The Stock Status of Skipjack Tuna (*Katsuwonus pelamis*) in Tomini Bay and Its Surrounding Areas, Indonesia

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Abstract. Skipjack tuna (*Katsuwonus pelamis*) is an essential part of tuna, skipjack tuna, and mackerel tuna trades in Indonesia as the species is an economic commodity with export value. Tomini Bay is one of the areas in Indonesia with intensive skipjack tuna exploitation activities using purse seine fleets. Such a high fishing rate requires management efforts to maintain the species population’s sustainability. This study was conducted in April 2018–December 2019 at a fish landing site in Gorontalo City with a total sample of 8,833 skipjack tunas. The population dynamics, recruitment, and utilization rate were analyzed using FISAT II application and ELEFAN program. The results showed that the length at first capture (Lc) was 31.8 cmFL (in 2018) to 32.2 cmFL (in 2019) at around 1.3 year old. The fish recruitment occurred all year long, peaking in May at 16.12%. In addition, the utilization rate (E) of the species was 0.47, meaning that the species was already moderate to fully exploited. The suggested practical management efforts to maintain the population of the skipjack tunas in the area are to stop the fishing efforts from growing and control the size of the mesh for fishing.

1. Introduction

Indonesia is an archipelagic country with a 6.32 million km² water area and 99,093 km coastline, and therefore the country produces abundant fishery resources [1]. Fishery resources from Indonesian waters are demersal, large pelagic, small pelagic fishes, and shrimps, and crustaceans. According to [2], among the essential commodities in capture fisheries in Indonesia are tuna and skipjack tuna. Skipjack fishery is an essential resource for tuna, skipjack tuna, and mackerel trade, and it has become a high-value export commodity. Indonesia is an exporting country for 16% tuna, skipjack tuna, and mackerel tuna (209,410 tons) (2013) and is a member of the Indian Ocean Tuna Commission (IOTC) with the highest production (around 25.22% per year) [3].

Tuna, mackerel tuna, and skipjack tuna are fished in most of Indonesia’s seas, i.e., the seas west of Sumatra, south of Java, north of Java, in Makassar, until the sea in Papua. According to [4], skipjack (*Katsuwonus pelamis*) is a fast-swimming fish belonging to the Scombridae family widely distributed in tropical and subtropical waters. In Indonesia, skipjack tuna (*Katsuwonus pelamis*) is fished using multi-gear, meaning that the species can be caught using various fishing gears. According to [5]; [6] skipjack tuna is caught using pole and line, handline, trolling line, traditional seine net, purse seine, drift gill net, and sometimes using Rambo (giant boat lift net). As various fishers can exploit skipjack tuna resources and the species can be caught all year long because the fishing grounds are determined according to the different seasons in each location [2], this multi-gear fishing can lead to uncontrollable exploitation of the species.
Furthermore, as fishers increasingly understand that the species like to school under floating objects, the owners of the purse seine fleets expand their fishing ground and increase the number of the fleet [7]. Therefore, more fishing fish aggregating devices (FADs) are used, escalating the risk of decreasing the sustainability of the skipjack tuna [3]. In addition, the WCPFC Science Commission in [8] stated that the use of purse seine and FAD fishing gears evokes 3 implications for the sustainability of the skipjack tuna resources, i.e. fishing capacity is increased, juvenile/young fish are caught, and non-target fish are accidently caught. Uncontrolled exploitation changes the structure of skipjack tuna population in the seas.

Tomini Bay in Fisheries Management Area (FMA) 715 is one of the marine areas with large skipjack tunas. In 2017, the entire FMA 715 produced 106,063 tons of skipjack tuna resources and became the second-largest producer of the species after FMA 714 [1]. Contributing 33% large pelagic fish (up to 30,610 tons), the Tomini Bay area is well-known for their potential resource (Suwarso in [9]). In addition, according to the Ministry of Maritime Affairs and Fisheries in 2014, the production of tuna, skipjack tuna, and mackerel tuna in the area was 20% of the national production [3]. The species is fished using large pelagic purse seines, and as it is a fast-swimming fish with a wide range, its management must be carried out simultaneously with other areas, not fragmented by specific areas only. The species’ movement is mainly influenced by several aspects, i.e., prey, ambient temperature, and oxygen [10] [11].

Furthermore, according to [12], the sustainable exploitation of the species requires scientific studies that can serve as the basis for managing the resource, both sub-regionally and regionally. In addition, [13] stated that sustainable fisheries management must meet 6 aspects, i.e. fish resources, habitat, ecosystem, fishing technique, socio-economic, and institutional. The management of the resource is implemented not only to keep the resource sustainable and to maintain the fishermen’s sustainable livelihood. Therefore, this scientific study on the exploitation status of the species is expected to serve as a reference and an input for policymakers in determining the management to be put in place to maintain the sustainability of skipjack tuna resource in Indonesia, particularly in Tomini Bay and its surrounding areas.

2. Materials and Methods

2.1 Data Collection

The study was carried out in 2 years, i.e., in May–December 2018 and in January–December 2019. The data was collected at Tenda Fish Landing Base (PPI Tenda) in Gorontalo by the researchers assisted by an enumerator who collected data daily. The enumerator collected data on the size of the skipjack tuna (Katsuwonus pelamis) (Figure 1) landed at PPI Tenda from their fishing grounds in Tomini Bay and its surrounding areas. See Figure 2 for the fishing grounds of the skipjack tuna in Tomini Bay based on the data collected by the enumerator. A total of 8,833 skipjack tunas were used as samples in this study. The samples were measured from the tip of the mouth to the tail fork (FL) using a tape measure.

![Figure 1. Skipjack tuna (Katsuwonus pelamis)](image)

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2.2 Data Analysis

The data collected were analyzed and tabulated monthly to acquire an overview of the size structure of the caught fish with a 3 cm class interval. The distribution of the fish size structure was used as the basis for calculating the mean length at first capture (Lc) of the fish caught using purse seine. The analysis was carried out using a standard logistic curve with 50% of the cumulative frequency [14]. On the other hand, the population dynamic parameters such as growth rate (K), asymptotic length (L∞), natural mortality (M), total mortality (Z), and fishing mortality (F) were analyzed using FiSAT program (FAO-ICLARM Stock Assessment Tools) [15]. The asymptotic length (L∞) and the growth rate (K) were estimated using ELEFAN I Program (Electronic Length Frequency Analysis) developed by [16] and [15]. In addition, the total mortality (Z) was analyzed using catch curve method that was the slope (b) between Ln N/t and the relative age [17]. The theoretical age when the skipjack tuna’s length equals to zero (t0) was estimated using an empirical equation by [18] in [17], while the natural mortality (M) was analyzed using a formula by [18]. In addition, in [17], the fishing mortality (F) can be acquired by subtracting natural mortality (M) from the total mortality (M) (F = Z – M). Finally, the exploitation status (E) was calculated by dividing the fishing mortality (F) by the total mortality (Z) (E = F/Z).

3. Results and Discussion

3.1 Size structure and the length at first capture

In general, the size structure of the skipjack tuna (Katsuwonus pelamis) in 2018–2019 was 21–51 cmFL (Table 1). The dominant size of the fish was 33 cm FL (in 2018) and 30 cm FL (in 2019) (Figure 2). They were smaller than those caught in the Flores Sea using huhate (pole and line) (25–74 cm with modus 42 cmFL) and in Indian Ocean (20–65 cm FL), Makassar Strait (12.5–72.5 cm FL), Flores Sea 19.5–69.5 cmFL), Maumere (26–69 cm FL), North Maluku (26–72 cmFL), India (12–82 cmFL), Pacific Ocean (33.1–74.6 cmFL), Indian Ocean west of Java (20–64 cmFL), Indian Ocean west of Sumatera (18–70 cmFL), and Aceh’s west and north and west sea areas (25–51 cmFL) [5]; [6]; [19]; [20]; [21]; [22]; [23]; [24]; [25]; and [26]. The difference in the size may be due to different fishing gears and sizes used and water conditions, including foods available in the environment. The difference was also due to the nature of the species, i.e., the smaller and young ones are usually found near the water surface or FADs, while the bigger ones are in the deeper water [27]. In addition, [8] stated that skipjack tunas caught around FADs are usually smaller sizes smaller than those caught...
outside the FAD areas. Therefore, the fish caught in Tomini Bay waters were young and small-sized as they were caught using purse seine with FADs as an aid for the fishing gear.

Table 1. The size structure of the fork length (FL) of *Katsuwonus pelamis* in Tomini Bay, 2018–2019

| Fork Length (cm) | 2018 | 2019 |
|------------------|------|------|
| 21               | 47   | 45   |
| 24               | 64   | 232  |
| 27               | 292  | 531  |
| 30               | 867  | 1415 |
| 33               | 1012 | 928  |
| 36               | 773  | 878  |
| 39               | 264  | 320  |
| 42               | 363  | 521  |
| 45               | 23   | 100  |
| 48               | 2    | 120  |
| 51               | 1    | 35   |
| **Total**        | 3708 | 5125 |

The data above indicated that the fish size shifted, affecting the size at first capture (Lc). The Lc of the skipjack tuna was 31.8 cm (2018) and 32.2 cm (2019) (Figure 4). These Lc were smaller than those caught in the sea areas north and west of Aceh (38.2 cm FL) [26]. The Lc of the fish was smaller than 40 cm FL, while in several other locations, the sizes of the fish at first gonad maturity (Lm) were all greater than 40 cmFL, among others in Bone Gulf (46.5 cm FL), North Maluku (43 cm FL), Flores (41.1 cm FL), Kagoshima, Japan (40.5 cm FL) (female) and (37.6 cm FL) (male), the Indian Ocean south of Java (39.4 cm FL) and west of Sumatera (35.99 cm FL), and India (41 cm FL) [6]; [19]; [23]; [25]; [28]; and [29]. Therefore, the skipjack tunas caught in the Tomini Bay area were allegedly young ones that had yet to reach their first gonad maturity. However, fish’s first gonad maturity may vary depending on each location as it is influenced by various aspects, including food, environment, and the samples measured. According to [30], gonad maturity is influenced by age, size, sex, species, and habitat environment.

The findings above indicated that the skipjack tunas in Tomini Bay had not reached their catchable size, and it was in line with IOTC in [7] that stated the catchable-size of the fish is greater than 50 cm
According to [25], most fish caught by purse seine is below their size at their first gonad maturity (Lm). Based on the results of the study by the Ministry of Maritime Affairs and Fisheries stated in the Decree of the Minister of Maritime Affairs and Fisheries No. 107/KEPMEN-KP/2015 concerning Management Plan for Tuna, Skipjack Tuna, and Mackerel Tuna Fisheries, the size at the first capture (Lc) of skipjack tunas caught by purse seine in FMA 715 is smaller than their size at first gonad maturity (Lc < Lm).

![Figure 4. Size at first capture (Lc) of Katsuwonus pelamis in Tomini Bay, (a) 2018; (b) 2019](image)

3.2 The population dynamics, recruitment, and the exploitation status

Based on the analysis on the size structure, the growth rate (K) of the skipjack tuna was 0.6 per year, with asymptotic fork length (FL∞) 55.05 cmFL (Figure 5). According to [17], a growth rate greater than 0.5 belongs to slow growth category. The growth rate of the skipjack tuna in this area was in line with the growth rate of those caught in Andaman Sea [31]. However, the growth rate was different from those in other areas, among others in Indian Ocean south of Java (K = 0.27 per year) and west of Sumatera (K = 0.22 per year) [25], north and west of Aceh (K = 0.22 per year) [26], North Maluku (K = 0.29–0.3 per year) [27], and Maumere (K = 0.55 per year) [22], as well as in south of Java (K = 1.1 per year) according to another research by [20]. The difference was possible because according to [32] the difference in K is directly proportional to the size of the samples measured during the study. In addition, according to [20] and [33], food availability also influences the growth rate (K). Skipjack tuna feeds on fish, squid, fish debris, and some crustaceans [19]. Sufficient food provides energy for fish to grow, and subsequently the difference in the growth rate (K) affects the time the fish require to reach their asymptotic fork length (FL∞).

![Figure 5. The frequency distribution of the total length (TL) of Katsuwonus pelamis in Tomini Bay, 2018–2019](image)
Furthermore, the recruitment of the fish in the area occurred all year long, and the highest was in April to June, with peak recruitment in May (16.12%) (Table 2). According to [34], recruitment correlates with fish spawning and natural mortality that influence the abundance of exploitable fish stocks. The all-year-long recruitment process of the skipjack tuna indicated that the fish is a partial spawner. According to [17], fish living in tropical waters spawn all year long. The recruitment of the skipjack tuna in this area was different from the recruitment of those found in the Andaman Sea (the highest recruitment in August), India (May to November), the Indian Ocean south of Java (March and September), and west of Sumatera (January to March and June to August) [6]; [25]; and [31]. The difference in the recruitment period of the fish in a different area was due to their different spawning process that depended on the environmental condition and individual growth rate. According to [33], spawning depends on species, age, temperature, environment, and food availability.

Table 2. The recruitment of *Katsuwonus pelamis* in Tomini Bay

| Month    | Recruitment (%) |
|----------|-----------------|
| January  | 6.16            |
| February | 9.59            |
| March    | 8.77            |
| April    | 14.61           |
| May      | 16.12           |
| June     | 16.05           |
| July     | 13.41           |
| August   | 5.81            |
| September| 4.82            |
| October  | 4.05            |
| November | 0.61            |
| December | 0               |

Growth rate affects the time required for fish to reach their adult and asymptotic sizes. The sizes of the skipjack tunas in the area at the age of 1, 2, 3, and 4 years were 28.7 cm FL, 40.6 cm FL, 47.1 cm FL, and 50.7 cm FL, respectively (Figure 6). However, they required up to 10 years of age to reach their asymptotic length (55.05 cm FL). These were different from the findings on the skipjack tunas in the Andaman Sea, where at the age of 1, 2, 3, and 4 years their sizes were 38.1 cm FL, 54.4 cm FL, 63.4 cm FL, and 68.3 cm FL, respectively; in India 36.3 cm FL, 58 cm FL, 71.5 cm FL, and 79.6 cm FL, respectively, and in the Indian Ocean 37 cm FL, 46 cm FL, 55 cm FL, and 64 cm FL, respectively [6]; [25]; and [31]. The difference in the sizes was due to their different growth rate, and it also indicated that the fish grew rapidly at a young age and the growth slowed down when they reached their asymptotic length. Therefore, when young fish dominate the catch, the number of adult fish will decline, influencing the process of adding individuals in waters.
Figure 6. The growth curve of *Katsuwonus pelamis* in Tomini Bay

The fishing mortality of the fish in the area was \( F = 0.96 \) per year, with natural mortality \( M = 2.06 \) per year. The high natural mortality rate of fish can occur due to the change in environmental temperature that has a significant influence on skipjack tunas’ vertical and horizontal movements [11]. On the other hand, fishing mortality is affected by using various fishing gears of different sizes, causing the catch to consist of young fish. Based on the comparison of the natural mortality (M) and the fishing mortality (F) of the skipjack tuna in Tomini Bay, the exploitation rate of which was \( E = 0.47 \) (moderate to fully exploited), indicating the exploitation of the fish already requires precautionary management to keep the resource sustainable. is in line with the Decree of the Minister of Maritime Affairs and Fisheries No. KEP.45/MEN/2011 concerning the Estimated Potential of Fish Resource in the Fisheries Management Areas of the Republic of Indonesia which states that the exploitation rate of skipjack tunas is moderate in the FMA-RI 713, FMA-RI 714, and FMA-RI 715.

Therefore, management efforts are imperative, as continuous uncontrolled exploitation will definitely lead to overfishing skipjack tuna in the area, eventually compromising the resource's sustainability. According to [35], there are two types of overfishing, i.e., growth overfishing and recruitment overfishing. The condition of the skipjack tunas in the area, i.e., they were caught at a young age, will lead to growth overfishing. According to [9], uncontrolled exploitation will cause population decline because young fish are caught before they contribute to the environment, and therefore management efforts are necessary, including regulating the size of the fishing gears and the size of the mesh used. In addition, according to [25], the selectivity of the fishing gears can become one of the solutions in regulating the size of the exploited fish.

However, the management should not be implemented only by the local government of Gorontalo as the landing area, but also by the other areas situated in Tomini Bay and other areas such as Maluku and Papua. The management should be implemented in cooperation with other areas, not by an administrative area only, because the distribution of the resource can extend beyond the jurisdiction of a region and even a country [10] and [13]. Coordination among regions must be carried because skipjack tunas are fished using purse seine with FADs as the aids, and therefore conflicts among fishers are prone to occur. According to Gafa and Subani in [7], fish in Tomini Bay can last up to 340 days under FADs, and, because of this, lack of coordination will incite spite among fishers. Based on the recommendation of the Decree of the Minister of Maritime Affairs and Fisheries No. 107/KEPMEN-KP/2015 concerning Management Plan for Tuna, Skipjack Tuna, and Mackerel Tuna Fisheries, the use of purse seine fishing gear to catch skipjack tuna must be controlled/reduced in numbers, but pole and line, handline, and trolling line are allowed to be developed.

Joint management can be carried out by involving agencies, including skipjack tuna fishermen organizations. The fishermen can have an active role in joining the efforts to maintain the
sustainability of the resource after learning about the lifecycle of the skipjack tunas. The government can implement various policies by utilizing satellite technologies to allow them to map skipjack tuna fishing grounds, FAD locations, and equip fishing boats with location trackers. These efforts can help the monitoring agency, i.e. the Directorate General of Surveillance for Marine and Fisheries Resources of the Ministry of Marine Affairs (PSDKP-KKP), to detect fishing boats encroaching fishing grounds. In addition, each local government can cooperatively enforce policies to control the number and the size of fishing gears to keep skipjack tuna resources in Tomini Bay waters and its surroundings sustainable.

4. Conclusions and Suggestions
The skipjack tunas (Katsuwonus pelamis) in Tomini Bay caught using purse seine were 21–51 cm FL in size, with the size at capture 31–33 cmFL. The fish had a slow growth rate with its fishing mortality (F) lower than the natural mortality (M), and its status was moderate to fully exploited. Management efforts cannot be carried out jurisdictionally because they are fast-swimming and highly-migrating fish. Therefore it is imperative to have joint coordination among sub-regional and regional areas in controlling the number and the size of the fishing gears and educating the fishermen on resource sustainability.

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