Biology and population dynamics analysis of fringescale sardine (*Sardinella fimbriata*) in Bali Strait waters, Indonesia

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**Abstract.** Fringescale sardine (*Sardinella fimbriata*) is small pelagic fish that has an increasing production every year. This can trigger the occurrence of overfishing, so it is necessary to study the biology and dynamic population of fish. This research was conducted in December 2016 - May 2017. The purpose of this research was to determine the biological aspects and population dynamic of fringescale sardine (*S. fimbriata*) in Bali Strait. Samples were obtained from surface gillnet landed in Muncar fishing port, with 1471 of fish. Results showed that sex ratio was about balanced with the proportion of 55% male and 45% female. Length and weight relationship was negative allometric patterns. Length of first mature (Lm) male and female was 11.95 cm and 10.79 cm respectively. Based on dynamics population analysis it was found that length at first capture (Lc) was 10.44 cm. While K, L∞ and t0 were 0.54/year, 19.6 cm and -0.149 year respectively. In addition there was only one peak recruitment occured in 7th month of recruitment pattern. Another analysis indicated that a value of natural mortality (M) was 1.38 with sea surface temperature (SST) of 29.45°C. According to length frequency data total mortality (Z) was 6.41 so that fishing mortality (F) was calculated to be 5.03. Hence value of exploitation rate (E) was 0.79. It can be concluded that the fisheries resources status is categorized as overfishing.

**1. Introduction**

Bali Strait is the waters that connects Flores Sea and Madura Strait in the North and Indian Ocean in the South. The north side of the strait is very narrow shallow waters. It is about 1.00 miles in width and 50 meters in depth. While in south of the strait is wider and deeper. It is about 28.00 miles in width and 200.00 meters in depths [1].

Fringescale sardine (*Sardinella fimbriata*) is one of the small pelagic fish that has enough production in the Bali Strait. Exploitation in 2012 amounted to 406 tons, in 2013 of 882.9 tons and in 2014 of 1097.5 tons [2]. Although the catch of this fisheries resource has tended to increase, however the stock still needs to be managed properly in order to keep its sustainability. It is therefore research about biology and population dynamic of the fish need to be done for sustainability purpose.

This research has several purposes, namely: (1) to know the biology parameters; (2) to identify the aspect of population dynamics covering growth parameter, mortality, recruitment pattern, yield per recruit and biomass per recruit; (3) expect the rate of exploitation and the status of fish exploitation fringescale sardine (*S. fimbriata*) in Bali Strait waters.
2. Materials and methods

2.1 Time and Place
This research was conducted at the beginning of December 2016 until May 2017, with sampling taken in fish auction hall (FAH) Muncar Banyuwangi (Figure 1), while research and observation was done in Aquaculture Laboratory of Fish Reproduction Division Faculty of Fishery and Marine Science, Brawijaya University Malang.

![Figure 1. Research location in Muncar, Banyuwangi East Java](image)

2.2 Types and Research Methods
This research uses a qualitative approach that takes into account the clarity of elements and objectives, subjects, data sources that already exist and is detailed from the beginning, and performs data analysis after all data has been collected. The research used descriptive research method, which is intended to describe the existing phenomenon, which took place today or the past.

2.3 Procedures
Sample of fringescale sardine (S. fimbriata) was taken randomly from the catch of surface gillnet in Bali Strait waters and then analyzed in Universitas Brawijaya laboratory. While length and weight of fish are measured by using ruler with 1 mm accuracy and analytical scale with accuracy of 0.01 gram.

2.4 Measurement of Sea Surface Temperature
Sea surface temperature (SST) data will be taken from NASA ocean color website here: [http://oceancolor.gsfc.nasa.gov/](http://oceancolor.gsfc.nasa.gov/). These data are then processed by using Seadas and Microsoft excel applications.

3. Data analysis
The process of data analysis using Microsoft Excel and FAO-ICLARM Fish Stock Assessment Tools (FISAT II). Microsoft Excel program used to analyze the biology of the fish, while FISAT II program used to analyze the growth parameters (L∞, K and t0), mortality, recruitment patterns, yield per recruit (Y/R), biomass per recruit (B/R).

3.1 Biological Analysis
3.1.1 Length and Weight Relationships. Analysis of length and weight of fish used Pauly equation [3] as follow:

\[ W = aL^b \]

This equation then change to be linear equation in order to obtain value of variables a and b. This linear equation is:
Ln \( W = \ln a + b \ln L \) ...........................(2)

Where:
- \( W \) = body weight (g)
- \( L \) = total length of fish (cm)
- \( a \) = intercept
- \( b \) = slope

To find out whether there is a difference to the value of \( b \) obtained t-count with the following formula:

\[ t_{\text{count}} = \frac{b - 3}{Sb} \] ...............................(3)

Where: \( Sb \) = standard error of the value of \( b \)

Length and weight relationship can be seen from:
1. If \( t \) count < \( t \) table then \( H0 \) accepted, which means \( b = 3 \) (isometric).
2. If \( t \) count > \( t \) table then \( H1 \) accepted, which means \( b \neq 3 \) (allometric), namely:
   a. If \( b > 3 \), it means allometric positive.
   b. If \( b < 3 \), means allometric negative.

3.1.2. Sex Ratio. According to Effendie (2002) sex ratio can be obtained by using the comparison:

\[ P_j (\%) = \frac{A}{B} \times 100 \% \] ...............................(4)

Where:
- \( P_j \) = sex ratio (male / female)
- \( A \) = number of species of fish (male / female)
- \( B \) = total number of individual fish available.

To see the uniformity of sex was used chi square test (Steel and Torrie, 1991):

\[ X^2_{\text{count}} = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \] ...............................(5)

Where:
- \( X^2 \) = a value for a random \( X^2 \) converter whose distribution of samples approaches the chi square distribution
- \( O_i \) = frequency of male / female fish observed
- \( E_i \) = expected frequency, (male + female) / 2
- \( X^2_{\text{table}} = (0.05; df) \) ...............................(6)

Where :
- \( Df \) = (number of rows-1) \times (number of columns-1)

Hypothesis:
- \( X^2 \) count < \( X^2 \) table, Accept \( H_0 \) means no real difference.
- \( X^2 \) count > \( X^2 \) table, Reject \( H_0 \) which means there is a real difference.

3.1.3 Gonad Maturity Level. Gonad maturity level is determined 5 levels of gonad maturity [4] namely (1) Undeveloped; (2) Begin to develop; (3) Growing; (4) Ripe; and (5) Post spawning.

3.1.4 Gonado Somatic Index (GSI). The formula for calculating GSI is as follows [6]:

\[ GSI = \frac{W_g}{W_b} \times 100\% \] ...............................(7)

Where:
- GSI = gonado somatic index
- \( W_g \) = gonad weight (gram)
- \( W_b \) = body weight (gram)

3.1.5 Length at First Mature Analysis. Illustration of length at first mature (Lm) of fish is performed using Pauly formula as follows [3]:

\[ Q = \frac{1}{1 + e^{-a(L-Lm)}} \] ...............................(8)

Where:
Q = the fraction of the long class of gonads mature
1 = value indicating 100% mature
e = 2.718
a = constants
L = long class interval (cm)
Lm = length of fish when 50% ripe gonads
The equation is transformed into linear form into:
\[ \ln \left( \frac{Q}{(1-Q)} \right) = -a \times L_{50} + a \times L \]
Furthermore the value of the first fish length of mature gonad is calculated through:
\[ L_{50} = -\frac{a}{b} = -\frac{\text{intercept}}{\text{slope}} \] ..............................(9)

3.2 Population Dynamics Analysis
3.2.1 Von Bertalanffy's Growth Parameters. The values of \( L_\infty \) and \( K \) are derived from the calculation of the von bertalanffy growth equation model using the FISAT II program [3]. Growth curve obtained from the formula Sparre and Venema [7]:
\[ L_t = L_\infty (1 - \exp(-kt)) \] ..............................(10)
Where:
\( L_t \) = length at age \( t \)
\( L_\infty \) = asymptotic length
\( k \) = growth constant
\( t_0 \) = age of the fish at zero length
To calculate the value of \( t_0 \) using the Pauly formula [3]:
\[ \log(-t_0) = -0.3922 - (0.275 \times \log(L_\infty)) - (1.038 \times \log(k)) \] .............................(11)

3.2.2 Length at First Capture Analysis. Length at first capture (\( L_c \)) analysis using equations according to Sparre and Venema [7]:
\[ \Delta \ln FC(z) = a - b \times (L + \frac{dL}{z}) \]
Where:
\( \Delta \ln FC(z) \) = ln the difference in the length class
\( Z \) = the difference of two classes of length
\( (L + \frac{dL}{z}) \) = upper limit of each class length
\( a, b \) = constants
Then the equation becomes:
\[ L_c = \frac{a}{b} \] ..............................(12)

3.2.3 Mortality Rates. Total mortality (\( Z \)) was analyzed by length converted catch curve analysis approach in FISAT II with Beverton and Holt equation [8]. While estimation of natural mortality (\( M \)) is conducted based on Pauly equation [9]:
\[ Z = \frac{k(L_\infty - L)}{(L_\infty - L')} \] ..............................(13)
\[ \ln M = -0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.463 \ln T \] ..............................(14)
Where:
\( Z \) = total mortality
\( L_\infty \) = average length of fish caught (cm)
\( L' \) = minimum length of fish (cm)
\( M \) = natural mortality (per year)
\( T \) = average surface temperature of waters (\(^\circ\)C)
The fishing mortality is derived from Gulland equation [10]:
\[ F = Z - M \] ..............................(15)

3.2.4. Exploitation Rate. The rate of exploitation (\( E \)) using the Gulland equation [10]:
\[ E = \frac{F}{Z} \] ..............................(16)
Where:
E = exploitation rate
F = mortality of capture
Z = total mortality

To know the level of exploitation in the following way:
\[ TP = \frac{E}{0.5} \times 100\% \] .................................(17)

Exploitation status is as follows [11][12]:
1. E < 25% : Unexploited
2. E = 25% - 50% : Lightly exploited
3. E = 50% - 75% : Moderately
4. E = 75% - 100% : Fully exploited
5. E = 100% - 150% : Over exploited
6. E > 150% : Depleted

3.2.5 Recruitment Pattern. The determination of recruitment pattern is done by recruitment patterns of FISAT II program. The recruitment pattern is determined by using the predetermined frequency distribution data [3].

3.2.6 Yield per Recruit (Y/R) and Biomass per Recruit (B/R). Estimation of Y/R and B/R can be done by FISAT software by clicking access-Beverton and Holt Y/R knife edge analysis by entering M/K value.

The estimation is calculated based on Spare and Venema equation [7]:
\[ \frac{Y}{R} = E \times \frac{U m}{K} \left[ 1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} + \frac{U^3}{1+3m} \right] \] .................................(18)
\[ \frac{B}{R} = \frac{(Y/R)}{F} \] .................................(19)

Where:
\[ U = 1 - \frac{L_c}{L_{oo}} \]
\[ m = \frac{1-E}{M/K} \]
\[ E = \frac{Z}{F} \]
B/R = biomass per recruit
Y/R = yield per recruit
F = fishing mortality

4. Results and discussion
4.1 Biological aspects of fish
4.1.1 Sex Ratio. Fringescale sardine (S. fimbriata) obtained during the study amounted to 1,471 fish consisted of 802 male (55%) and 669 female (45%) (Figure 2). Sex ratio between male and female was 1.2 : 1.

Figure 2. Proportion of sex ratio of fringescale sardine (S. fimbriata)

Based on chi-square test it was found that \( X^2 \) count was lower than \( X^2 \) table with value equal to 12.025 <12.706, so that it can be concluded that there is no significant difference between male and female or balance.

4.1.2 Length and Weight Relationship. It was found that length weight relationship has very close relationship which is shown by correlation coefficient (r) value of 0.732 with equation \( W = 0.0097L^{2.946} \) (Figure 3). The relationship of length and weight describes the pattern of fish growth shown from the value b.
Figure 3. Graph of length and weight relationship

The result of t-count analysis found that the value of T count (18.17) > T table (1.96) which means reject H1 that is value of b ≠ 3 or allometric growth. From these results then seen the result of regression value b that is 2.94 which means that the growth can be said allometric negative.

4.1.3 Gonad Maturity Level. Overall, the proportion of immature fringescale sardine (S. fimbriata) is 62% and mature gonad is only 38%. The results indicated that there has been growth overfishing in the waters of the Bali Strait, since the catch is dominated by immature fish (Figure 4).

4.1.4 Gonado Somatic Index (GSI). The development of gonad maturity is generally indicated by value of GSI and the result varied by sampling but all GSI values was below 20% (Figure 5). It meant that the fish is able to conduct reproduction activity more than once per year.

4.1.5 Length at first mature (Lm) analysis. Calculation of Length at first mature (Lm) of fish was done separately male and female fish. It was obtained that Lm for male and female was 11.95 cm and 10.79 cm respectively (Figure 6).
Figure 6. Length at First Mature (Lm) of fringescale sardine (*S. fimbriata*) (a) male (b) female

4.2 Dynamic population aspect

4.2.1 Separation of Fish Age Group according to frequency distribution

The frequency distribution of fringescale sardine (*S. fimbriata*) was analyzed using Bhattacharya method (Figure 7).

| Parameter | 31th Dec | 01st Jan | 29th Jan | 26th Feb | 26th Mar | 02nd Apr | 24th Apr | 03rd May |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Mean      | 10.88    | 10.89    | 10.9     | 11.09    | 11.29    | 11.36    | 12.14    | 12.17    |
| SD        | 0.49     | 0.5      | 0.44     | 0.36     | 0.36     | 0.41     | 0.6      | 0.6      |
| R-Square  | 0.856    | 0.826    | 0.905    | 0.978    | 0.974    | 0.903    | 0.811    | 0.635    |
| S.I       | n.a      | n.a      | n.a      | n.a      | n.a      | n.a      | n.a      | n.a      |
| Population| 200      | 136      | 190      | 197      | 200      | 195      | 197      | 128      |
The result of the above bhattacharya analysis (Table 1) is seen in the mean of each month moving from small size to larger size, so it can be said that fish is one stock and 1 cohort. the separation index is less than two then there is no possibility to separate between the two sets of sizes due to the large overlap between the size groups [7].

4.2.2 Length at First Capture (Lc). The length at first capture (Lc) analysis based on total sample obtained was 10.44 cm. This value was lower than Lm value for both, male and female fish (Figure 8). When the Lc < Lm value of the fish is not feasible to be caught, because the fish has not spawned yet. If exploitation is done continuously, it will jeopardize the availability of stock.

4.2.3 Growth Parameters. The determination of the value of K and L∞ is done through the response surface section where we find the highest Rn value. The yield of the VBGF plot growth curve (Figure 9) showed the frequency of the rebounded length with the growth curve which indicates a cohort, and the initial growth occurs in August. While value t₀ obtained was -0.149 years. Theoretically the long asymptotic length (L∞) of fringescale sardine (S. fimbriata) can be achieved at the age of 6.5 years. Von Bertalanfly's long-term growth equation is Lt = 19.6 \(1 - e^{(-0.54 (t + 0.149))}\). From the equation obtained growth curve.

Table 2. Parameters of growth of fringescale sardine (S. fimbriata) in Bali strait

| Parameters | Value | Unit |
|------------|-------|------|
| Rn         | 0.934 |      |
| L∞         | 19.6  | Cm   |
| k          | 0.54  | year |
| t₀         | -0.149| year |

For the growth curve we can see the VBGF plot as follows:

Figure 9. Restructured length frequency distribution output from FISAT II with superimposed growth curve.

Figure 10. Graph of growth rate of fringescale sardine (S. fimbriata)
Based on the growth curve (Figure 10), it is seen that the longest rapid growth occurs at a young age and slows with the age of the fish until it reaches its asymptotic length where the fish will not grow any longer.

4.2.4 Recruitment Pattern. Recruitment can be interpreted as the addition or inclusion of individuals into fishing ground at the occurrence of fishing (Figure 11). It can be seen in Figure 11 that the recruitment pattern only has one peak in one year, so it can be said that the fringescale sardine \(S. fimbriata\) in the waters of Bali Strait experienced one recruitment in one year. The graph shows that the recruitment occurred every month for a year. In addition, July is the peak of recruitment (26.66%).

![Figure 11. Recruitment proportion of fringescale sardine (S. fimbriata) in one year](image)

4.2.5 Mortality Rate. The result of mortality calculation (Figure 12) of fringescale sardine \(S. fimbriata\) in Bali Strait was total mortality (Z) of 6.41, natural mortality (M) of 1.38 with sea water temperature 29.5°C, fishing mortality (F) of 5.03 and exploitation (E) of 0.79.

![Figure 12. FISAT II output of linearized length-converted of catch curve](image)

The results of the rate of exploitation indicate that the catch has exceeded the optimum limit. Gulland [14] suggested that in an optimally exploited stock the fishing mortality rate (F) is equal to the natural mortality rate (M) or the rate of exploitation (E) is equal to 0.5.

4.2.6 Exploitation rate and prediction of fishery status. The value of the Exploitation rate (E) of this study was 0.79 per year. It meant that fishery status was in overfishing condition. There are three things that must be done in managing fish stocks, catching arrangements, arrange fishing arrangements (fishing time, number of fishermen and the number of fishing fleets) and catching techniques (the size of the net eye and the mode of operation of fishing gear).

4.2.7 Yield per Recruit (Y/R) and Biomass per Recruit (B/R). Calculation analysis toward yield and biomass availability obtained that values of Y/R and B/R were 0.02 and 0.147 respectively (Figure 13).
Figure 13. Isobar graph (a) yield per recruit (b) biomass per recruit

The resulting intersection for Y/R (Figure 13) in red means that the utilization rate is maximal. Y/R value means a number of fish entering the waters of 0.02 that was caught by fishermen. The result of B/R analysis (Figure 13) informed that the remaining biomass of fish entering the waters is 0.147. B/R in blue meant that there is less biomass available so the addition of fishing effort is not recommended.

The relative results of Beverton and Holt indicate that on the green line (E.10) is the maximum economic yield target (MEY), on the red line (E.50) indicates the index for sustainable yield and on the yellow line (E.max) is the rate of exploitation at maximum sustainable yield (MSY) [15]. From the graph (Figure 14) it can be concluded that 0.265 is the level of exploitation with maximum economic yield, 0.229 indicates optimal exploitation rate and 0.354 is the level of exploitation at the time of MSY.

Figure 14. Illustration of Y/R and B/R relationship.

5. Conclusion
1. The length weight relationship of fish formed a negative allometric growth pattern. The proportion of gonad maturity level showed 62% immature and 38% had mature gonads. The length at first mature (Lm) of male and female is 11.95 cm and 10.8 cm respectively.
2. Several values of dynamic population parameter are Asymptotic length (L∞) = 19.18 cm, growth rate (K) = 0.54 per year, t0 = -0.149 years, and length at first capture (Lc) = 10.44 cm. While mortality rates values are total mortality (Z) = 6.41, natural mortality (M) = 1.38 with temperature 29.45°C, and fishing mortality (F) = 5.03. Recruitment pattern occurs once a year, peak at month 7 with proportion of 26.66%. In addition, values of Y/R and B/R are 0.02 per year and 0.147 per year respectively.
3. Exploitation rate (E) is 0.79 per year indicating that the stock is in overfishing condition.

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