Population growth and fishery status of the Lorjuk shellfish (Solen sp.) on Pamekasan beaches, Indonesia

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Abstract. Solen sp. is classified as a Pelecypoda which is found in certain waters in Indonesia. Solen sp. is utilized as fresh and processed food. Alarminglly, catching Solen sp. continuously will reduce the number of its population in the world. The research aims to determining the population growth of Solen sp. and its fishery status on Talang Siring Beach, Pamekasan. The results of the research show that the range of Solen sp. length is between 1.8 and 4.4 cm. The growth calculation is \( L_t = 5.5 \times (1 - e^{-0.07(t + 0.006)}) \). The growth of Solen sp. calculated by the ELEFAN I method in the FISAT II software produces the value \( (L_\infty = 5.5 \text{ cm}, k = 0.07/\text{year}) \). Estimation of the length at time \( t_0 \) calculated by Pauly's empirical formula is \( t_0 = -0.006 \). The natural rate of mortality \( (M) \) is 2.23/year, and the capture mortality \( (F) \) is 5.72/year and total mortality \( (Z) \) is 7.96/year. The exploitation rate \( (E) \) is 0.72/year. The conclusion of the research is that the Solen sp. on Talang Siring beach, Pamekasan is overfished. Therefore, it is necessary to regulate a fishing time and protection to Solen sp. so that the population remains everlasting and sustainable.

1. Introduction
Currently, Solen sp. is a species of shellfish that is economically marketable in Indonesia [1,2] and in the world [3,4]. Solen sp. immerses itself in coastal sediments and then forms a hole as deep as 60 cm. The hole is opened at surface of the sediments and a flume is formed in which is easily revealed with a scoop or crowbar. Fishing technique affects the caught Solen sp. size [5,6]. Solen sp. size on the Talang Siring Beach, Pamekasan is found in the range between 1.8 and 4.4 cm, average \( (2.8 \pm 0.41) \) cm.

Genetic relationship among Solen sp. from Pamekasan coast and east coast of Surabaya by applying DNA Barcode COI method shows that Solen regularis in Surabaya is similarly related to Solen regularis from Malasya with 96.86% similarity, while Solen sp. on Pamekasan Beach have a similarity of 82.69% [1].

High market demand on Solen sp. to be food impacts on fishing effort that is more intensively carried out, so it is feared to decrease Solen sp. population, although the decline is not yet known due to the absence of fishing production data. A result of the research [7] on the East Coast of Surabaya shows that mortality rate due to fishing \( (F) \) Solen regularis is 2.01/year, and the exploitation rate \( (E) \) is 0.50/year. These data show that over fishing Solen regularis on the East Coast of Surabaya has occurred. Utilizing fisheries resources sustainably becomes an effort to prevent over exploitation and to maintain a balance between fishing requires and conservation efforts. Therefore, it is necessary to manage the Solen sp. fishing in order to ensure the availability and the sustainability in its habitat.
The research aims to determining population growth of Solen sp., including its growth patterns, mortality, exploitation rates and utilization status on Pamekasan Beach and comparing it with Solen regularis on the East Coast of Surabaya.

2. Materials and methods

2.1. Sampling sites
The research was conducted on Talang Siring Beach, Pamekasan at 7° 8'30.00 "S and 113° 35'21.00"E coordinates (Figure 1) on August, 2018 to July, 2019. Sampling was taken every two weeks. The collected samples during the research was 5841 shellfishes. Samples were taken from the intertidal area on a substrate of mud sand at low tide by using a rake that is driven into the substrate and the substrate behind the beach. Solen sp. contained in the substrate mound is taken by hand and stored in 5% formaldehyde in seawater immediately after capture [3]. Morphometric measurements include length (L) and width (W). Length measurement uses caliper with 0.1 cm accuracy and the weight uses analytical scales with 0.01 gram accuracy.

![Figure 1. Research location](image)

2.2. Length-weight relationship
Length-weight measurement applies a formula W = a L^b. W is the weight of Solen sp. (gram), L is the length of Solen sp. (cm), a is an intercept (the curve intersection of the length-weight relationship with the y-axis) and b is an estimator of the length-weight growth pattern. If b = 3 indicates isometric growth which means the length and weight increase is the same, b ≠ 3 shows allometric growth, b <3 indicates that an increase in length is faster than body weight, and b> 3 indicates that an increase in body weight is faster than length [8].

2.3. Von Bertalanffy's growth
Growth measurement applies the formula Lt = L∞ (1-e^-k (t-t0)) [9]. Estimation of theoretical age (t0) at which the length of Solen sp. is equal to 0 (zero) uses empirical equation [10], that is Log (t0) = 0.3922 to 0.2752 (Log L∞) - 1.038 (log k). L∞ is the maximum length of Solen sp. theoretically (asymptotic length), k is the coefficient of growth rate (per unit time) and t0 is the theoretical age of Solen sp. at time that the total length of the shell is zero.
2.4. Mortality rate

Measurement of mortality rate uses the formula [11] with equation \( Z = \frac{k (L - L_c)}{L - L_c} \). The natural mortality rate \( (M) \) is calculated based on the empirical method [10] ie \( \log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log k + 0.4634 \log T \). The fishing rate \( (F) \) can be calculated by subtracting \( M \) value to value \( Z \), with the formula \( F = Z - M \).

2.5. Exploitation rate \( (E) \)

Calculating the utilization or undertaking rate (exploitation rate) applies the formula \([12]\) in a way of comparing the rate of fishing mortality \( (F) \) with a total mortality rate \( (Z) \). If \( E > 0.5 \) indicates a high level of fishing experience (over fishing), \( E < 0.5 \) indicates a low level of exploitation (under fishing) and \( E = 0.5 \) indicates optimal utilization [9].

3. Result and discussion

3.1. Length-weight relationship

The analysis results on the length-weight relationship of \( Solen \) sp. is \( W = 0.064 L^{2.450} \) with 0.928 correlation coefficients (Figure 2). The average value that \( b = 2.450 \pm 0.016 \) indicates a negative allometric \( (b < 3) \), i.e. the shell length growth is faster than the weight growth one or thin. These are the same as the research results [7] on \( Solen regularis \) on the East coast of Surabaya with a value of \( W = 0.038 L^{2.798} \) and correlation coefficients = 0.949. Length-weight relationship of \( Solen \) sp. in Indonesia is the same as \( Solen dactylus \) in Iran, i.e. \( W = 0.0001 L^{2.5921} \) with correlation coefficients = 0.96 for all analyzed specimens with \( p < 0.001 \) [13], as \( Solen strictus \) in Korea with correlation = 0.91 [14] and as \( Ensis arcuatus \) in Ireland with a correlation coefficients = 0.97 [15].

Length-weight relationship is used in fisheries biology research to explain changes in individual size, to show organism growth patterns, to obtain index of population physical conditions and to evaluate habitat quality [16]. Length-weight growth is influenced by several factors including food and adaptation to the environment [8]. Available feed in intertidal areas, especially in sandy substrate is relatively few, i.e. the plankton types that is easily carried by stream. The observation at the research location obtains plankton types of \( Chrysophyta \) class with \( Cyclotella, Navicula, Nitzschia, Synedra \) and \( Thalassionema \) genus in diversity index \( (H') = 1.508 \) and dominance index \( (D) = 0.247 \).

Inhabiting clams in intertidal areas depend on a plankton carrying stream, because they are benthic organisms and suspension eaters. The \( Solen \) sp.’s ability to adapt in this area in which its body is small and slim makes it easy to dig the substrate quickly, after the passing wave has moved animals from the substrate prior to the water to bring it out. In addition to \( Solen \) sp., small \( Donax \) shells and razor shells from \( Siliqua \) genus can also do as well this adaptation [17]. Organism to adapt in this area requires a large energy; its weight is reduced; and the growth is more focused on the length. Therefore, the growth pattern includes a negative allometric. That its shape is mild and does not move into the deeper grooves and is stable against the undercurrent is an attempt to survive [18]. The elongated shape of some species such as \( razor clam \) infauna allows them to dig deeper by using low energy to save themselves from predators [19]. \( Ensis macha \) type including \( Solen \) sp. has a length ratio greater than the weight in order to be more stable against the pull of the undercurrent and to make it easily to adapt to be an effectively benthic organism. That changes in its weight growth is relative to the length growth can be regarded as the result of a shift in the individual's life from plankton to actively explore the young mussels, which is part of the life shells cycle [3].
3.2. Von Bertalanffy’s growth

The result of analysis on Solen sp. growth parameters by applying ELEFAN I method in FISAT II software is $L_\infty = 55$ mm and $k = 0.07$/year. Estimation of $t_0$ by using the empirical formula [10] is obtained the value of $t_0 = -0.006$. Equation of von Bertalanffy’s growth is

$$ Lt = 5.5 \left(1 - e^{-0.07 (t + 0.006)}\right). $$

The result of research [7] on Solen regularis on East Coast of Surabaya shows that $L_\infty = 80$ mm, $k = 0.07$ year and the value of $t_0 = -0.003$. Solen dactylus in the Persian Gulf, Iran grows around 22-29 mm each year. $L_\infty$ parameter of each transect near the coast and that far from the coast is estimated: 101 and 108 mm; $k$ value of each transect is 0.27/year and 0.28/year; and $t_0$ of each transect is -0.99 and -0.94 [13]. Ensis macha in Argentina and Chile obtains $L_\infty$ value as 154 - 153 mm, $k = 0.27$/year - 0.28/year, and $t_0 = -0.08 - -0.72$ [3]. Ensis arcuatus has $L_\infty$ value as 145 - 159 mm, $k = 0.28 - 0.43$/year and $t_0 = -0.26 - -0.3$ [14]. Ensis arcuatus growth [20] occurs rapidly in the first three years of life. It increases 50 - 80 mm in the first year, 33-37 mm between the first and second years and 14-18 mm between the second and third years; it decreases between the fourth and sixth years (an increase approximately 5-10 mm), and an asymptotic growth phase is around the age of 8-9 years (more increases lower than 5 mm per year). The asymptotic size ($L_\infty$) varies between 140 and 174 mm, while the growth constant ($k$) ranges between 0.24 and 0.57 per year.
Table 1. k, to and L∞ values of various Solen and Ensis species

| No | Species                  | K Value (year) | t0 Value | L∞ Value (cm) | Reference |
|----|--------------------------|----------------|----------|---------------|-----------|
| 1  | Solen dactylus           | 0.27           | -0.99    | 10.1          | [13]      |
| 2  | Ensis macha              | 0.27 – 0.28    | -0.08 - 0.072 | 15.4 - 15.3  | [3]       |
| 3  | Ensis arcuatus           | 0.28 – 0.43    | -0.26 - 0.30 | 14.5 - 14.9  | [14]      |
| 4  | Ensis arcuatus           | 0.24 – 0.57    | -         | 14.0 - 17.4   | [20]      |
| 5  | Solen regularis          | 0.07           | -0.006   | 8.0           | [7]       |
| 6  | Solen sp. in Pamekasan  | 0.07           | -0.003   | 5.5           | (on process) |

Solen sp. growth on Pamekasan beaches obtains L∞ value relatively smaller than Solen regularis one on East Coast of Surabaya and Solen sp. and Ensis sp. growth in another country. Solen sp. length average during the research ranges between 1.8-4.4 cm. Growth pattern differences of the same species are due to several factors such as sample size, sex differences, and other external factors [21]. Solen sp. living in tropic regions have relatively smaller shells. The results of the research [4] on Solen regularis in Malaysia shows that the size is relatively the same as those on East coast of Surabaya, i.e. 60.72 ± 9.77 mm in Asajaya Laut, while in pufferfish 58.44 ± 5.65 mm. Higher Solen sp.’s growth coefficients are allegedly due to maximum metabolism might occur in tropical countries in which there are no seasonal obstacles. In subtropical regions such as in northern part of the Persian Gulf, it can provide a good place for sea shells to grow and reproduce as impacts of seasonal winds, high nutrient concentrations and available phytoplankton [12].

3.3. Mortality and exploitation rate
Calculating Solen sp.’s natural mortality rate (M) with annual waters temperature average, 27 °C on Pamekasan beaches results 2.23/year. This result is more substantial than calculating the natural mortality rate (M) on east coast of Surabaya with annual waters temperature average, 28 °C i.e. 2.05/year [7]. The natural mortality rate, 2.23/year indicates that Solen sp. mortality rate in the research location is highly classified, because [10] the fish natural mortality rate (M) is stated high if the M value reaches 1.5/year.

Analysis on total mortality (Z) by applying equation [9] in FISAT II software results that the total mortality value (Z) on Pamekasan beach is 7.96/year which is greater than the total mortality (Z) on east coast of Surabaya, i.e. 4.05/year. The total mortality values are influenced by natural mortality (M) and capture mortality (F). Solen sp. fishing mortality rate on Pamekasan beach at 5.72/year is greater than the capture mortality on east coast of Surabaya with a value of 2.01/year. This condition shows that the Solen sp. fishing pressure on Pamekasan beach is bigger than the one on east coast of Surabaya. It indicates that the fishing has been over carried out. The concept of optimum fishing rate developed by [10] states that the optimum fishing rate is reached if the value is equal to the natural mortality rate (Foptimum = M). [11] states that if the value is F > M, the fishery status has been overexploited, while [22] states that if the fishing mortality is higher than the natural mortality of a fish resource, it indicates that an imbalance has occurred in the stock. Fishing technique will affect the caught Solen sp. size [2,6]. Solen sp. fishing on Pamekasan beach goes on throughout the year by using rake tool that can take Solen sp. in various sizes. Unfortunately, it impact on large morphology damage and mortality which are more substantial as by hand fishing technique on east coast of Surabaya that can choose the size and the morphology damage can be minimized. Mortality charts can be seen in Figure 4.
According to [9], the high mortality as impact of fishing factors is due to the businesses in fishing grow largely. In addition, there are many businessmen using the fishing gear; there are no operational area restrictions; the local government or related agencies poorly socialize an importance of preserving fish resources to the fishermen; and there are no regulations governing the size of shellfish that can be caught and may be traded. These factors cover fish and shellfish. [23] explains that if the fishing effort is so large or appropriate to match the available parent population, the population will continuously decline and at some level the organism will be extinct.

The exploitation rate (E) on Pamekasan coast obtains the value, 0.72/year. The rate informs us that 72% of Solen sp. on Pamekasan beach has been caught. The optimum exploitation rate has been reached if it is equal to 0.5/year (Eoptimum = 0.5 / year) [10]; therefore, Solen sp. exploitation rate on Pamekasan beach has exceeded the value threshold of optimum exploitation rate or over fishing. Calculating exploitation on Pamekasan beach results that the Y/R value is 0.013, while the B/R value is 0.157 (Figure 5). These values illustrate that the remaining biomass in the nature is 15.7%. Recently, 13% of the 15.7% remaining biomass has been caught. Thus, the Solen sp. population now is very little. Therefore, it is very necessary to limit fishing activities in order that biomass population in the waters increases again. Parameters that can be managerially controlled are the fishing mortality rate (F) or regulating the fishing time and number.

4. Conclusion
Solen sp’s growth rate on Talang Siring beach, Pamekasan is (k) 0.7/year; the age at length is equal to zero (t0) -0.06; the maximum length (L∞) is 5.5 cm; the natural mortality (M) is 2.23/year; the fishing mortality (F) is 5.72/year; the total mortality (Z) is 7.95/year; and the exploitation rate is 0.72/year. The exploitation rate has reached overfishing. Therefore, the local government should regulate the
fishing time by paying attention to local wisdom the community holds. Forwardly, Solen sp. population on Talang Siring beach, Pamekasan can be long-lastingly and sustainably maintained.

5. References

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