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Estimation of abundance index of swordfish caught by Japanese longliners by the habitat model1[1]

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Introduction

The habitat model (Hinton and Nakano, 1996) is one of good ways to standardize catch and effort data caught by longline gears, especially for non target species. This is because the vertical and horizontal coverage of gear is usually not enough for the ones of non-target species, and this cause complicated situation in CPUE standardization with the traditional GLM method (Yokawa, 2003). This study is first trial to estimate effective fishing effort of swordfish in the north west and central Pacific, where swordfish partly fished as non-target.

Materials and Methods

1. Effective fishing effort

Effective fishing effort on swordifsh 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 $$E_{at} = \sum_d h_{atd} \qquad (2)$$

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 using data collected by time, depth, and temperature recorders as well as information about detail of gear configuration obtained form fishing masters

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 swordfish.

2. Depth distribution of longline hook

(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 in a particular depth zone, we use data by TDRs attached to the position near by hook. Data of TDRs 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 records the time, depth, and temperature data in every 10 seconds. Because time interval of data collection of TDR is very short, we assumed the each data of 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 speed of hook sinking/rising, we can estimated hook-resting time in each depth layer by aggregating total number of TDR records counted in each depth layer.

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 Shoyo-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 NHF=5 to 10th line of NHF=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) Longline gear configuration and operation time for the model input

Table 2 shows the input parameters for the catenary model used in this study. For shallow setting, the average values of the data obtained by the questionnaire on retired fishing masters of surface longliners. For deep setting, values were decided based on the general information obtained by the interview to the fisherman, operated in the Atlantic. For the periods before 1975 when information about NHF is not available, NHF=5 were assumed for all operation.

Because vertical probability pattern of swordfish change by day and night, operation time is important factor for CPUE. In this study, operation time was assumed as follows based one some questionnaires to fishing masters;

night setting (NHF is 3 and 4); 70% for night time and 30% for daytime

day setting (NHF is >5); 30% for night time and 70% for daytime

That is very rough estimates, and will be to be improved. Concerning operations which NHF is 5, at least part of them were night setting (based on interview to fishing masters) but not enough information is collected by now to estimate its ratio. In this study, it arbitrary assumed as 50% for night time and 50% for daytime.

Because most of longliners changes their starting time of gear setting and retrieving by the time of sun rise and sun set, seasonal change of operation time (night/day) was ignored.

(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 in which hook is moving fastest so that the mode of hook resting time is coincide with the depth calculated by catenary model.

d) For the operation with NHF = 3 – 9 during in 1980's and 1990, the gear configurations in 1975 – 79 (Table 2) were applied. For the operation with NHF = 10 – 15 in 1990's, the gear configurations in 1980's 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 NHF =< 15 than those at the operation with NHF >= 16.

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.

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 in the Shoyo-Maru research 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 Fig. 5, formula of $y = -0.0075s + 1.1345$ was used to estimate shoaling rate from current data in this study.

Oceanic currents data for the Pacific in the years of 1980 – 1997 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 NHF = 3- 9, the shear current was obtained from the data of 15 and 75 m, 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 NHF = 10 –24, the shear current was obtained from the data of 35 and 136 m, 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 NHF = 10 - 24 obtained by the re-gridded data.

The center depth of each layer is multiplied shoaling rate 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 assumed to move into new layer.

For periods before 1980, monthly average values between 1980 and 1989 were applied, and for periods after 1997, monthly average values between 1990 and 1997 were applied.

4. Vertical distribution pattern of swordfish

Takahashi *et. al.* (2003) reports vertical distribution pattern of swordfish estimated by data collected by an archival tag (70days in summer) in the north west Pacific (Fig. 6). Weight of tagged fish was about 120 kg. The paper also reports that vertical distribution of swordfish seemed to be related with water temperature during day time and depth during night time.

In this study, vertical distribution pattern of all swordfish was assumed to follow the observed one of water temperature by Takahashi *et. al.* (2003) during day time, and the one by depth during night time. Historical data of under water temperature are obtained by a web site of Joint Environmental Data analysis Center (http://jedac.ucsd.edu/DATA_IMAGES/index.html).

5. Standardization of CPUE calculated with effective fishing effort

Basic catch and effort data used in the estimation of effective fishing effort was obtained from the Japanese longline fishery statistics compiled at the National Research Institute of Far Seas Fisheries for 1952-2002. Two kinds of Databases were used. The Database-I has the information of catch number and number of hooks used which year, month and 5x5 blocks aggregated and rose to 100 percent coverage, while the new Database-II, starting from 1975, contains additional information for the gear configuration, i.e. the number of branch lines between floats. For the limitation of oceanographic data, effective effort could only estimated for periods after 1995 and area up to 40N.

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.

CPUE of swordfish calculated by effective fishing effort is adjusted seasonal and areal effect using GLM with following model;

CPUE= μ +Year+Area+Quarter+Area*Quarter+Year*Area+Year*Quarter+e.

As Year*Area interactions were significant, the weighted mean of CPUE in each year by the size of areas are summed up to get total abundance index. Area stratification used in GLM is shown in Fig. 7.

Results

Figures 8 shows trends of yearly amount of effective effort (EE) and nominal effort (NE, number of hooks). In the periods between late 1960's and 1970's, relative level of EE is higher than that of NE, and after that EE becomes higher than NE. Trends of un-standardized CPUE are not so different between the one with effective effort and number of hooks (Fig. 9).

Standardized CPUEs with effective effort by area are shown in Fig. 10. Values of CPUE in area 1 is highest, and area 5 is lowest. General downward trends are observed in all area for periods of mid 1980's and beginning of 2000's.

Standardized CPUEs with effective effort by two regions and total area are shown in Fig. 11. Continuous decreasing trends are observed since mid 1980's for both regions and total area.

Discussions

This study is first trial for estimation of effective fishing effort of swordfish caught by longliners in the north west and central Pacific. Japanese longline data in the north west and central Pacific offers a good example for testing adequacy of the habitat model used in analysis, because this is only waters where shallow setting operation is still remain with some large scale.

One of profitable points of the habitat model in CPUE analysis is that it was way to overcome problems caused by shortage of horizontal and vertical coverage in the historical data, with proper information about under water movement of gear and fish. Table 2 shows historical changes of some important factors which determine depth of set hook. Such changes are very hard to incorporate into GLM model. Although data shown in Table 2 are obtained by limited number of observations from retired fishing masters, they can be improved in future.

Shortage of information to identify target species in the Japanese longline statistics is one of major problem in this study. Questionnaires to retired fishing masters prove that they started night surface operation targeting swordfish in very early periods of the history of fishing. Deficiency of information about NHF in the statistics before 1975 hampered to pick up data of night setting. This might be improved if the logbook data were checked. Such study should be done in near future.

Vertical probability pattern of swordfish used in this study is obtained by information from only one tagged fish. It can easily be supposed that it would change by size of fish, season, area and other factors. More information about vertical distribution should be necessary to construct more reliable model.

Difference between vertical probability pattern of swordfish and vertical pattern of CPUE of swordfish would also be confirmed. Some swordfish fisherman insist that too much shallower setting (<30m depth) has effect to decrease CPUE of swordfish in particular season and area. This could be examined by a research using time, temperature, and depth recorders attached to branch lines.

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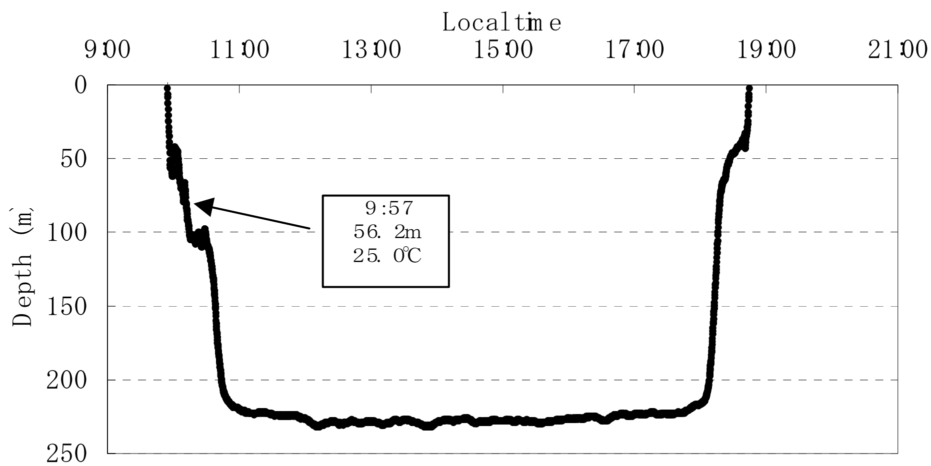

Fig. 1 Example of time-depth data of longline hook when Atlantic blue marlin was caught by a next deeper branch line with probe. Data collected in 4th of November 2000 in position in 4.6 S and 17.6 W.

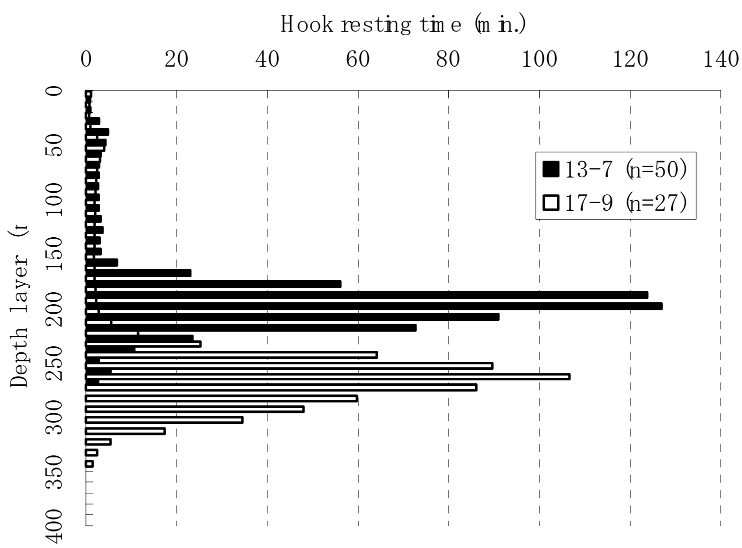

Fig. 2 Estimated distribution of hook resting time by 10 m depth layer of 7th line in Number of hooks between float (NHF) =13 (13-7) and 9th line for NHF=17 (17-9). Calculated depth of hook by caternary model was 200 m for 13-7 and 240 m for 17-9 respectively. ‘n’ means the number of TDR data available from one operation.

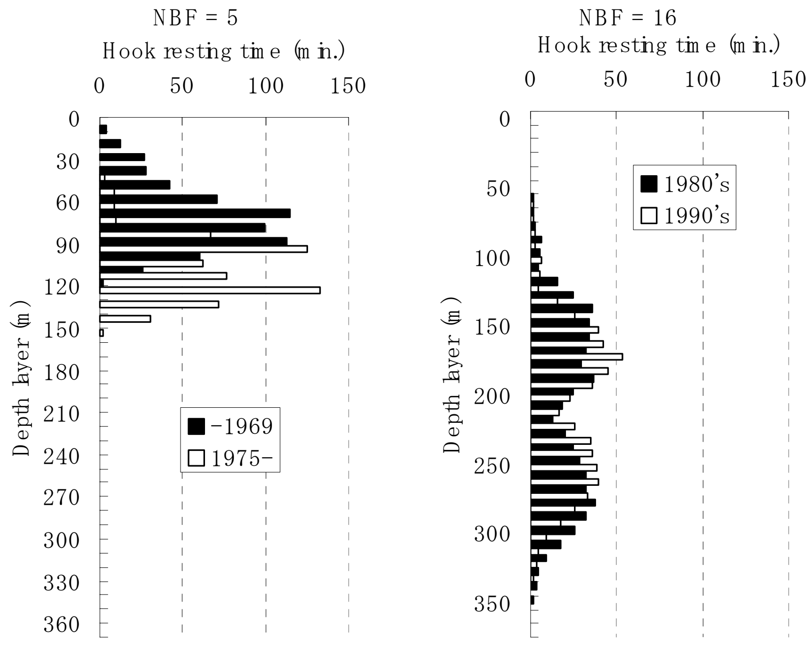

Fig. 3. Comparison of the estimated hook resting time by depth layer with no gear shoaling in the different periods. Right panel shows the comparison between the period 1959 – 1969 and 1975 – 1999 for the operation with NHF = 5, and left shows the comparison between 1980's and 1990's for the operation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

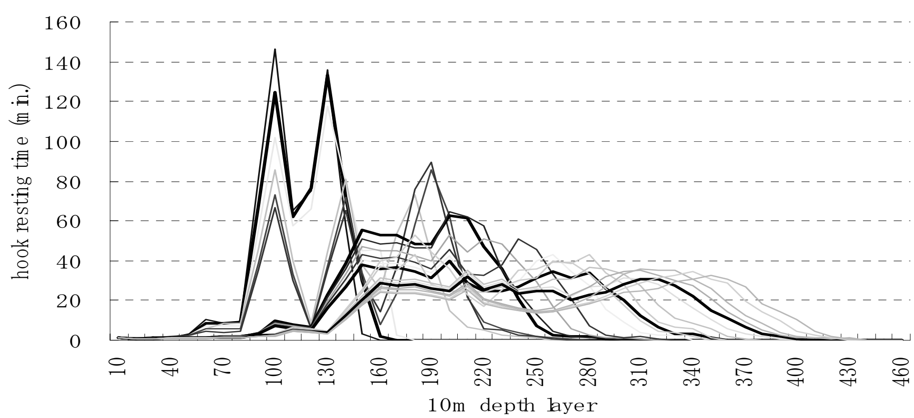

Fig. 4. Estimated Hook resting time by depth layers of operations with NBT = 3 – 24. All the values were scaled into the total set at 10 hours. Data of 1975 – 2002 for NBT = 3 – 9, data of 1980 - 2002 for NBT = 10 –15, and data of 1990 - 2002 for NBT = 16 – 24 were used for drawing line in the graph. Data of operation with 5, 10, 15, and 20 NBT were shown in bold line.

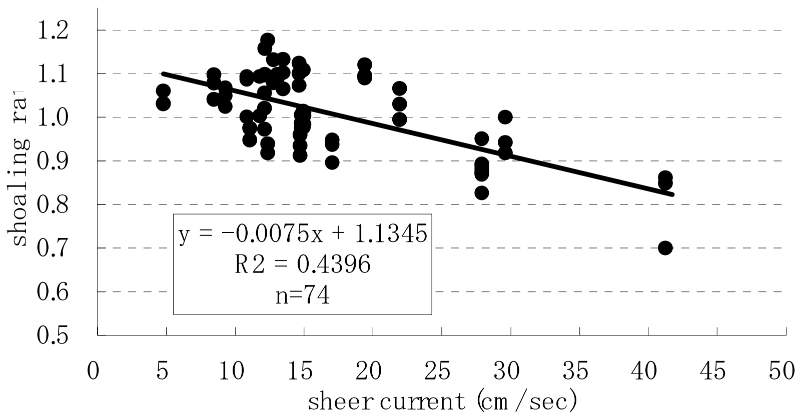

Fig. 5. Relation ship between observed shoaling ratio and shear current. Data obtained by the longline research in the tropical Atlantic in 2000 by Shyoyo-Maru.

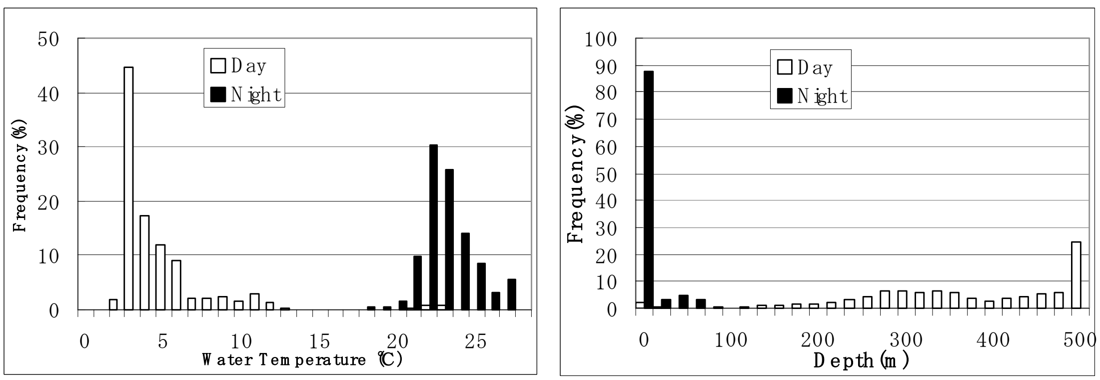

Fig. 6. Vertical distribution pattern of swordfish during day and night time. Referred from Takahashi *et. al.*, (2003).

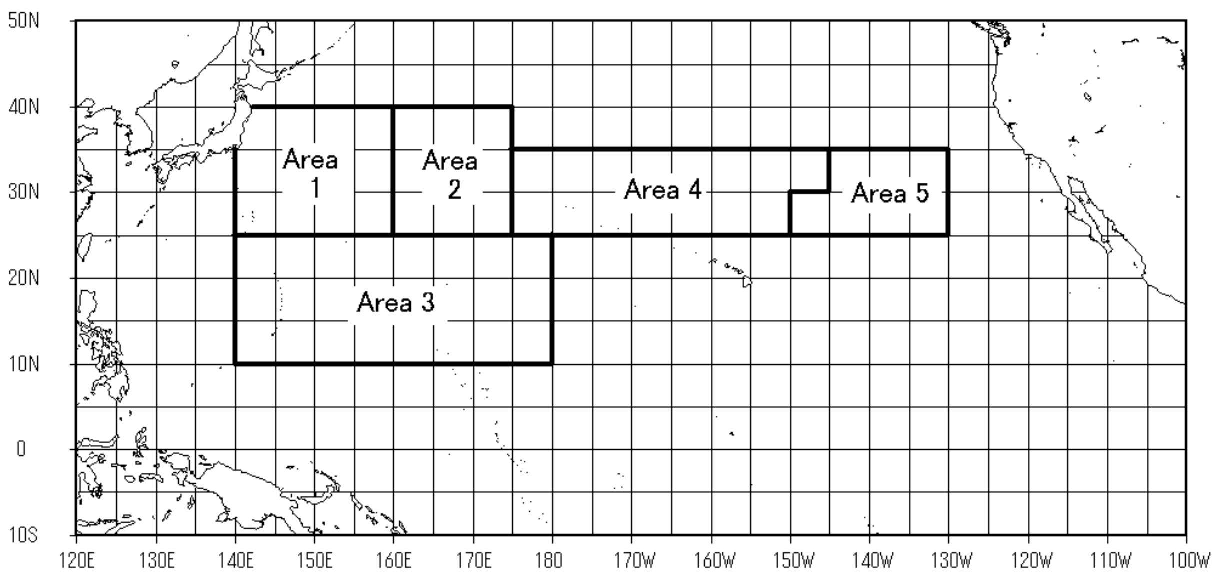

Fig. 7. Area stratification used in analysis of catch per unit effective effort.

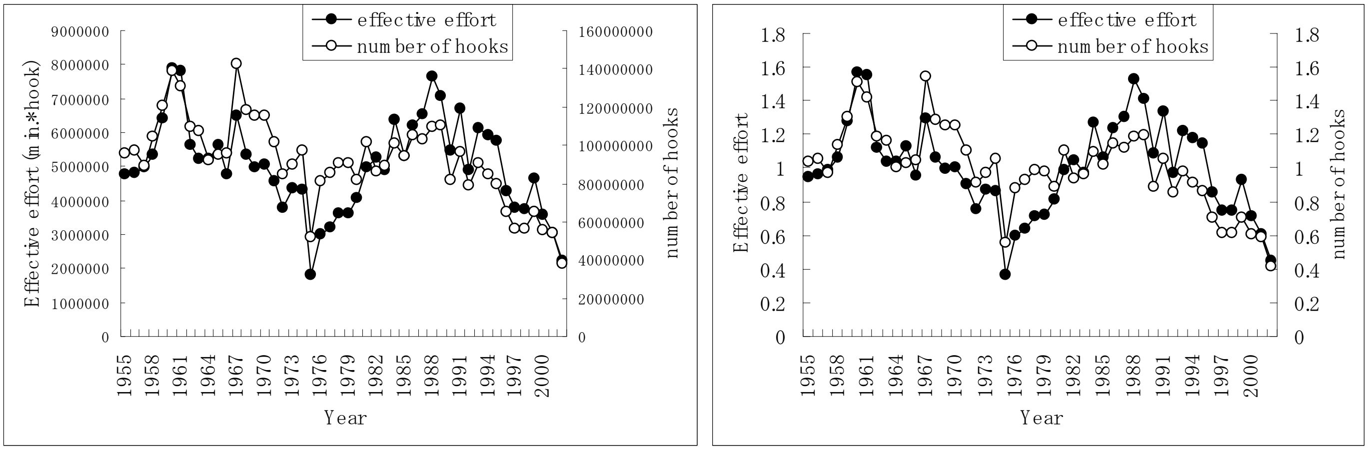

Fig. 8. Yearly amount of effective effort (min*hooks) and total number of hooks (left), and trends of their scaled values (right,scaled to their average which set at 1.0) Data north of 40N are not used.

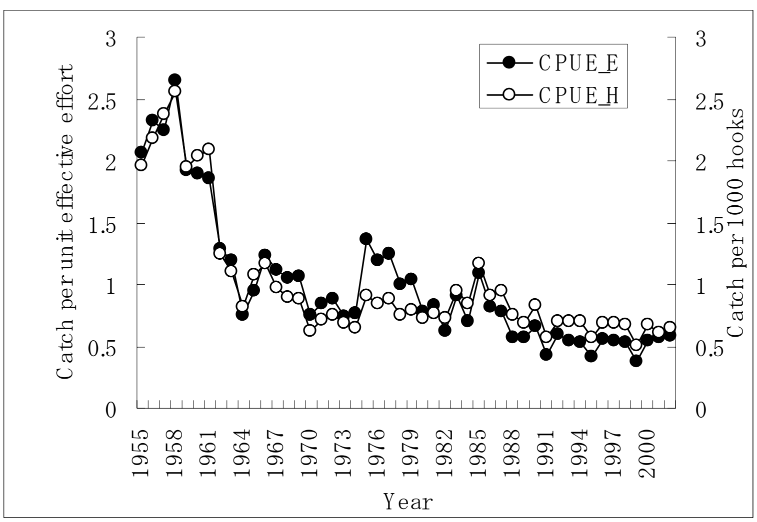

Fig. 9. Yearly trend of swordfish catch number per unit effective effort (CPUE_E, 100 mim. x hook) and per 1,000 hooks (CPUE_H). All values are scaled to their average which set at 1.0.

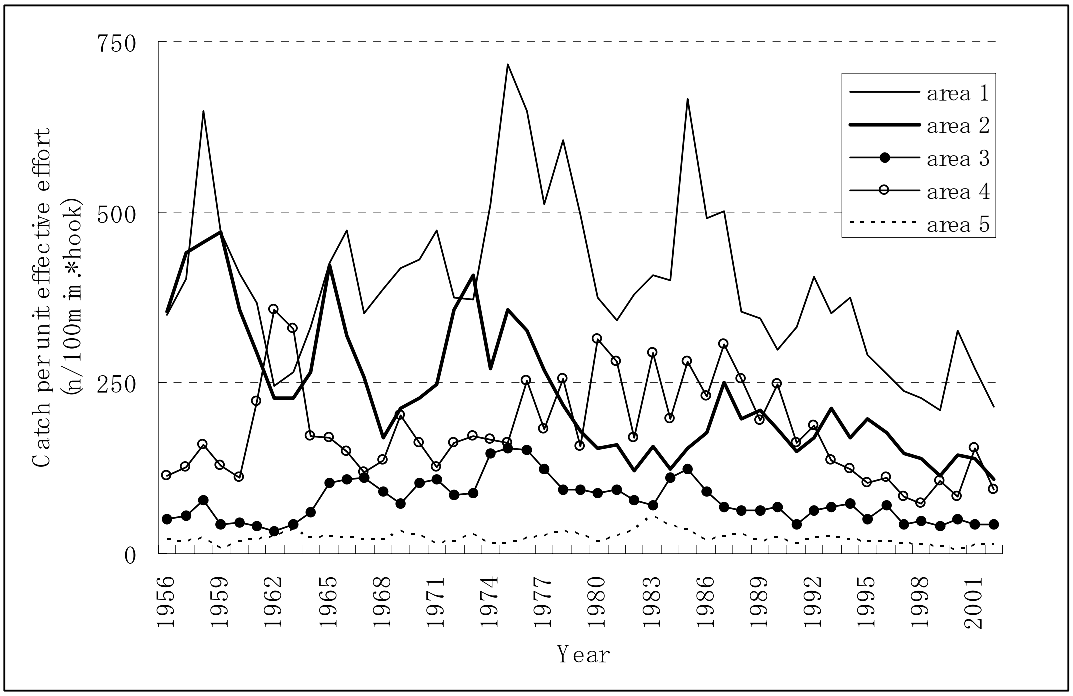

Fig. 10. Standardized catch per unit effective effort (n/100 min.* hook) by area.

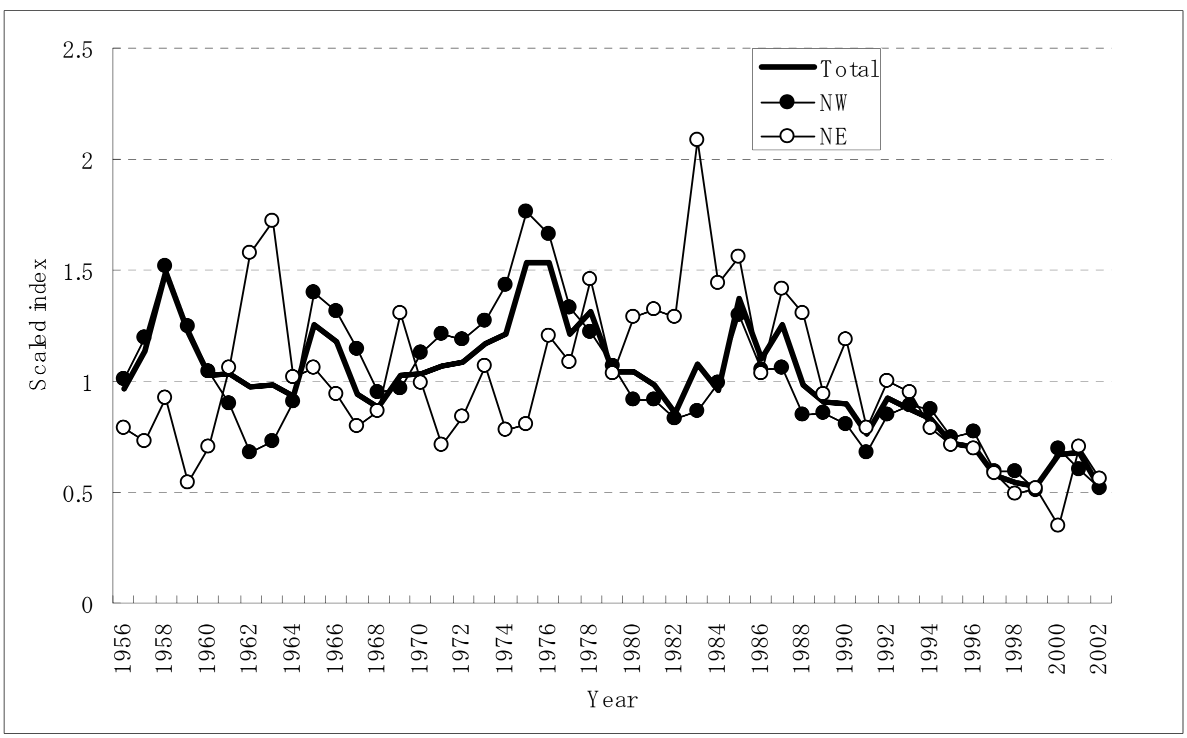

Fig. 11. Standardized catch per unit effective effort (n/100 min.* hook) for total area (Total), north west region (NW, area 1, 2 and 3), and north east region (NE, area 4 and 5). All values scaled to their average which set at 1.0.

Table 1. Summery of time-temperature-depth recorder (TDR) data used in the estimation of vertical hook distribution.

Number of hooks between floats	Number of line TDR attached	No. of TDR data used	catenary model depth (m)	Depth layer hook stayed longest time
5	3	70	87.5	90.0 - 99.9
15	2	26	83.4	80.0 - 88.9
13	7	50	200.6	200.0 - 209.9
13	10	39	172.1	160.0 - 169.9
15	4	43	116.8	120.0 - 129.9
15	8	29	145.4	130.0 - 139.9
15	4	16	191.3	200.0 - 209.9
15	11	10	209.9	210.0 - 219.9
15	8	16	235.1	240.0 - 249.9
17	9	66	239.6	240.0 - 249.0
19	7	67	227.3	230.0 - 239.9
19	10	36	243.7	260.0 - 269.9

Table 2. Input parameters for the catenary model used in this study. Values for shallow setting are the average of the data obtained by the questionnaire on retired fishing masters of surface longliners. For deep setting, values were decided based on the general information obtained by the interview to the fisherman, operated in the Atlantic.

Shallow setting (NHF<10)

	Length of float line	Length of branch line (m)	Distance between float (m)	Shortening ratio
1950’ s	14	17	31	0.8
1960 - 64	17	23	47	0.8
1965-69	18	30	50	0.8
1970-74	18	27	48	0.8

1975-	20	35	50	0.8

Deep setting (NHF>=10)

	Length of float line	Length of branch line (m)	Distance between float (m)	Shortening ratio
1980's	40	40	50	0.85
1990's	45	50	50	0.9