Biological aspect and dynamic population of fringescale sardine (*Sardinella fimbriata*: Valenciennes, 1847) in Prigi waters Trenggalek, East Java, Indonesia

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Abstract. Fringescale sardine (*Sardinella fimbriata*) is one of important species caught in Prigi waters, Trenggalek, East Java. The existence of fringescale sardine as marine fisheries commodity plays an important role in Prigi fisheries community. This research was conducted in Prigi waters from December 2018 to July 2019 aimed to determine the biological aspects, to illustrate some dynamic population parameters, and to identify food composition. This study applied a descriptive method and random sampling for data collection. There were 1,375 fish have been assessed with total length (TL) ranging from 10 cm to 20.4 cm. Results indicated that growth patterns of the fish was negative allometric with length weight relationship equation was $W = 0.014L^{2.804}$. Sex ratio of male and female obtained was 1:1. The gonad maturity level analysis found that proportion of mature and immature fish was equal. The gonadosomatic index value was ranged from 0.57% to 2.42%. The values of length at first capture and length at first mature were 15.35 cm and 16.07 cm, respectively. The growth rate equation obtained in this study was $Lt = 26.75 \cdot (1 - e^{-0.92(t+0.178)})$. Mortality rates, total and fishing were 1.709 and 0.286, respectively, while the exploitation rate was 0.167. Additional assessment showed that the main food of the fringescale sardine was phylum Arthropods with index of preponderance (IP) value was 61.5%. It can be concluded that the fish was a plankton feeder and status of the stock was in over fishing condition.

1. Introduction

Fringescale sardine (*Sardinella fimbriata*) is one of important species caught in Prigi waters Trenggalek, East Java. The existence of fringescale sardine as marine fisheries commodity plays an important role in Prigi fisheries community. Hence, the marine and fisheries department (MFD) has provided very important place to land the catch in this area, namely Archipelago Fishing Port (AFP) of Prigi located in Tasikmadu Village, Watulimo District, Trenggalek Regency. The AFP of Prigi is the main choice for fishermen to carry out the fish landing process [1].

Fish resources in Indonesia waters apply common property and open access management. The utilization makes all fishermen try to exploit as much fish resources as possible to maximize profits [2]. Fringescale (*S. fimbriata*) belongs to a group of small pelagic fish that live in surface area of the seawaters. Small pelagic fish resources have a role for regional economic development. The existence of fringescale is very popular in the market so that the utilization of fringescale is also high, therefore fishing activities must be controlled properly in order to keep resource sustainability.
The use of fish resources must be based on sustainable principles so that they can be utilized in the future. The concept of sustainable fisheries requires effective methods based on scientific data. Information on biological aspects is needed so that small pelagic fish resources can be managed properly, especially the fringescale sardine (*S. fimbriata*). The objectives of this study were to determine the biological aspects, illustrate some dynamic population parameters, and identify food consumption of fringescale sardine (*S. fimbriata*).

2. Material and method

This research applied descriptive and random sampling methods and was conducted from December 2018 to July 2019 in Prigi waters, Trenggalek Regency, East Java. Primary data was obtained from fish samples caught by purse seine and landed in Prigi. Number of samples collected was 1,375 fish. They were assessed for biology and dynamic population analysis. The number of sample for stomach content observation was 250 fish. Another primary data was food identification of fish stomach content. Secondary data consisted of information obtained from the port office and fisheries journals. The biological aspects consisted of length-weight relationship, sex ratio, gonad maturity level (GML), gonadosomatic index (GSI), length at first capture (Lc), length at first mature (Lm), and food composition. In addition, two parameters of growth were also assessed, namely the theoretical maximum length or asymptotic length ($L_\infty$) and the growth rate coefficient (K).

2.1. Length and weight relationship

Length weight relationship was assessed based on Saputra et al., [3] using the following formula:

\[ W = a \cdot L^b \]  

Where:
- \( W \) = Weight (gr)
- \( L \) = Length (cm)
- \( a \) = Intercept
- \( b \) = Constant

The equation was then converted into a linear equation so that the form of the equation becomes: 

\[ \ln W = \ln a + b \cdot \ln L. \]  

Justification for relationship (allometric or isometric) was analyzed by the t-test. If the t-count value was greater than t-table, it meant that the value of \( b \neq 3 \) or allometric. In contrast the value of t-count is smaller than t-table, it meant that the value of \( b = 3 \) or isometric.

2.2. Sex ratio

Sex ratio analysis was obtained by using the following mathematical formulas: [4]

\[ NK = \frac{\sum J}{\sum B} \]  

Where:
- \( NK \) = sex ratio
- \( \sum J \) = number of male
- \( \sum B \) = number of female

Then the sex ratio was analyzed using chi square analysis [5]:

\[ E_{ij} = \frac{(nio \times noj)}{n} \]  

Where :
- \( E_{ij} \) = theoretical frequency that is expected to occur
- \( nio \) = number of lines to i
- \( noj \) = number of columns to j
n = number of frequencies or value of observation

2.3. Gonad maturity level (GML)
Observation of the gonad maturity level (GML) was done by looking at the shape, size, color, and texture of the gonad. Description of the GML stage was divided into 5 phases [6], namely immature (I), developing (II), ripening (III), ripe or fully mature (IV), and spent (V).

2.4. Gonadosomatic index (GSI)
The Gonadosomatic Index was obtained using the following equation [7]:

\[
GSI = \frac{W_g}{W} \times 100\% 
\]  

Where:
\(W_g\) = gonad weight (gr)
\(W\) = fish weight (gr)

2.5. Length At First Mature (Lm)
The Length at first mature (Lm) was used to predict the length of the first gonadal ripe using the formula [8]:

\[
Q = \frac{1}{1 + e^{a(L - L_m)^b}} 
\]

Where:
\(Q\) = the long class fraction which is ripe gonad
\(L\) = maximum value that indicates 100% mature
\(E\) = 2.718
\(A\) = constant
\(L_m\) = length of fish when 50% is cooked gonad

The equation was then converted into a linear form below. The length of the first time gonads mature was calculated using the following formula:

\[
L_m = \frac{-a}{b} 
\]

Where:
a = intercept
\(b\) = slope

2.6. Length at first capture (Lc)
The Length at first capture (Lc) was referred to Agustina et. al. [9] with the formula:

\[
SL = \frac{1}{1 + \exp(S1 - S2*L)} 
\]

\[
\ln \left[ \frac{1}{SL - 1} \right] = S1 - S2*L 
\]

\[
L_{50\%} = \frac{S1}{S2} 
\]

Where:
\(SL\) = logistic curves
\(S1\) = a
\(S2\) = b
2.7. Growth parameter

Growth parameters (K and \(L_\infty\)) are estimated through applications using the Electronic Length Frequency Analysis (ELEFAN-1) method on computers in the FISAT application. Estimated growth parameters are calculated as Von Bertalanffy's formula [8,10]:

\[
Lt = L_\infty (1 - e^{-K(t-t_0)})
\]  
(10)

Where:
- \(Lt\) = fish length at age \(t\) (unit of time)
- \(L_\infty\) = maximum theoretical length (asymptotic length)
- \(K\) = growth coefficient (unit of time)
- \(t_0\) = theoretical age when the length is zero

2.7.1. Maximum Length \(L_\infty\). The formula of maximum length or asymptotic length (\(L_\infty\)) of fish is performed as follow:

\[
L_\infty = \frac{L(t)}{1 - e^{-K(t-t_0)}}
\]  
(11)

Where:
- \(L_\infty\) = the maximum length of fish can be achieved without fishing activity
- \(k\) = coefficient of growth parameter (per year)
- \(t\) = age of fish (years)
- \(t_0\) = the theoretical age of a fish when the length is zero (years)

2.7.2. Coefficient of growth parameter (K). Formula used to perform growth parameter coefficient (K) was as follow [8]:

\[
K = \left(\frac{1}{\Delta t}\right) \times \ln b
\]  
(12)

Where:
- \(K\) = Coefficient of growth parameter (per year)
- \(\Delta t\) = Difference from relative age
- \(b\) = slope

2.7.3. Fish theoretical age (\(t_0\)). The value \(t_0\) was representing theoretical age of fish at zero length calculated using the following formula:

\[
\text{Log} (-t_0) = -0.3922 - 0.2752 \text{log} (L_\infty) - 1.038 \text{log} K
\]  
(13)

2.7.4. Natural mortality (M). The natural mortality rate (M) is estimated using the empirical Pauly’s formula [11]:

\[
\text{Ln} M = -0.0152 - 0.279*\text{ln} L_8 + 0.6543*\text{ln} K + 0.463*\text{ln} T
\]  
(14)

Based on this equation, Pauly suggested that the calculation of fish group be multiplied by 0.8 so that for fringescale (\(S. fimbriata\)) the estimated value would be 20% lower.

\[
M = 0.8 e^{-0.0152 \times 0.279*\text{ln} L_8 + 0.6543*\text{ln} K + 0.463*\text{ln} T}
\]  
(15)

Where:
- \(M\) = Natural mortality
- \(L_\infty\) = Asymptotic length in Von Bertalanffy’s growth equation
\( K \) = Growth coefficient on Von Bertalanffy's growth equation

\( T \) = Average water surface temperature (°C)

2.7.5 Total mortality (Z). The total mortality value was calculated with the following equation:

\[
Z = \frac{K(L_\infty - L)}{L - L'}
\]

Where:

- \( Z \) = Total mortality
- \( K \) = Coefficient of growth parameter (per year)
- \( L_\infty \) = The maximum length that a fish can achieve if it does not experience natural mortality or catch mortality (cm)
- \( L' \) = The smallest size of fish (cm)
- \( L \) = Size of fish average length (cm)

2.7.6 Fishing mortality (F). Formula to determine fishing mortality rates (F) is as follow:

\[
F = Z - M
\]

2.7.7 Exploitation rate (E). Comparison between fishing mortality (F) and total mortality (Z) is used to predict exploitation rate (E) of fish stock. This formula is as follow:

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

Where:

- \( E \) = Exploitation value
- \( F \) = Mortality arrest
- \( Z \) = Total mortality

If:

- \( E > 0.5 \) : Over fishing
- \( E = 0.5 \) : Maximum Sustainable Yield (MSY)
- \( E < 0.5 \) : Under fishing

2.8 Food composition

The composition of plankton in the fish stomach uses a graphimetric method according to Omar et al. [4]:

- Fitoplankton (a): \( \% X_a = \frac{a}{(a+b)} \times 100\% \)

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

Where:

- \( X_a \) = phytoplankton composition (%)
- \( X_b \) = zooplankton composition (%)
- \( A \) = phytoplankton found
- \( B \) = zooplankton found

Knowing the fish eating habits is done by calculating the largest part of the index. This method is a combination of the frequency and volumetric method by multiplying the percentage volume of one type of food by the percentage frequency of occurrence of one type of food. The product of multiplication is divided by the total number of multiplications of all types of food and multiplied by one hundred percent according to the equation:
\[ IP = \frac{V_i \times O_i}{\sum V_i \times O_i} \times 100\% \]  \hspace{1cm} (21)

Where:
- \( IP \) = index of propederance (%)
- \( V_i \) = percentage of volume of one type of food (ml)
- \( O_i \) = percentage frequency of occurrence for one type of food (ind)
- \( \sum V_i O_i \) = total amount of multiplication of \( V_i \times O_i \) from all foods

Based on IP values, food can be divided into three groups, namely:
- Main food, if IP > 40%,
- Complementary food, if IP 4 – 40%,
- Addition food, if IP < 4%.

3. Results

The length of fringescale (\( S. fimbriata \)) collected ranged from 10 cm to 20.4 cm and the weight of fish ranged from 8 grams to 80 grams. Length frequency consisted of several length class, with the highest was at 17-18 cm interval (294 fish) and the smallest catch at intervals of 20-21 cm (3 fish) (Figure 1).

**Figure 1.** Length frequency of fringescale (\( S. fimbriata \)).

3.1. Length weight relationship

The equation of length weight relationship was \( W = 0.014L^{2.804} \) with Rsquare 0.899 (Figure 2) which means that the length affected the weight of fish by 89%. The results of the T-test showed that the values of t count and t table are 7.747 and 1.961, respectively. If t count > t table 0.05, value of \( b \neq 3 \) or negative allometric growth patterns. It means that growth length was more dominant than growth length.
3.2 Sex Ratio
The sex ratio was used to compare the number of male and female fish in a population. The results showed that the fish consisted of 327 male (49%) and 348 female (51%), respectively. Chi square analysis obtained male and female ratio was 1:1 with values of $x^2$ count and table were 0.00526 and 3.841 respectively which means that there is no real difference between the ratio obtained with the expected ratio.

3.3. Gonad maturity level (GML)
Male or female fish have a variety of GML (I-V). Observation of the frequency of female and male TKG shows that from December 2018 to July 2019 was relatively balanced. This study found that there were 463 mature fish and 462 immature fish (Figure 3).

3.4. Gonadosomatic index (GSI)
The value of gonadosomatic index (GSI) of fish in Prigi waters varies considerably every month. The highest GSI was obtained in February 2019, while the lowest GSI was obtained in December 2018 (Figure 4). The average of GSI obtained in December 2018, January, February, March, April, June and July 2019 were 0.57%, 1.64%, 2.42%, 1.47%, 2.04%, 0.98% and 1.05%, respectively (Figure 4). The smallest IKG value occurred in December (0.57%), while the largest value observed in February (2.42%). Gonad weight increase was usually followed by an increase in body weight. The GSI value will decrease if the fish have spawned.
3.5. Length at first mature (Lm)
Length at first mature (Lm) was used to estimate the length of the fish when it first grows. The total Lm was 16.07 cm (Figure 5). The number of fish caught with a length of more than 16.07 cm was 509 fish, while fish with a length of less than 16.07 cm was 416 fish. The difference in size and age of fish when the gonads first mature between one species and another species is very possible.

![Figure 5. Length at first mature.](image)

3.6. Length at first capture (Lc)
Length at first capture (Lc) was used to predict the first time the fish is caught. From the calculation, it was found that the Lc value was 15.35 cm (Figure 6). Lc value in several research locations were vary due to the condition of the waters and the awareness of the fishermen.

![Figure 6. Length at first capture.](image)

3.7 Growth parameters
3.7.1. Values of L∞, K, and t0. Obtained asymptotic length (L∞) and growth rate coefficient (K) were 26.75 cm and 0.92 per year and the value of t0 is -0.178 year (Figure 7). The fish growth rate coefficient (K) is considered high if it is in the range of 0.5-1.
3.7.2. Mortality rate. The estimated results of fringescale sardine ($S. fimbriata$) mortality were as follows: total mortality 1.71, natural mortality 1.42, and fishing mortality 0.29. Based on the results of the total mortality analysis, it can be seen that the natural mortality value (M) is greater than the value of fishing mortality (F).

3.7.3. Exploitation rate ($E$). The result of the calculation between total mortality and fishing mortality is the rate of exploitation. The rate of exploitation obtained was 0.17. This means that the condition of the fringescale sardineery ($S. fimbriata$) in Prigi waters is still sustainable or under exploited because the value of $E < 0.5$.

3.8. Food composition
The gastric composition of fringescale was consisted of plankton species originating from different phyla and each phylum has a different IP value. The IP values of each phylum were as follows: Annelida (0.6%), Arthropoda (61.5%), Bacillariophyta (9.3%), Charophyta (0.4%), Chlorophyta (2.4%), Chordata (1.2%), Ciliophora (1.6%), Bacteria (2.2%), Cyanobacteria (3.1%), Dynophyta (0.0%), Echinodermata (0.03%), Mollusca (1.2%), Myzozoa (0.4%), Ochrophyta (15.3%), and Protozoa (0.8%) (Figure 8). Arthropoda was the main food as its IP > 40%. Bacillariophyta and Ochrophyta were complementary foods because IP values ranged from 4 - 40% while other phyla were complementary foods.

4. Discussion

Propedence Index of fringescale ($S. fimbriata$) showed that fringescale is plankton eaters. Water conditions also affect food supplies in these waters.
4.1. **Length weight relationship**
The results showed that the b-value of fringescale was 2.804, meaning the growth pattern of fringescale was negative allometric. Fish length increase was faster than weight gain. The results of this analysis can be used to determine the condition of a population and find out the health of fish.

Basically allometric growth is temporary for example due to changes related to gonadal maturity, while isometric growth is proportional. Fish growth assessed from the value of b can be caused by several factors, such as differences in age, gonadal growth, gender and habitat conditions [13].

4.2. **Sex ratio**
The ratio of males and females of fringescale (*S. fimbriata*) in nature was estimated to be 1:1, meaning that the number of male and female fish caught was equal. Sex ratio is important to know because it affects the stability of the fish population in nature. Differences in the number of sexes in the population are due to differences in age, growth patterns [14].

4.3. **Gonad maturity level (GML)**
The GML value shows information about the condition of the fish in the gonadal phase which is not mature, almost mature, mature, reproductive and saline. Information about GML provides information that the fish is in the spawning stage or has finished spawning. This study found fish that were in mature stages, with the discovery of fish that had matured gonads indicating that the fish had spawned.

The GML illustrates the level of fish sexual maturity. Most metabolic results are used during the gonadal development phase. Generally the development of gonads in female fish is 10-25% of body weight, and male fish ranges from 5-10% [15].

4.4. **Gonado somatic index (GSI)**
The average GSI value of this study ranged from 0.57% - 2.42%, the GSI value of which less than 20% explains that the fish spawn more than once a year.

The GSI is a comparison between gonadal weight and body weight. Changes in the value of GSI are closely related to the stage of egg growth. The gonad will reach its maximum when the fish spawn and then decrease during spawning until it is finished [16].

4.5. **Length at first mature (Lc)**
The size of the fish for the first time mature is the size of the fish at the time of gonad ripe. In this study the size of the first gonad matured was 16.07 cm.

The size of the fish at first gonads mature are usually influenced by the abundance and availability of food, temperature, light period, and environmental factors in each different habitat. Environmental conditions have an impact on the size of the fish when gonads mature for the first time [15].

4.6. **Length at first capture (Lc)**
This study found the size of fish when first caught was 15.35 cm. The size of the fish when it was first caught is related to the size of the fish when it first gonads is concluded that fish are not yet of a reasonable size.

The size of a fish that is worth catching is a fish that has a greater length than the length of the first gonad mature. The large size of fish that is not suitable for capture reveals that there are fishermen who do not know the fishing season [16].

4.7. **Growth parameter**
4.7.1. **Value of L∞, K, t0**
The values of L∞, K and t0 were calculated to perform the equation of the growth parameter, namely is \[ L_t = 26.75(1-e^{-0.92(t + 0.178)}) \].

Growth is an increase in length and weight at one time. Growth affects fish stocks in one area. Positive growth in stock does not increase the amount of stock but increases the amount of biomass in a stock [17].
4.7.2. Mortality rates. Natural mortality is mortality caused by predators including cannibalism, illness, stress conditions when spawning, starvation, and aging. Mortality due to predation, starvation and several other causes are influenced by environmental conditions. The same species can have different mortality values depending on predators and competitors which are also influenced by fishing activities [8].

4.7.3. Exploitation rate. The rate of exploitation is the rate of utilization of fish resources by fishing activities. If the rate of exploitation has exceeded the optimum exploitation limit of 50%, the fish in the area have experienced more biological completeness [9]. Biological capture can be classified as growth overfishing and overfishing recruitment. Growth overfishing occurs when the catch is dominated by small fish at the size of growth, while overfishing recruitment occurs when exploitation activities catch more fish that are ready to spawn (spawning stock) or mature gonad mature fish [3].

4.8. Food composition
Fish can be divided into 3 groups based on their food; there are herbivores, carnivores and omnivores. However, overlap often occurs due to circumstances around the habitat. Generally, fish have adaptations to their food habits [18].

Several researches reported that the composition of food in the stomach of fringescale are plankton. Food habits depend on age, place of residence, predation and food chain in a population. This is in accordance with the results of this study that the gastric contents of fringescale found were plankton.

5. Conclusion
Length weight relationship of fish was negative allometric with equation \( W = 0.014L^{2.804} \). The length at first capture was 15.35 cm. The growth parameter value; \( L_{\infty} = 26.75 \) cm, \( t_0 = -0.178 \) year dan \( K = 0.92 \) per year. The reproductive aspects of this species had a sex ratio of 1: 1 where male fish are equal to female fish. The composition of the stomach contents of fringescale (Sardinella fimbriata) obtained during the study was calculated by the Index of Preponderance method and it was concluded that Arthropods were the main food because of IP>40%, Bacillariophyta and Ochrophyta were complementary foods because IP values range from 4-40% while others phyla were complementary foods with IP between 1-4%.

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