Standardization of catch rate for black marlin (*Istiompax indica*) exploited by the Japanese tuna longline fisheries in the Indian Ocean (1971-2015)

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Abstract

We updated the standardized CPUE (catch number per 1,000 hooks) of black marlin (*Istiompax indica*) caught by the Japanese tuna longline vessel between 1971 and 2015. The Japanese longline set by set catch and effort statistics from 1971 to 2015 were used. Total number of operational data is 1,269,199 (unit: set) and zero catch ratio of black marlin is 93%. Since the proportion of zero catch is large, the core (hot spot) area approach based on the 1-degree area was applied by filtering Japanese longline catch and effort data. After filtering, total number of set used in the analysis decreased to 18,560 sets and zero catch ratio to 58%.

In addition, zero catch ratios are largely different by two periods. The zero catch ratio in the earlier half of the period (1971-1990) is low (around 40%) while high (around 80%) in the later period (1992-2015). Thus, we divided the data into these two periods and applied different GLM (log and delta-type 2 step model) for each period respectively. Then we calculated relative CPUE for each period setting the estimates of 1991 year as 1 and made standardized CPUE for the whole period. Large divergence between the standardized CPUE and the nominal CPUE was not observed in both periods, which likely suggested that this approach is plausible, although there was a large gap in standardized CPUE between two periods. The resultant standardized CPUE suggested the general decreasing trend during 1971-2015 with occasional spikes.

1. Introduction

We updated the standardized CPUE (catch number per 1,000 hooks) of black marlin (*Istiompax indica*) caught by the Japanese tuna longline vessel between 1971 and 2015. In past, standardization of CPUE of this stock was conducted one time (Uozumi 1998).

In this analysis, we focused on the period between 1971 and 2015 and did not include the data before 1970, considering the shift of target species around 1970s. In the 1950s and 60s some of the Japanese longline fishery targeted billfishes (mainly striped and black marlins) in the Indian Ocean, while after the early 1970s, it has targeted mainly bigeye, yellowfin, and southern bluefin (Uozumi 1998, Nishida and Wang 2013). It is suggested that this shift would accompany with the change of pattern of operation such as gear configurations (i.e., gear depth) and area of fishing, and would affect the analysis of standardization.

The aim of this study is to provide abundance index for black marlin in the Indian Ocean as input data for stock assessment by the 14th IOTC working party on billfish (WPB14) in 2016.

2. Materials and methods

(1) Data filtering

The Japanese longline set by set catch and effort statistics from 1971 to 2015 were used. Total number of operational data is 1,269,199 (unit: set) and zero catch ratio of black marlin in all data is 93%. Since the proportion of zero catch is large, the core (hot spot) area approach based on the 1-degree area was applied by filtering Japanese longline set by set catch and effort data. This method was applied in previous studies (Nishida and Wang 2013, Yokoi et al. 2016). The hot spots and the core area were defined as follows;

A) Hot spot is defined as the grid at 1 by 1 degree with positive catch more than 6 years in all of the quarter. The 6 year is not necessarily consecutive
B) Core area is the area with high density of hot spot judged by the eye

The total number of 1 by 1-degree compartment is 4,892 in the whole Indian Ocean. As a result of the application of the procedures and criteria above, 133 hot spots and three core area, i.e. Southwest (SW; between 18°S and 38°S and between 20°E and 41°E), Northwest (NW; between 5°S and 11°N and between 50°E and 70°E) and Central east (CE; between 14°S and 3°N and between 89°E and 120°E) were defined (Figure 1).

The core-areas include 111 hot spots, which were used for the further analyses. As a result of filtering above, total number of set used in the analysis is 18,560 and zero catch ratio is 58%.
In addition, zero catch ratios are largely different by two periods (Figure 2). The zero catch ratio in the earlier half of the period (1971-1990) is low (around 40%) while high (around 80%) in the later period (1992-2015). Thus, we divided the data into these two periods and applied different GLM (log and delta-type 2 step model) for each period respectively.

(2) Data division

For division of the data into two periods, we set the criteria at which the zero catch ratio of 60%, which corresponds to 1991. As described later, we applied different GLM for each period, thus direct comparison of two estimate is not appropriate. In order to address this problem, we conducted GLM for the period between 1971 and 1991 (earlier period) using log normal GL and between 1991 and 2015 (latter period) using delta-type 2 step model, respectively. Then we calculated relative CPUE for each period setting the estimates of 1991 year as 1.0 and compared each series of estimates connecting at 1991. Similar approaches were used in the past in the CCSBT (Commission for the Conservation of Southern Bluefin Tuna) (reference is under search).

(3) GLM analyses

Explanatory variables

In the standardization procedure, we evaluated the effect of year, season (quarter), core area, materials of main line, materials of branch line, gear (number of hooks between floats :NHBF), and effect of area of 1 by 1 degree (1×1: Hot spot) on the CPUE of black marline.

The core area is defined in Figure 1. Regarding gear effect, NHBF from 1971 to 1974 is not available from logbook, therefore the NHBF was assumed to be 5 for these years because the dominant NHBF in 1975 is five. The number of hooks between float (NHBF) were categorized into 6 classes (1: <=7, 2: 8-10, 3: 11-13, 4: 14-16, 5: 17-19, 6:>=20). The materials of main and branch lines composed of Nylon and others, which are available since 1994. The materials before 1993 was assumed as "others". All of the explanatory variables are categorical variables.

Response variable

The effects of factors were assessed using GLM procedure (log normal error structure model for the early period and delta-type 2 step model for the later period, R ver. 3.3.1, R Development Core Team.).

To stabilize the variance and satisfy the assumption of normality, natural log-transformations were conducted for dependent variables, which is CPUE (catch number of black marline per 1000 hooks). In order to avoid the base of logarithm to be zero, which corresponds to zero catch of black marline in a set, the 1/10 of the average CPUE for whole period was added to all CPUE.

The latter period applied delta-type two step model). In this two-step method, the ratio of zero-catch is estimated by the logit model with logit-link function (PA) in the first step as delta model. In the second step, log normal model to the data with a positive catch is applied.

GLM models by period

Step 1 Early period model (1971-1991)

Log normal model

ln (CPUE + constant) = mean + year + quarter + core-area + ML + BL + NHBF + [1×1] + year*quarter + quarter*area + err1

Step2 Latter period model (1991-2015)

Delta long model

PA= mean + year + quarter + core-area + ML + BL + NHBF + [1×1] + year*quarter + quarter*area + err2

ln (CPUE + constant) = mean + year + quarter + core-area + ML + BL + NHBF + [1×1] + year*quarter + quarter*area + err1 *where*

ln	:	*natural logarithm,*
CPUE	:	*catch in number of black marlin per 1,000 hooks,*
Constant	:	*10% of overall mean of CPUE*
PA	:	*nominal presence and absence of catch*
Mean	:	*overall mean,*
Year :	*effect of year,*	
Quarter	:	*effect of fishing season (1; Jan.-Mar., 2; Apr.-Jun., 3; Jul.-Sep., 4; Oct.-Dec.),*
core-area	:	*effect of sub-area (Figure 1;SW, NW,CE),*
ML	:	*effect of material of main line (0; unknown, 1; others, 2; Nylon),*
BL	:	*effect of material of branch line (0; unknown, 1; others, 2; Nylon),*
NHBF	:	*effect of gear depth (category of no. of hooks between floats),*
[1×1]	:	*effect of area of 1 by 1 degree (Hot spot),*
err1	:	*error term of log normal model, ~ Normal (0, σ^2),*
err2	:	*error term of delta model, ~ Bin(n, p).*

3. Results and discussion

Annual CPUE standardized by GLM combined in two periods were shown in Table 1 and Figure 3 in relative scale. In the relative scaled CPUE, 1991 year was set up as 1.0. The standardized CPUE in the first period is rather stable in 1.0-1.4 then there was the sharp decrease in 1992-1993, afterwards it level drastically dropped to the 0.2-0.4 level except spikes in two years (1998-1999). Large divergence between the standardized CPUE and the nominal CPUE was not observed in both periods (Figure 5).

The latter period is high zero catch ratio. The main factor for the temporal change of high zero catch ratio in the latter period is considered to be related to a change of gear configuration (Figure 4). Gear configuration of the early period mainly consists of shallow gear (gear1~gear2). But, that of the latter period shifted to mainly deep gear (gear5~gear6).

Black marlin that inhabit the shallow water (Chiang et al. 2015) is suggested to be hardly encountered with longline gear below its habitat depth has become hard to catch. To handle the change of zero catch ratio, (a) we incorporate number of hooks between floats to correct biases caused by changes of gear (hooks) configurations (Figure 4) and (b) we divided the period of data into the early period and the latter period to apply different models (GLM) for each period.

The reason of the sharp decrease in 1992-1993 is difficult to explain. This because (a) the nominal CPUE fits to GLM well and no anomalies in residuals and (b) we incorporate number of hooks between floats to correct biases caused by changes of gear (hooks) configurations.

In order to improve the analysis for black marline based on Japanese logbook data with high zero catch ratio in latter period, application of habitat model would be useful in the future work.

Appendix A shows ANOVA Table suggesting that “season” and “core area” interaction show high statistical significant affect to the nominal CPUE. This implies that nominal CPUE are highly affected by season and area. In addition, 1x1 degree effect also shows high statistical significant affect to the nominal CPUE. This may imply that anomalies of environmental and other effects occurred in each 1x1 cells by season are very high, which was adjusted by this covariate.

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Table 1. Standardized CPUE for annual CPUE of black marlin caught by Japanese longline vessels in the Indian Ocean which are expressed in relative scale as 1991 of 1.0.

Year	Relative CPUE	Year	Relative CPUE
1971	1.330	1994	0.487
1972	1.177	1995	0.518
1973	1.223	1996	0.282
1974	1.201	1997	0.291
1975	1.009	1998	0.754
1976	1.071	1999	0.898
1977	1.331	2000	0.317
1978	1.225	2001	0.275
1979	1.078	2002	0.371
1980	1.266	2003	0.280
1981	1.180	2004	0.342
1982	1.001	2005	0.161
1983	1.093	2006	0.584
1984	1.216	2007	0.449
1985	1.183	2008	0.373
1986	1.158	2009	0.351
1987	1.225	2010	0.422
1988	1.087	2011	0.399
1989	1.081	2012	0.267
1990	0.986	2013	0.182
1991	1.000	2014	0.398
1992	1.176	2015	0.595
1993	1.003		

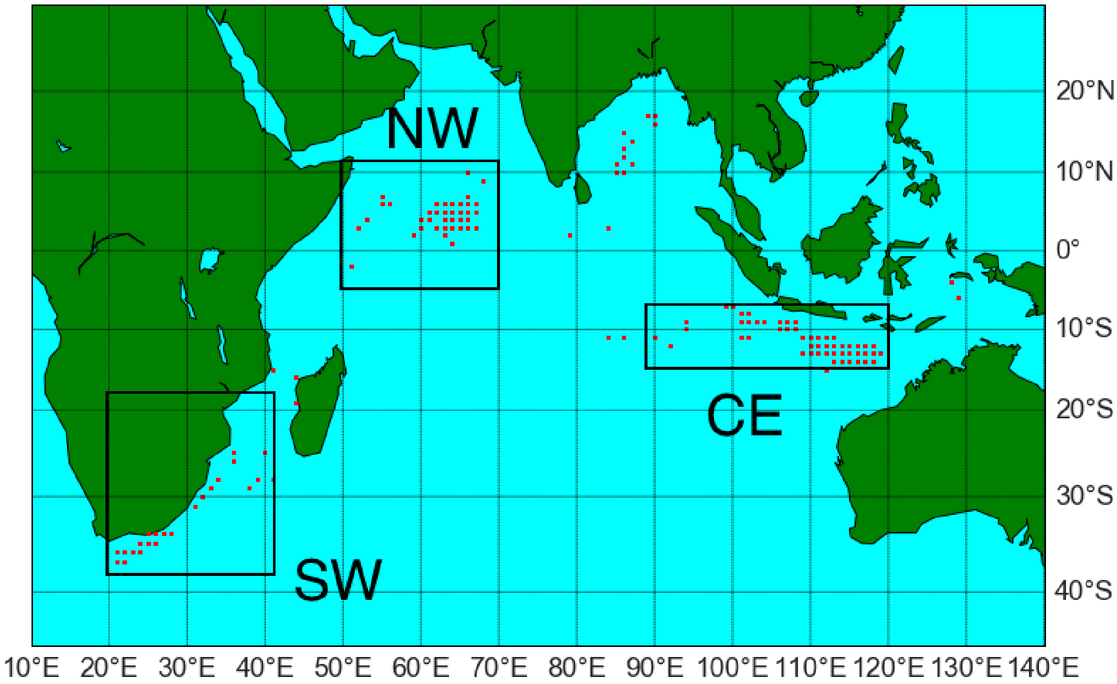


Figure 1. Three core area (SW, NW and CE) and hot spots (red square) used in CPUE standardization of black marlin caught by Japanese longline vessel in the Indian Ocean.

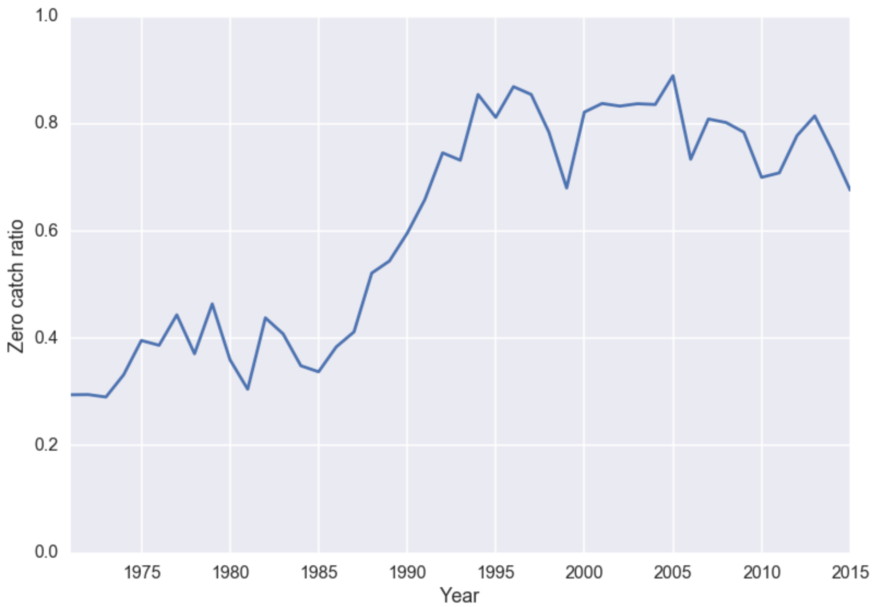


Figure 2. Annual zero catch ratio of black marlin caught by Japanese longline vessel in the Indian Ocean.

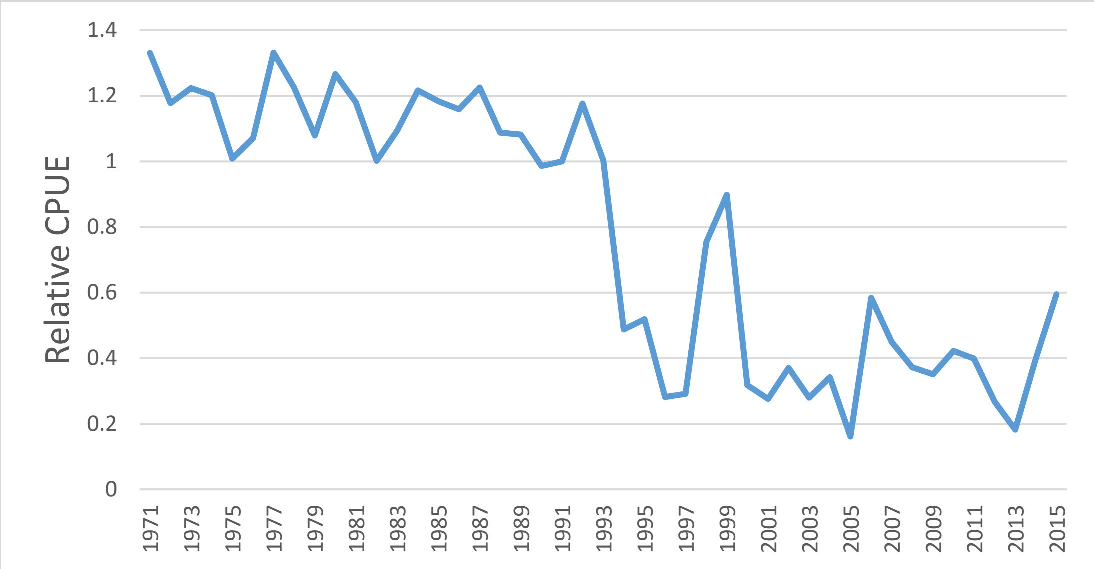
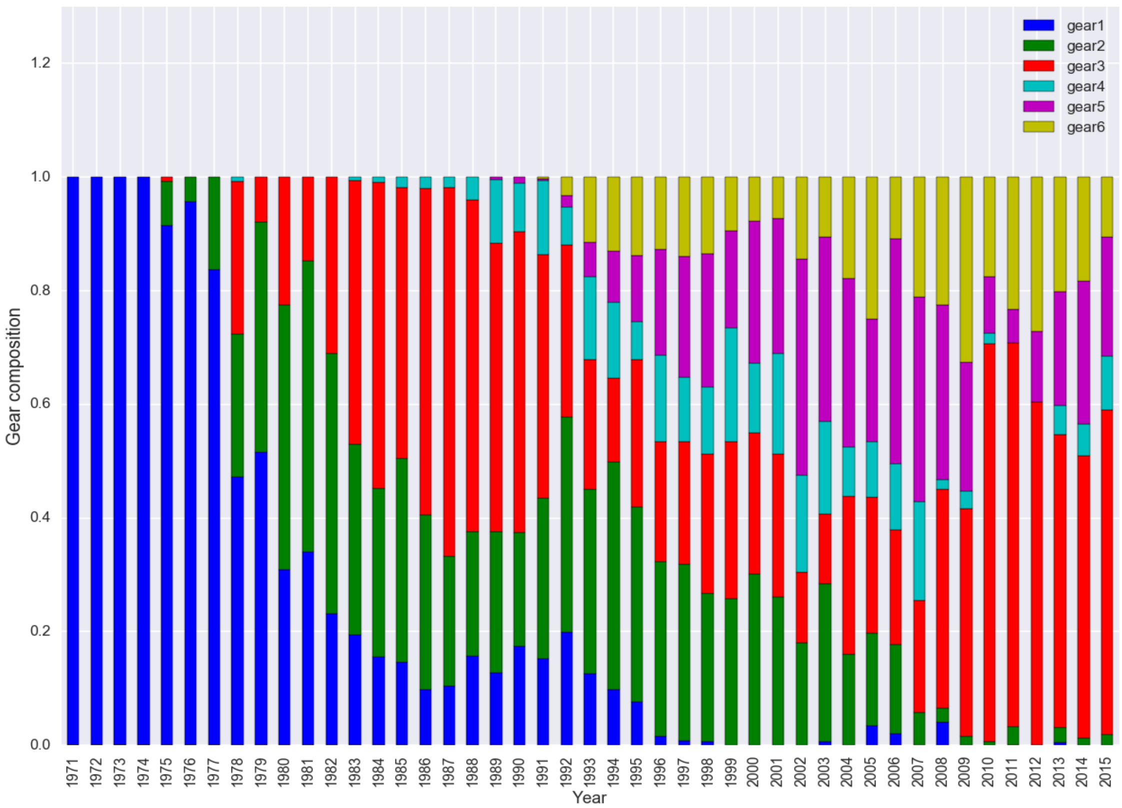


Figure 3. Annual trend of standardized CPUE of black marlin caught by Japanese longline vessels in the Indian Ocean which is expressed in relative scale as 1991 estimates of 1.0.



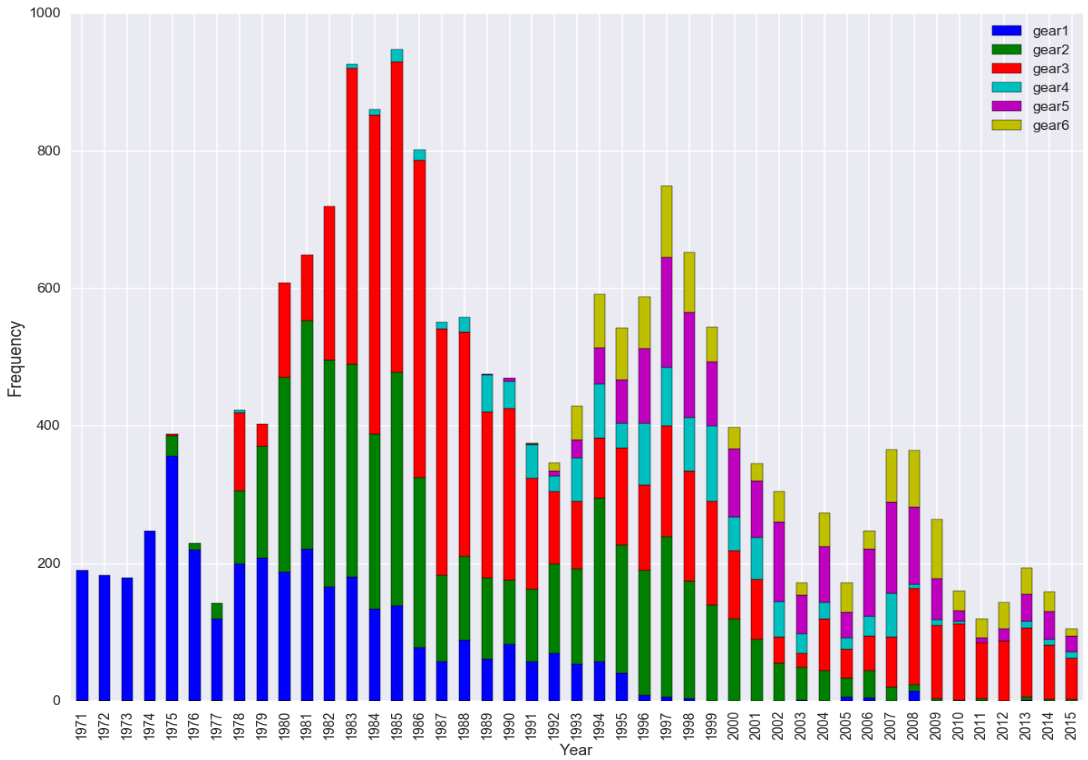
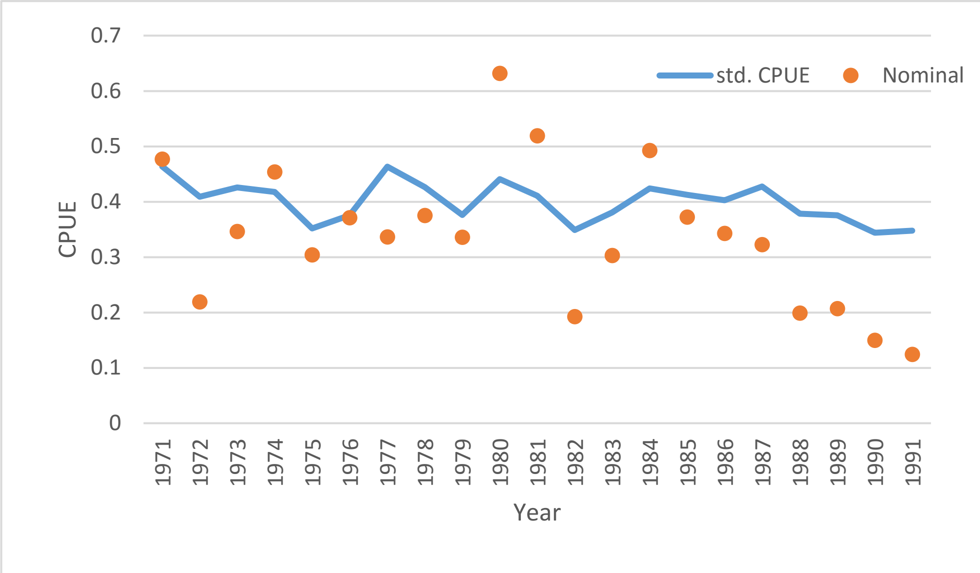


Figure 4. Annual gear composition (upper) and gear frequency (lower; unit is set) of black marlin caught by Japanese longline vessels in the Indian Ocean.



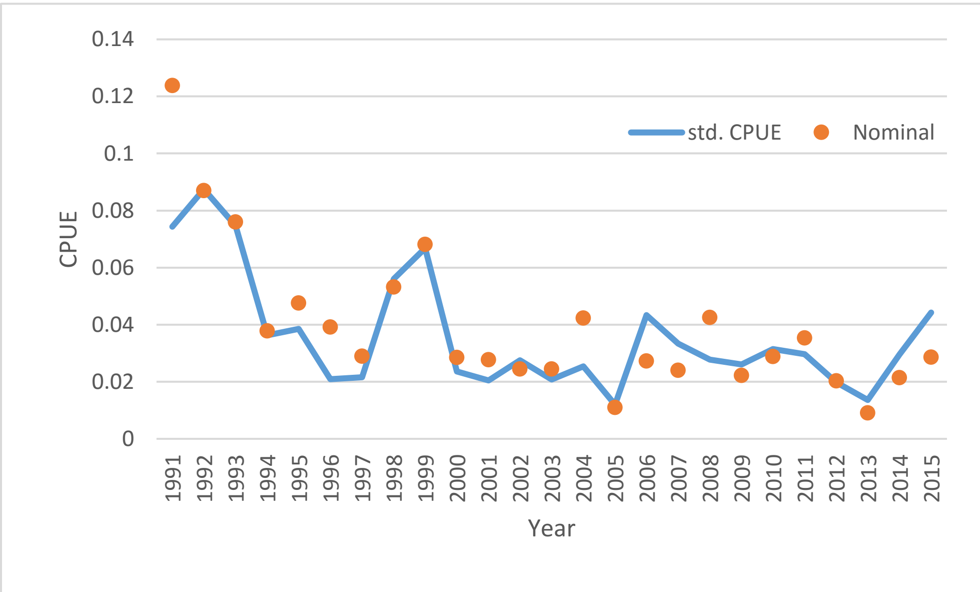


Figure 5. Annual trend of standardized CPUE of black marlin caught by Japanese longline vessels in the Indian Ocean in real scale.

Appendix A. Result of ANOVA table for CPUE of blue marlin

Step1 : Early period (1971-1991)).

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Analysis of Deviance Table (Type III tests)

Response: logCPUE
Error estimate based on Pearson residuals

                                              SS    Df        F    Pr(>F)
as.factor(year)                            19.28    20   5.3841 6.322e-14 ***
as.factor(quarter)                         17.51     3  32.5953 < 2.2e-16 ***
as.factor(1×1)                            166.44   108   8.6075 < 2.2e-16 ***
as.factor(NHBF)                            10.29     5  11.4950 4.342e-11 ***
as.factor(year):as.factor(quarter)         58.64    60   5.4583 < 2.2e-16 ***
as.factor(quarter):as.factor(core-area)   335.96     6 312.7430 < 2.2e-16 ***
Residuals                                1812.44 10123
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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Step 2. Latter period (1991-2015)

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Analysis of Deviance Table (Type III tests)

Response: logCPUE2
Error estimate based on Pearson residuals

                                             SS   Df       F    Pr(>F)
as.factor(year)                           59.48   24  3.2421 2.199e-07 ***
as.factor(quarter)                         2.24    3  0.9774  0.402496
as.factor(1×1)                           248.63   98  3.3189 < 2.2e-16 ***
as.factor(ML)                              0.08    2  0.0502  0.951031
as.factor(BL)                              8.27    2  5.4110  0.004551 **
as.factor(NHBF)                            4.12    5  1.0783  0.370438
as.factor(year):as.factor(quarter)        90.57   72  1.6456  0.000672 ***
as.factor(quarter):as.factor(core-area)   83.58    6 18.2238 < 2.2e-16 ***
Residuals                               1196.34 1565
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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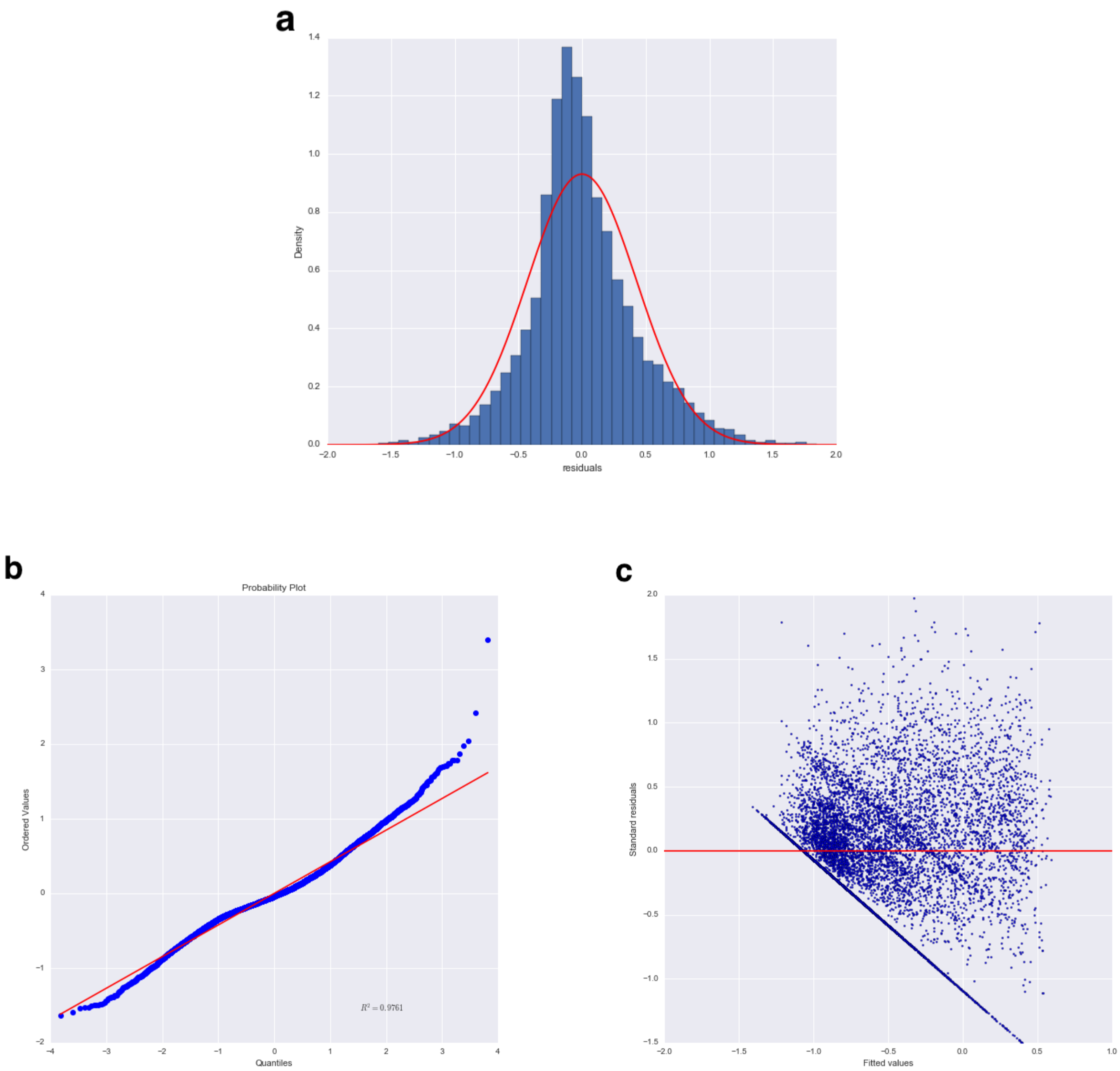
Appendix B. Standardized and nominal CPUEs for black marlin in the early period caught by Japanese longline vessels in the Indian Ocean in real scale.

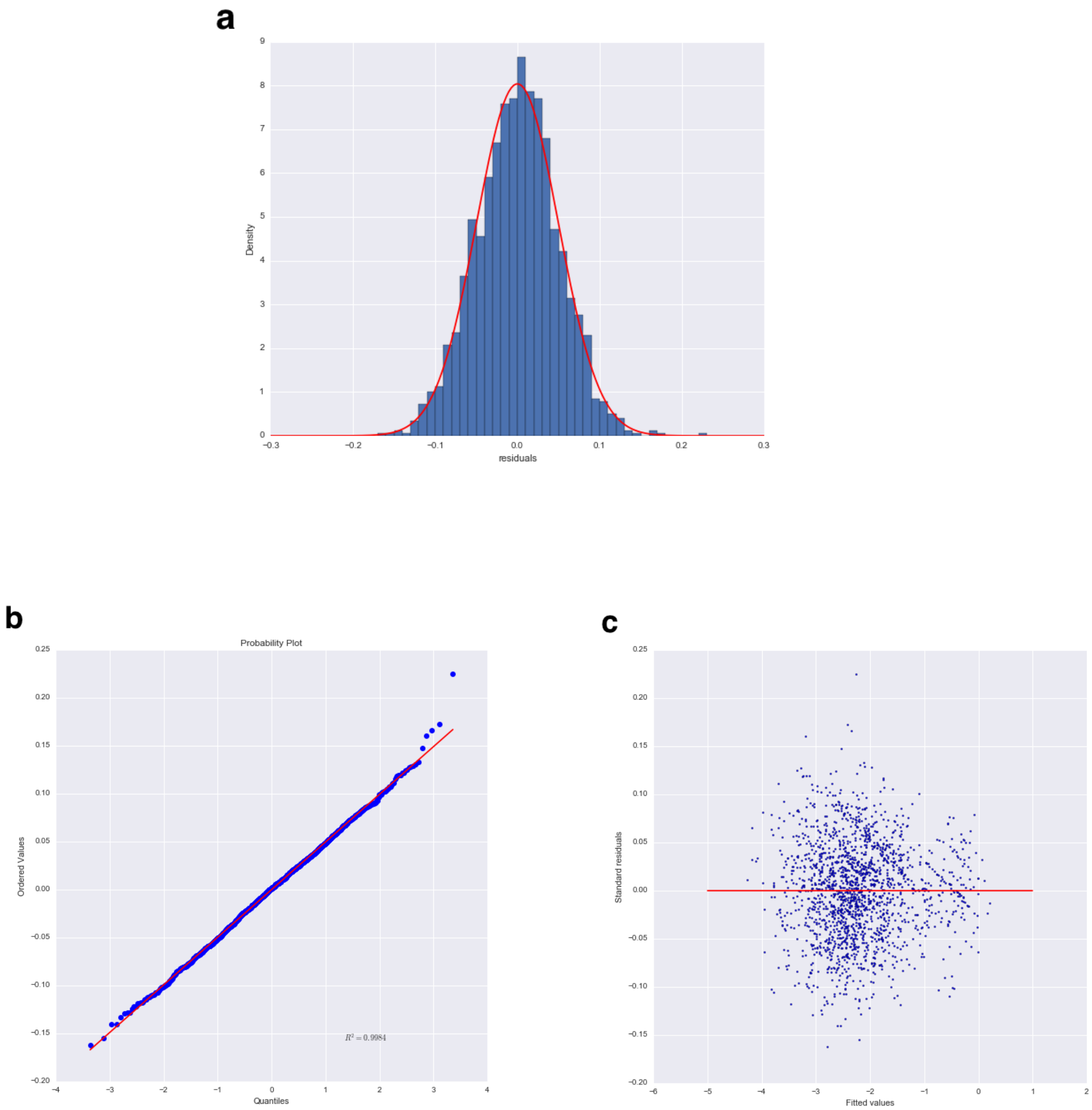
Year	std. CPUE	Nominal
1971	0.463659159	0.476674776
1972	0.409079873	0.218618395
1973	0.425963285	0.345828428
1974	0.417692709	0.453642763
1975	0.351669097	0.303840087
1976	0.375799455	0.37084114
1977	0.463341804	0.335946346
1978	0.426637407	0.37515361
1979	0.376281528	0.335440837
1980	0.441062094	0.631512823
1981	0.410995005	0.51887825
1982	0.349090017	0.192323781
1983	0.38091052	0.302587047
1984	0.4239116	0.492103254
1985	0.412505302	0.371875352
1986	0.402863904	0.342520746
1987	0.427504028	0.322580059
1988	0.378399227	0.198635622
1989	0.37575467	0.206661324
1990	0.343993285	0.14958992
1991	0.347599267	0.123886258

Appendix C. Standardized and nominal CPUEs for black marlin in the latter period caught by Japanese longline vessels in the Indian Ocean in real scale.

Year	std. CPUE	Nominal
1991	0.074378497	0.123886258
1992	0.08747683	0.087053647
1993	0.074637047	0.076067997
1994	0.03623805	0.037820788
1995	0.038541553	0.047630786
1996	0.020958075	0.039227609
1997	0.021631033	0.028962581
1998	0.056075023	0.05320239
1999	0.066768579	0.068225342
2000	0.023594813	0.028514737
2001	0.020479394	0.02771682
2002	0.027572715	0.024493111
2003	0.020822245	0.024535059
2004	0.025424804	0.042345614
2005	0.011964872	0.010976164
2006	0.043415131	0.027286904
2007	0.033405303	0.024099324
2008	0.027717226	0.04257273
2009	0.026073107	0.022275203
2010	0.031416307	0.028832597
2011	0.029663996	0.035401425
2012	0.019825946	0.020324442
2013	0.013557634	0.009085818



Appendix D. Diagnosis of standardized CPUE in the early period (1971-1991) based on the log normal GLM (step 1). a: Residual histogram, b: Q-Q plot and c: residual plot for CPUE of blue marlin caught by Japanese longline vessels in the Indian Ocean



Appendix D. Diagnosis of standardized CPUE in the latter period (1991-2015) based on the delta log normal GLM (step 2). a: Residual histogram, b: Q-Q plot and c: residual plot for CPUE of blue marlin caught by Japanese longline vessels in the Indian Ocean