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VERTICAL DISTRIBUTION OF 17 PELAGIC FISH SPECEIS IN THE LONGLINE FISHERIES IN THE EASTERN PACIFIC OCEAN

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ABSTRACTS

Pelagic deep longline was widely used in targeting tunas of high economic values with other fish species caught incidentally as bycatch. Identifying characteristics of vertical distribution of fish species that interact with longline can provide critical information needed for the development of effective measures to mitigate bycatch species and is essential for ecosystem conservation. Much work has been done to investigate the vertical distribution of pelagic species; however, most of the work was focused on single species. The objective of this study is to estimate depth distribution of species captured in the China's tuna longline fishery and to evaluate the difference in depth distribution among species. We estimated depth distribution for 17 frequently captured species based on a Chinese longline fishing trip targeting bigeye tuna in the eastern Pacific Ocean during February-November 2006. The mean depth and depth distribution of 13 bycatch species were significantly different from that of the targeted bigeye tuna. Mean depth and depth distribution were found to be not different significantly between the females and males for 7 species. An analysis using generalized linear model suggests that species, latitude, longitude and month had significant influences on depth of hook at which a fish was captured. The information derived from such a study can play an important role in avoiding/reducing bycatch in pelagic fisheries.

KEY WORDS: pelagic species, vertical distribution, longline, bycatch, Pacific Ocean

1. INTRODUCTION

Pelagic longlines are the most widespread fishing gears in the open ocean and are primarily used to target tuna and billfish (Worm et al. 2005). The depth at which fish are captured can provide critical information to understand the impacts of longline fisheries on target and bycatch species (Bigelow et al. 2006). Deploying depths for longline hooks can greatly improve catches of desired species, such as bigeye tuna (Suzuki et al. 1977; Boggs 1992) and billfishes (Suzuki 1989; Boggs 1992), and reduce bycatch of other species, such as sharks (Gilman et al. 2007) and sea turtles (Gilman et al. 2006).

Different approaches can be taken to obtain vertical distribution information for pelagic species. Acoustic telemetry, using tags equipped with pressure sensors, represents an appropriate tool to observe vertical movements of individual pelagic fish in their habitat (Bach et al. 2003). This technique has been used to study vertical movement behavior of several tropical tuna and tuna-like species (e.g., bigeye tuna and skipjack; Bach et al. 2003). Archival tag that measure depth and temperature is a promising tool to investigate vertical behavior of pelagic species over a long time (Gunn and Block 2001). Longline equipped with time-depth recorders (TDRs), which provide information on the time and depth at which the fish took the hook (Bach et al. 2003; Boggs 1992), was widely used in recent years (Boggs 1992; Mizuno et al. 1999; Bigelow et al. 2006). The advantage of TDRs compared to acoustic telemetry or archival tagging is that a large number of individuals of different sizes and species in different environmental conditions can be sampled (Bach et al. 2003).

However, applications of a large number of TDRs on real fishing vessel are time-consuming, and in practice are rarely available for commercial longline sets (Bigelow et al. 2002). TDRs based depth monitoring is more suitable on vessels for survey fishing than on commercial vessels. Longline set configuration and hook depth can be predicted using catenary algorithms (Yoshihara 1951; Yoshihara 1954; Suzuki et al. 1977). Although predicted depth may differ from actual observed depth (e.g., by TDRs), as the direction, velocity of ocean currents and wind may have important influence on catenary shape and hook depth (Ward and Myers 2006), catenary method has been frequently used for estimating hook depth in pelagic longline fisheries (Hinton and Nakano 1996; Bigelow et al. 2002; Ward and Myers 2005; Bigelow et al. 2006; Ward and Myers 2006; Bigelow and Maunder 2007), after correcting the predicted depth by using appropriate approaches (e.g., Yano and Abe 1998; Ward and Myers 2005).

Much work has been done to investigate the vertical distribution of fish species of economically and/or ecologically importance based on data collected in longline fisheries. Most of the work is, however, focused on single species, e.g., bigeye tuna (Bigelow et al. 2002; Bach et al. 2003), yellowfin tuna (Song et al. 2004), blue marlin (Luo et al. 2006), bigeye thresher shark (Nakano et al. 2003), and blue shark (Bigelow and Maunder, 2007). Limited studies are focused on multiple species depth distribution. For example, the depth distribution of 37 pelagic species caught in pelagic longlines in the Pacific Ocean have been inferred by generalized linear mixed models

(Ward and Myers 2005). For the purpose of understanding vertical distribution of fish species interacting with longlines, a comparative study on differences in depth distribution among species is needed. This topic had been rarely dealt with in previous studies.

In this study, based on a Chinese longline fishing trip with onboard scientific observer in the eastern Pacific Ocean (EPO), we estimated hook depth for different pelagic species, and compared the differences in vertical distributions between targeted species and bycatch species. For species with sufficient samples, sex-specific depth distributions were compared. Factors influencing depth of hook-captured fish were also evaluated and identified. The information derived from such a study can play an important role in avoiding/reducing bycatch in pelagic fisheries.

2. MATERIALS AND METHODS

2.1. Data collection

All fishes analyzed in this study were collected based on a fishing trip during February - November 2006 in the Chinese longline observer program in the eastern Pacific Ocean. This trip was conducted by a typical frozen longline vessel, targeting bigeye tuna. The longliner was equipped with a 120-130 km long nylon filament-made mainline, 40-50 m long floatlines, and 46 m long branchlines with an interval of 45-48 m. The number of hooks between floats (HBF) was 17 or 18 and "*J* " type of tuna hook was used. Setting began between 2 ~ 9 a.m. and hauling began between 2 ~ 3 p.m. On average, 2500~3000 hooks were deployed for each set.

Set-specific latitude, longitude, and gear configurations, including speed of vessel (8~14 knot) and speed of shooting mainline (6~8 m/s, averaging three observations of early start of shooting, mid of shooting and close to end of shooting), HBF, length of mainline per basket, length of branchline and floatline, were recorded. Fishes captured were randomly sampled during hauling and information on hook number and biological measurements (including sex, length and weight) were recorded. Excluding species which were mostly captured by shark hooks on floats and species with sample size less than 30, a total of 17 species (2343 individuals from 211 sets) were analyzed in this study (Table 1). Most sets were conducted in the eastern Pacific Ocean (Fig. 1).

2.2. Depth estimation

Hook depth was calculated using the catenary method (Yoshihara 1951; Yoshihara 1954), which predicted the depth according to the longline configurations using the following equation:

$$D_j = h_f + h_b + \frac{L}{2}\left\{\left(1+\cot^2\varphi^\circ\right)^{\frac{1}{2}} - \left[\left(1-\frac{2j}{n+1}\right)^2 + \cot^2\varphi^\circ\right]^{\frac{1}{2}}\right\} \qquad (1)$$

where D_j is the depth of *j*th hook (for each basket, the two hooks closest to the floats are both numbered 1, assuming that branchlines were hung symmetrically), h_f and h_b are the length of floatline and length of branchline, respectively, L is the length of mainline in unit basket, n is the number of branchline in unit basket, and φ° was the angle between horizontal line and tangential line of the mainline at connecting points of mainline and floatline. Because it was difficult to make direct measurement, φ° was solved by iteration of the sagging rate using following formula (Yoshihara 1954):

$$k = \cot(\varphi^\circ)\ln[\tan(45^\circ + \frac{\varphi^\circ}{2})] \qquad (2)$$

where k is the sagging ratio, which is defined as the length of horizontal line divided by the length of mainline between unit baskets, and can be estimated as the ratio of the speed of the mainline thrower to speed of vessel (Bigelow et al. 2006). In this study, speed of the line thrower and speed of vessel were changed slightly throughout the observer trip. The range of k was between 0.760 and 0.804, thus, by solving Eq. (2), φ° ranged from 60.0 to 55.5°.

Within-set correction of hook depth

The catenary method from Eq. (1) results in a single depth value for each longline hook. However, actual hook depth may vary both between- and within-sets (Bigelow et al. 2002). In this study, sagging ratio k for each set was observed, thus φ° value for each set were calculated using Eq. 2. Between-set variability of hook depth was, therefore, not considered here.

Within-set variability of hook depth in longline gear was observed based on TDRs data in previous studies (Boggs 1992; Yano and Abe 1998; Bigelow et al. 2006; Rice et al. 2007; Bacha et al. 2009). Yano and Abe (1998) found a linear increase in depth variation as hooks were deployed deeper (Bigelow et al. 2002). Following Bigelow et al. (2002), we corrected hook depth D_j using the following linear relationship developed by Yano and Abe (1998):

$$\sigma(D_j) = 8.73 + 4.4j \qquad (3)$$

where $\sigma(D_j)$ was the standard deviation of hook depth D_j, j was the hook number as described above. For each D_j calculated by Eq. (1), 1000 random samples of hook depth from normal distributions $N \sim (D_j, \sigma^2(D_j))$ was generated and the mean of which was regarded as estimated depth of hook j.

Correction of shoaling influence

Actual hook depth is usually much shallower than that predicted using the catenary equation. This deviation is often referred to as longline shoaling (Bigelow et al. 2006; Bacha et al. 2009). It is a common practice to express longline shoaling in term of a percentage (Bach et al. 2009).

This percentage, also called correction factor, has been empirically used to adjust the hook depth calculated from the catenary method (Suzuki et al. 1977; Hinton and Nakano 1996). Correction factor may differ greatly in different oceanic areas due to different oceanographic conditions. Suzuki et al. (1977) estimated a shoaling of 15% (i.e., actual depth reaching 85% of predicted depth) to correct calculated hook depth in the equatorial Pacific. This factor was adopted by Hinton and Nakano (1996). Bigelow et al. (2006) estimated a shoaling of 21% in the central North Pacific (5-40°N, 127-174°W), base on the method of estimating sag ratio same as the one used in this study. Ward and Myers (2006) used a shoaling of 25% to correct hook depth of bigeye tuna in the tropical northern Pacific Ocean. The most recently published shoaling value was around 19%, which was derived from the tropical southern Pacific Ocean (5-20°S, 134-153°W; Bach et al. 2009). Considering the difficulty in obtaining the exact shoaling estimate, three shoaling value, i.e., 25%, 20% and 15%, were assumed to correct the predicted hook depth after the within-set correction, as described in the above paragraph. Thus, three depth values were obtained as the final depth estimates for each hooked fish.

2.3. Statistical analysis

The statistic, interquartile range (IQR), was used to show the difference in depth distribution among species. This statistics tends to be robust to outliers and extreme values which are common and often result from abnormal errors in the field. Because depth distribution may not be necessarily normal, we chose a non-parametric method, two-sample Wilcoxon test, to examine whether the mean depth of bigeye tuna differed significantly from that of bycatch species. The Kolmogorov-Smirnov goodness-of-fit test was used to examine whether depth distribution of bigeye tuna differed from that of bycatch species (Venables and Ripley 1999). Simple Bonferroni adjustment (target *p*-value/number of pairs to be tested) was used to adjust the significant level for pairwise comparisons, which may decrease the risk of Type I error (i.e., tend to find more significant differences than there actually are; Holm 1979). Differences in depth distribution between females and males were also evaluated. For all the comparisons described above, we only used the depth estimates derived from using shoaling factor of 20%.

We further used generalized linear model to investigate the impacts of the following five explanatory variables to explain the variation of depth where a fish was captured:

$$Depth \sim Species + Normlength + Month + Latitude + Longitude + e \quad (4)$$

where, *Depth* of the fish captured was obtained by methods described in previous sections (only the depth estimated from 20% shoaling used), *Species* was the factor of species, including 15 species, *Normlength* was the dimensionless fish length, derived from the raw length data for each species by using Min-max normalization method, thus *normlength* of different species had the same length range (i.e., 0~1), *Month* (Feb-Nov), *Latitude* and *Longitude* (approximated into 5×5° grid and the midpoint used) represented the month and position that the a fish was captured (fish captured in the same set shared the information of these three variables), *e* was error structure of respond variable *Depth*, which was assumed as Gaussian distribution and thus the link function for this GLM model was identity. The performance of the model in explaining the variation of

Depth was evaluated using pseudo-coefficient of determination (R^2-pseudo) (Swartzman et al. 1992). The *p*-values based on an ANOVA *F*-ratio test were used to determine the significance of each additional factor. GLM was implemented using the S-Plus program (S-Plus 7).

3. RESULTS

Depth range and distribution

In addition for the targeted bigeye tuna, we estimated ranges of depth at which 16 bycatch species were hooked in the longline fishery, including 3 tuna species, 2 billfish species, 4 shark species and 7 other species under the three shoaling assumptions defined above (Table 2). The minimum depth of hook capturing a fish was estimated at 92, 98, and 104 m for the shoaling assumption of 25 %, 20%, and 15%, respectively. The maximum depth of hook that caught fish was 253, 269, and 286m, for the three shoaling factors, respectively (Table 2). Bigeye tuna were captured at the deepest mean depth, and wahoos were captured at the shallowest mean depth. Interquartile range (IQR) plots indicated that depth distributions varied greatly among species (Fig. 2).

Comparison of depth between BET and bycatch species

Differences in mean depth and depth distribution between each of the 16 bycatch species versus bigeye tuna were summarized in Table 3. The two-sample Wilcoxon test indicated that, except for bigeye thresher, velvet dogfish and sickle pomfret, each of the other 13 bycatch species had significantly different mean depth from that of bigeye tuna, at the adjusted significant level of 0.05 (i.e., $p = 0.0031$; Table 3). This was consistent with the results of evaluating differences in the depth distribution between bigeye tuna and bycatch species. The Kolmogorov-Smirnov goodness-of-fit test suggested that, except for bigeye thresher, velvet dogfish and sickle pomfret, each of the other 13 bycatch species had significantly different depth distributions from that of bigeye tuna at the adjusted significance level of 0.05 (i.e., $p = 0.0031$;Table 3).

Difference in depth distribution between sexes and size

The difference of mean depth between females and males was tested for 7 species (Table 4). The Wilcoxon rank-sum test indicated that for bigeye tuna, it is significantly different in mean depth between females and males at the p of 0.05, but not different at the adjusted p of 0.05 (i.e., $p = 0.0071$). For each of the other 6 species, there was no significant difference in mean depth and depth distribution between the females and males (Table 4). Capturing depth and individual length was plotted for 15 species, and no obvious trend in the relationship between capturing depth and length was found for any of these species (Fig. 3).

Factors influencing captured depth

The GLM analysis indicated that only 25.94% of the variation of fish capturing depth could be explained by the proposed model (Table 4). The ANOVA suggested that species, latitude, longitude and month had significantly effects on the fish capturing depth, while individual length did not have significant effects (Table 4). The diagnostics of linearity of quantile-quantile plot for residuals indicated that our assumption of normal distribution of fish capturing depth was appropriate (Fig. 4).

4. DISCUSSION

Longline shoaling is the most significant factor accounting for the deviation between predicted hook depth derived using the catenary method and actual depth. We selected the shoaling factors of 25%, 20% and 15% to correct predicted depth for pelagic species captured by the longline. These three shoaling factors were chosen based on the results derived from previous studies. Similar methods had been adopted by other authors (e.g., Hinton and Nakano 1996; Ward and Myers 2006). Environmental factors, such as current velocity, shear, and wind, may contribute to longline shoaling (Boggs 1992; Bigelow et al. 2006). Using generalized linear models, Bach et al. (2009) found that the shoaling was significantly influenced by (1) the tangential angle φ°, which was the strongest predictor, and (2) the current shear and the direction of setting.

Due to the limitation of field work duration and the number of TDRs, most shoaling factors were not estimated by monitoring all hook positions between two successive floats. For instance, Bigelow et al. (2006) estimated the deep longline shoaling by monitoring TDRs attached to the middle position on the mainline between two floats. Similar technique was applied by Bach et al. (2009). This may be a source of error for the estimation of longline shoaling factors. Moreover, a variety of gear configurations and deployment strategies may also cause errors when applying a shoaling factor derived from one gear configuration to another. Shoaling for shallow longline gear was much higher than that for deep longline. Boggs (1992) estimated the average shoaling factor of the mainline at 46% and 32%, respectively, from the two surveys off Hawaii waters.

Identifying the differences in fish capturing depth may provide additional information for developing the method of mitigating bycatch by setting longline in deep waters targeting bigeye tuna. This study indicated that bigeye tuna had different depth distributions from most bycatch species (Table 3), which was supported by the results that species was a significant factor influencing the depth of hook at which a fish was captured (Table 5).

Yellowfin tuna, albacore, skipjack, swordfish, blue marlin, pelagic stingray, longnose lancetfish, bigscale pomfret, escolar, black gemfish and wahoo were captured at shallower depth than bigeye tuna (Fig. 2 and Table 3). It is likely that setting longline hooks in deeper waters can reduce catch rates of these bycatch species. Beverly et al. (2009) confirmed that eliminating shallow hooks from standard tuna longlines significantly reduced catch rate of swordfish and wahoo. Nakano et al. (1997) also found that catch rates of skipjack, blue marlin and wahoo decreased with the depth of longline hook being deployed. Another species, sickle pomfret, showed no significant differences in depth distribution from bigeye tuna (Table 3), which was consistent with the results of Beverly et al. (2009) who found that eliminating shallow hooks in the upper 100m of the water column from standard tuna longlines significantly increased catch rate of sickle pomfret.

Shark bycatch was also an important issue in tuna longline fisheries across the tropical oceans. This study indicated that the blue shark and crocodile shark showed different depths at which they were captured, compared with bigeye tuna (Table 3), i.e., they were captured in the shallower water than bigeye tuna (Fig. 2). This can be reflected by the finding that setting longline in shallow waters generally has higher shark catch rates than setting longline in deep waters (Gilman et al. 2007). Statistical tests in this study suggested other two species, bigeye thresher and velvet dogfish, were captured at the same depth distribution as bigeye tuna (Table 3). Nakano et al. (1997) found that catch rate of bigeye thresher shark increased with the depth of hook deployed. Therefore, adjusting longline gear in certain depth ranges can reduce catches of some species but increase catches of the other species (Nakano et al. 1997).

Diel vertical migration, diving into deep water at daytime and swimming up to shallow water during night, is an obvious factor influencing depth distribution and possibility of being captured for many species. Of the 17 species in this study, diel vertical migration was observed in the bigeye tuna (Holland et al. 1990b; Dagorn et al. 2000; Musyl et al. 2003), yellowfin tuna (Holland et al. 1990b), skipjack (Yuen 1970), swordfish (Carey and Robison 1981), blue marlin (Holland et al. 1990a), blue shark (Carey et al. 1990) and bigeye thresher shark (Nakano et al. 2003). Diel vertical migration range, however, may differ among different species. Bigeye tuna was mainly distributed between 220 and 240 m during day time and between 70 and 90 m at night (Holland et al. 1990b). Whereas yellowfin tuna moved in short water layers than bigeye, they stayed at an average daytime depth of 71.3m and an average night depth of 47.3m (Holland et al. 1990b). Blue marlin moved closer to the surface at night, which is consistent with the behavior reported for skipjack (Yuen 1970), swordfish (Carey and Robison 1981) and bigeye thresher sharks (Nakano et al., 2003), but differ from the striped marlin (Holland et al., 1990a). However, vertical movement and distribution pattern for majority of pelagic species are still less understood. Collecting depth information covering the whole day time period was essential to provide enough information for understanding diel vertical movement pattern and developing appropriate fishing strategy for maintaining catch rates of targeted species, and reducing bycatch at the same time.

This study suggested that fish size had little impacts on how deep the fish was caught (Table 5), as was illustrated in Fig. 3. Dagorn et al. (2000) used ultrasonic telemetry to find that the vertical movement patterns of small bigeye tuna were different from those of large individuals. Adult bigeye tuna in the tropical Pacific Ocean may inhabit beyond the depth range of longline (Bigelow et al. 2002), and down to 600 m or deeper in the Pacific Ocean (Hanamoto 1987; Ward and Myers 2006). However, Bach et al. (2003) also demonstrated that the vertical distribution of bigeye tuna during daytime is relatively constant and does not depend on the fish size. The depth distribution of adult yellowfin tuna near the Hawaiian Islands was also found to be essentially identical to that of the juvenile (Holland et al. 1990b). This study also did not show obvious trend in fish capturing depth and sizes of bigeye tuna and yellowfin tuna, as well as other species (Fig. 3).

This study demonstrated that month, latitude and longitude had significant impacts on the depth of fish captured in the longline fishery (Table 5). This might result from spatial-temporal variations of oceanographic conditions, which were considered as factors influencing vertical movements of pelagic fishes, e.g., bigeye tuna (Hanamoto 1987), yellowfin tuna (Holland et al. 1990b) and bigeye thresher shark (Nakano et al. 2003). Seasonal differences in the distribution depth for albacore had been observed in the North Pacific (Uosaki 2004). Temperature and dissolved oxygen concentration can explain the vertical distribution of yellowfin tuna (Cayré and Marsac 1993), as we know these two factors may vary with latitude and longitude. Thermocline, which is an important factor influencing the vertical movement of pelagic fish, e.g., blue marlin (Holland et al. 1990a), is much deeper in the west than in the east of the tropical Pacific Ocean (Ward and Myers 2006). Most of the blue marlins in Hawaii spent a long time far from the surface. This may be due to the deeper depth of the thermocline in Hawaii (35-90 m), compared with that off California coast (15-25 m; Holland et al. 1990a).

5. CONCLUSION

If the entire depth range of the species is targeted by longline, the depth distribution at which fishes were captured can provide enough information for understanding real depth distribution. However, commonly used longlines targeting tunas or billfishes are not deployed to cover all the ranges of depth distribution for all bycatch species. Thus, the depth range of all fish species derived from the longline fishery may only cover part of the depth ranges in their natural habitats. More experiments with different depth range coverages are needed to improve the quantification of depth distributions of targeted and bycatch fish species.

Investigating biological or ecological mechanisms for different depths for pelagic species can improve our understanding of their vertical movement patterns. Reducing catch rates of some species may increase catch rates of others. We need to consider trade-off of catch rates among targeted species, protected species, and other ecologically/economically important species in determining the depth ranges of longline fisheries. Therefore, it is critical to identify fish species that play key roles in ecosystem dynamics and to investigate their vertical distribution for developing optimal operational depth ranges for pelagic longline fisheries.

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Table 1 Species captured by in the longline fishery in the eastern Pacific Ocean during February - November 2006. The data were measured and documented by an onboard scientific observer.

Common name	Scientific name	Code
bigeye tuna	*Thunnus obesus*	BET
yellowfin tuna	*Thunnus albacares*	YFT
albacore	*Thunnus alalunga*	ALB
skipjack	*Katsuwonus pelamis*	SKJ
swordfish	*Xiphias gladius*	SWO
blue marlin	*Makaira mazara*	BUM
blue shark	*Prionace glauca*	BSH
bigeye thresher	*Alopias superciliosus*	BTH
velvet dogfish	*Zameus squamulosus*	SSQ
crocodile shark	*Pseudocarcharias kamoharai*	PSK
pelagic stingray	*Dasyatis violacea*	PLS
longnose lancetfish	*Alepisaurus ferox*	ALX
bigscale pomfret	*Taractichthys longipinnus*	TAL
sickle pomfret	*Taractichthys steindachneri*	TST
escolar	*Lepidocybium flavobrunneum*	LEC
black gemfish	*Nesiarchus nasutus*	NEN
wahoo	*Acanthocybium solandri*	WAH

Table 2 Estimated depth ranges (m) under different shoaling assumptions for 17 fish species captured by in the longline fishery in the eastern Pacific Ocean during February - November 2006.

		BET	YFT	ALB	SKJ	SWO	BUM	BSH	BTH	SSQ
shoaling-25%	Max	253	249	246	230	236	232	234	234	230
	Min	92	92	92	92	93	92	92	95	95
	Mean	193	160	152	132	157	142	150	177	172
shoaling-20%	Max	269	265	262	245	252	247	250	250	245
	Min	98	98	99	98	99	98	98	101	101
	Mean	205	171	162	141	167	152	160	189	184
shoaling-15%	Max	286	282	279	260	267	263	265	266	261
	Min	104	104	105	104	105	104	104	108	108
	Mean	218	182	173	150	178	161	170	200	195
	n	941	291	196	32	70	35	118	55	33

		PSK	PLS	ALX	TAL	TST	LEC	NEN	WAH
shoaling-25%	Max	233	236	239	245	241	242	236	214
	Min	96	93	99	98	96	92	92	92
	Mean	161	139	179	182	180	167	157	117
shoaling-20%	Max	238	251	255	262	257	258	252	228
	Min	102	99	105	105	103	98	99	98
	Mean	172	148	191	194	192	178	167	125
shoaling-15%	Max	253	267	271	278	273	274	268	241
	Min	109	105	112	111	109	104	105	104
	Mean	183	158	203	206	204	190	178	133
	n	49	70	70	94	37	115	64	73

Table 3 The observed *p*-values for testing the difference in mean depth between bycatch species and bigeye tuna (Wilcoxon rank-sum test), and for testing the difference in depth distribution between bigeye tuna and bycatch species (Kolmogorov-Smirnov goodness-of-fit test)

	Wilcoxon rank-sum test	Kolmogorov-Smirnov goodness-of-fit test
	BET	BET
	p-value	*p*-value
YFT	<0.0001	<0.0001
ALB	<0.0001	<0.0001
SKJ	<0.0001	<0.0001
SWO	<0.0001	<0.0001
BUM	<0.0001	<0.0001
BSH	<0.0001	<0.0001
BTH	0.0152	0.0204
SSQ	0.0040	0.0230
PSK	<0.0001	<0.0001
PLS	<0.0001	<0.0001
ALX	0.0023	0.0004
TAL	0.0014	0.0014
TST	0.0440	0.0105
LEC	<0.0001	<0.0001
NEN	<0.0001	<0.0001
WAH	<0.0001	<0.0001

Note: significant level of 0.05 was adjusted as: 0.05/16 = 0.0031 (Simple Bonferroni adjustment for multiple comparisons).

Table 4 The observed *p*-values for testing the difference in mean depth between females and males (Wilcoxon rank-sum test) and for testing the difference in depth distribution between females and males (Kolmogorov-Smirnov goodness-of-fit test) of 7 species.

	Wilcoxon rank-sum test	Kolmogorov-Smirnov goodness-of-fit test
	p-value	*p*-value
BET	0.0482	0.0366
YFT	0.3251	0.5450
SWO	0.9725	0.9942
BSH	0.8348	0.6827
BTH	0.6433	0.3576
PSK	0.2689	0.2170
PLS	0.4428	0.8756

Note: The significance level of 0.05 was adjusted as: 0.05/7 = 0.0071 (Simple Bonferroni adjustment for multiple comparisons).

Table 5 The ANOVA results for a generalized linear model relating depth of fish captured by the longline to five explanatory variables.

factors added sequentially	Df	Deviance	Resid. Df	Resid. Dev	*F*-ratio	*p*-value
NULL			2242	4788650		
Normlength	1	2260	2241	4786390	1.4162	0.2342
Latitude	1	10721	2240	4775668	6.7178	0.0096
Longitude	1	17412	2239	4758256	10.9099	0.0010
Month	1	74319	2238	4683937	46.5667	0.0000
Species	16	1137682	2222	3546255	44.5528	0.0000

R^2-pseudo = 0.2594

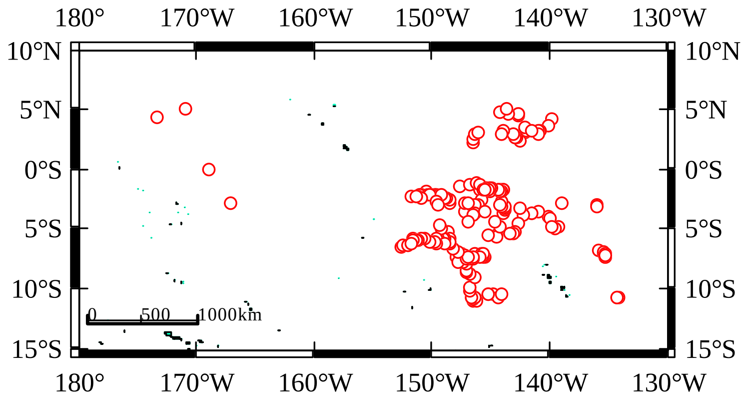

Figure 1 Set position for the fishing observer trip in the Chinese longline fishery in the eastern Pacific Ocean during February -November 2006

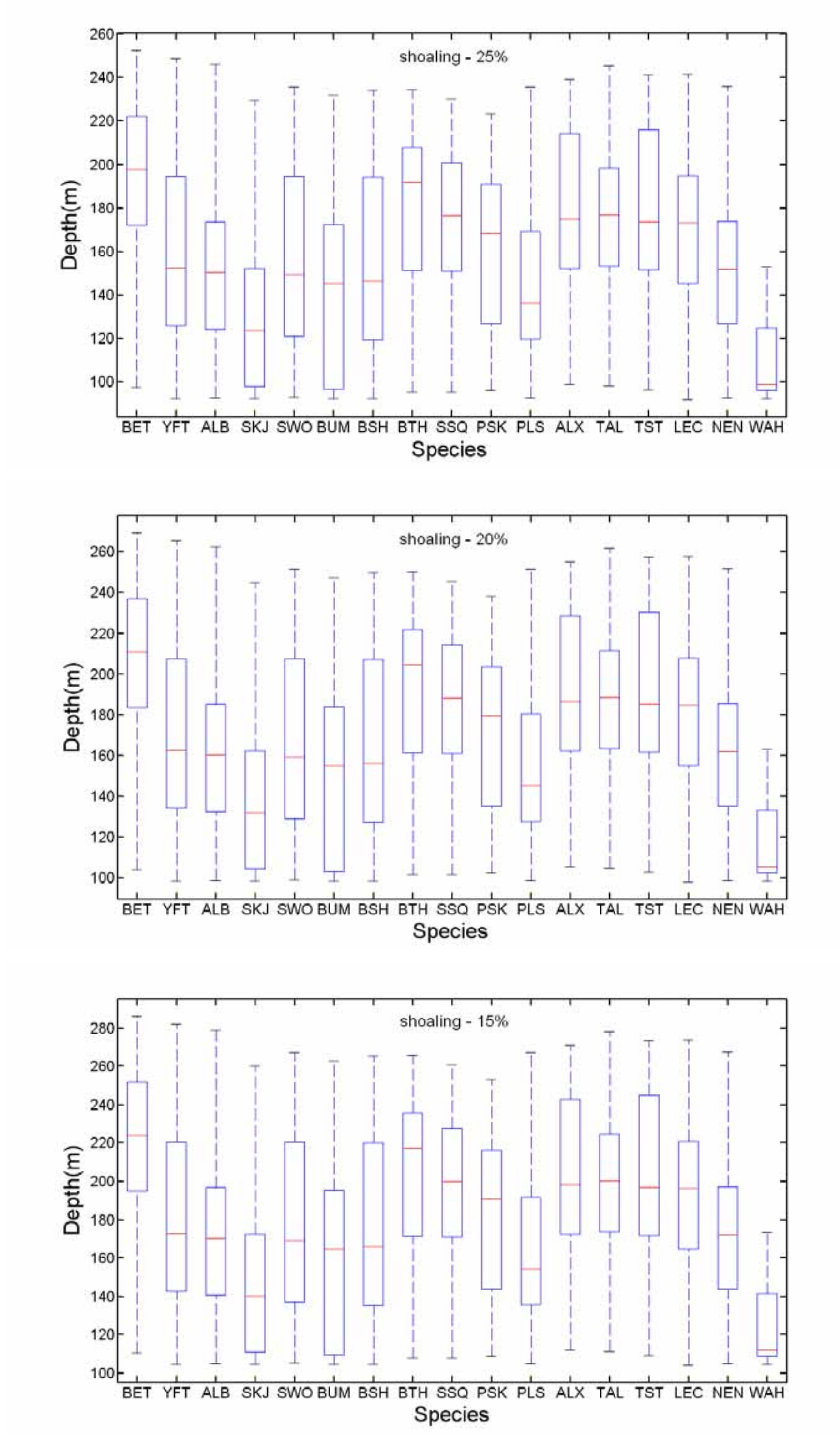

Figure 2 The box-plot of the estimated depth ranges under different shoaling assumptions for 17 species captured in the longline fishery in the eastern Pacific Ocean, Feb-Nov 2006 (the center line is the median depth, the edges of the box are the 25th and 75th percentiles, respectively, and the whiskers extend to the most extreme data points)

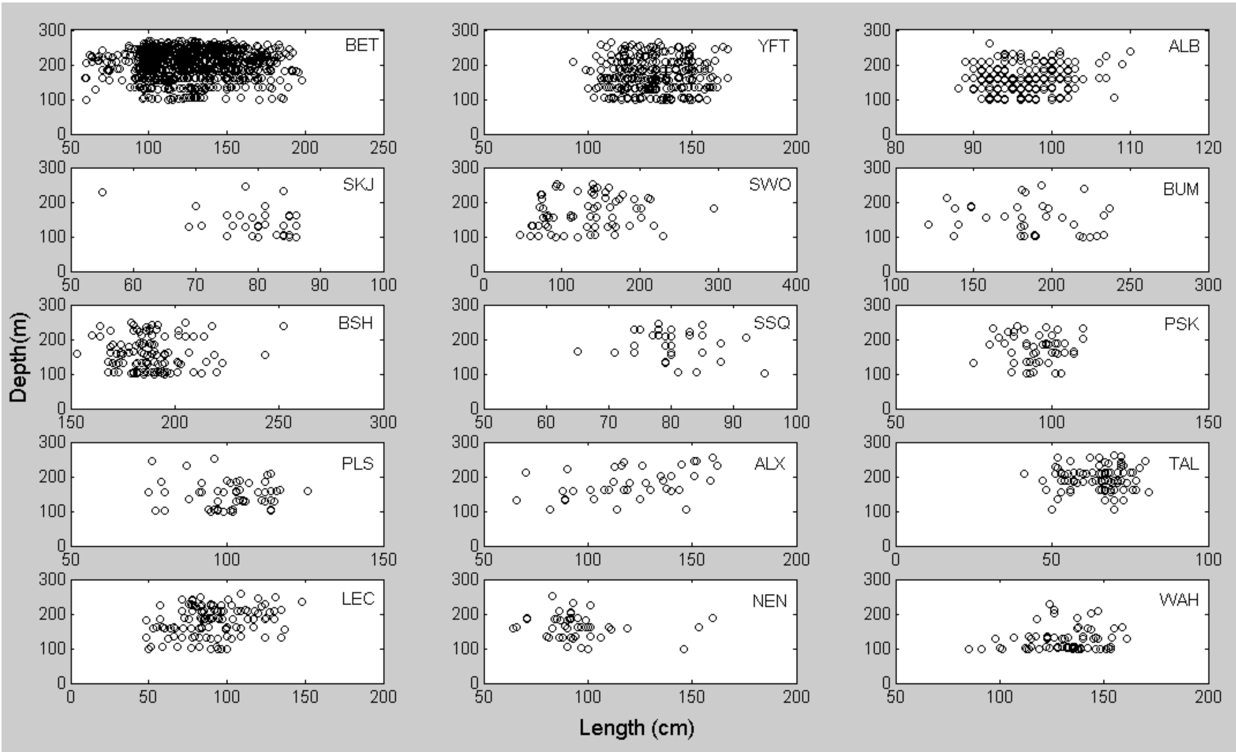

Figure 3 Relationships between the depth at which fish was hooked (estimated from 20% shoaling correction) and length for 15 pelagic species captured in the longline fishery in the eastern Pacific Ocean, Feb-Nov 2006.

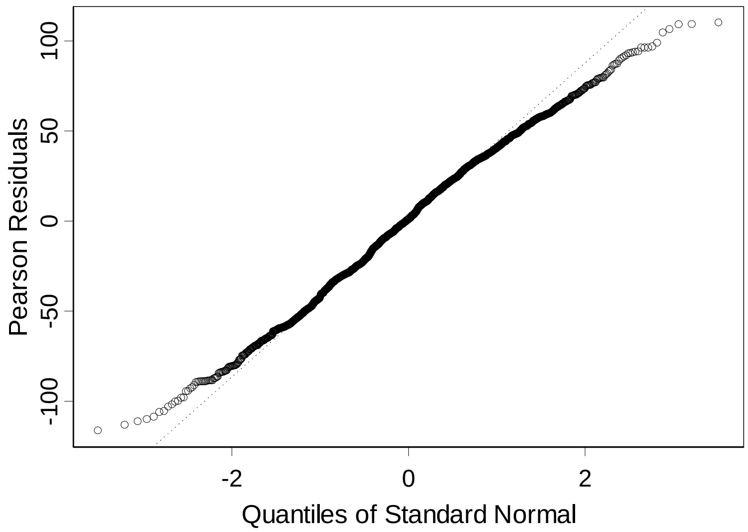

Figure 4 The quantile-quantile plot of residuals for the depths at which fishes were hooked from fitting a generalized linear model relating the fish hooking depth to the five explanatory variables