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A comparison of two CPUE calculation methods for longline fishing

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Abstract: The soak time in longline fishing have impacts on the fishing efficiency, catch rates, fishing mortality of target species and CPUE. Based on the data collected in the tuna longline survey from September 2005 to December 2005 in Indian Ocean, the soak time models with two modes of hook retrieval concerning with every branch line in each operation were built. The fishing efforts were counted by soak time (10000 hours) and the conventional number of hooks (1000 hooks) respectively. The CPUEs of bigeye tuna (*Thunnus obesus*) for the entire water column and each water layer of each survey site were calculated respectively, and the t-test was applied to test the significant differences between two CPUEs which based on different methods. The results showed that (1) Except to No. 1 and No. 25 hook, the total soak time of the hooks varied fluctuant in a small range at every operations (about 10h); (2) The soak time model can be used to estimate the soak time of each hook accurately; (3) There were significant differences between the CPUEs of bigeye tuna calculated based on the soak time and the conventional number of hooks; (4) Except to 200.0-239.9 m and 280.0-319.9 m water layers, there were significant differences between the CPUEs of bigeye tuna calculated based on the soak time and the conventional number of hooks. It is suggested that the soak time of fishing gear can be used for calculation of the CPUE. The soak time reflects the effective fishing effort because the soak time of fishing gear include the number of branch lines, the time of deployment, the period of waiting time and the mode of retrieval. The accuracy of CPUE will be improved while the soak time of branch lines was counted as a part of fishing effort.

Key words: tuna longline; soak time; CPUE; bigeye tuna (*Thunnus obesus*); Indian Ocean

Introduction

There are some advantages presented by longline fisheries, i.e. higher quality of catch, higher selectivity, lower fuel consumption and lower impacts to the ecosystem (Bjordal and Løkkeborg, 1996). The use of longline is encouraged by fisheries management authorities (Sutterlin *et al.*, 1982; Bjordal, 1989). The catch rates (CPUEs) of the catch species in the longline fisheries are affected by many factors, such as the skill of the crew members and the technique used, biological and environmental factors (Sutterlin *et al.*, 1982; Bjordal, 1989; Zhan, 1995). The soak time of fishing gear in water will influence the fishing efficiency, the CPUE and the mortality of target species and non-target species (Carruthers *et al.*, 2011). In the previous studies, Sivasubramaniam (1961) stated that there was no significant variation in yellowfin tuna (*Thunnus albacares*) catches with increasing soak time. Løkkeborg and Pina (1997) found that the soak time did not impact the CPUE in demersal longline. However, in the recent studies, the obvious relationship between CPUE and soak time has been proposed. By GLM model, Carruthers *et al.* (2011) found that the CPUE of swordfish (*Xiphias gladius*) didn't increase with the minimum soak time (from the end of deployment to the start of retrieval), but a linear relationship exhibited between CPUE and maximum soak time (from the end of deployment to the end of retrieval). Thus, the minimum soak time should be shortened to reduce the bycatch mortality and meanwhile the CPUE of swordfish remains unaffected. Skud (1978) demonstrated that the total catch of Pacific halibut (*Hippoglossus stenolepis*) increased with time at a gradually decreasing rate in demersal longline. Other studies have shown that shorter soak time contributed to the reduction of sea turtle bycatch (Gilman et al., 2006; Vega and Licandeo, 2009) and the mortality of hooked fishes (Ogura *et al.*, 1980; Carruthers *et al.*, 2011). Vega and Licandeo (2009) pointed out the soak time influence the CPUEs of swordfish and blue shark (*Prionace glauca*) greatly in the swordfish longline fishery. So far, the relationship between the soak time of tuna longline fishing gear and the CPUEs of bigeye tuna has been rarely studied (Sivasubramaniam, 1961; Ward *et al.*, 2004). Campbell (2012) suggested that CPUE should be standardized by the comprehensive analysis and including more fine scale information influencing the fishing efficiency of longline gear. Based on the data collected in the tuna longline survey from September 2005 to December 2005 in the Indian Ocean, the calculation models of soak time for every branch line were built by two modes of hook retrieval in this study. We applied the calculation models of soak time to calculate the fishing efforts of bigeye tuna (*Thunnus obesus*) with soak time (10000 hours) and the respective CPUE. We compared the bigeye tuna CPUE calculated by the soak time fishing effort with the CPUE calculated by the traditional no. of hooks. This can provide the reference for accurately calculate and standardize CPUE.

1 MATERIALS AND METHODS

1.1Materials

Data were collected from longliner Huayuanyu No.18, which having a total length of 26.12 m, register length of 24.0 m, molded breadth of 6.05 m, molded depth of 2.70 m, gross tonnage of 150.00 tons, net tonnage of 45.00 tons, main engine power of 407 kW.

The survey was conducted from September 16, 2005 to December 12, 2005 and there were 50 survey sites (Fig. 1). In this study, the total hooks of conventional and experimental gear were 58960 and 18400 hooks. The individuals of bigeye tuna were 289 and the hook code where bigeye tuna were caught was recorded.

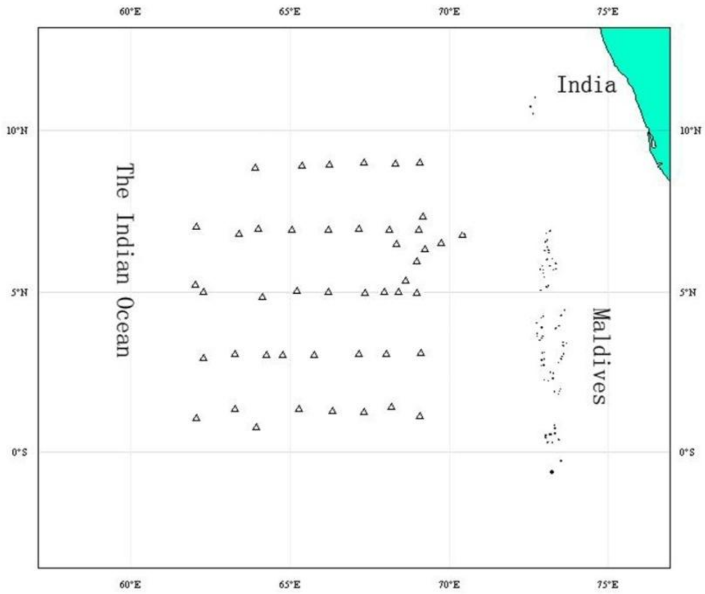


Fig.1 Survey area and sites

1.2 Fishing gear and methods

The longline gear consist of a 360 mm diameter hard plastic floats, 6 mm diameter nylon float line and 22 m length, 3.6 mm diameter monofilament main line. The first section of the branch line was made of polypropylene and was 1.5 m long. The second section was made of nylon monofilament and was 1.8 mm diameter. The third section was made of 0.5 m long and 1.2 mm diameter stainless steel wire. There were two parts in the first section, connected with a leaden barrel swivel. The first section and the second section directly connected, without swivel. The second section and the third section connected with swivel. The third section connected with hooks directly. The overall length of branch line was about 16 m.

We used two kinds of fishing gear in this study. The conventional fishing gear and experimental fishing gear. Conventional gear was used as a control group without message weight. The configuration of conventional fishing gear between two floats was shown in Fig. 2. There were 25 hooks between two successive floats. We used 1.5 kg and 2.5 kg (in water) message weight in the experimental gear and the message weight replaced the No.1 and No.25 branch line. Experimental gears were deployed at the beginning position of the whole fishing gears, 1.5 kg message weight experimental gear in the first, followed by 2.5 kg message weight experimental gear. The configuration of experimental fishing gear between two floats was shown in Fig. 3. There were 23 hooks between two successive floats.

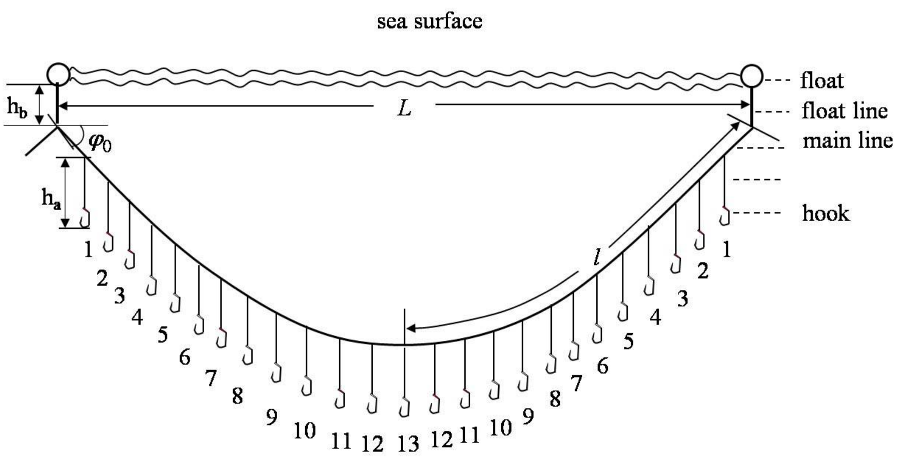


Fig.2 The configuration of fishing gear between two floats

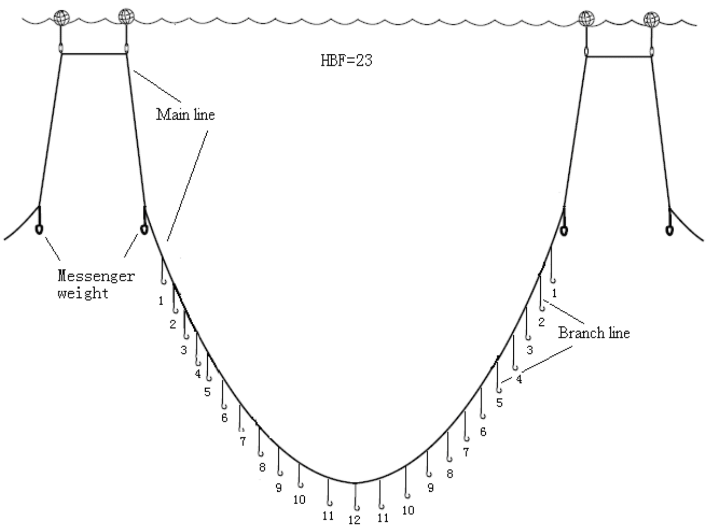


Fig.3 The configuration of experimental fishing gear between two successive floats

In the operation, the vessel speed was about 4.30 m s^{-1} and line shooter speed was about 5.58 m s^{-1}. The time interval between deploying the fore and after branch lines was 8 s, 25 hooks deployed between two floats. In most cases, the fishing vessel used 100 circle hooks, 368 experimental hooks, and 200 to 1500 ring hooks per set. The total hooks per set ranged from 700 to 2200 hooks (Song *et al.*, 2009). There were no significant differences between the conventional gear and experimental gear in the catch rates of bigeye tuna. There were no significant differences in the catch rate of bigeye tuna between the ring hooks and circle hooks. The data for conventional gear, experimental gear, ring hook, and circle hook can be combined to analyze (Song *et al.*, 2008; 2009).

When the experimental fishing gear was deployed, the first branch line close to float was absent and the second one was replaced by messenger weight with different weight (1.5 kg and 2.5 kg in water), other parameters were unchanged. The amount of the experimental hook per type was 46 and 368 hooks in total were deployed in each site.

In general, the gear deployment occurred from 05:00 to 09:00 local time, lasted for about 4 hrs. The gear was retrieved between 15:30 and 21:00, lasting for 8 to 10 hours. Sampling sites were selected in accordance with the traditional tuna fishing grounds of the Indian Ocean, but the actual sampling sites were slightly different from those that were planned due to logistical problems.

During the investigation, the following operational data were also collected: deployment position and time, course and speed, line shooter speed, number of hooks, time of retrieving lines, code of hook with which a fish was caught, number of hooked bigeye tuna per day, and hooked position of bigeye tuna.

1.3 Instrumentation and methods

The hook depth and the sinking rate were measured and recorded by seven TDRs (TDR 2050, RBR Co., Ottawa, Canada). The depth measurement error of TDRs was within ±0.05 % in depths of 10-740 m. Taking into account the accuracies of data from the instrument and requirement of the study, the data of depth was processed to one effective decimal place.

While deploying the longline, TDRs were attached to connecting points between the mainline and the branch line for various no. of branch lines. The branch line was replaced by the rope of TDR. In the end, the depth of every hook position was measured by these TDRs. The length and material of the ropes which were used to connect the TDRs were same as that of the branch lines.

1.4 **Data analysis methods**

1.4.1 Determination of the hook depth

Based on the operation parameters and theoretical hook depth (D_ψ), the calculation model of the hook depth was built by the multiple linear regression method (Li and Luo, 2003). In this study, there were 225 conventional hooks and 109 experimental hooks measured by TDR and were used to develop the hook depth calculation models. The theoretical hook depth of conventional gear was calculated by the catenary curve equation (Saito, 1992) written as:

$$D_\Psi = h_a + h_b + l\left[\sqrt{1+\cot^2\varphi_0} - \sqrt{\left(1-\frac{2\psi}{M_k}\right)^2 + \cot^2\varphi_0}\right] \quad (1)$$

$$L = V_2 \times M_k \times \Delta t \quad (2)$$

$$l = {V_1 \times M_k \times \Delta t}/{2} \qquad (3)$$

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

where D_ψ, h_a, h_b, l were theoretical hook depth, branch line length, float line length, half of the main line length, respectively. φ_0 was the angle between the horizontal line and the tangent of the connecting position of the float line and mainline and was calculated by sag ratio because it was difficult to be measured in the field. ψ was hook number ($\psi = 1, 2, ..., 13$). M_k was the subsection number of the main line between two successive floats, that was the number of branch line plus 1. L was the sea surface distance between two successive floats. V_1 and V_2 were the line shooting speed (m s^{-1}) and vessel speed. Δt was the time interval of two successive branch lines deployed.

For the conventional fishing gear, the hook depth was mainly affected by wind speed (V_w), hook number (ψ) and wind angle ($\sin Q_w$). The calculation formula for prediction hook depth of conventional gear was:

$$D_T = D_\Psi \times [10^{0.008} \times \psi - 0.153 \times (\sin Q_w)^{0.01} \times V_w^{0.078}] \qquad (5)$$

The theoretical hook depth of experimental gear could be calculated by:

$$D_\Psi = h_a + h_b + l\left[\sqrt{1+\cot^2\varphi_0} - \sqrt{\left(1-\frac{2\psi}{M_k}\right)^2 + \cot^2\varphi_0}\right] + d \qquad (6)$$

$$\boldsymbol{L = V_2 \times M_k \times \Delta t} \qquad (7)$$

$$l = {V_1 \times M_k \times \Delta t}/{2} \qquad (8)$$

$$\tau = {L}/{2l} = {V_2}/{V_1} = \cot\varphi_0 sh^{-1}(\mathrm{tg}\varphi_0) \qquad (9)$$

where d was the depth of messenger weight, the meanings of other symbols were the same as those noted above.

For the experimental fishing gear, the hook depth was mainly affected by current velocity on the surface (V_s), hook number (ψ) and weight of messenger weight (W). The calculation formula for prediction hook depth of experimental gear was:

$$D_T = D_\psi \times (10^{-0.004} \times V_s - 0.056 \times W - 0.016 \times \psi - 0.075) \qquad (10)$$

The depth of each hook was calculated by the prediction hook depth calculation models. Because there were no catch in 0-40 m water layer, and a few tunas were caught in 40-80 m water layer, we counted the total soak time of hooks, number of hooks and caught individuals of bigeye tuna for 80.0-119.9 m, 120.0-159.9 m, 160.0-199.9 m, 200.0-239.9 m, 240.0-279.9 m, 280.0 m-319.9 m water layers (q = 1,2,3,4,5,6) and each site (q = 0).

1.4.2 The soak time estimation

We assumed that T_{1s}^k and T_{1f}^k were starting and ending time of deploying longline gear at the *k-th* operation, respectively; T_{2s}^k and T_{2f}^k were starting and ending time of retrieval. There were $M_k + 1$ floats (*i.e.* M_k sections). There were 25 hooks between two successive floats. T_3^k was assumed as the elapsing time from the end of deploying to the start of retrieval. The time interval of deploying two successive hooks was $\Delta t = 8s$. The time at which all branch lines between two successive floats were deployed was ΔT_d. Owing to the fixed line shooting speed of deployment, the time interval between two successive hooks (Δt) was used as the time unit to calculate the soak time of fishing gear in the time process of deployment. Many factors affected the line retrieval speed, such as the distribution of catches among branch lines. The line retrieval speed was assumed to be constant during retrieval in this study. We assumed there were three parts of total soak time for each operation, and T_1^k, T_2^k, T_3^k indicated the soak time during deploying, retrieval, and the elapsing time from the end of deploying to the start of retrieval, respectively. Two models for retrieval were: (1) retrieval was started from the starting position of deploying; (2) retrieval was started from the end position of deploying. Based on these assumptions, the soak time of *j-th* hook in *i-th* float, and *k-th* operation was calculated as follows:

(1) Retrieval was started from the starting position of deploying

$$T_1^k = M_k(N+1)\Delta t - (i-1)\Delta T_d - j\Delta t \quad (11)$$

$$\Delta T_d = (N+1)\Delta t \quad (12)$$

$$T_2^k = [(N+1)(i-1)+j]\frac{T_{2f}^k - T_{2s}^k}{(N+1)M_k} \quad (13)$$

$$T_3^k = T_{2s}^k - T_{1f}^k \quad (14)$$

$$t_{i,j}^k = T_1^k + T_2^k + T_3^k \quad (15)$$

$$t_{i,j}^k = [(M_k - i + 1)(N+1) - j]\Delta t + [(N+1)(i-1)+j]\frac{T_{2f}^k - T_{2s}^k}{(N+1)M_k} + T_{2s}^k - T_{1f}^k \quad (16)$$

(2) Retrieval was started from the end position of deploying

$$T_2^{k\prime} = [(N+1)(M_k - i) + (N+1) - j]\frac{T_{2f}^k - T_{2s}^k}{(N+1)M_k} \quad (17)$$

$$t_{i,j}^{k}{}' = T_1^k + T_2^{k\prime} + T_3^k \quad (18)$$

$$t_{i,j}^{k}{}' = [(M_k - i + 1)(N+1) - j][\Delta t + \frac{T_{2f}^k - T_{2s}^k}{(N+1)M_k}] + T_{2s}^k - T_{1f}^k \quad (19)$$

Soak time of each hook when it was stable was computed. That is, the total soak time minus settling time of each hook. In this study, we assumed that the settling time of each hook (1~25) between two successive floats was constant in the successive floats at random, and was defined as $t_j^k (j=1,2,\cdots,25)$. The settling time of each hook was measured by the TDR. We calculated the average settling time for each hook (1~25) between two successive floats in the investigation (Table 1). The soak time of each hook when it was stable was:

Retrieval was started from the start position of deploying:

$$T_{i,j}^k = t_{i,j}^k - t_j^k \quad (20)$$

Retrieval was started from the end position of deploying:

$$T_{i,j}^{k}{}' = t_{i,j}^{k}{}' - t_j^k \quad (21)$$

Table 1 The settling time of conventional gear (1~25)

No	1/25	2/24	3/23	4/22	5/21	6/20	7/19	8/18	9/17	10/16	11/15	12/14	13
settling time (h)	0.81	0.85	0.91	0.97	1.03	1.07	1.12	1.15	1.21	1.25	1.28	1.32	1.35

Table 2 The settling time of experimental gear (1~23)

No	1/23	2/22	3/21	4/20	5/19	6/18	7/17	8/16	9/15	10/14	11/13	12
settling time (h)	0.2	0.29	0.38	0.47	0.53	0.61	0.65	0.74	0.80	0.84	0.91	1.01

Because retrieval was started from the end position of deploying in this study, the total soak time of *q -th* water layer (*q*=1,2,3,4,5,6) at *k-th* (*q*=0) operation:

$$T_{st}^{kq} = \sum_{i=1}^{M_k} \sum_{j=1}^{N} T_{i,j}^{kq} \quad (22)$$

where $T_{i,j}^{kq}$ was the total soak time of *q -th* water layer at *k-th* operation.

1.4.3 The calculation method of CPUE

(1) The calculation method of CPUE of *q-th* water layer at *k-th* operation in effort

units of ten thousand hours:

$$CPUE'_{kq} = \frac{N_{kq}}{T_{st}^{kq}} \times 10000 \qquad (23)$$

where N_{kq} was the individuals of bigeye tuna in *q-th* water layer at *k-th* operation.

(2)The calculation method of CPUE of *q-th* water layer at *k-th* operation in effort units of one thousand hooks:

$$CPUE_{kq} = \frac{N_{kq}}{F_{kq}} \times 1000 \qquad (24)$$

where F_{kq} was the number of hooks of *q-th* water layer at *k-th* operation.

1.4.4 The comparison of $CPUE'_{kq}$ and $CPUE_{kq}$

Because the $CPUE'_{kq}$ and $CPUE_{kq}$ had different dimensions, we made data dimensionless processing before the comparison, the method was as follows (Ma, 2000):

$$Y = \frac{X - x_{\min}}{x_{\max} - x_{\min}} \qquad (25)$$

where Y is the data after processing, X was raw data, $x_{\min} = \min(X)$ was the minimum of X, $x_{\max} = \max(X)$ was the maximum of X. After data dimensionless processing, the value was $[0,1]$.

The significance of difference between $CPUE'_{kq}$ and $CPUE_{kq}$ was tested by T-test (Cai and Yue, 2004).

3. RESULTS

3.1 Soak time

In this study, we can calculate the soak time of every branch line at each site. The longest soak time was 22.8 h while the shortest was 4.6 h. Combining the total soak time of each set and observing the trend (Fig.4), the total soak time was in the range of 10000-33000 h at each set. The soak time of the first hook was shown in Fig.4, the trend was consistent with the total soak time fluctuation trend. There was the similar trend for 2-25 hooks. In order to further distinguish the soak time difference among different hook no., the soak time of no. 1-25 branch line at the first set was shown in Fig.5. The results of other sets were the same as the first set.

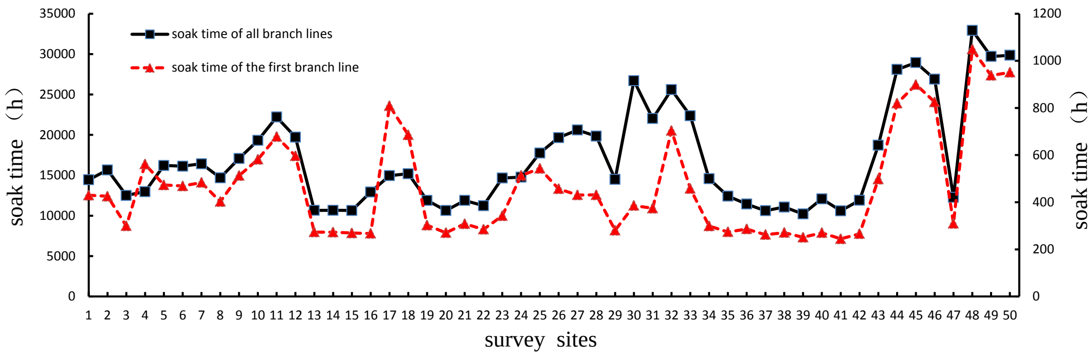


Fig.4 The trend of all branch lines' soak time and the first branch line's soak time

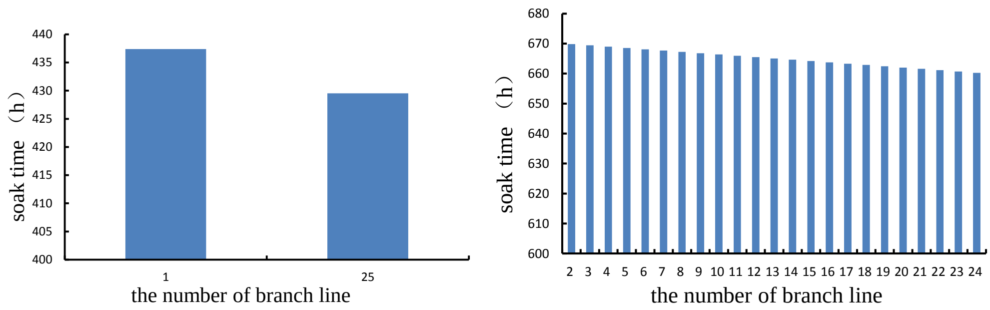


Fig.5 The soak time of no. 1-25 branch line at the first set

3.2 The comparison of two CPUEs of bigeye tuna

The comparison result of two CPUEs of bigeye tuna was shown in Fig.5. The trend of two CPUEs of bigeye tuna was basically the same. There was significant difference between two CPUEs by using T-test to test the dimensionless data at each site (Table 3, $p < 0.05$).

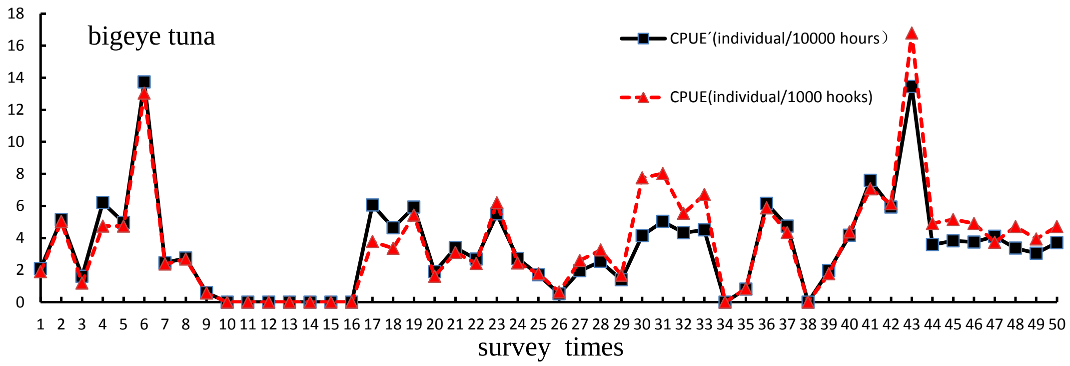


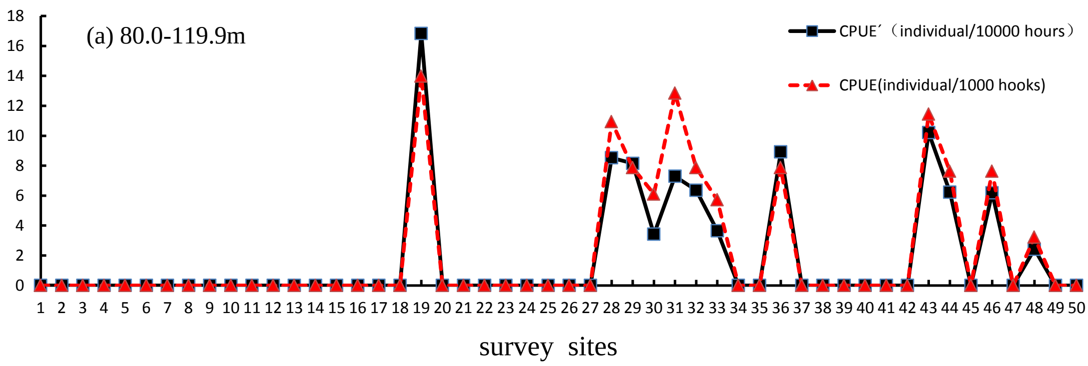
Fig.6 The comparison between $CPUE'_{kq}$ and $CPUE_{kq}$ of bigeye tuna at each set

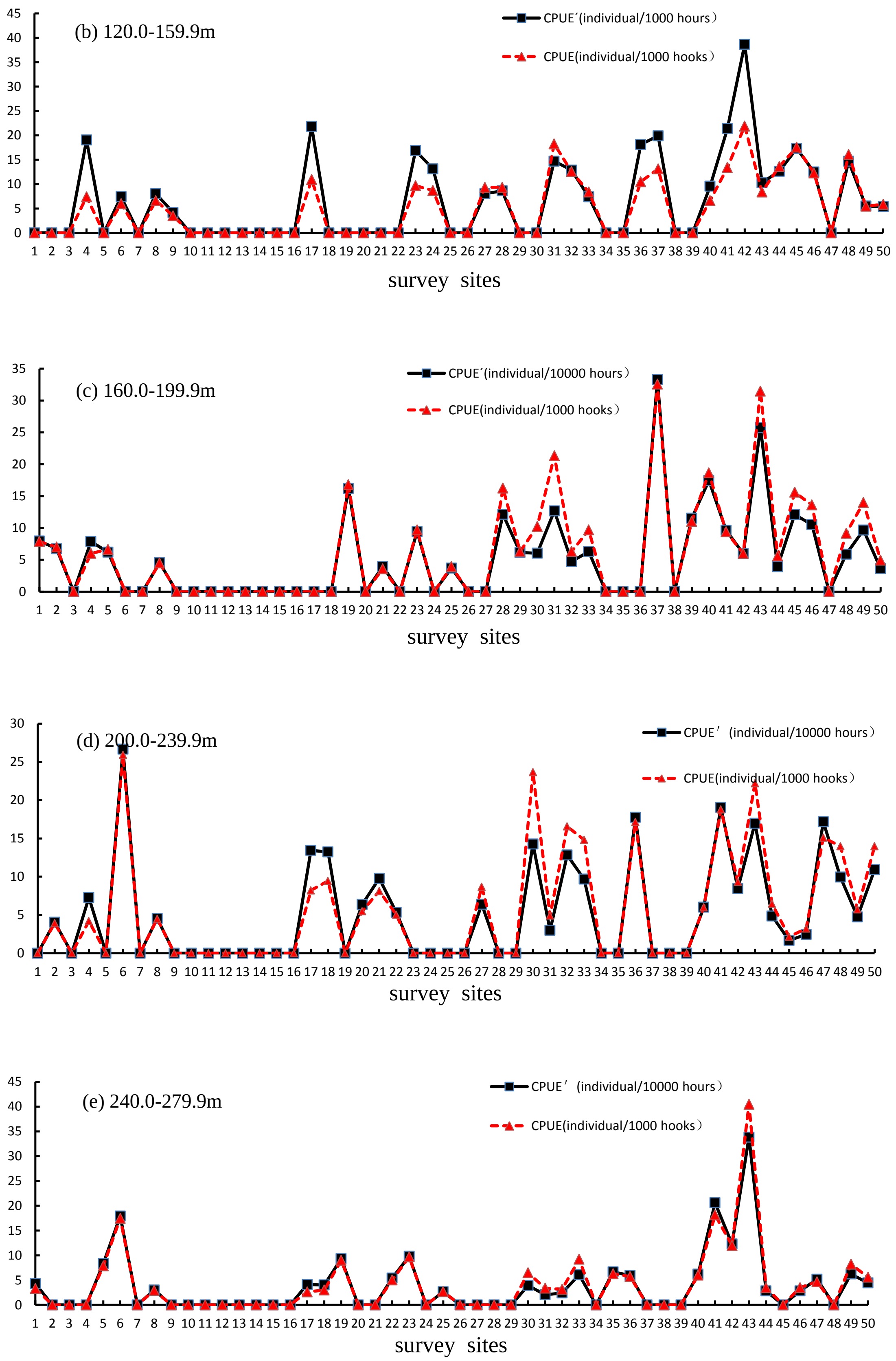
Table 3 The T-test result of the CPUEs of bigeye tuna at each site

	$CPUE_{kq}$	$CPUE'_{kq}$
Observed value	41	41
average	0.239	0.272
variance	0.0368	0.0435
p-value	0.0095	

3.3 The comparison of two CPUEs of bigeye tuna at different water layers

The comparison results of two CPUEs of bigeye tuna at different water layers showed that there were significant differences between two CPUEs of bigeye tuna in most of water layers, except the 200.0-239.9 m and 280.0-319.9 m water layers (Fig.7, Table 4).




(b) 120.0-159.9m
CPUE′(individual/1000 hours）
CPUE(individual/1000 hooks）
survey sites
(c) 160.0-199.9m
CPUE′(individual/10000 hours）
CPUE(individual/1000 hooks）
survey sites
(d) 200.0-239.9m
CPUE′ (individual/10000 hours）
CPUE(individual/1000 hooks）
survey sites
(e) 240.0-279.9m
CPUE′ (individual/10000 hours）
CPUE(individual/1000 hooks）
survey sites

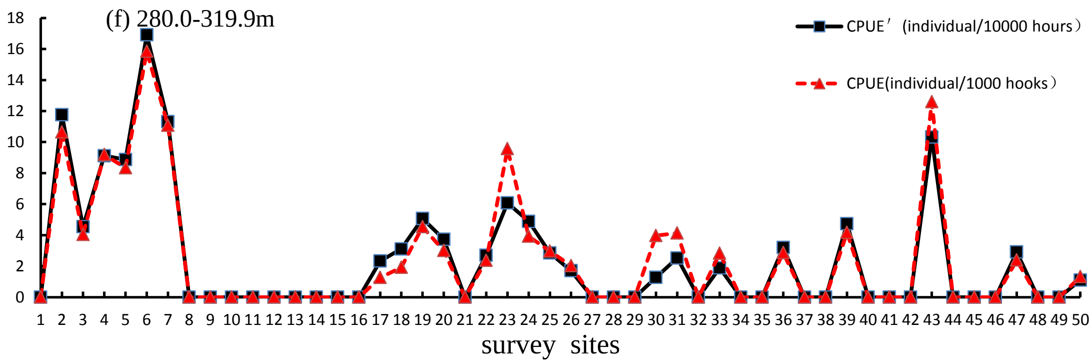


Fig.7 The comparison results of $CPUE'_{kq}$ and $CPUE_{kq}$ of bigeye tuna at different water layers

Table 4 The T-test result of two CPUEs of bigeye tuna at different water layers

	Water layers	No. of observation	$CPUE_{kq}$	$CPUE'_{kq}$	*p*-value
average	80.0-119.9m	12	0.499	0.342	0.0059
	120.0-159.9m	24	0.388	0.275	0.0029
	160.0-199.9m	27	0.270	0.208	0.0006
	200.0-239.9m	26	0.359	0.329	0.255
	240.0-279.9m	25	0.142	0.175	0.002
	280.0-319.9m	23	0.286	0.269	0.350

3 DISCUSSION

(1) The reasons for the little change of the total soak time of different branch line

We found that the total soak time of different branch line fluctuated in a small range (about 10 hours). The reasons might be the regular distribution of branch line, and the total soak time of branch line decline from the 2nd to the 24th branch line. This trend depended on the mode of hauling. There was increasing trend from the 1st to the 25th when retrieval started at the beginning position of the deploying, and vice verse. The total soak time of the 1st and the 25th branch line were less than other branch lines because we deployed eight groups experimental gear and the1st or the 25th branch line were absent.

(2) The soak time model of fishing gear

The model can estimate the soak time of each branch line accurately. In the future, we suggest that the soak time could be used as the fishing effort and to standardize the CPUE of longline fisheries. There was significant difference between two types of CPUE of bigeye tuna in different survey sites. There were significant differences between two types of CPUE of bigeye tuna in most of water layers except to 200.0-239.9 m and 280.0-319.9 m water layers. There were significant differences between two types of CPUE of bigeye tuna when different fishing efforts were used. The soak time of each branch line included the number of branch line and the soak time of branch line and it reflected the effective fishing effort. Carruthers *et al.* (2011) used GLM model to analyze the influence of operating parameters and environmental factors on the swordfish and blue shark's CPUE. The results showed that the soak time had significant impact on swordfish and blue shark's CPUE. Ward *et al.* (2004) analyzed that the CPUEs of tuna and sea turtles when soak time was 20 h were less than the CPUE when the soak time was 5 h. It illustrated that the soak time was a major factor that affected CPUE and not always positive impact. Morgan and Carlson (2010) found that the catch rates of Atlantic bottom shark longline fisheries increased fastest between 5-12 h after deployment. Ogura *et al.* (1980) suggested that the increasing degree of the bottom longline fishery catches decreased gradually over time. Maunder and Punt (2004) pointed out that the appropriate variables should be identified and selected in the CPUE standardization. The higher resolution of the time, space, fishing parameter, and environment variables should be used and combined with the data of fish physiology and fish behavior to standardize the fishing effort and the CPUE (Maunder and Punt, 2004).

(3) Reasons of no significant difference in two CPUEs for part of water layers

In the water layers of 200.0-239.9 m and 280.0-319.9 m, there were no significant differences between two types of CPUE of bigeye tuna. It might be caused by sampling bias.

(4) Prospect

In the future, it is necessary to use higher accurate survey data to compare two kinds of CPUE in the water layers of 200.0-239.9 m and 280.0-319.9 m to confirm that if there is significant difference. In addition, we should collect data of other bycatch species, such as sharks, other tunas, and so on, to analyze if there is any significant differences between two kinds of CPUE.

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