Modeling the hook depth of tuna longline in the tropical areas of the Indian Ocean

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Abstract: To have a better understanding of the hook depth for tuna longline, a survey on the tuna longline fishing ground was conducted from 1st October to 30th November 2006 in the tropical areas of the Indian Ocean. The longliner *Yueyuanyu No.168* was as the platform for data sampling. We considered hook depth rate (Q') as the dependent variable, and the current shear coefficient ($\tilde{K}$), the wind speed (V_w), the hook code (N), $SinQ_W$, $Sin\gamma$, the weight of the messenger weight (W) as the independent variable. We developed the hook depth rate model and hook depth model by the analysis of covariance with completely randomized design of general linear model with the software SPSS (version 13.0). The results indicated that the wind and surface current effects on the hook depth might be ignored; the undercurrent of the equator would be the key factor affected the hook depth; there were negative correlation between hook depth rate and current shear, angel of attack; and the hook depth rate were declining along the increasing of the hook code. Based on the comparison between the hook depth calculated by the model and the actual hook depth measured by TDR (almost all of the differences were within 30m, the max difference attained to 50m), it is suggested that a predicted hook depth model could be developed by this method.

Key words: modeling the hook depth, longline, the tropical areas, and the Indian Ocean

1 INTRODUCTION

Many studies were conducted on the hook depth of tuna longline. Current shear between the surface layer and the thermocline layer was assumed as the key factor to affect the actual hook depth (Boggs, 1992). Mizuno *et al*. (1998) have studied the sag ratio fluctuate and its impact on the underwater shape of the longline. Mizuno *et al*. (1999) also estimated the 3 dimensional underwater shape of longline with concurrent

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oceanographic condition of current monitored by an Acoustic Doppler Current Profiler (ADCP). Bigelow *et al*. (2002) developed the calculate equation at different surface current velocity by Logistic regression. Wan *et al.* (2002; 2005) used the numerical model and the model experiment in flume tank predicting the fishing operation status of tuna longline, and Wan *et al.* (2004) measured the shape of the longline under the water in flume tank at the static water current and the certain shortening ratio by digital image software. Lee *et al.* (2005) also did the same experiment as Wan et al., but they analyzed the shape by the different current velocity, angel of attack and shortening ratio. Bigelow *et al*. (2006) studied the relationship between the hook depth and the environmental factors by general linear model (GLM) and general additive model (GAM). Song and Gao (2006), Song *et al.* (2006a, 2006b) also considered that the actual hook depth was mainly impacted by the gear drift velocity (It is the drift velocity over the ground resulting from the force of wind and current, denoted as V_g), wind speed (It is measured by anemoscope, denoted as V_w), wind direction (It is measured by compass, denoted as C_w), angle of attack (It is the angle between prevailing course in deploying gear and drifting direction of fishing gear, denoted as Q_w) and wind angel (It is the angle between wind direction and prevailing course in deploying gear, denoted as γ) . These data were analyzed by the stepwise regression. Miyamoto *et al*. (2006) used an ultrasonic positioning system and a buoy with a communications satellite measured the 3-dimensional underwater shape of tuna longline in the field. Although there were many studies in previous, there was no study on the hook depth model by field measured data in the tropical areas of the Indian Ocean, especially while the impacts of the undercurrent of the equator. In this study, base on the date (fisheries date, hook depth measured by Temperature Depth Recorder (TDR) and the 3 dimensions (in abbreviation:3D) of current measured by ADCP) collected from the Chinese tuna longliner in the Indian Ocean, we developed the hook depth prediction model for the tuna longline in the tropical areas of the Indian Ocean. It could be referenced for the analyzing the vertical distribution of the tuna, understanding its habitat environment, and also could provide some information for the CPUE standardization and the stock assessment.

2 MATERIALS AND METHODS

2.1 Fishing vessels and fishing equipments

Longliner *Yueyuanyu No.168*, equipped with super spool, was used as platform for data sampling. The vessel's overall length, registered breadth, registered depth, gross tonnage, net tonnage and main engine power was 25.68m, 6.00m, 2.98m, 125.00t, 44.00t and 318.88kW, respectively.

Fishing equipments were including super spool (type: LP“48*80”-) and super spool line shooter (type: LS-4).

2.2 Investigation duration and areas

The sampling activity was mainly limited within the area defined by 03º07´S~04º07´N, 62º12´E~71º15´E from 1st October to 30th November 2006. There were 36 sampling sites (Fig.1).

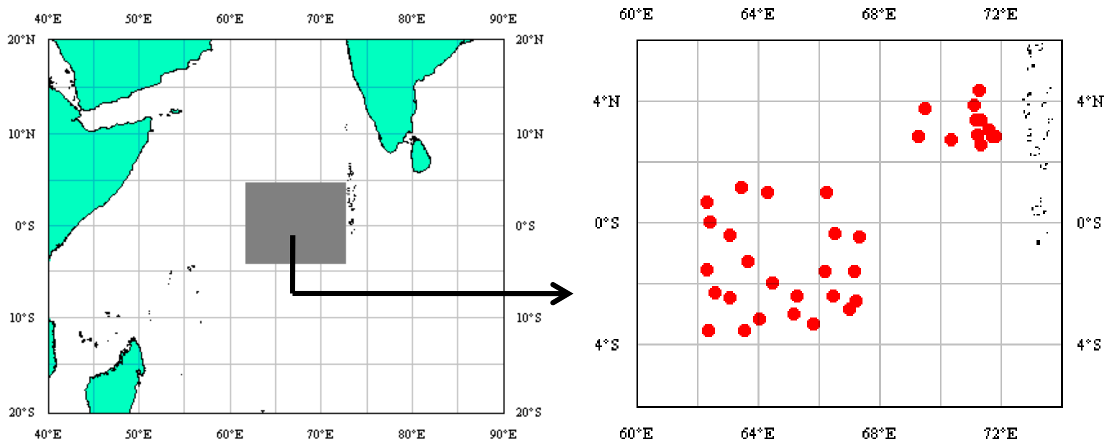


Fig.1 Investigation areas and sites

2.3 Fishing gear and method

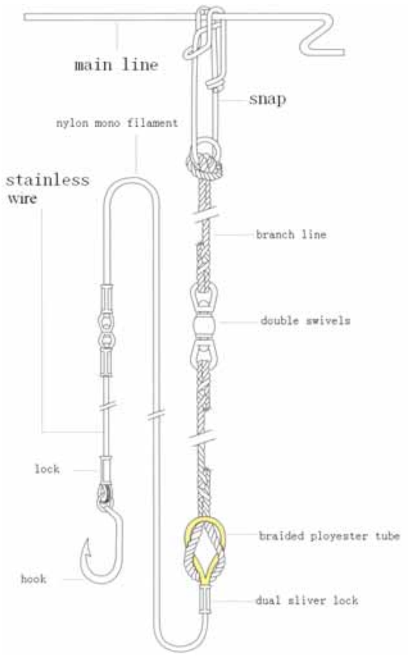
The longline gear consisted of 3.6 mm diameter monofilament main line, 360mm diameter hard plastic floats, 6mm diameter nylon float line and 2 types of branch line ending in ring hook or circle hook. The length of main line, float line was 110km and 30m, respectively. For the branch line, the first section was the 6mm diameter polypropylene (0.8m long), the second section was the 1.8mm diameter nylon (16m long), and the third section was the 1.2mm stainless wire (0.5m long). The first and second section was connected with no swivel. There was a swivel between second and third section. The third section connected with the hook directly (Fig. 2a). The total length of the branch line was about 18m.

Two kinds of fishing gear were used in this study, the conventional gear and the experimental gear. The experimental gears were using 4 types of messenger weight, 0.5kgs, 1.0kgs, 1.5kgs and 2.5kgs in water. The configuration of the branch line was almost the same as that of the conventional gear.

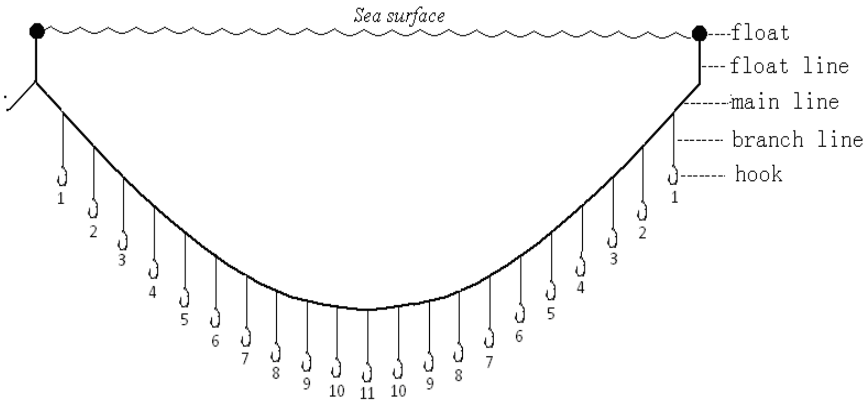
For the conventional gear, in general, the starting time of deploying was between 00:00 and 02:00 local time, and lasted for about 5 hours. The time of retrieving was between 10:00 and 12:00. One operation would be lasted for 8 to 12 hours. During the deployment, the vessel's speed was about 3.855m.s^{-1}, line shooter speed was at 5.654m.s^{-1}, and time interval between deploying fore and after branch lines was about 8s. The length of main line between the two branch lines was 41.2m and there were 21~23 hooks between two floats (HBF). For the conventional gear, there were 400~2400 hooks in each deployment. The bait was the lancet fish and the squids (about 150g). For the experimental gear, we didn't cast branch line at the first two deploying signals and at the last two deploying signals between two floats, and instead of a messenger weight at the second signals before and after deploying the float, respectively. The main line length from the connecting site of float line to the messenger weight was about 83m, and two branch lines were absent. The HBF was reduced to 17~19, and the other parameters of deploying were not changed. There were 400 experimental hooks for each deployment. The sketches for two kinds of fishing gear were shown in the Fig. 2b and Fig. 2c (including the arrangement for hook code).

2.4 Instrumentation

Sampling instruments included TDR (2050) (RBR Co., Canada), and 3D ADCP (Aquadopp), (NORTECK Co., Norway). The hook depth measured by TDR, and the depth measurement error of the TDR was within ±0.05% in depths of 10m-740m. The ADCP measured the 3D current (East/North/Up), and the measurement error was within ±0.005m.s^{-1}.



a



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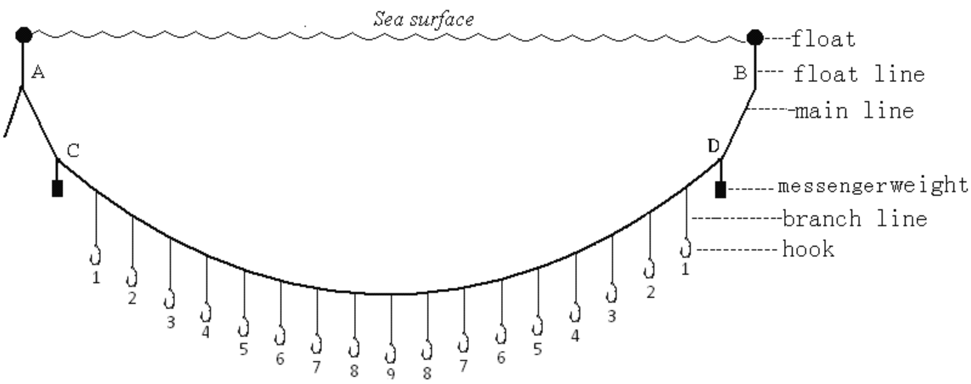

C

Fig. 2 The configuration and the under water shape of the fishing gear

(a: the configuration of the branch line; b: conventional gear; c: experimental gear, HBF=21)

2.5 Investigation methods and items

We measured 3D current of the certain water depth by ADCP after deploying the gear. The total length of the steel wire for deploying the ADCP was about 600m, but its actual depth reached was from 150m to 580m because the impacts of wind and the current. We measured the hook depth the hook could reach by TDR. In this study, we collected the hook depths measured by TDRs, 137 for conventional gear and 138 for experimental gear, in total 275. In the experimental gear, we collected the hook depths which were impacted by messenger weight of 1kg, 1.5kg, 2kg and 2.5kg. There were 34, 34, 35 and 35 hook depths, respectively.

The following data were also collected: deployment position and time, course and speed, line shooter speed, number of HBF, time interval between deploying fore and after branch lines, number of hooks, time of retrieving lines, hook code at which fish was caught, number of hooked tuna per fishing operation, and tuna hooked positions.

In addition, there was difference between the speed indicated in the line shooter and the actual shooting speed. The actual shooting speed versus the speed indicated in the line shooter was 0.9104.

2.6 Data processing methods

Data processing methods and procedures were indicated in Fig.3.

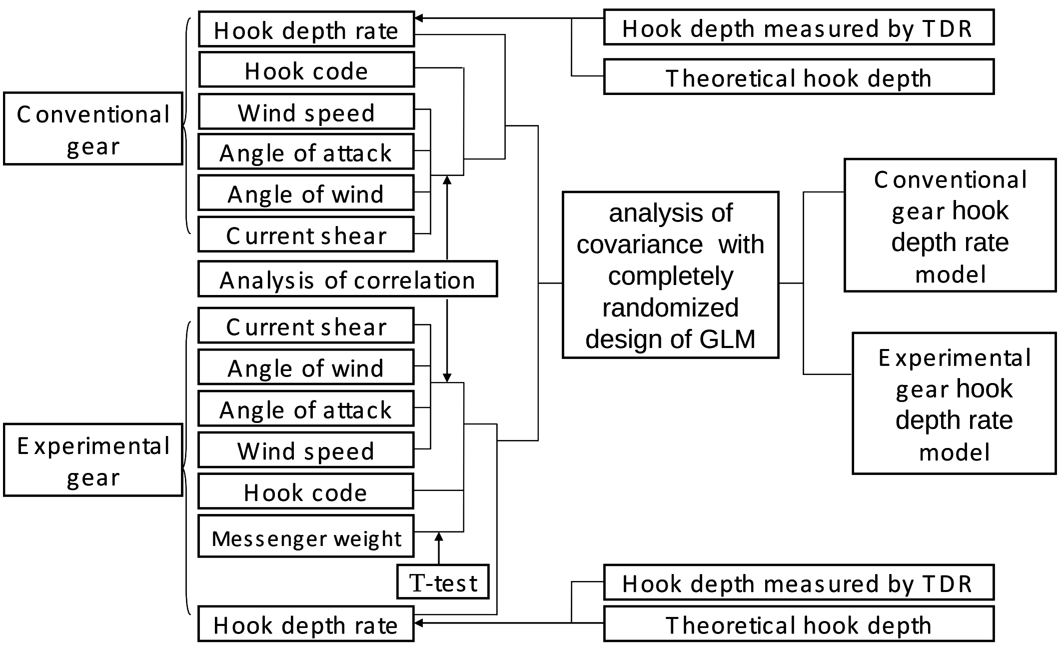

Fig.3 Data processing methods and procedures

For conventional fishing gear

The theoretical hook depth were calculated by the catenary curve equation (Saito, 1992) indicated as

$$D_j = h_a + h_b + l\left[\sqrt{1+\cot^2\varphi_0} - \sqrt{\left(1-\frac{2j}{m}\right)^2 + \cot^2\varphi_0}\right] \quad (1)$$

$$L = V_2 \times m \times t \quad (2)$$

$$l = 0.9104 V_1 \times m \times t / 2 \quad (3)$$

$$k = L/2l = V_2/V_1 = \cot\varphi_0 sh^{-1}(\mathrm{tg}\varphi_0) \quad (4)$$

where h_a is the length of the branchline; h_b is the length of the floatline; l is half of the arc length of mainline between two floats; j is the numbers of branch line and m is the number of subsections between the two floats ($m= j+1$); φ_0 (°) is the angle between the horizontal line and the tangent of the connecting site of the float line and mainline; L is the length between two floats; V_2 is the vessel velocity (m.s^{-1}); t is the time interval between deploying fore and after branch lines; V_1 is the shooter speed indicated in the line shooter (m.s^{-1}). We used shortening ratio to calculate φ_0 because it was difficult to be measured in the field.

For experimental fishing gear

For experimental fishing gear, the shape of the main line was changed because of the messenger weight. We must recalculate the impact of the messenger weight. In the investigation, we measured the depth of the connecting site where the messenger weight was connected to the main line 12, 13, 11, 14 times for 1kg, 1.5 kg, 2 kg and 2.5kg, respectively by TDRs. We assumed the arithmetic average value of depth for respective type of messenger weight as the sink depth of the connecting site where the messenger weight was connected, denoted as d_w. We also assumed that the sink depth of one type of messenger weight was the constant during the survey. We suggested that along the weight of messenger weight increasing, the sink depth of the connecting site also increased. The sink depth for 1kg, 1.5kg, 2kg and 2.5kg messenger weight was 54.0m, 59.7m, 65.0m and 67.7m, respectively.

In this study, we assumed the main line between site C and site D (Fig.2c) as the catenary curve, so we calculated the theoretical hook depths following the catenary curve equation. We assumed that the main line between A and C, B and D were the beeline. According to the vertical depth of the C and D measured by TDRs, we could calculate the horizontal distance between A and C, B and D, then we could calculate the horizontal distance between C and D, denoted as L', and the equations were as

$$D_j' = h_a + h_b + d_w + l\left[\sqrt{1+\cot^2\varphi_0'} - \sqrt{\left(1-\frac{2j}{m}\right)^2 + \cot^2\varphi_0'}\right] \quad (5)$$

$$L' = V_2(m+4)t - 2\sqrt{(1.821V_1 t)^2 - d_w^2} \quad (6)$$

$$l = 0.9104V_1 \times m \times t \big/ 2 \quad (7)$$

$$k' = L' \big/ 2l = \cot\varphi_0' sh^{-1}(\mathrm{tg}\varphi_0') \quad (8)$$

where the D_j' is the hook depth (m); d_w is the sink depth of the connecting site where the messenger weight was connected (m); L' is the horizontal distance between C and D (m); φ_0' (°) is the angle between the horizontal line and the tangent of C or D. The other parameters are the same as the equation 1~4.

The definition of the hook depth rate

In this study, we defined that the hook depth rate as the rate of actual arithmetic average hook depth (D_f) measured by TDR versus the theoretical hook depth (D_t) , denoted as Q'.

$$Q' = \frac{D_f}{D_t} \times 100\% \quad (9)$$

Brief introduction of the various impact factors

In this study, we assumed that the hook depth rate mainly affected by wind, current, the setting position of the hook (hook code) and the other operational parameters. For the experimental gear, we considered the weight of messenger weight as another factor. We described some factors as below.

(1) Wind

The wind velocity measured by anemoscope, denoted as V_w; wind direction measured by compass, denoted as C_w.

(2) Current

Bigelow *et al.* (2006) suggested that the impact factor to the hook depth was not the absolute velocity of the current, but the current shear among the different water layers. Based on this suggestion, we processed the original data which measured by ADCP, the equations were shown as

$$K = \log\left(\frac{\int_0^z \left\| \frac{\partial \vec{u}}{\partial z} \right\| dz}{Z}\right) \tag{10}$$

The above expression could be approximated as

$$\tilde{K} = \log\left\{\frac{\sum_{n=1}^{N}\left[\left(\frac{u_{n+1}-u_n}{z_{n+1}-z_n}\right)^2+\left(\frac{v_{n+1}-v_n}{z_{n+1}-z_n}\right)^2\right](z_{n+1}-z_n)}{\sum_{n=1}^{N}(z_{n+1}-z_n)}\right\} \tag{11}$$

where $\tilde{K}$ is the log-transformed vertical current shear, u_n is the velocity component along the latitude in the water layer *n*, v_n is the velocity component along the longitude in the water layer *n*, and z_n is the depth of the water layer *n*.

In this study, we used $\tilde{K}$ as an impact factor of the current shear.

(3) Hook code

Bigelow *et al.*(2002) indicated that there were difference of sag ratio for different hook position (hook code) while the other oceanographic condition were the same. We introduced the hook code as an impact factor to the hook depth rate, denoted as *N*.

(4) Fishing parameters

Fishing parameters included the angle of attack (Q_w) and wind angel (γ).

(5) The weight of the messenger weight

We tested the impacts of messenger weight by paired samples test. If there was significant difference between two kinds of messenger weight, we would introduce it into the model. If there was no significant difference, we would eliminate it.

Modeling the hook depth

In this study, we divided the whole surveyed sites into two group modes according to the depth of deepest hook (D_m). We classified the sites of the fishing operation (D_m<200m) into the first group, and the other sites (D_m>200m) were classified into the second group. We developed the relationship model between hook depth rate and oceanographic environment, the grouping mode for conventional gear (137 hooks) and experimental gear (138 hooks) by analysis of covariance by completely randomized design in GLM with SPSS software (version 13.0).

3 RESULTS

The relationship between the theoretical hook depth calculated by catenary curve and the observed average hook depth measured by TDR were shown in Fig.4.

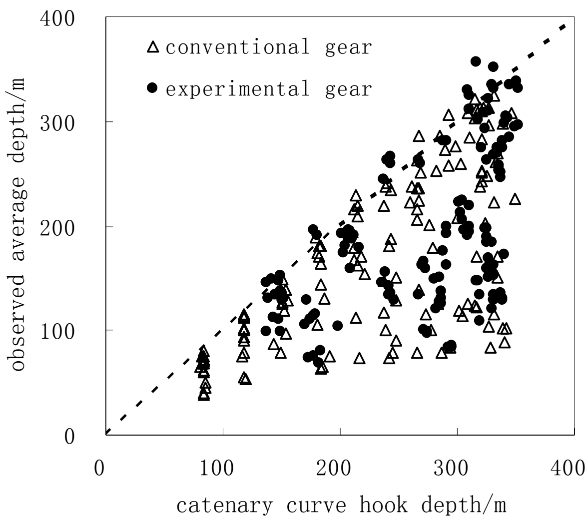

Fig.4 A comparison of catenary curve hook depth and observed average hook depth

3.1 The relationship between hook depth rate and impact factors

The relationship between hook depth rate and impact factors was shown in Table 1. It was suggested that, in the conventional gear, there was the positive correlation between Q' and V_w, and the level of significance was bigger than 0.05; there was the negative correlation between Q' and $\tilde{K}_c$, $sinQ_w$ and $sin\gamma$. The significance level was higher than 0.05 for $sinQ_w$, but it was less than 0.01 for the other two factors. So we eliminated two factors of V_w and $sinQ_w$ based on the significance level when modeling the conventional gear. And based on the same principle, we eliminated the two same factors for modeling experimental gear.

Tab.1 The correlation between the hook depth rate and the impact factors

Q'		V_w	$\tilde{K}_c$	$sinQ_w$	$sin\gamma$
Conventional gear	Coefficient of correlation	0.121	-0.565**	-0.116	-0.426**
	Significant level	0.154	0.000	0.171	0.000
Experimental gear	Coefficient of correlation	0.038	-0.538**	0.159	-0.213*
	Significant level	0.658	0.000	0.063	0.012

* denoted as the significance level higher than 0.05; and ** denoted as the significance level less than 0.01.

We tested whether there were significant impacts of different types of messenger weight for the hook depth by paired samples test. It indicated that there was no significant difference between two of any kinds of messenger weight (P_{23}=0.129, P_{24}=0.218, P_{25}=0.164, P_{34}=0.680, P_{35}=0.898 and P_{45}=0.197)*.

3.2 The calculation models of hook depth rate

According to the depth of deepest hooks (D_m) of each operation site, we divided the 34 sampled sites into two groups. In the first group, there were 12 sampled sites; we obtained 45 and 62 hook depths measured by TDRs for conventional and experimental gear, respectively. In the second group, there were 22 sampled sites; we obtained 92 and 76 hook depths measured by TDRs for conventional and experimental gear, respectively.

Conventional gear (137 hook depth)

We assumed the model as

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*P_{23}, P_{24}, P_{25}, P_{34}, P_{35}, and P_{45} denoted as the significance level of difference for hook depth between 1and 1.5kg, 1 and 2kg, 1and 2.5kg, 1.5 and 2kg, 1.5 and 2.5kg, and 2 and 2.5kg messenger weight.

$$Q_c = a_c + b_c N_c + c_c \tilde{K}_c + d_c \sin\gamma_c + group_c \quad (12)$$

where Q_c denoted as the predicted hook depth rate; $\tilde{K}_c$ is the current shear coefficient; $\sin\gamma_c$ is the value of sine estimator for the angle of attack γ_c, (the same as below); a_c, b_c, c_c, and d_c are the coefficient of the respective variables.

We analyzed the data of conventional gear by SPSS software (version 13.0). The results were shown in Table 2 and 3.

Tab. 2 Tests of effect between-subjects

Source	type	df	Mean square	F	Sig.
Modified model	6.124*	4	1.531	145.859	0.000
a_c	0.008	1	0.008	0.716	0.339
b_c	0.164	1	0.164	15.654	0.000
c_c	0.268	1	0.268	25.523	0.000
d_c	0.306	1	0.306	29.173	0.000
$group_c$	2.245	1	2.245	213.846	0.000
error	1.428	136	0.01		
total	82.979	141			
Adjusted total	7.552	140			

* R^2 =0.811 (adjust coefficient R^2=0.805)

Tab. 3 Parameters estimate

Parameters	B	Std. deviation	t	Sig.	95% confidence interval	
					Upper limited	Lower limited
a_c	0.289	0.149	1.942	0.054	-0.005	0.583
b_c	-0.010	0.003	-3.957	0.000	-0.015	-0.005
c_c	-0.291	0.058	-5.052	0.000	-0.405	-0.177
d_c	-0.186	0.034	-5.401	0.000	-0.254	-0.118
[$group_c$ =1]	-0.335	0.023	-14.623	0.000	-0.381	-0.290
[$group_c$ =2]	0					

The analysis of the main results:

From the modified model of tests of effect between-subjects, we suggested there were linear regression correlation between hook depth rate and hook code, current shear coefficient and $\sin\gamma_c$ (F=145.859, P<0.05(Sig.=0.000); Table 2). We suggested that the adjust average of hook depth rate for two groups were different

(Sig. =0.000，P (Sig. =0.000) <0.05).

Based on Table 3, we suggested:

The first group (45 hook depths):

$$Q_{c1} = -0.046 - 0.291\tilde{R}_{c1} - 0.01N_{c1} - 0.186\sin\gamma_{c1} \tag{13}$$

The second group (92 hook depths):

$$Q_{c2} = 0.289 - 0.291\tilde{R}_{c2} - 0.01N_{c2} - 0.186\sin\gamma_{c2} \tag{14}$$

Based on the equation 9, the predicting depth of the conventional gear defined as

$$D_{fc}' = D_t \times Q_c \tag{15}$$

Experimental gear (138 hook depths)

We assumed the model as

$$Q_e = a_e + b_e N_e + c_e \tilde{R}_e + d_e \sin\gamma_e + group_e \tag{16}$$

where a_e, b_e, c_e and d_e are the coefficient of the respective variables.

We analyzed the data of conventional gear by SPSS software (13.0). The results were shown in Table 4 and 5.

Tab.4 Tests of effect between-subjects

Source	Ⅲ type	df	Mean square	F	Sig.
Adjusted model	5.429[a]	4	1.357	96.808	0.000
a_e	0.001	1	0.001	0.058	0.810
b_e	0.402	1	0.402	28.692	0.000
c_e	0.062	1	0.062	4.407	0.038
d_e	0.336	1	0.336	23.949	0.000
$group_e$	2.923	1	2.923	208.502	0.000
Error	1.865	133	0.014		
total	75.946	138			
Adjusted total	7.294	137			

The analysis of the main results:

Based on the modified model of tests of effect between-subjects, we suggested there were linear regression correlation between hook depth rate and hook code, current shear coefficient and $\sin\gamma_e$ (F=96.808, P<0.05 (Sig. =0.000); Table 4).

We suggested that the adjust average of hook depth rate for two groups were different (Sig. =0.000, P (Sig. =0.000) <0.05).

Tab. 5 Parameters estimate

parameters	B	Std. deviation	t	Sig.	95% confidence interval	
					Upper limited	Lower limited
a_e	0.207	0.177	1.169	0.245	-0.114	0.558
b_e	-0.020	0.004	-5.356	0.000	-0.027	-0.012
c_e	-0.073	0.035	-2.099	0.038	-0.143	-0.004
d_e	-0.327	0.067	-4.894	0.000	-0.459	-0.195
[$group_e$=1]	-0.331	0.023	-14.440	0.000	-0.377	-0.286
[$group_e$=2]	0					

Based on Table 5, we suggested:

The first group (62 hook depths):

$$Q_{e1} = -0.124 - 0.327\tilde{K}_{e1} - 0.02N_{e1} - 0.073\sin\gamma_{e1} \quad (17)$$

The second group (76 hook depths):

$$Q_{e2} = 0.207 - 0.327\tilde{K}_{e2} - 0.02N_{e2} - 0.073\sin\gamma_{e2} \quad (18)$$

Based on the equation 9, the predicting depth of the conventional gear defined as

$$D_{fe}' = D_t \times Q_e \quad (19)$$

4 DISCUSSIONS

4.1 Environment factors' impact on the actual hook depth

In this study, the discussions were focused on the wind, surface current, equatorial undercurrent and current shear. We assumed that wind's impact on the actual hook depth was weak because the wind force acted on the floats only. Song and Gao (2006) modeled the relationship between the observed average hook depth measured by TDRs and environmental factors by using of the stepwise regression and the results showed that the wind was eliminated from the model. It was consistent to the above assumption. Otherwise, Bigelow *et al.*(2006) analyzed the relationship using the GLM and GAM and the results showed the explanatory ability for shoaling of the wind force was very low (4.6%). In this study, the wind velocity also had the lower relationship with the hook depth rate (0.121 for conventional gear; 0.038 for experimental gear) by correlation analysis (P>0.05, Tab.1). So we suggested that the impact of wind force on the actual hook depth could be ignored.

Generally, the tuna longliner often operates in the open seas, where the surface current means the current above 10m depth. For longline gear, only float and a part of float line are located above 10m depth and the main part is under 30m depth. Bigelow *et al.* (2006) suggested that the explanatory ability for shoaling of the surface current was 1.6%. So, the surface current should not be the decisive factor for the shoaling.

Equatorial undercurrent emerges in the north-east monsoon season in the Indian Ocean and the depth range is from 40 to 300m. The velocity of current is about 0.50-0.60m.s^{-1} commonly and the highest velocity (0.80m.s^{-1}) is at 100m depth (Li and Liu, 1999). Based on the 3D current data measured by ADCP, we considered that a part of investigated sites (the first group) located in the equatorial undercurrent with higher average current shear index (-2.41) and it was lower (-2.58) for the second group. That was one of the reasons why the hook depth rate was smaller in the equatorial areas. Also, the constant item margin in the hook depth model between the first group and the second group are higher (for conventional gear: 0.335; for experimental gear: 0.331), it was suggested that equatorial undercurrent might be the key factor to impact on the hook depth. The constant item margin in the hook depth model between the first group and the second group of the experimental gear was smaller than that of the conventional gear because of using the messenger weight which may eliminate the impact of the equatorial undercurrent.

Both Boggs (1992) and Mizuno *et al.* (1998, 1999) regarded the current shear between the surface layer and the thermocline layer as the primary factor and suggested that the degree of shoaling and mainline shape was consistent with the observed vertical shear rather than absolute current speed. And Bigelow *et al.* (2006) also expressed the same suggestion. It was suggested that the current shear should be considered as one of the key factors while the relationship between the hook depth rate and the impact factors was discussed. Results of correlation analysis showed that there was negative significant relationship between the hook depth rate and the current shear.

4.2 Operation parameters' impact on the hook depth

Song and Gao (2006) considered that both angle of attack (γ) and wind angel (Q_W) might impact to the hook depth. In this study, there was the negative significant relationship between the hook depth rate and *sinγ*; there was no significant relationship between the hook depth and the $sin Q_W$.

Otherwise, the hook depth rate might differ from the depth that the hook could reach at the same gear configuration, environment factors and operation parameters. Bigelow *et al.* (2002) considered that the shoaling ratio would increase along the hook depth increasing. In this study, we considered the hook code as one impact factor in the hook depth model and the result showed that the hook depth rate reduced along the hook code increasing.

4.3 Hook depth calculation and prediction

In order to model the hook depth and to predict the mainline underwater shape more accurately, many trials were made and various models were developed to amend the catenary curve depth. Mizuno *et al.* (1998) studied the fluctuation of sagging or shortening ratio and Mizuno *et al.* (1999) attempted to predict the mainline shape of underwater longline gear, but these two trials didn't take the wind and current as the direct factors to calculate or predict the hook depth. Wan *et al.* (2002;2004;2005) studied the static shape and mechanic analysis of longline gear by model experiment in flume tank, image analysis and the numberic simulation, but they were only the theoretical calculation at the stable or static sea current and fixed shoaling ratio. Lee *et al.* (2006) did the similar study in which they considered various current velocities, angel of attack and shortening ratio, but they didn't consider there were different current (e.g. velocity and direction) impactions at the different depth layer. In the study of Miyamoto *et al.*(2006), an ultrasonic positioning system generally used to investigate the underwater behavior of marine organisms, and a buoy with a communications satellite, have been used, and the 3D underwater shape of tuna longline fishing gear was measured. They suggested this technique was effective in recording the underwater shape of the fishing gear in 3D. In particular, it was effective for detecting the depth of the branch line at the time of line setting in real time.

However, a technical problem remained in this experiment. The change in shape of the longline with time could not be seen. Bigelow *et al.* (2002) studied the predicted hook depth at different surface current velocity by Logistic Regression. The difference between predicted depth and observed depth were within 20m. But it was based on 13 HBF, which might not be fit for 20 HBF. The correlation coefficient between shoaling ratio and surface current was lower (R^2=0.28). These were limited the model's application to this survey. Bigelow *et al.* (2006) modeled the relationship between actual hook depth and theoretical hook depth, wind force, current shear force, current velocity (data obtained from OCGM model) by GLM and GAM, but they didn't develop the detailed formula. Song and Gao (2006) analyzed the relationship between observed average hook depth and theoretical hook depth considering the environment factors (fishing gear drift speed, angle of attack, wind velocity, wind angle) by multivariate regression and developed the hook depth model (R=0.748), but it was only fit for the sea areas with simplex sea environment condition and it was not fit for the equatorial undercurrent areas. In this study, analysis of covariance was used to predict the hook depth. The estimated deepest catenary hook depths were typically from 310 to 350m during the survey, but the observed deepest depths were only from 90m (the equatorial sea areas) to 320m. We choose 200m as the standard to group the investigated sites and obtained the models (for conventional gear: R^2=0.805; for experimental gear: R^2=0.737). Based on the comparison between the hook depth calculated by the model and the actual observed hook depth measured by TDR, almost all of the differences were within 30m, the max difference attained to 50m. We suggested an accurate hook depth model could be developed by this method.

5 CONCLUSIONS

When we analyzed the relationship between the hook depth and the environmental factors, the wind and surface current effects on the hook depth might be ignored. It is suggested that the undercurrent of the equator would be the key factor affected the hook depth; there were negative correlation between hook depth rate and current shear, angel of attack; and the hook depth rate were declining along the increasing of the hook code. The standard to group the investigated sites was 200m hook depth and the models (for the conventional gear: R^2=0.805; for the experimental gear: R^2=0.737) were developed. Based on the comparison between the hook depth calculated by the model and the actual observed hook depth measured by TDR (almost all of the difference were within 30m, the max difference attained to 50m), it was suggested that an accurate hook depth model could be developed by this method.

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