# Updated CPUE standardizations for Yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized liner 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 and Bergin 2000).

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 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 mt (Chang et al. 2008). 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. 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 (Chang et al. 2008; Haward and Bergin 2000).

Total annual yellowfin tuna catches by Taiwanese longline fishery averaged 14,600 t over the period 2008 to 2010 and the 2010 catch was 13,800 t (Figure 1). During the last two years, the fishery has been moving off the coast of Somalia due to active piracy in the area. It turned out no fishing operation occurred in Arabian Sea, which with relatively high yellowfin catch in the previous years, in 2010. The yellowfin catch being taken in western Indian Ocean form a smaller percentage of the total catch in 2010 (25%) than the previous years (43% for 2008-2009 and 65% for 2000-2007).

### 1.2 The yellowfin status in the Indian Ocean

The mean yellowfin tuna catch over the 2007-2009 period of 310,000 t is in the middle of MSY level (250,000-350,000 t). According to various of catch rates for different fleets, fishing mortality is likely to have exceed the MSY-related levels. The stock of yellowfin tuna has recently become very close to be overexploited. Catch should reduce below 300,000 t to maintain stock levels (IOTC 2010).

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

For stock assessment purposes, the standardizations of CPUE for Yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean were conducted by generalized linear model (GLM) and generalized linear mixed model (GLMM) based on daily set-by-set catch and effort data with 5 degree by 5 degree resolution from 1979 to 2009.

For understanding the environmental influence on CPUE variations, the standardizations of CPUE for Yellowfin were carried out based on daily set-by-set catch and effort data with 1 degree by 1 degree resolution from 1995 to 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 155 m (155 m is the representative depth where YFT are caught by LL), IOI, SOI and Di pole index (DPI). The significant environment factors were thermo-cline depth, temperature at depth of 155 m and Shear current (Yeh et al. 2010).

In the previous study, the rule of data extraction is to exclude the high catch composition with BET>75% and catch logged as zero or the information is entirely unavailable for YFT or ALB, due to the data coming from specific BET-targeting fishing activities; and to exclude yellowfin catch recorded at zero due to incomplete information in the data provided (Yeh et al. 2010).

### 1.4 Purpose of the study

To provide an update of indices of abundance for yellowfin tuna from the Taiwanese longline fishery presented for the period 1979-2010.

## 2 Material and Method

In this study, the researchers follow the procedure adopted in previous study (Yeh et al. 2010) but with recent data updates and some adjustments. Compare to the previous study, the principle of data extraction is replaced by the following rules: (1). Main target species are all zero catches; (2). The number of hooks per set are less than 1,000 hooks or are larger than 5,000 hooks; and (3). The location of fishing operation is beyond the concerned area (Figure 2).

### 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 1979-2010 and daily set-by-set catch and effort data with 1 degree by 1 degree resolution from the logbooks of Taiwanese longline fishery from 1995-2010 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 2010. 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.

### 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, season (Jan.-Mar., Apr.-Jun., Jul.-Sep., and Oct.-Dec.), area (Areas 1 to 5, 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. Four categories of Bigeye catch composition (catch of Bigeye / catch of Bigeye, Yellowfin and Albacore) are defined as, 1: <=24%; 2:24%-55%; 3: 55%-75% 4: >75%.

2. 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%.

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 5), tropical Indian Ocean (Area 2 and Area 5) and Area 1 from 1979 to 2010.

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 yellowfin tuna,
*c* is the constant value ( 0.1),
$\mu$ 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,

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

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

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

### 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 ($p<0.0001$) in the analysis of CPUE by the effective effort. The calculation was done using GLM and MIXED 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 annual-based GLM analyses for the whole Indian Ocean, the tropical Indian Ocean, and the Area1, separately. The R squares for the model of all runs were at least 0.5. The RBET factor, as a target proxy, explained relatively large amount of variance for the whole Indian Ocean and the tropical cases. For Area 1 case, the RALB, also as a target proxy, explained relatively large amount of variance.

Annually nominal and standardized CPUEs obtained from GLMs for are shown for the whole Indian Ocean, the tropical Indian Ocean, and the Area1 separately in Fig. 3-5. Relative standardized CPUE series for all three cases show similar decreasing trends from 2004. Quarterly nominal and standardized CPUEs obtained from GLMs for are shown for the whole Indian Ocean, the tropical Indian Ocean, and the Area1 separately in Fig. 6-8. Relative standardized CPUE series for the whole and tropical Indian Ocean show similar seasonal pattern with relative high catch rate in the first or the fourth seasons. Relative standardized CPUE series for the Area 1show relative high catch rate in the second or third seasons. Distributions of the standardized residuals and the qqplots for annually-based GLMs are showed in Fig. 9-14. 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 of GLM for yearly based CPUE for Whole Indian Ocean (Above), Tropical Area (Middle), and Area 1 (Bottom) from 1979 to 2010.

Whole Indian Ocean

| Source | DF | Sum of Squares | Mean Square | F-value | P-value |
|---|---|---|---|---|---|
| Model | 284 | 836803.223 | 2946.490 | 2903.880 | <.0001 |
| Error | 655227 | 664841.523 | 1.015 | | |
| Corrected Total | 655511 | 1501655.746 | | | |
| | R-Square | Coeff Var | Root MSE | LnCPUE Mean | |
| | 0.557258 | 1851.367 | 1.007310 | 0.054409 | |
| Source | DF | Type III SS | Mean Square | F-value | P-value |
| year | 31 | 9966.91501 | 321.51339 | 316.86 | <.0001 |
| Area | 4 | 5613.33081 | 1403.3327 | 1383.04 | <.0001 |
| Season | 3 | 612.28211 | 204.09404 | 201.14 | <.0001 |
| ralb | 2 | 89862.62186 | 44931.31093 | 44281.5 | <.0001 |
| rbet | 3 | 95739.54851 | 31913.18284 | 31451.7 | <.0001 |
| year*season | 93 | 11039.10536 | 118.70006 | 116.98 | <.0001 |
| year*Area | 124 | 9376.88985 | 75.62008 | 74.53 | <.0001 |
| Area*season | 12 | 9339.94596 | 778.32883 | 767.07 | <.0001 |
| Area*rbet | 12 | 4341.07696 | 361.75641 | 356.52 | <.0001 |

Tropical Area

| Source | DF | Sum of Squares | Mean Square | F-value | P-value |
|---|---|---|---|---|---|
| Model | 170 | 408355.2466 | 2402.0897 | 2665.78 | <.0001 |
| Error | 440016 | 396491.0430 | 0.9011 | | |
| Corrected Total | 440186 | 804846.2896 | | | |
| | R-Square | Coeff Var | Root MSE | LnCPUE Mean | |
| | 0.50737 | 221.5460 | 0.949254 | 0.428468 | |
| Source | DF | Type III SS | Mean Square | F-value | P-value |
| year | 31 | 12156.4672 | 392.1441 | 435.19 | <.0001 |
| Area | 1 | 399.862 | 399.862 | 443.76 | <.0001 |
| season | 3 | 556.6269 | 185.5423 | 205.91 | <.0001 |
| ralb | 2 | 34279.2366 | 17139.6183 | 19021.1 | <.0001 |
| rbet | 3 | 264609.066 | 88203.022 | 97885.5 | <.0001 |
| year*season | 93 | 7961.5604 | 85.6082 | 95.01 | <.0001 |
| year*Area | 31 | 1176.5457 | 37.9531 | 42.12 | <.0001 |
| Area*season | 3 | 713.919 | 237.973 | 264.1 | <.0001 |
| Area*rbet | 3 | 756.4707 | 252.1569 | 279.84 | <.0001 |
| year | 31 | 12156.4672 | 392.1441 | 435.19 | <.0001 |

Area 1

| Source | DF | Sum of Squares | Mean Square | F-value | P-value |
|---|---|---|---|---|---|
| Model | 185 | 20760.97307 | 112.22148 | 132.66 | <.0001 |
| Error | 12910 | 10921.20818 | 0.84595 | | |
| Corrected Total | 13095 | 31682.18125 | | | |
| | R-Square | Coeff Var | Root MSE | LnCPUE Mean | |
| | 0.655289 | 56.35082 | 0.919755 | 1.632195 | |
| Source | DF | Type III SS | Mean Square | F-value | P-value |
| year | 31 | 374.280926 | 12.073578 | 14.27 | <.0001 |
| season | 3 | 8.15681 | 2.718937 | 3.21 | 0.0219 |
| ralb | 2 | 1451.471476 | 725.735738 | 857.89 | <.0001 |
| rbet | 3 | 948.94398 | 316.31466 | 373.92 | <.0001 |
| year*season | 66 | 902.085445 | 13.667961 | 16.16 | <.0001 |
| year*rbet | 80 | 535.421224 | 6.692765 | 7.91 | <.0001 |

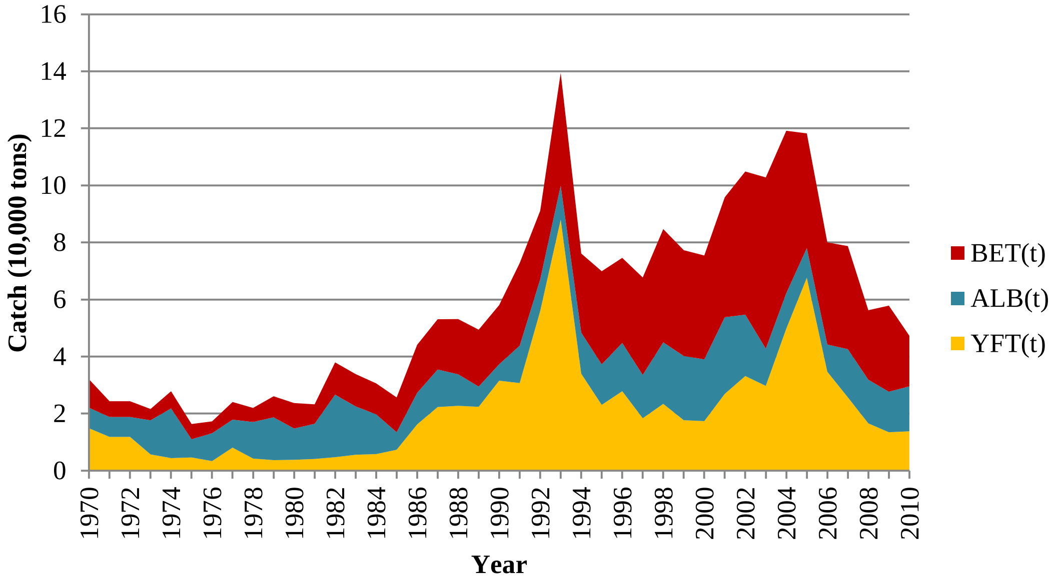


Figure 1. Nominal catches (metric tons) of main target species caught by Taiwanese longline fishery in the Indian Ocean over the period 1970 to 20010.

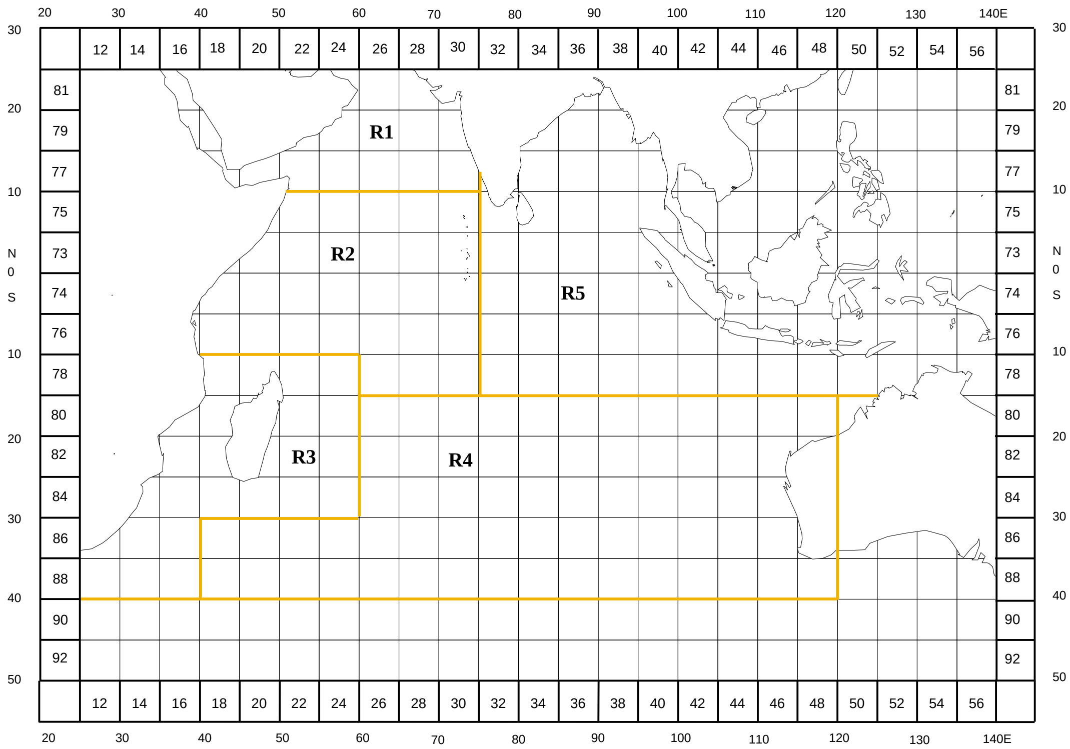


Figure 2. Area stratification used for the standardization of CPUE for yellowfin tuna in the Indian Ocean in 2010.

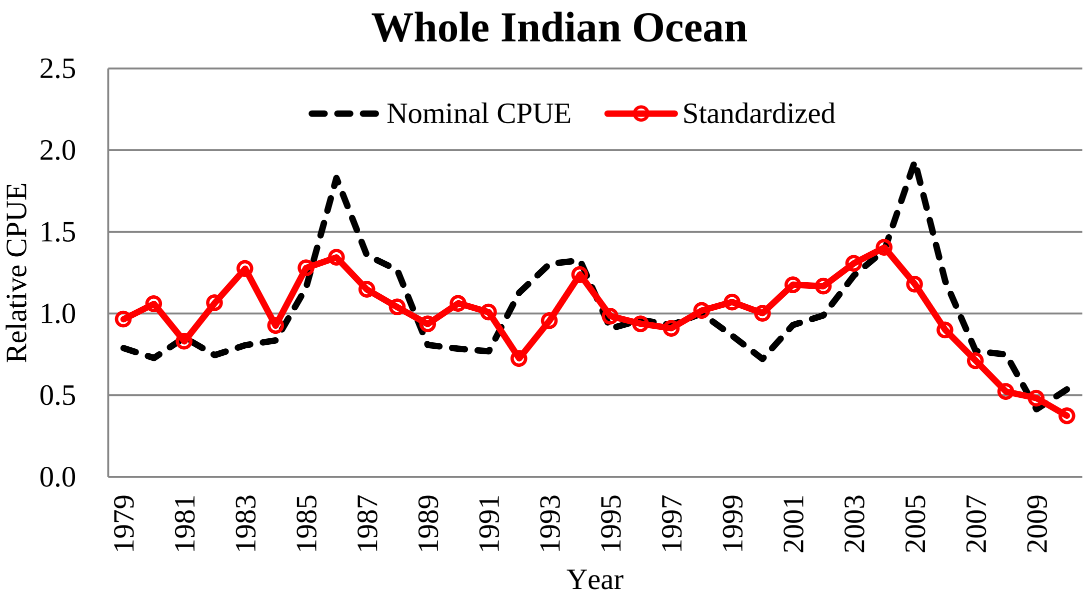


Figure 3. Relative nominal and standardized annually CPUE series for the whole Indian Ocean from 1979 to 2010.

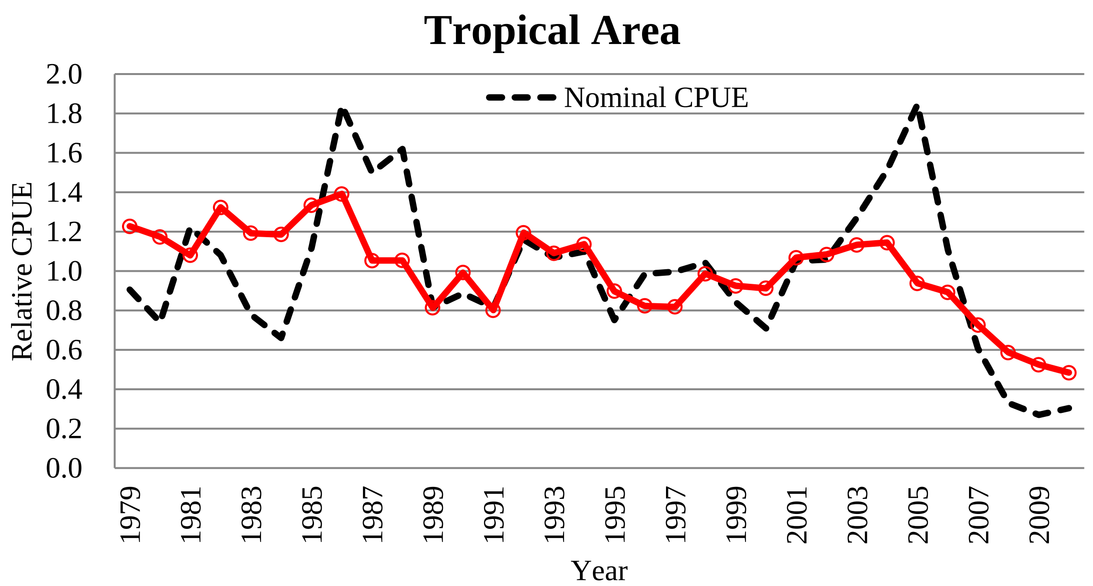


Figure 4. Relative nominal and standardized annually CPUE series for the tropical Indian Ocean from 1979 to 2010.

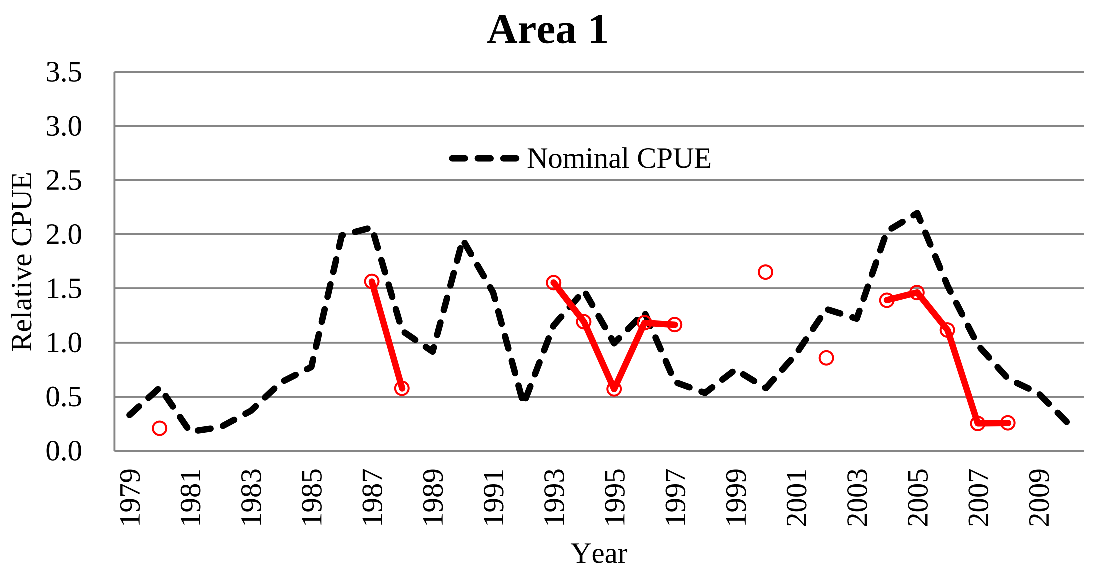


Figure 5. Relative nominal and standardized annually CPUE series for the Area 1 from 1979 to 2010.

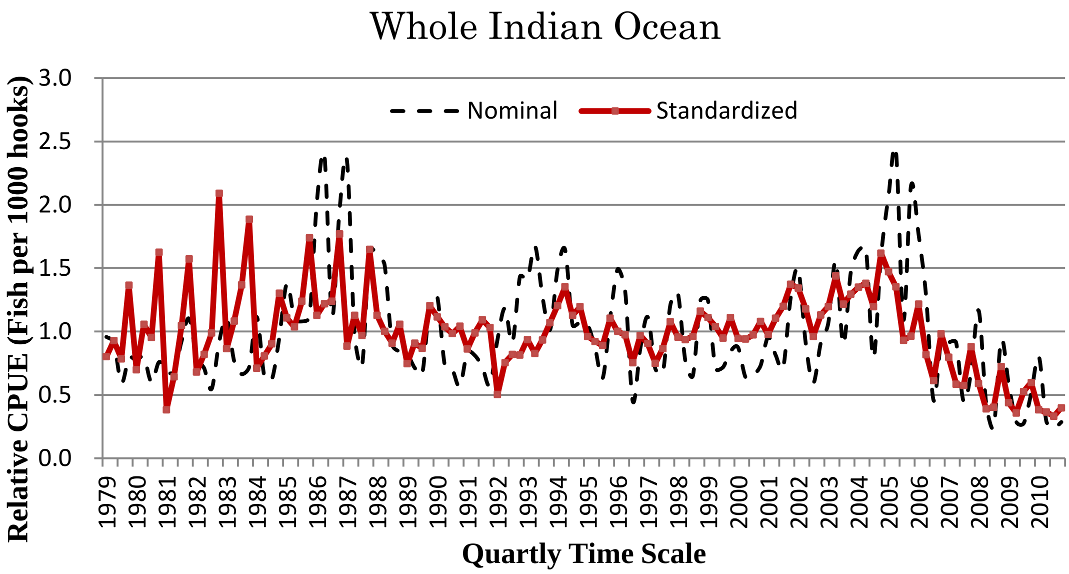


Figure 6. Relative nominal and standardized quarterly CPUE series for the whole Indian Ocean from 1979 to 2010.

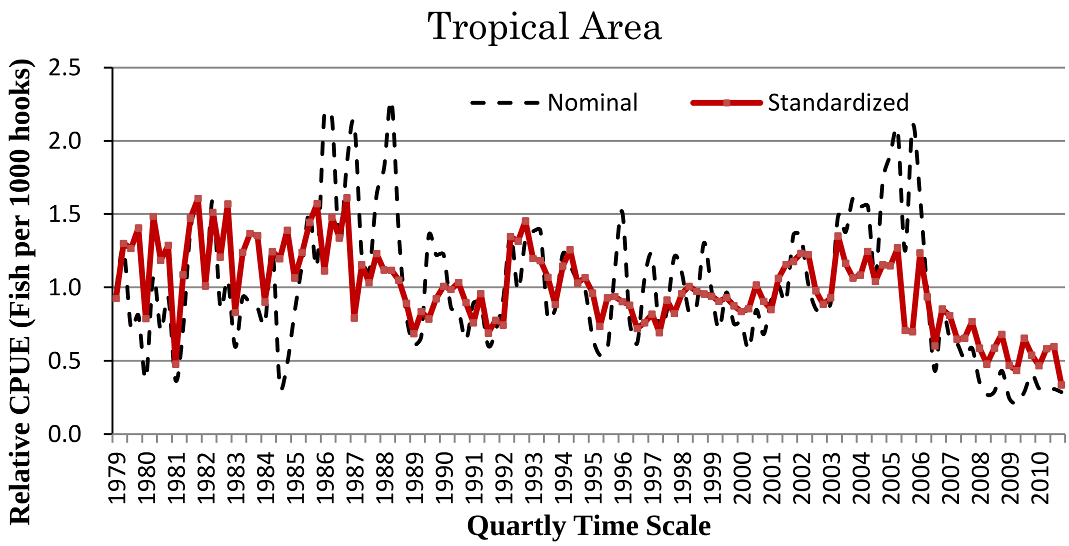


Figure 7. Relative nominal and standardized quarterly CPUE series for the tropical Indian Ocean from 1979 to 2010.

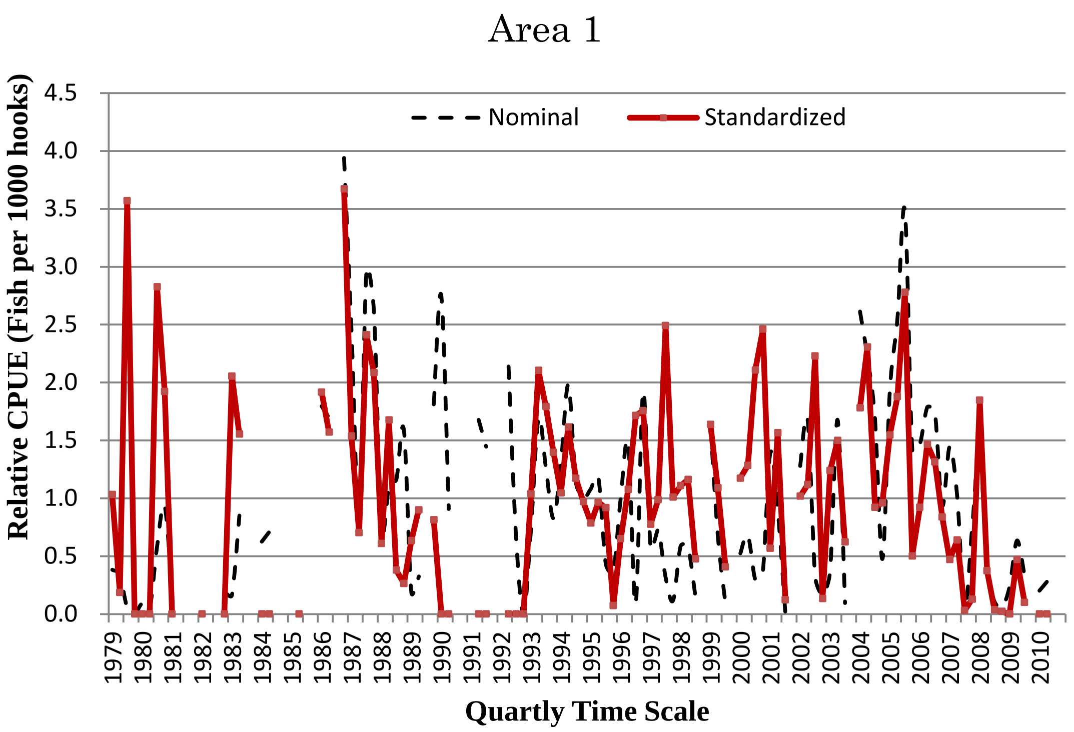


Figure 8. Relative nominal and standardized quarterly CPUE series for the Area 1 from 1979 to 2010.

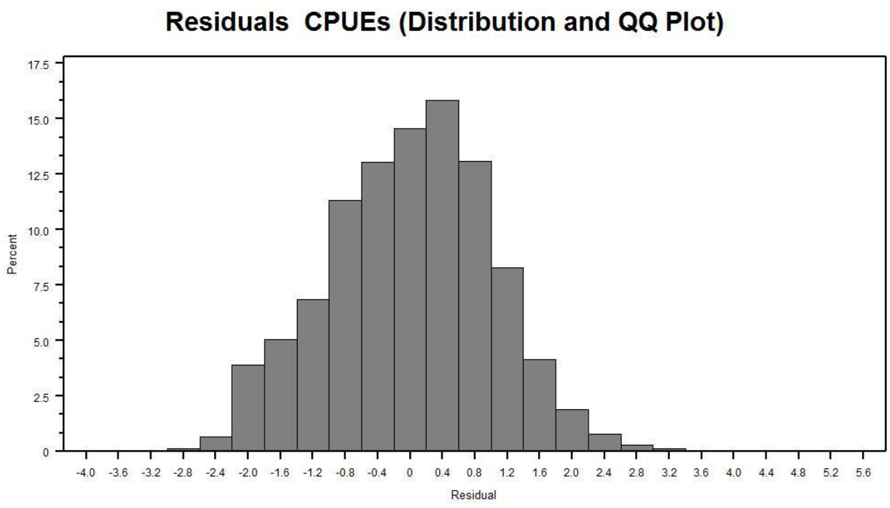


Figure 9. The residuals distribution of annual based CPUE standardization for the whole Indian Ocean from 1979 to 2010.

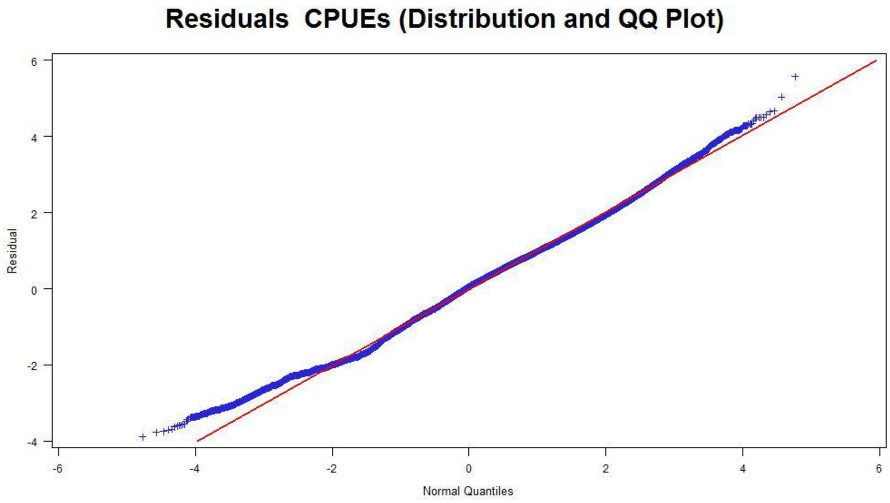


Figure 10. The QQPlot of annual based CPUE standardization for the whole Indian Ocean from 1979 to 2010.

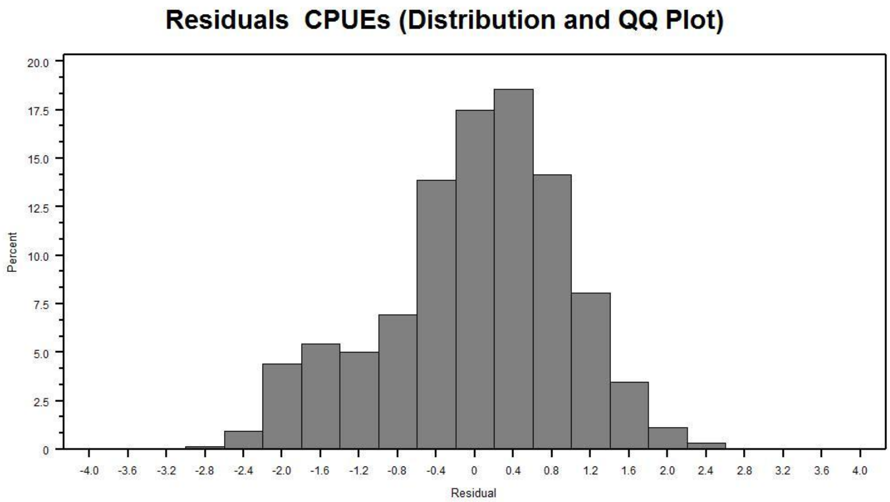


Figure 11. The residuals distribution of annual based CPUE standardization for the tropical Indian Ocean from 1979 to 2010.

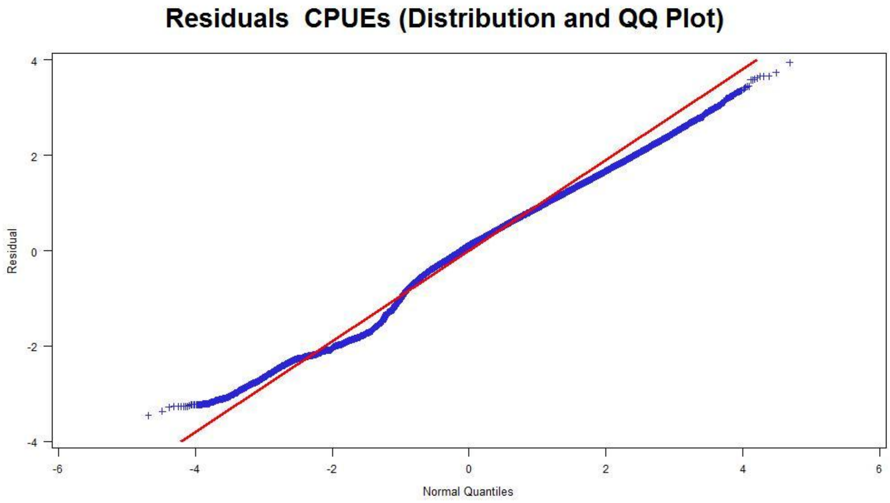


Figure 12. The QQPlot of annual based CPUE standardization for the tropical Indian Ocean from 1979 to 2010.

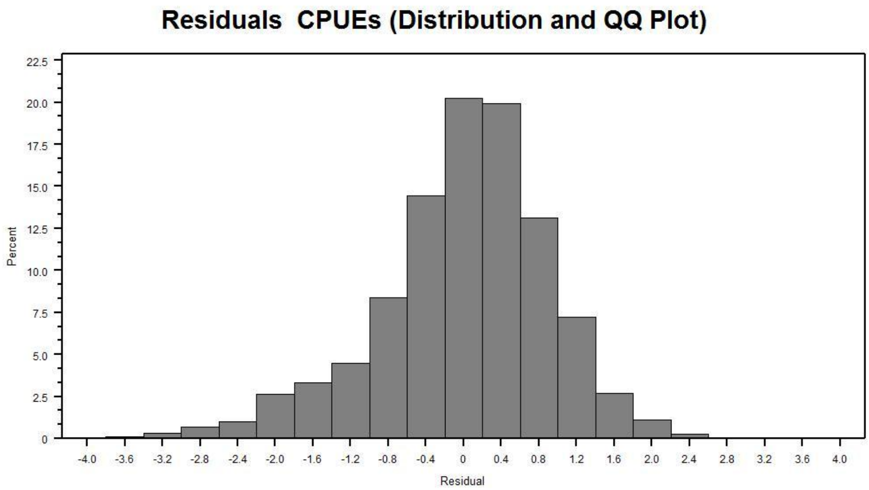


Figure 13. The residuals distribution of annual based CPUE standardization for the Area 1 from 1979 to 2010.

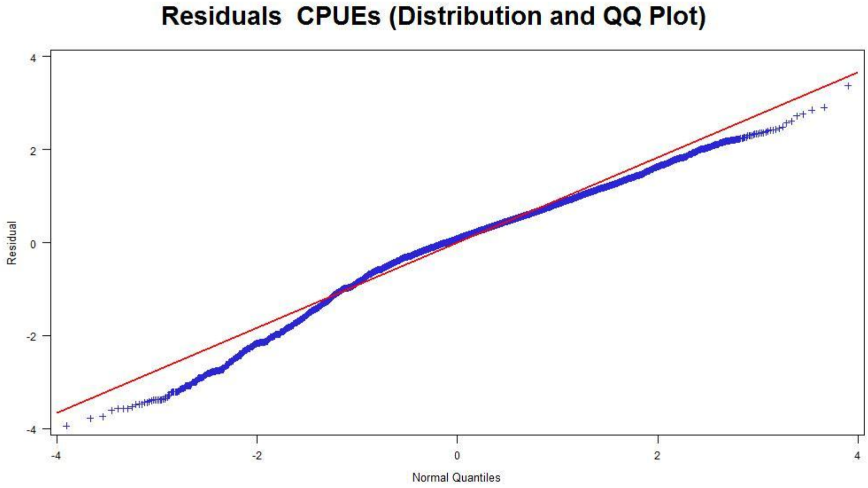


Figure 14. The QQPlot of annual based CPUE standardization for the Area 1 from 1979 to 2010.

## 4 References

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