Environmental preferences of longlining for bigeye tuna (*Thunnus obesus*) in the tropical high seas of the Indian Ocean

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Abstract: A survey on bigeye tuna fishing ground has been carried out on board the longliners, Huayuanyu No.18 and No.19 in the tropical high seas of the Indian Ocean from September 15^{th} to Dec. 12^{th}, 2005. The depth of the hooks which having tuna caught have been simulated individually by modeling the relationship between the theoretical hook depth and the actual average hook depth measured by TDRs by means of stepwise regression method, and their relevant water temperature, salinity chlorophyll-a and dissolved oxygen (DTSCO), which indicate environment conditions of bigeye tuna inhabiting, have also been estimated by the simulated hook depth and the environment profiles. By analyzing the catch rate of bigeye tuna at different range of depth, temperature, salinities, chlorophyll-a and dissolved oxygen based on sampled bigeye tuna data, the results indicate the environmental preferences of bigeye tuna are as following: the DTSCO range, closely correlated to catch rate, is 160.0～219.9m, 13.0～15.9℃, 35.20～35.49‰, 0.030～0.059μg/L and 1.00～2.49mg/L respectively. The DTSCO range of the bigeye tuna's more closely correlated to catch rate, is 160.0～179.9m, 14.0～14.9℃, 35.40～35.49, 0.040～0.049μg/L and 2.00～2.49 mg/L respectively.

Key words: *Thunnus obesus*, depth, temperature, salinity, chlorophyll-a, dissolved oxygen, longline, the Indian Ocean

Indian Ocean Tuna Commission (IOTC) has conducted intensive studies on bigeye's biological characteristics (Praulai Chantawong, 1999; Praulai Nootmorn, 2004), the resources assessment (Daniel Ricard, 2002; Tom Nishida, 1999; Takayuki Matsumoto, 2000; Tom Nishida, 2001; Alain Fonteneau, 2004; Hsu C C, 2000), their distribution (Somvanshi V S, 1999), the optimum water temperature (Masahiko Mohri, 1999), and so on. At present, most of studies on the bigeye tuna optimum water depth, temperature and salinity are based on catenary curve depth. Because bigeye tuna is the targeting species of Chinese tuna longline fishing fleets in the Indian Ocean, it has been studied by Chinese scientists on the biological characteristics (Ye Z J, Wang Y J and Gao T X, 2003; Song L M and Gao P F, 2006a), the catching efficiency of longline fishing at the different depth(Ye Z

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J, Liang Z L, Xing Z L and Gao Z J, 2001), configuration and design of longline fishing gear (Ye Z J and Xing Z L , 1999) , the correlation of temperature difference of 50 to 150m water layers versus longline hooking rate of bigeye tuna in the Indian Ocean (Feng B and XU L X, 2004), and captured depth, water-temperature and salinity of bigeye tuna (*Thunnus obesus*) in Maldives waters (Song L M and Gao P F, 2006b). The optimum chlorophyll-a and DO level of bigeye tuna based on the actual measured data has not been reported.

In this paper, the ranges of depth, temperature, salinity, chlorophyll-a and DO (DTSCO) closely correlated to and more closely correlated to catch rate are discussed based on the observer data , including catch rate of bigeye tuna , water temperature, salinity, chlorophyll-a content, dissolved oxygen measured by CTD and the Submersible Data Logger, and actual hook depth measured by TDR, obtained during the longline experimental cruises on 2 Chinese longliners from Sep. to Dec. 2005 in the tropical high seas of the Indian Ocean. Results will be referenced to the further study on the habitat of bigeye tuna (SEAPODYM, and HSI models) and CPUE standardizing.

1. Materials and methods

1.1 Fishing vessels, fishing gear and methods

Longliners *Huayuanyu No.18* and *No.19,* which data has been collected, have super spool and chill sea water equipment. The vessel's particular of the LOA, mould breadth, mould depth, gross tonnage, net tonnage and main engine power is 26.12m, 6.05m, 2.70m, 150.00t, 45.00t and 407.00 kW, respectively.

The longline gear consists of 3.6 mm diameter monofilament main line, 360mm diameter hard plastic floats, 5mm diameter nylon float line and 2 types of branch line ending in ring hook or circle hook. The length of main line, float line, branch line is 110km, 22m, 16m, respectively. Two sets fishing gear have been used in the study. The conventional gear which the vessels used is as reference for comparative. The trial gears were assembled as 16 types of gear with 4 groups of weight (0.5kgs, 1.0kgs, 1.5kgs and 2.5kgs in water). In general, the time of shooting and deploying gear was between 03:00 and 06:00 at local time, and then lasted for 5 hours in fishing. The time of retrieving and handling on the gear was at 12:00 to 15:00, the total operation would be lasted for 10 to 12 hours. During deploying gear, the vessel's speed was about 4.3ms^{-1}, line shooter speed was about 6.2 to 7.0ms^{-1}, time interval between fore and after branch lines set out was about 7.8s, the length of main line between two branch lines were 43.5m and there were 25 hooks per basket (HPB).

The fishing boats were targeting bigeye tuna mainly, and the bycatch including yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), albacore (*Thunnus alalunga*) and billfish (Istiophoridae), and their operating was in 0º47′N～10º16′N，61º40′E～70º40′. The locations, where data collected by means of Submersible Data Logger (XR-620), CTD (SBE37SM) and TDR (2050) are shown in Fig.1. The investigation time was from Sep.15 th to Dec.12th, 2005 and each boat fished 54 days.

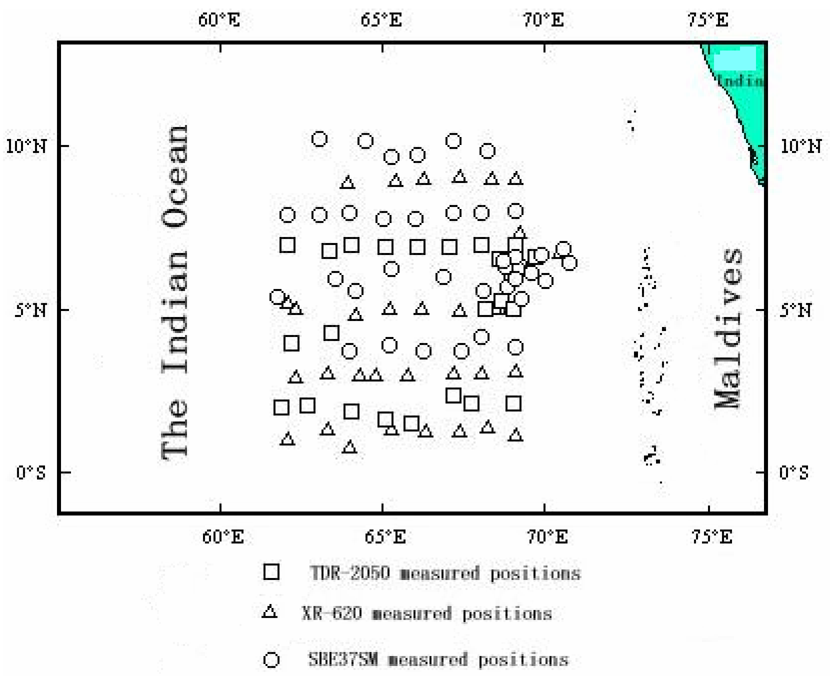

Fig.1 TDR, XR-620, SBE37SM measured locations

1.2 Instrumentation

Investigation instruments include Submersible Data Logger XR-620 and TDR-2050 (RBR Co. Canada) and SBE37SM (CTD, SeaBird Co. USA), each boat has equipped 7 TDRs. The measurement range of temperature, conductivity, DO and chlorophyll-a of XR-620 are 5 to 35□, 0 to 2mS/cm, 0 to 150％, 0.02 to 150μg/L, respectively. The accuracy of data is 0.002□, 0.0003mS/cm, 1％ of DO measurement range, less than 2% of chlorophyll-a measurement range, respectively. The actual depth of hook approached and water temperature measured by TDR, the accuracy on depth measurement is ±0.05% in range 10m-740m, and the accuracy on temperature is ±0.002□, the conductivity of the CTD is 0.0003s/m. Considering the accuracies of data from varied instruments and requirements of the study, the data of depth and temperature have been processed to keep one effective decimal only, and the other items of as salinity, DO and CPUE keep two decimals and chlorophyll-a having three decimals respectively in this paper.

1.3 Investigation method and items

There were 80 planned positions to be investigated, but the actual investigation positions were lightly inconsistent with the plan. XR-620 (some of positions) had recorded water temperature, salinity, DO and chlorophyll-a vertical profiles in some of days after setting gear. SBE37SM (other of positions) had recorded water temperature, salinity vertical profiles and TDR (2050) had also recorded water temperature vertical profiles in some of days after setting gear. The data beyond the measurement range were estimated from vertical profile aided the trend line.

The following data were collected, including setting position and time, course and speed, line shooter speed , number of HPB, the time interval between two hooks, the numbers of hook, the time of retrieving line, hook code which hooked fish, individuals of hooked bigeye tuna per day, bigeye tuna hooked positions.

1.4 Methods

By the ranges of depth, temperature, chlorophyll-a and DO, the catch rate and the individuals of hooked bigeye tuna were analyzed by clustering (Tang Q Y and Feng M G, 2002) to estimate the depth, temperature, chlorophyll-a and DO range closely correlated to and more closely correlated to catch rate.

1.4.1 Theoretical depth

The theoretical hook depth (519) was calculated by the catenary curve equation (Saito S.J, 1992) based on the identified hook code, which was also measured by TDR-2050 to record the actual hook depth.

1.4.2 Modeling the relationship between theoretical depth and actual average hook depth

The relationships between theoretical depth and actual average hook depth (2 types of fishing gear: conventional gear and trial gear) had been modeled by stepwise regression method in DPS software. For the conventional fishing gear, we considered that the actual hook depth was mainly impacted by gear drift velocity (Vg), wind speed (V_w), wind direction (C_w), washing angle (Q_w) and wind angel (γ) in this paper. The actual hook depth changed constantly at a certain range. For the trial fishing gear, we thought of the weight in the water as an additional factor in the model. In the equation, Vg means the fishing gear drift velocity to the ground by the resultant force of wind and current, V_w measured by anemoscope,C_w measured by compass. Q_w means the angle between prevailing course in deploying gear and drifting direction of fishing gear. γ means the angle between wind direction and prevailing course in deploying gear.

For conventional fishing gear, we assume that the following equation fits the relationship between theoretical depth (D_T) and actual average depth ($\overline{D}$).

$$\overline{D} = b_0 + b_1 D_T + b_2 V_w^{\ 2} + b_3 V_g^{\ 2} + b_4 \sin \gamma + b_5 \sin Q_w \qquad (1)$$

By DPS , the model is

$$\overline{D} = 0.30 + 0.67 D_T + 1.03 V_w^2 + 47.21 \sin Q_w$$ (R=0.8349, F=187.0649, p=0, S=47.1438) (2)

For trial fishing gear, we assume that the following equation fits the relationship between theoretical depth (D_T) and actual average depth ($\overline{D}$).

$$\overline{D} = b_0 + b_1 D_T + b_2 W + b_3 V_w^2 + b_4 V_g^2 + b_5 \sin\gamma + b_6 \sin Q_w$$ (3)

By DPS，the model is

$$\overline{D} = 96.53 + 0.69 D_T - 17.03W - 19.73 V_g^2$$ (R=0.6593, F= 68.4305, p=0, S= 67.6504) (4)

By this 2 models, the $\overline{D}$ is defined simulated hook depth.

1.4.3 Hooking temperature, salinity, chlorophyll-a and DO

Among 624 inds of the hooked fish, 242 inds' (sample coverage 38.78%) temperature, 147 inds' salinity (sample coverage 23.56%), 77 inds' (sample coverage 12.34%) chlorophyll-a, and 77 inds' (sample coverage 12.34%) DO which indicate environment conditions of bigeye tuna inhabiting, was calculated from temperature, salinity, chlorophyll-a, and DO vertical profiles measured by XR-620, SEB37SM and TDR-2050 guided by the simulated hook depth.

1.4.4 Data processing

(1) The method of classifying the depth, temperature, salinity, chlorophyll-a and DO

It was classified to the hooked fish that the hook depth ranged from 40.0m to 399.0m with 20m intervals, the water temperature ranged from 10.0 to 28.9℃ with 1℃ intervals, the salinity ranged from 33.80 to 36.79 with 0.1 intervals, the chlorophyll-a ranged from 0.030ug/L to 0.099ug/L with 0.010ug/L intervals and above 0.100ug/L as a range, the dissolved oxygen ranged from 0.5 to 3.99mg/L with 0.5mg/L intervals. There were, in total, 18 ranges in depth, 19 ranges in water temperature, 20 ranges in salinity, 8 ranges in chlorophyll-a and 9 ranges in dissolved oxygen.

(2) The CPUE in the different ranges of depth, temperature, salinity, chlorophyll-a and DO

Individuals of hooked bigeye tuna whose hook code was identified and the numbers of hook which were sampled in different depth, water temperature, salinity, chlorophyll-a and DO ranges, were calculated by the frequency statistic method, showed in N_{Sij}(indicated in N_{S1j}, N_{S2j}, N_{S3j}, N_{S4j}, N_{S5j}) and H_{Sij} (indicated in H_{S1j}, H_{S2j}, H_{S3j}, H_{S4j}, H_{S5j}) respectively. The percentages of N_{Sij} of the total individuals of hooked bigeye tuna (indicated in N_S) whose hook code were identified were calculated and they were indicated in P_{ij} (indicated in P_{1j}, P_{2j}, P_{3j}, P_{4j}, P_{5j}, showed in equation 5). The percentages of H_{Sij} of the total sampled hooks (conventional hooks and trial hooks indicated in H_S and H_S' respectively) were calculated and they were indicated in P_{Hij} (conventional hooks indicated in P_{H1j}, P_{H2j}, P_{H3j}, P_{H4j}, P_{H5j}, showed in equation 6, and trial hooks indicated in P_{H1j}', P_{H2j}', P_{H3j}', P_{H4j}', P_{H5j}', showed in equation 7). Individuals of total hooked bigeye tuna (indicated in N) and hooks which were divided into totally (conventional hooks indicated in H; trial hooks indicated in H′) different depth, water temperature, salinity, chlorophyll-a and DO ranges, were estimated based on the sample data, and they were indicated in N_{ij} (indicated in N_{1j}, N_{2j}, N_{3j}, N_{4j}, N_{5j}, showed in equation 8) and H_{ij} (conventional hooks recorded as H_{1j}, H_{2j}, H_{3j}, H_{4j}, H_{5j}, showed in equation 9 and trial hooks as H_{1j}', H_{2j}', H_{3j}', H_{4j}', H_{5j}', showed in equation 10, H_{2j}, H_{3j}, H_{4j}, H_{5j}, H_{2j}',H_{3j}', H_{4j}', $H_{5j}'$was estimated based on the water temperature, salinity, chlorophyll-a and DO ranges of 2 types of fishing gear corresponding to the depth range) respectively. The numbers of hook （indicated in H_{Tij}）in different depth, water temperature, salinity, chlorophyll-a and DO ranges was the sum of conventional hooks and trial hooks per day（showed in equation 11）. Bigeye tuna catch rates in different depth, water temperature, salinity, chlorophyll-a and DO ranges (indicated in $CPUE_{ij}$) were calculated by N_{ij} and H_{ij} (showed in equation 12). They can be indicated in the following equations:

$$P_{ij} = N_{Sij} / N_S \qquad (5)$$

$$P_{Hij} = H_{Sij} / H_S \qquad (6)$$

$$P_{Hij}' = H_{Sij}' / H_S' \qquad (7)$$

$$N_{ij} = P_{ij} \times N \qquad (8)$$

$$H_{ij} = P_{Hij} \times H \qquad (9)$$

$$H_{ij}' = P_{Hij}' \times H' \qquad (10)$$

$$H_{Tij} = \sum_{k=1}^{n} H_{ij} + \sum_{k=1}^{m} H_{ij}' \qquad (11)$$

$$\mathrm{CPUE}_{ij} = N_{ij} / H_{Tij} \qquad (12)$$

In the equations 5 to 12: k means operating days (n: for conventional hooks; m: for trial hooks) ,i=1,2,3, 4,5, when calculate the data by different depth ranges, water temperature ranges, salinity ranges, chlorophyll-a ranges, DO ranges, j=1,2,3,……18, j=1,2,3,……19, j=1,2,3,……20, j=1,2,3,……8, j=1,2,3,……7, respectively.

2 Results

2.1 The DTSCO range closely correlated to CPUE

The CPUE (inds/1000hooks) at different depth, water temperature, salinity, chlorophyll-a and DO ranges of the tropical high seas of the Indian Ocean shows in figure 2,3,4,5 and 6. By the figures and the clustering analysis, the DTSCO range of the bigeye tuna closely correlated to CPUE is 160.0～219.9m, 13.0～15.9□, 35.20～35.49, 0.030～0.059μg/L and 1.00～2.49mg/L respectively.

2.2 The DTSCO range more closely correlated to CPUE

By the figures and the clustering analysis, the DTSCO range of the bigeye tuna more closely correlated to CPUE is 160.0～179.9m, 14.0～14.9□, 35.40～35.49, 0.040～0.049μg/L and 2.00～2.49 mg/L in the tropical high seas of the Indian ocean, and the CPUE is 6.50, 7.26, 6.37, 5.70 and

5.52 inds/1000hooks, respectively.

3 Discussions

(1) Keith A. Bigelow (2002) has studied the simulated hook depth at different surface current speed by Logistic Regression method. Keith A. Bigelow (2006) modeled the relationship among actual hook depth and theoretical hook depth by catenary curve, wind force, current shear, current speed (data

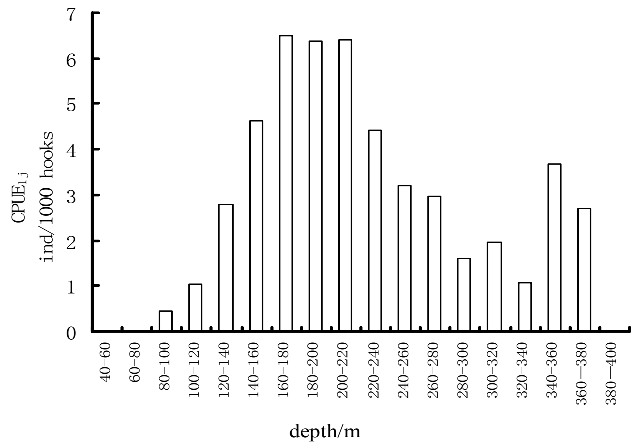

Fig. 2 *Thunnus obesus* cpue by depth ranges

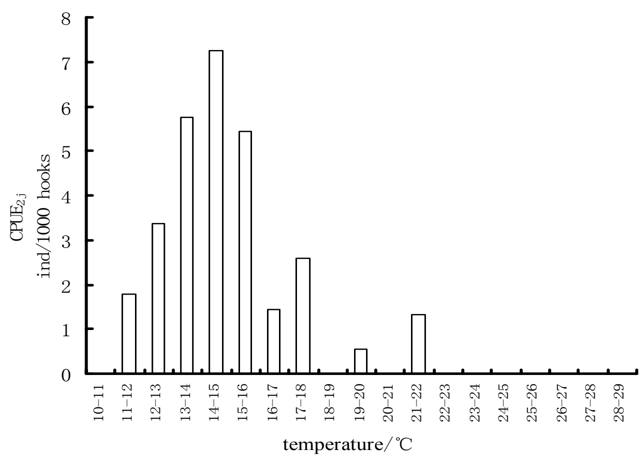

Fig.3 *Thunnus obesus* cpue by temperature ranges

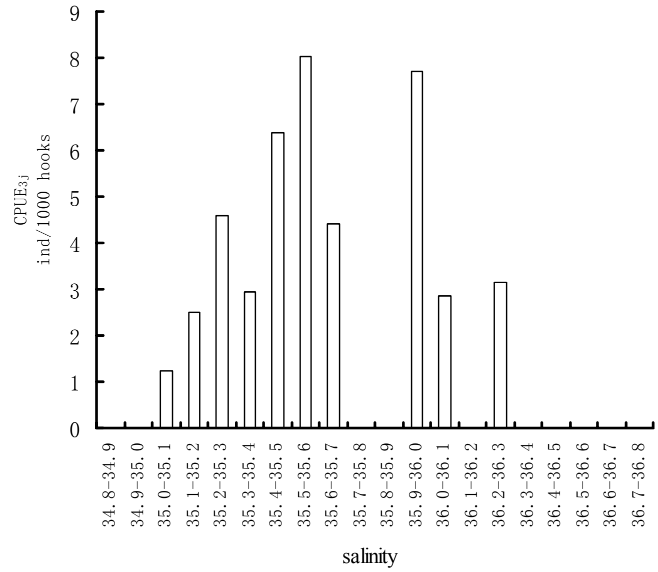

Fig.4 *Thunnus obesus* cpue by salinity ranges

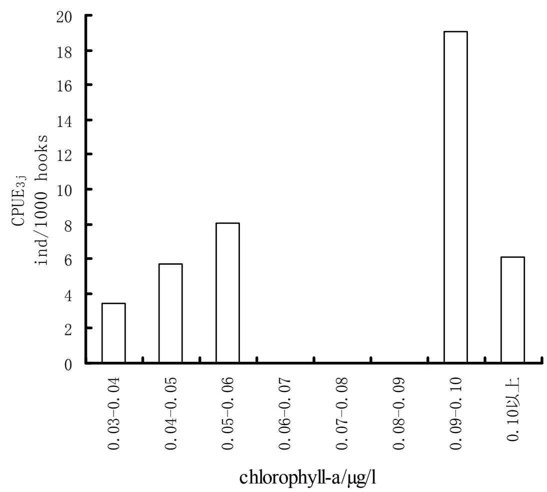

Fig.5 *Thunnus obesus* cpue by chlorophyll-a ranges

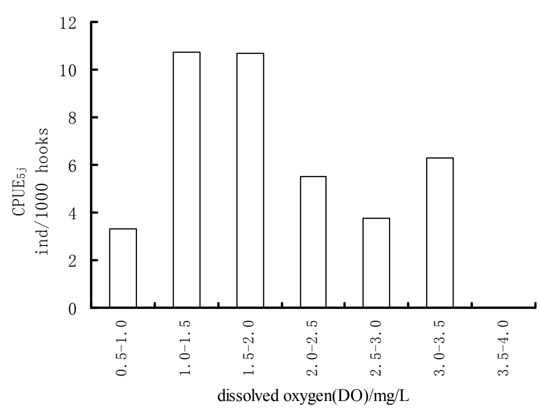

Fig.6 *Thunnus obesus* cpue by DO ranges

come from OCGM model) by GLM and GAM. Song L M (2006b), analyzed the relationship between actual average hook depth and theoretical hook depth considering the environment factors (fishing gear drift speed, wash angle, wind speed, wind angle) by stepwise regression method. In this paper, the same method was adopted as Song L M (2006b). Actually, fishing gear drift speed and wind angle are the combined indexes which are influenced by current shear at different depth, wind speed and wind direction at different position. Now, we can not compare the accuracy for the simulated hook depth based on those methods because of the limitation of data. We can test the models based on actual measured data and establish new model by using measured 3 dimensions current data from 0m to 400m combined with mechanics analysis to improve the accuracy of the hook depth model.

(2) When the bigeye tuna as the targeting species, we suggest deploying the hook depth within the range of depth, water temperature, salinity, chlorophyll-a and DO more closely correlated to catch rate to get higher bigeye tuna CPUE and to mitigate the bycatch of shark, sea turtle and other species. In addition, if any disparities exist among the depth range, water temperature range, salinity range, chlorophyll a range, and DO range, the water temperature range should be considered as the main factor since the bigeye tuna is sensitive to the water temperature's fluctuation and the water temperature. Fish body temperature is the main factor to limit the fish behavior (Brill, R.W, H. Dewar and J.B. Graham, 1994).

(3) Dagorn (2000) has studied the movement patterns during a day by ultrasonic telemetry, it shows that bigeye tuna can reach the deepest layer (400-500m) during day and can stay 0-100m during night. During this investigation, fishing gear remained longer in the water during day than night, the catch rate in the depth range of 160.0-219.9m (much deeper) was higher than others which was consistent with the result suggested by Dagorn on the whole. Also it validated the practicability of this hook depth model.

(4) We conclude that, in the high seas of the Indian ocean, optimum swimming depth and temperature range of bigeye tuna is from 160.0m to 219.9m and from 13.0℃ to 15.9℃ which correspond to the results (depth, 160.0-239.9m, temperature, 12.0℃-15.9℃) by Jiang L B (2005) who adopted the same approach but based on theoretical depth (the fishing vessel is the Chinese deep-frozen longliner , 18 HPB). In addition, Masahiko Molhri (1999) has studied the relationship between bigeye tuna vertical distribution and water depth or water temperature based on theoretical hooks depth (1986-1987, Japanese longliner, 11HPB), and the results showed the highest catch rate took place when the range of depth and temperature was 261m to 280m and 12℃ to 13℃ respectively and which shows a difference to our results (depth 160.0m-179.9m, temperature 14.0℃-14.9℃). Song L M (2006b) studied the optimum depth and temperature range of bigeye tuna was from 50.0 to 209.9m, 13.0 to 29.9℃ respectively in Maldives waters, and with the highest catch rate was from

70.0 to 89.9m, 27.0-27.9℃, respectively. The captured depth, and water temperature of the sampled dead and stiffness bigeye tuna is 63.0-203.0m, 14.0-27.0℃, and dominates in the range of 63.0-134.0m, 16.0-27.0℃, respectively. According to the comparison of the depth between the simulated hook depth and theoretical depth during the investigation, in general, the former is shallower than the latter. It is suggested that the former can reflect the bigeye tuna vertical distribution more exactly. Different distribution results may be obtained by different fishing gear configuration, operating depth, time of shooting and deploying gear, ocean environment factors and different data processing method. It is suggested that there are some limitations (the limitation of reached hook depth) to analyze the bigeye tuna's habitat based on the commercial data, although the commercial data can reflect the fisheries more directly. It is also suggest that we should study it by tagging method further.

(5) The salinity range of the bigeye tuna closely correlated to catch rate is from 35.20 to 35.49, and the range more closely correlated to catch rate is from 35.40 to 35.49 in this paper. Feng B (2004) thought the salinity was quite stable and the change was not notable at space-time within a year, the salinity had less relationship to bigeye tuna distribution in the Indian Ocean. Qualitative analysis by GIS showed that the optimum salinity range of bigeye tuna was from 34.5-35.4(Feng B, 2004) which corresponded to the results of Hunter J R (1987) who studied on bigeye tuna in the South Pacific Ocean. Song L M (2006b) studied the optimum salinity range of bigeye tuna was from 35.00- 35.79 in Maldives waters, and with highest catch rate was from 35.70-35.79. The captured salinity of the sampled dead and stiffness bigeye tuna is 34.94-35.42, and dominates in the range of 35.30-35.42, respectively. It indicated that the optimum salinity range of bigeye tuna is extensive.

(6) The chlorophyll-a range of the bigeye tuna closely correlated to catch rate is from 0.04μg/L to 0.05μg/L in this paper. Feng Bo's study (2004) by qualitative analysis of GIS indicated that higher catch rate was distributed in the water with low chlorophyll-a (0.02μg/L-0.16μg/L), and also indicated the lower catch rate occurred in higher chlorophyll-a season. The phenomenon of lag showed the biology strategy for maintaining ecological balance under a certain ocean environment.

(7) The DO range of the bigeye tuna closely correlated to catch rate is from 1.0mg/L to 2.0mg/L in this paper which corresponds to the results (0.5-1.0mL/L beyond) of minimum DO level of Hanamoto (1987) studied on bigeye tuna in the Pacific Ocean. In addition, Mohri (1998) suggested that the minimum DO level for bigeye tuna was 1.0mL/L (0.7mg/L). During this investigation, when the DO level was from 0.07-0.85mg/L at the depth of 60-320m, the catch rate (CPUE) of bigeye tuna was zero. All information indicate that DO will become the restrictive factor for bigeye tuna vertical distribution when less than 1.0mL/L.

(8) The results in this paper are based on the analysis on the relationship between the catch rate (CPUE) and each single environment factor. We should get an integrated factor considering different weight of each single factor, and analyze the relationship between the integrated factor and bigeye

tuna vertical distribution.

(9)The above conclusions were obtained based on this investigation. We will consider the biological factors, food web and water current factors to study the vertical distribution with the larger individuals of sample tuna, hook depth measured by TDR and measured times of Submersible Data Logger.

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