Sex ratio and size at first maturity of razor clam Solen sp. in Pamekasan and Surabaya coastal area, East Java, Indonesia

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Abstract. Solen sp. is one species of Pelecypoda class that has commercial value. Size at first maturity is one of the reproductive aspects needed for the management of fishery resources. This study was aimed to estimate the sex ratio and the size at first maturity of Solen sp. Samples were collected from the coast of Pamekasan and Surabaya from October 2017 to September 2018. The sex ratios were analyzed using chi-quadrat-test while the size at first maturity was obtained from the first size of the third-gonadal-maturity stage. Sex ratio of male and female Solen sp. in the coast of Surabaya was 0.898: 1.049 and Pamekasan beach was 1.065: 0.928. In the coast of Pamekasan, male Solen sp. reached gonadal maturity stage at the size of 260 mm, and female at 263 mm, while in Surabaya the males reached gonadal maturity stage at the size of 570 mm and the female at 585 mm.

1. Introduction
Solen sp. locally known as Lorjuk or bamboo clam is one of fisheries resources having high economic value [1-2] and can be consumed in fresh or processed forms. The previous study [3] found that Solen sp. in Surabaya 96.86% similarity and Solen sp. in Pamekasan 82.69% similarity to Solen regularis. The higher the demand for Solen sp. as food material is, the more intensive the fishing effort will be [4-7], so that their population decline may occur. The fishing technique of Solen sp. will also affect the number of catches, size and substrate destruction [8]. The fishing technique using “garu” in Pamekasan will yield small-sized Solen sp. and cause a destruction of the bottom substrate. The fishing technique with the fine stick in Surabaya coast yields big-size individuals and does not cause substrate damage.

Sustainable use of fisheries resources tries to prevent excessive exploitation and to maintain the equilibrium between the number of catches and conservation. Over exploitation can happen when too many small individuals are caught or not enough time left for the small individuals to grow since young individuals entering the fishing ground will be fished. Size at first gonadal maturity (Lm) or 50% mature individuals has been taken as the reference of minimum size regulation catchable to prevent stock decline. This reference has been used by many fisheries manager as fish stock management measure [9-11] for 100 years to let the mature individuals lay eggs at least once or to protect the immature individuals [12]. The approach method is based on the ecosystem rules, such as an impact on stock, habitat, food web, and non-target species, besides productivity and mortality of the species, predator-prey interaction, competition, carrying capacity, population variability, and environmental parameters. The exploitation rate (E) of Solen sp. in Surabaya for the time period of 2014-2015 was 0.50/yr [7]. It indicates that 50% of Solen sp. population have got fishing pressures
and this condition reveals that *Solen* sp. has reached the optimum exploitation since $E$ value equals to 0.5/yr. Biomass per Recruitment (B/R) is same as Yield/Recruitment (Y/R), 0.014/yr, meaning that 1.4%/yr of *Solen* sp. population was taken in Surabaya coast. Equal B/R to Y/R reflects that the number of *Solen* sp. catches is same as the number of biomass in the waters.

Previous finding [13] found that gonad maturity level (GML) of *Solen* sp. in Surabaya coast reached maturity level (phase III) in May, and started spawning (phase IV) in June, and gonad development declined up to resting phase (level 0) in September. In October, gonad maturity level returned to maturity level (II and III). Increased gonad maturity level of *Solen* sp. was followed with oocyte diameter development as equation $GML = 0.522 \pm 0.528$ oocyte diameter with the correlation of 79.2 %.

This study was intended to know the sex ratio and the size at first gonad maturity of razor clam *Solen* sp. in Pamekasan and Surabaya coasts as basic catchable size determination for *Solen* sp. resource management.

2. Methods
2.1. Sampling sites and method
*Solen* sp. sampling was carried out in two locations, Pamekasan coast, Madura, at the geographic position of $07^\circ08'30.1"S$ and $113^\circ35'21.4"E$, and Surabaya coast at $07^\circ08'33.5"S$ and $113^\circ35'27.1"E$ (Figure 1). It was done in October 2017 to September 2018. Gonad maturity and histological observations were conducted in the Laboratory of Biology, Airlangga University, while the morphometric study was done in Aquaculture Laboratory, Hang Tuah University.

![Figure 1. Sampling site.](image)

Thirty specimens were observed at each sampling every two weeks[14] for 12 months. Samples were preserved in 5% formaldehyde soon after fishing [1]. Total length was recorded using a 0.01 cm-caliper. Observations on sex ratio and gonad maturity used fixation and staining method [1], and gonad maturity levels were grouped based upon the photomicrographic illustration of gametogenic scale in *Ensis arcuatus* [2].
2.2. Data analysis
Sex ratio was estimated using the following formula:

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

where \( NK \) = sex ratio, \( \Sigma J \) = number of male Solen sp. (ind.), and \( \Sigma B \) = number of female Solen sp. (ind.).

Sex ratio was calculated using Chi-Square \((\chi^2)\) test in the form of confidence table [15]

\[ X^2 = \sum_{i=1,2,3} \frac{(fi - F)^2}{F} \]

where \( \chi^2 \) = sex distribution value, \( fi \) = observation i, \( F \) = expected value i, iis 1,2,3, and \( S \) = number of observations. The testing criteria are as follows: sex ratio will be 1:1 if \( \chi^2_{cal.} \leq \chi^2_{tab.} \) \((\alpha=0.05)\) and sex ratio will be 1:1 if \( \chi^2_{cal.} > \chi^2_{tab.} \) \((\alpha=0.05)\).

Determination of size at first maturity was done by separating size interval, from the smallest to the biggest. Size classes were divided into 10 size groups for Solen sp. from Surabaya and 6 groups for those from Pamekasan. Size at first maturity is the size related with 50% gonad maturity. It followed Udupa’s method [16], in which gonad maturity level was determined on the size group following the Spearman-Karber equation:

\[ m = x_k + \frac{x}{2} - (x\sum pi) \]

Where \( m \) = logarithm of length at first gonad maturity
\( x_k \) = logarithm of length at 100% of gonad maturity
\( x \) = difference of median logarithm
\( r_i \) = number of mature gonad of class i
\( pi \) = proportion of gonad maturity in class i \((pi = r_i/n_i)\)
\( q_i \) = \(1 – pi\)
\( pl \) = \( r_i/n_i \) if \( n_i \neq n_i+1 \) for \( i = 1, 2, \ldots k-1 \) and
\( pl \) = \( r_i/n \) if \( n = n_i = n_i+1 \) for \( i = 1, 2, \ldots k-1 \)

Mean size at first maturity was obtained as antilog \( (m) = M \).

Estimation of size at first maturity of Solen sp. was carried out by taking all male and female samples into a single group, because both sexes had the same number of maturity levels from I to IV. The total length of Solen sp. was then divided into size class intervals from the smallest to the largest. The asymptotic length \((L_\infty)\) estimation was also done using the Von Bertalanffy equation following Ford-Walford and Chapman [17] method by plotting \( L_t \) against \( L_t + 1 \):

\[ L_{t+1} = a + b*L_t \]

\( L_\infty \) was obtained from \( a / (1-b) \) and \( b = \exp (-K\Delta t) \)

3. Results and discussion
3.1. Sex ratio
Solen sp. sex was histologically observed. The sex difference was determined based gonad appearance, in which female gonad was white with milk texture, while male gonad was beige and granular [2]. Female and male gonads are presented in Figure 2.
Sex ratio is one of the reproductive parameters to determine the availability of mature males and females expected to spawn. In normal condition, male-female ratio is indicated with 1:1 ratio. Besides, the sex ratio could also reveal excessive exploitation on one of the sexes or environmental changes [18]. It was calculated based on sampling time has done for one year. The Chi-Square test with sampling time and study site is demonstrated in Table 1.

Table 1 shows that from 471 individuals of Solen sp. collected in Surabaya coast, there are 122 males and 249 females, and in Pamekasan coast, 720 individuals are caught consisting of 367 males and 353 females. Sex ratio studies in various countries highly varied. There were 364 males and 330 females of Solen regular is collected in Malaysia, 344 males and 366 females in Asia Jaya Laut [14], 65 males and 59 females of S. dactylus in Buntal [11], 67 males and 93 females of Zenatia in New Zealand [19], 202 males and 169 females of Ensis siligua in Irish Sea [20], 200 males and 194 females of S. marginatus in South Tunisia [21].

The sex ratio of Solen sp. in Surabaya coast was 0.898:1.049 and in Pamekasan coast, it was 1.065: 0.928. The Chi-Square test found $F^2_{\text{calc}} > T^2_{\text{tab.}}$, meaning that Solen sp. in Surabaya coast did not have 1:1 sex ratio. The Chi-Square test found $F^2_{\text{calc}} < T^2_{\text{tab.}}$, meaning that Solen sp. sex ratio in Pamekasan coast was 1:1. Solen sp. sex ratio difference between Surabaya coast and Pamekasan coast could result from the different environmental condition, particularly substrate particle, organic matter, and fishing method [8] that eventually affect the male-female ratio [18]. Spawning, especially clam, in nature is highly determined by the occurrence of males and females in the same location. The occurrence of male and female individuals is an important factor in supporting the sustainability of a population in nature since it will tend to ease the fertilization [18].
Table 1. Solen sp. sex ratio in Surabaya coast and Pamekasan coast.

| Observations | Surabaya Coast | Pamekasan Coast |
|--------------|----------------|-----------------|
|              | No. individuals | Sex Ratio | No. individuals | Sex Ratio |
|              | Male  | Female | Male  | Female | Male  | Female | Male  | Female |
| October 2017 | 13    | 16     | 0.813 | 1.231 | 16    | 14     | 1.143 | 0.875 |
| November 2017| 13    | 17     | 0.765 | 1.308 | 15    | 15     | 1.000 | 1.000 |
| December 2017| 14    | 16     | 0.875 | 1.143 | 16    | 14     | 1.143 | 0.875 |
| January 2018 | -     | -      | -     | -     | 16    | 14     | 0.875 | 1.143 |
| February 2018| -     | -      | -     | -     | 13    | 17     | 0.765 | 1.308 |
| March 2018    | 14    | 15     | 0.933 | 1.071 | 13    | 17     | 0.765 | 1.308 |
| April 2018    | 13    | 15     | 0.867 | 1.154 | 15    | 15     | 1.000 | 1.000 |
| May 2018      | 13    | 15     | 0.867 | 1.154 | 14    | 16     | 0.875 | 1.143 |
| June 2108     | 13    | 16     | 0.813 | 1.231 | 17    | 13     | 1.308 | 0.765 |
| July 2108     | 14    | 16     | 0.875 | 1.143 | 16    | 14     | 1.143 | 0.875 |
| August 2018   | 14    | 16     | 0.875 | 1.143 | 16    | 14     | 1.143 | 0.875 |
| September 2018| 14    | 16     | 0.875 | 1.143 | 15    | 15     | 1.308 | 0.765 |
| Total samples | 222   | 249    | -     | -     | 367   | 353    | -     | -     |
| Mean          | -     | -      | 0.898 | 1.049 | -     | -      | 1.065 | 0.928 |

The sex ratio of Solen sp. in Surabaya coast is not balanced, in which females are more than males. In several bivalve species, sex ratio varies enough, but it is, in general, balanced. The same-sex ratio is also found in S. marginatus in Tunisia [21], S. tachicosel in Vietnam [22], and S. gordonis in Japan [23]. The condition reflecting more females than males is one of the reproductive strategies of a population to increase the possibility of reproductive success. In normal condition, different sex ratio is a reproductive strategy in certain environmental condition. An occurrence tendency of more females than males in the lentic environment or more males than females in the lotic aquatic environment is one of the reproductive strategies to optimize the reproductive success [24]. Solen sp. is a species living in lotic waters, the intertidal area exposed to open air for certain period of time in the form of land and be submerged in other time with tidal change variations, temperature, waves, salinity, and substrate difference [8,25]

3.2. Size at first maturity (Lm)
Size at first gonad maturity (Lm) of Solen sp. is the smallest size of mature individuals. The present study found that male Solen sp. in Pamekasan coast started spawning at 2.60 cm long and the females at 2.63 cm long. In Surabaya coast, the males spawned at 5.70 cm long and the females at 5.85 cm long. The size difference in spawning activity is dependent upon the size distribution in nature. Size
at first gonad maturity of *Solen dactylus* occurs at 4.61 cm long [11]. *Ensis arcuatus* reaches maturity in 2–3 years old with the maximum length of 8.5 cm [6]. *Solen tachicosel* in Vietnam [22] reached gonad maturity at 6.96 cm long, and *Callista chione* spawns for the first time at 5.81 cm, even though 3.0 cm-individual has, in fact, spawned [26].

Based on the calculation or size at first maturity, it appears that size at first gonad maturity of females is bigger than males. Table 2 demonstrates maximum length and length at first gonad maturity of *Solen* and *Ensis* for different species.

Table 2 shows that the longer the size of *Solen* sp. and *Ensis* sp. is, the bigger the size at first gonad maturity will be. *Solen* sp. in Pamekasan coast has the smallest size of *Solen* sp. in the world with the maximum length of 55 mm, while *Solen* sp. in Surabaya could reach the maximum length of 80 mm so that their size of initially spawning is also relatively smaller than those in Asia and Europe. This size at first maturity is different from that previous findings [2,14] that the smallest size of spawning *Solen* sp. is 4 cm long. The difference in size at first gonad maturity reveals the presence of different reproductive strategy of each species since the size of *Solen* sp is influenced by environmental factors and different fishing techniques. The fishing method could limit the individual size of fish catches [8] and will affect the estimation of size at first gonad maturity.

| No | Species                        | $L_{mx}$ (mm) | $L_{m}$ (mm) | Reference |
|----|--------------------------------|---------------|--------------|-----------|
| 1  | *Solen dactylus* (Iran)        | 101           | 46.1         | [19]      |
| 2  | *Ensis macha* (Argentina)     | 154 - 153     | 112          | [1]       |
| 3  | *Ensis arcuatus* (Ireland)    | 145 - 149     | 85           | [6]       |
| 4  | *Ensis arcuatus* (Spain)      | 140 - 174     | -            | [25]      |
| 5  | *Solen* sp. (Pamekasan)       | 55            | 26.0         | In process|
|    |                                |               | 26.3         |
|    | *Solen* sp. (Surabaya)        | 80            | 57.0         | In process|
|    |                                |               | 58.5         |

The difference in size at first gonad maturity could also result from the environmental factors, i.e food availability assisting the gonad maturity process. Higher food abundance will accelerate gonad maturity process [14,21]. Fishing pressures cause the environmental disturbance on reproductive activities as well. When fish are caught at a very young age (immaturity) growth overfishing will occur [27]. Intensive exploitation makes the species have a reproductive strategy to be earlier mature than normal to produce the next generations. Nevertheless, fishing activities of small individuals are usually caused by demands [28] so that the fish population experiences fishing pressure on all size classes. Uncontrolled fishing activities could yield the change in species relative abundance, and negatively impacts on the water fertility and size at first gonad maturity. This condition occurs in *Solen* sp. in Pamekasan coast with relatively high fishing pressures using “garu” that makes all size be caught [8].

4. Conclusion

The sex ratio of *Solen* sp. in Surabaya coast was 0.898 : 1.049 in Surabaya coast and 1.065 : 0.928 in Pamekasan coast. The male and female ratio was not in 1:1 ratio in Surabaya coast, but those in Pamekasan coast had 1:1. Male *Solen* sp. in Pamekasan started spawning at 2.60 cm long and the females at 2.63 cm long, while in Surabaya coast, males started spawning at 5.70 cm long and females at 5.85 cm long. This difference is caused by environmental factors and fishing pressures. Thus, fishing season and size limitation should be done in order to sustainably maintain their population.
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