Productivity and susceptibility analysis of Yellowfin Tuna (Thunnus albacares) landed at Sodohoa Fishing Base, Kendari City, Indonesia

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Abstract. Yellowfin tuna (Thunnus albacares) is a fisheries resource with high economic value, and in Indonesia it is an important export commodity. The purpose of this study was to determine the productivity and susceptibility of yellowfin tuna landed at Sodohoa Fishing Base in Kendari, Southeast Sulawesi, Indonesia. This research was conducted from May to July 2017. Both primary and secondary data were collected. Data analysis was implemented using Productivity and Susceptibility Analysis (PSA). The results indicated that productivity and susceptibility of yellowfin tuna were both at a moderate level. Therefore, utilization of yellowfin tuna in this region could be sustainable.

1. Introduction

Kendari City is a fishing base in Eastern Indonesia which is located directly facing the Banda Sea. There are two fishing ports currently operating in Kendari. The ports are Kendari Ocean Fishery Port (PPS Kendari) and Pangkalan Pendaratan Ikan (PPI) Sodohoa. The Banda Sea, with an area of 50,000 km², occupies a strategic position within fisheries management area 714. One fisheries resource that is widely exploited by fishermen operating in the Banda Sea is yellowfin tuna (Thunnus albacares). Yellowfin tuna is a fish resource offering good prospects for fishermen to increase their income (unpublished data, PPI Sodohoa 2017). However, continuous fishing without any management measures will result in declining populations and decreased fish size.

One of the risk-based approaches currently under development to evaluate these issues aims to determine the productivity and susceptibility of fisheries resources, also using risk-based ecological and depletion analysis approaches to yellowfin tuna catches in the Banda Sea. This approach is becoming one of the practical tools that are expected to produce solutions for sustainable pelagic fisheries management.

The purpose of this study was to determine the productivity and susceptibility of yellowfin tuna catches landed in PPI Sodohoa. The results of this research will provide information to the policy makers and enforcers on the level of yellowfin tuna productivity and susceptibility to help enable the determination of management steps. In addition to informing management, the research will also add to the body of scientific knowledge as serve as a basis for further research.
2. Materials and Methods

Data were collected from PPI Sodohoa, while yellowfin tuna fecundity and stomach contents were analysed in the Laboratory of the Faculty of Fisheries and Marine Sciences, Halu Oleo University, Kendari City, Southeast Sulawesi Province, Indonesia. The study was conducted from May to July 2017. The study area is shown in Figure 1.

![Figure 1. Map of the study area (yellowfin tuna fishing grounds)](image)

Primary data in this study was collected directly in PPI Sodohoa. Primary data collection on yellowfin tuna productivity attributes were: total length (cm), weight (g), gonad development, and stomach contents. Yellowfin tuna were sampled using simple random sampling method. Primary data collection on the parameters contained in the susceptibility attribute was done through descriptive survey methods implemented according to [1], enabling the collection of data or information about a population by using samples considered as representative of the population. Characteristics of this research method are that information is obtained from the sample by asking questions, and that the collected information can be used to describe certain aspects. The information was collected through interviews with the fishermen and related agencies as respondents using questionnaires.

Secondary data retrieved during this research was yellowfin tuna production data obtained from PPI Sodohoa. Other information was obtained from relevant literature on the productivity parameters and susceptibility of yellowfin tuna. The growth coefficient parameters (k) and \( L_\infty \) can be predicted by using the Von Bertalanffy equation through Ms Excel. The estimation of the value (theoretical age of the fish at length equal to zero) is obtained through the equations of Pauly in [2]:

\[
\log (-t_0) = 3.3922 - 0.2752 (\log L_\infty) - 1.038 (\log K)
\]

where: 
- \( L_\infty \) = the asymptotic average length 
- \( k \) = Growth rate coefficient 
- \( t \) = average age or time 
- \( t_0 \) = average time or age when the length was zero.

According to [3], the value of \( K \) can be known as the maximum age of a fish. Estimation of the maximum age of fish (\( t_{max} \)) can be obtained using the following formula:
Pauly [2] also suggested taking into account the habits of schooling fish species. For these species, natural mortality is multiplied by a value of 0.8, so that for species that school as adults, like skipjack and yellowfin tuna, the estimated value of natural mortality becomes 20% lower, as follows:

\[ M = 0.8 \left( -0.0152 - 0.2791 \ln L_\infty + 0.6543 \ln k + 0.463 \ln T \right) \]

where:
- \( M \): Natural mortality
- \( L_\infty \): the asymptotic average length from the Von Bertalanffy growth equation (mm)
- \( k \): Growth coefficient
- \( t_0 \): average time or age when the length was zero
- \( T \): average water temperature (ºC)

After the total mortality rate (Z) and natural mortality rate (M) are known, the fishing mortality rate can be determined by the formula in [4]:

\[ F = Z - M \]

Fecundity can be determined by using a combined model, i.e. a combination of gravimetric and volumetric methods. Fish fecundity can be calculated using the following formula in [5]:

\[ F = \frac{G}{Q} \times N \]

where:
- \( F \): Fecundity (quantity)
- \( Q \): Sample weight of gonad (g)
- \( G \): Total weight of gonad (g)
- \( N \): Quantity of sample fecundity

The assessment of productivity and susceptibility can be expressed in a scatter plot. The x-axis represents the productivity while the y-axis represents the susceptibility. This graph provides an overview of the susceptibility of each species of fish. Based on [6], the value of susceptibility is derived from the formula:

\[ v = \sqrt{(p - 3)^2 + (s - 1)^2} \]

where:
- \( v \): Total susceptibility score
- \( p \): Productivity
- \( s \): Susceptibility

A susceptibility value (v) above 1.8 indicates that a fish has a high risk of susceptibility to fishing activities. The susceptibility index has three categories, i.e. less vulnerable (v <1.6), moderately susceptible (1.6 ≤ v <1.8) and highly susceptible (v ≥ 1.8). The average values of the productivity and susceptibility values were used to determine the qualitative category (high: V <2, intermediate: V = 2, low: V <3) for each fish stock studied.

3. Results
Productivity indicates the ability of resources (fish stocks) to recover from damage caused by fishing pressure. The results of the assessment of productivity attributes for yellowfin tuna landed in PPI Sodoho are shown in Table 1.
Table 1. Productivity attribute of yellowfin tuna landed at PPI Sodohoa

| Productivity attribute     | Unit      | Value     | Score | Data quality |
|----------------------------|-----------|-----------|-------|--------------|
| Intrinsic growth (r)       | % year    | 0.20\(^{(2)}\) | 2     | 4            |
| Maximum age                | year      | 9.60\(^{(3)}\) | 1     | 1            |
| Maximum length             | cm        | 81.53\(^{(3)}\) | 2     | 1            |
| Growth coefficient (k)     | year      | 0.33\(^{(3)}\) | 2     | 1            |
| Natural mortality          |           | 0.26\(^{(3)}\) | 1     | 1            |
| Fecundity                  | quantity  | 4,730,775\(^{(3)}\) | 3     | 4            |
| Reproductive strategy      |           | Total spawner\(^{(3)}\) | 2     | 1            |
| Recruitment pattern        | %         | 17.93\(^{(3)}\) | 2     | 4            |
| Age at first maturity      | year      | 2.5\(^{(1)}\) | 2     | 4            |
| Trophic level              |           | 4.4\(^{(1)}\) | 1     | 4            |

\(^{1}=\[6]\); \(^{2}=\[7]\); \(^{3}=\text{primary data (this study)}

From the data in Table 1, the estimated maximum age of yellowfin tuna is around 9-10 years with a maximum length of around 80 cm and a k value of 0.33. The natural mortality (M) of yellowfin tuna was 0.26 with a reproductive strategy including spawning throughout the year. Intrinsic growth of yellowfin tuna is around 0.20 per year with an age at first maturity of 2.5 years. The yellowfin tuna recruitment pattern (around 18%) is considered medium, while the trophic level is high (4.4), indicating that this species is a medium to top level predator, feeding on a variety of carnivorous prey.

Susceptibility reflects the tendency for resources (fish stocks) to be caught so as to threaten population decline. The values of attributes or parameters enabling the estimation of susceptibility were obtained from interviews with fishermen and relevant literature. The data were characterized by data quality (1 = data obtained directly in the field; 4 = data obtained from relevant literature), and scored using a scoring system with 3 values: 1= low susceptibility; 2 = medium susceptibility; and 3 = high susceptibility (Table 2).

Table 2. Susceptibility attributes for yellowfin tuna landed at PPI Sodohoa

| Susceptibility attribute                   | Details                                                                 | Score | Data quality |
|-------------------------------------------|-------------------------------------------------------------------------|-------|--------------|
| Management strategy                       | The stock was not limited and was not tightly controlled. \(^{(3)}\)    | 3     | 1            |
| Overlap area                              | Fish were present in the fishing ground 25 % \(^{(3)}\)                | 2     | 1            |
| Geographical concentration                | Distributed in fishing ground 95.63% \(^{(2)}\).                       | 1     | 4            |
| Vertical overlap                          | Fish at the same depth: 65% \(^{(3)}\).                                | 3     | 1            |
| Fishing mortality (F)                     | 0.56 \(^{(3)}\)                                                        | 2     | 1            |
| Fish biomass                              | 46.56 %\(^{(2)}\).                                                     | 1     | 1            |
| Seasonal migration                        | Seasonal migration decreased the overlap of fish \(^{(3)}\).           | 1     | 4            |
| Schooling or habit response               | Schooling habit increases the efficiency of fishing gear \(^{(3)}\).    | 3     | 1            |
| Morphology affected by fishing            | Morphology not significantly affected by fishing \(^{(3)}\).           | 2     | 1            |
| Survival after capture                   | Survival post capture around 85% \(^{(3)}\).                          | 1     | 1            |
| Economic value                            | Price around Rp. 20,000/kg making fishing economically viable \(^{(3)}\)| 3     | 1            |
| Impact of fishing gears on habitat        | No adverse effects on the environment from troll lines and purse seine nets were observed \(^{(3)}\)| 1     | 1            |
The PSA analysis combined the scores of productivity and susceptibility attributes. The results of this analysis for yellowfin tuna landed at PPI Sodohoa are presented in Figure 2.

![Figure 2](image)

**Figure 2.** Results of the PSA (productivity and susceptibility analysis) of yellowfin tuna landed at PPI Sodohoa

Based on Figure 2, the PSA analysis indicates that the productivity and susceptibility of yellowfin tuna landed at PPI Sodohoa had the same values, i.e. 2. However the susceptibility index presented in Table 3 is somewhat lower, in the less susceptible category.

| Susceptibility parameters | Yellowfin Tuna |
|---------------------------|---------------|
| Index Value               | 1.41          |
| Category                  | less susceptible |

4. Discussion

Productivity is the ability of a fisheries resource to sustain a population (stock) which is subject to reduction due to fishing pressure. Productivity is one of the parameters used in PSA to evaluate the ability of depleted fisheries resources to recover [8]. There are ten aspects of resource biology and environmental conditions reflected in the attributes used in this study: intrinsic growth, maximum age, maximum size, growth coefficient, mortality, fecundity, reproductive patterns, recruitment patterns, gonad maturity, and trophic level.

The present study showed that the maximum length attained by this fish was 81.53 cm with a growth coefficient of 0.33 per year. Previous research on yellowfin tuna in Oman [3] reported a maximum length of 196.0 cm with a growth coefficient (k) of 0.42 per year, while a study in the Banda Sea, Indonesia [9] reported values of $L_\infty = 70.1$ cm and $k = 0.260$. The difference in yellowfin tuna maximum length and growth coefficient between these two different locations could be due to internal factors affecting the fish and/or different environmental conditions. According to [10], growth is defined as the increase in length and weight during a given time period. Fish growth is influenced by internal and external factors. Internal factors are usually difficult to control because many are innate, being contained in the genes of a species or individual; they include heredity, sex, age, and disease. The main external factors affecting fish growth are food and water temperature. In addition, [11] also stated that indicators that influence growth include the abundance and size of available food; water temperature, dissolved oxygen, and other water quality parameters; age and gonad maturity. Furthermore, growth rates vary during fish ontogeny, tending to be slower in older fish.
The results of the study regarding the maximum age of yellowfin tuna (9.60 years) show that yellowfin tuna generally have a fairly long life. This can be expected for large, slow-growing fishes. It has been suggested [12] that fish with higher growth coefficients (k) have a high growth rate and usually take a short time to reach their maximum length; while fish with low growth coefficient (k) values take a long time to reach their maximum length, and tend to live longer. Furthermore, the growth coefficient value (and thus fish growth rate) will affect the age composition (structure) of fish populations, their reproductive capacity, and natural mortality [14].

In this study, the value of natural mortality of yellowfin tuna was 0.26 while the fishing mortality was 0.56. These values indicate that, for the yellowfin tuna landed at PPI Sodohoa, fishing mortality was greater than natural mortality. A similar situation has been reported from the seas around Oman [3], with a total mortality of 0.80, while natural mortality was lower at 0.57. Differences in the mortality value of yellowfin tuna between locations could be due to differences in exploitation rates.

The fecundity of yellowfin tuna calculated in this study (4,730,775) referred to the number of mature oocytes in gonads (ovaries) at maturity level IV. Determination of the age at first maturity in this study was conducted based on a literature study. This was done because yellowfin tuna and skipjack tuna is a large pelagic fish species, suspected to have strong kinship. In addition, the alleged kinship of yellowfin tuna and skipjack tuna also reside in the same family that is Scombridae. This approach is supported by the statement in [15] that in studies using PSA there are five categories of data quality, where for fish without data on productivity parameters such as fecundity, the missing parameters can be obtained from data on similar fishes from the same genus or family. In FishBase, the global database of fishes [6], the average age at first maturity given for yellowfin tuna is 2.5 years. According to [14], although yellowfin tuna are relatively long-lived, some fish have mature gonads at the age of one year, although most yellowfin tuna spawn for the first time at 2 to 3 years of age. These fish spawn throughout the year in the open sea.

Observations on yellowfin tuna gut contents indicated that this fish belongs to the guild of carnivores. Observed gut contents included shrimp, small fish and squid. The classification of this large fish as a predator which can prey on smaller fish or other organisms is in line with the statement by [14] that yellowfin tuna are greedy and fast-spawning predators. The trophic level indicates that this fish belongs to a high consumer level in the food pyramid. Lower trophic levels generally indicate greater productivity. Stocks with low productivity and high susceptibility are considered to be vulnerable to over fishing, while stocks with high productivity and low susceptibility are considered the least vulnerable [15]. Low-productivity fish species are potentially more prone to over-exploitation because of this high risk [16]. The intrinsic growth rate \( r \) is a descriptor of the productivity of a stock [17].

5. Conclusion
The results of this study indicate that both the productivity and susceptibility of yellowfin tuna landed at PPI Sodohoa are at a moderate level. Therefore, it should be possible for the exploitation of yellowfin tuna in this region to be sustainable.

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