Received: 1 October, 2011

A comparison of calculation methods of an integrated habitat index for yellowfin tuna in the Indian Ocean

Yaping WU[1], Liming Song[1,2]
(1.College of Marine Sciences, Shanghai Ocean University, Shanghai 201306, China
2.The Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources, Ministry of Education, Shanghai Ocean University, Shanghai 201306，China)

Abstract: Based on the survey of *Huayuan yu no.18* in the Indian Ocean in 2005, we applied the data, such as the weighted and arithmetic average value of temperature, salinity, chlorophyll-a concentration , dissolved oxygen concentration, other environmental variables, the interactions among them , and the nominal CPUE and standardized CPUE which was calculated by the deterministic habitat based standardization , to build four "integrated habitat index" models of yellowfin tuna (*Thunnus albacares*) by the quantile regression method. We applied the *F* test and *T* test to analyze them. The results showed that, the main distribution area that yellowfin tuna inhabit was in 3°N-6°30′N, 62°E-67°E, the temperature, dissolved oxygen concentration have significance to spatial distribution of yellowfin tuna and whether salinity effect the spatial distribution of yellowfin tuna, it need further study. This study suggested that we should take temperature and dissolved oxygen into account when we study the integrated habitat index and predict CPUE; if the time series is shorter, such as less than one year, we could apply nominal CPUE and the arithmetic average value of environmental variables to study the integrated habitat index of yellowfin tuna by the quantile regression method; if the time series is longer, it would be better to put the nominal CPUE and weighted average environment variables into the quantile regression model to study the integrated habitat index of yellowfin tuna, but the operation parameter of fishing gear and environment factors should exist large scale change, it need further study.

Key words: *Thunnus albacares*; integrated habitat index; CPUE; environmental variable

---

Corresponding author at: College of Marine Sciences, Shanghai Ocean University, 999 Huchenghuan Road, Lingangxincheng, Shanghai 201306, China.Tel.: +86 21 61900311; fax: +86 21 61900304.

E-mail address: lmsong@shou.edu.cn

1 Introduction

Study the distribution of fishes' habitat is beneficial to the effective exploitation, utilization and management of the fishery resources. Currently, there were many methods to analyze the prediction abundance and the habitat distribution of yellowfin tuna (Allen and Punsly 1984; Mohri and Nishida 2000; Maury et al 2001; Romena 2001; Shono et al.2002; Nishida et al. 2003; Anda-Montañeza et al 2004; Song et al. 2008; Song and Wu 2011). Many environmental variables were applied to the methods as explanatory variable, but the key variables were different (Mohri and Nishida 2000; Maury et al. 2001; Romena 2001; Shono et al. 2002; Nishida et al. 2003; Song et al. 2008; Song and Wu 2011). There were also many scholars to study the organisms' habitat distribution (Terrell et al. 1996; Eastwood et al. 2003; Vinagre et al. 2006; Song et al. 2007) by quantile regression method. Dunham et al (2002) used quantile regression method to study the spatial distribution of mountain trout （*Oncorhynchus clarki*） resource, Song and Zhou (2010) used quantile regression model to study the habitat integrate index of bigeye tuna (*Thunnus obesus*) in the Indian Ocean. For the integrated habitat index model, there were some controversy in choosing the environmental variables and the processing methods (Feng et al 2007; Zhang 2008; Song and Zhou 2010). In this paper, for the purpose of choosing the environmental variables and methods reasonably to study the habitat distribution of yellowfin tuna, we applied the weighted average and arithmetic average value of temperature, salinity, chlorophyll-a concentration, dissolved oxygen concentration and horizontal current, thermocline strength, and the interaction among them, nominal CPUE and standardized CPUE (which were estimated by deterministic habitat based standardization (detHBS)) to build four "Integrated Habitat Index" models of yellowfin tuna by the quantile regression method, and applied the *F* test and *T* test to analyze them.

2 Materials and methods

2.1 Materials

Data were collected from operations on longliner, *Huayuanyu no.18*, in 2005. The vessel' s 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 407.00kW, respectively.

The vessels fished between September 15 and December 12. Fishing took place mainly between about 1°N and 10°N and between about 62°E and 70°E (Fig.1). The data collected locations were shown in Fig.1. During the survey, the fishing vessel targeted bigeye tuna, and the bycatch included yellowfin tuna, swordfish (*Xiphias gladius*), albacore (*Thunnus alalunga*) and billfishes (*Istiophoridae*).

The configuration of fishing gear in the survey: the longline gear consists of 3.6 mm diameter monofilament main line, 360 mm diameter hard plastic floats, 6 mm diameter nylon float line; The length of float line is 22 m; The first segment of branch line is 3 mm diameter polypropylene, the length is 1m; The first segment of the branch line was directly linked to the second segment, no swivel; the second segment was linked to the third segment by a swivel; the third segment was directly linked to the hook. The experimental gears were assembled as eight types of gear; the first segment of the experimental branch line was linked up the second segment using four kinds of plumbic swivel. The experimental branch line was assembled by two sorts of sinker above the hook, and part of them assembled by luminous sleeve above the hook. The detail information about the fishing gear can be referred in Song et al (2008, 2009).

In general, the time of shooting and deploying gears was between 05:00 and 09:00 at local time, and then lasted for four hours. The time of retrieving and handling on the gears was at 14:00 to 22:00, the total operation would be lasted for eight to ten hours. According to the survey plan, the captain determined the positions for collecting the data. During deploying gear, the vessel's speed was about 4 to 4.4 ms^{-1}, line shooter speed was about 5.5 to 5.9 ms^{-1}, time interval between fore and after branch line set out was about 7.8 s and there were 25 hooks per basket (HPB).

During deploying experimental gear, the first hook near to float was absent, the second hook was replaced with two kinds of different messenger weight, other parameters were invariable, there were eight types of gear, 50 experimental hooks each type, totally 400 experimental hooks per set. In addition, in order to avoid sea turtle bycatch, 100 circle hooks were deployed each set.

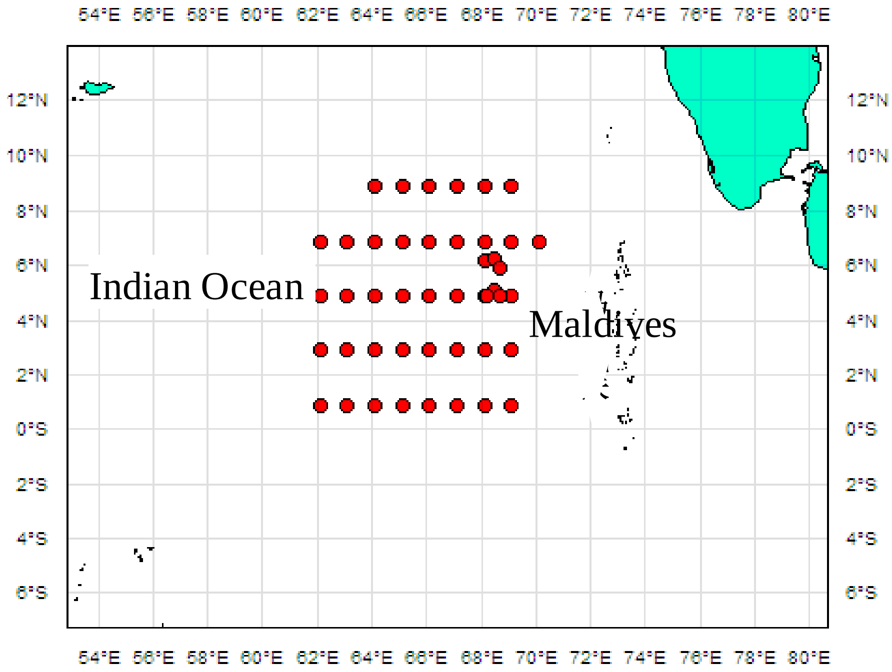

Fig.1 the setting positions for *Huayuanyu no.18* before the survey

2.2 Data processing

2.2.1 The catch rate of yellowfin tuna in depth stratum j, CPUE$_j$

We applied the following hook depth prediction model (Song 2008; Song and Wu 2011) to predict the hook depth, for the traditional gear and experimental gear, respectively.

$$D_{\mathrm{ptq}} = 1.2023 V_w^{0.078} (\sin\gamma)^{0.010} q^{-0.153} D_{tq} \qquad \text{(n=248, r=0.8074)} \qquad (1)$$

$$D_{\mathrm{peq}}' = 0.9908 (V_g')^{-0.056} q'^{-0.075} M^{0.} D_{eq}' \qquad \text{(n=271, r=0.7625)} \qquad (2)$$

In equation (1), D_{ptq} is the predicted hook depth of traditional gear for the hook position code *q*; V_w is the wind speed; $\sin\gamma$ is the sine of angle of attack γ; *q* is the hook position code; and D_{tq} is the theoretical catenaries hook depth of traditional gear for the hook position code *q*. In equation (2), D_{peq}' is the predicted hook depth of experimental gear for the hook position code q'; V_g' is the experimental gear drifting speed; q' is the hook position code; *M* is the weight of messenger weight; and D_{eq}' is the theoretical catenaries hook depth of experimental gear for the hook position code

q' .

The data for the yellowfin tuna were grouped into the particular depth strata. In this study, the data were assigned to nine depth strata of 40 m each (0-40 m, 40-80 m, …, 320-360 m).

Based on the hook depth prediction model (Song 2008; Song and Wu 2011) and the method in Song et al (2008, 2009), we calculated the number of the yellowfin tuna (N_j was defined as the catch number of traditional fishing gear, N_{tj}' was defined as the catch number of experimental fishing gear)and hooks (H_j was defined as the hooks of traditional fishing gear, H_{tj}' was defined as the hooks of experimental fishing gear）in specific depth strata for the whole investigation, where there were four kinds of experimental fishing gears with different messenger weight (defined as t). The catch rates of yellowfin tuna at a particular depth stratum was calculated by the following equation (Song and Wu 2011):

$$CPUE_j = \frac{(N_j + \sum_{t=1}^{4} N_{tj}')}{(H_j + \sum_{t=1}^{4} H_{tj}')} \times 1000 \qquad (3)$$

where depth strata j=1,2,3,……9.

2.2.2 Nominal CPUE and standardized CPUE

For the longline fishery, we usually used the number of hooks which were deployed in specific time as nominal fishing effort (Biglow *et al.*, 2002).

We applied “detHBS” to calculate the effective fishing effort (Biglow *et al.*, 2002, Song and Wu 2011):

$$f_i = E_i \sum_j h_{ij} p_j \qquad (4)$$

where f_i is the effective fishing effort for the station i, E_i is the nominal fishing effort for station i (thousand hooks) j is the depth stratum, h_{ij} is the proportion of hook number in depth stratum j and station i, and p_j is the habitat preference index of yellowfin tuna in depth stratum j calculated using the following equation:

$$p_j = \frac{CPUE_j}{\sum CPUE_j} \qquad (5)$$

where $CPUE_j$ is the nominal $CPUE$ of yellowfin tuna in depth stratum j.

The nominal *CPUE* and standardized *CPUE* in station *i* were calculated by the following equation:

$$CPUE_{ni} = \frac{N_i}{E_i} \times 1000 \qquad （6）$$

$$CPUE_{ei} = \frac{N_i}{f_i} \times 1000 \qquad （7）$$

where $CPUE_{ni}$ and $CPUE_{ei}$ is the nominal *CPUE* and standardized *CPUE* of yellowfin tuna in station *i*; and N_i is the number of fish caught in station *i*.

2.2.3 Developing quantile regression models

The arithmetic average environmental variables of whole water bin:

$$ENV_i' = \sum ENV_{ij} / 9 \qquad （8）$$

The weighted average value of environment variables based on the catch rate of depth stratum *j* at sampling station *i* was calculated, following Song *et al.* (2007) , Song and Zhou (2010), as:

$$ENV_i = \sum（CPUE_j ENV_{ij}）/ \sum CPUE_j \qquad （9）$$

where ENV_i' and ENV_i were the arithmetic average environmental and weighted average environmental variable of whole water bin, the environmental variable includes temperature (T_i), salinity (S_i), chlorophyll-a concentration (Ch_i), dissolved oxygen concentration (DO_i), horizontal current (HC_i), and vertical current (WC_i) at sampling station *i* from *HYY 18*, and ENV_{ij} was the value of the above environmental variables at sampling station *i* in depth stratum *j* (*i.e.*, 80～120 m, 120～160 m, . . ., 320～360 m). T_{ij}, S_{ij}, Ch_{ij}, and DO_{ij} were the arithmetic means measured with the XR- 620 at sampling station *i* in depth stratum *j*. HC_{ij} and WC_{ij} were the arithmetic means measured with the Submersible Data Logger (XR- 620, RBR Co., Ottawa, Ontario, Canada) at sampling station *i* in depth stratum *j*.WC_{ij} were the arithmetic means measured with the three dimension (3D) Aquadopp Current profile (ADCP), Aquadopp-2000 (NORTECK Co., Vangkroken, Norway) at sampling station *i* at depth stratum *j*.

The shear of horizontal current component (denoted as ξ) was estimated by integrating the original data measured with the Aquadopp-2000 from the near-surface to the largest predicted hook depth (z) at each sampling station *i* (Bigelow et al., 2006). The coefficient ξ was used to study the potential *CPUE* of sampling station *i*.

$$\xi = \log\left\{ \frac{\sum_{j=1}^{7} \left[\left(\frac{\beta_{j+1} - \beta_j}{\tau_{j+1} - \tau_j} \right)^2 + \left(\frac{\delta_{j+1} - \delta_j}{\tau_{j+1} - \tau_j} \right)^2 \right]^{\frac{1}{2}} (\tau_{j+1} - \tau_j)}{\sum_{j=1}^{7} (\tau_{j+1} - \tau_j)} \right\} \qquad （10）$$

Where v_j was the North-South component of current in the depth stratum j, u_j was the East-West component of current in the depth stratum j, z_j was the depth of depth stratum j.

Thermocline intensity (TI_i) (°C m^{-1}) was calculated by temperature profile measured by XR-620 at station i (Song and Wu 2010) as:

$$TI_i = \frac{T_u - T_b}{D_b - D_u} \qquad （11）$$

where T_u, T_b, D_u, and D_b was thermocline’s upper temperature (°C), bottom temperature (°C), upper depth (m) and bottom depth (m).

In this study, the quantile regression model was developed based on the data measured by *Huayuanyu no.18* at the 30 sampling stations from the 48 sampling stations, we only measured the environmental variables (temperature, salinity, chlorophyll-a concentration, dissolved oxygen concentration) at the 30 sampling stations, owing the limitation of the sea condition. The quantile regression model was initially developed by Koenker and Basset(1978）.

In this paper, the full regression model for describing the relationship between the predicted weighted average nominal *CPUE* ($C\hat{P}UE_{wni}$) and predicted weighted average standardized *CPUE* ($C\hat{P}UE_{wei}$) at sampling station i, versus T_i, S_i, Ch_i, DO_i, WC_i, ξ_i, TI_i, and their interaction terms can be written as:

$$\begin{aligned}C\hat{P}UE_{wni} &= C_{wni} + a_{wni}T_i + b_{wni}S_i + c_{wni}Ch_i + d_{wni}DO_i + e_{wni}\xi_i + f_{wni}WC_i + g_{wni}TI_i + h_{wni}TS_i + k_{wni}TCh_i + l_{wni}TDO_i + m_{wni}T\xi_i \\ &+ n_{wni}TWC_i + o_{wni}TTI_i + p_{wni}SCh_i + q_{wni}SDO_i + r_{wni}S\xi_i + s_{wni}SWC_i + t_{wni}STI_i + u_{wni}ChDO_i + v_{wni}Ch\xi_i + w_{wni}ChWC_i + \\ &x_{wni}ChTI_i + y_{wni}DO\xi_i + z_{wni}DOWC_i + aa_{wni}DOTI_i + ab_{wni}\xi WC_i + ac_{wni}\xi TI_i + ad_{wni}WCTI_i + \varepsilon_{wni} \qquad (12)\end{aligned}$$

$$\begin{aligned}C\hat{P}UE_{wei} &= C_{wei} + a_{wei}T_i + b_{wei}S_i + c_{wei}Ch_i + d_{wei}DO_i + e_{wei}\xi_i + f_{wei}WC_i + g_{wei}TI_i + h_{wei}TS_i + k_{wei}TCh_i + l_{wei}TDO_i + m_{wei}T\xi_i \\ &+ n_{wei}TWC_i + o_{wei}TTI_i + p_{wei}SCh_i + q_{wei}SDO_i + r_{wei}S\xi_i + s_{wei}SWC_i + t_{wei}STI_i + u_{wei}ChDO_i + v_{wei}Ch\xi_i + w_{wei}ChWC_i + \\ &x_{wei}ChTI_i + y_{wei}DO\xi_i + z_{wei}DOWC_i + aa_{wei}DOTI_i + ab_{wei}\xi WC_i + ac_{wei}\xi TI_i + ad_{wei}WCTI_i + \varepsilon_{wei} \qquad (13)\end{aligned}$$

The full regression model for describing the relationship between the predicted arithmetic average nominal *CPUE* ($C\hat{P}UE_{ani}$) and predicted arithmetic average standardized *CPUE* ($C\hat{P}UE_{aei}$) at sampling station i, versus T_i', S_i', Ch_i', DO_i', WC_i', ξ_i, TI_i, and their interaction terms can be written as:

$$\begin{aligned}C\hat{P}UE_{ani} &= C_{ani} + a_{ani}T_i' + b_{ani}S_i' + c_{ani}Ch_i' + d_{ani}DO_i' + e_{ani}\xi_i + f_{ani}WC_i' + g_{ani}TI_i' + h_{ani}TS_i' + k_{ani}TCh_i' + l_{ani}TDO_i' + m_{ani}T\xi_i' \\ &+ n_{ani}TWC_i' + o_{ani}TTI_i' + p_{ani}SCh_i' + q_{ani}SDO_i' + r_{ani}S\xi_i' + s_{ani}SWC_i' + t_{ani}STI_i' + u_{ani}ChDO_i' + v_{ani}Ch\xi_i' + w_{ani}ChWC_i' + \\ &x_{ani}ChTI_i' + y_{ani}DO\xi_i' + z_{ani}DOWC_i' + aa_{ani}DOTI_i' + ab_{ani}\xi WC_i' + ac_{ani}\xi TI_i' + ad_{ani}WCTI_i' + \varepsilon_{ani} \qquad (14)\end{aligned}$$

$$
\begin{aligned}
C\hat{P}UE_{aei} &= C_{aei} + a_{aei}T_i' + b_{aei}S_i' + c_{aei}Ch_i' + d_{aei}DO_i' + e_{aei}\xi_i + f_{aei}WC_i' + g_{aei}TI_i' + h_{aei}TS_i' + k_{aei}TCh_i' + l_{aei}TDO_i' + m_{aei}T\xi_i' \\
&+ n_{aei}TWC_i' + o_{aei}TTI_i' + p_{aei}SCh_i' + q_{aei}SDO_i' + r_{aei}S\xi_i' + s_{aei}SWC_i' + t_{aei}STI_i' + u_{aei}ChDO_i' + v_{aei}Ch\xi_i' + w_{aei}ChWC_i' + \\
& x_{aei}ChTI_i' + y_{aei}DO\xi_i' + z_{aei}DOWC_i' + aa_{aei}DOTI_i' + ab_{aei}\xi WC_i' + ac_{aei}\xi TI_i' + ad_{aei}WCTI_i' + \varepsilon_{aei} \qquad (15)
\end{aligned}
$$

where C_{wni}, C_{wei}, C_{ani}, C_{aei} is the constant, TS_i is the interaction of temperature and salinity, TDO_i is the interaction of temperature and dissolved oxygen concentration, which is the same to other variables, and ε_{wni} , ε_{wei} , ε_{ani} , ε_{aei} is the error term at sampling station *i*. The values of $a_{wni}, b_{wei}, c_{wei} \dots \dots ad_{aei}$ are their corresponding parameters.

It is more appropriate to select θ values between 0.50 and 0.95 to build the upper-quantile model (Feng et al., 2007). For the quantile regression, all variables were initially included in the model. The statistical significance of each variable in the model was then evaluated by the rank-score test (Cade and Richards, 2001). If the significance value, *P*, was greater than 0.05, the variable was excluded from the model. The *P*-values for all variables and their interaction terms included in the model were re-evaluated whenever a variable was excluded. This process was repeated until the *P*-values of all the independent variables and their interaction terms in the model were less than or equal to 0.05, then obtained the optimal model. In this study, we used the statistical software Blossom to process the data, which was developed by Midcontinent Ecological Science Center (U.S.Geological Survey).

2.3 **Developing *IHI* models**

IHI_{wni}, IHI_{wei}, IHI_{ani}, and IHI_{aei} were calculated by the following equations:

$$IHI_{wni} = C\hat{P}UE_{wni} \Big/ max(C\hat{P}UE_{wni}) \qquad （16）$$

$$IHI_{wei} = C\hat{P}UE_{wei} \Big/ max(C\hat{P}UE_{wei}) \qquad （17）$$

$$IHI_{ani} = C\hat{P}UE_{ani} \Big/ max(C\hat{P}UE_{ani}) \qquad （18）$$

$$IHI_{aei} = C\hat{P}UE_{aei} \Big/ max(C\hat{P}UE_{aei}) \qquad （19）$$

Where $max(C\hat{P}UE_{wni})$, $max(C\hat{P}UE_{wei})$, $max(C\hat{P}UE_{ani})$, and $max(C\hat{P}UE_{aei})$ were the maximum value of $C\hat{P}UE_{wni}$, $C\hat{P}UE_{wei}$, $C\hat{P}UE_{ani}$, and $C\hat{P}UE_{aei}$.

2.4 The expression of *IHI* isolines

Based on the estimates derived above, the *IHI* isolines distributions were developed using the software Sufer 6.0 (Golden Software, 1996)

2.5 The predictive power of the *IHI* model

Owing to range of the *IHI* value was between 0 and 1, we used homogeneity test of variances (*F* test) to verify the values estimated from *IHI* models, then got the difference among the variance of the *IHI* values, if there were no significant difference in variances, we would choose equal variance *T*- test to analyze the *IHI* models; if there were significant difference in variance, we would choose paired-sample *T*-test to analyze the values estimated from *IHI* models, then determine the optimal model.

3 **Results**

3.1 The predicted CPUE at sampling station *i*

The optimal models of the catch rate $CP\hat{U}E_i$ at sampling station *i* were developed. The optimal models were derived as:

$$CP\hat{U}E_{wni} = -125.46 + 7.15T_i + 108.49DO_i - 6.05TDO_i \qquad \theta=0.95 \qquad （20）$$

$$CP\hat{U}E_{wei} = -20635.03 + 1003.13T_i + 583.16S_i + 106.55DO_i - 28.40TS_i - 524TDO_i$$

θ=0.35 （21）

$$CP\hat{U}E_{ani} = -45441.39 + 2398.90T_i + 1410.93S_i + 424.56DO_i - 74.47TS_i - 22.55TDO_i$$

θ=0.85 （22）

$$CP\hat{U}E_{aej} = -274779.23 + 14596.12T_i + 8508.92S_i + 3045.87DO_i - 451.94TS_i - 162.43TDO_i$$

θ=0.95 （23）

In equation 20, weighted average T_i, DO_i ,and the interaction term TDO_i were identified as key variables; in equation 21, weighted average $T_{i,}$ S_i DO_i ,and the interaction terms TDO_i and TS_i were identified as key variables; in equation 22 and 23, arithmetic average $T_{i,}$ S_i DO_i ,and the interaction terms TDO_i and TS_i were identified as key variables.

$CP\hat{U}E_{wni}$, $CP\hat{U}E_{wei}$, $CP\hat{U}E_{ani}$, and $CP\hat{U}E_{aei}$ of yellowfin tuna estimated by the quantile regression were shown in Fig.2. In Fig.2, the predicted CPUE ($CP\hat{U}E_{wni}$ and $CP\hat{U}E_{ani}$) estimated by using the nominal *CPUE* were relative lower; the predicted CPUE ($CP\hat{U}E_{wei}$ and $CP\hat{U}E_{aei}$) estimated by using the standardized *CPUE* were relative higher, where the $CP\hat{U}E_{aei}$ was the highest.

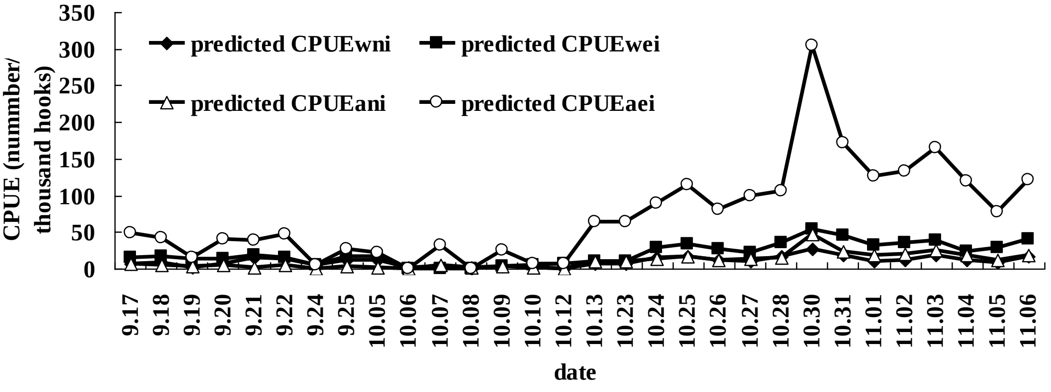

Fig.2 The distribution of $\hat{CPUE}_{wni}$, $\hat{CPUE}_{wei}$, $\hat{CPUE}_{ani}$, and $\hat{CPUE}_{aei}$ at specific stations

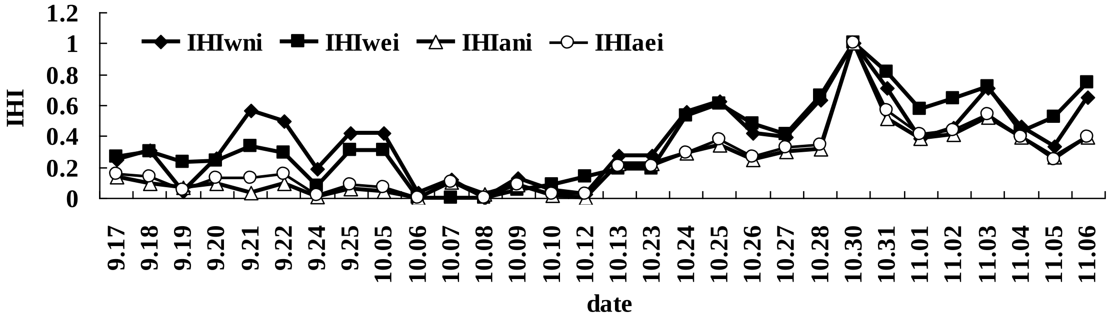

Fig.3 The distribution of IHI_{wni}, IHI_{wei}, IHI_{ani}, and IHI_{aei} at specific stations

Table 1 *F*-test on the differences among *IHIs* that obtained from the investigated data

F test		*F*	*P*(F<=f) single tail
IHI_{wni}	IHI_{ani}	1.269	0.263
IHI_{wei}	IHI_{aei}	1.783	0.063
IHI_{wni}	IHI_{wei}	0.710	0.181
IHI_{ani}	IHI_{aei}	0.998	0.537

Table 2 *T*-test for equal variance among *IHIs* that obtained from the investigated data

T test		*t* statistics	*P*(T<=t) two tail
IHI_{wni}	IHI_{ani}	2.512	0.014
IHI_{wei}	IHI_{aei}	1.812	0.075
IHI_{wni}	IHI_{wei}	0.209	0.835
IHI_{ani}	IHI_{aei}	-0.277	0.782

3.2 The *IHI* distribution

The distribution of yellowfin tuna *IHI* estimated by different models was shown in Fig.3. In Fig.3, the IHI_{wni} and IHI_{wei} were calculated on the basis of regression models developed by using the weighted average value of environment variable. The distributions of IHI_{wni} and IHI_{wei} had the almost similar trends, but there were some differences between them. The IHI_{ani} and IHI_{aei} were calculated on the basis of regression models developed by using the arithmetic average environmental variable. The distributions of IHI_{ani} and IHI_{aei} had almost similar trends, but there were some differences between them.

The results of *F* test showed there were no significant differences between IHI_{wnj} and IHI_{wej}, IHI_{wnj} and IHI_{ani}, IHI_{wei} and IHI_{aei}, IHI_{ani} and IHI_{aei} ($p>0.05$, Table 1). The results of *T* test showed that, there were no high significant differences between IHI_{wni} and IHI_{ani} ($0.01<P<0.05$), and there were no significant differences between IHI_{wni} and IHI_{wei}, IHI_{wei} and IHI_{aei}, IHI_{ani} and IHI_{aei} (P>0.05).

In Fig.4, the higher IHI_{wni} value were mostly distributed in the area 3°N-6°30′N, 62°E-67°E; the higher IHI_{wei} value were mostly distributed in the area 3°N-7°N, 62°E-67°E and 3°30′N-6°20′N, 67°E-70°20′E, the higher value area of the IHI_{wei} was larger than that of the IHI_{wni}. The higher IHI_{ani} value were mostly distributed in the area 4°N-6°30′N, 62°E-67°20′E, and which was almost similar to IHI_{aei}. In Fig.4, the high value area of IHI_{wni} and IHI_{wei} (IHI >0.35) were much larger than that of the IHI_{aei} and IHI_{ani}.

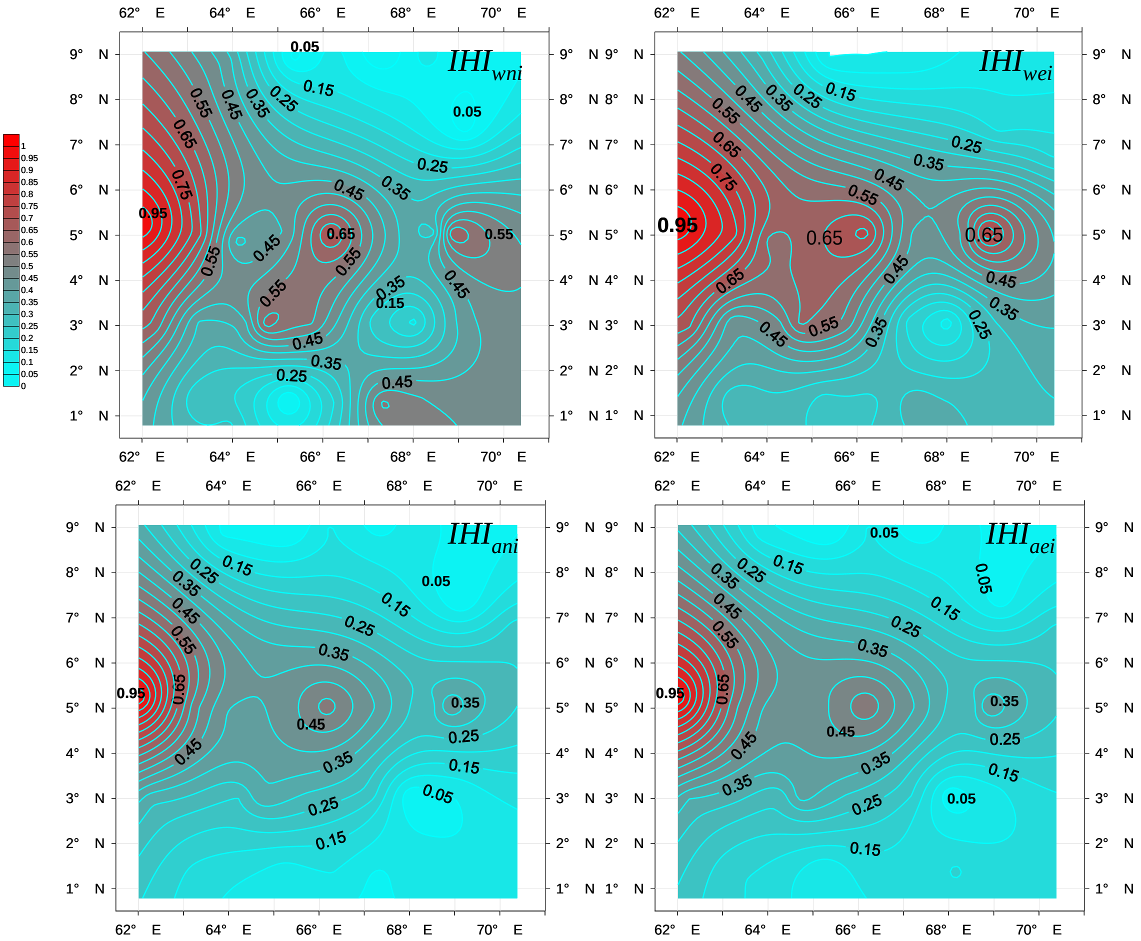

Fig.4 The distribution of IHI_{wni}, IHI_{wei}, IHI_{ani}, and IHI_{aei} at investigation area

4 Discussion

4.1 The key environment variables

The habitat preference of yellowfin tuna has close relationship to temperature and dissolved oxygen, and whether salinity influences the spatial distribution of yellowfin tuna, it needs further study. There were no significant difference between IHI_{wni} and IHI_{wei}, IHI_{wni} and IHI_{ani}, IHI_{wei} and IHI_{aei}, IHI_{ani} and IHI_{aei} (Table 2), so we can not determine if salinity influence the habitat distribution of yellowfin tuna. The seasonal migratory route of yellowfin tuna is related to the sea current (Anda-Montañeza et al. 2004), temperature, salinity and dissolved oxygen concentration (Korsmeyer et al, 1997). Cayré (1991) found dissolved oxygen and temperature gradient influenced the vertical movement of yellowfin tuna greatly, in western Indian Ocean, and the range of dissolved oxygen concentration in 2.52 ～ 2.94mg/L could influenc the general movement of yellowfin tuna. Maury et al. (2001) mentioned the temperature was the main limiting conditions, which influence the oxygen output of the heart, and limit the moving speed. Nishida et al. (2001) reported that the distribution of adult yellowfin tuna was influenced by the spatial and seasonal change of water temperature. Brill et al. (1999) defined temperature as limit factors on trail, they indicated that the temperature, dissolved oxygen and thermocline depth influenced the spatial distribution of adult yellowfin tuna in the Hawaii Islands waters, if changed the range of depth, temperature, salinity, chlorophyll-a and dissolved oxygen, the range of temperature would be the main factor. Song et al. (2008) found that the yellowfin tuna hooking rate was higher in the two salinity ranges: 35.30～35.69 and 35.99～36.39, and they suggested that salinity had less influence on yellowfin tuna’s distribution. Romena (2001) suggested that salinity had less influence on the distribution of yellowfin tuna because no steady salinity range produced high hooking rates, the salinity could possible provide an indirect explanation on their abundance. In this study, we used different environment variables and CPUEs to study the integrated habitat index, the comparison of the four models showed that temperature, dissolved oxygen were the crucial variables to the spatial distribution of yellowfin tuna. So, we suggest to using temperature and DO data which yellowfin tuna inhabit to standardize CPUE and study the integrated habitat index of yellowfin tuna.

4.2 Comparison on the methods of *IHI*

The trends of predicted CPUEs were determined by the value of environment variables. The results of equal variance *T*-test showed, there was no significant difference between IHI_{wni} and IHI_{ani}, IHI_{wei} and IHI_{aei}, IHI_{wni} and IHI_{wei}, or IHI_{ani} and IHI_{aei} (Table 2). That mean *IHI* could be calculated by using the weighted or arithmetic average environment variables, and the nominal or standardized *CPUE*. In Fig.4, there were some differences in the *IHIs* between the regression value estimated by using the weighted average environment variables and the arithmetic average environment variables. The distribution of highest and lowest values estimated by using the weighted average environment variables was almost consistent with that estimated by using the arithmetic average environment variables. But the result showed the IHI_{wni} and IHI_{wei} were more precise than IHI_{ani} and IHI_{aei}. In this study, the standardized CPUE were estimated and used to predict the resource abundance of yellowfin tuna (Song and Wu 2011). The data processing of IHI_{wei} were relative complex, which can increase computational accidental errors in process. So in this study, we suggest that we could input the nominal CPUE and arithmetic average environment variables into the quantile regression model to study the integrated habitat index if the time series of the data is short; that it would be better to input the nominal CPUE and weighted average environment variables into the quantile regression model to study the integrated habitat index for the long term time series data because the operation parameter of fishing gear and environment factors might exist significant change.

Acknowledgements

The project is funded by Ministry of Agriculture of P.R of China under Project of Fishery Exploration in High Seas in 2005 (Project No.Z05-30), Shanghai Leading Academic Discipline Project (Project No. S30702), and the National High Technology Research, Development Program of China (Project No. 2007AA092202), and the Initiation Fund for Doctors of Shanghai Ocean University (Project No. B-8202-08-0290). We thank the general manager Fang Jingmin, vice general manager Huang Fuxiong and the crews of tuna longliners, *et al.* of Guangyuang Fishery group Ltd of Guangdong province for their supporting to this project.

References

Allen R and Punsly R (1998) Catch rates as indices of abundance of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean. Bull. Inter-Amer. Trop. Tuna Comm, 18(4): 301–379.

Anda-Montañeza JAD, Amador-Buenrostrob A and Martínez-Aguilarc S, et al.(2004) Spatial analysis of yellowfin tuna (*Thunnus albacares*) catch rate and its relation to *El Nino* and *La Nina* events in the eastern tropical Pacific. Deep-Sea Res II, 51(5 / 6): 575—586.

Bigelow KA, Hampton J, Miyabe N (2002) Application of a habitat-based model to estimate effective longline fishing effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). Fish. Oceanogr., 11(3):143–155.

Brill R W, Block B A, Boggs C H, et al. (1999) Horizontal movements and depth distribution of large adult yellowfin tuna (*Thunnus albacares*) near the Hawaiian Islands, recorded using ultrasonic telemetry: implications for the physiological ecology of pelagic fishes [J]. Marine Biology, 133: 395-408.

Cade BS and Richards JD (2001) User manual for blossom statistical software. Colorado: Midcontinent Ecological Science Center U. S. Geological Survey, 1~106.

Cayre´ PA (1991) Behavior of yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging. Aquat Liv Res 4:1–12

Dunham JB, Cade BS, Terrell JW (2002) Influence of spatial and temporal variation on fish-habitat relationships defined by regression quantile. Trans. Am. Fish. Soc., 131: 86～98.

Eastwood PD, Geoff JM, Carpentier A, et al (2003) Estimating limits to the spatial extent and suitability of sole (*Solea solea*) nursery grounds in the Dover Strait. Journal of Sea Research, 50: 151～165.

Feng B, Chen XJ, Xu LX（2007）Study on distribution of *Thunnus obesus* in the Indian Ocean on habitat suitability index. Journal of fisheries of China, 31(6): 805—812

Koenler R, Bassett G (1978) Regression quartiles. Econometrica, 50: 43~61.

Korsmeyer KE, Lai NC, Shadwick RE, et al (1997) Heart rate and stroke volume contributions to cardiac output in swimming yellowfin tuna: response to exercise and temperature. Exp. Biol., 200(14): 1975-1986.

Maury O, Gascuel D, Marsac F, et a1 (2001) Hierarchical interpretation of nonlinear relationships linking yellowfin tuna (*Thunnus albacares*) distribution to the environment in the Atlantic

Ocean.Fish. Aquat. Sci.,58(3): 458—469.

Mohri M and Nishida T (2000) Consideration on distribution of adult yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on Japanese tuna longline fisheries and survey information. IOTC Proceedings No. 3:276-282.

Nishida T, Bigelow K, Mohri M，et al (2003) Comparative study on Japanese tuna longline CPUE standardization of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on two methods:-general linear model (GLM) and habitat-based model (HBM)/GLM combined-(1958-2001). IOTC Proceedings no. 6:48-69.

Nishida T, Mohri M, Itoh K, et a1 (2001) Study of bathymetry effects on the nominal hooking rates of yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) exploited by the Japanese tuna longline fisheries in the Indian Ocean, IOTC Proceedings no. 4: 191-206.

Romena, NA (2001) Factors affecting distribution of adult yellowfin tuna (*Thunnus albacares*) and its reproductive ecology in the Indian Ocean based on Japanese tuna longline fisheries and survey information. IOTC Proceedings no. 4: 336 –389.

Song LM, Gao PF, Zhou YQ, Zhang Y (2007) Habitat environment integration index of *Thunnus obesus* in the high seas of the Central Atlantic Ocean based on the quantile regression. Journal of fisheries of China, 31(6): 798-804.

Song LM, Zhang Y, Xu LX, et al (2008) Environmental preferences of longlining for yellowfin tuna (*Thunnus albacares*) in the tropical high seas of the Indian Ocean. Fish. Oceanogr., 17: 239-253.

Song LM (2008) Integrated Habitat Index of Bigeye Tuna（*Thunnus obesus*）in the Indian Ocean——Based on Longlining Data. Shanghai: Shanghai Ocean University.

Song LM, Zhou J, Zhou YQ, et al (2009) Environmental preferences of bigeye tuna, Thunnus obesus, in the Indian Ocean: an application to a longline fishery. Environ. Biol. Fish., 85:153–171.

Song LM, Zhou YQ (2010) Developing an integrated habitat index for bigeye tuna (*Thunnus obesus*) in the Indian Ocean based on longline fisheries data. Fish. Res., 105:63–74..

Song LM, Wu YP (2011) Standardizing CPUE of yellowfin tuna (*Thunnus albacares*) longline fishery in the tropical waters of the northwestern Indian Ocean using a deterministic habitat-based model .J Oceanogr. DOI: 10.1007/s10872-011-0055-y.

Shono H, Okamoto H, Nishida T (2002) Standardized CPUE for yellowfin tuna (*thunnus albacares*) of the Japanese longline fishery in the indian ocean by generalized linear models [R]. IOTC Proceedings no. 5: 240-247.

Surfer (1996) Surfer for Windows (Win32): Surface Mapping System, Version 6.04. Golden Software Inc.,Golden, USA.

Terrell JW, Cade BS, Carpenter J, et al (1996) Modeling stream fish habitat limitation from wedge-shaped patterns of variation in standing stock. Trans. Am. Fish. Soc., 125: 104～117.

Vinagre C, et al (2006) Habitat suitability index models for the juvenile soles, *Solea solea* and *Solea senegalensis*, in the Tagus estuary: Defining variables for species management. Fisheries Research, 2006(82):140～149.

Zhang Y (2008) Modeling Habitat Environment Integration Index for Bigeye Tuna (*Thunnus obesus*) in Marshall Islands Waters. Shanghai: Shanghai Ocean University 1-62.