Growth, mortality, food consumption, and exploitation status of bullet tuna *Auxis rochei* (Risso, 1810) caught in Prigi waters, Trenggalek, East Java

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Abstract. The bullet tuna (*Auxis rochei*) is the smallest tuna species and has high economic importance in Prigi waters, Trenggalek, East Java. This research aimed to identify growth and mortality rates and to evaluate the exploitation status of *A. rochei*. Assessment of growth parameters (L∞ and K), mortality coefficients (Z, M, and F), and exploitation ratio (E = F / Z) was conducted based on catches during December 2019 - March 2020 for total samples of as many as 2203 fish. The samples had a fork length (FL) range between 18.0 and 28.0 cm and were analyzed using FAO-ICLARM Stock Assessment Tools (FiSAT) software. The results suggested that the length and weight relationship was negative allometric. The sex ratio was 1:1.53. Gonad maturity level (GML) was found in both male and female levels I, II, and III. While gonadosomatic index (GSI) value reached the highest average of 0.18%. The values of length at first maturity (Lm) and length at first capture (Lc) were 24.20 cm and 23.86 cm, respectively. Mollusca (plankton) was the dominant food, with an index preponderance (IP) value of 32.8%. The growth rate analysis obtained length infinity (L∞) = 29.90 cm FL; K = 0.46 per year and t_0 = -0.45 year. The values of total mortality (Z), natural mortality (M), and fishing mortality (F) were 3.8, 1.12, and 2.68, respectively. The exploitation rate (E) was 0.71, indicating that the fish were being overfished, and a reduction effort is required to protect the remaining stocks.
Key Words: exploitation rate, index preponderance, length-weight relationship, population dynamics, Von Bertalanffy growth formula.

Introduction. The bullet tuna (*Auxis rochei* (Risso, 1810)) is a mesopelagic fish type (Uchida 1981; Collette & Nauen 1983; Macías et al 2005; Jasmine et al 2013) and turns into the most fish caught in Prigi waters Trenggalek East Java by purse seine. The bullet tuna has specific characteristics, such as a motif on its back starting from the end of the pectoral fin and is the smallest tuna species in the Indian Ocean. The species is also abundant in the Mediterranean Sea where it is spread throughout the tropical and subtropical waters.

Recently, fish population dynamics changed. Study of exploiting marine species is essential. In fisheries science, identifying self-sustaining components within natural populations is essential for stock identification. Stock identification is a prerequisite for stock assessment and fishery management. The identification can be used to apply population models that assume that the group of individuals has homogeneous vital rates (e.g., growth, maturity, and mortality) and a closed life cycle, in which previous generations produce young fish in the group within the same species (Cadrin et al 2013). Additionally, stock identification entails identifying self-sustaining components in natural populations which are necessary for better stock assessment of fisheries. Furthermore, it is expected that fish populations are assumed to be partially reproductively isolated and comprise subpopulations (Shaklee & Currens 2003; Marcil et al 2006; Cadrin et al 2013; Hilborn & Walters 2013).

The exploitation of fish stocks could lead to environmental degradation. Thus, managing and controlling fish resources is essential (Purwaningsih et al 2012). Holland & Ginter (2001) reported that common property management is key in ensuring effective use to provide secure fisheries management for the overall total allowable catch (TAC) in the Alaska region. Furthermore, the allocation must be done to reasonably small and homogeneous groups defined by gear, mode of operation, and target species or species group. However, the case of bullet tuna on the south coast of East Java waters, such as Prigi waters, is a bit complex. Most catch data come from incomplete information; hence there is no current quantitative stock assessment for the bullet tuna in the Prigi waters. The lack of fishery data on a few fishing gears and studies on many aspects of the bullet tuna fishery has resulted in a scarcity of knowledge to assess the impact of catch rate on resource availability.

Additionally, research in this area is expected to focus on the time series formulation of catch per unit effort (CpUE), stock composition, growth, mortality, and maturity. The sustainable biomass, catch, and effort-targeted reference points are yet to be established. This research aimed to identify growth and mortality rates and the exploitation status of bullet tuna caught in Prigi waters. These data can be used to evaluate the status of fish resources in the southern waters of East Java, especially in the Trenggalek area.

Material and Method

Description of the study. This study employs a quantitative descriptive and random sampling approach to data collection. The research was conducted from December 2019 to March 2020 in the Prigi waters, Trenggalek Regency, East Java. Primary data collection was samples of fish caught by purse seine and landed at Prigi Archipelago Fishing Port (AFP). The data included the length-weight of the fish, gonad maturity level (GML), and plankton identification in the fish stomach. Secondary data were also collected from books, Prigi AFP, annual reports, and supporting literatures. Parameters to be analyzed in this study included length-weight relationship, sex ratio, GML, gonadosomatic index (GSI), length at first maturity (Lm), food composition, length at first capture (Lc), mortality and exploitation rate, yield per recruitment (Y/R), and biomass per recruitment (B/R) using FISAT II tools.

Length-weight relationship. Length-weight relationship can be calculated based on the equation (Fuadi et al 2016; Sravishta et al 2018; Bintoro et al 2019a; Bintoro et al 2020a; Firdaus et al 2020) as follows:

$$W = a\,L^b$$

where: W = weight;
L = length;
a = intercept;
b = estimation of growth pattern in length-weight.

The equation was then transformed into a linear equation that becomes Ln W = ln a + b ln L. Determination of the growth pattern was carried out by a further test using a t-test. If the value of the t-count is less than the value of the t-table (T-count < T-table), the growth is considered isometric. In contrast, if the value of the t-count is higher than the value of the t-table (T-count > T-table), the growth is considered allometric.

Sex ratio. Analysis of sex ratio can be calculated based on the equation (Dahlan et al 2015; Bintoro et al 2020a) as follows:

$$SR = \frac{\sum M}{\sum F}$$

where: SR = sex ratio;
∑M = number of male fish;
∑F = number of female fish.

Then the ratio between male and female fish was calculated using chi-square (Hasanah et al 2019) as follows:

$$X^2 = \frac{\sum (Oi - Ei)^2}{Ei}$$

where: X^2 = chi-square;
Oi = number of observed frequencies;
Ei = number of expected frequencies.

Gonad maturity level (GML). Analysis of the gonad maturity in fish was carried out morphologically by considering the gonad conditions, including shape, size, and color. There are 5 phases of gonad development with criteria (Dahlan et al 2019; Bintoro et al 2021) as depicted in Table 1.

Table 1

The phase of gonad maturity development

GML	*Female*	*Male*
I	The ovary is like a thread, long, to the forebody cavity, and the surface is slippery.	Testes are like thread, transparent in color.
II	The ovary is larger, the color is yellowish, and the eggs are not visible.	Testes are larger, milky white color.
III	The ovary is yellow, and morphologically the eggs begin to appear.	The surface of the testes looks jagged, the color is getting whiter, and the size is getting bigger.
IV	The ovary gets bigger; eggs are yellow, and easily separated. Oil grains are visible, filling 1/2 - 2/3 of the abdominal cavity.	In the preserved state, it breaks easily; the testicles get thicker.
V	Wrinkled ovaries, thick walls, and leftover eggs are found near the release.	Anterior and posterior parts of testis are filled.

Gonadosomatic index (GSI). Analysis of the gonad somatic index can be calculated based on the equation (Agustiari et al 2017; Bintoro et al 2019b) as follows:

$$\text{GSI} = \frac{G_w}{B_w} \times 100$$

where: GSI = gonadosomatic index;
Gw = gonad weight;
Bw = body weight.

Length at first maturity (Lm). The length at first maturity (Lm) is the length where 50% of individuals have been mature at least once in a time. Lm can be calculated based on the equations by Tweddle & Turner (1977) with following formulae:

$$P = \frac{1}{1+e^{-(a+bLm)}}\,;\ Lm = -a/b$$

where: P = the total length of mature fish;
a = intercept;
b = slope;
e = natural number;
Lm = length at first maturity.

Food composition. The composition of plankton as food in the stomach can be calculated using the gravimetric method (Herawati et al 2019; Bintoro et al 2020a) as follows:

$$\text{Phytoplankton (a): } \%X_a = \frac{a}{a+b} \times 100$$

$$\text{Zooplankton (b): } \%X_b = \frac{b}{a+b} \times 100$$

where: Xa = phytoplankton composition (%);
Xb = zooplankton composition (%);
a = phytoplankton;
b = zooplankton;
a+b = the amount of plankton found.

Food composition was also analyzed by using the index of preponderance (IP) formula (Lelono & Bintoro 2019) as follows:

$$IP = Vi \times Oi / (\Sigma(Vi \times Oi)) \times 100$$

where: IP = index of preponderance;
Vi = percentage by volume of one type of food;
Oi = percentage of occurrence of one type of food.

Feeding habits can be divided into three groups based on the IP value as follows:
IP > 40%: as the main food;
IP 4-40%: as a complementary food;
IP < 4%: as a food additive.

Growth parameters. The analysis of the estimated growth parameters can be calculated using the von Bertalanffy formula (Sparre & Venema 1998; Gayanilo et al 2005; Bintoro et al 2019b; Bintoro et al 2020a; Bintoro et al 2020b; Lelono et al 2021) as follows:

$$L_t = L_\infty (1 - e^{-k(t-t_0)})$$

where: L_t = length of the fish at age year t (cm);
L_∞ = possible maximum length of fish;
t_0 = theoretical age of fish at zero length;
t = year;
k = growth coefficient;
e = natural number; e = 2.71.

The values of growth parameters, including L_∞ and k, were obtained using the electronic length-frequency analysis (ELEFAN) I method on FISAT II, while t_0 was calculated using the following equation (Pauly 1983; Sparre & Venema 1998; Gayanilo et al 2005):

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

Length at first capture (Lc). Analysis of the length at first capture can be calculated based on the equation (Gayanilo et al 2005; Bintoro et al 2020b) as follows:

$$Fc(L) = \frac{n \times dL}{S\sqrt{2\pi}} \times e^{\left[\frac{(L-\bar{L})^2}{2s^2}\right]}$$

where: Fc (L) = frequency of fish included in the class length;
dL = interval of each class length;
π = 3.14;
e = 2.72;
n = number of samples in sampling;
L = long class middle value;
$\bar{L}$ = average length of one fish cohort;
s = standard deviation of the average length.

Then the equation is transformed into a linear form as follows:

$$\Delta \ln Fc(z) = a - b\left[L + \left(\frac{dL}{2}\right)\right]$$

where: $\Delta \ln Fc(z)$ = the difference between length classes in ln;
$L + \left(\frac{dL}{2}\right)$ = upper limit of each length class;
a and b = constants

The value of Lc then be calculated by comparing the intercept and slope values as follows:

$$Lc = -\frac{a}{b}$$

Mortality and exploitation rate. The mortality rate was divided into natural mortality (M) and fishing mortality (F). Natural mortality can be calculated using the equation (Pauly 1983; Kartini et al 2017; Bintoro et al 2020a) as follows:

$$\ln M = -0.0152 - 0.279 \times \ln L\infty + 0.6543 \times \ln K + 0.463 \times \ln T$$

where: M = natural mortality;
$L\infty$ = the asymptotic length of the von Bertalanffy growth equation;
K = growth coefficient ($month^{-1}$);
T = mean annual surface temperature (°C).

Meanwhile, fishing mortality (F) can be calculated using the following equation:

$$F = Z - M$$

The exploitation rate (E) is calculated by comparing the fishing mortality (F) to the total mortality rate (Z) as follows:

$$E = \frac{F}{F+M} = \frac{F}{Z}$$

Fishing mortality and exploitation rate can be used to estimate the status of fisheries in certain waters. If E < 0.5 or F < M then under fishing; E = 0.5 or F = M then maximum sustainable yield (MSY); E > 0.5 or F > M then overfishing.

Yield-per-recruitment (Y/R) and biomass-per-recruitment (B/R). Estimates of yield-per-recruitment (Y/R) and biomass-per-recruitment (B/R) were analyzed using the FISAT II program with knife-edge Beverton and Holt Y/R analysis. The input parameters are M/K, Lc/L_∞, and E.

Results. Samples obtained during the study were 2203 fish for measuring length and weight and 179 fish for observing sex ratio. In addition, there were only 152 fish available for GML, GSI, and Lm analysis because 27 fish were unidentified. Another assessment was also taken of 25 stomach contents for food composition identification. The analysis indicated that the length-frequency distribution of bullet tuna ranged from 18 to 28.0 cm, with an average size of 21.67 cm and weight ranging from 66 to 222 g. The highest frequency was found in the class interval of 22-23 cm for as many as 894 fish, while the lowest frequency with only one fish was in the class interval of 27-28 cm (Figure 1).

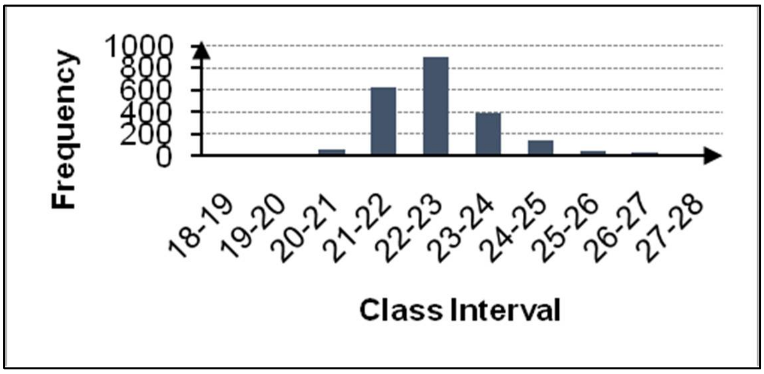


Figure 1. Length frequency distribution.

Length-weight relationship. Analysis of the length-weight relationship obtained the equation $W = 0.013FL^{2.9843}$ and $R^2 = 0.864$, which means that length affects weight by 86% (Figure 2). Based on the t-test analysis, the value of the t-count is higher than the t-table (29.2669 > 1.9610) hence b ≠ 3. Then the relationship is negative allometric. The length growth is faster than the weight growth (Figure 2).

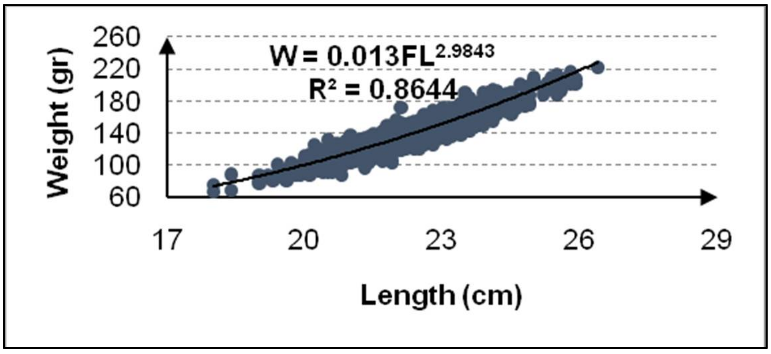
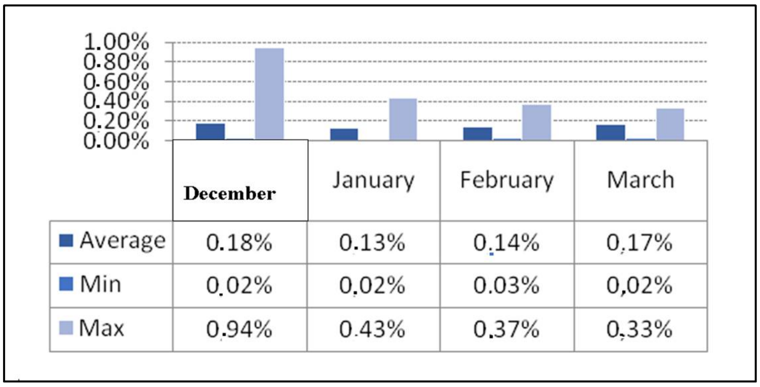


Figure 2. Length-weight relationship.

Sex ratio. The samples which have been successfully identified in this study were 152 fish consisted of 60 male and 92 female. While 27 of fish were unidentified. The proportion of male and female fish is 34:66%. Based on the chi-square test analysis, the ratio between males and females is 1:1.53 with x^2count less than x^2table (0.0886 < 3.8415), which means that there is no significant difference between the ratio obtained and the expected ratio.

Gonad maturity level (GML). The GML analysis determines the maturity level of the gonad, aiming to know the condition of the maturity level of fish. The level of gonad maturity found in this study was GML I until III, for both male and female. The analysis also showed that based on 152 fish identified, immature fish dominated samples with 81% (123 fish). At the same time, the rest, 29 fish (19%) was mature fish.

Gonadosomatic index (GSI). The value of GSI was found to be varied monthly. The average GSI obtained in December 2019, January 2020, February 2020, and March 2020 were 0.18%, 0.13%, 0.14%, and 0.17%, respectively (Figure 3).



	December	January	February	March
Average	0.18%	0.13%	0.14%	0.17%
Min	0.02%	0.02%	0.03%	0,02%
Max	0.94%	0.43%	0.37%	0,33%

Figure 3. Gonadosomatic index.

Length at first maturity (Lm). The Lm is one of the growth parameters used to determine the fish length in the first mature condition. The Lm obtained in this study based on 152 fish identified, was 24.20 cm (Figure 4). There were only four fish with a length greater than 24.20 cm, while the fish with a length measurement of less than 24.20 cm was 148 fish.

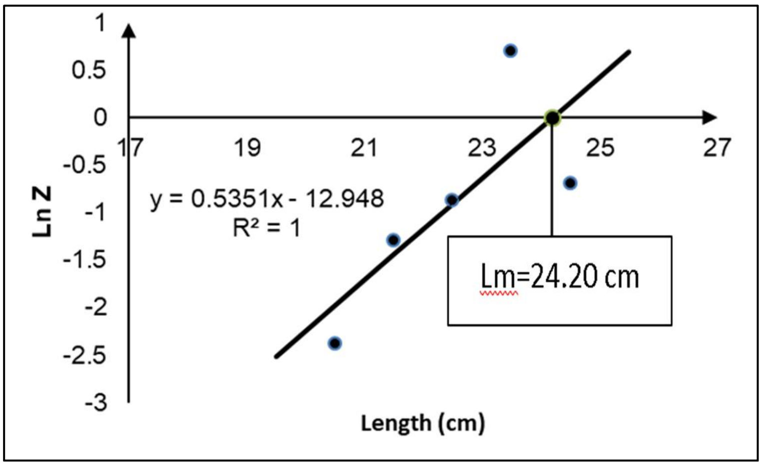


Figure 4. Length at first maturity (Lm).

Composition of stomach contents*.* The stomach content analysis of bullet tuna found that the food consisted of several plankton species with different phyla. The value of index preponderance (IP) of each plankton was as follows: Mollusca (32.8%), Ochrophyta (28.4%), Chordata (23.2%), Dinoflagellata (5.3%), Chlorophyta (3.7%), Cnidaria (3.5%), Arthropoda (1.3%), Haptophyta (0.9%), and Rotifera (0.9%). Based on IP calculations obtained, Mollusca, Ochrophyta, Chordata and Dinaflagellata were as complementary foods with IP values of 4-40%, while Chlorophyta, Cnidaria, Arthropoda, Haptophyta, and Rotifera were as additive foods with an IP value of < 4%.

Growth parameters*.* The results of growth parameters analysis obtained asymptotic length (L_∞) = 29.90 cm, growth coefficient (K) = 0.46 $year^{-1}$, and t_0 = -0.45 $year^{-1}$ so that the von Bertalanffy equation is $L_t = 29.90\ (1\text{-}e^{-0.46(t+0.45)})$.

Length at first capture (Lc)*.* The results of the analysis of Lc of bullet tuna during the study obtained a value of 23.87 cm (Figure 5). It showed that Lc value was smaller than Lm value (Lc < Lm). Hence it is assumed that immature fish dominates the catch.

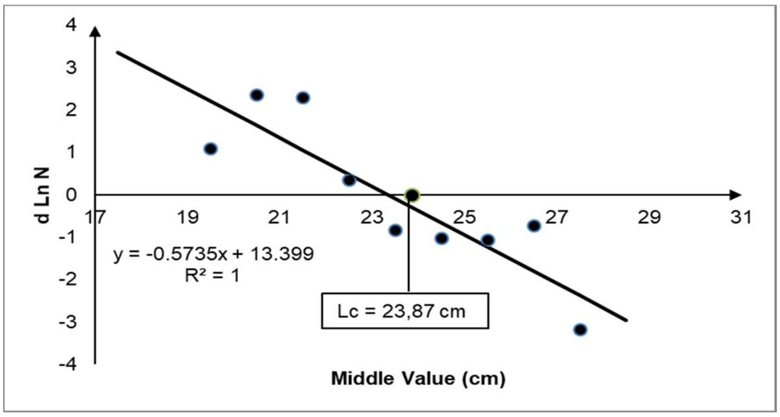


Figure 5. Length at first capture (Lc).

Mortality and exploitation rate*.* Mortality rate analysis illustrated that values of total mortality (Z), natural mortality (M), and fishing mortality (F) were 3.80, 1.12, and 2.68, respectively. Further, the value of exploitation rate (E) was 0.71. Hence, the fishery status of bullet tuna in Prigi waters was considered an overfishing condition due to a higher value of fishing mortality than natural mortality and a greater value of E (more than 0.5).

Yield per recruitment (Y/R) and biomass per recruitment (B/R)*.* The yield per recruitment analysis (Y/R) obtained a value of 0.097, showing that the proportion of bullet tuna that enter the waters and are successfully caught by fishermen is 9.7%. In comparison, biomass per recruitment (B/R) analysis obtained a value of 0.219, which indicates that the remaining biomass of fish entering the waters was 21.9%. The exploitation rate (E) that maximizes Y/R (Emax) was 1.00 $year^{-1}$, the exploitation rate at which slope function Y/R (E_{10}) is 1.00 $year^{-1}$, and the exploitation rate that reduces the initial biomass to half (E_{50}) occurs at 0.44 $year^{-1}$.

Discussion. Bullet tuna length-weight relationship analysis yielded the b value of 2.984, indicating a negative allometric growth tendency, which means that the increase in fish length is faster than the increase in weight, resulting in a thin body of tuna in Prigi waters. The shape of the fish's body is also related to its swimming habit. Slim-bodied fish are often active swimmers who devote most of their energy to mobility and growth.

Changes in b values associated with growth patterns are caused by ecological and biological factors and geographic and temporal differences in sample locations and periods. The ecological elements considered are the spawning season, water quality, temperature, salinity, pH, sampling technique, and sample site. While biological parameters such as gonad development rate, growth phase, sex, and eating habits are considered (Hargiyatno et al 2013).

One male fish can fertilize one female fish when the sex ratio between the sexes is close to 1:1. The sex ratios of some populations, on the other hand, deviate from the norm in response to environmental factors such as temperature, mortality, fish behavior, and population growth rate (Dahlan et al 2019). The present study showed that the ratio between male and female fish was 1:1.53, which indicates a balanced condition between male and female fish.

The phases of gonad development can be determined when the fish spawned, recently spawned, or have already spawned. The state of gonads' maturity increases as the fish grows in length and weight. The catch was dominated by immature fish in this study, making it unsuitable for harvesting. Recruitment overfishing occurs when the catch is dominated by mature fish. In contrast, growth overfishing occurs when immature fish is the dominant catch (Tarigan et al 2017).

The average GSI values found in this study ranged from 0.13 to 0.18%. The GSI value of less than 20% indicates that the fish can spawn more than once a year. The average GSI value in female fish is generally greater than in male fish because the ovarian weight gain is always superior to the testicular weight gain. The weight gain in male fish ranges from 5 to 10% of body weight, while the female fish ranges from 10 to 25% of body weight (Persada et al 2016). Whereas for those caught in the Mediterranean coast, GSI was calculated for females indicating spawning generally occurred between May and September (Kahraman et al 2010).

Lm or length at first ripe gonad is used for determining the smallest size of the fish worth catching. This study obtained a value of Lm above 24.20 cm which means that the size of fish worthy of capture is above 24.20 cm, while fish caught with a size below the value of Lm indicated that the fish is immature because the fish has not got yet an experience conducting spawning activity. The Lm value may differ because it relates to the size of the first ripe gonad. At the same time, the fish of the same size are not necessarily ripe at the same time for each individual. Temperature, diet, gender, hormones, and aquatic circumstances all play a role in the difference in length at initial maturity (Hasibuan et al 2018).

Molluscs were the most common sort of food found in fish stomachs. It was thus determined that bullet tuna is a carnivorous predatory fish with molluscs, crustaceans, and small fish as their primary food source. Several studies found that the stomach contents of fish vary depending on the habitat and abundance of prey in the waters. Feeding patterns are influenced by prey availability in the ecosystem (Arula et al 2012).

Growth parameters analysis of bullet tuna illustrated that the asymptotic length (L_∞) of fish was 29.90 cm which meant that the fish was a fast-growth type at a young age and tended to grow slower down constant when reaching the asymptotic length. Fish with a lower growth coefficient generally had a long lifespan, whereas fish with a higher growth coefficient would have a shorter lifespan. The difference in growth parameters was usually influenced by season, fish size, fishing gear, fishing area, and food availability (Faizah et al 2014). The asymptotic length of bullet tuna found in Prigi waters was too small compared to previous research. In Turkish Mediterranean waters, the asymptotic length of bullet tuna for males, females, and total was 60.4 cm, 49.2 cm, and 57.4 cm, respectively (Kahraman et al 2011).

The fish's length determines the smallest size of fish that can be exploited at first capture (Lc). The Lc value is frequently linked to the first-maturity length (Lm). The Lc value in this investigation was 23.87 cm, which was less than the Lm value. As a result, it indicated that the fish was caught in the immature stage. The Lc value was influenced by the fishing gear used. One of several indicators for selective fishing gear is the higher value of Lc than Lm. This condition indicated that more than 50% of the fish are caught in mature conditions (Masuswo & Widodo 2016).

Natural mortality in a species is affected by predation, disease, stress, spawning, age, and food availability in the habitat. Meanwhile, fishing mortality is related to the rate of exploitation. The higher the fishing mortality rate, the higher the exploitation rate (Kartini et al 2017). Based on fishing mortality level (F = 2.68), exploitation of bullet tuna in Prigi waters was categorized as high fishing intensity due to its value of F higher than 1. Therefore, controlling efforts such as fishery utilization, fishing gear limitations, decreasing trip amount, and gear and mesh sizes adjustment must be done (Noegroho & Chodrijah 2015).

The increased rate of biomass exploitation will lead to a decline in biomass stock. At the same time, an increase in the yield exploitation rate will increase the catch. The remarkable drop in biomass necessitates a policy in the bio-eco-techno-socio-economic role to ensure that stock management is more prevalent (Sutjipto et al 2013).

Conclusions. Bullet tuna in Prigi waters has a high growth rate with short life spans. The fishery status of the bullet tuna is considered an overfishing condition due to two factors, namely a higher value of fishing mortality than natural mortality and a greater value of exploitation level (E) (more than 0.5). Therefore, a precautionary approach to the bullet tuna resource management should be taken into account by ensuring below MSY point of exploitation level.

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Conflict of interest. The authors declare that there is no conflict of interest.

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