Pelagic longline fishery for albacore tuna (*Thunnus alalunga)* yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) in the high seas of eastern Pacific ocean.

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This study highlighted the occurrence of a pelagic long line fishery targeting albacore tuna, yellowfin tuna and bigeye tuna in the high seas of eastern Pacific Ocean. Species selectivity of the fishing method was assessed. Hook depth, statistics of at-vessel survival rate grouped by hooks number, length frequency, weight frequency, length weight relationship, relative condition factor and Fulton’s condition factor were estimated for the target species. This fishing method proved highly selective for albacore tuna, where catches accounted for about 85% of catches, while other resources such as yellowfin tuna amounted to 4.8% and big eye tuna accounted for 9.70%. The results showed that, fish size increased with deeper depths. Hook No. 8 located at a critical depth indicated that fork lengths of tuna registered above this depth were significantly smaller than that those captured below it. Logistic regression model suggested a significant effect of hook depth on the catch efficiency. The highest density of catch efficiency was located at the depth of 167.57 m. An alternative strategy showed that hooks deployed at the depths ranging from 124 to 211 m will result in a more considerable fishing efficiency. The analyses also showed that the relative condition factors (Krel) of the three fish species were greater than (1) implying that they were in good physiological condition at the time of capture.

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Pelagic Longline Fishery for Albacore Tuna (*Thunnus Alalunga)* Yellowfin Tuna (*Thunnus Albacares*) and Bigeye Tuna (*Thunnus Obesus*) in The High Seas of Eastern Pacific Ocean.

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ABSTRACT

This study highlighted the occurrence of a pelagic long line fishery targeting albacore tuna, yellowfin tuna and bigeye tuna in the high seas of eastern Pacific Ocean. Species selectivity of the fishing method was assessed. Hook depth, statistics of at-vessel survival rate grouped by hooks number, length frequency, weight frequency, length weight relationship, relative condition factor and Fulton’s condition factor were estimated for the target species. This fishing method proved highly selective for albacore tuna, where catches accounted for about 85% of catches, while other resources such as yellowfin tuna amounted to 4.8% and big eye tuna accounted for 9.70%. The results showed that, fish size increased with deeper depths. Hook No. 8 located at a critical depth indicated that fork lengths of tuna registered above this depth were significantly smaller than that those captured below it. Logistic regression model suggested a significant effect of hook depth on the catch efficiency. The highest density of catch efficiency was located at the depth of 167.57 m. An alternative strategy showed that hooks deployed at the depths ranging from 124 to 211 m will result in a more considerable fishing efficiency. The analyses also showed that the relative condition factors (Krel) of the three fish species were greater than (1) implying that they were in good physiological condition at the time of capture.

Keywords: catch efficiency; hooks; hook depth; length weight relationship; relative condition factors.

INTRODUCTION

Tuna is a saltwater fish that belongs to the Scombridae family. This family of swimmers (with records of 80 km/h) has more than a dozen species (Yagishita Yuta 2018). The most important in the eastern Pacific Ocean are: Albacore Tuna, thunnus alalunga (Bonnaterre 1788); Yellowfin Tuna, thunnus albacares (Bonnaterre 1788) and Bigeye tuna, Thunnus obesus (Lowe 1839, L Xu et al. 2008).

The main fisheries of Albacore Tuna (*Thunnus alalunga*) are in temperate and tropical waters. It is exploited by Asian long liners and its catch volume is estimated at 68,000 tonnes and is very slightly overexploited but the biomass of the stock is not affected (Froese et al. 2012, 2016). The Yellowfin Tuna have sizes between 40 cm and 170 cm (1.2 kg and 100 kg) (Collete B 2011). Spawning biomass has increased in recent years and the level of fishing mortality in the eastern Pacific is slightly below the exploitation level at Maximum Sustainable Yield (MSY) (Froese et al. 2016). Big eye tuna can grow up to 250 centimetre (98 inches) or 8 feet, in length. Maximum weight of individuals probably exceeds 180 kg, with the all-tackle angling record standing at 178 kg (Arrizabalaga, H. 2008). Its stock exploited in 2015 was 78,000 tons. It is at full exploitation level with spawning stock biomasses and fishing mortality close to the values associated with MSY) (Froese et al. 2016).

The weight–length relationship (WLR) and Fulton's condition factor (K) are two main parameters used in fishery research and have been closely related since they were first proposed (Froese 2006). These parameters are essential, since various important biological aspects, namely; general well-being of fish, appearance of first maturity, onset of spawning, which can be assessed using the condition factors deriving from the said relationship (Le Cren ED 1951, Dakua S et al. 2015). Also, for conversion of growth-in length equations to growth-in-weight, for use in stock assessment models, estimating biomass from length data, calculating total weight of fish caught from length-frequency data, determining the relative condition factor of small fish compared to large fish and for comparing between regional life histories of certain fish species (Wootton 1992, Pauly 1993, Petrakis and Stergiou, 1995; Goncalves et al. 1996; Binohlan and Pauly 1998; Moutopoulos and Stergiou 2002, Gh Moradinasab et al. 2012). Although the WLR and K may reflect the growing conditions of some fish, a study combining the analysis of both indices has been reported. As a result, consistent trends reflecting the characteristics of Albacore Tuna (*Thunnus alalunga*); Yellowfin Tuna (*Thunnus albacares*) and Bigeye tuna (*Thunnus obesus*) populations in the high seas of eastern Pacific Ocean are being worked on.

The depth at which key target species are captured is fundamental to understanding the impacts of tuna long line fisheries on target species and by catch (Bigelow et al. 2006). The actual fishing depth that a hook can reach is determined by many factors, such as fishing gear, fishing operations parameters. The optimal fishing depths for commercially important pelagic species caught on longlines could be determined in situ by instruments, such as sonar (Bullis 1955), expendable bathy-thermographs (Matsumoto et al. 2001), micro-BTs (Okazaki et al. 1997, Mizuno et al. 1999), depth recorders (Saito 1973, Hanamoto 1974, Nishi 1990), ultrasonic positioning system (Miyamoto et al. 2006) and temperature-depth recorders (Beverly 2005, Bigelow et al. 2006). The hook depths with gear configuration can also be calculated by catenary geometry (Yoshihara 1951, 1954). The theory predicting that a line suspended with a vertical load equal over its entire length will take the form of a catenary absence of corruption factors (Bigelow et al.

2006).To investigate the relationship between the structure of tuna longline gear and fishing methods on gear performance and fishing characteristics, fishing rate, fork length distribution and mortality rate at different depths, as well as the fishing mortality rate, were studied using the survey of tuna longliners from 18 January 2014 to 26 December 2015 in the eastern Pacific Ocean. A statistical analysis was made of the relationship between hook immersion time and fishing rate in order to determine the characteristics of the longline fishery and to provide an important scientific basis for improving the efficiency of fishing and fishing selectivity of fishing gear. The present study also provides a pre-comprehensive analysis of biological parameters (fork length frequency, WLR and K) in catches of tuna sampled by longline.

1. MATERIALS AND METHODS

1.1. Survey Information

This study was carried out using the longliner "xin shi ji 71" with a total length of 56.5m, a width of 8.5m, a depth of 3.65 m , a tonnage of 634 tons and the main engine power is 735kW. During a period from 18 January 2014 to 26 December 2015 in the East Pacific high seas east of Tahiti Island, French Polynesia(14°S; 115°W and 23°S ;124°W)(fig 1). The depth range of the hooks was from 100 m to 330 m. This study involved a total of 622 individuals including 528 specimens of Albacore Tuna, 63 of Bigeye tuna and 31 of Yellowfin Tuna. For each fish, we measured the total fork length (Lt) to the nearest centimetre, determined the total weight (Wt) and the number of each hook.

Figure 1. Distribution of deployment locations in survey of tuna longline

1.2. Fishing gear structure and fishing operations

The main rope of longline is woven with 8 strands of nylon monofilament and has a diameter of 5.4 mm. The structure of the secondary line is an automatic shackle (with a loop) connected to a red polyester cable 4 mm in diameter (PES) of 2 m in diameter by means of a box-type swivel. Connect a 1.3mm diameter nylon monofilament, an S-shaped swivel and a hook with a total length of 26m; the floatation cable consists of 80 braided polyester strands (PES), 5.5 mm in diameter and 25 m in length; the float material is injection molded ABS, with a diameter of 360 mm and a static buoyancy of 24.5 kg. The average speed of the rope during the rope launching process is 9.6 Kn, the average rope speed is 6 m / s and each branch is equipped with 26 branching lines. The length of the main rope between the two lines is 33 m and 3770 hooks are placed each time. The start and end time of the rope is generally from 5:00 to 11:00 for 6 hours; the start and end time of the hook is usually 14:00 to 17:00 the next day, 15 hours. The method of attachment is from the beginning of the rope throw (at the start) and from the end of the rope throw (at the start), and the average speed of the hook is 4.5 Kn.

1.3. **Estimation of longline fishing**

The longline fishing between two floating balls is catenary under the influence of the current. The hooks on the symmetrical side of the catenary between two floating balls are numbered from shallow to deep. Assuming that the catenary between two floating bales has the same shape and that the distance between the floating bales is constant during operation, the longline fishing principle proposed by Yoshihara [15] is used to calculate the depth of each hook. And the horizontal distance between the hook and the nearest floating ball.

$$D_j = h_a + h_b + \frac{L}{2} * \left[\sqrt{1 + cot\,\theta^2} - \sqrt{\left(1 - \frac{2*j}{N}\right)^2 + cot\theta^2}\right] (1)$$

$$H_j = \frac{L}{2*tan\theta} * sinh^{-1} * \left(\tan\theta * \frac{2*j-N-1}{N+1}\right) + \frac{H}{2} \qquad (2)$$

where $D_j$is the depth of catenary hook (j), $h_a$the length of branch line, $h_b$the length of float line, L half of stretched length of the main line deployed between two consecutive floats, j the number of the catenary hook between floats (j =1,2,….26) and $N$is HBF (hooks between floats) + 1, $H_j$is the horizontal distance between successive floats.

The angle θ between the horizontal and tangential line of the main line where the float line was attached (degrees from horizontal) was taken from the relationship:

$$K=\frac{H}{2*L}=cot\theta^2*sinh^{-1}(tan\theta) \qquad (3)$$

Where k is the sag ratio, H is the horizontal distance between successive floats. Because the catenary angle could not be estimated for all TDR monitored sets, 30–85° is considered as appropriate angles, which corresponded to sag ratios ranging from 1.04 to 3.57 (Bigelow et al., 2006). Catenary depths were not estimated for sets with sag ratios outside of this range.

1.4. **relationship between hook depth and fishing efficiency**

The fishing process of longliners can be regarded as sampling the catch of hooks with different water depths between two floaters and repeating M test, the results of the catch are captured (expressed as "1") and uncaptured (expressed as "0"), which belong to the binomial distribution of 0-1 response, so the relationship between hook depth and fishing efficiency is very important. It uses the connection function to express the Logistic regression model of the logit logic function in the two distribution families. The response variable is the fishing efficiency at a certain depth, which is expressed as the cumulative fishing efficiency at the depth of 100 m. For example, the fishing efficiency at the depth of 100 m is the proportion of the total catch of all the hooks in the depth of 100 m. The probability of successful fishing can be predicted by this model:

$$Logit(P)=\ln\left(\frac{P}{1-P}\right)=\beta_0+\beta_1 * D \qquad (4)$$

Where, P represents the catch efficiency, i.e. the ratio of the number of catches (tails) caught in a certain depth to the total number of catches; D is the hook depth (m);β0 is the intercept; β1 is the regression coefficient of the model, and the significance level is set at 0.05.

1.5. **Fork length and Weight frequency**

Fork length frequency was calculated with a 5 cm fork length interval between 80 cm and 115 cm for albacore tuna, 85 cm and 150 cm for yellowfin tuna and 75 cm and 180 cm for bigeye tuna.

Weight frequency was calculated with a 3 kg weight interval between 12 kg and 33 kg for albacore tuna, 11kg and 75 kg for yellowfin tuna and between 12 kg and 108 kg for bigeye tuna.

The frequency formula is as follows:

$$F_i=\frac{n_i}{N}*100\% \qquad (5)$$

Where F_i the frequency is for a certain interval, n_i is the number of specimens in one fork length interval or weight interval, and N is the total number of specimens in one cruise.

1.6. **Weight–length relationship**

The length-weight relationships were estimated using the following equation (Froese, 2006): W

$$= a\,Lt^b \qquad (6)$$

Where W is whole-body weight (kg), Lt is the total fork length (cm), is *a* constant and *b* is allometric coefficient. This allometric rate varies from 2 to 4, but most often is close to 3 (N'da et al., 2006; Layachi et al., 2007). The value of the allometric coefficient determines the type of growth: *b* = 3, the growth is isometric, so the specific density of the fish does not change, *b* <3, the growth is allometric minor, that is to say that the fish lengthens faster than it grows and *b*> 3, the allometry is greater, that is to say that the fish grows faster than it lengthens. (Anderson and Neumann 1996, Sparre and Venema 1998).

Since the Length-Weight functional relationship (6) is nonlinear the coefficients *a* and *b* cannot be obtained directly, and therefore, it needs to be further transformed into a linear equation by taking logarithms of both sides:

$$\text{Log W=Log a +b Log L}t(7)$$

1.7. Fulton's condition factor and relative condition factor

For each individual, relative condition factor (*Krel*) and Fulton's condition factor (*K*) were calculated by following equations (Le cren 1951, Froese 2006):

$$K_{rel}=\frac{W}{aLt^{b}}(8) \qquad \text{K}=\frac{W}{Lt^{3}}*100(9)$$

Where *W* is the whole body wet weight (g), *Lt* is the total length (cm), and *a and b* are the parameters of length-weight relationship.

2. RESULTS

2.1. catch characteristics of different hooks

The horizontal distance between two adjacent floats in longline fishing is 712 m, and the theoretical calculation depth of the hook ranges from 78 m to 287 M. Two hooks in each basket are theoretically at the same depth, as shown in Figure 2. The estimated depth of hooks for longline fishing can be obtained by modifying the floating rate (Table 1).

Figure 2. Vertical distribution of two float longline hooks

Table 1: Estimated depth of each hook of longline

During the survey, a total of 622 Albacore Tuna, Bigeye tuna and Yellowfin Tuna were randomly sampled. Amongst different hook position, hook 7 (the median number of hooks) captured the most, up to 100, hook 1 had no registered catch, hook 2 and hook 13 only caught 7 and 5, respectively. The species of albacore tuna (representing 85% of individuals) captured measured 83 ~ 120 cm, of the dominant fork length fell in the range 95 ~ 105 cm representing 77.4% of the total. The results showed that there was no significant difference in fork length between hook No. 2 and hook No. 13 and other hooks ($P > 0.1$). There was no significant difference between hook No. 3, 4, 5, 6 and 7, and there was no significant difference between hook No. 8, 9, 10, 11 and 12. There was a significant difference in species length between the two hooks ($P < 0.1$). The number of species and the distribution of fork length caught by different hooks are shown in Figure 3. Local weighted regression (red solid line) and linear regression (green solid line) were used to fit the relationship between fork length and hook number respectively. The results showed that the fork length of long fin tuna caught by hook 2-7 was almost the same. With the increase of hook depth, the individual size of species increased slightly, and the water layer (192m) of hook 8 was one.

Table 2: *P* value of multiple comparisons (t-test) for the fork length caught by different hooks

Figure 3. Fork length distribution (blue) and number of individuals (red) caught by different hooks.

2.2. Logistic model of hook depth and catch efficiency

Logistic regression model showed that the effect of hook depth on fishing efficiency was extremely significant ($P<0.05$, Table 3). The catching efficiency distribution model of the hook depth distribution (the catching efficiency distribution of the hook distribution depth) is as follows:

$$P=\frac{e^{-8.450699+0.050431*D}}{1+e^{-8.450699+0.050431*D}}(12)$$

Table 3: Estimates of modelled parameters by Logistic regression

The model indicates that the fishing probability density of the 167.57 m water depth is the greatest. The depth of longline fishing hooks is more limited and has a number of discrete variables, and it is more efficient to organize it in the upper and lower water bodies of the water layer. If the maximum water catchment depth (167.57 m) is used as a reference, the confidence interval of the hook depth to obtain 80% of the catch is 124 ~ 211 m (figure 4, A and B respectively represent the distribution function map of fishing efficiency and the probability density function map), that is, the hook is arranged in this water depth interval, will have a higher probability of successful fishing.

Figure 4. Logistic regression between catch efficiency and hook depth.

2.3. Fork length and Weight frequency

Fork length frequency

The lengths of 95 to 100 cm are dominant in albacore tuna because they represent 55.067% of the total specimens caught, the least dominant or the least capturing ones have lengths lower than 90 cm with a representation of 1.721% of the total of the specimens and also lengths greater than 110 cm with a representation of 1,912% of the total specimens. The size of albacore tuna ranged from 80 to 130 cm (Figure 5). For the yellowfin tuna, the lengths ranging from 105 to 130 cm were dominant because they represent 59.26% of the total of the specimens. The size of the yellowfin tuna ranged from 85 to 150 cm (Figure 6). Finally, for Bigeye tuna, the lengths from 125 to 165 cm were dominant because they represented 60% of the total specimens. The size range of bigeye tuna varied from 75 to 175 cm (Figure 7).

Figure 5. Albacore tuna length frequency

Figure 6. Yellowfin tuna length frequency

Figure 7. Bigeye tuna length frequency

Weight Frequency

For the albacore tuna, the dominant weight interval was from 15 to 21 kg because they represented 76.0994% of the total specimens. The weight of the albacore tuna ranged from 12 to 33 kg (Figure 8). While the dominant weight interval for yellowfin tuna, 21 to 26 kg and from 36 to 41 kg and they represented 44% of the total specimens. The weight of the yellowfin tuna ranged from 11 to51 kg (Figure 9). Finally, for Bigeye tuna, the weight from 33 to 51 kg were dominant because represented 40% of the total specimens. The weight range of bigeye tuna varied from 9 to 93kg (Figure 10).

Figure 8. Albacore tuna weight frequency

Figure 9. Yellowfin tuna Weight frequency

Figure 10. Bigeye tuna Weight frequency

2.4. Length- Weight relationship

For these three- tuna species, the calculated parameters are summarized in Table 4. The allometric coefficients of the three species are less than three which means that these species grow fast as they grow. There are strong correlations between weights and different sizes because all values are high. Figures 11, 12, 13 show the linear regression curves for each species.

Table 4: Length-weigh relationship of albacore tuna, yellowfin tuna and bigeye tuna

Figure 11: Relationship between fork length and weight of albacore tuna (*Thunnus alalunga).*

Figure 12. Relationship between fork length and weight of yellowfin tuna (*Thunnus albacares).*

Figure 13. Relationship between fork length and weight of bigeye tuna (*Thunnus obesus*).

2.5. Fulton's condition factor and relative condition factor

The condition factors (k) for the three species are on average 1.92 ± 0.15, 1.41 ± 0.18 1.74 ± 0.42 respectively for *Thunnus alalunga, Thunnus albacares, Thunnus obesus*, and relative condition factors (krel) on average 1.01 ± 0.08, 1.34 ± 0.31, 1.02 ± 0.2 respectively for these species. The mean values of K are greater than 1 which means that our specimens were in good condition. Table 5 summarizes the calculated values of K and Krel for each species and Figures 14 to 16 illustrates the distribution of K values of the three species according to different classes of fork length. The k values are high in *Thunnus alalunga* when lengths are between 100 cm and 110 cm. The k values are high in *Thunnus alalunga* when the lengths are between 100 cm and 110 cm with a value of 1.95, in *Thunnus albacares* between 85 cm and 90 cm with a value of 1.81 and in *Thunnus obesus* between 85 cm and 95 cm with a value of 2.43.

According to the distributions of K the *Thunnus obesus* have higher values. By contrast, on average *Thunnus alalunga* has higher k values than the other species and *Thunnus albacares* has a higher average Krel value.

Table 5: Mean ± standard deviation of Condition factor (K) and Relative condition factor (Krel)

Figure 14. Condition factor (K) per fork length (cm) class of albacore tuna (*Thunnus alalunga*).

Figure 15. Condition factor (K) per fork length (cm) class of yellowfin tuna (*Thunnus albacares*).

Figure 16. Condition factor (K) per fork length (cm) class of bigeye tuna (*Thunnus obesus*)**.**

DISCUSSION

3.1. Vertical distribution characteristics of individual size of tuna

The vertical distribution characteristics of tuna are related to individual size, and the smaller individual fish are distributed in shallower water layers. This phenomenon has been reported in archival marker tracking tests such as albacore tuna (Cosgrove R et al. 2014, 2015**,** Williams A J et al. 2015), bigeye tuna (Fuller D W et al. 2015, Musyl M K et al. 2003) and yellowfin tuna (Dagorn Let al. 2000; Schaefer K M et al. 2014). According to one view, juvenile tunas cannot fully utilize their own heat preservation mechanism as adults and therefore cannot dive deeper into water (Dickson K et al. 2000); another point of view is that juvenile tunas have changed in the process of growing dietary habits, adults tend to eat in deeper waters (Goñi N et al. 2008). Longline fishing usually catches adult albacore tuna (representing 85% of our individuals) individuals with a fork length of 90-105cm (Harley Set al. 2014), and the fork length of this study ranges from 83-110 cm. The size of the body of the fish increases with the depth of the hook, but the relationship is not very close because of the narrowness of its length (Figure 3, comparison of the length distribution at the fork of the hook 8-13 and hook 1 -7). This may be due to the fact that the hooks in this study are distributed between 60 and 230 m. Fish with smaller body lengths tend to inhabit the surface and are less likely to be caught. For example, satellite archive data labelled by Cosgrove et al. 2014 showed that the average depth of albacore tuna with a fork length of 78 cm was 19 m and that it moved vertically in shallow waters at 50 m, while the tagged release test of Childers et al.2011 suggested that albacore tuna larvae were distributed in the shallow mixed layer at 50 m most of the time. However, the positive correlation between fish size and habitat depth distribution should be further investigated from the day-night catch capture period and the fishing area, since tuna populations typically a type of "W migration" or "V" large scale vertical migration. Alternating day and night, that is, they mainly live in warm surface waters with a layer of shallow mixture at night. Dive into the colder waters deeper at dawn. This type of behaviour was also significantly different in different waters, such that temperate white tuna showed no behavioural diving during the day (Williams A J et al. 2015). Therefore, future studies should take into account the effects of different fishing areas and catch time on the vertical distribution of individual albacore size.

3.2. **Hook depth distribution with optimal fishing efficiency**

The probability of fishing each hook of a longline can simply be expressed as a relationship, i.e. the product of the fishing probability density per unit of time and the depth range of the hook affecting the length of the hook. Fish population and integration is carried out during soaking time. Assuming that each hook affects the fish population (the fish may be attracted to some vertical extent around the depth of the hook) and the soaking time is the same, the probability of fishing for the hook depends on this probability density function. Due to tuna habitat preferences, its distribution is very dense in some depth. According to the logistic statistical model, this study considered the fishing probability density of the 167.57 m water layer to be the greatest. Although the vertical distribution of white tuna is large, if the hook is placed in the water layer with a high probability of fishing object density, the best fishing performance will be obtained. In this study, a fishing efficiency of 80% was chosen as the candidate fishing strategy. Based on the highest catch depth (167.57 m), operating water depth was extended up and down to a fishing rate of 124-

211 m. The most common method for precise hook depth placement is to adjust the shortening ratio, the length of the float cable, the length of the branch line, and the time or distance interval of the cable. For example, if the brackets of this study are more concentrated in the 124-211 m water layer, it is necessary to increase the length of the float cable or bypass line and increase the rate of shortening by reducing the speed of the cable. Although adjusting the depth of the hook is extremely practical, adjusting the hook strategy requires more comprehensive considerations, such as the total length of the line, the hook distribution density, the adequacy of the consistency of the work cycle, etc., any factor. Adjustment can upset the balance of the strategy as a whole. For example, if you reduce the speed of the cable, the density of the hooks will increase in the space, which will cause a strong interference or an interesting overlap between the hooks (when the cable is in a fixed time mode); or a reduction in the total number of hooks, effort and work are not obtained. Effective use (when the string is in fixed distance mode).

3.3. **length-weight relationship**

Parameters *a* and *b* of relationship between lengths and weights indicate allometric growth of fishes (Froese 2006). These parameters are influenced by many ecological and individual factors (Perc¸in and Akyol 2009). Generally only the values of b are taken into account when interpreting the results from the length-weight relationship (Froese 2006). In this study the parameters of the length-weight relationship showed an allometric regression of 2.7135 for albacore tuna, 2.3275 for yellowfin tuna and 2.4047 for bigeye tuna. The growth was negatively allometric for all species. Mohamed H and Alaa Eldin (2012) , Zhenhua M, and Gang Yu (2016) have similar results according to the studies of L Xu et al (2008). The growth of yellowfin tuna and bigeye tuna was positively allometric.

As the target species, albacore tuna accounted for most of the longline catch, 85% compared to other species such as yellowfin tuna and bigeye tuna, which accounted for only 15% of our specimens. This result indicates that the pelagic longline used in the eastern Pacific to catch albacore is highly selective for this species. (Coll et al. 2010, Macías et al. 2012).

Length data for 528 albacore tuna specimens showed that fork lengths ranged from 83 to 128 cm, for yellowfin tuna the 31 specimens showed that fork lengths ranged from 82 to 153 cm and bigeye tuna the 63 specimens showed that fork lengths ranged from 76.6 cm to 180 cm. However, fish in the length class between 95 cm and 100 cm accounted for most of catches (55%) of albacore tuna, between 105 cm and 130 cm accounted for most of catches (59.26%) for yellowfin tuna and between 125 cm and 165 cm accounted for most of catch (59.26%) for bigeye tuna.

The K and Krel values were also used as a parameter to estimate the characteristics of fish body structures, such as *b* values for some fork length. However, the arguments between K, Krel and *b* have lasted since 1920 (Froese 2006).In this study, the mean value of albacore tuna K is greater than that of other species, indicating that albacore tuna specimens caught had thicker bodies than other fish in the same length range for the two other species (Figures 14 to 16). However, we recognize that empty stomachs can induce a decrease in K values (Perc¸in and Akyol 2009).

However, fish with high K are not the biggest fish species. It can be noted that K value of the albacore tuna, with fork length between 83 and 90 cm is 2.2, while the K is 1.81 for the yellowfin tuna between 85 and 90 cm and 2.3 for the bigeye tuna of the length between 75 and 95 cm. These results may indicate that increasing environmental sensitivity to larger / older and premature fish (Stenseth et al., 2002) may result in a decrease in their K values. During our study, we found that K values showed an increasing trend for tuna less than 100 cm. However, K values decreased when lengths greater than 120 cm in albacore tuna, 140 cm in yellowfin tuna and 145 cm in bigeye tuna.

This allows us to suggest the division of the population structure of the three species into two stages (growth stage and old stage), this will help to study the sensitivity to environmental conditions for older fish (Shaofei J et al. 2015). We suggest that *b* values should primarily be used to evaluate growth rates because of their high growth rate at growth stage, whereas K values should be used to assess the sensitivity of fish to environmental factors or health conditions.

The presence of few fish with lengths greater than 110 cm in albacore's tuna, 135 cm in yellowfin tuna and 145 cm in bigeye tuna in our specimens. This may indicate a case of growth overfishing, or confirm a size-based vertical distribution so that larger size groups live at deep water layer out of reach for the fishing depth in the present study.

CONCLUSION

This article provides information on relationship between the depth distribution of the hook and the length distribution, the survival rate of the hooks of each group of hook and fork lengths using the logistic regression model, the relationship between the depth fishing and the effectiveness of fishing has been analyzed statistically. On parameter values from the length-weight, relative condition factor and Fulton condition factor of catches of albacore tuna (Thunnus alalunga) and yellowfin tuna (Thunnus albacares) on the high seas Eastern Pacific. There is a weak positive correlation between the size of the body of the fish and the depth of the hook. The 192 m (the layer of water where the hook is) is the critical layer of water. The shallow layer of species has a length well below the depth of the water layer. The deeper the capturing water layer, the higher the survival rate of the transported fish. In addition, the effect of hook depth on fishing efficiency is extremely important. The fishing probability density of the 167.57 m layer of water is the largest. Depending on the depth of the water, 80% of the catches are caught between 124 and 211 m deep. It can be said that the three fish in this study showed a negative allometric growth pattern indicated by the growth coefficient (*b* <3). The three fish species were in a good state indicated by the calculated condition factor (K> 1).

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TABLES

Table 1: Estimated depth of each hook of longline

Hook number	1	2	3	4	5	6	7	8	9	10	11	12	13
Estimated depth(m)	63.2	84.2	105.3	124.7	143.4	161.2	177.4	192.0	204.9	215.5	223.6	229.2	232.5

Table 2: *P* value of multiple comparisons (t-test) for the fork length caught by different hooks

Hook number	2	3	4	5	6	7	8	9	10	11	12
3	0.446										
4	0.494	0.871									
5	0.394	0.983	0.818								
6	0.269	0.689	0.505	0.599							
7	0.274	0.715	0.518	0.618	0.940						
8	0.701	0.063	0.052	0.008	0.001	<0.001					
9	0.788	0.099	0.091	0.021	0.004	0.002	0.813				
10	0.291	0.008	0.005	<0.001	<0.001	<0.001	0.195	0.148			
11	0.616	0.100	0.102	0.048	0.020	0.017	0.791	0.679	0.489		
12	0.581	0.090	0.092	0.043	0.018	0.016	0.730	0.624	0.547	0.945	
13	0.478	0.159	0.173	0.132	0.089	0.090	0.571	0.517	0.994	0.697	0.731

Table 3: Estimates of modeled parameters by Logistic regression

Coefficients	Estimate	Standard deviation	Z- statistics	*P*
β_0	−8.450699	0.200235	-42.20	<0.001
β_1	0.050431	0.001131	44.61	<0.001

Table 4: Length-weigh relationship of albacore tuna, yellowfin tuna and bigeye tuna

species	equation	a	b	R²	allometric
albacore tuna (thunnus alalunga)	$Wt= 7.109E\text{-}05Lt^{2.7135}$	7.109E-05	2.7135	0.7494	Minor
yellowfin tuna(thunnus albacares)	$Wt= 0.000458Lt^{2.3275}$	0.000458	2.3275	0.7378	Minor
bigeye tuna (Thunnus obesus)	$Wt = 0.0003063Lt^{2.4047}$	0.0003063	2.4047	0.8495	Minor

Table 5: Mean ± standard deviation of Condition factor (K) and Relative condition factor (Krel)

species	Weight range (kg)	Size range(cm)	Range of K	Range of Krel	Mean ± SD K	Mean ± SD Krel
albacore tuna (thunnus alalunga)	12-33	83-128	1.38 - 2.74	0.78 - 1.41	1.92 ± 0.15	1.01 ± 0.08
yellowfin tuna(thunnus albacares)	11-61	82-153	1.17-1.84	0.81 -1.89	1.41 ± 0.18	1.34 ± 0.31
bigeye tuna	9 -93	76.6 - 180	1.04 - 3.58	0.65 - 1.67	1.74 ± 0.42	1.02 ± 0.2

(Thunnus obesus)						

Figure Captions

Figure 1. Distribution of deployment locations in survey of tuna longline

Figure 2. Vertical distribution of two float longline hooks

Figure 3. Fork length distribution (blue) and number of individuals (red) caught by different hooks.

Figure 4. Logistic regression between catch efficiency and hook depth.

Figure 5. Albacore tuna length frequency

Figure 6. Yellowfin tuna length frequency

Figure 7. Bigeye tuna length frequency

Figure 8. Albacore tuna weight frequency

Figure 9. Yellowfin tuna Weight frequency

Figure 10. Bigeye tuna Weight frequency

Figure 11. Relationship between fork length and weight of albacore tuna (thunnus alalunga)

Figure 12. Relationship between fork length and weight of yellowfin tuna (*thunnus albacares)*

Figure 13. Relationship between fork length and weight of bigeye tuna (*Thunnus obesus*)

Figure 14. Condition factor (K) per fork length (cm) class ofalbacore tuna (*thunnus alalunga*).

Figure 15. Condition factor (K) per fork length (cm) class of yellowfin tuna (*thunnus albacares*).

Figure 16. Condition factor (K) per fork length (cm) class of bigeye tuna (Thunnus obesus)**.**

Figure 1

Fig 1. Distribution of deployment locations in survey of tuna longline

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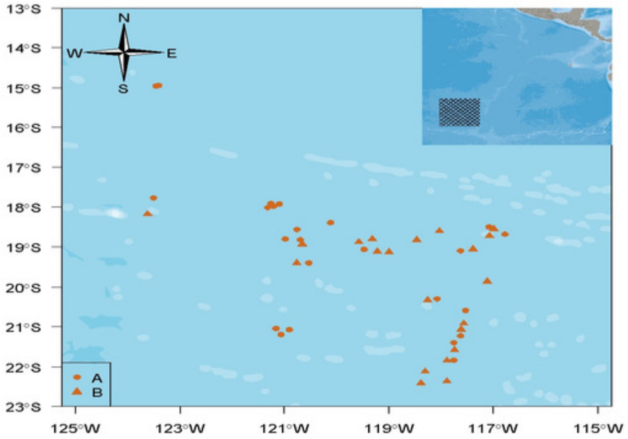
N
W
E
S
13°S
14°S
15°S
16°S
17°S
18°S
19°S
20°S
21°S
22°S
23°S
125°W
123°W
121°W
119°W
117°W
115°W
● A
▲ B

Figure 2

Fig 2. Vertical distribution of two float longline hooks

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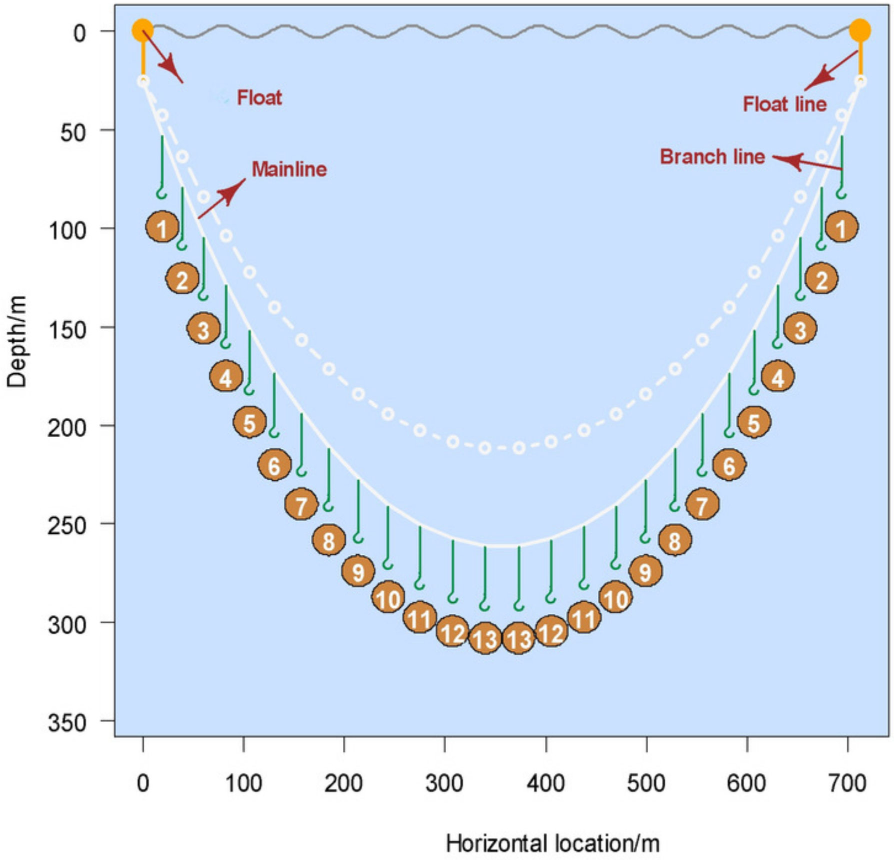

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Figure 3

Fig 3. Fork length distribution (blue) and number of individuals (red) caught by different hooks.

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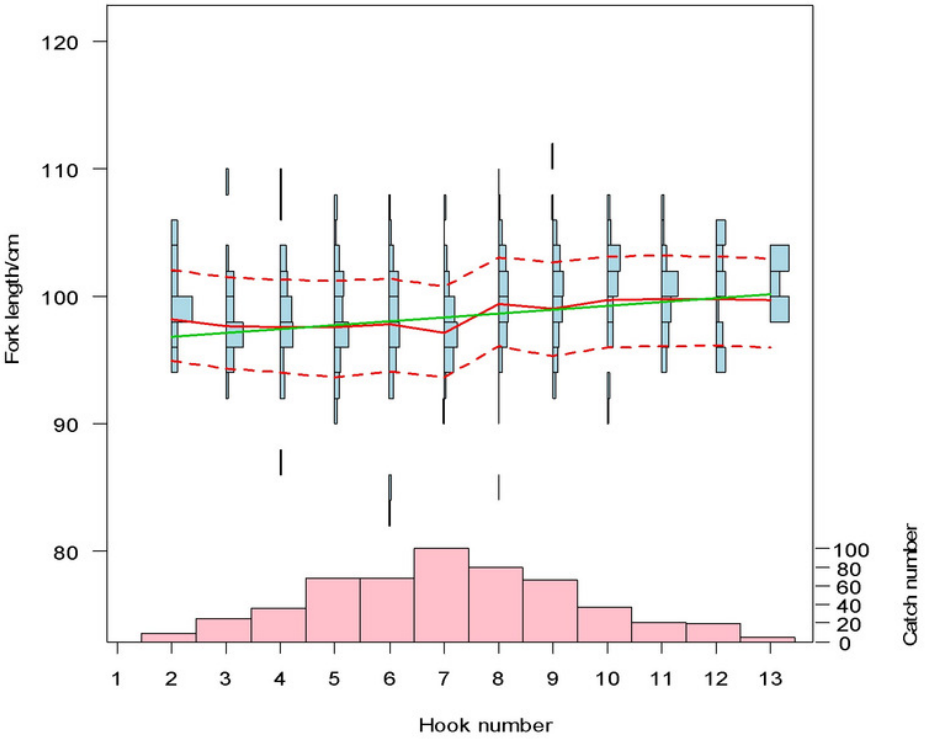
Fork length/cm
120
110
100
90
80
Catch number
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Hook number

Figure 4

Fig 4. Logistic regression between catch efficiency and hook depth.

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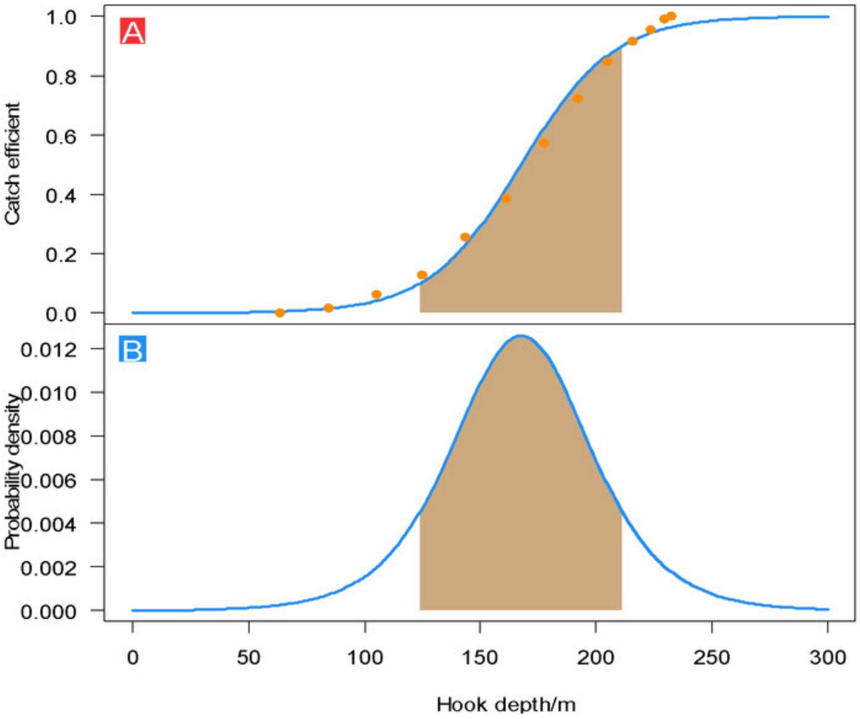

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Figure 5

Fig 5. Albacore tuna length frequency

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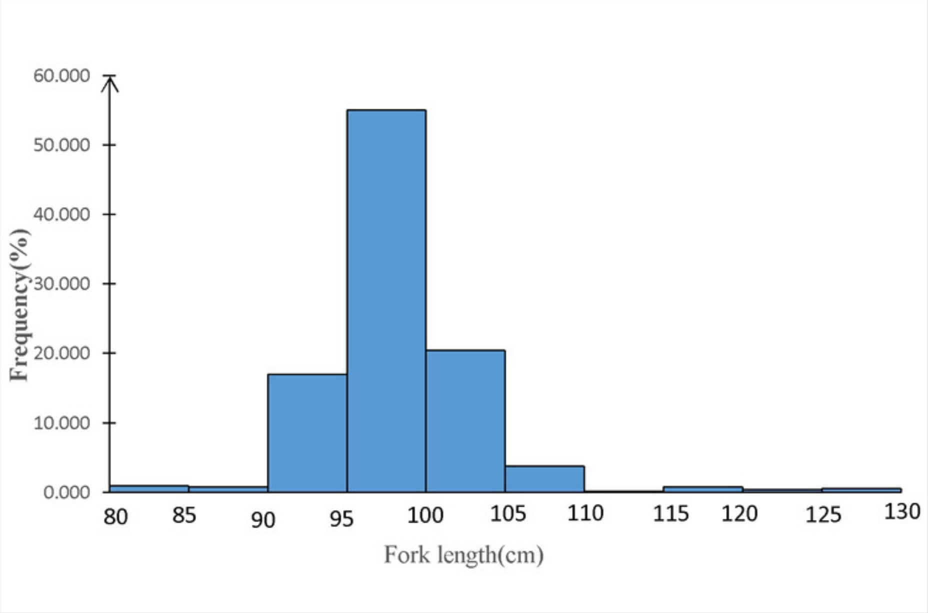
60.000
50.000
40.000
30.000
20.000
10.000
0.000
Frequency(%)
80
85
90
95
100
105
110
115
120
125
130
Fork length(cm)

Figure 6

Fig 8. Albacore tuna weight frequency

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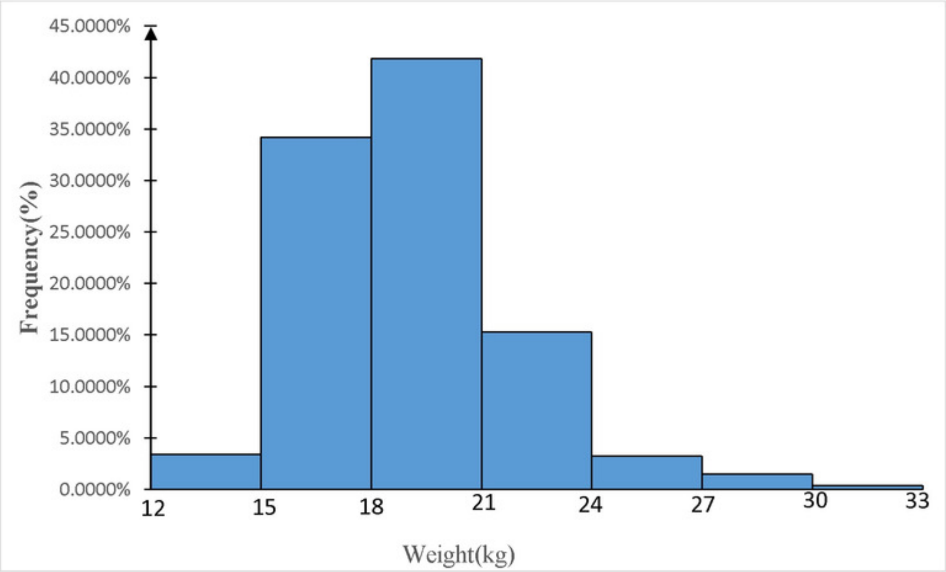
45.0000%
40.0000%
35.0000%
30.0000%
25.0000%
20.0000%
15.0000%
10.0000%
5.0000%
0.0000%
Frequency(%)
12
15
18
21
24
27
30
33
Weight(kg)

Figure 7

Fig 7. Bigeye tuna length frequency

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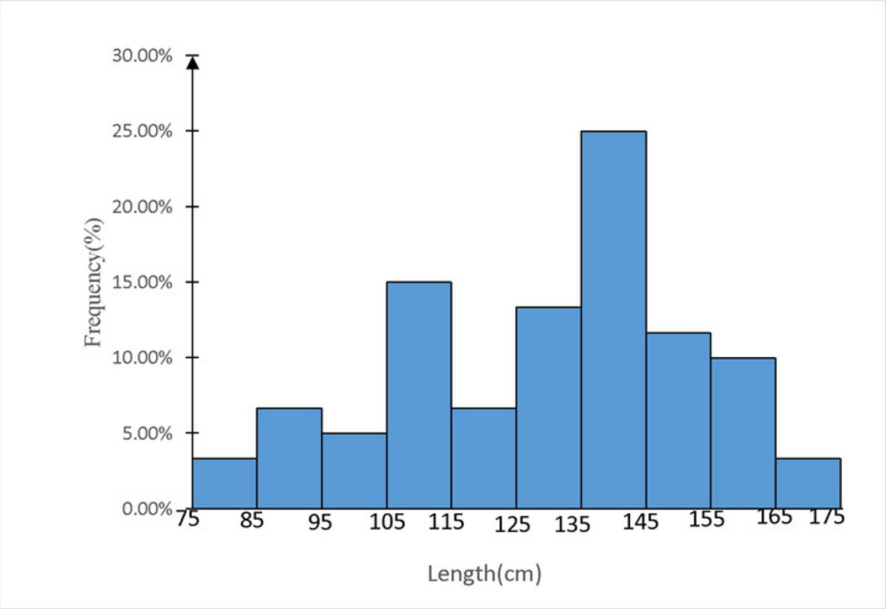

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Figure 8

Fig 6. Yellowfin tuna length frequency

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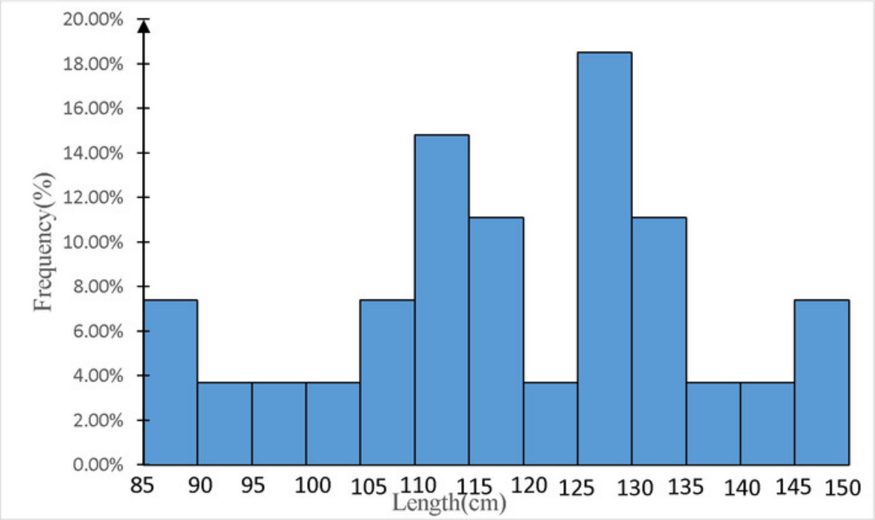

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Figure 9

Fig 9. Yellowfin tuna Weight frequency

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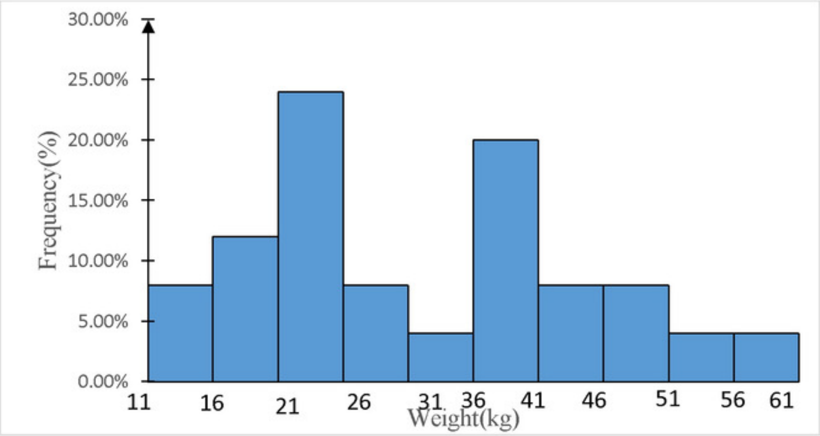

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Figure 10

Fig 10. Bigeye tuna Weight frequency

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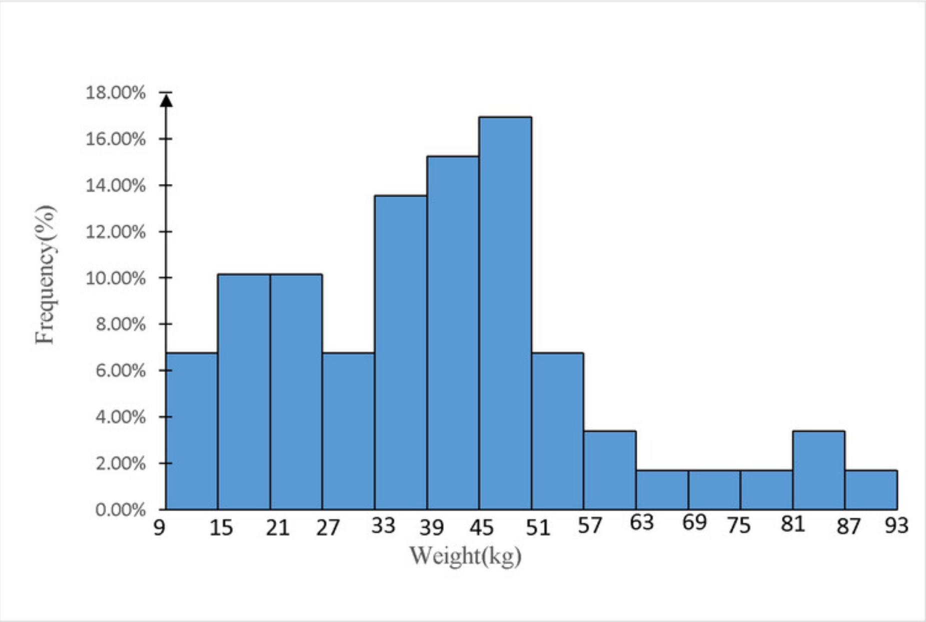
Frequency(%)
18.00%
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
9
15
21
27
33
39
45
51
57
63
69
75
81
87
93
Weight(kg)

Figure 11

Fig 14. Condition factor (K) per fork length (cm) class of albacore tuna (*thunnus alalunga*).

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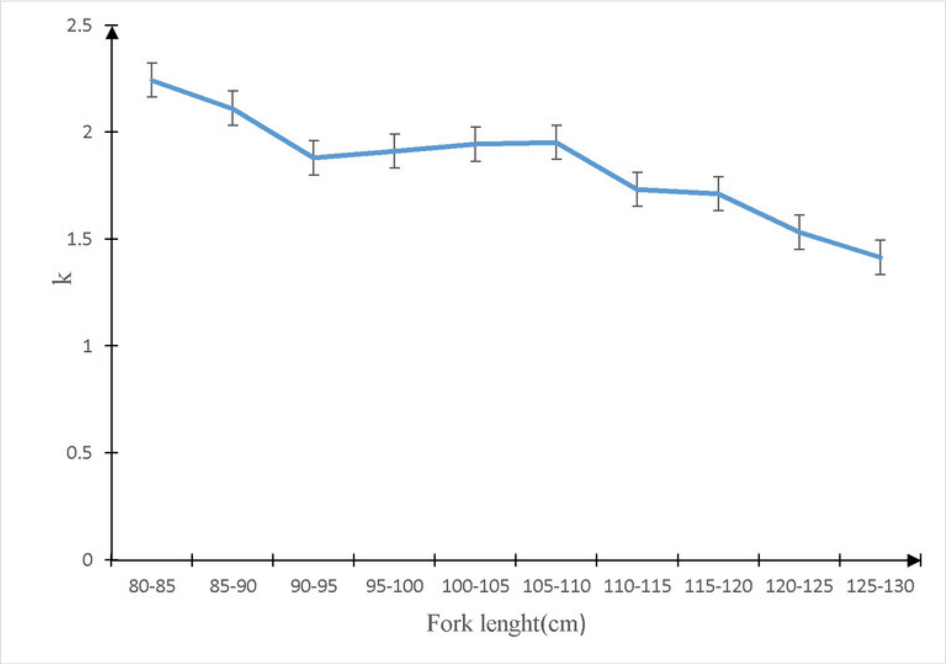

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Figure 12

Fig 15. Condition factor (K) per fork length (cm) class of yellowfin tuna (*thunnus albacares*).

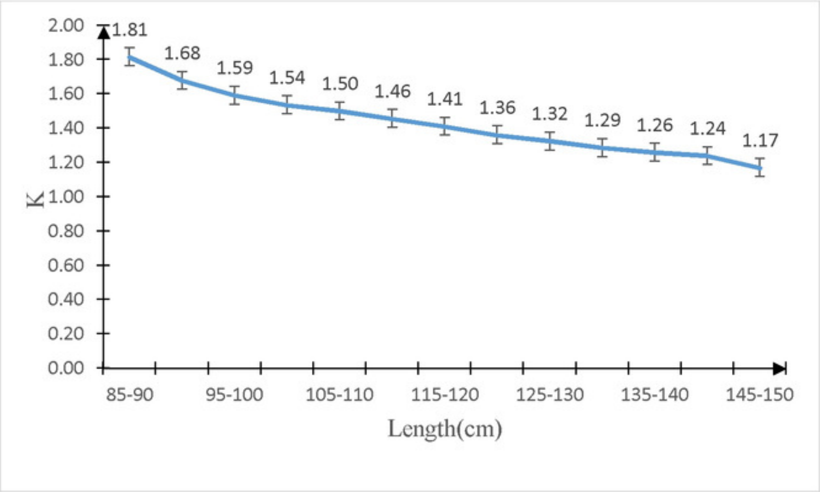

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Figure 13

Fig 16. Condition factor (K) per fork length (cm) class of bigeye tuna (Thunnus obesus).

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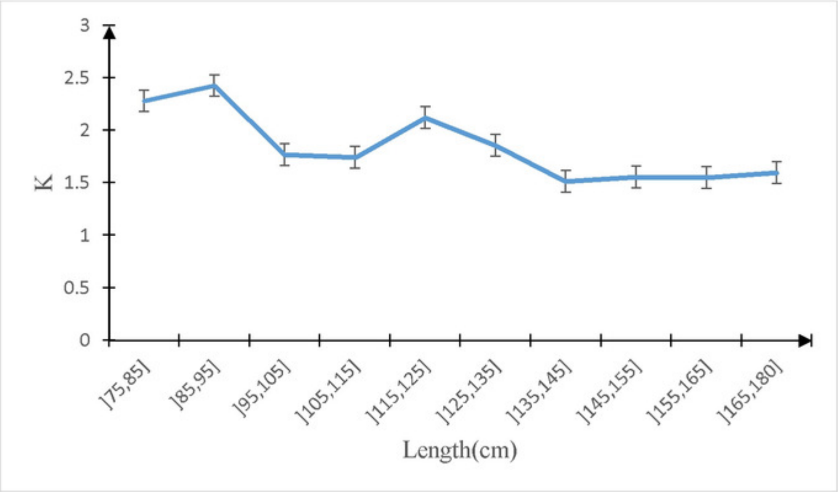

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Table 1(on next page)

list of all tables

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species	equation	a	b	R^2	allometric

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yellowfin tuna(thunnus albacares)	Log W= - 3.3391 + 2.3275Log L	0.000458	2.3275	0.7378	Minor
bigeye tuna (Thunnus obesus)	Log W = - 3.5139 + 2.4047Log L	0.0003063	2.4047	0.8495	Minor

Table 5: Mean ± standard deviation of Condition factor (K) and Relative condition factor (Krel)

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Figure 14

Figure 11.Relationship between fork length and weight of albacore tuna (thunnus alalunga

Figure 11. Relationship between fork length and weight of albacore tuna (*thunnus alalunga*)

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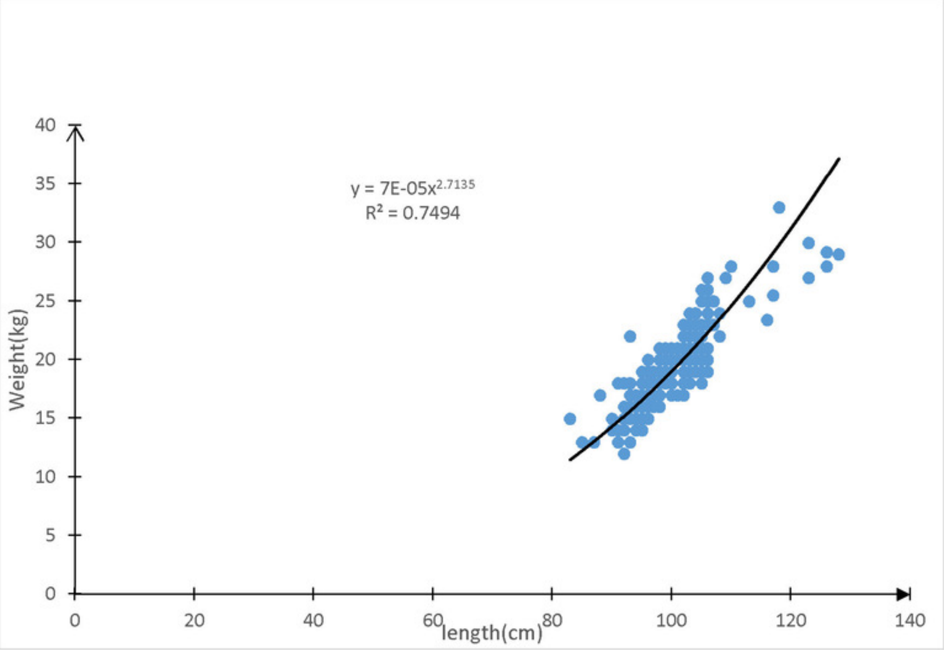

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Figure 15

Figure 12. Relationship between fork length and weight of yellowfin tuna (*thunnus albacares)*

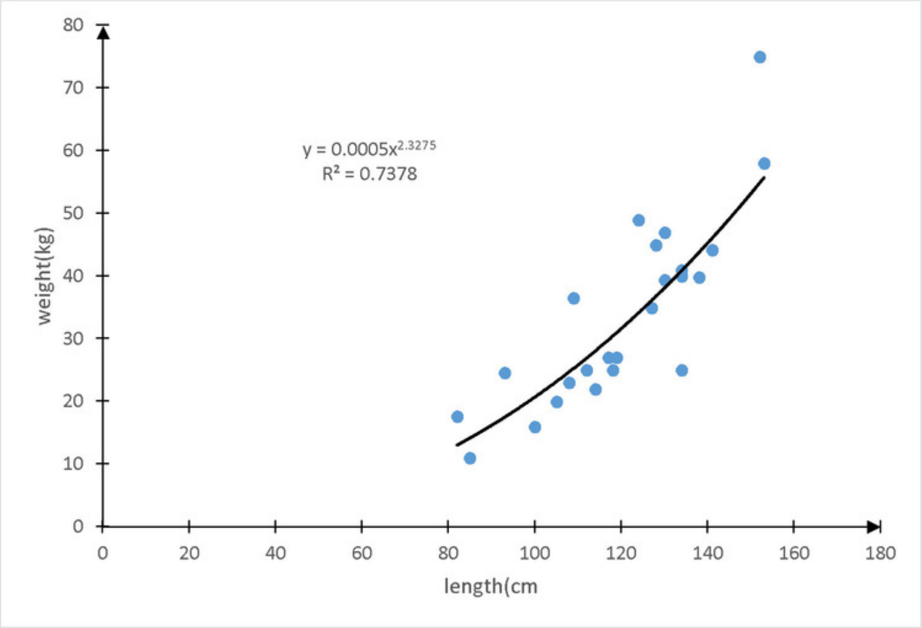

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Figure 16

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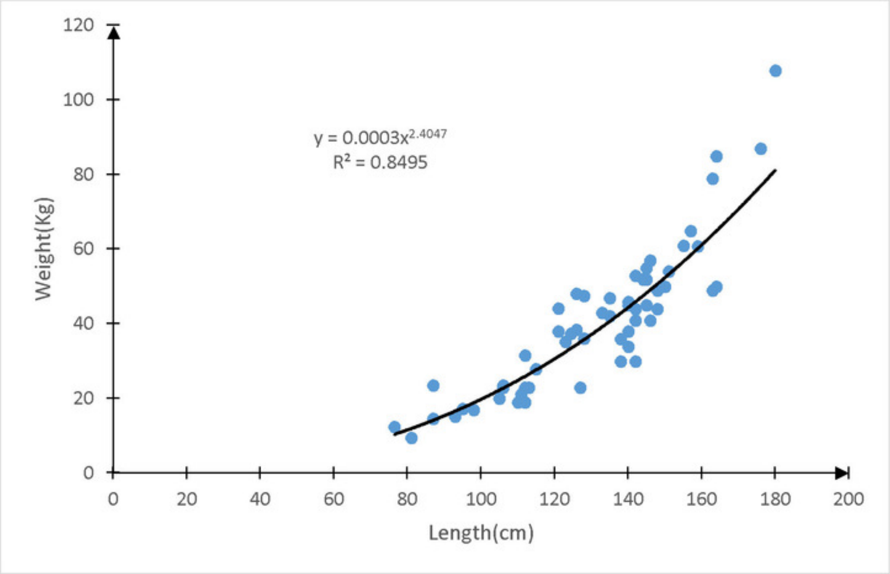
y = 0.0003x^2.4047
R² = 0.8495
Weight(Kg)
Length(cm)
0
20
40
60
80
100
120
0
20
40
60
80
100
120
140
160
180
200