocean (Area 1 - Area 5) and South Area (Area 6 and Area 7) from 1980 to 2012.

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.

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

where *CPUE* is the nominal CPUE of bigeye tuna,

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

μ is the intercept,

Y is the effect of year,

M is the effect of quarter,

A is the effect of fishing area,

T is the Target proxy,

Interactions is the interactions between main effects,

ε is the error term, $\varepsilon \sim N(0, \sigma^2)$.

Fishing areas used in this study were defined b nine areas based on the IOTC statistics areas for bigeye tuna in the Indian Ocean (Fig. 2):

- Area 1: The open sea off the Somalia;
- Area 2: The waters around the Maldives;
- Area 3: The waters around the Seychelles;
- Area 4: The waters around the Chagos Archipelago;
- Area 5: The western Tropical Area ;
- Area 6: Mozambique Channel;
- Area 7: The open sea off the Australia.

2.3 Statistical runs

This study has conducted a set of standardization runs using logbook data by GLM models. 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 1-3 show the ANOVA tables for the annual-based GLM analyses for the whole Indian Ocean, the tropical and South Indian Ocean separately. The R squares for the model of three runs were between 0.24 and 0.36. The RYFT factors, as a target proxy, explained relatively large amount of variance for all three regions.

Annual and quarterly nominal and standardized CPUEs obtained from GLMs for are shown for the whole, tropical and south Indian Ocean separately in Fig. 3-8. The annual nominal CPUE was ranged between 4 fish/1000 hooks and 9 fish/1000 hooks in whole Indian Ocean. It is noted that the quarterly nominal CPUE reached the highest value, 11 fish/1000 hooks at the second quarter in 2012 for the recent decades. The comparison of the monthly spatial distribution of nominal CPUE by 5x5 degree grid resolution was made for the latest three years (figure 10-12). It is shown that the fishing effort was more aggregated in the western tropical Indian Ocean and the nominal CPUE was relative higher in 2012 than other year. Besides, the number of vessels targeting bigeye tuna increased to alter the compositions of fishing type (targeting on bigeye, or albacore, or both) for Taiwanese longline fleet in 2012 (data provided by OFDC). Therefore, generally speaking, the nominal CPUE in the tropical and whole Indian Ocean and catch of bigeye are significant high in 2012.

As for the standardized CPUE series, they showed very similar trend with the nominal

CPU in the tropical and whole Indian Ocean since the variation explained by the factors in the GLMs is limited. Distributions of the standardized residuals, the qqplots, and plot of residuals against year effect for annually-based GLMs are showed in Fig. 12-20. All cases appear to deviate slightly from normal distribution and show some extent of divergence for left tail. However, they are not statistically significant different with normal distribution.

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

Whole Indian Ocean

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	93	153725.1828	1652.959	3309.16	<.0001
Error	542054	270761.2215	0.4995		
Corrected Total	542147	424486.4043			

	R-Square	Coeff Var	Root MSE	lnbetcpue Mean
	0.362144	48.48457	0.70676	1.457701

Source	DF	Type III SS	Mean Square	F-value	P-value
year	32	8017.57199	250.54912	501.59	<.0001
Area	6	2399.18395	399.86399	800.51	<.0001
season	3	1073.42404	357.80801	716.32	<.0001
ryft	2	20744.45371	10372.22685	20764.8	<.0001
ralb	2	7375.28827	3687.64413	7382.53	<.0001
Area*season	18	2229.18746	123.84375	247.93	<.0001
season*ryft	6	353.39291	58.89882	117.91	<.0001
Area*ralb	12	588.85491	49.07124	98.24	<.0001
Area*ryft	12	898.27393	74.85616	149.86	<.0001

Table 2. ANOVA table for the annual based CPUE standardization for the tropical Indian Ocean from 1980 to 2012.

Tropical Indian Ocean

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	77	72312.5162	939.1236	1951.97	<.0001
Error	466062	224229.5598	0.4811		
Corrected Total	466139	296542.076			
	R-Square	Coeff Var	Root MSE	lnbetcpue Mean	
	0.243852	43.01877	0.693625	1.612377	
Source	DF	Type III SS	Mean Square	F-value	P-value
year	32	7337.01071	229.28158	476.56	<.0001
Area	4	27.79283	6.94821	14.44	<.0001
season	3	412.95099	137.65033	286.11	<.0001
ryft	2	35919.44744	17959.72372	37329.4	<.0001
ralb	2	4704.0229	2352.01145	4888.66	<.0001
Area*season	12	973.66983	81.13915	168.65	<.0001
season*ryft	6	456.54385	76.09064	158.15	<.0001
Area*ryft	8	760.89481	95.11185	197.69	<.0001
Area*ralb	8	70.27153	8.78394	18.26	<.0001

Table 3. ANOVA table for the annual based CPUE standardization for the South Indian Ocean from 1980 to 2012.

South Indian Ocean

Source	DF	Sum of Squares	Mean Square	F-value	P-value
Model	53	26575.45257	501.42363	587.86	<.0001
Error	75954	64786.00025	0.85296		
Corrected Total	76007	91361.45282			

	R-Square	Coeff Var	Root MSE	lnbetcpue Mean
	0.290883	321.6363	0.92356	0.287144

Source	DF	Type III SS	Mean Square	F-value	P-value
year	32	2539.32441	79.35389	93.03	<.0001
Area	1	46.54797	46.54797	54.57	<.0001
season	3	249.04455	83.01485	97.33	<.0001
ryft	2	2121.93834	1060.96917	1243.86	<.0001
ralb	2	11902.52716	5951.26358	6977.16	<.0001
Area*season	3	49.54575	16.51525	19.36	<.0001
season*ryft	6	386.03107	64.33851	75.43	<.0001
Area*ryft	2	4.88674	2.44337	2.86	0.057
Area*ralb	2	156.68331	78.34165	91.85	<.0001

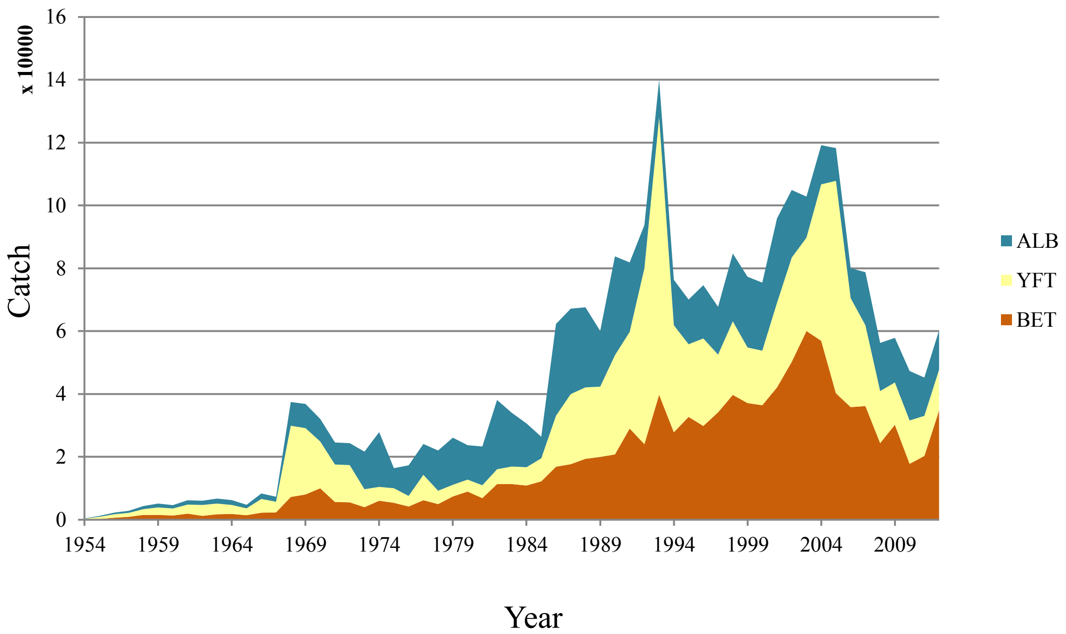

Figure 1. Nominal catches (10,000 mt) of main target species caught by Taiwanese longline fishery in the Indian Ocean over the period 1954 to 2012.

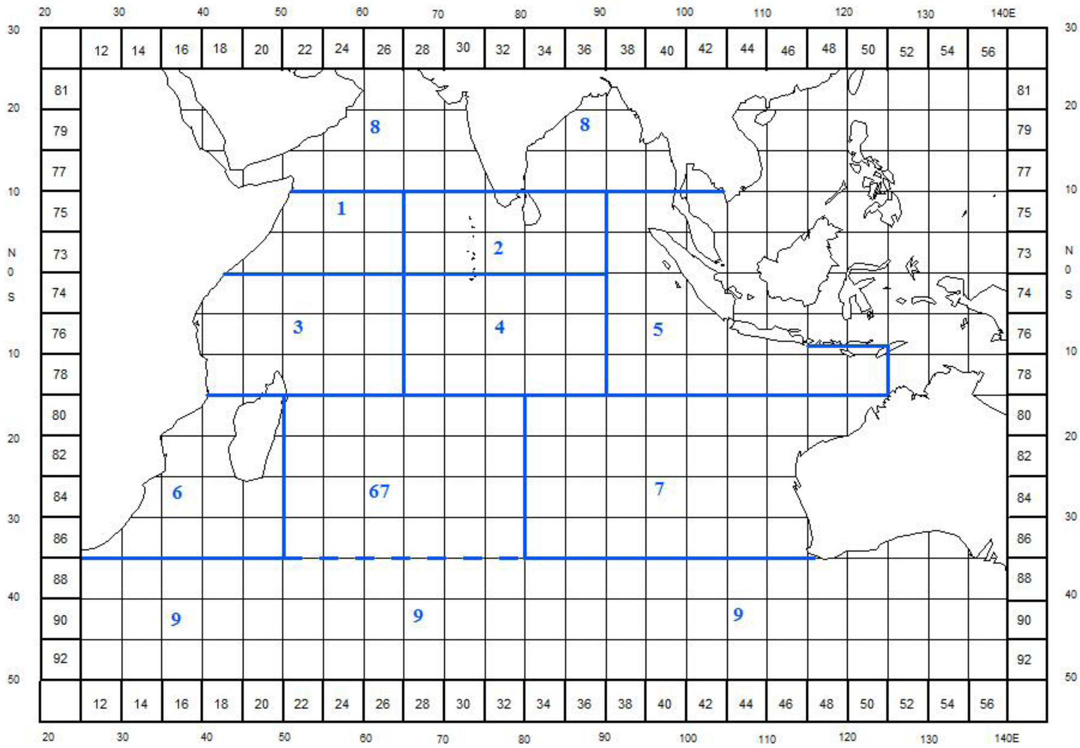

Figure 2. Area stratification used for the standardization of CPUE for bigeye tuna in the Indian Ocean in 2012.

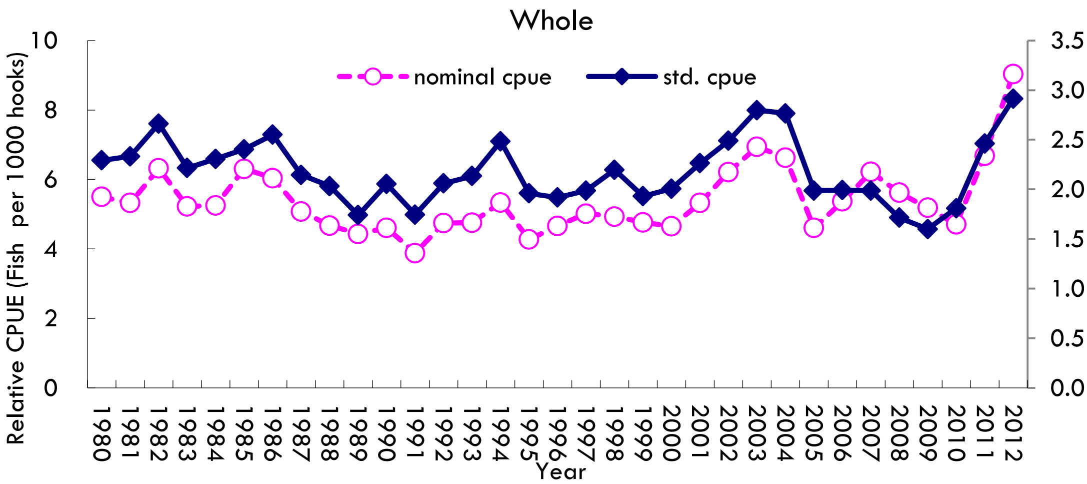

Figure 3. Nominal and standardized annually CPUE series for Bigeye in the whole Indian Ocean from 1980 to 2012.

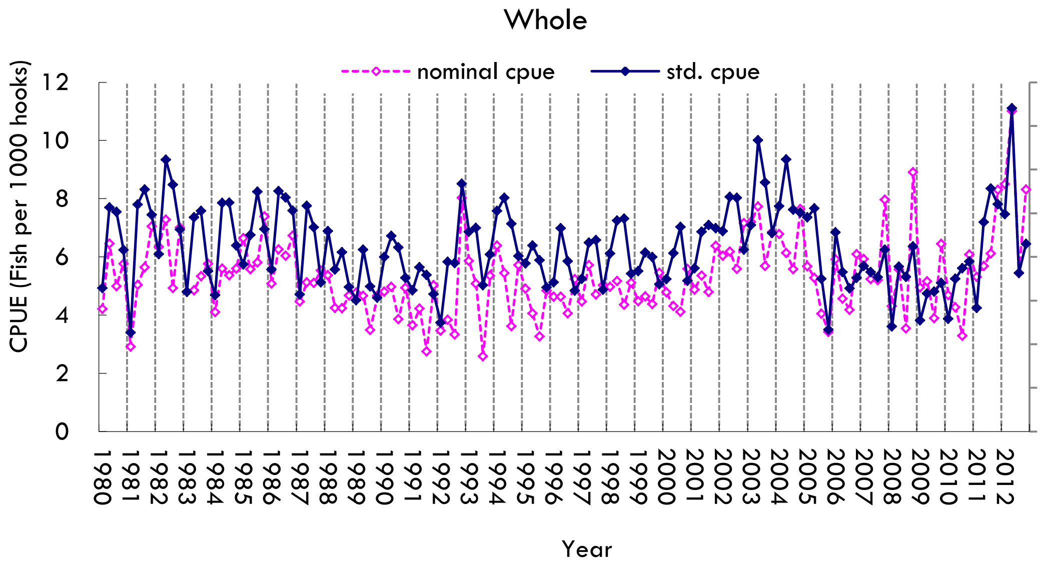

Figure 4. Nominal and standardized quarterly CPUE series for Bigeye in the whole Indian Ocean from 1980 to 2012.

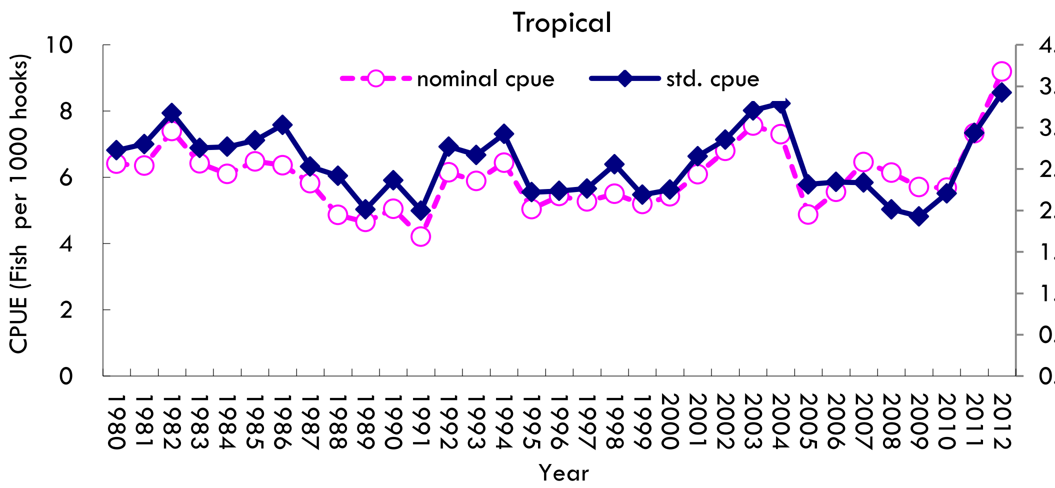

Figure 5. Nominal and standardized annually CPUE series Bigeye in the tropical Area from 1980 to 2012.

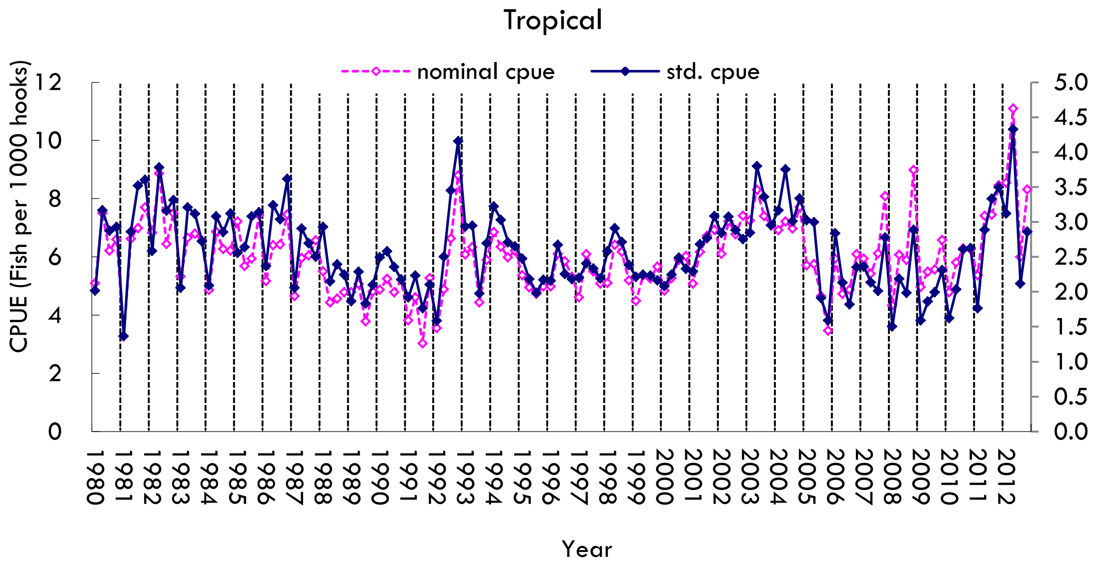

Figure 6. Nominal and Standardized quarterly CPUE series for Bigeye in the tropical Indian Ocean from 1980 to 2012.

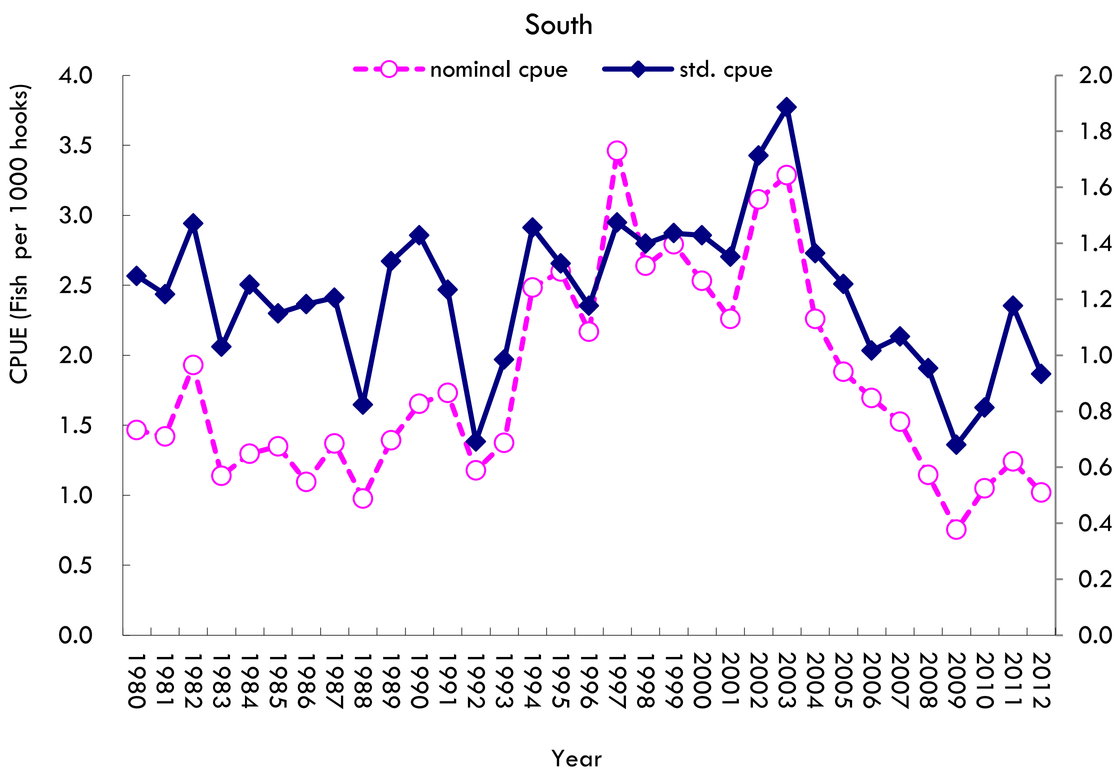

Figure 7. Nominal and standardized annually CPUE series Bigeye in the South Area from 1980 to 2012.

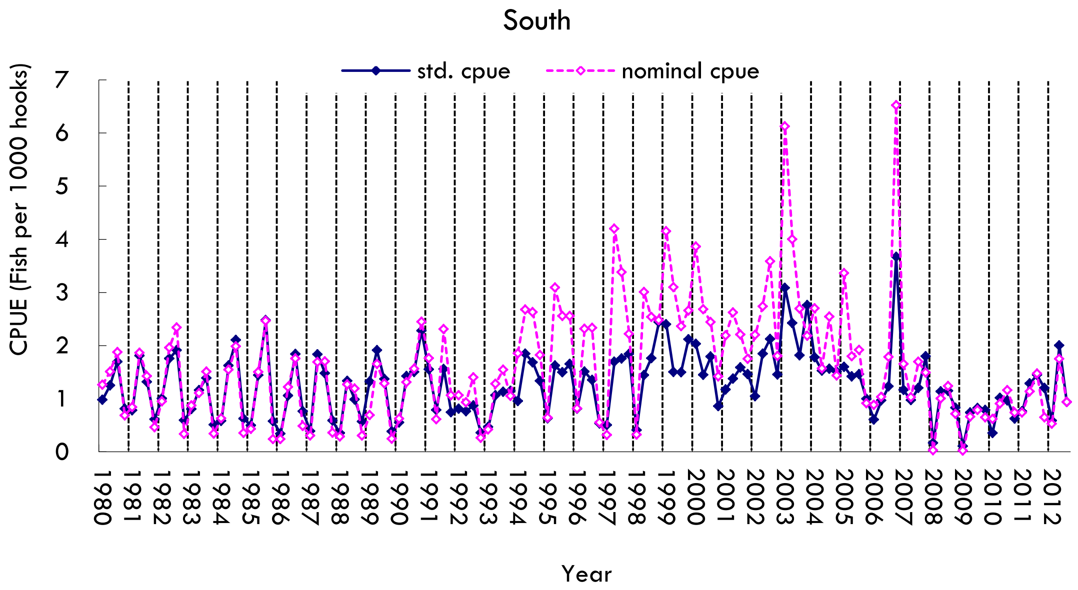

Figure 8. Nominal and Standardized quarterly CPUE series for Bigeye in the South Indian Ocean from 1980 to 2012.

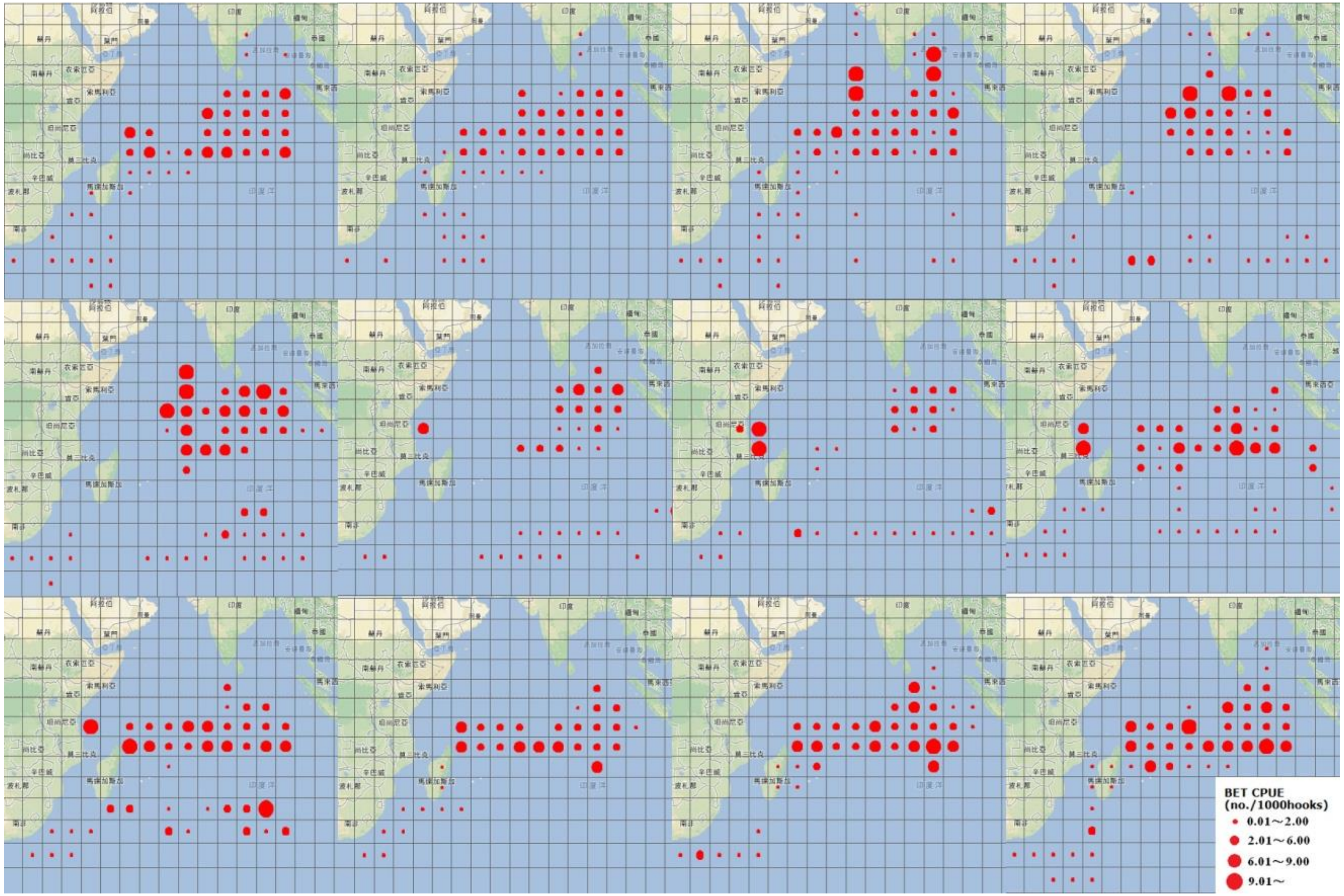

Figure 9. The monthly spatial distributions of BET CPUE for Taiwanese longline fishery in 2010.

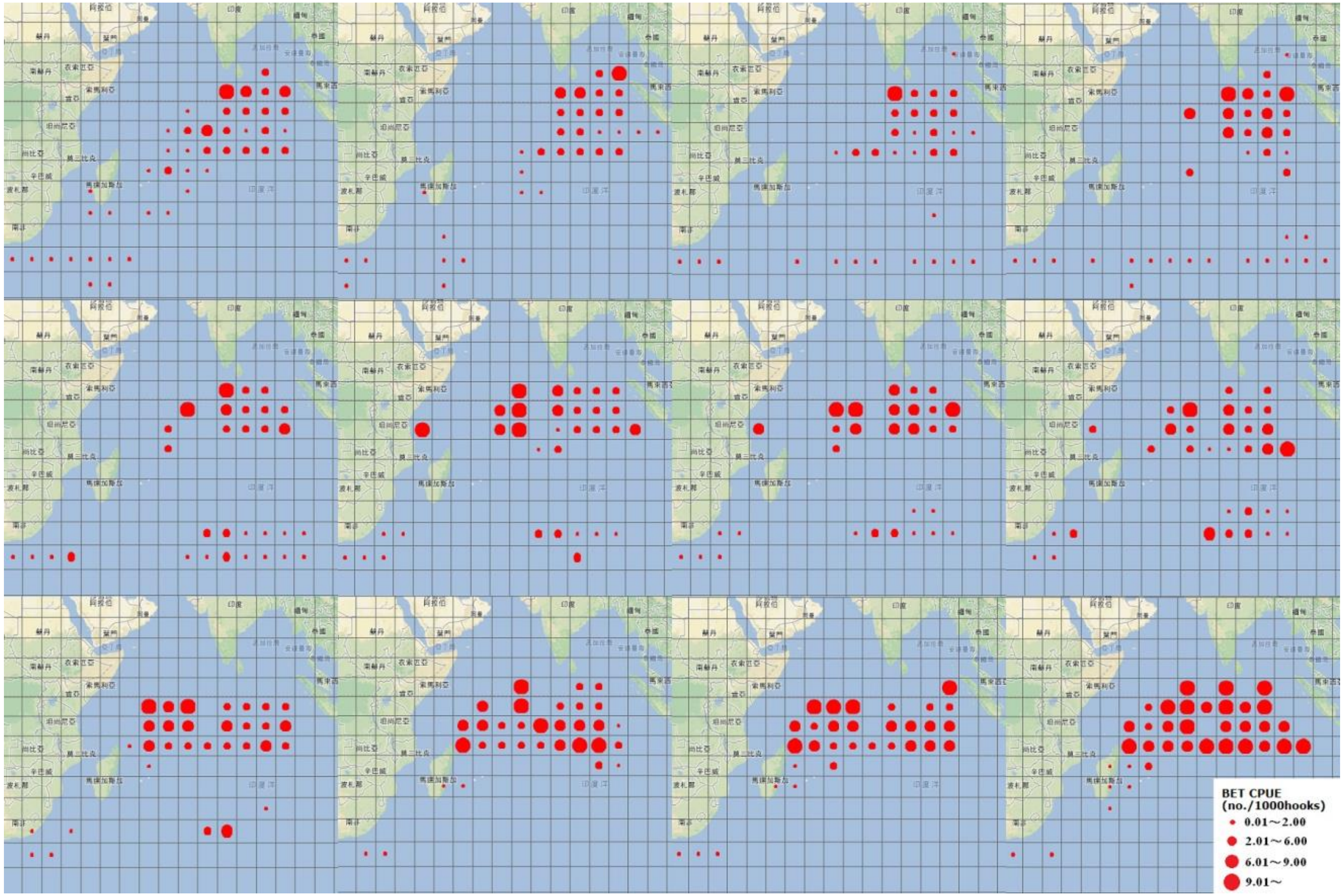

Figure 10. The monthly spatial distributions of BET CPUE for Taiwanese longline fishery in 2011.

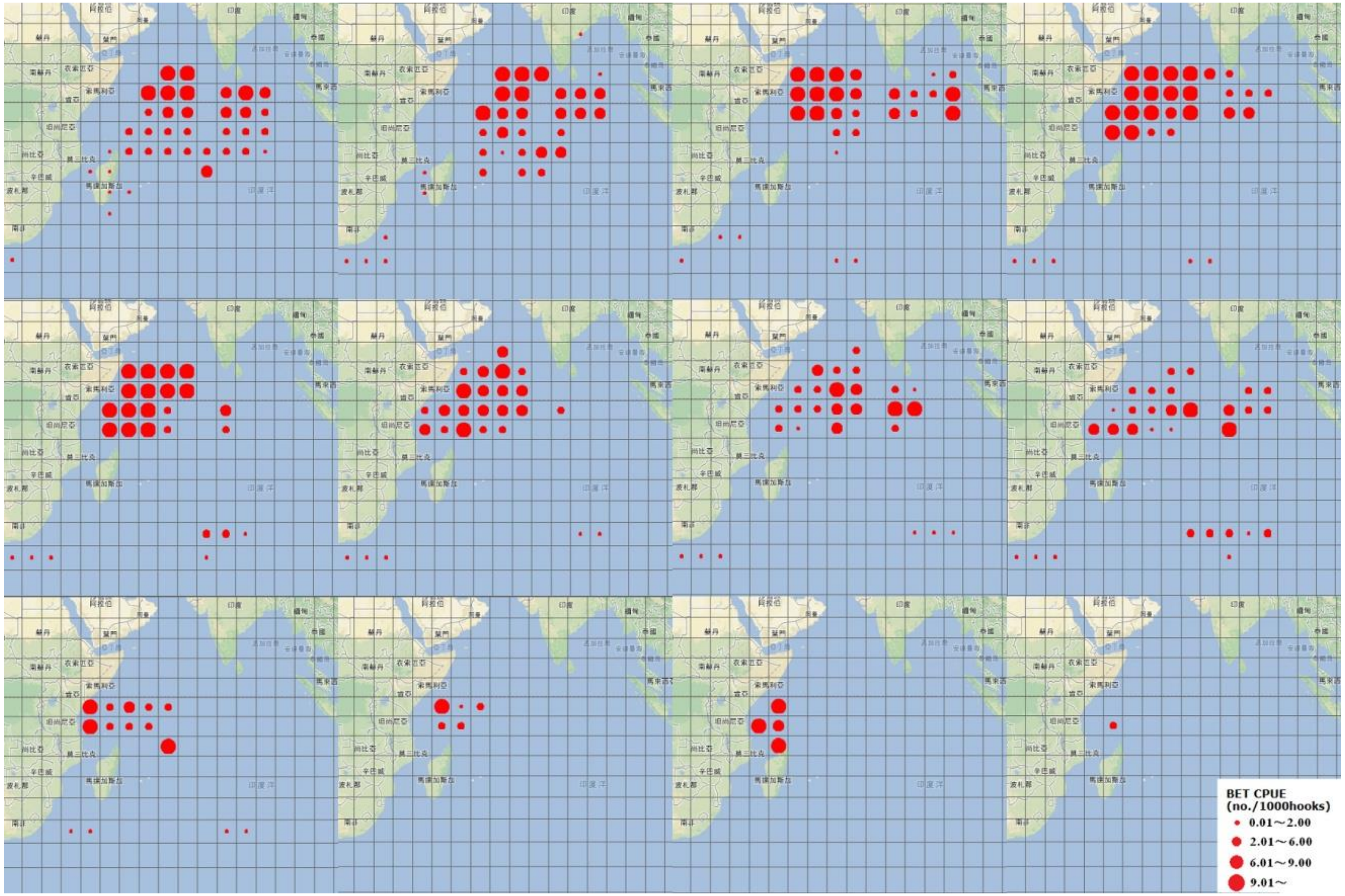

Figure 11. The monthly spatial distributions of BET CPUE for Taiwanese longline fishery in 2012.

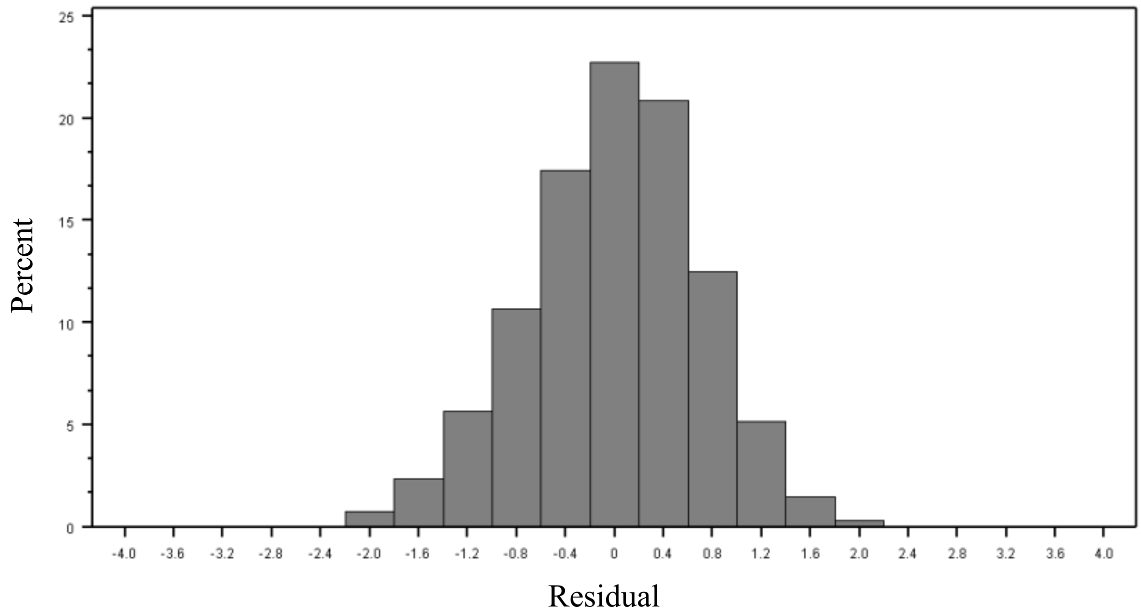

Figure 12. The residuals distribution of annual based CPUE standardization for the whole Indian Ocean from 1980 to 2012.

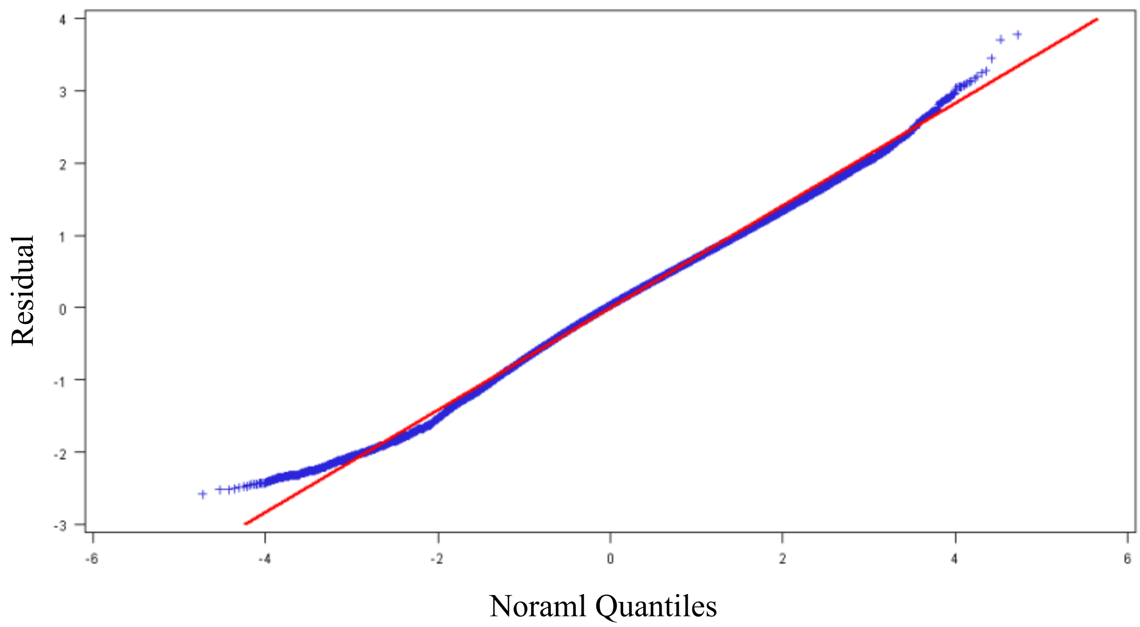

Figure 13. The QQPlot of annual based CPUE standardization for the whole Indian Ocean from 1980 to 2012.

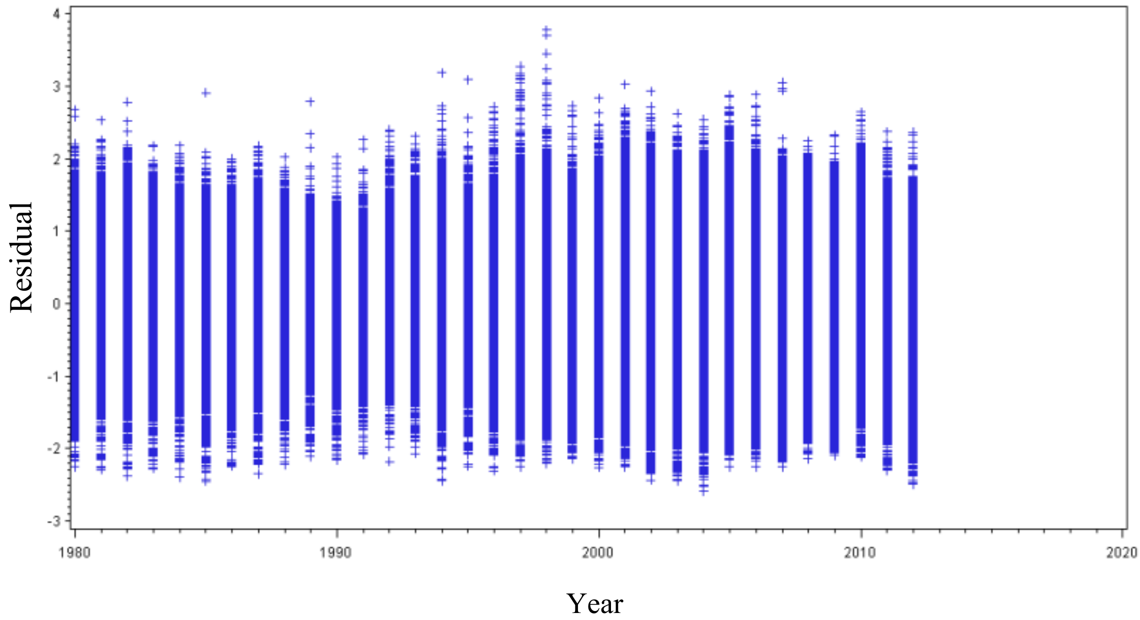

Figure 14. The Plot of residuals against the year effect in annual based CPUE standardization for the whole Indian Ocean from 1980 to 2012.

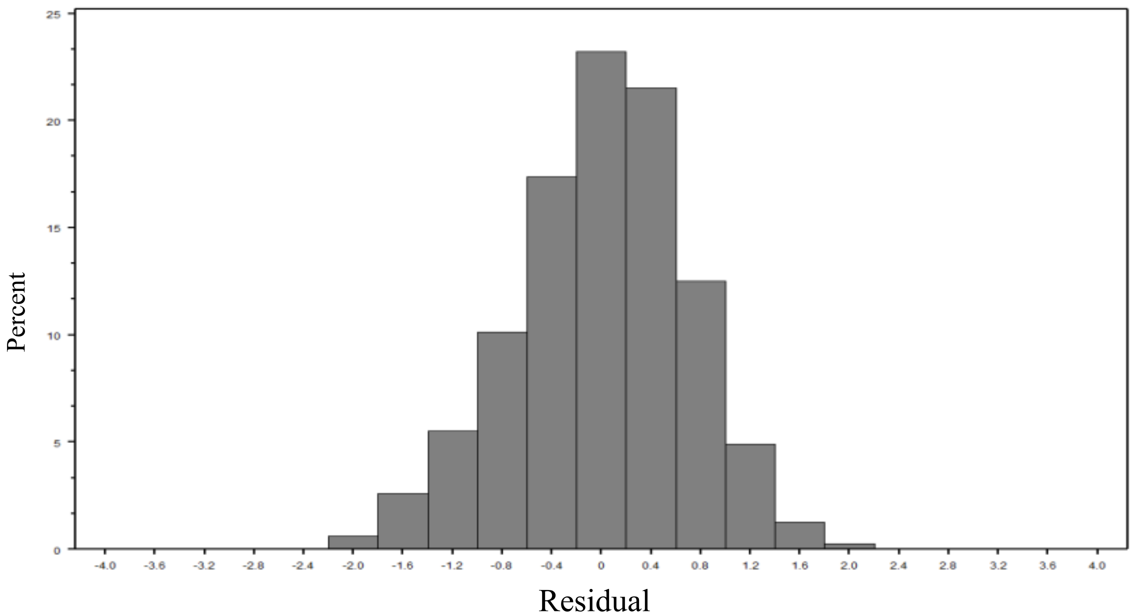

Figure 15. The residuals distribution of annual based CPUE standardization for the tropical Indian Ocean from 1980 to 2012.

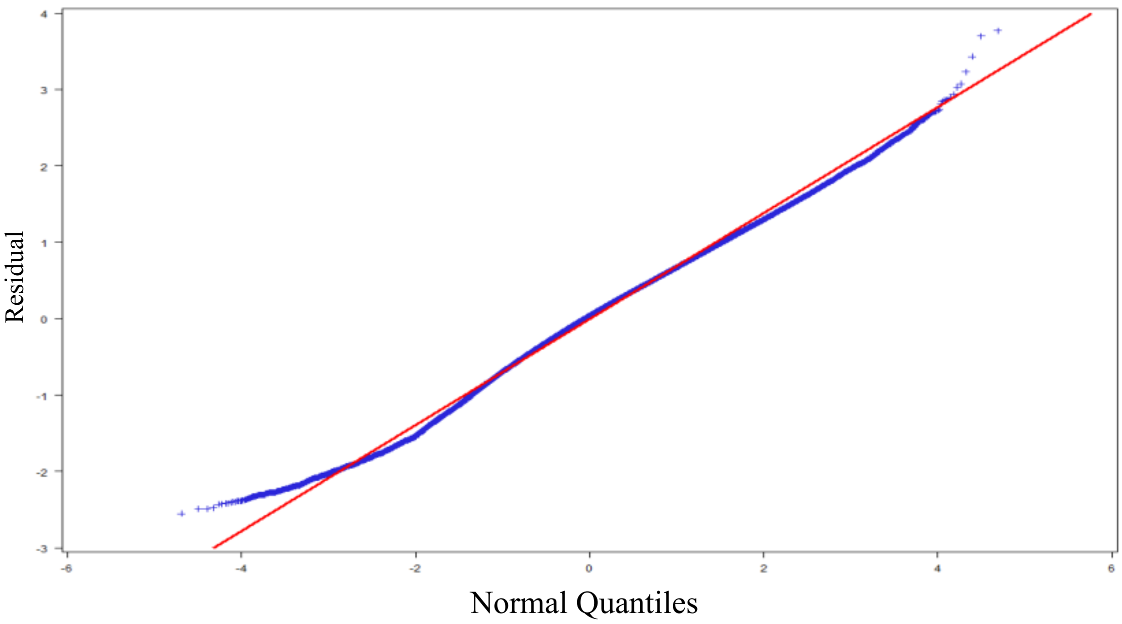

Figure 16. The QQPlot of annual based CPUE standardization for the tropical Indian Ocean from 1980 to 2012.

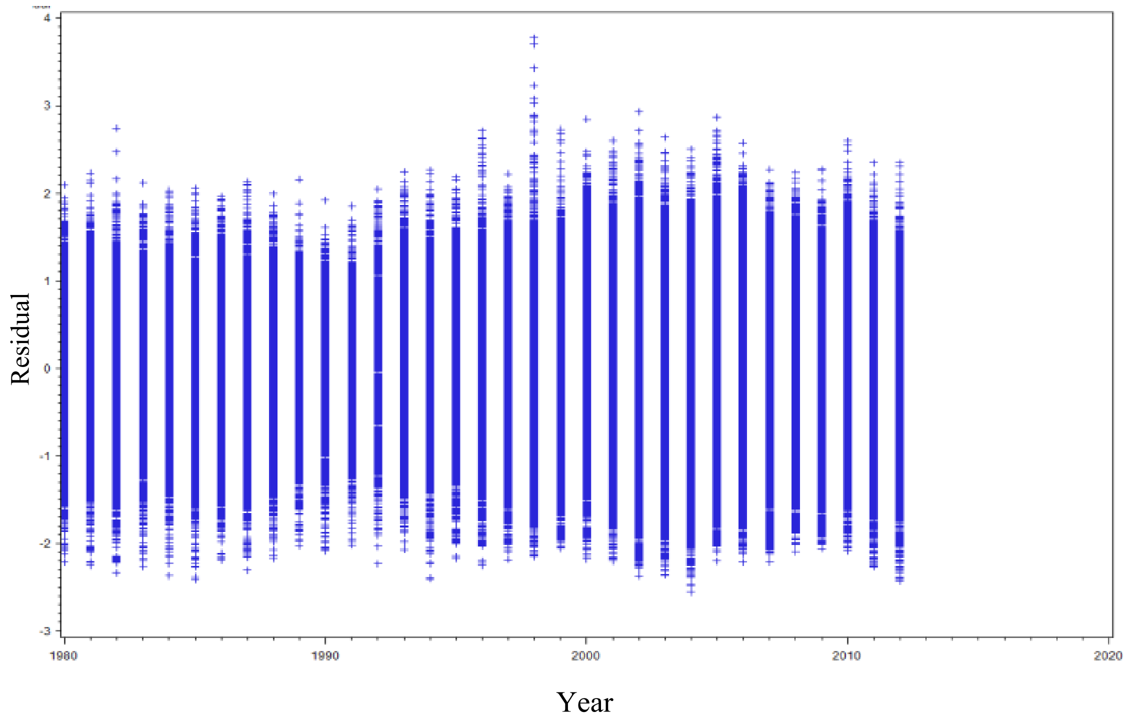

Figure 17. The Plot of residuals against the year effect in annual based CPUE standardization for the tropical Indian Ocean from 1980 to 2012.

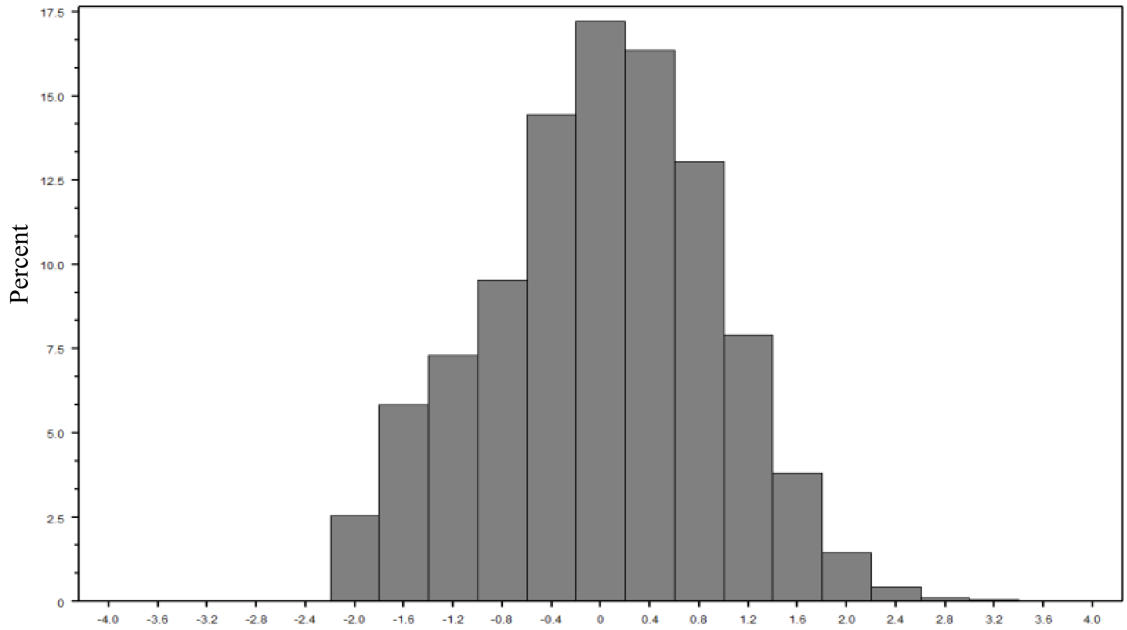

Figure 18. The residuals distribution of annual based CPUE standardization for the South Indian Ocean from 1980 to 2012.

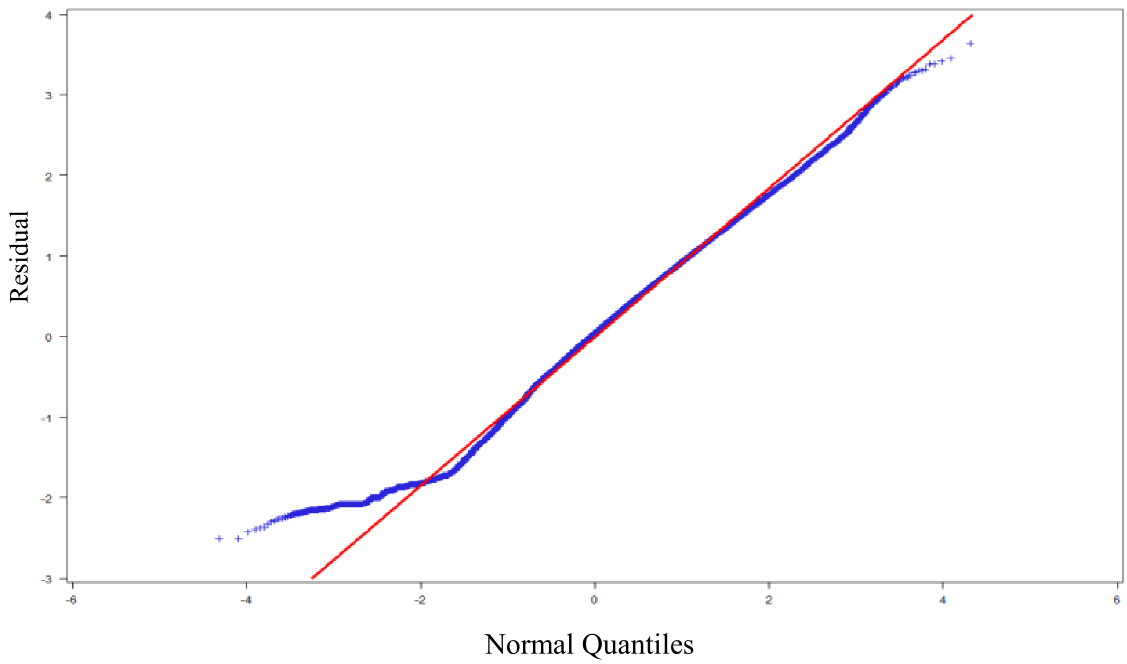

Figure 19. The QQPlot of annual based CPUE standardization for the South Indian Ocean from 1980 to 2012.

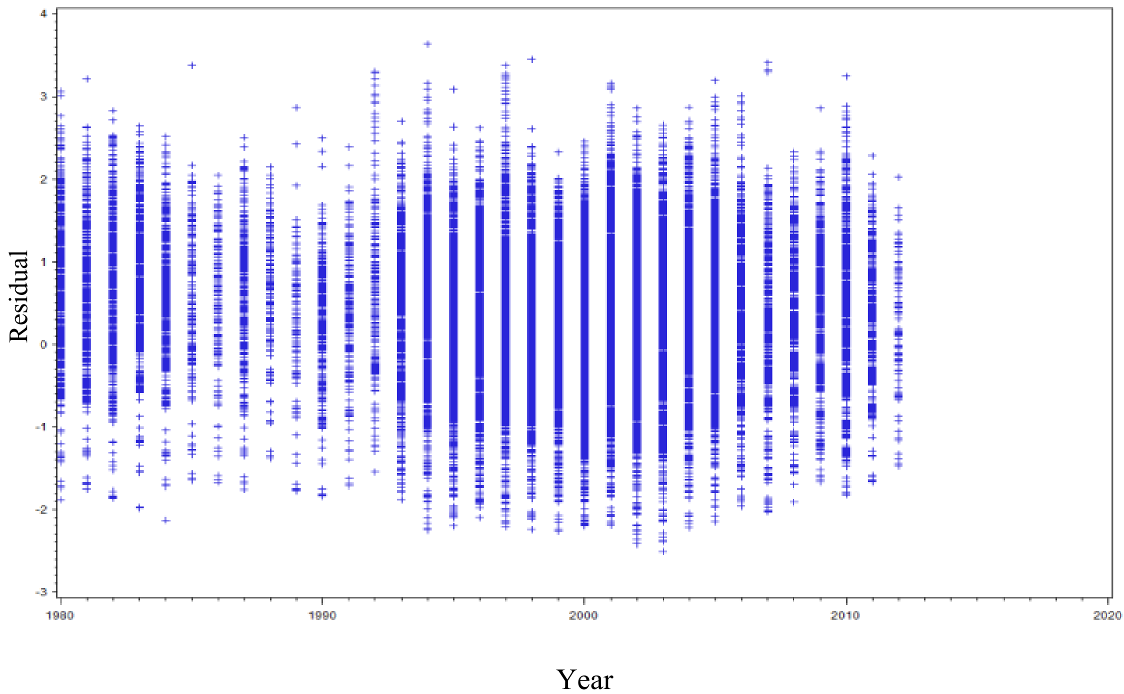

Figure 20. Plot of residuals against the year effect in annual based CPUE standardization for the South Indian Ocean from 1980 to 2012.

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