Some Biological Parameters of Yellowfin Tuna (*Thunnus albacares*) from the Handline Fishery in the Eastern Part of the Banda Sea

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Abstract. Export quality yellowfin tuna (*Thunnus albacares*) from the handline fishery in the Banda Sea (Ambon and Seram) is vital in supporting coastal communities. To ensure its sustainability, information on their biological parameters is essential, especially for harvest strategy purposes. A combination of port sampling and fisheries surveys were conducted from January to October 2016 to monitor the catch, effort, size (length and weight), and maturity level of yellowfin tuna. An equal catch proportion of yellowfin and bigeye tuna was found during surveys in Masohi, Seram Island. In contrast, two-thirds of the catch landed in Ambon was dominated by yellowfin tuna. The catch rate varied between 25.5-71.9 kg/day. Length of samples distributed between 65-152 cm FL (mode=104 cm FL), whereas estimated live weight ranged from 6.12-148.92 kg. Both females ($W=0.000001*FL^{3.7199}$) and males ($W=0.000001*FL^{3.7438}$) possessed allometric growth. The proportion of males was twice that of females (1: 0.5), where most (47%) of samples were found to be mature. The estimated total mortality ($Z$) is 1.04/year, with the natural mortality ($M$) and fishing mortality ($F$) around 0.55/year and 0.49/year, respectively. The stock condition allegedly reaching its optimum level tagged by the length at first caught ($L_c$) was slightly higher in comparison to length at first maturity ($L_{m50}$) and utilization rate ($E$) below 0.55/year.

1. Introduction

Indonesia is considered as one of the largest tuna and tuna-like producers globally, contributing more than 16% in 2015 [1,2]. In the eastern part of Indonesian waters, the Banda Sea plays a pivotal role in the livelihood of coastal communities. Historically, it is well known as the primary fishing ground for longlines since the late 1960s [3]. Still, traditionally, artisanal fishing practices have been commenced since the early days, utilizing various fishing gears [4,5].

The Banda Sea belongs to Fisheries Management Area 714 (WPPNRI-714), with Kendari as one of the biggest landing sites in the western part. In the opposite leg, it is divided into Ambon, Banda Neira, and Seram. Since the disappearance of longline fishery in the late 2000s, the exploitation is dominated by the combination of the fish aggregating device (FAD) associated with a handline and troll line, targeting yellowfin tuna (*Thunnus albacares*) [6,7]. However, the utilization of FAD has
kept the catch at a high level [8], moreover with the arrival of purse seine and pole and line in recent years [9–11]. Some studies have been undertaken in the last decades to monitor the yellowfin tuna at a sustainable level, e.g., size distribution and potential fishing ground from longline fishery [12,13], population parameters [7], fishing capacity [14] and reproductive biology [15] from handline. The characteristics of troll line catch [4] and the stock status indicator [5] were also reported. However, comprehensive studies about their biological traits, including the exploitation level are rarely explored, primarily due to a lack of reliable time-series data.

This study intended to investigate some biological aspects and population parameters of yellowfin tuna from handline fisheries in the eastern part of the Banda Sea waters. The information is expected to provide some inputs to the management of tuna resources in this particular area.

2. Methodology
2.1. Data collection
The catch and effort data were acquired from port authorities (PPN Ambon) from 2012-2017 (5 years) (Figure 1). Whereas the biological data, e.g., length, weight, gonad maturity, were obtained during several surveys conducted in Masohi, Seram Island on January, February, March, April, May, June, July, Augustus, September, and October 2016.

Figure 1. Map of the study area, projecting the Banda Sea and landing sites in Ambon and Masohi. (Remarks: the shaded area is the expected handline tuna fishing ground)

2.2. Data Analysis
The sex ratio was determined for all fish pooled and for each by month. Comparison if sex ratio departed from the expected 1:1 rate was determined by Chi-square test at 95% confidence level. The length-weight relationship was calculated by the least square method for combined sexes using the equation, as follows:

\[ W = al^b \] (1)

To test \( b=3 \) or \( b\neq3 \), we used Student's t-test under the R stats package version 4.1.0 [16], testing the hypothesis \( H_0: \beta=3 \) (isometric) and \( H_1: \beta\neq3 \) (allometric). The t-statistic was calculated as 

\[ t = \frac{b-3}{S_b} \text{, where } S_b = \sqrt{\left(\frac{1}{n-2}\right) \cdot \left[\frac{S_y^2}{s_y} - b^2\right]} \]  

(2)

\( s_y \) and \( s_x \) are the standard
deviations of \( y \) and \( x \), respectively. The significance of the t-value was calculated at 5% level of significance with (n-2) degrees of freedom [17].

The size at first maturity is explained as the cumulative size frequency distribution at which 50% of the individuals in the sample size are mature (visual observation, see Schaefer & Orange [18]). The threshold calculated using logistic model, where \( p \) is the proportion of mature females at length \( (L) \), \( a \), and \( b \) are parameters to be estimated. The calculation was performed using the sizeMat package inside R version 4.1.0 [19].

\[
\logit(p) = a + bL
\]  

Length at which 50% of females are mature is defined as

\[
L_{50} = -\frac{a}{b}
\]  

Population parameters such as asymptotic length \( (L) \) and growth coefficient \( (K) \) were estimated using Electronic Length Frequency Analysis (ELEFAN) under FISAT II software [20]. Natural mortality was calculated based on the empirical equation from [21] as follows:

\[
\log M = -0.0066 - 0.279 \log L^\infty + 0.6543 \log K + 0.4634 \log T
\]

Total mortality \( (Z) \) was estimated based on the length converted catch curve [21], while fishing mortality was derived from subtracting \( Z \) with \( M \).

\[
F = Z - M
\]

Exploitation rate \( (E) \) was assumed as fishing mortality divided by total mortality, following equation from [21]:

\[
E = \frac{F}{Z} = \frac{F}{F + M}
\]

The recruitment pattern was estimated using ELEFAN by inputting \( L \), \( K \), and \( t_0 \) if available [20]. Recruitment pattern intended to monitor any new adding stock into the population of particular species (i.e., yellowfin tuna) on an annual basis, based on its length frequency distribution.

3. Results and Discussion

3.1. Catch Dynamics

Handline fleets in the Banda Sea are usually characterized by wooden-type or fiberglass boats of less than five gross tonnages. Operated by single or two persons and the fishing will last for a couple of hours or the whole day. They mostly dependent on FADs and targeting large tuna (above 25 kg) destined for export. It dominates the fleet's composition by nearly a half, followed by purse seine, pole, line, and a small fraction of longline (Figure 2). However, more than three quarter was from purse seine fleets (Figure 3).

The annual catch trend between 2012-2017 was varied but showing a repeated cycle every three years (Figure 4). The pattern, especially from 2014 onwards, probably related to strict law enforcement of IUU (Illegal, Unreported and Unregulated) fishing. It caused a heavy downfall to the fishing industry in the next two years but adversely affected small-scale fisheries and stock conditions [22,23], where the production bounced back and reached the highest in 2017.

The mean monthly catch (all gears) revealed that peak fishing season happened in the 3rd quarter of the year, between July-September. A completely different result compared to the study from Haruna et al. [24], in which the peaks occurred at the beginning of the northwest monsoon in November. Since the correlation between catches and seasonal changes relatively minor, it means the stock is always available, and fishing practice can be commenced throughout the year [25], which probably explained the discrepancies. Interestingly, the monthly catch rate from handline fleets, calculated from scientific port sampling in Masohi, showed a relatively stable trend throughout the year (Figure 5). Which somewhat similar to previous findings by Haruna et al. [24].
**Figure 2.** Fleets proportion targeting tuna and tuna-like species based in Ambon.

**Figure 3.** The proportion of the main tuna catches by gear.

**Figure 4.** Historical catch of yellowfin tuna landed in Ambon.

**Figure 5.** Average monthly production (all gears) and catch rate of yellowfin tuna from handline fleets based in Ambon. Values were scaled by dividing their means.
3.2. Sex Ratio
Of all 1154 yellowfin tuna samples, more than two-third (786) was males, and the rest (368) was females. The sex ratio between females and males was unbalanced (1:2) (Chi-square test, \( p < 0.05 \)). A different result compared to the previous study by Wagiyo et al. [26], but relatively similar to the condition in the eastern Indian Ocean [27]. According to Prihatiningsih et al. [28], the imbalance occurred because the captured fishes are unlikely to belong to the same spawning area, so there is a slim probability of being caught at once. Further, Nikolsky [29] explained the sex proportion of fishes could be determined before and during the spawning season.

3.3. Maturity
The average length at 50% of yellowfin tuna caught by handline was 107.2 cm FL, considerably between the previous studies from Chodrijah [15] and Damora & Baihaqi [7] 100.6 cm FL and 131.8 cm FL, respectively. On the other hand, the length at first maturity was estimated at 106.7 cm FL, relatively similar to the previous study by Itano [30] in the western and central Pacific Ocean (including the southern part of Maluku) and still in the range of several studies in the west part of the central Indian Ocean [31] and the western Indian Ocean [32] wherein between 75.0-113.7 cm FL. Effendi [33] assumed that if a species’ geographical distribution varied by more than 5 degrees, there are likely discrepancies in length and age when reaching maturity. Further, the phenomenon probably caused by the variability in ecological conditions.

3.4. Size Distribution
A total of 1154 size (length and weight) data of yellowfin tuna have been successfully obtained during port sampling and fisheries surveys in 2016. Overall, the length ranged from 65-152 cm FL (mean = 107±15.1 cm FL). Despite more male yellowfin samples (786) than female (368), its average length was lower, 105±15.3 cm FL compared to 112±13.5 cm FL, respectively. The result was between the study from troll line fishery [4] and carrier vessel [15] in the surrounding Banda Sea. According to the threshold proposed in this study, most of the females (~76%) and at least 50% of males were classified as mature (Figure 7).
3.5. Morphometric relationship

Most of the yellowfin landed in Masohi were gilled, gutted and headed. Therefore a raising factor of 1.36 [34] was needed to estimate the live weight. Overall, all the models exhibit a tight fit to the data ($R^2 > 0.87$) with the possible exception of a few individuals. Further, Student's t-test confirmed that all yellowfin tuna, regardless of the sexes, possessed allometric growth (p<0.05) with exponent parameter ($b$) above 3.5 and within a 95% confidence interval. However, it is still unclear why the $b$ values were above range for tropical fishes, which is between 2.5-3.5 [35]. Probably due to inconsistent measurement in the field related to non-standard processed products landed.

Figure 7. Size distribution by sex of yellowfin tuna landed in Masohi, Seram Island.

3.6. Biological parameters

The growth rate ($K$) of yellowfin tuna estimated at 0.33/year, which indicate a slow growth pattern [36]. Asymptotic length ($L_\infty$) calculated around 159 cm FL. The result somewhat between the study from Hartaty & Sulistyaningsih [37] in the northeastern Indian Ocean and Dortel et al. [38] in the

Figure 8. Length and weight relationship of females, males, and pooled sexes of yellowfin tuna landed in Masohi, Seram Island.
western Indian Ocean. Furthermore, both values were inserted into length converted catch curve to obtain the mortality rates (Z, M and F).

The estimated total mortality rate (Z) was 1.04/year, the natural mortality rate (M) expected 0.55/year and the suspected fishing mortality rate (F) was 0.49/year. These produced more plausible results than previous research from Damora & Baihaqi [7] and Hartaty & Sulistyaningsih [37], whereas their results probably overestimated. The exploitation rate (E) was derived by dividing the natural mortality by total mortality (E=F/Z) [21]. Based on that assumption, the exploitation level of yellowfin tuna from the handline fishery in the eastern part of the Banda Sea has to reach its optimum (0.47). Although there is room for increasing the effort, it should be maintained at the current level due to the precautionary approach. Noting that only a fraction of the length data was used for the analysis, more extended datasets are vital in producing more robust assessments in the future.

4. Conclusion

An equal catch proportion of yellowfin and bigeye tuna was found during surveys in Masohi, Seram Island. In contrast, two-thirds of the catch landed in Ambon was dominated by yellowfin tuna. Most of the females (~76%) and at least 50% of males were classified as mature, forming an allometric growth pattern, regardless of the sexes. The proportion of males was twice that of females (1: 0.5). The estimated total mortality (Z) is 1.04/year, with the natural mortality (M) and fishing mortality (F) is around 0.55/year and 0.49/year, respectively. The stock condition was allegedly reaching its optimum level characterized by a slightly higher length at first caught (Lc) than a length at first maturity (Lm50), and the estimated utilization rate (E) was below 0.55/year. Although there is room for increasing the effort, it should be maintained at the current level due to the precautionary approach.

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