Fisheries characteristics and spawning potential ratio of frigate tuna (*Auxis thazard*) in Gulf of Tomini

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Abstract. Frigate tuna (*Auxis thazard*) is a pelagic fish that has important economic value in Indonesian fisheries. The aim of this research was to determine fishery characteristics, population parameters and spawning potential ratio of frigate tuna in Gulf of Tomini. This research was conducted in 2020-2021, frigate tuna from Gulf of Tomini were caught using handliner and purse seiner. The sampling sites were established in Gorontalo, Ampana and Bitung, Indonesia. The catch composition of purse seine was dominated by small pelagic fish, while frigate tuna accounts for 10.81% of the total catch. The handline catch was dominated by large pelagic fish such as yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*), while frigate tuna has a smaller percentage, namely 1.87%. Purse seine and handline fishing ground were around fish aggregating devices (FADs), in the Gulf of Tomini, Molucca Sea and the Banda Sea. Purse seine and handline vessels do not fish in the east season in July-September. Purse seine catch per unit effort (CPUE) was the highest in April, September and the lowest in October-November, with an average of 781 kg trip^{-1}, while handline CPUE was highest in August, September and lowest in June-July, with an average of 32 kg trip^{-1}. The size structure ranges from 13 to 44 cm with an average of 29 cm fork length. The value of Lc_{50} = 29.1 cm is greater than the value of Lm_{50} = 26 cm. The length infinity ($L\infty$) = 46.2 cm, growth rate (K) was 0.385 year^{-1} and t_0 -0.0517. The maximum lifespan of frigate tuna (t_{max}) is 8 years. Natural mortality (M) was 1.06 year^{-1}, fishing mortality (F) was 1.03 year^{-1}, total mortality (Z) was 2.09 year^{-1}, exploitation rate (E) was 0.49 year^{-1}, and spawning potential ratio (SPR) value was currently 0.38. There are indications that recruitment overfishing is occurring, so it is necessary to regulate the selectivity of fishing gear, especially purse seines. The status of frigates tuna status is still safe, but efforts are needed to be controlled because the level of exploitation is almost close to the optimum level.

Key Words: exploitation rate, frigate tuna, growth, mortality, spawning potential ratio.

Introduction. The frigate tuna (*Auxis thazard*) is one of the Scombridae family species, with a maximum total length of up to 65 cm (Cayré et al 1993). However, the commonly caught size is 25-40 cm, depending on the fishing gear used and the season and location of capture (Colette & Nauen 1983). Frigate tuna is an epipelagic and neritic fish, but it can also occur in oceanic waters in the tropical and subtropical regions. The species has a preference of depth range up to 50 m of the water column, with a localized migratory habit and mainly restricted to continental shelves and oceanic islands (Collette & Nauen 1983; Maguire et al 2006). Juveniles and pre-adults are found over the continental shelf (Deepti & Sujatha 2012). Gulf of Tomini is part of the Fisheries Management Area (FMA) 715 Indonesia, which includes the waters of Gulf of Tomini, the Molucca Sea, the Halmahera Sea, the Seram Sea, and Berau Bay. Fishermen typically use purse seine, handline, and pole and line to catch frigate tuna. Currently, frigate tuna fishing in FMA 715 often use fish aggregating devices (FADs).

The production of frigate tuna in FMA 715 over the past five years (2019-2023) has increased trend, peaking in 2022 at 35,743 tons and then decreasing to 16,073 tons in 2023. There is currently no specific stock status for skipjack tuna in FMA 715; instead, there is a stock status for large pelagic fish, which is an aggregate of all large pelagic fish such as neritic tuna except for tunas and skip jack (Minister decree/MMAF, No. 19/2022). The east-facing Gulf of Tomini boasts an average depth of 1500 meters and connects to both the Molucca Sea and the Sulawesi Sea. The Gulf of Tomini waters is water area with a high distribution of phytoplankton and zooplankton (Setyadji & Priatna 2011), this gulf boasts rich marine natural resources and a variety of potential pelagic fishery resources (Wiadnyana 1998).

Noegroho et al (2013), Hartaty & Setyadji (2016), Sulistyaningsih et al (2020), Tampubolon et al (2016), and several other writers have conducted research on frigate tuna in Indonesian waters. Research on frigate tuna in the Gulf of Tominis remains scarce, underscoring its significance and its potential contribution to sustainable fishery management. This research aims to determine the characteristics of fisheries, population parameters, and the spawning potential ratio (SPR) of frigate tuna. We expect the results of this study to establish sustainable management policies for frigate tuna resources.

Material and Method

Time and research location. The research was conducted in the Gulf of Tomini from 2020 to 2021, with sampling locations in Gorontalo, Ampana, and Bitung in Indonesia (Figure 1). The data gathered encompasses information on catch composition, fishing grounds, production, effort, catch per unit effort (CPUE), fork length, weight, and gonad maturity. The landed frigate tuna comes from purse seiner and handliner.

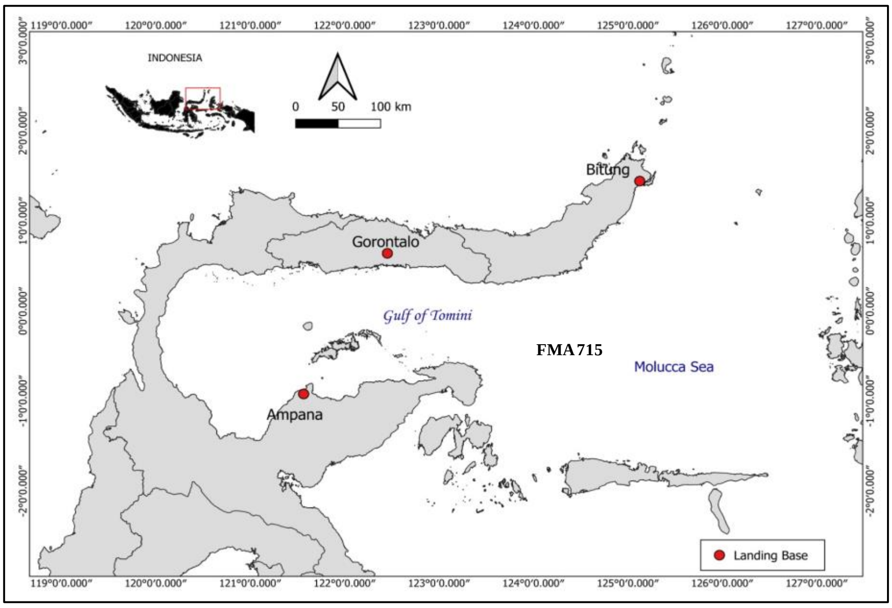

Figure 1. Research location map.

Catch composition and size structure. We obtained the catch composition data through direct observation at the landing site, using information collected by enumerators. The catch composition is presented in percentage form, with each species caught by each type of fishing gear. The analysis of catch composition is formulated as follows:

$$\text{Catch composition} = \frac{n_i}{N_i} \times 100$$

where: n_i = the weight of a particular fish species (kg);

N_i = the total weight of the catch (kg).

The fork length of frigate tuna samples was collected monthly from 2020 to 2021. Next, we created the length-frequency distribution using a 1 cm class interval. Size structure was observed to see the fishing gear's selectivity, the caught fish's dominant size, and growth analysis. The fishing ground was created based on a grid map prepared with a size of 1 degree, and each cell was assigned a grid number. The enumerators, who interviewed the fishermen, filled in the grid map. The results are presented as spatially shaded maps for purse seine and handline fishing gear.

Catch per unit effort (CPUE). Catch and effort data were obtained by recording the landing data of each vessel at the landing port. Data collection was assisted by enumerators, who also recorded operational data of the vessels and the size of the frigate tuna. CPUE was formulated according to Sparre & Venema (1999) as follows:

$$CPUE = \frac{c}{e}$$

where: c = total catch (kg);
e = total efforts.

Growth estimation. The size structure of the frigate fish was obtained by creating a length frequency from the lengths of the fish collected during the study. Fish sampling was conducted randomly at fish landing sites and fish collectors. The length of the fish was measured using a measuring board with centimeter units. From the length measurements, the percentage frequency of length was then calculated in 1 cm class intervals. Growth parameters (K and L∞) were estimated using the electronic length frequency analysis (ELEFAN-1) method on a computer with the FiSAT software (Gayanillo et al 1996). The following equations are based on the Von Bertalanffy (Beverton & Holt 1957) equation:

$$Lt = L\infty\ [1\text{-}exp^{-K(t-to)}]$$

where: Lt = length at age t (cm);
L∞ = asymptotic length (cm);
K = parameter describing the rate of reaching L∞ ($year^{-1}$);
t_0 = theoretical age when the fish is of zero length (year).

The equation of Pauly (1983) serves as the basis for the calculation of the parameter t_0 (age at 0 years):

$$Log\ (-t_0) = 0.3922 - 0.2752\ Log\ (L_\infty) - 1.038\ Log\ (K)$$

The equation of Alagaraja (1984) estimates the maximum age of the frigate tuna (t_{max}):

$$t_{max} = \left(-\frac{1}{K}\right) ln\left(1 - \frac{0.95L_\infty}{L_\infty}\right)$$

Mortality. Natural mortality (M) of frigate tuna was obtained based on the empirical equation of Zhang & Megrey (2006), namely:

$$M = \frac{\beta K}{e^{K(C_i.t_{max}-t_0)-1}}$$

where: M = natural mortality ($year^{-1}$);
Ci = constant for pelagic fishes is 0.33;
t_{max} = maximum age of the fish (year);
β = growth coefficient concerning a length to weight.

The equation yields the fishing mortality (F) based on the estimation of total mortality (Z) and M values:

$$Z = F + M \quad or \quad F = Z - M$$

$$E = F/Z$$

where: Z = total mortality ($year^{-1}$);
F = fishing mortality ($year^{-1}$);

M = natural mortality ($year^{-1}$);
E = exploitation rate ($year^{-1}$)

The cubic equation of Ricker (1975) provides the basis for the length-weight relationship:

$$W = aL^b$$

where: a = constant;
W = the weight of the frigate tuna (g);
L = the fork length of the frigate tuna (cm);
b = the growth coefficient.

The average length at first capture (Lc) and gonad maturity (Lm). The equation of Gunderson (1976) estimates the average length at first gonad maturity (Lm_{50}) based on the logistic function of the proportion of mature gonad fish to immature gonad fish:

$$P_m = \frac{1}{1 + e^{-(a+bL)}}$$

where: P = the proportion of mature gonad fish (%);
L = the length of the fish (cm);
a and b = constants.

The equation -a/b yields the average size at first gonadal maturity (Lm_{50}).

We estimated the average size at first capture (Lc_{50}) using a logistic function by plotting the frequency of each age class, which we then converted into length. The average size at first capture (Lc_{50}) uses the equation (Sparre & Venema 1992):

$$S_t = \frac{1}{[1 + exp(T1 - T2(t)]}$$

where: St = the selectivity at age t;
T1 and T2 = constants;
t = the age in length classes (year).

We obtained the average age at first capture from T1/T2.

Spawning potential ratio. This study uses the length-based spawning potential ratio (SPR) as one of its models to determine biological reference points, which are based on the percentage of fish reproductive potential that remains in the wild (Hordyk et al 2015a, b). The estimation of SPR requires several growth and population parameters for frigate tuna (Table 1). We obtain the SPR by comparing the proportion of spawning stock biomass per recruit under capture conditions to the spawning stock biomass per recruit under no-capture conditions (Goodyear 1993; Hordyk et al 2015a, b). Clark (2002) recommends 40% SPR as the optimal SPR point, and in this study, it is used as an indicator in determining the stock status of frigate tuna in Gulf of Tomini.

Table 1

Input parameter for SPR analysis

Parameter	*Description*
F	Fishing mortality
K	Growth rate
M	Natural mortality
t0	Theoretical age when the fish is of zero length
L∞	Length infinity
a	Constant
b	Slope of length-weight relationship
Lc	Length at first capture
Lm	Length at first maturity

In the calculation of SPR value, some population parameters data are required: mortality (M), fishing mortality (F), asymptotic length (L∞), growth rate (K), and life history data consisting of the size at first gonad maturity (Lm) and the size at first capture (Lc), as well as the constant values a and b from the length-weight relationship (Hordyk et al 2015b).

Prince et al (2015a) developed the following method for analyzing SPR by size:

$$SPR_t = \frac{\sum_{t=0}^{t} EP_t}{\sum_{t=0}^{tmax} EP_t}$$

$$EP_t = (N_{t-1^e} - M)f_t$$

where: SPR_t = spawning potential ratio in year t;
EP_t = the reproduction output at age t;
N_t = the number of individuals at time t, with N_0 being 1000;
M = natural mortality ($year^{-1}$);
f_t = the average fecundity (eggs).

However, since f_t's value is unavailable, we calculated EP_t using the following equation:

$$EP_t = N_t \times W_t \times m_t$$

where: W_t = the weight of the fish at age t (g);
m_t = the average size of fish with mature gonads (cm).

The status of fish exploitation based on the SPR value refers to Ault et al (2008), which has three categories: over exploitation (SPR < 20%), fully exploitation (SPR > 20-30%), and under exploitation (> 30-50%).

Results. Catch composition of purse seine was dominated by small pelagic fish, such as *Decapterus macrosoma* (31.8%), *Decapterus macarellus* (24.45%), and *Selar crumenopthalmus* (13.60%). Figure 2 shows that frigate tuna, at 10.81%, and *Katsuwonus pelamis*, at 10.09%, dominate the large pelagic fish.

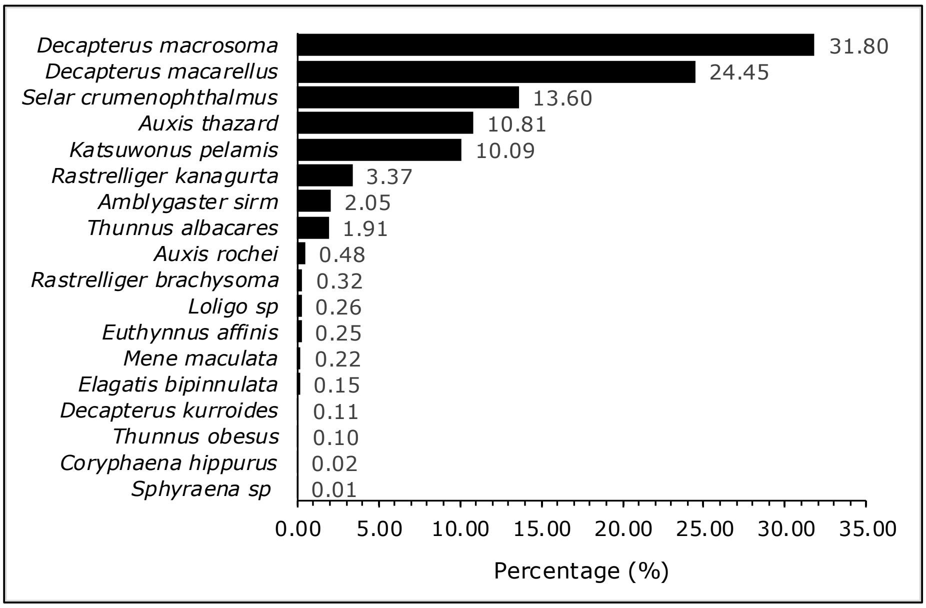

Figure 2. The catch composition of purse seiner.

Figure 3 shows that *Thunnus albacares* (60.01%) and *Katsuwonus pelamis* (21.04%) dominate the composition of handline catches. Compared to purse seine, the percentage of frigate tuna caught with handline is significantly smaller, at 1.87%.

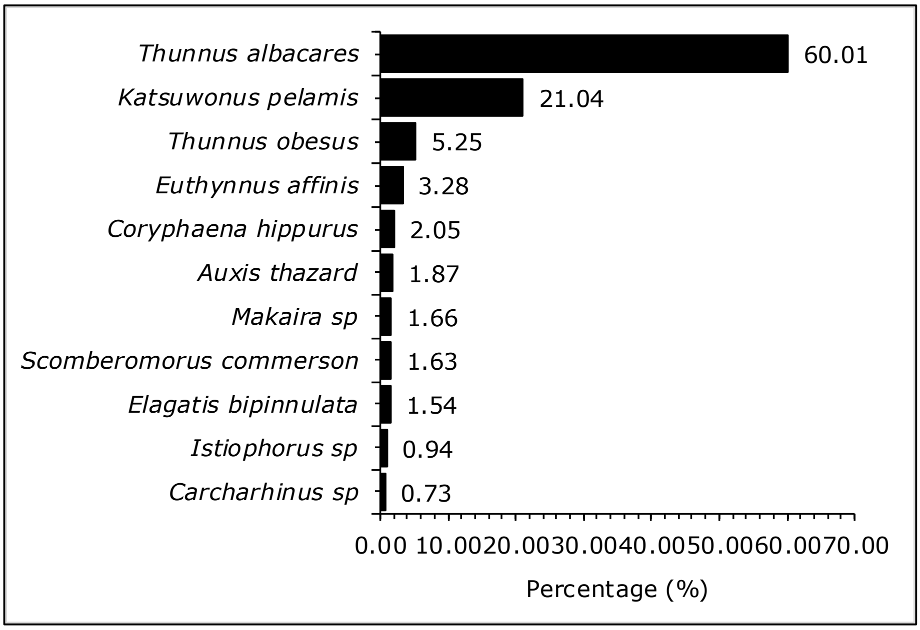

Figure 3. The catch composition of handliner.

Fishing ground. The Gulf of Tomini, parts of the Molucca Sea, and occasionally the northern side of the Banda Sea are areas where purse seine fishing gear can be found. Purse seine vessels are larger than handline vessels, 20-30 GT, allowing them to catch fish in fishing grounds farther from their home port (Figure 4). The handline-catching fishing ground spans almost all waters of Gulf of Tomini and parts of the western Molucca Sea. (Figure 5). Purse seine and handline both have almost the same fishing ground, namely at the FADs. Even though so far the interaction between purse seine and handline fishermen has been well established, the potential for conflict between the two being very possible.

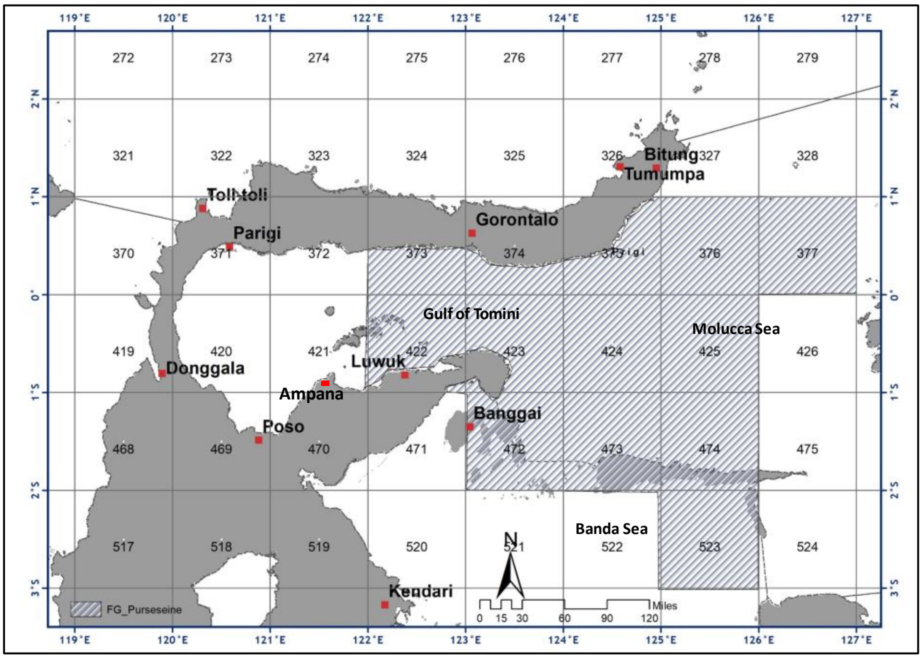

Figure 4. Purse seine fishing ground.

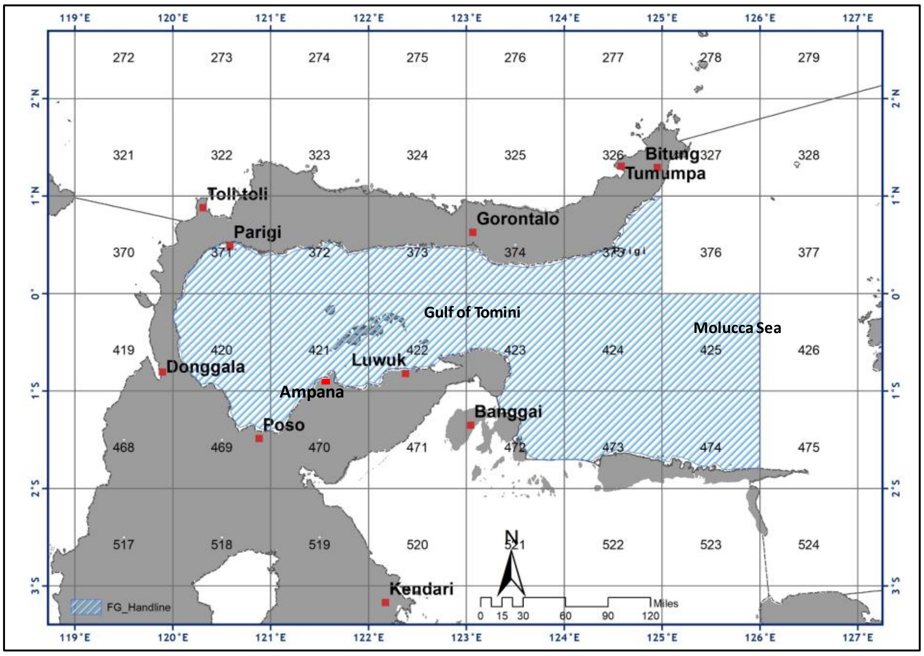

Figure 5. Fishing ground of handline.

Catch per unit effort (CPUE). CPUE purse seine was highest in April and September and lowest in October-November, with an average of 781 kg trip^{-1}, while handline CPUE was highest in August and September and lowest in June-July, with an average of 32 kg trip^{-1}. (Figure 6).

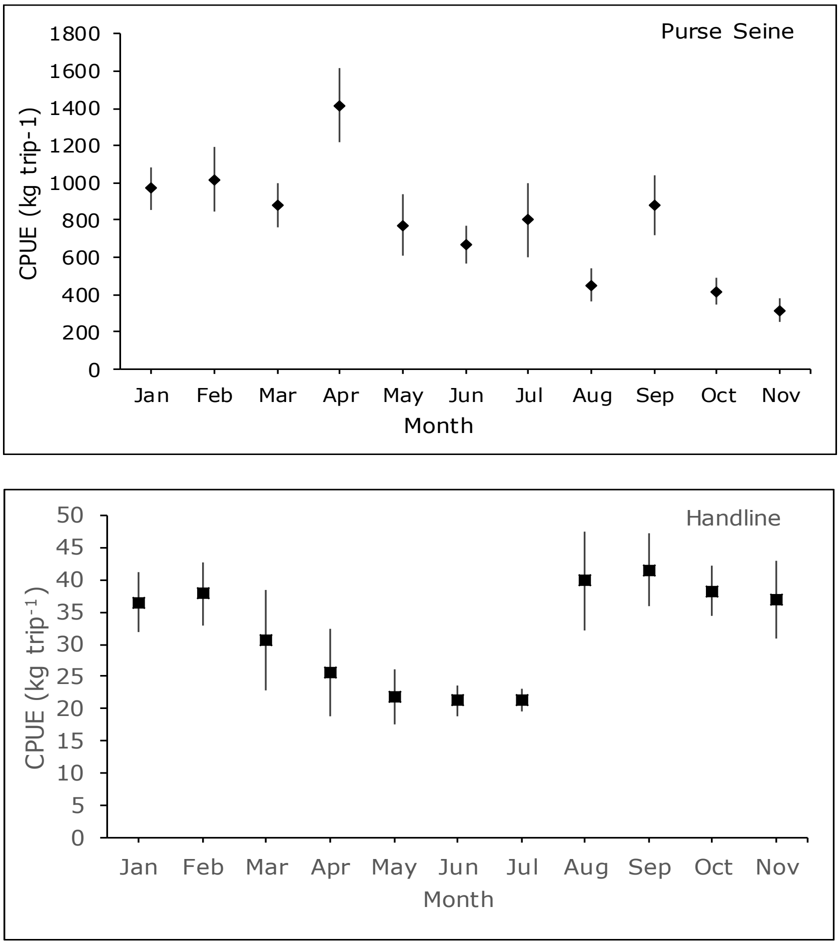

Figure 6. CPUE purse seine and handline in the Gulf of Tomini.

Size structure. The size of frigate tuna in Gulf of Tomini ranges from 13 to 44 cm, with an average length of 29 cm (Figure 7).

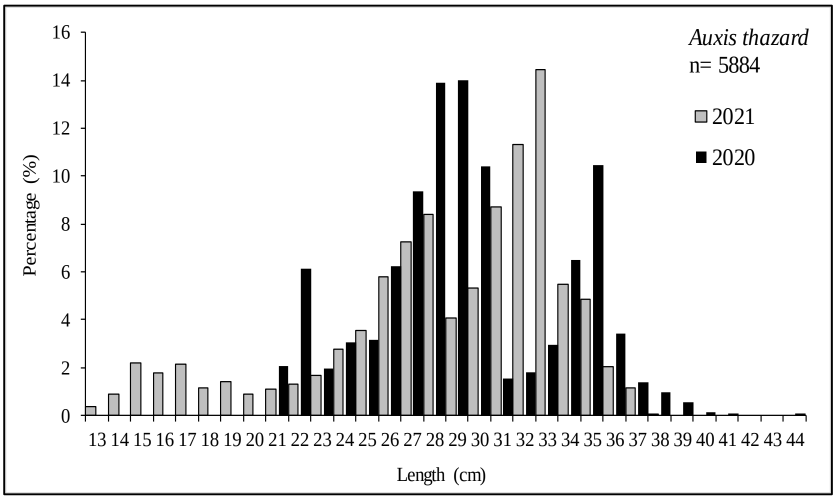

Figure 7. Frequency distribution of the length of frigate tuna in 2020-2021.

Growth. Based on the monthly modal shifts in 2020 and 2021, we found that frigate tuna has an asymptotic length ($L\infty$) of 46.2 cm, a growth rate (K) of 0.385 cm year^{-1}, and a theoretical age of -0.0517 when length equals 0 (t_0). This gives us the Von Bertalanffy growth equation for frigate tuna as $Lt = 46.2(e^{(-0.385(t+0.0517))})$ (Figure 8). The maximum age of the frigate tuna (tmax) is 8 years. At the ages of 1 and 2 years, the frigate tuna reaches lengths of 15 and 25 cm, respectively.

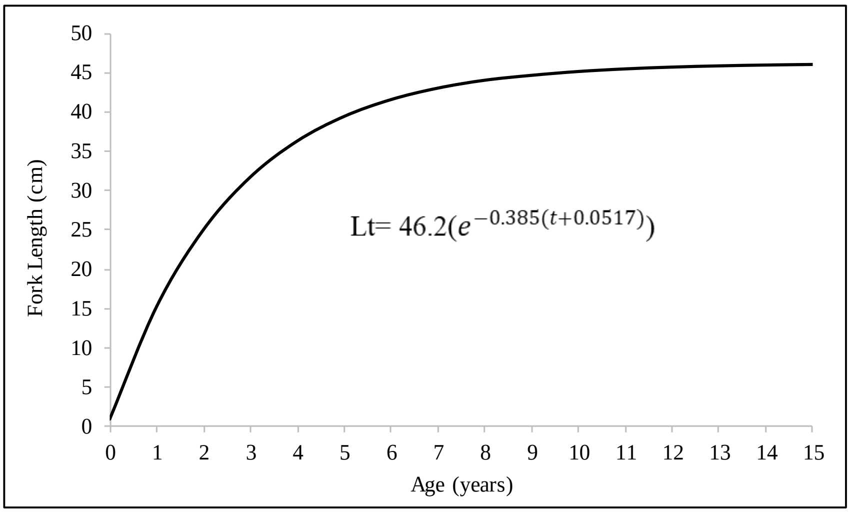

Figure 8. Von Bertalanffy growth curve for frigate tuna (*Auxis thazard*).

The length-weight relationship of frigate tuna follows the equation $W = 0.007L^{3.251}$ (Figure 9). The length-weight relationship yields a positive allometric growth pattern (b > 3), with a value of a = 0.007 and b = 3.251 (Figure 9). The growth coefficient (b) greater than 3 indicates a positive allometric growth pattern, showing that the weight growth of the fish is more dominant than its length.

Mortality rate. The natural mortality rate (M) is 1.06 year^{-1}, the fishing mortality rate (F) is 1.03 year^{-1}, and the total mortality (Z) is 2.09 year^{-1} (Figure 10). The exploitation rate (E) of 0.49 year^{-1} is nearing the optimum point, which is E = 0.5.

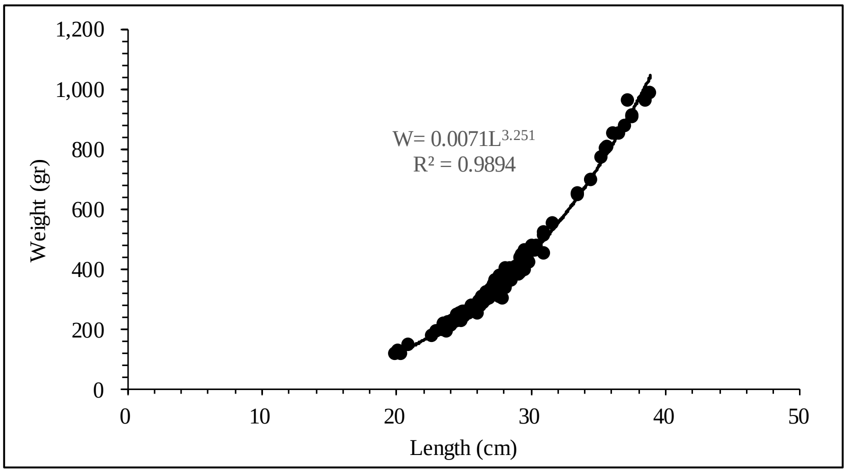

Figure 9. Length-weight relationship of the frigate tuna (*Auxis thazard*).

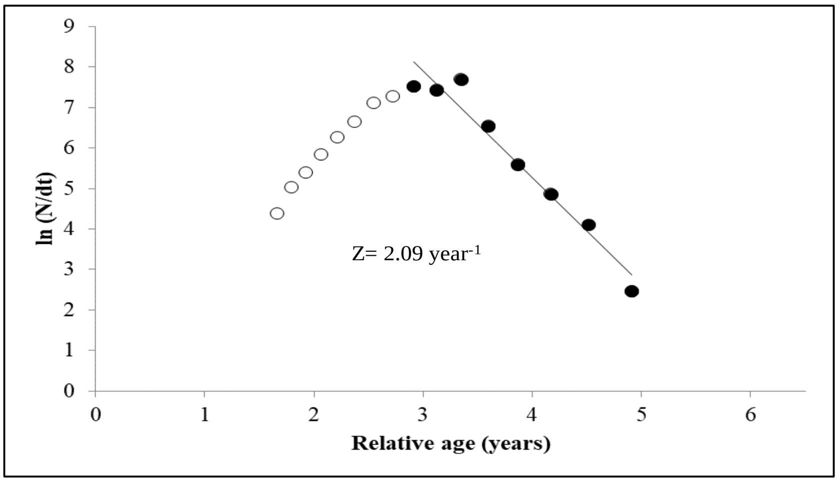

Figure 10. Length converted catch curve for frigate tuna.

The length at first capture and the length at first maturity. The length at first capture of frigate tuna with the handline (Lc_{50} = 29.1 cm) is larger compared to the average size at first gonadal maturity (Lm_{50} = 26 cm) of frigate tuna (Figure 11). This condition indicates that most of the caught frigate tuna are mature fish.

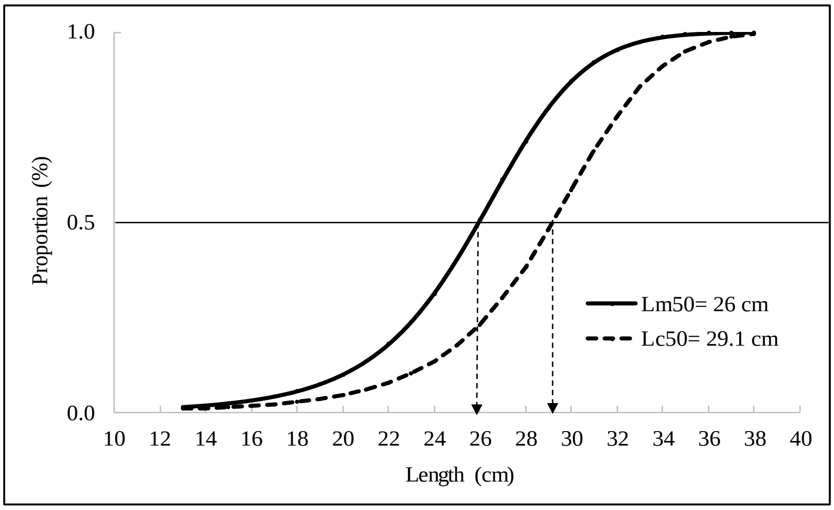

Figure 11. The length at first capture and the length at first maturity for frigate tuna.

Spawning potential ratio (SPR). The SPR value of frigate tuna is 0.38 (38%), or still greater than the limit reference point of SPR (20%). Figure 12 presents the SPR value and fishing mortality for the frigate tuna.

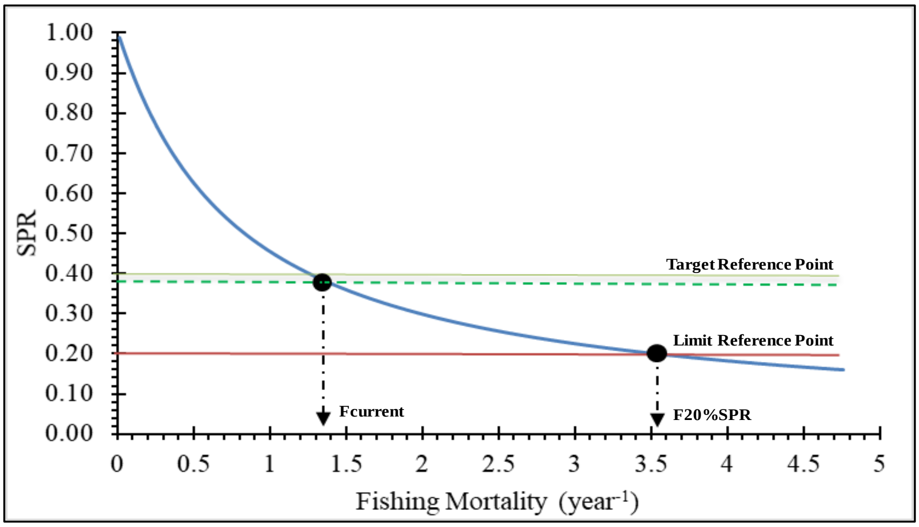

Figure 12. Spawning potential ratio of frigate tuna in the Gulf of Tomini.

Discussion. The catch of frigate tuna using purse seine is greater than with handline. A variety of fish species make up the catch when using a purse seine. This demonstrates the diversity of fish species found in the FADs area. In addition to providing many benefits, the use of FADs also has the potential for overfishing, increased bycatch, environmental pollution, and ghost fishing (Pons et al 2023). According to its specifications and permits, purse seine targets small or large pelagic fish, but the results show that it can catch almost all types of fish in the FADs area. Similarly, handlines that target tuna around the FADs also catch another fish, as they utilize various types of hooks to the specific fish they aim to catch. Similarly, in the Gulf of Tomini, the types of fishing gear operated around FADs in the waters of Palabuhanratu include handlines, trollines, kite lines, and float/drift lines (Hargiyatno et al 2013).

The purse seine fishing ground is predominantly in the FADs area, and it rarely operates outside the FADs. The purse seine fishing season is not continuous throughout the year; it ends during the East Wind. The East Wind season is a wind that blows from the East to the West, blowing slowly with moderate to strong force, causing high waves. The east wind blows from July to September. Large purse seine vessels occasionally venture out to sea to conduct fishing operations around the islands. This ensures that the vessels can seek shelter near the islands in the event of strong winds or high waves. During certain seasons, the fishing grounds also extend to the Maluku Sea and Banda Sea. The fishing ground for handline is dominant around deep coastal waters, where the nearest FADs are located. During the East season, handlines do not operate, except those with fleets larger than 20 GT. If extreme weather occurs, then handlines do not operate. Handlines operating around the FADs target large pelagic fish such as tuna and skipjack, unlike handlines operated by fishermen outside FADs, where the target catch is usually reef fish or demersal fish.

While the average CPUE of purse seine surpasses that of handline, a closer examination reveals that small pelagic fish dominate purse seine, while large pelagic fish dominate by handline. Both fishing gears operate around FADs, yet their distinct selectivity results in a significantly different catch composition. The East Wind season, which runs from July to September, also leads to a decline in the CPUE of both handline and purse seine. The purse seine's catch results declined in August, while the handline catch results decreased in July. Strong winds and high waves primarily caused the decline in the CPUE value, as several boats refrained to fishing. The difference in purse seine catch results each month is very significant. This is because during periods of strong winds or high waves, purse seine boats continue to fishing, shifting their fishing grounds to areas closer to or around the island. This allows the boats to seek shelter if the weather becomes unpredictable.

The trend of handline CPUE changes every month with smoother variations and spikes starting in September. This also indicates that the peak season for catching large pelagic fish with handlines occurs from September to November and January to February. Yellowfin tuna and skipjack tuna dominate the handline catch, despite the handline's lower average CPUE compared to purse seine. The catch of frigate tuna is greater using purse seine than with handline. CPUE as a temporal abundance index shows a greater abundance of frigate tuna with purse seine. We need longer time series data to observe the trend of CPUE. The CPUE of purse seine and handline decreases during the East season. This information slightly deviates from Nugraha & Suwarso's (2006) assertion that fishing activities in Gulf of Tomini take place from October to May, with a significant decrease from June to September.

The infinity length of frigate tuna in the waters of Gulf of Tomini reaches 46.2 cm with a growth rate coefficient of 0.385 year^{-1}. Table 2 lists the comparison of infinity length (L∞) and growth rate (K) in various waters.

Table 2

Growth parameters of frigate tuna in several waters

Area	*L∞ (cm)*	*K year^{-1}*	*References*
West Java	51.5	1.0	Dwiponggo et al (1986)
Thailand	47.2	0.80	Yesaki (1982) in Yesaki & Arce (1993)
Taiwan	48.17	0.5	Tao et al (2012)
Indian coast	57.95	1.2	Abussamad et al (2013)
West Sumatera	47.9	0.58	Hartaty & Setyadji (2016)
South Bali	50	0.3	Pratiwi & Suryaningtyas (2022)
Gulf of Tomini	46.2	0.385	This study

The difference in L∞ and K values is influenced by several factors, both internal and external. Schluderman et al (2009) stated that the internal factors affecting growth rate are genetic and physiological. Meanwhile, the most significant external factors are interactions (competition and predation) and environmental conditions (such as food availability, temperature, and salinity). Litvak & Leggett (1992), Keckeis & Schiemer (1992), Pepin et al (2003), and Magnussen (2007) have reported these findings. Gjedrem (2000) asserted that environmental factors influence 70-80% of fish growth, with genetic factors accounting for the remaining percentage. This indicates that the difference in productivity between one aquatic area (ecosystem) and another results in differences in fish growth rates.

Both fishing and natural mortality in frigate tuna indicate a high value. While controlling natural mortality is challenging, we can still manage fishing mortality through strategies such as effort regulation, seasonal closures, or other management measures. Table 3 lists the comparison of mortality and exploitation rates for frigate tuna. Hartaty et al (2014) reported a higher exploitation rate in the waters of West Sumatra.

Table 3

Mortality and exploitation rate of frigate tuna

Location	*Z*	*M*	*F*	*E*	*Reference*
Taiwan Strait	1.31	0.91	0.40	0.31	Tao et al (2012)
Indian water	4.89	1.65	3.24	0.66	Ghosh et al (2012)
West Sumatera	1.71	1.08	0.63	0.37	Hartaty et al (2014)
Belawan, Sumatera	1.95	0.43	1.46	0.74	Dewi (2015)
Gulf of Tomini	2.09	1.06	1.03	0.49	This research

However, catch control is necessary because the exploitation level is nearly reaching the optimum level (E = 0.5). The total mortality rate for frigate tuna in Gulf of Tomini is higher compared to the waters of West Sumatra, Belawan and Taiwan Strait as well according to the Table 3. Several factors, including food availability, disease, environment, competition, and the presence of predators, influence the difference in natural mortality. Differences in fishing pressure cause the difference in fishing mortality and total mortality. Because selective fisheries only target certain size classes within a stock in their analysis, the use of an exploitation rate (E) of 0.5 as a reference point often results in bias (Hordyk et al 2015b).

The proportion of uncaught fish that have the potential to spawn after fishing pressure is known as the spawning potential ratio (SPR) (Mace 1994; Walters & Martell 2004; Prince et al 2015b). In Gulf of Tomini, the estimated SPR of frigate tuna is 0.38, or 38%, indicating that approximately 38% of this fish population remains uncaught and has the potential to spawn. According to Ault et al (2008) and Prince (2015a), the SPR reference point sets a minimum threshold of 20% and a target reference point of 40%. In Gulf of Tomini, the frigate tuna's SPR surpasses the minimum reference point and falls short of the target reference point. This suggests that its exploitation remains safe, allowing for proper supervision of development efforts. The status of frigate tuna when viewed from fishing mortality is still safe, because the F current value is 1.34, which is less than the F value of the 20% limit reference point SPR (3.55). The F current value produces a SPR value of 38%.

This can be interpreted as meaning that exploitation of frigate tuna is currently still safe because the fishing pressure that causes fishing mortality is still low. Indications of recruitment overfishing were found based on the average length at first capture being larger than the size at first maturity. With this indication, it is necessary to regulate the selectivity of fishing gear, especially purse seines, regulate the fishing grounds and fishing seasons. From the SPR value shows that the fishing of frigate tuna is still safe, but catch and efforts need to be controlled because the level of exploitation is almost close to the optimum level.

Conclusions. Frigate tuna are caught more often with purse seine than with handline. Small pelagic fish like Indian scad and mackerel scad dominate from purse seine catch, while large pelagic fish like yellowfin tuna and skipjack tuna dominate from handline catch. The FADs area is the main fishing grund for purse seine and handline. The highest purse seine CPUE is in April and September and the lowest in October-November, while the highest handline CPUE is in August and September and the lowest in June-July, when the CPUE decreases due to the East season characterized by strong winds and high waves. The length infinity ($L\infty$) was 46.2 cm, growth rate (K) was 0.385 year^{-1} and t_0 -0.0517. The maximum lifespan (tmax) of frigate tuna is 8 years. The natural mortality (M) was 1.06 year^{-1}, fishing mortality (F) was 1.03 year^{-1}, total mortality (Z) was 2.09 year^{-1} and exploitation rate (E) was 0.49 year^{-1}. The average catch size surpasses the size of mature gonads, a sign of overfishing recruitment has occurred. This necessitates to regulation of selectivity in fishing gear, such as adjusting the meshsize of purse seine and the type of hook used. We classify the level of exploitation as moderate to optimal, necessitating the control of effort or catch. The status of frigate tuna is still considered safe because the SPR value is still greater than the SPR limit reference point.

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References

Abussamad E. M., Koya K. P., Rohith P., Kuriakaose S., 2013 Neritic tuna fishery along the Indian coast and biology and population characteristics of longtail and frigate tuna. IOTC–2013–WPNT03–18 Rev_2, 8 pp.

Alagaraja K., 1984 Simple methods for estimation of parameters for assessing exploited fish stocks. Indian Journal of Fisheries 31(2):177-208.
Ault J. S., Smith S. G., Luo J., Monaco M. E., Appeldoorn R. S., 2008 Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. Environmental Conservation 35(3):221-231.
Beverton R. J. H., Holt S. J., 1957 On the dynamics of exploited fish populations. Great Britain, Ministry of Agriculture, Fisheries and Food, Fishery Investigations, Volume 19, 533 pp.
Cayré P. M., Diouf T., 1983 Estimating age and growth of little tunny*, Euthynnus alletteratus,* off the coast of Senegal, using dorsal fin spine sections. In: Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. Prince E. D., Pulos L. M. (eds). Washington, NOAA Technical Report NMFS 8, pp. 105-110.
Cayré P., Amon Kothias J. B., Diouf T., Stretta J. M., 1993 Biology of tuna. In: Resources, fishing and biology of the tropical tunas of the Eastern Central Atlantic. Fonteneau A., Marcille J. (eds), FAO Fisheries Technical Paper 292, FAO, Rome, pp. 147-244.
Clark W. G., 2002 $F_{35\%}$ revisited ten years later. North American Journal of Fisheries Management 22:251-257.
Collete B. B., Nauen C. E., 1983 FAO special catalogue*.* Vol. 2 Scombrids of the world: an annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date. FAO Fisheries Synopsis No., 125 vol 2, FAO, Rome, 137 pp.
Deepti V. I., Sujatha K., 2012 Fishery and some aspects of reproductive biology of two coastal species of tuna, *Auxis thazard* (Lacepède, 1800) and *Euthynnus affinis* (Cantor, 1849) off North Andhra Pradesh, India. Indian Journal of Fisheries 59(4):67-76.
Dewi K., 2015 [Analysis of growth and exploitation rates of frigate tuna *Auxis thazard* landed at Village Unit Cooperative Gabion, Belawan Ocean Fishing Port, North Sumatera]. BSc Thesis, North Sumatera University, 72 pp. [in Indonesian]
Dwiponggo A., Hariati T., Banon S., Palomares M. L., Pauly D., 1986 Growth, mortality and recruitment of commercially important fishes and penaeid shrimps in Indonesian waters. ICLARM Technical Reports 17, 91 pp.
Gayanilo Jr. F. C., Sparre P., Pauly D., 1996 FAO-ICLARM stock assessment tools (FiSAT) user's guide. FAO Computerised Information Series (Fisheries) No. 8, FAO, Rome, 126 pp.
Ghosh S., Sivadas M., Abdussamad E. M., Rohit P., Said Koya K. P., Joshi K. K., Chellappan A., Rathinam M. M., Prakasan D., Sebastine M., 2012 Fishery, population dynamics and stock structure of frigate tuna *Auxis thazard* (Lacepede, 1800) exploited from Indian waters. Indian Journal of Fisheries 59(2):95-100.
Gjedrem T., 2000 Genetic improvement of cold-water fish species. Aquaculture Research 31(1):25-33.
Goodyear C. P., 1993 Spawning stock biomass per recruit in fisheries management: foundation and current use. In: Risk evaluation and biological reference points for fisheries management. Smith S. J., Hunt J. J., Rivard D. (eds), Special Publications in Fisheries and Aquatic Science 120, pp. 67-81.
Gulland J. A., 1983 Fish stock assessment: a manual of basic methods. Wiley and Sons, New York, 223 pp.
Gunderson D. R., 1976 Population biology of Pacific Ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte sound region, and their response to fishing. Fishery Bulletin 75(2):369-403.
Hargiyatno I. T., Anggawangsa R. F., Wudianto, 2013 [Hand lines fishery in Palabuhanratu: technical performance of fishing gear]. Jurnal Penelitian Perikanan Indonesia 19(3): 121-130. [in Indonesian]
Hartaty H., Setyadji B., 2016 [Population parameter of frigate tuna (*Auxis thazard*) in the Sibolga and adjacent waters]. BAWAL 8(3):183-190. [in Indonesian]
Hartaty H., Amalia A. C., Mashar R., 2014 [Estimation of population parameters for cob balaki (*Auxiz thazard*) in the West Indian Ocean of Sumatra]. Best Research Results Seminar, pp. 183-189. [in Indonesian]

Hordyk A., Ono K., Sainsbury K., Loneragan N., Prince J., 2015a Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES Journal of Marine Science 72(1):204-216.

Hordyk A. R., Ono K., Valencia S., Loneragan N. Prince J., 2015b A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES Journal of Marine Science 72(1):217-231.

Keckeis H., Schiemer F., 1992 Food consumption and growth of larvae and juveniles of three cyprinid species at different food levels. Environmental Biology of Fishes 33:33-45.

Litvak M. K., Leggett W. C., 1992 Age and size-selective predation on larval fishes: the bigger-is-better hypothesis revisited. Marine Ecology Progress Series 81(1):13-24.

Mace P. M., 1994 Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Canadian Journal of Fisheries and Aquatic Sciences 51(1):110-122.

Magnussen E., 2007 Interpopulation comparison of growth patterns of 14 fish species on Faroe Bank: are all fishes on the bank fast-growing? Journal of Fish Biology 71(2): 453-475.

Maguire J. J., Sissenwine M., Csirke J., Grainger R., Garcia S., 2006 The state of world highly migratory, straddling and other high seas fishery resources and associated species. FAO Fisheries Technical Paper No. 495, FAO, Rome, 84 pp.

Ministerial Decree of Marine Affairs and Fisheries (MMAF) Republic of Indonesia No. 19/2022 [Estimation of potential fish resources, number of fish catches allowed, and level of resource utilization fish in the state fisheries management area of the Republic Indonesia], Jakarta. [in Indonesian]

Noegroho T., Hidayat T., Amri K., 2013 Some biological aspects of frigate tuna (*Auxis thazard*), bullet tuna (*Auxis rochei*), and kawakawa (*Euthynnus affinis*) in West Coasts Sumatera IFMA 572, Eastern Indian Ocean. IOTC–2013–WPNT03–19, 13 pp.

Nugraha B., Suwarso, 2006 [Yellowfin tuna (*Thunnus albacares*) fisheries in Marisa waters, Tomini Bay]. BAWAL 1(3):107-111.

Nybakken J. W., 1992 [Marine biology: an ecological approach]. PT Gramedia. Jakarta, 480 pp. [in Indonesian]

Pauly D., 1983 Some simple methods for the assessment of tropical fish stocks. FAO Fisheries Technial Paper No. 234, FAO, Rome, 52 pp.

Pepin P., Dower J. F., Davidson F. J. M., 2003 A spatially explicit study of prey-predator interactions in larval fish: assessing the influence of food and predator abundance on larval growth and survival. Fisheries Oceanography 12(1):19-33.

Pons M., Kaplan D., Moreno G., Escalle L., Abascal F., Hall H., Restrepo V., Hilborn R., 2023 Benefits, concerns, and solutions of fishing for tunas with drifting fish aggregation devices. Fish and Fisheries 24(6):979-1002.

Pratiwi M. A., Suryaningtyas E. W., 2002 [Growth aspect of frigate tuna (*Auxis thazard* Lacepède, 1800) in Kusamba waters in East season]. Jurnal Perikanan Unram 12(1): 66-73. [in Indonesian]

Prince J., Hordyk A., Valencia S. R., Loneragan N., Sainsbury K., 2015a Revisiting the concept of Beverton-Holt life-history invariants with the aim of informing data-poor fisheries assessment. ICES Journal of Marine Science 72(1):194-203.

Prince J., Victor S., Kloulchad V., Hordyk A., 2015b Length based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. Fisheries Research 171:42-58.

Ricker W. E., 1975 Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research of Canada 191, 382 pp.

Schluderman E., Keckeis H., Nemeschkal L., 2009 Effect of initial size on daily growth and survival in fresh water *Chondrostoma nasus* larvae: a field survey. Journal of Fish Biology 74(4):939-955.

Setyadji B., Priatna A., 2011 [Spatial and temporal distribution of plankton in Tomini Bay, Sulawesi]. BAWAL 3(6):387-395. [in Indonesian]

Sparre P., Venema S. C., 1992 Introduction to tropical fish stock assessment Part 1. Manual. FAO Fisheries Technical Paper No. 306/1, FAO, Rome, 376 pp.

Sparre P., Venema S., 1999 [Introduction to tropical fish stock assessment (translation)]. Kerjasama dengan Organisasi Pangan dan Pertanian Perserikatan Bangsa-Bangsa, Pusat Penelitian dan Pengembangan Perikanan, Badan Penelitian dan Pengembangan Pertanian, Jakarta, 438 pp. [in Indonesian]
Sulistyaningsih R. K., Jatmiko I., Agustina M., 2020 CPUE standardization of frigate tuna (*Auxis thazard*) caught by purse seine off the coast of Western Sumatera (FMA 572). Indonesian Fisheries Research Journal 26(1):11-17.
Tampubolon P. A. R. P., Novianto D., Hartaty H., Kurniawan R., Setyadji B., Nugraha B., 2016 Size distribution and reproductive aspects of *Auxis* spp. from West Coast Sumatera, Eastern Indian Ocean. Research Institute for Tuna Fisheries, Ministry of Marine Affairs and Fisheries, Indonesia, 8 pp.
Tao Y., Mingru C., Jianguo D., Zhenbin L., Shengyun Y., 2012 Age and growth changes and population dynamics of the black pomfret (*Parastromateus niger*) and the frigate tuna (*Auxis thazard thazard*), in the Taiwan Strait. Latin American Journal of Aquatic Research 40(3):649-656.
Walters C., Martell S. J. D., 2004 Fisheries ecology and management. Princeton University Press, Princeton, N. J., 448 pp.
Wiadnyana N. N., 1998 [Distribution and variation of phytoplankton pigments in Tomini Bay, North Sulawesi]. Seminar Kelautan LIPI-UNHAS, Ambon4-6 Juli199, pp. 248-259. [in Indonesian]
Yesaki M., Arce F., 1993 A review of the *Auxis* fisheries of the Philippines and some aspects of the biology of frigate (*A. thazard*) and bullet (*A. rochei*) tunas in the Indo-Pacific region. FAO Fisheries Technical Paper 336(2):409-439.
Zhang C. I., Megrey B. I., 2006 A revised Alverson and Carney model for estimating the instantaneous rate of natural mortality. Transactions of the American Fisheries Society 135:620-633.

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