The grow-out of abalone (*Haliotis squamata*) at different shelter shape on growth and survival and its marine environmental influences at Lembongan Bay coastal waters

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Abstract. Abalone has an economic value in the world. The larval rearing technique of abalone has produced successfully at Gondol Research and Development Institute for Mariculture, Bali, Indonesia. However, the grow-out of abalone has not well documented yet. The purpose of this experiment is to examine the shelter shape in relation to growth and survival for abalone (*Haliotis squamata*) grow-out culture in the tidal area. The shelter made from PVC piping. The shape of shelter as a treatment of this experiment was A) round; B) square and; C) without shelter. The data of growth and survival rate were analyzed using analysis of variance. The result showed that the shelter for the grow-out of abalone was significantly affected growth in terms of shell length and wet weight (P<0.05) while the survival did not influence (P>0.05). It seems that the shelter was correlated with the feeding behavior of abalone had resulted in different for their growing. The water quality such as salinity, dissolved oxygen, water temperature, and water current was within the optimal range for abalone. We found that round shelter shape is the best for grow-out abalone at the tidal area.

1. Introduction

Abalone (family Haliotidae) exists worldwide and found in a range of habitats from temperate rocky coasts to tropical reefs. There are approximately 56 species of abalone [1]. Abalone aquaculture over the last decade has increased its share of the world abalone market with the decline of abalone fisheries [2]. Abalone fisheries have gradually decreased from almost 20,000 mt in the 1970s to less than 9,000 mt in 2008 due to over-exploitation, illegal harvesting, disease, and habitat degradation [3].

Abalone culture had been done initially in 1935 in Japan and developed in 1970 where breeding and larval rearing up to juveniles had been produced successful [4]. Abalone culture technology has established in several countries, and the industry can be considered to be entering a maturation phase. The most important producing countries include China: 5,000 tons p.a., Taiwan: 3,000 tons p.a., South Africa: 700 tons per annum (p.a.), Australia: 450 tons p.a., Chile: 254 tons p.a., USA: 240 tons p.a. and Mexico: 40 tons p.a. [2].

Abalone has an economic market value, especially, China, Korea, Japan, Singapore, and Australia. There are 7 species of Haliotis in Indonesia but only two species such as *Haliotis asinin* and *Haliotis squamata* had been cultured from broodstock up to juvenile stage management. Therefore, the
research focusing on grow-out has not studied yet. Yunus et al. [6] reported that the main problem of abalone (*Haliotis asinina*) culture is lack of technique for larval rearing and low survival effect on seed supply. Recently, larval rearing of abalone (*Haliotis squamata*) had been established by [7]. However, the grow-out of this abalone species has still obstacles due to a lack of rearing techniques. Therefore, to improve the survival and growth of abalone (*Haliotis squamata*) should be carried out in order to fulfill the market demand.

Some efforts to improve survival and growth of abalone has investigated such as water temperature and photoperiod [8], pH, water stability, and diet [9], stocking density [10], and water depth in the net cage [11], and different shelter type [12]. However, different shelter shape in abalone culture for growth-out has not reported. The purpose of this experiment is to examine the shelter shape in relation to growth and survival for abalone (*Haliotis squamata*) grow-out culture in the tidal area.

2. Materials and methods
2.1. Location of the experiment
The experiment was located at Lembongan Village, Nusa Penida Island, Klunkung District, Bali, Indonesia (Figure 1). The culture period of abalone for grow-out was conducted for five months (June to October 2015).

![The location of abalone culture.](image1)

2.2. Experimental setup
The juvenile of abalone with 3.70±1.97 cm in shell length and 8.06±0.98 g in wet weight obtained from the Gondol Research and Development Institute for Mariculture was used. During the culture period, Abalone fed with seagrass (*Glacilaria sp*) once per every three days with 5% per biomass. To measurement of length and wet growth, 20 abalones were sampled every month. The stocking density of abalone was 100 individuals per net bag with 45 diameters and 80 cm long. 12 net bags were placed in the tidal area. The net bag completed with plastic rope on two sides of the edge's net bag and connected to the stick in order to avoid wave and water current flow when the tide occurs (Figure 2). Water quality parameters such as water temperature, salinity, dissolved oxygen (DO), and water current were observed every month.
Figure 2. The placement of the net bag for the grow-out of abalone.

The shelter with a different shape (round and square) made from 4 “PVC piping” as a treatment was used (Figure 3). The length of the shelter was 25 cm. one net bag containing 12 shelters. The treatments of the experiment were A) round; B) square, and: C) without shelter.

Figure 3. The shape of shelter: A) round and B) square.

2.3. Data recording
Parameters observed in this experiment such as survival and growth (shell length and wet weight). Survival rate and growth were calculated using a formula based on [8]:

\[ S(\%) = \frac{N_i - N_t}{N_i} \times 100 \]  

[1]

Where \( N_i \) and \( N_t \) are the numbers of live organisms present at time 0 and at time \( t \), respectively.

Absolute growth (shell length and wet weight) based on a formula;

\[ W = W_t - W_o \]  

[2]

Where \( W \) is absolute growth of wet weight (g) or shell length (cm), \( W_o \) is growth of wet weight at initial (g) and/ growth of shell length at initial (cm), \( W_t \) is growth of wet weight at the end (g) and/ growth of shell length at the end. 20 Abalones for each experimental unit were sampled to measure the length using calipers and to measurement the weight using digital balance (ACIS AD600). The number of Abalones at all treatments by the end of the culture period were counted in order to survival rate data.
2.4. Tidal influence analysis
Marine environmental influences, i.e. tidal dynamics, in the site location “Lembongan bay coastal waters” is analysis using Fast Fourier Series-Modeling based on Topex/Poseidon altimetry satellite datasets which are provided by Agency for Marine and Fisheries Research and Development through the INDESO Project [13]. The sea surface elevation data, periods of January 1, 2013 – November 27, 2015, is derived to be tidal elevations and tidal transports in 3 (three) virtual stations. More than 2 years of time-series data is used to avoid larger error variations during investigation [14]. Those stations are represented for the site location (Station Pasut-Lembongan-02; 115°26'37.54"E, 8°41'48.56"S), and other two for looking up the interaction between Lombok Strait (Station Pasut-Lembongan-03; 115°29'11.84"E, 8°39'51.03"S) and The Indian Ocean (Station Pasut-Lembongan-01; 115°24'25.07"E, 8°42'28.60"S), see Figure 4. The analysis will only be focused on June - October/November 2015, as the same period for the experimental of abalone culture was conducted at Lembongan village (near Station Pasut-Lembongan-02). Form factor index value has been computed in order to determine tidal type in the site location, including also tidal transports [15].

![Figure 4. Tidal current analysis stations map.](image)

2.5. Water quality analysis
The water quality parameter such as temperature, pH, and dissolved oxygen, salinity, and water current was measured every 15 days. Temperature, pH, dissolved oxygen, and salinity were measured using multi parameters water checker (Hanna model HI98194) while the salinity was measured using a digital refractometer (Hanna model HI96822) while water current was measured using current meter acoustic (JDC, model FL-KIT1).

2.6. Statistical analysis
Statistical analysis using a completed randomized design with three replications for each treatment using ANOVA was performed. Post Hoc multiple comparisons of Tukey’s test was used in order to determine the difference between the treatments.

3. Results and discussion
3.1. Results
3.1.1. Tidal current pattern at Lembongan Bay
The marine environment at Lembongan Bay influences by the mixed tide prevailing semidiurnal since the form factor at station Pasut-Lembongan-02 is 0.415. The other two stations also have the same range of form factor (0.395-0.458), which means the Indian Ocean and Lombok Strait giving dominant influences to the seawater dynamics at Lembongan Bay coastal waters, see Table 1. In this case, constituents of principal lunar (M2) and principal solar (S2) more dominant compared to the lunisolar diurnal (K1) and principal lunar diurnal (O1). While each constituent has different periods i.e. 12.42 hours for M2, 12.00 hours for S2, 23.93 hours for K1, and 25.82 hours for O1. Those composite generate twice a day tide with different time periods between first and second tide. Ebb tide happened in the morning ~05:00 WITA and also ~18:00 WITA, while flood tide happens at 11:00 WITA and sometime near midnight ~24:00 WITA, see Figure 5. During June 2015, the maximum elevation happened in the day (10:00-11:00 WITA), then start from mid of September to the end of November 2015 the maximum elevation reveals almost at the midnight (23:00 – 24:00 WITA). This mixed-diurnal tide of Lembongan is confirmed also by [16] which investigates the harmonic constituents in Badung Straits, which located in the west of side Lembongan bay coastal waters, using ~2 months (June-July 2014) current profile time series data.

Table 1. Four mains constituents to compute form factor for tidal type determination.

| Constituent | Pasut-Lembongan-01 | Pasut-Lembongan-02 | Pasut-Lembongan-03 |
|-------------|-------------------|-------------------|-------------------|
|             | Ampl [m]          | Phase [°]         | Ampl [m]          | Phase [°]         | Ampl [m]          | Phase [°]         |
| M2          | 0.646             | 50.980            | 0.624             | 51.920            | 0.584             | 53.760            |
| S2          | 0.356             | 104.490           | 0.343             | 104.760           | 0.319             | 105.260           |
| K1          | 0.244             | 172.430           | 0.247             | 173.440           | 0.253             | 175.250           |
| O1          | 0.152             | 159.990           | 0.155             | 160.230           | 0.160             | 160.680           |
| Form Factor | 0.395             | 0.415             | 0.458             |

*Ampl.: amplitude of sea level [m]

Table 2. Tidal elevation and transport January 2013-November 2015.

| Stations                  | Tidal Elevation | Tidal Transport |
|---------------------------|-----------------|-----------------|
|                           | Min [m] | Max [m] | Average [cm] | Min [m²/s] | Max [m²/s] | Average [m²/s] |
| Pasut-Lembongan-01        | - 1.122 | 1.250   | 0.025         | 0.099      | 0.188      |
| Pasut-Lembongan-02        | - 1.093 | 1.219   | 0.026         | 138.886    | 174.034    | 165.289         |
| Pasut-Lembongan-03        | - 1.038 | 1.133   | 0.027         | 52.733     | 65.632     | 62.718          |

Tidal current characteristic in Lembongan bay coastal waters (Station Pasut-Lembongan-02), in general, is generated by the differential of elevation between sea level dynamics at The Indian Ocean (Station Pasut-Lembongan-01) and sea level at Lombok Strait (Station Pasut-Lembongan-03), see Figure 5. Currents will be flowing from the highest sea surface level to the lowest sea surface level, through the Lembongan channel. During the ebb period, the current will be flowing from Lombok Strait to the Indian Ocean, passing the Lembongan bay coastal waters. In the opposite direction, flood current flows will be going to Lombok Strait from the Indian Ocean, in this case, is also passing the Lembongan bay coastal waters. The slow tidal current in Lembongan bay coastal waters is happened because of a very small difference between tidal surface level in Station-Pasut-Lembongan-01 and Station-Pasut-Lembongan-03, see Table 2 of Tidal Elevation. The average magnitude of tidal transport in Station Pasut-Lembongan-02 (165.289 m²/s) is higher than in two others since the topographic feature of the Lembongan channel amplified the magnitude of passing flow transport between other two stations, see Table 2 of Tidal Transport. The influence of topographic feature has confirmed by...
those tidal transports, in general, flowing between Southwest and Northeast direction follows the channel, see Figure 6. This flow characteristics, between the Indian Ocean and Lombok Strait, was founded also by [17].

![Tidal Elevation June 4-5, 2015](image1)

**Figure 5.** Tidal elevation on June 4-5, 2015.

![Tidal Transport Vector June - October 2015](image2)

**Figure 6.** Tidal transport on June – November 2015.
3.1.2. Survival of abalone

The survival rates of abalone cultured at different shelter shapes and without shelter (Figure 7).

The survival rate (Figure 7), both round and square shelters (99.33%) were the highest compared to without shelter (98.67%). Statistical analysis revealed that no significant difference among the treatments in terms of survival rate at the different shelters (P>0.05). This fact that the shelters did not affect the survival of abalone for grow-out.

3.1.3. The growth pattern of abalone

The growth pattern of shell length and wet weight of abalone cultured at different shelter shapes and without shelter in the tidal (Figure 8).
Generally, the growth pattern both of shell length and wet weight showed an increase with increasing in culture period. The growth pattern of shell length of all the treatments from June to July tended to similar but after August to October, the round shelter was the highest followed by the square shelter and without the shelter (Figure 8). This can be stated that shelter affects the growth of shell length and wet weight.

3.1.4. Absolute growth of shell length and wet weight

Absolute growth, both of shell length and wet weight of abalone was better than that of abalone without shelter (P<0.05). Statistical analysis revealed that abalone culture at different shelter shapes and without shelter was significantly differenced among the treatments in terms of absolute growth (P<0.05). Round and square shape shelters showed significant differences compared to without shelter in relation to the growth of abalone (P<0.05). This indicated that the shelter affected abalone growth.
Absolute shell length (Figure 9A) of abalone at a round shelter (1.69±0.02cm) was the highest followed by the square shelter (1.63±0.06cm) and without shelter (1.18±0.28cm). Absolute wet weight (Figure 9B) was also the highest find at abalone with round shelter (16.78±1.31g) compared to abalone with shelter square (15.83±0.66g) and without shelter (11.40±2.9g).

3.1.5. Water quality
Water quality parameters, such as water temperature, salinity, pH, and dissolved oxygen (DO) has been measured in Lembongan bay coastal water in a different time, are compiled for further marine environmental influences analysis, see Table 3.

| Parameters       | Unit | Range value   | The ideal condition for abalone |
|------------------|------|---------------|---------------------------------|
| Water temperature| °C   | 29.13 ± 1.22  | 27 – 28.5 [7]                   |
| Salinity         | ppt  | 34.20 ± 1.30  | 30 – 35 [17]                    |
| pH               |      | 7.67 ± 0.69   | 7.9 – 8.1 [18]                  |
| Dissolved oxygen | mg/L | 5.04 ± 1.20   | >4 [19]                         |

Water quality is important for living aquatic organisms. Water quality parameters measured during the experiment showed within the optimal range for abalone. The experiment location could be recommended that such kinds of water quality parameters seemed to be sufficient for the abalone (Haliotis squamata) culture due to the optimal ranged.

3.2. Discussion
The environment of Lembongan Island based on monitoring and policy analysis such as wind, water quality, water current, the impact of the settlement, suitable site, and socio-infrastructure are most suitable for abalone culture [20].

The utility of shelter with different material that affects the growth and survival of abalone have been investigated [12]. However, the present experiment is focused on shelter shape which different from [12] have been reported. The result of the present experiment showed that the use of shelter has a significant effect on the abalone (Haliotis squamata) growth where abalone cultured using shelter was better than that of without shelter in relation to their growth. The growth pattern both of shell length and wet weight of abalone culture using shelter had higher than that of abalone without shelter had been reported [12, 22]. Such conditions can be stated that the existing of shelter is suitable for their growth (Figure 9). The present experiment suggested that the growth of shell length was higher than that of without shelter might be related to their behavior, especially, feeding activity. [22] reported that the behavior of abalone stack on the shelter has reduced mobility and less energy to obtain food. On the other hand, the present experiment suspected that the shelter is not only as a stack for abalone but shelter might be can reduce the wave or water current flow through the shelter, which has resulted in insufficient for feeding activity. [23] reported that water flow has also affected growth. Although abalone habitat at the open coast or intertidal that most intense wave action but abalone also needs essentially static water condition [24].

Benson et al [12] reported that abalone (Haliotis laevigata) with an initial mean weight 2.53±0.37 g and length of 21.92±1.53 mm showed higher increase the growth of shell length of 4.51±0.14 mm and wet weight of 0.63±0.11 g using Besser block shelter while plastic corrugated sheeting provided low a mean growth of 2.61±0.28 mm in the shell length and 0.32±0.10 mm in the wet weight. Moreover stated that abalone preferred to grow on and be sheltered in the culture rather than that without sheltered and increase in surface area.
Rusdi [7] stated that the optimal pH value was ranged from 7.95-8.07. Water temperature was ranged from 28-30ºC [25]. Salinity was ranged from 30-35 ppt. Dissolved oxygen was more than 4 ppm. The present experiment showed that the water quality such as temperature, dissolved oxygen, pH, and salinity (Table 1) was within the optimal range for the abalone (Haliotis squamata) growth. Therefore, water quality cannot be considered caused by different growth for abalone.

4. Conclusion

Based on the result of this experiment can be concluded that shelter had influenced growth both of shell length and wet weight of abalone but the shelter shape did not affect. The round shape is the most suitable shelter to grow-out abalone (Haliotis squamata) culture. Water quality parameters such as salinity, water temperature, dissolved oxygen, and water current are within the optimal range for abalone culture.

5. References

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Acknowledgments
The authors wish to thank Dwi, Komang; and Erik from Udayana University for their support during the experiment. The author also would like to thank Dr. Joni Haryadi for technical advice and guidance. A gratefully thank you also goes to Sari Novita who mostly done the tidal data preparation and its harmonic analysis in the Marine and Coastal Data Laboratory, under Research & Development Center for Marine & Coastal Resources (P3SDLP), Ancol Timur, Jakarta. Research and Development Center for Aquaculture acknowledged for having funded the supply of the grow-out abalone research (APBN TA. 2013/2014). Further analysis and manuscript generation is funded by national budget finance (APBN TA. 2016) for the Agency for Marine and Fisheries Research and Development.