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ESTIMATION OF ABUNDANCE INDEX OF WHITE MARLIN CAUGHT BY JAPANESE LONGLINERS IN THE ATLANTIC OCEAN

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SUMMARY

An abundance index of white marlin in the Atlantic Ocean was estimated by using set-by-set data of Japanese longliners. For the calculation of CPUE, effective fishing effort of Japanese longliners on white marlin, which was estimated by the habitat model (Hinton and Nakano, 1996), and catch in number of white marlin, were used. Because no information about the vertical distribution pattern of white marlin was available, effective fishing effort was estimated with the pattern of Pacific striped marlin (Hinton, 2002). CPUE was also calculated by effective fishing efforts estimated by six other vertical distribution patterns, such as the one of Pacific blue marlin (Hinton and Nakano, 1996) and swordfish (Hinton and Deriso, 1998), as well as the number of hooks used in a operation for the sensitivity test.

CPUE standardization was conducted by a delta lognormal approach with binomial distribution for the model of proportion of positive catch sets and lognormal distribution for the model of positive CPUE sets (Lo et al, 1992). Because estimated effective fishing effort per operation was changed drastically by the gear configuration expressed as the number of hooks between floats and area, a factors of the amount of effective fishing effort per operations was included in the analysis of proportion of positive catch sets.

The trend of obtained abundance indexes did not change so much when white marlin was assumed to be distributed mainly in the surface mixed layers. The trend of the abundance index calculated with number of hooks was relatively comparable to the ones calculated with effective fishing effort which were estimated with the assumption that white marlin were mainly distributed below from the thermocline. These results indicated the fact that CPUE standardization using the number of hooks was biased and the estimated abundance index in the study should better reflect the actual dynamics of the white marlin population.

RÉSUMÉ

Un indice de l'abondance du makaire blanc dans l'océan Atlantique a été estimé en utilisant les données des palangriers japonais opération par opération. Pour le calcul de la CPUE, on a utilisé l'effort de pêche effectif des palangriers japonais sur le makaire blanc, lequel a été estimé par le modèle de l'habitat (Hinton et Nakano, 1996), ainsi que la capture numérique du makaire blanc. Etant donné qu'il n'y avait aucune information sur le schéma de distribution verticale du makaire blanc, l'effort de pêche effectif a été estimé avec le schéma du marlin rayé du Pacifique (Hinton, 2002). La CPUE a aussi été calculée à partir des efforts de pêche effectifs estimés par six autres schémas de distribution verticale, tels que celui du makaire bleu du Pacifique (Hinton et Nakano, 1996) et de l'espadon (Hinton et Deriso, 1998), ainsi que le nombre d'hameçons utilisés dans une opération menée pour tester la sensibilité.

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La standardisation de la CPUE a été réalisée par une approche delta-lognormale avec une distribution binomiale pour le modèle de proportion de séries de captures positives et de distribution lognormale pour le modèle de séries de CPUE positives (Lo et al, 1992). Etant donné que l'effort de pêche effectif estimé par opération a changé radicalement par la configuration d'engin exprimée comme étant le nombre d'hameçons entre les flotteurs et la zone, un facteur du volume de l'effort de pêche effectif par opération a été inclus dans l'analyse de la proportion des séries de captures positives.

La tendance des indices d'abondance obtenus a peu changé lorsque l'on a postulé que le makaire blanc était réparti principalement dans les couches mixtes de surface. La tendance de l'indice d'abondance, calculée en fonction du nombre d'hameçons, était relativement comparable à celles calculées en fonction de l'effort de pêche effectif qui ont été estimées selon l'hypothèse que le makaire blanc était principalement distribué en-deçà de la thermocline. Ces résultats ont indiqué que la standardisation de la CPUE en utilisant le nombre d'hameçons était faussée et que l'indice d'abondance estimé dans l'étude devrait mieux refléter la dynamique réelle de la population de makaire blanc.

RESUMEN

Se estimó un índice de abundancia de aguja blanca en el océano Atlántico utilizando datos por lance de los palangreros japoneses. Para calcular la CPUE se utilizaron el esfuerzo efectivo de pesca de los palangreros japoneses sobre la aguja blanca, que se estimó mediante el modelo de hábitat (Hinton y Nakano, 1996), y la captura en número de la aguja blanca. Como no se disponía de información sobre el patrón de distribución vertical de la aguja blanca, el esfuerzo de pesca efectivo se estimó con un patrón del marlin rayado del Pacífico (Hinton, 2002). La CPUE también se calculó mediante el esfuerzo de pesca efectivo estimado mediante otros seis patrones de distribución vertical, como el de la aguja azul del Pacífico (Hinton y Nakano, 1996) y pez espada (Hinton y Deriso, 1998), así como con el número de anzuelos utilizados en una operación de prueba de sensibilidad.

La estandarización de la CPUE se realizó mediante un enfoque delta lognormal con una distribución binomial para el modelo de proporción de las series de capturas positivas y una distribución lognormal para el modelo de series de CPUE positivas (Lo et al, 1992). Dado que el esfuerzo de pesca efectivo estimado por operación se vio drásticamente modificado por la configuración del arte expresada en número de anzuelos entre flotadores y zonas, se incluyó en el análisis de la proporción de series de capturas positiva un factor relacionado con el volumen del esfuerzo de pesca efectivo por operaciones.

La tendencia de los índices de abundancia obtenidos no cambió tanto cuando se asumió que la aguja blanca se distribuía de forma regular en las capas mixtas de la superficie. La tendencia del índice de abundancia calculado en función del número de anzuelos era relativamente comparable con los calculados con el esfuerzo de pesca efectivo, que se estimaron bajo el supuesto de que la aguja blanca se halla sobre todo por debajo de la termoclina. Estos resultados indican que la estandarización de la CPUE que utiliza el número de anzuelos estaba sesgada y que el índice de abundancia estimado en el estudio debe reflejar mejor la dinámica real de la población de aguja blanca.

KEY WORDS

White marlin, effective effort, delta log normal

1. INTRODUCTION

Information about the longline gear configuration which expressed by the number of branch lines between floats (NBF) is widely used in the CPUE standardization to estimate the difference of longline catch ability among variety of operational pattern. Difference of catch ability among different operation pattern usually can be estimated by the statistical model such as GLM, if the coverage of data were wide enough. This could be the case for the targeted species of the fishery as fishery widely covers the main distribution area of this species and as a result of this, coverage of data can be wide enough for the statistical analysis. But for the non-target species such as billfishes caught by Japanese longliners, coverage of data from the fishery cannot always be high enough for some parameter estimation.

Uozumi (1999) indicated that catch and effort data of Japanese longliners operated in the Pacific did not cover the vertical and horizontal distribution area of billfishes and this cause the uncertainty in the results of the stock assessment of billfishes. Yokawa and Uozumi (2000) pointed out that it also happened in data of Japanese longliners operated in the Atlantic. Because the fishing ground and gear configuration of Japanese longliners changed drastically and these changes occurred suddenly, it would be very difficult to obtain balanced data to conduct CPUE standardization. As a result of this, the result of GLM analysis using logbook data indicated that the value of the standardized CPUE of deep longline operation became larger than that of surface longline operation. This means that deep longline operations catch more blue marlin than surface longline operation, which does not consistent with the observed vertical distribution pattern of blue marlin and logline hooks. Although Takeuchi (2000) suggested the possibility that the observed drastic change of operation pattern of data by Japanese longliners in the Atlantic might not cause serious problem in the CPUE standardization by using model case study. However, Uozumi (2000) conducted retrospective analysis of the stock assessment of Atlantic blue marlin by non-equilibrium production model (ASPIC), and indicated that ASPIC output with complete time series of data set (1956-1999) was completely different from the one with data series for the two of three most recent decades. This strongly suggests the possibility that the CPUE standardized using GLM approach is unrealistic. The use of effective fishing effort is demonstrated to provide better information on changes in abundance than the effort by logbook data for tuna and billfishes in the Pacific (Hinton and Nakano 1996; Bigelow, Hampton and Miyabe; 2000 Yokawa and Takeuchi; 2001). This study applied habitat model in estimating effective fishing effort of Japanese longliners for white marlin, and standardized CPUE with it to estimate abundance index.

2. MATERIALS AND METHODS

2.1 Effective fishing effort

Effective fishing effort on Atlantic blue marlin was defined by the sum of the product of distribution ratio of fishes and hooks by time, area, depth strata as described by the former study (Hinton and Nakano 1996; Bigelow, Hampton and Miyabe (2000)).

$$f_{at} = \sum_{d} h_{atd} p_{atd} \qquad (1)$$

where f_{at} is amount of effective effort in a particular area (a) and time (t).
h_{atd} is amount of fishing effort in a particular area (a), time (t) and depth layer (d).
p_{atd} is the proportion of the fish population in a particular area (a), time (t) and depth layer (d).

and $E_{at} = \sum_{d} h_{atd}$ (2)

where E_{at} is amount of effort by logbook in a particular area (a) and time (t).

Data about E_{at} was obtained from the logbook of Japanese longline fishery for 1967-2000. Vertical distribution pattern of effort (h_{atd}) was estimated by using data of time.

The amount of fishing effort of a particular depth layer was estimated as the sum of hook resting time of that layer. Proportion of the fish population in a particular depth layer was estimated by the results of past biotelemetry study of marlins.

2.2 Depth distribution of longline hook

2.2.1 Vertical distribution of hook resting time

Figure 1 shows an example time-depth data of longline hook, which was hooked by Atlantic blue marlin during the hook being deploying. Data collected by the time-temperature-depth-recorder (TDR, product of Murayama electric Co., LTD; SBT-500). This observation clearly indicates that time for gear deploying and retrieving must be taken into account for the calculation of the effective fishing effort. Boggs (1992) reported that striped marlin (17 %) and spearfish (20 %) were also caught by deploying and retrieving hook in the longline research in off Hawaii waters.

To estimate the proportion of hooks fishing in a particular depth zone, we used data by TDRs attached to near the hook, which were collected during Shoyo-maru research cruise in the eastern Pacific in 1999 (Miyabe *et al.* in press) and in the tropical Atlantic in 2000 (Miyabe *et al.* in press). TDR recorded the time, depth, and temperature data in every 4, 5 or 10 seconds. Because time interval of data collection of TDR is very short, we assumed the each data by TDR represent the depth of hook for the period between data recording, e.g. if TDR were set to record data in every 10 seconds and it recorded the depth of hook in a particular moment as 20.0 m depth, then we assumed the hook was stayed in 20.0 m for 10 seconds. If we set reasonably large width of depth layer in compare to the vertical moving speed of hook and time interval of TDR data recording, we can estimated hook-resting time in each layer by aggregating total number of TDR records counted in each depth layer and multiplied by the length of time interval of TDR data recording.

Figure 2 shows the hook-resting time by 10 m depth layer for 7th branch line of 13 hooks between floats and 9th branch line with 17 hooks between floats. Values showed in the graph were the average of all TDR data attached to the designated line. In each case, one notable peak was observed in a layer near the calculated depth of hook by catenary model (200 m for former one and 240 m for later one, estimation method was followed by the one in Mizuno *et al..*, 1997).

In this study, the vertical distribution of hook resting time explained above was used in estimating the amount of fishing effort in a particular layer with no gear shoaling. For this purpose, adequate TDR data were picked up from the results of Shyoyo-maru longline research cruises in 1999 in the Eastern Pacific and in 2000 in the tropical Atlantic. The criteria for the data selection were as follows:

a) More than 10 TDR data, which have not been affected by fish hooking or gear trouble, were available in the same branch line in an operation.

b) The difference between calculated depth of hook by the catenary model and the observed average depth of hook by TDR data was within 10%. The average depth of hook was obtained by taking average of hook depth for the period between one hour after hook setting and one hour before hook recovering.

c) No particular tendencies were observed for the movement of hooks.

Table 1 shows the summary of TDR data used in the estimation of the vertical distribution of hook resting time as model cases. Total of 12 data from 3rd line of NBF=5 to 10th line of NBF=19 were available. In all case, depth layers which hooks stayed longest time were same or close to the ones with the depth calculated by catenary model.

2.2.2 Longline gear configuration for the model input

Table 2 shows the input parameters for the catenary model used in this study. For the period before 1974, the average values of the data obtained by the questionnaire on 45 retired fishing masters were used. For the period 1980s and 1990s, values were decided based on the general information obtained by the interview to the 7 fishermen.

2.2.3 Depth distribution of longline hook

By using the vertical distribution pattern of hook resting time in **Figure 1** and **Table 1**, and the parameters in **Table 2**, vertical distribution of total hook resting time of each operation of Japanese longliners was estimated by following step;

a) Calculate set depth of hook by using catenary model.

b) Pick up the TDR data from 12 model cases in **Table 1**, which have close value of set depth calculated by catenary model.

c) Adjust the total number of depth layer by adding/deleting the number of layer which hook is moving fastest so that the peak of the mode of hook resting time is coincide with the depth calculated by catenary model.

d) For the operation with NBF = 3-9 during in 1980's and 1990, the gear configurations of 1975-1979 **(Table 2)** were applied. For the operation with NBF = 10-15 in the 1990s, the gear configurations of 1980s were applied. Based on the recent report of the observer program for the Japanese longliners in the Atlantic Ocean (Matsumoto and Miyabe 1997, 1998, 1999), fishermen used the relatively shorter length of float and branch line when they conducted operation with NBF < 16 in compare to the operation with NBF > 15.

e) For the period before 1970, the speed of hook setting and retrieving was set at three times higher than the other period. The electric line hauler was introduced to Japanese longliner in the Atlantic in 1970 and before this year, fisherman set/retrieved gear by hand. The speed of gear setting and retrieving by hand was arbitrary decided by the general information of retired fishing master (Ishida, personal comm.).

f) It was assumed that each hook stayed under water for 10 hours throughout the period analyzed. Calculated time of single hook resting in each depth layer was adjusted to this value. The calculated value of total hook resting time in each depth layer in a stratum was used as the total amount of effort of that layer with no gear shoaling.

Figures 3 and 4 shows the picked up results of the estimation.

2. 3 Effect of current

Mizuno *et al.* (1997) indicated that shear current was one of the main factors, which caused gear shoaling. In this study, effect of current was included into the model estimating the effective effort. However, Mizuno *et al.* (1997) also indicated that depth of the bottom end of float line had not changed with rather strong shear current. Based on this, the shoaling rate of the hook was assumed to be expressed as following formula;

$$y = a\sqrt{(c_{nv} - c_{nf})^2 + (c_{ev} - c_{ef})^2} + b \qquad (3)$$

$$s = \sqrt{(c_{nv} - c_{nf})^2 + (c_{ev} - c_{ef})^2} \qquad (4)$$

where y is shoaling rate.

c_{nf} is NS component of velocity of current at the depth of the bottom of float line.
c_{nv} is NS component of velocity of relative strongest current to the one of the bottom of float line within the depth between the bottom of float line and bottom of branch line.
c_{ef} is EW component of velocity of current at the depth of the bottom of float line.

c_{ev} is EW component of velocity relative strongest current to the one of the bottom of float line within the depth between the bottom of float line and bottom of branch line.
a and b is constant.
s is shear current.

To obtain estimated value of a, the TDR and ADCP (CI-35, Furuno Co. Ltd.) data by Shyoyo-Maru longline research cruise in 2000 in the tropical Atlantic were used. Shoaling rate was obtained by dividing the observed average value of hook setting depth by the theoretical value. Average hook setting depth was calculated with the method to take average of hook depth for the period between one hour after hook setting and one hour before hook recovering. Values calculated with more than 10 TDR data in the same branch line in an operation were used.

ADCP were taking NS and EW component of current velocity by every one minute for the depth of 10, 42, 74, 107, and 139 m. Current velocity in each layer was obtained by taking the average of data at each depth for the start and end of an operation. As the depth of float line was 25 m or 50 m, current velocity of 42 m depth was assumed to be the one at the depth of bottom end of float line.

Figure 5 shows the relationship between observed shoaling rate and shear current. As shown in **Figure 5**, formula of $y = -0.0075s + 1.1345$ was used to estimate shoaling rate from current data in this study.

Oceanic currents data for Atlantic in the years of 1980-1989 were obtained from an Ocean Global Circulation Model (OGCM) developed at the National Center of Environmental Prediction (NECP, Behringer, Ji and Leetmaa 1998). This model has 1.5 degrees and one-month resolution, and 27 vertical layers (0-3000 m). Data for each layer was re-gridded to 5 degrees to correspond with the longline catch and effort data.

For the operation with NBF = 3-9, the shear current was obtained from the data of 15-75 m layers (7 layers), of which the current of 15 m layer was assumed to be the one at the bottom end of float line. For the operation with NBF = 10-24, the shear current was obtained from the data of 35-136 m layers (10 layers), of which the current of 35 m layer was assumed to be the one at the bottom end of float line. For the years with no current data available, monthly average for 1980-1989 was used. **Figure 6** shows the distribution of the shear current for the operation with NBF = 10 - 24 obtained by the re-gridded data.

The middle depth of each layer multiplied shoaling rate of each time-area stratum, and grade of one of the product was rounded off to obtain the new depth layer, which the hook drifted by the shear current. If the calculated new depth layer was different from the original one, all the effort was moved into new layer.

2.4 Vertical distribution pattern of white marlin

To estimate the vertical distribution pattern of white marlin, it was assumed that vertical movement of white marlin was regulated by the change of temperature with depth (Brill and Lutcavage; 2001)

Because no information about vertical distribution pattern of white marlin were available so far, pattern of Pacific striped marlin estimated by the biotelemetry study (Hinton, 2002) were used to estimate effective fishing effort in this study. Effective fishing efforts were also estimated with other six vertical distribution pattern **(Table 3)**, such as the one for Pacific blue marlin (Hinton and Nakano, 1996) and swordfish (Hinton and Deriso, 1998), and these effective efforts were used for sensitivity test. Fishing effort obtained by number of hook used in a operation was also included into the sensitivity analysis.

2.5 Standardization of CPUE calculated with effective fishing effort

Set by set data of Japanese longliners data of Japanese longliners (1967-2000) were used in this study. All Data from EEZ zone were excluded from analysis. CPUE standardization was conducted by a delta lognormal approach with binomial distribution for the model of proportion of positive catch sets and lognormal distribution for the model of positive CPUE sets (Lo et al, 1992).

Because estimated effective fishing effort per one operation was changed drastically by different operation pattern (target species, area, and season) and this difference was thought to influence on the ratio of positive catch, a factor of the amount of effective fishing effort per operations (AEF) was included in the model of proportion of positive catch sets.

For the model of proportion positive catch sets, factors of year, quarter, area, and AEF were included. For the model of positive CPUE, factors of year, quarter, area were included, and interaction terms of ayear*area, year*quarter were included into the model as random effect.

For the analysis of CPUE calculated by number of hooks as fishing effort, factor of gear configuration (NBF) was also included into the both model of proportion of positive catch sets, and factor of AEF was excluded from the model of positive catch. Interaction term of area*gear was introduced into the model of positive CPUE as random effect.

With regard to the gear configuration, 3 to 24 hooks between floats were observed in the statistics used. These 21 levels were categorized to 6 levels (3-5, 5-6, 7-9, 10-11, 12-15, and 16-24 hooks between floats) arbitrarily. AEF was categorized to 8 levels (<100, 100-200, 200-300, 300-500, 500-1000, 1000-2500, 2500-5000, >5000 minutes of hook resting time).

Subarea stratification used in the standardization is shown in **Figure 7**. The fittings for the model, was done through SAS/STAT statistical package (Ver. 8.02).

3. RESULTS AND DISCUSSIONS

The results of CPUE analysis were shown in **Figures 8-12**. Observed CPUE (n/1000 hooks) of positive catches showed gradual decreased trends throughout period analyzed with sudden spikes in early 1970’s and some peaks, while observed proportion of positive catch showed sudden decrease from 1967 to 1972 **(Figure 8)**. Frequency distributions of log CPUE of positive catch was skewed a bit **(Figure 9)**, while chi-square residuals of positive CPUE dispersed rather evenly. Residual of proportion positive catches in the period of 1980-2000 was disposed to positive **(Figure 9)**. This indicates the predicted values in 1980-2000 were underestimated. Standard errors of standardized CPUE were rather large **(Figure 11)**, which supposed to be caused by the introductions of interaction terms of fixed factors as random effect. Introduction of year*area interaction as random effect is kind of compromise when the coverage of data is low. Since 1980’s, main fishing ground of Japanese longliners shifted from western Atlantic to eastern Atlantic where the margin of white marlin distribution area (Yokawa and Uozumi; 2000).

A sudden increase of observed and standardized CPUE of positive catches was observed from 1969-1970. This supposed be caused by the assumptions of habitat model. In the 1960s, Japanese longliners retrieved longline gear by hand. In the present study, the speed of gear retrieving was assumed to be one third of those in the period after 1969 when longliners introduced electric line hauler, based on questionnaires to retired fishing masters. Because white marlin mainly distributes in surface mixed layer, high weight was given for the hook resting time of this layer in the calculation of effective fishing effort. So, slower line hauling resulted in the larger effective effort. In addition to this, NBF was uniformly assumed to be 5 in 1967-69, while it was assumed to be 6 in 1970-1974 as target species of Japanese longliners change from yellowfin tuna and albacore in 1960’s to bigeye tuna and albacore in 1970-1974. Further investigation would be necessary to build a model closer to reality.

A sudden decrease of observed and standardized proportion of positive catch operations to total was observed in the period of 1967-1972. The reasons of this supposed to be change of operation pattern of Japanese longliners, or nature of white marlin – some fishing masters claims that CPUE of white marlin decreased drastically only a few years after first fishing – but could not figure out them in this study. Further investigation should be conducted.

General trend of standardized CPUE of white marlin did not changed so much when the fish sumed to distribute mainly in the surface mixed layer (**Figure 13**, Patterns 1-3). As vertical distribution pattern of Atlantic white marlin believed to be not so different from the ones of Pacific striped marlin or Pacific blue marlin, standardized CPUE obtained in this study supposed to be not far from the one that calculated with actual vertical distribution pattern of Atlantic white marlin. Trends of standardized CPUE calculated with the number of hooks as fishing effort, instead of effective effort, showed relatively closer to trends of the ones which calculated with effective fishing effort of Pacific swordfish (Pattern 5) or more deeply distributing fish (Pattern 7). This results suggests that fact that the trend of standardized CPUE calculated with the number of hooks as fishing effort is unrealistic.

Although the precision of estimated abundance index of white marlin in this study was low, this index supposed to better reflect actual dynamics of white marlin population than former methods, which used number of hooks as fishing effort.

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Table 3. Six patterns of vertical distribution probability for white marlin. Pattern 2 is estimated vertical distribution probability for Pacific blue marlin, pattern 3 is for striped marlin and pattern 5 is for swordfish. All other patterns were arbitrary developed for sensitivity analysis of habitat of white marlin.

Relative Temp (&) to surface	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5	Pattern 6	Pattern 7
0	85.00%	75.89%	52.24%	30.00%	14.54%	30.00%	0.50%
-1	10.00%	13.76%	21.89%	10.00%	5.39%	10.00%	0.50%
-2	4.00%	5.82%	9.45%	10.00%	0.73%	10.00%	0.50%
-3	2.00%	2.13%	5.47%	10.00%	1.17%	10.00%	0.50%
-4	0.20%	1.17%	3.98%	10.00%	1.35%	10.00%	1.00%
-5	0.20%	0.54%	3.48%	10.00%	3.31%	5.00%	1.00%
-6	0.20%	0.52%	1.99%	10.00%	4.43%	5.00%	5.00%
-7	0.10%	0.15%	1.00%	5.00%	10.26%	5.00%	5.00%
-8	0.10%	0.02%	0.50%	5.00%	4.25%	5.00%	7.50%
-9	0.01%	0.00%	0.00%	0.00%	11.41%	2.00%	7.50%
-10	0.00%	0.00%	0.00%	0.00%	16.82%	1.00%	10.00%
-11	0.00%	0.00%	0.00%	0.00%	5.16%	1.00%	10.00%
-12	0.00%	0.00%	0.00%	0.00%	4.34%	1.00%	15.00%
-13	0.00%	0.00%	0.00%	0.00%	3.12%	1.00%	10.00%
-14	0.00%	0.00%	0.00%	0.00%	2.02%	1.00%	10.00%
-15	0.00%	0.00%	0.00%	0.00%	2.08%	1.00%	7.50%
-16	0.00%	0.00%	0.00%	0.00%	3.07%	1.00%	5.00%
-17	0.00%	0.00%	0.00%	0.00%	6.56%	1.00%	2.50%
-18<=	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%

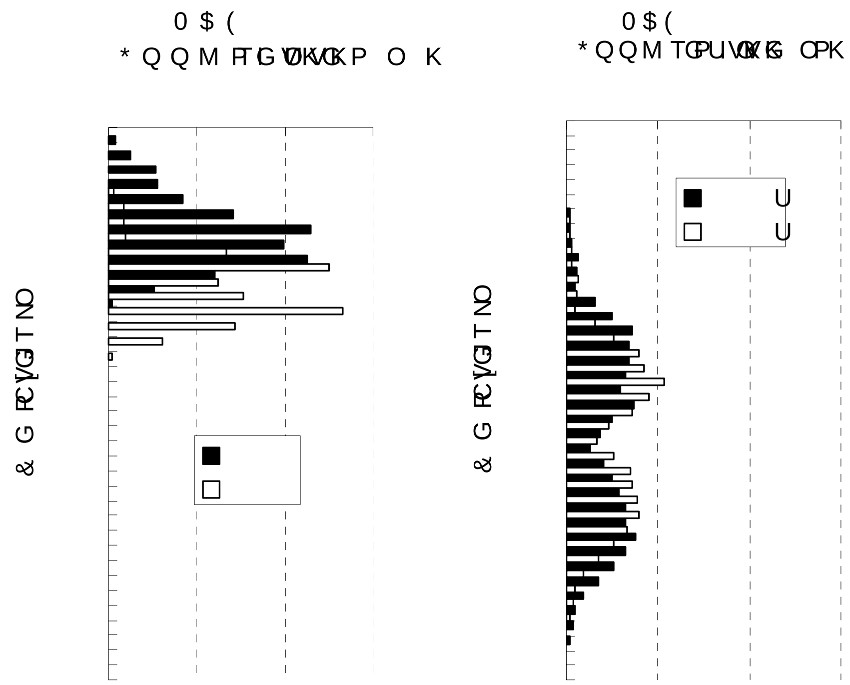


Fig. 3. Comparison of the estimated hook resting time by depth layer with no gear shoaling in the different periods. Right panel shows the comparison between the period 1959 – 1969 and 1975 – 1999 for the operation with NBF = 5, and left shows the comparison between 1980's and 1990's for the operation with NBF = 16. All the value scaled into the total which was set for 10 hours.

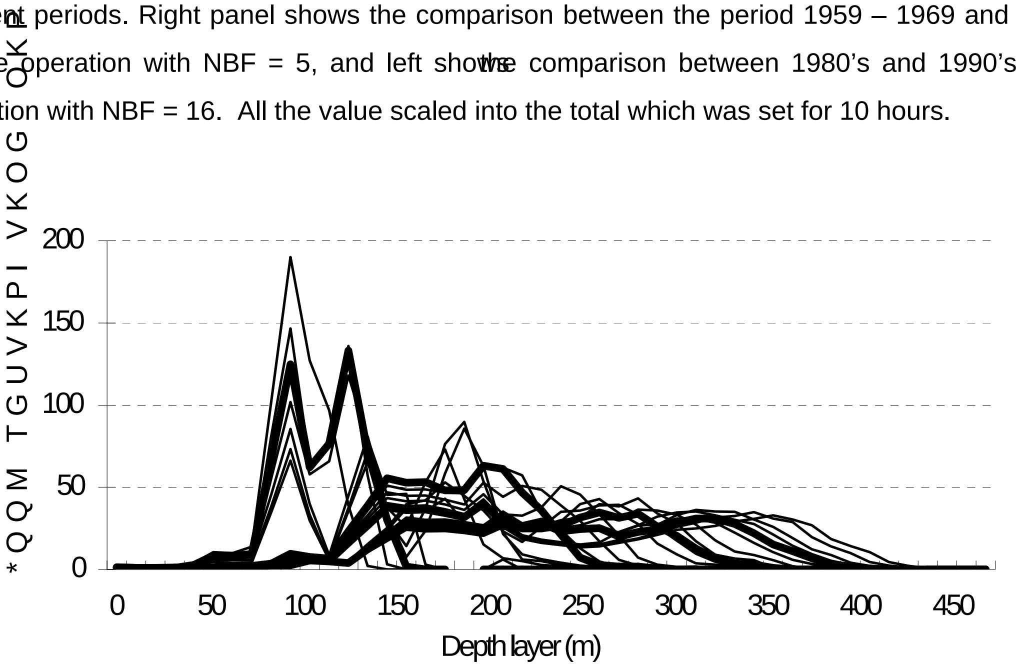


Fig. 4. Estimated Hook resting time by depth layers of operations with NBT = 3 – 24. All the values were scaled into the total set at 10 hours. Data of 1975 – 79 for NBT = 3 – 9, data of 1980's for NBT = 10 –15, and data of 1990's for NBT = 16 – 24 were used for drawing line in the graph. Data of operation with 5, 10, 15, and 20 NBT were shown in bold line.

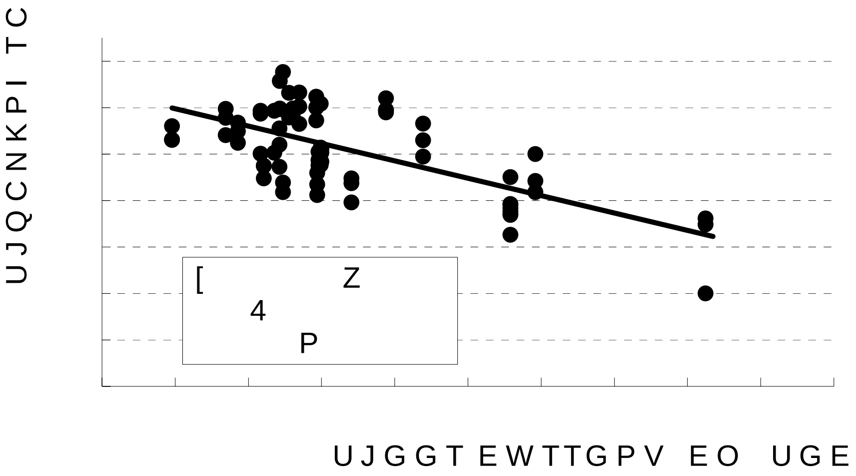


Fig. 5. Relation ship between observed shoaling ratio and sheer current. Data obtained by the longline research in the tropical Atlantic in 2000 by Shyoyo-Maru.

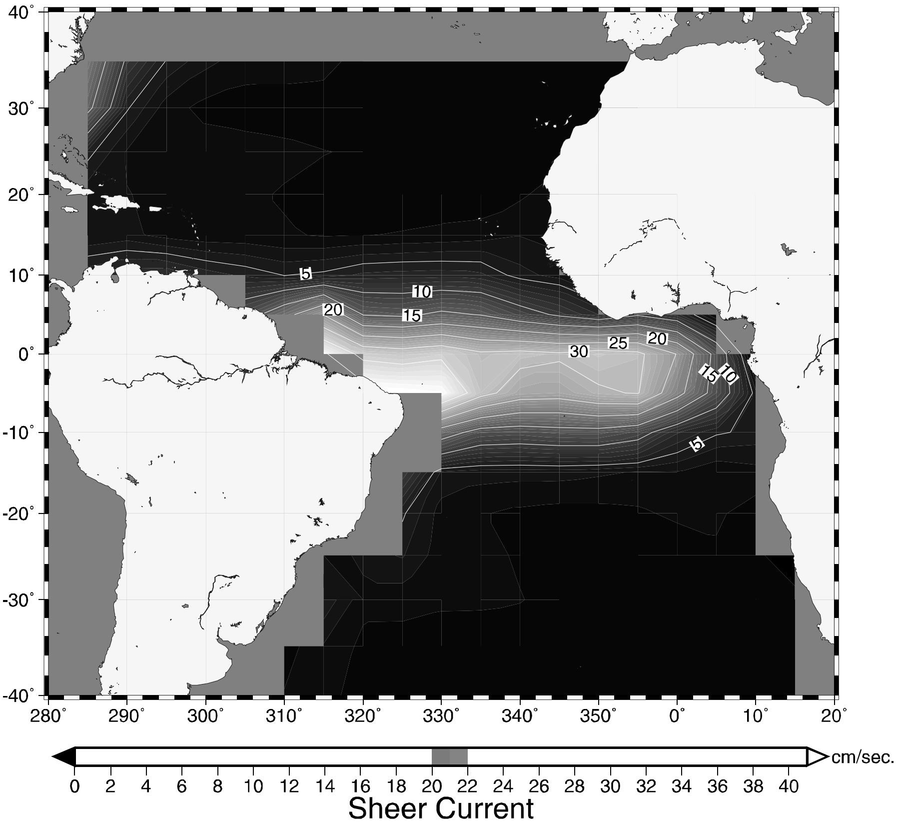


Fig. 6. The distribution of the sheer current for the option with NBT = 10 – 24 in 1980’s. The re-gridded data (5 degree) was used.

Fig. 7. Area stratification used in the standardization of catch per unit effective fishing effort.

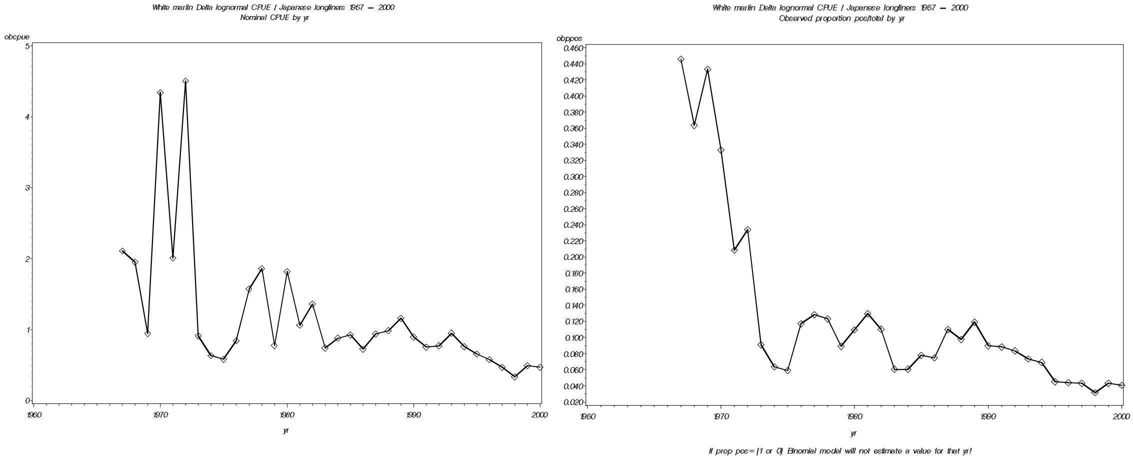


Fig. 8. Trends of nominal CPUE (n/1000 hours, left) and observed proportion of positive catch (right).

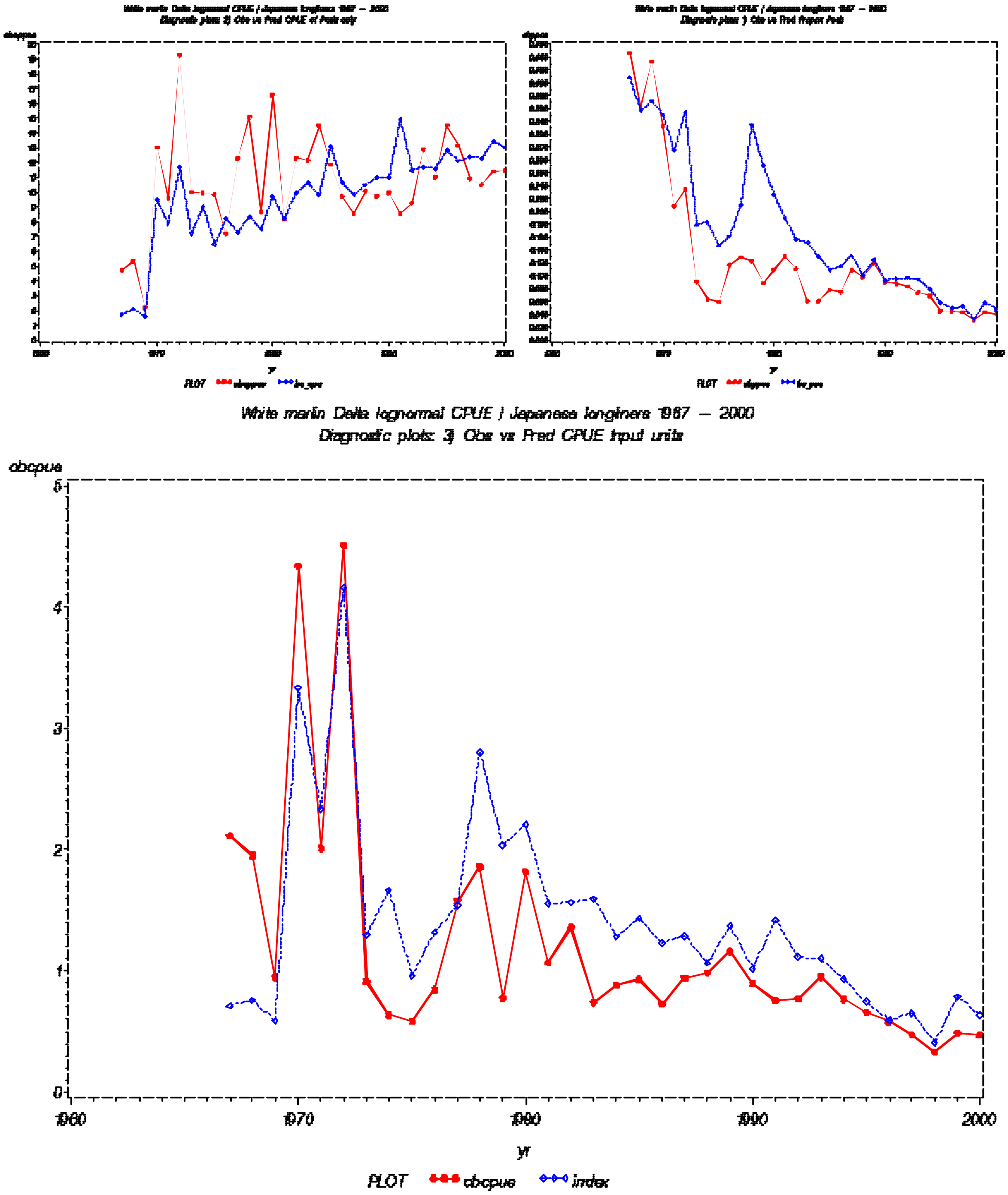
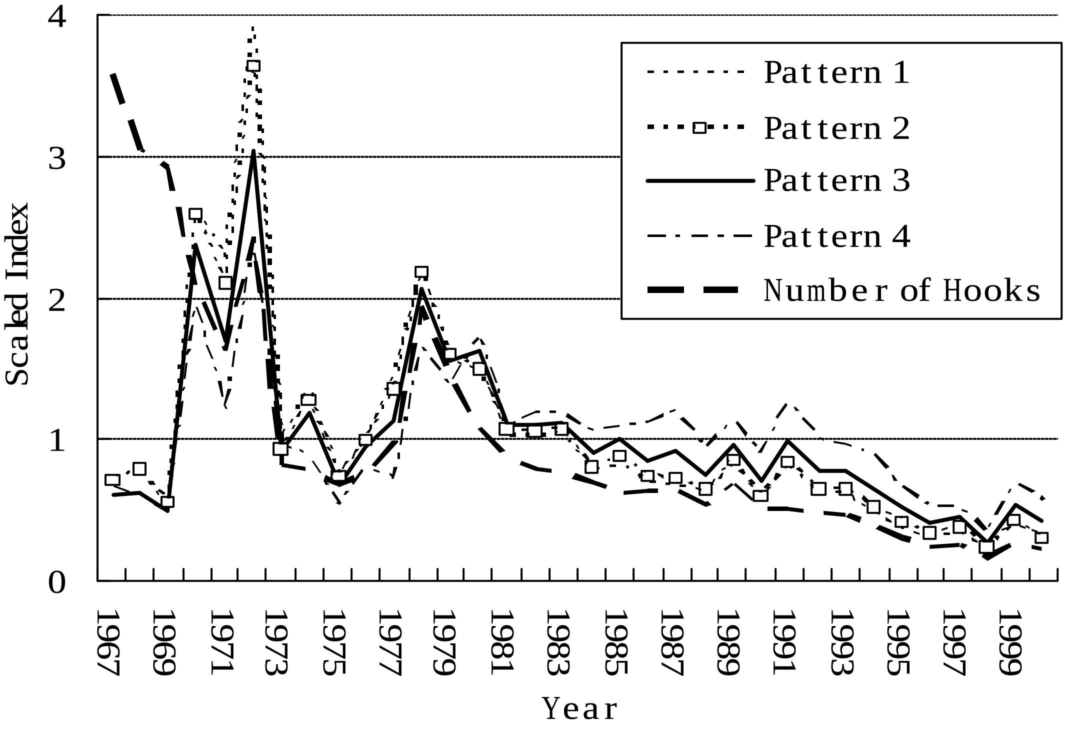


Fig. 12. Trends of standardized and observed CPUE of positive catches (left top), proportion of positive catches (right top), and CPUE (bottom).



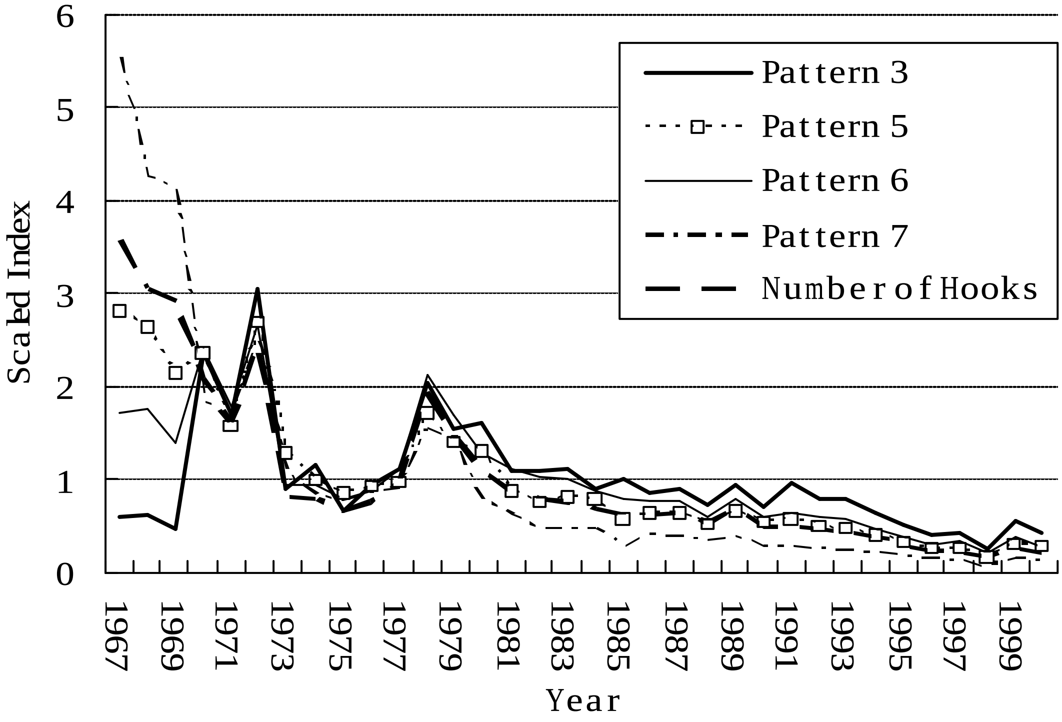


Fig. 13. Trends of standardized CPUE estimated with effective fishing effort (7 patterns in Table 3) and number of hooks. Pattern 3 was the one adopted in this study.