Update of Japanese longline CPUE for Blue Marlin *Makaira nigricans* in the Pacific Ocean[1] standardized applying habitat model

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Abstract

Japanese abundance indices of blue marlin (*Makaira nigricans*) caught by offshore and distant water longline fishery in the Pacific Ocean were updated during 1994 to 2014. We applied a deterministic habitat-based standardization model (HBS; Hinton and Nakano 1996) using the same data filtering and assumptions as those used in Kanaiwa et al. (2013). Confidence intervals were estimated using a bootstrap method. Standardized CPUE had a quite narrow confidence intervals and showed a generally consistent trend throughout the periods except for the first two years. The annual trend was almost similar to those in the previous work (Kanaiwa et al. 2013), differing only slightly in 2000s. This difference was attributed to the new temperature at depth based on the oceanographic data from NOAA and to corrected logbook data. The consistent level of the abundance indices suggests that the abundance of blue marlin in Pacific Ocean has been relatively stable since 1996.

Introduction

In the 2013 stock assessment, abundance indices of blue marlin caught by the Japanese longline fishery in the Pacific Ocean were separated into two periods: 1975-1993 and 1994-2011 to account for changes of operation: i.e. depth of hooks that has a strong association with hooks between float (HBF) and targeted fish (WCPFC 2013). For the latter period a deterministic habitat-based standardization model (HBS; Hinton and Nakano, 1996) was applied (Kanaiwa et al. 2013). The HBS estimates the effective fishing effort as the joint probability of the vertical distribution of hooks in the water column and the distribution of the species which is changed by variations in vertical thermal structure, oxygen level, or food availability (Hinton and Nakano, 1996). This paper provides updated Japanese abundance indices of blue marlin (*Makaira nigricans*) caught by the offshore and distant water longline fishery during 1994 to 2014 in the Pacific Ocean using the HBS.

Materials and Methods

Data source

Set-by-set logbook data from the Japanese offshore and distant water longline fishery in the Pacific Ocean was used to standardize CPUE from 1994 to 2014. Among these data are such as set by set information on fishing location (1 degree latitude by 1 degree longitude), fishing date (day, month, year); catch in number of tunas, billfishes and sharks by species; gear configurations, ship name and the registered prefecture, sea surface temperature (SST), fishery type such as offshore longliner (vessel tonnage is 20-120 MT) and distant-water longliner (vessel tonnage is larger than 120 MT), and information on gear configuration, including HBF, length of branch line, length of float line, and length of the mainline between branch lines.

Oceanographic data from NOAA

(http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.GODAS/.monthly/) was used to estimate the temperature at depth for 1994-2014. The oceanographic data contains a mixed layer depth (MLD: NOAA NCEP EMC CMB GODAS monthly ocean_mixed_layer_bot) and potential temperature at depth (PTD: NOAA NCEP EMC CMB GODAS monthly BelowSeaLevel). MLD was defined as the depth at which the temperature was 1 °C below sea-surface temperature (Hinton and Nakano, 1996). Isotherm depths were estimated by Akima's interpolation method (Akima, 1970) between depths of the nearest bounding temperatures.

Filtering of logbook data

The logbook data was filtered by area, SST, fishery type, and number of HBF in order to remove records for operations not targeting tunas and billfish (e.g. targeting swordfish). We used data from the tropical and temperate waters of the Pacific Ocean between 30 °S to 30 °N and with SST (as measured by the vessel) greater than 20 °C. The longline fishery can be separated into three types of fishery by target species: swordfish, sharks, and tunas. We used only tuna longline fishery because blue marlin is frequently caught by the tuna longline fishery as a bycatch. We removed the data which have improbable number of HBF more than 25 and less than 3.

Habitat-based standardization model

Effective fishing effort was derived using a deterministic habitat-based standardization model (HBS). The HBS model comprised three components (Kanaiwa et al. 2013): (I) Gear model which estimates the vertical distribution of hooks: (II) Habitat preference model which estimates the vertical distribution of blue marlin (III) Habitat model which determines the depth and temperature of mixed layer and the depth of isotherms.

<u>Gear model</u>

Vertical distribution of hooks in the water column was estimated using the catenary curve model (Yoshihara 1951; Suzuki et al. 1977):

$$D_i = h_a + h_b + L\left\{\left(1 + \frac{1}{\tan(\varphi)^2}\right)^{0.5} - \left[\left(1 - 2\frac{j}{n}\right)^2 + \frac{1}{\tan(\varphi)^2}\right]^{0.5}\right\} \quad (1)$$

where:

D_i ; depth of j-th hook

h_a ; length of branch line

h_b ; length of float line

L ; half of length of the mainline in unit basket n ; number of intervals between the branch lines in unit basket (number of branch line plus 1)

j ; j-th branch line in unit basket (sequential number of the branch lines or hooks counted from either one end of the unit basket)

φ ; a parameter of catenary angle made between horizontal line and tangential line of the mainline at the connecting points of mainline and float lines.

The parameter of catenary angle was calculated using the following equation with an actual catenary angle θ: $\varphi = \theta\pi/180$. We used θ = 72° based on the value used in Kanaiwa et al. (2013). The depth at 85-percent of the theoretical depth derived from equation (1) was used to adjust the hook depth because previous studies showed that the actual observed hook depths were shallower than those of derived depth (Saito 1975; Boggs 1992). As a large number of operational data have no information about gear configuration (length of branch line, length of float line, and length of mainline in unit basket), we used mean values derived from operational data with information of the gear configuration. The mean value was calculated using data pooled by prefecture, area (north of 20 °N, 0-20 °N, 0-20 °S, south of 20 °S), quarter (Jan.-Mar., Apr.-Jun., Jul.-Sep., Oct.-Dec.), material of mainline (nylon, others), and HBF (3-5, 6-9, 10-14, 15-17, 18-25). If there was no prefecture information, the mean value was calculated using the pooled data by area, quarter, material of mainline, and HPF.

Habitat preference model

The vertical distribution of blue marlin population was estimated from acoustic telemetry data (Brill et al. 1993, Block et al. 1992). The data for the nine individual fish were averaged to obtain a species-specific estimate of time at temperature relative to mixed layer on the range of Δt = (0, -1°C, -2°C,⋯,-8°C). We used the same values applied by Hinton and Nakano (1996) that are the percentage of the blue marlin population at temperatures (°C) relative to temperature of the mixed layer (Table 1).

Habitat model

The depth and temperature of the mixed layer and the depth of isotherms at temperatures relative to temperature of the mixed layer were derived from the environmental data as described in the data source section.

Effective fishing effort (hooks) was computed using the joint probability of the vertical distribution of hooks in the water column and the distribution of blue marlin. Standardized CPUE was defined as the total catch of blue marline over the total effective fishing effort. The catch was weighted using the relative size of 1×1 areas (Table 2). Annual relative abundance indices were obtained by averaging the standardized CPUEs.

Bootstrap

The 95% confidence interval (CI) and coefficient of variation (CV) of standardized CPUE were estimated using a bootstrap. The process of the bootstrap is as follows:

1) Extract the weighted catch of blue marine, effective number of hooks, and year from the original operational data (set by set data).
2) Split the operational data by year.
3) For the subset data in each year, allocate the number (index) from 1 to total number of the row.
4) For the subset data in each year, sample the one operational data from the subset data with replacement.
5) For the subset data in each year, repeat the sampling in (4) until total number of sample reaches to total number of the row.
6) Conduct the (3) - (5) for the subset data of entire years.
7) Repeat the (2) – (6) until the iteration reaches to 3000.

Results

Annual trends of nominal CPUE of blue marlin showed a slight decreasing trend until 2012 and uptrend in 2013 and 2014, while the standardized CPUE showed a generally consistent trend throughout the periods except for the first two years: i.e. 1994 and 1995 (Table 3, Fig.1). The level of the standardized CPUE after 2011 was more or less consistent. The observed trend was slightly different than that used in the previous assessment (Kanaiwa et al. 2013). This is difference would be attributed to the newly calculated temperature at depth based on the oceanographic data from NOAA and the corrected logbook data. The 95 % confidence intervals of standardized CPUEs were quite narrow for 1994-2014 and the coefficient of variation (CVs) were very small due to a large number of annual observations (>20,000) of operational data.

Discussion

Japanese longline fishery catches immature and mature female blue marlin ranging between 100 and 300 cm eye to folk length, with the mode between 180 and 200 cm (Kimoto and Yokawa 2012a). In addition, the catch and effort data of the Japanese longline fishery were collected from a wide range of areas in the Pacific Ocean (Kimoto and Yokawa 2012b). These facts suggest that the abundance indices of blue marlin caught by the Japanese longline fishery may well represent the trends of abundance of blue marlin in the Pacific. The relatively consistent level in the abundance indices indicate that the population of blue marlin in Pacific Ocean has been stable since 1996. The nominal catch of blue marlin has been decreasing since 1994 in association with the decrease of total number of hooks (Table 3). The Japanese commercial offshore and distant water longline fisheries commonly target tunas such as bigeye tuna, and blue marlin is frequently caught as bycatch. Therefore, the decrease in the total number of hooks generally means the decrease in the fishing pressure on species caught by the Japanese longline fishery. Blue marlin is well known to the preferences for particular habitat-related factors such as SST, ocean fronts, current speed, oxygen content, prey availability, and mixed layer depth etc. affecting its distribution and vulnerability to being caught (Molony 2005; Boyce et al. 2008), so that habitat model seems to be suitable for blue marlin when the CPUE is standardized.

In this study, we used fixed values for the gear model (e.g. a catenary angle of 72 ° and 85 percent of the theoretical depth as a fishing depth of hooks) based on the Hinton and Nakano (1996). These values could be changed by the materials of mainline, water current, and speed of the vessel. Bigelow et al. (2006) examined the accuracy of catenary algorithms for predicting fishing depths and they indicated that capture depths using the traditional catenary equations: i.e. (Yoshizawa 1951; Suzuki et al. 1977) may be biased without the benefit of temperature-depth recorders affixed to longline. Additionally, the model is recognized that there is uncertainty in the habitat preference estimates. An example of the criticism is that the method may not consider feeding behavior (Goodyear et al. 2003). Maunder et al. (2005) developed the statistical HBS method, which is based on HBS. They integrate the model with a general linear model framework and estimated the temperature preference profile using the tagging observation data as a given prior. The statistical framework allows model selection and estimation of uncertainty. They demonstrated the better performance of the stat-HBS than the deterministic HBS in the application to the main area of longline catch for big eye in the western and central of the Pacific Ocean. In future work, application of the stat-HBS to the estimation of the abundance indices of blue marline in the Pacific Ocean might be effective.

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Table 1. The percentage of the blue marlin population at temperatures (°C) relative to temperature of the mixed layer as determined by acoustic telemetry (Hinton and Nakano 1996).

Relative temperature to temperature in the mixed layer	0	-1	-2	-3	-4	-5	-6	-7
Percentage of blue marline	75.9	13.8	5.8	2.1	1.2	0.5	0.5	0.22

Table 2. Relative size of area (1 x 1 degrees) to average size of area for the weighting of standardized CPUE.

Lat	Lat (km)	Lon (km)	Area (1x1)	Relative value	Lat	Lat (km)	Lon (km)	Area 1x1	Relative value
0.00	110.57	111.32	12308.43	1.05	16.00	110.65	107.04	11843.85	1.01
1.00	110.57	111.30	12306.66	1.05	17.00	110.66	106.49	11784.17	1.00
2.00	110.57	111.25	12301.13	1.05	18.00	110.68	105.91	11721.15	1.00
3.00	110.57	111.17	12291.96	1.05	19.00	110.69	105.29	11654.57	0.99
4.00	110.74	111.05	12297.23	1.05	20.00	110.70	104.65	11584.54	0.99
5.00	110.58	110.90	12262.88	1.04	21.00	110.71	103.97	11510.95	0.98
6.00	110.58	110.72	12242.86	1.04	22.00	110.73	103.26	11433.91	0.97
7.00	110.58	110.50	12219.20	1.04	23.00	110.74	102.52	11353.41	0.97
8.00	110.59	110.25	12191.88	1.04	24.00	110.75	101.75	11269.56	0.96
9.00	110.60	109.96	12160.92	1.03	25.00	110.77	100.95	11182.25	0.95
10.00	110.60	109.64	12126.40	1.03	26.00	110.78	100.12	11091.48	0.94
11.00	110.61	109.29	12088.24	1.03	27.00	110.80	99.26	10997.58	0.94
12.00	110.62	108.90	12046.52	1.02	28.00	110.82	98.36	10900.21	0.93
13.00	110.62	108.49	12001.16	1.02	29.00	110.83	97.44	10799.58	0.92
14.00	110.63	108.04	11952.35	1.02	30.00	110.85	96.49	10695.50	0.91
15.00	110.64	107.55	11899.99	1.01					

Table 3. Nominal values, standardized CPUE, area weighted standardized CPUE and the scaled value by the mean value, and the coefficient of variations (C.V.) of blue marlin caught by Japanese offshore and distant water longline fishery in Pacific Ocean from 1994 to 2014.

Year	Nominal Catch	Nominal Hooks	Nominal CPUE (/1000hooks)	Nominal CPUE weight (/1001hooks)	Standardized Hooks	Standardized CPUE (/1000hooks)	Standardized CPUE weight (/1001hooks)
1994	100720	196189189	0.513	0.532	8371857	12.03	12.46
1995	99590	185889156	0.536	0.553	6844009	14.55	15.02
1996	45950	142196892	0.323	0.333	5750698	7.99	8.24
1997	64123	132575548	0.484	0.501	5858334	10.95	11.34
1998	59702	142846077	0.418	0.431	5681301	10.51	10.85
1999	47399	119919066	0.395	0.408	5556788	8.53	8.80
2000	47597	126198862	0.377	0.390	5408873	8.80	9.10
2001	46818	141438379	0.331	0.342	6352012	7.37	7.61
2002	44657	144160996	0.310	0.321	5581578	8.00	8.28
2003	46737	135897056	0.344	0.356	4750093	9.84	10.17
2004	41428	106606002	0.389	0.403	3443664	12.03	12.47
2005	35516	88903160	0.399	0.413	3393027	10.47	10.82
2006	30391	84448876	0.360	0.372	2941764	10.33	10.68
2007	25130	73541514	0.342	0.353	2930345	8.58	8.86
2008	23463	70825775	0.331	0.341	3022486	7.76	8.00
2009	25493	71849359	0.355	0.367	2338948	10.90	11.27
2010	32540	92136056	0.353	0.365	3253388	10.00	10.35
2011	30520	90922707	0.336	0.347	4208682	7.25	7.49
2012	25866	86598590	0.299	0.308	2340218	11.05	11.40
2013	22600	73425527	0.308	0.317	2460445	9.19	9.46
2014	23687	62443129	0.379	0.392	2257857	10.49	10.83

Table 3 continued.

Year	Scaled standardized CPUE (Kanaiwa et al. 2013)	Scaled nominal CPUE	Scaled standardized CPUE	Scaled standardized CPUE weight	CV
1994	1.280	1.368	1.223	1.225	0.011
1995	1.501	1.427	1.479	1.478	0.013
1996	0.794	0.861	0.812	0.810	0.014
1997	1.179	1.289	1.112	1.115	0.014
1998	1.078	1.114	1.068	1.067	0.013
1999	0.859	1.053	0.867	0.866	0.013
2000	0.925	1.005	0.894	0.895	0.012
2001	0.805	0.882	0.749	0.749	0.011
2002	0.761	0.825	0.813	0.815	0.012
2003	0.904	0.916	1.000	1.001	0.014
2004	1.061	1.035	1.223	1.227	0.012
2005	0.983	1.064	1.064	1.064	0.015
2006	1.005	0.959	1.050	1.051	0.017
2007	0.902	0.910	0.872	0.872	0.013
2008	0.905	0.883	0.789	0.787	0.017
2009	1.100	0.945	1.108	1.108	0.022
2010	1.073	0.941	1.017	1.018	0.013
2011	0.885	0.894	0.737	0.737	0.016
2012		0.796	1.123	1.121	0.013
2013		0.820	0.934	0.930	0.016
2014		1.011	1.066	1.065	0.018

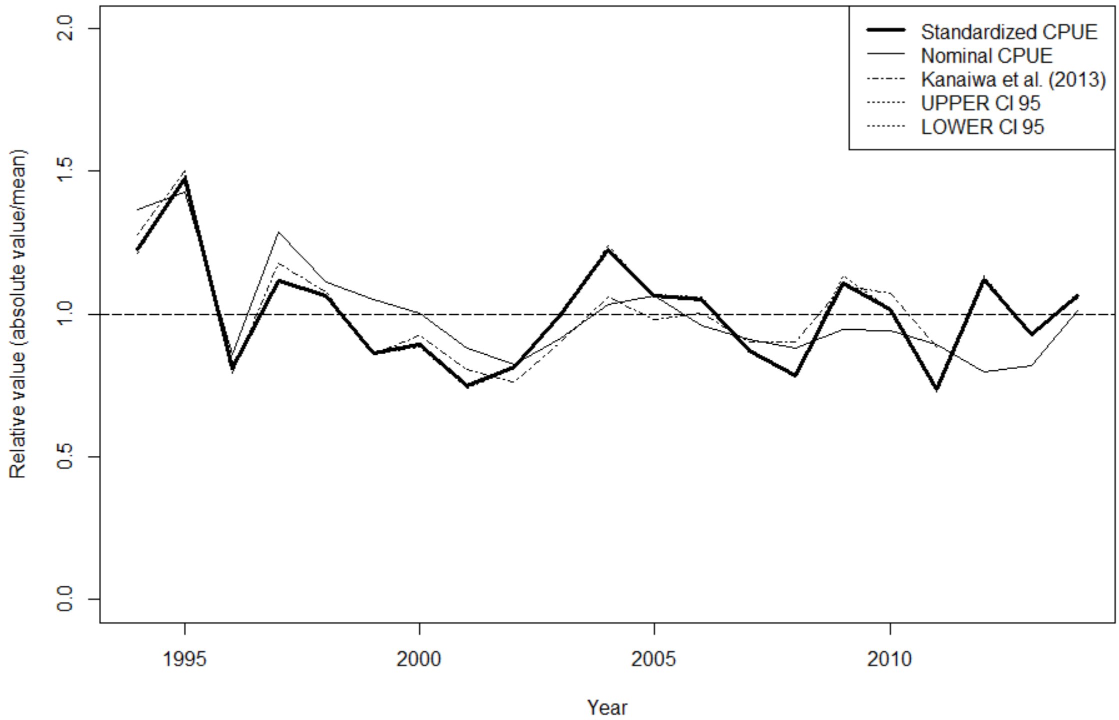

Figure 1. Annual trends of scaled nominal and standardized CPUE series of blue marlin in Pacific Ocean from 1994 to 2014. Standardized CPUEs were weighted by area. All CPUEs are scaled by the mean values. Previous standardized CPUEs are referred from the values in Kanaiwa et al. (2013).