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# Update of CPUE and catch for blue shark caught by Japanese longliner during 1971-1993 in the Indian Ocean

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**Summary**

This document paper presents the estimates of catch-per-unit-of-effort (CPUE) and catch of the blue shark caught by Japanese longline fishery in the Indian Ocean during 1971-1993 with the improvement of standardization methods. CPUE was standardized using zero-inflated negative binomial model after the data filtering on the basis of more than 54 % reporting rate (RR; number of sets with "sharks" recorded/total number of sets). A stepwise approach is used to choose the preferred explanatory variables and the best model is selected based on the AIC. Annual changes in the CPUE suggested that the historical population trend of blue shark during 1971-1993 were relatively stable with annual fluctuations. Annual changes in total catch number had increased until mids 1980s and then decreased until 1990.

**Keywords**

Blue shark, Indian Ocean, Logbook data, CPUE

## 1. Introduction

CPUE and catch of Japanese longline fisheries in the Indian Ocean during 1971 and 1993 were presented in the previous document paper (Hiraoka and Yokawa 2012). The filtering method used for the CPUE standardization was based on the reporting rate more than 80 % that was developed by the Atlantic data (Nakano and Clark 2006). Kai and Yokawa (2015) estimated an appropriate reporting rate which was more than 54 % for the logbook data collected by the Japanese longline fishery in the Indian Ocean, so that we apply the rate to the data filtering. Spatial distribution patterns of size and sex-ratios of blue shark in the Indian Ocean was examined using the huge data set collected through the cooperative research between several institutes and national scientists, information on blue shark catch at size (Rui *et al*. 2015). They indicated suitable four area stratifications, so that we apply them as well. Moreover, we changes the model from lognormal to zero-inflated negative binomial model because zero-inflated negative binomial model is better for the count data with a large number of zero catch data, and lognormal model is known to cause a large bias for an estimates of CPUE (Shono 2008). The purpose of this document paper is to improve the estimation methods that produces the more reliable standardized CPUE and catch for 1971-1993 than those in the previous working paper.

## 2. Material and Methods

### *2.1 Data sources*

Logbook data of Japanese longliners operating in the Indian Ocean from 1971 to 1993 were compiled by the National Research Institute of Far Seas Fisheries (NRIFSF). Set-by-set data used in this study included information on the number of cruise for each vessels, operational time (year, month, day), catch number, catch weight, amount of effort (number of hooks), number of branch lines between floats (hooks per float: hpf) as a proxy for gear configuration, location (longitude and latitude) of set by resolution of 1 × 1 degree square, and vessel identity. Logbook data from 1994 to 2013 was also used to estimate proportion of “blue shark” to “sharks” by area and season because there is no enough information about shark species prior to 1994.

### *2.2 Data filtering*

The data was filtered based on a criterion of more than 54 % reporting rate (RR; number of sets with “sharks” recorded/total number of sets) estimated by Kai and Yokawa (2015).

### *2.3 Data processing*

- Area stratification was conducted based on the recommendation by Rui *et al*. (2015). Indian Ocean was split into four areas at 25˚S and 80˚E (area 1 (SW), area2 (SE), area3 (NW), area 4 (NE)).
- Four seasons (1:January-March, 2:April-June, 3:July-September, 4: October-December ) were used and hooks per float (hpf) was separated into two (less than 10 and more than 9).
- Proportion of “blue shark” to “sharks” by area and season were used to estimate the blue shark catch through the multiplication of the “sharks” catch by the proportion. The values after the decimal point were rounded up.

### *2.4 CPUE standardization*

CPUE was standardized using generalized linear model. Zero-inflated negative binomial model was used for the standardization because the catch number is count data and the zero catch ratio was relatively high (24 %), and dispersion (variance / mean) ratio was 15.9. The full model is as follows;

$$Mean\ count\ catch = \beta_0 + \beta_1 \cdot year + \beta_2 \cdot area + \beta_3 \cdot season + \beta_4 \cdot hpf + \beta_5 \cdot year : area$$
$$+ \beta_6 \cdot year : season + \beta_7 \cdot area : season + \beta_8 \cdot hpf : area + \beta_9 \cdot hpf : season + \log(hook) + \varepsilon_1$$
$$False\ zero\ prob = \beta_0 + \beta_1 \cdot year + \beta_2 \cdot area + \varepsilon_2$$

where $B_0$~$B_9$ are coefficients for each factors, “year” is a year effect from 1971 to 1993, other factors; “area”, “season” and “hpf” are described above, “year:area”, “area:season”, “hpf:area”, “hpf:season” are two way interaction of each factor, “log(hook)” is a offset, $\varepsilon_1$ is error terms followed by negative binomial model with log link function, and $\varepsilon_2$ is error terms followed by binomial model with logit link function.

*2.5 Model selection*

A stepwise approach is used to choose the preferred explanatory variables and the best model is selected based on the AIC.

The least squared means (LSMEANS) of each explanatory variables were computed using the same estimation procedure as the SAS package. Lower and upper 95 % confidence intervals of the yearly changes in the CPUE were estimated using the bootstrap with three hundred nonparametric replicates for the best-fit model. These standardized CPUEs were compared with nominal CPUEs of blue hsark calculated by captured number ×1000/hook number. All computations were performed in R version 3.1.2 for Windows (R Development Core Team 2015). The zero-inflated negative binomial models were computed with the “pscl” libraries.

*2.5 Estimation of catch number*

Retained catch number of blue shark and total catch number including retained and unreported catch were estimated using the standardized CPUE and total effort (number of hooks) without data filtering. Area and season specific catch of blue shark were estimated using the proportion of the “blue shark” to “shark species” in Table 1.

**3. Results**

Full model (model 1) was selected based on the AIC (Table 2). The effects of each explanatory variables (year, quarter, area, hpf, and all two way interactions) on the fitting were statistically significant ($P(\chi^2) < 0.0001$) (Table A1). The changes in AIC indicated that the impacts of “Year-Area” and “Year-Season” effects were higher than any other effects (Table 2).

Annual trends of estimates of standardized CPUEs (least squares means) for blue shark for the best model was shown in Fig. 1 and Table 3. The trends were almost similar between nominal and standardized CPUEs but the absolute values of nominal CPUEs were little higher than those of standardized CPUE. The trend of standardized CPUE was relatively stable although annual fluctuation was relatively high. The 95% confidence intervals (CI) of the best fitted model were narrow (mean CV = 0.05).

Histograms of Pearson residuals for CPUE values under ZINB for 1971-1993 were shown in Fig. 2. The Pearson residuals were close to zero but there was a small negative bias which were also observed for all main effects (Fig. 3).

Annual changes of landed catch and estimated catch from standardized CPUE from 1971 to 1993 were largely different as for the trends as well as the absolute values (Fig. 4). The mean value of estimated total catch number including unreported catch was 7.4 times higher than those of landed catch number. Landed catch number is relatively stable throughout the period, while the trends of total catch number had increased from 1970's until mid-1980s except for 1974 and 1975, and then had decreased.

## 4. Discussions

This document paper estimated a historical population trend and catch number of blue shark in the Indian Ocean using zero-inflated negative binomial model with a great amount of Japanese longline data from 1971 to 1993. The results indicated that the historical population trend of blue shark was stable during 1971 and 1993, while the estimated total catch number had increased until mid-1980s and then decreased.

Logbook data north of 25˚S from 1994 to 2013 was not validated using the observer data with the same spatial-temporal data due to a shortage of the observer data (Kai and Yokawa 2015). Therefore, the CPUEs in the north areas are less reliable than those in the south areas. In addition, larger sizes of blue shark tended to occur in equatorial and tropical regions in Indian Ocean and smaller sizes in southern latitudes in more temperate waters (Rui *et al*.2015). In considerations of these facts, the trends of CPUE in north of 25˚S indicates the abundance indices of spawning stock biomass has less reliability, while those in south of 25˚S indicates the abundance indices of entire sizes has more reliability.

Proportion of "blue shark" to "sharks" by area and season for 1994-2013 were used to estimate the blue shark catch for 1971-1993. This strong assumption can be justified if the blue shark is incidentally caught by Japanese longliner without changing the targeting between two time periods. In the Pacific Ocean, Some Japanese offshore longliner is known to change the targeting from swordfish to blue shark and vice versa (Kai *et al*. 2014) but Japanese distant water longliner in the Indian Ocean have never targeted the blue sharks.

## Reference

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Table. 1 Proportion of “blue shark” to “sharks” by area and season. The mean values are calculated from logbook data during 1994 and 2013. Area stratification is the same as that used in the Rui *et al*. 2015.

| Season | Area 1 (SW) | Area 2 (SE) | Area 3 (NW) | Area 4 (NE) |
|---|---|---|---|---|
| 1 | 0.749 | 0.821 | 0.673 | 0.768 |
| 2 | 0.782 | 0.844 | 0.468 | 0.761 |
| 3 | 0.736 | 0.882 | 0.549 | 0.781 |
| 4 | 0.716 | 0.793 | 0.638 | 0.869 |

Table. 2 Model descriptions, Akaike information criterions (AIC), and a difference between AIC and minimum value of AIC ($AIC_{min}$).

| No | Model description (negative binomial) | AIC | $AIC\text{-}AIC_{min}$ |
|---|---|---|---|
| 0 | Y+S+A+H+YA+AQ+YQ+HA+HQ | 317,125 | 0 |
| 1 | Y+S+A+H+YA+AQ+YQ+HA | 317,133 | 8 |
| 2 | Y+S+A+H+YA+AQ+YQ+HQ | 317,437 | 312 |
| 3 | Y+S+A+H+YA+AQ+YQ | 317,595 | 469 |
| 4 | Y+S+A+H+YA+HA | 318,763 | 1637 |
| 5 | Y+S+A+H+YA+HQ | 319,180 | 2055 |
| 6 | Y+S+A+H+YA+AQ | 319,074 | 1948 |
| 7 | Y+S+A+H+YA | 319,315 | 2189 |
| 8 | Y+S+A+H | 322,271 | 5145 |
| 9 | Y+S+A | 322,989 | 5863 |
| 10 | Y+A | 323,443 | 6318 |

Table.3 Nominal CPUE, standardized CPUE, 95 % confidence intervals of the standardized CPUE with 500 bootstrap, Coefficient variation (C.V.), estimated retained catch, and estimated total catch (retain + other) from the standardized CPUE and all the effort during 1971 and 1993.

| year | Nominal CPUE | Standardized CPUE | Upper-95%CI | Lower-95% CI | C.V. | Estimated retained catch | Estimated total catch |
|---|---|---|---|---|---|---|---|
| 1971 | 1.27 | 1.27 | 1.33 | 1.21 | 0.03 | 27,437 | 70,968 |
| 1972 | 1.37 | 1.27 | 1.35 | 1.20 | 0.03 | 21,817 | 66,697 |
| 1973 | 1.03 | 0.91 | 0.97 | 0.86 | 0.03 | 11,437 | 61,797 |
| 1974 | 1.58 | 1.43 | 1.51 | 1.35 | 0.03 | 19,474 | 91,023 |
| 1975 | 1.97 | 1.72 | 1.82 | 1.60 | 0.03 | 17,770 | 135,700 |
| 1976 | 1.26 | 1.22 | 1.35 | 1.11 | 0.05 | 7,674 | 60,127 |
| 1977 | 1.46 | 1.59 | 2.02 | 1.28 | 0.12 | 4,897 | 74,231 |
| 1978 | 1.10 | 0.92 | 0.98 | 0.86 | 0.03 | 9,953 | 55,210 |
| 1979 | 1.74 | 1.48 | 1.59 | 1.37 | 0.04 | 8,231 | 100,304 |
| 1980 | 1.47 | 1.24 | 1.34 | 1.17 | 0.03 | 9,721 | 114,435 |
| 1981 | 1.39 | 1.17 | 1.30 | 1.09 | 0.04 | 10,592 | 109,550 |
| 1982 | 1.97 | 1.67 | 1.93 | 1.48 | 0.07 | 7,060 | 150,059 |
| 1983 | 1.11 | 0.99 | 1.07 | 0.91 | 0.04 | 11,635 | 113,378 |
| 1984 | 1.80 | 1.36 | 1.49 | 1.24 | 0.05 | 16,844 | 172,546 |
| 1985 | 1.40 | 1.25 | 1.35 | 1.17 | 0.04 | 20,899 | 174,009 |
| 1986 | 1.42 | 1.16 | 1.28 | 1.04 | 0.06 | 15,174 | 155,121 |
| 1987 | 1.48 | 1.11 | 1.18 | 1.03 | 0.04 | 19,530 | 119,140 |
| 1988 | 1.49 | 1.34 | 1.44 | 1.25 | 0.04 | 15,897 | 118,527 |
| 1989 | 1.35 | 1.19 | 1.33 | 1.08 | 0.05 | 14,375 | 108,422 |
| 1990 | 1.71 | 1.65 | 2.14 | 1.41 | 0.12 | 9,476 | 82,632 |
| 1991 | 1.33 | 1.23 | 1.34 | 1.13 | 0.05 | 10,891 | 67,694 |
| 1992 | 1.21 | 1.08 | 1.16 | 1.01 | 0.04 | 11,882 | 60,246 |
| 1993 | 1.86 | 1.63 | 1.85 | 1.40 | 0.07 | 14,997 | 96,023 |

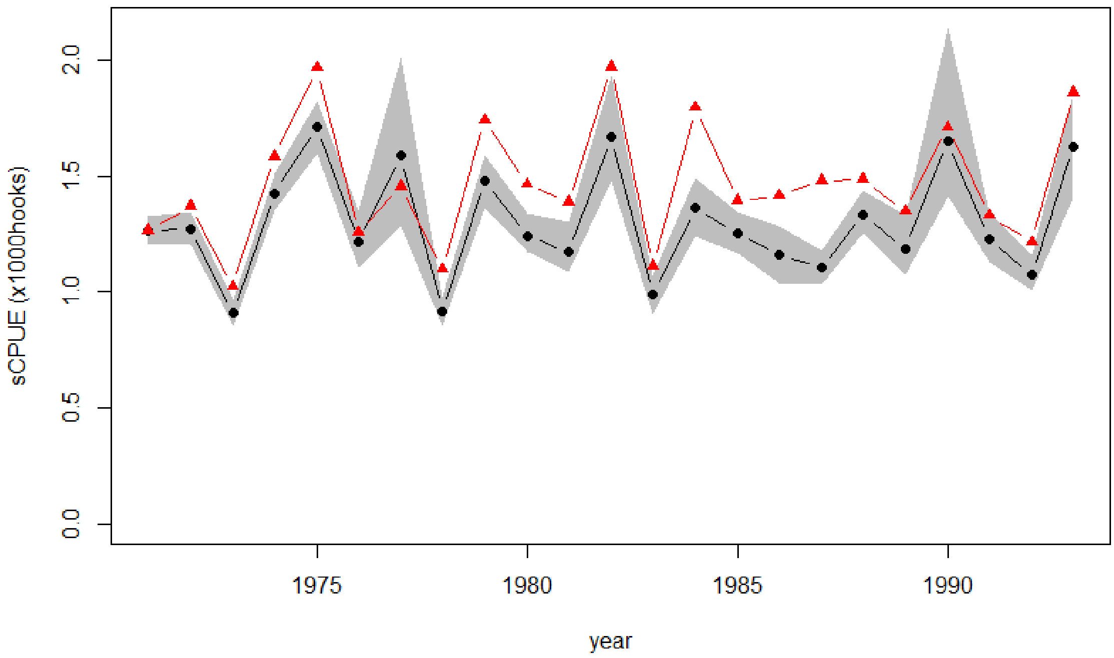


Fig. 1 Annual changes of nominal CPUE (red line with triangle) and standardized CPUE (black line with circle) with 95 % confidence intervals (shade) from 1971 to 1993.

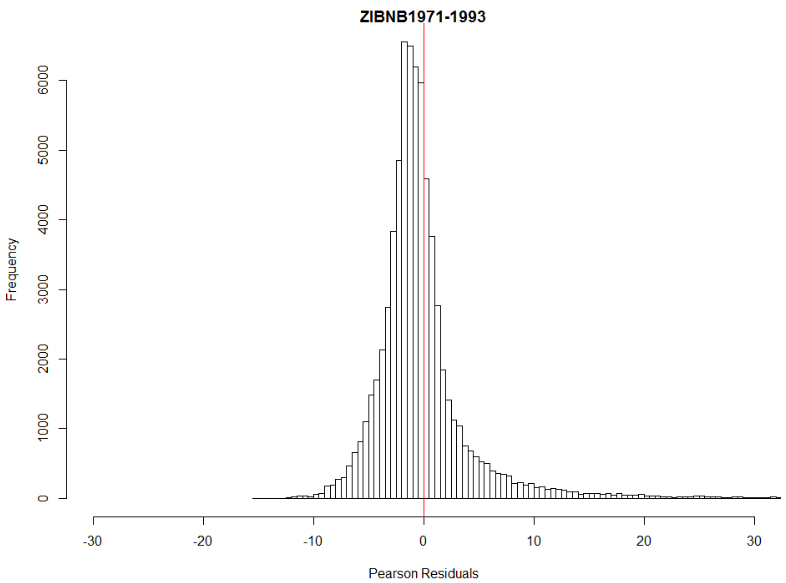


Fig. 2 Pearson residuals of zero-inflated negative binomial model.

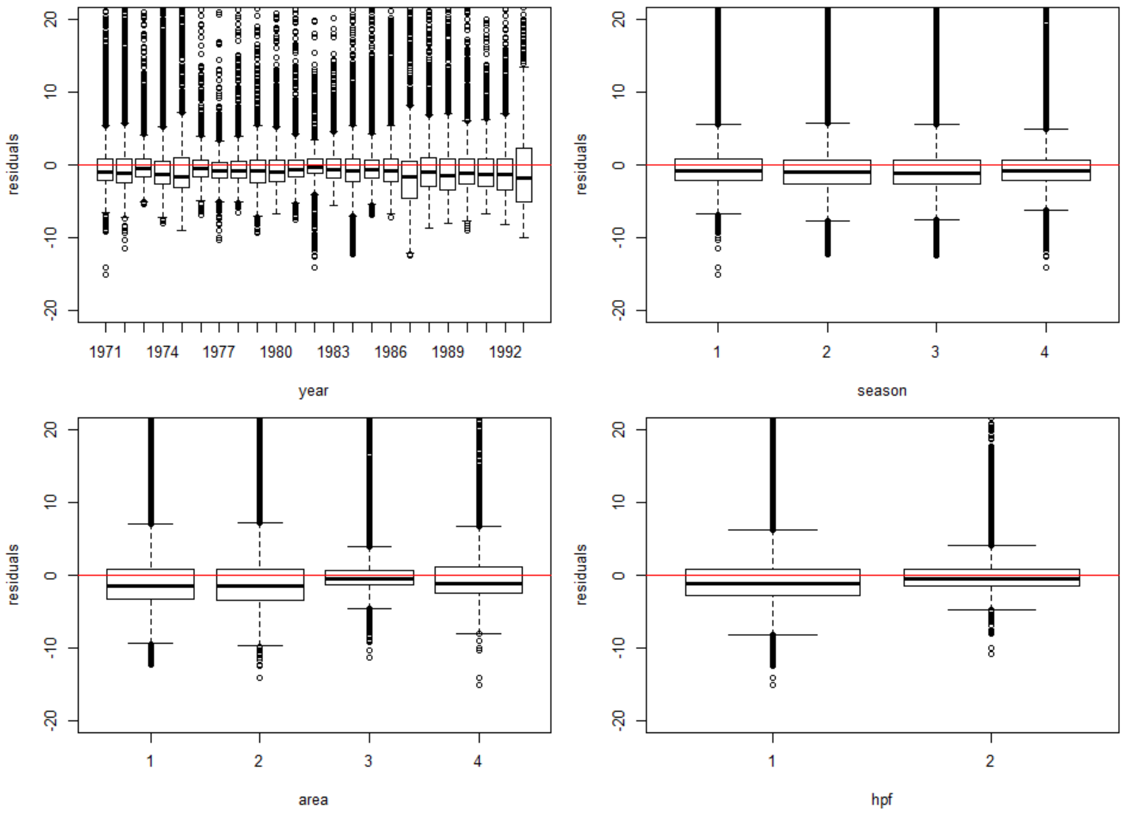


Fig. 3 Pearson residuals patterns of zero-inflated negative binomial model by main effects (year, season, area, hpf).

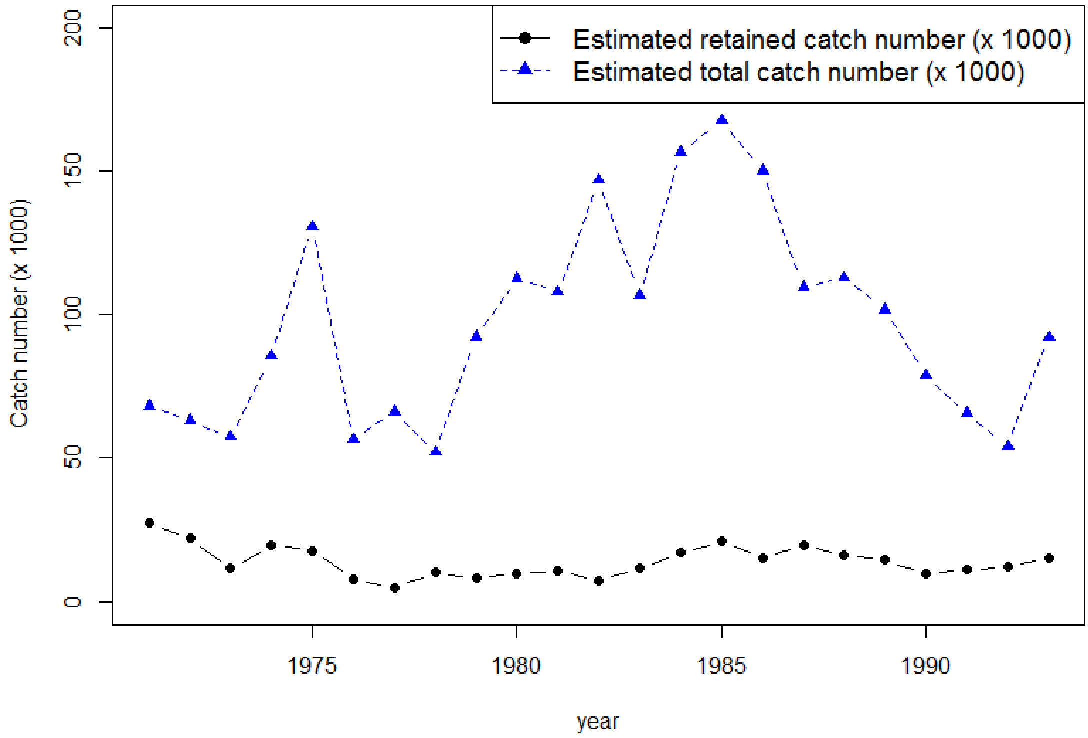


Fig. 4 Annual changes of landed catch and estimated catch from standardized CPUE from 1971 to 1993.

Appendix fig-1

Table A1. Analysis of Deviance Table (Type III tests).

Response: blue

| | LR Chisq | Df | Pr(>Chisq) | |
|---|---|---|---|---|
| as.factor(year) | 568.783 | 22 | 2.20E-16 | *** |
| as.factor(area) | 173.34 | 3 | 2.20E-16 | *** |
| as.factor(qt) | 43.639 | 3 | 1.80E-09 | *** |
| as.factor(hpf) | 198.835 | 1 | 2.20E-16 | *** |
| as.factor(year):as.factor(area) | 2853.658 | 66 | 2.20E-16 | *** |
| as.factor(area):as.factor(qt) | 235.467 | 9 | 2.20E-16 | *** |
| as.factor(year):as.factor(qt) | 1478.185 | 66 | 2.20E-16 | *** |
| as.factor(area):as.factor(hpf) | 324.765 | 3 | 2.20E-16 | *** |
| as.factor(qt):as.factor(hpf) | 14.301 | 3 | 0.002523 | ** |
| Residuals | 70394 | | | |