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Growth and Survival of Abalone, *Haliotis asinina* Linnaeus 1758, Reared in Suspended Plastic Cages

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ABSTRACT

The effects of different stocking densities and initial size on the growth and survival rate of the tropical abalone, *Haliotis asinina* were investigated in suspended plastic cages. The size of the plastic cages used throughout this experiment was 30×40×30 cm. During the experiment, a pre-determined amount of seaweed (*Gracilaria verrucosa)* was added to feed the animals once every 2-3 d. Water quality measurements were taken weekly and the mortality rate of abalone was observed in the morning. In the first experiment, four stocking densities (40, 60, 80, and 100 pieces/cage) with ten replicates were used. After six months, growth in terms of shell length and total weight of abalone at 60 pcs/cage were the highest with values of 35.5±2.8 mm, and 13.5±3.3 g, respectively. The survival rate (78.2%) at this stocking density was also the highest. The stocking density of 60 pcs/cage was chosen for the second experiment, where abalone of three initial size ranges (4-5, 7-8, and 10-11 mm) in shell length were investigated in the same manner as the first experiment. It was found that abalone with an initial size range of 10-11 mm showed the best survival rate (82%) compared with 4-5 mm (46.2%) and 7-8 mm (64.8%). Consequently, it is suggested that abalone with an initial size range of 10-11 mm in shell length should be stocked at a density of 60 pcs/cage for the first six months of the grow-out period using the suspended plastic cages system.

Keywords: abalone, *Haliotis asinina*, growth, survival

INTRODUCTION

Abalone is the common name given to the genus *Haliotis,* which means “sea ear”. There are about 70 species of abalone distributed worldwide (FAO/UNDP, 1990; Daume *et al.*, 1999). Abalone species are slow-growing, one-shelled gastropods that live in rocky and shallow waters near stands of algae. The abalone shell is characterized by a shallow, ear-shaped shell with a series of respiratory holes along the dorsal-lateral shell margin. They are mostly found on substrata of granite and limestone (Bryan and Qian, 1998). However, newly settled abalone prefer to live on encrusting coralline algae (Westaway and Norriss, 1997). They attach to the underside of rocks and boulders with their powerful muscular foot and they are not easily dislodged. Abalone occupy the low intertidal and high subtidal zones of exposed coasts in clear, well oxygenated, high salinity sea

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water (Fallu, 1991).

There have been extensive studies on commercially important abalone species for aquaculture. Every country has cultivated native species because of ecological considerations, and it is simpler to deal with the animals in relation to water quality (temperature and salinity) and suitable natural food. Development of cultured abalone from land-based and sea-based grow-out sites is limited by appropriate investment partners, native title issues and concerns over potential impacts on drift seaweed (Gosling, 2003). The Donkey's ear abalone (*H. asinina*) is being evaluated for culture in the tropical areas of the Pacific Ocean. Aquaculture development planning in several states has identified abalone as a high priority based on current investment and industry potential. This is especially true for the Pacific Ocean, particularly among the East Asian countries (SEAFDEC, 2000).

Successful efforts to develop hatchery techniques and the greater market value of some species have led several countries to introduce new species from other geographical areas. The introduced species of abalone can grow very well in a controlled environment, often even better than in their original habitat. However, there are ecological considerations in culturing exotic species, including possible ecological impacts, genetics and disease (Huner and Brown, 1985; Gallardo and Buen, 2003). In fact, East Asian countries are now in a position to become major contributors to world aquaculture production of abalone, following the very significant investment proposed in warm water abalone farms, with much of it having already been realized. Furthermore, Donkey's ear abalone culture techniques have been developed in Asian countries and there are principal states within the area that have invested in abalone culture.

Abalone species occupy a low position in world landing statistics with 11,500 tonnes in 1997 decreasing to 10,800 tonnes in 2005 (Gordon and Cook, 2001), and comprise less than 1% of the total mollusca landing. However, they are high prized gastronomically in many countries, especially in East Asia. The relative scarcity of abalone species and their high price on world markets have created much interest in their cultivation, with many countries undertaking support as a part of emerging industries.

The success of abalone aquaculture depends on selecting the best species for a given culture environment. The primary selection criteria are good growth and survival rate, locally available feed, proven culture technology and established markets (Fermin and Buen, 2002). Most importantly, production costs must allow for a reasonable profit margin at a price that is competitive with abalone from other sources. This strategy is still used today with a small number of farms growing to market size in land-based tanks and from rafts (Capinpin *et al.*, 1999; Spencer, 2002).

The present study aimed to investigate the influence of different stocking densities and initial size on the growth and survival rate of abalone reared in plastic cages.

MATERIALS AND METHODS

Experimental animals and conditions

The study was conducted at the commercial abalone farm at the NinhTho Experimental Station, Nhatrang, Vietnam. The abalone used for the experiments were juvenile *H. asinina* that originated from artificial spawning. Stocking densities of 40, 60, 80 and 100 pcs/cage, with an initial size range of 4-5, 7-8 and 10-11 mm were cultured in plastic cages measuring 30×40×30 cm. The plastic cages were suspended at a depth of 0.8 m in a 15 m^3 indoor tank that continuously received sand-filtered sea water at a turnover rate of 20 L/min. The water depth in the tank was maintained at 1m and aeration was provided through the tank bottom.

During the experiment, pre-determined amounts of seaweed (*Gracilaria verrucosa)* was added to feed the abalone once every 2-3 d. Uneaten seaweed was siphoned out and weighed prior to the next feeding time.

The abalone were reared in constant darkness with light only being turned on during feeding, surveillance and measurement. Water quality measurements were taken weekly and the mortality rate of the abalone was observed in the morning.

Tank parameter ranges were: seawater salinity 30-32.0%, temperature 23-31°C, water pH 7.8-8.4, dissolved oxygen 4.5-6 mg/L, NH_3-N: 0.01-0.03 mg/L, NO_2-N: 0-0.001 mg/L, PO^{3-}_4 0-0.02 mg/L , H_2S 0.001-0.004 mg/L and alkalinity 115-130 mg/L.

Experimental design

The experiment was carried out from September 2008 to March 2009.

Abalone length, width and weight were measured every month during the experiment. Mean weights were determined using a set of precision scales and taking the biomass total weight of all animals divided by the total number of animals. Shell length and width were measured to an accuracy of 1 mm using a digital camera.

Two separate experiments were carried out using abalone at different stocking densities per plastic cage and different initial mean shell lengths.

The first experiment involved growing-out for six months with four density classes of abalone at 40, 60, 80 and 100 pcs/cage with ten replicates. The initial size of the abalone per trial was 7-8 mm and the initial mean shell lengths were 7.3 ± 1.3, 7.2 ± 1.1, 7.4 ± 1.3 and 7.8 ± 1.9 mm and weights were 0.089 ± 0.019, 0.09 ± 0.01, 0.095 ± 0.02 and 0.12 ± 0.06 g, respectively for the four density classes.

The second experiment involved abalone that had been reared out for six months, with three different initial mean shell length classes of 4-5, 7-8 and 10-11 mm. The initial number of abalone per trial was 60 pcs/cage, each with ten replicates and the initial mean shell lengths were 3.9 ± 0.4 mm, 7.2 ± 1.0 mm and 10.8 ± 0.5 mm and weights were 0.03 ± 0.006 g, 0.10 ± 0.02 g and 0.21 ± 0.01 g, respectively.

Data analysis

From the length, width, body weight and survival rate data, monthly growth in terms of shell length (L), shell width (R), body weight (W) and survival rates (S) were determined using Equations 1,2 and 3:

$$L = [(L_f - L_i)/L_i]/Dn \quad (1)$$

$$R = [(R_f - R_i)/R_i] /Dn \quad (2)$$

$$W = [(W_f - W_i)/W_i] /Dn \quad (3)$$

where: L_f and L_i = shell length at final and initial shell length, respectively.

R_f and R_i = shell width at final and initial shell width, respectively.

W_f and W_i = body weight at final and initial body weight, respectively.

Dn = days of rearing.

The feed conversion ratio (FCR) was defined as the wet weight of seaweed consumed/ wet weight gain of abalone.

All statistical analyses were performed with SPSS 15.0. The relationship between growth and survival rate was analyzed using a paired t-test at the 5% probability level. Percentage data were arcsine-transformed prior to statistical analysis.

RESULTS

Growth and survival rate with different stocking density of abalone

The comparisons showed that abalone growing at low stocking density (40-60 pcs/cage) in the plastic cages had significantly greater growth than at the higher stocking density (80-100 pcs/

cage), starting from an average initial size of 7-8 mm and a body weight of 0.09 g. The mean shell lengths, wet body weights (Figures 1 and 2) and mean monthly growth of abalone reared in plastic cages with different stocking densities did not differ significantly during the first three months of culture.

There were significant differences (P=0.001 and P=0.01) in abalone length and weight and also in survival rate when taken over different time periods. After six months culture, there were significant differences (P=0.001 and P=0.02) in shell length and weight of abalone grown with a stocking density at 40 pcs/cage, compared with the two stocking densities at 80 and 100 pcs/cage (paired $t = 4.831$, $df=29$, $p=0.001 < 0.05$ and $t = 2.468$, $df=29$, $p=0.02 < 0.05$, respectively).

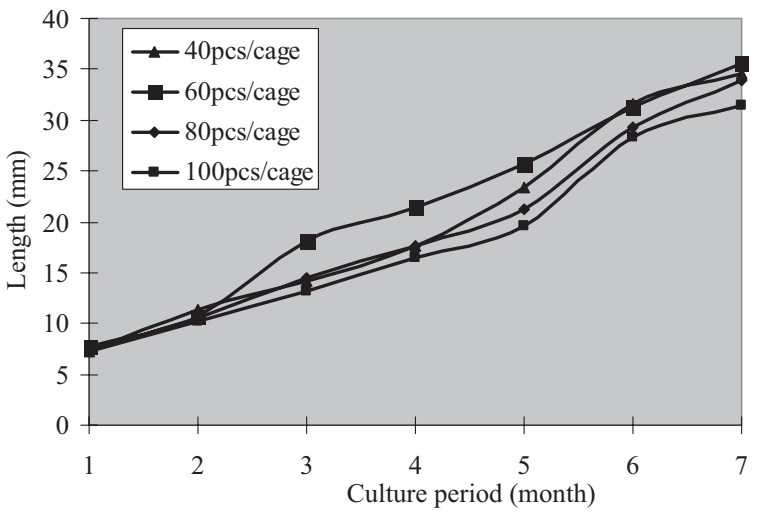

Figure 1 Increase in abalone length with different stocking densities.

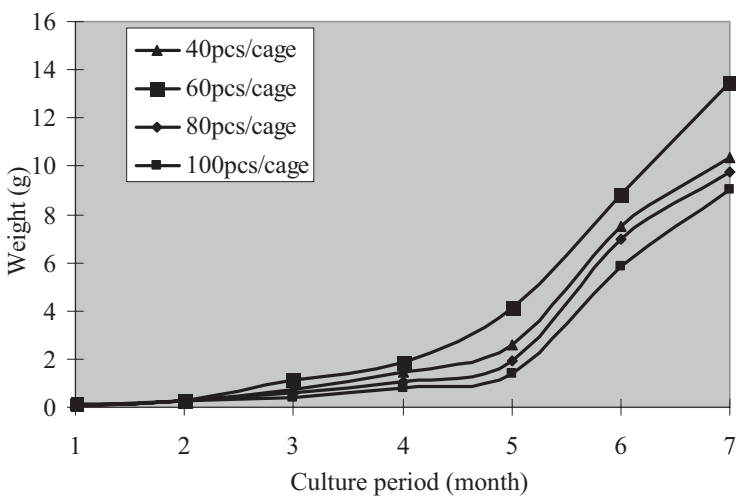

Figure 2 Weight increase with different stocking densities of abalone.

In addition, the stocking at 60 pcs/cage was found to have higher growth than cages with a stocking density at 80 and 100 pcs/cage (paired t = 3.866, df=29, p=0.01 < 0.05 and t = 6.227, df=29, p=0.001 < 0.05, respectively). There were no significant differences (P= 0.358>0.05) in growth of length between stocking densities of 40 and 60 pcs/cage, and also no significant differences (P=0.289>0.5) in growth of length between experimental stocking densities of 80 and 100 pcs/cage.

Figure 3 shows the survival rates of *H. asinina* fed with *G. verrucosa* at different stocking densities. Growth decreased as the stocking density increased and survival rates varied greatly throughout the experiment. The ranges, shown in Figure 3, may serve as a guide for determining the amount of *G. verrucosa* for effective management of survival. Generally, slower growing juveniles had monthly mortality rates that were relatively higher than larger individuals. The highest survival rate was at a stocking density of 60 pcs/cage, followed by 40, 80 and 100 pcs/cage. Abalone at stocking densities of 40-60 pcs/cage were also observed to have higher survival rates than those stocked at high densities with 80-100 pcs/cage.

Growth and survival rate with different initial size of abalone

Average monthly growth increment was calculated from measurements at six months. The average daily growth for 180 d (Dn=180) of shell length and weight of the group initially 4-5mm with density 60 pcs/cage was L=0.04 mm/day and W=2.21 g/day. There was highly variable growth within the groups initially 7-8 mm (L=0.02 mm/day, W=0.55 g/day) and initially 10-11 mm (L=0.01 mm/day, W=0.33 g/day).

The growth of the group initially 4-5 mm with a density of 60 pcs/cage showed greater variation in growth than both groups initially 7-8 and 10-11 mm over the six-month culture period (Figures 4 and 5), but the survival rate was lower (Figure 6). The survival rate of groups initially 10-11, 7-8 and 4-5 mm decreased with values of 82, 64.8 and 46.2%, respectively.

Interactions between the initial smaller sized and larger sized individuals were found to significantly affect the growth and survival rate of the juvenile abalone.

The overall average density with 60 pcs/cage (initial size = 10-11 mm, survival rate = 82% and FCR =13.2) was the highest compared to the groups 7-8 and 4-5 mm (Table 1). The larger initial

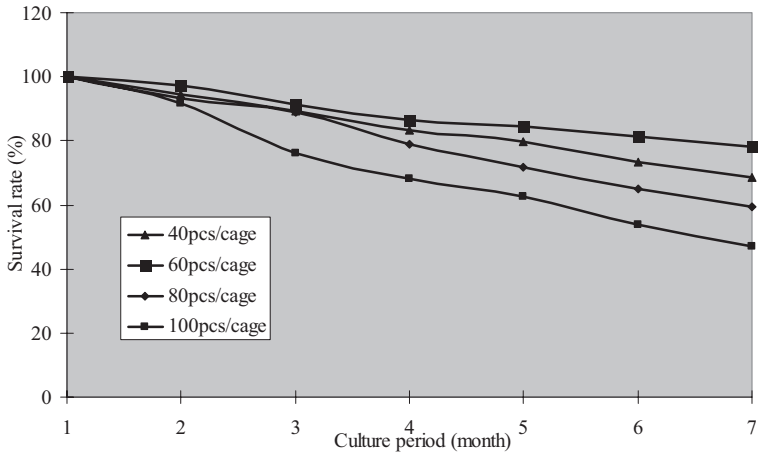

Figure 3 Survival rates with different stocking densities of abalone *Haliotis asinina* reared in plastic cages.

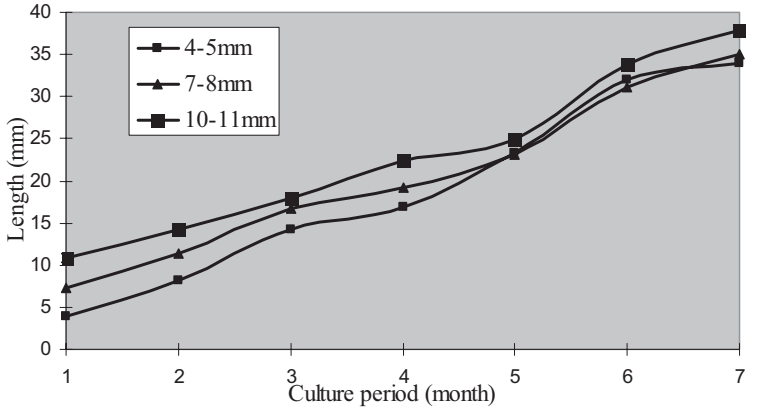

Figure 4 Changes in length for the different initial sizes of abalone during culture.

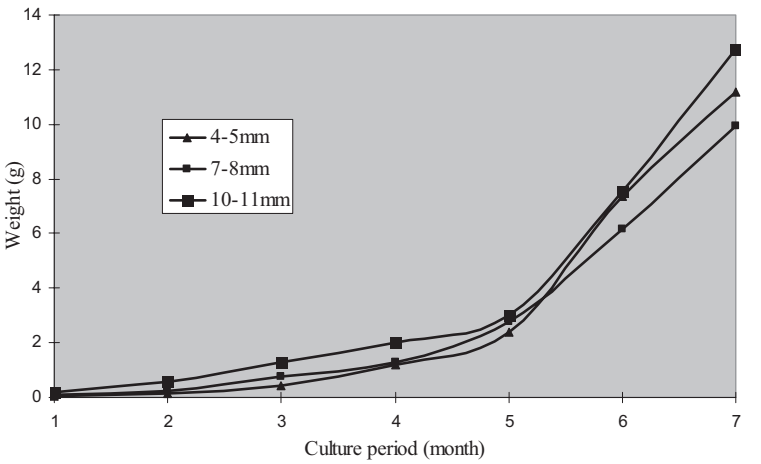

Figure 5 Changes in the weight for the different initial sizes of abalone during culture.

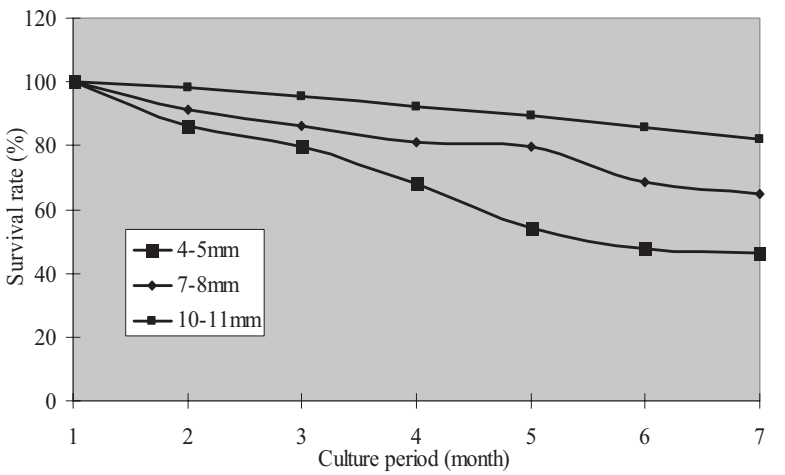

Figure 6 Survival rate for the different initial sizes of abalone *H. asinina* reared in plastic cages.

Table 1 FCR with different initial size of abalone.

Culture period (month)	Stocking density (pcs)/cage	Trial	FCR
6	60	4-5 mm	12.6
6	60	7-8 mm	11.3
6	60	10-11 mm	13.2

size of 10-11 mm in the density of 60 pcs/cage significantly improved the growth of abalone. With the limited initial size in the smaller groups of 4-5 and 7-8 mm, abalone were restricted in movement and they were unable to feed on enough diatom, which affected their growth. Management of the initial size for culture is one way to overcome the negative effects of stacking behavior on the survival rate and growth of abalone in culture.

DISCUSSION

Growth and survival rate with different stocking density of abalone

In plastic cages, the growth of individual abalone decreased as stocking density increased. Similar results have been reported in other studies on abalone in net cages and other culture systems (Capinpin and Corre, 1996), and with other shellfish (Jarayabhand and Newkirk, 1989).

The inverse relationship between growth and stocking density suggests that there is density dependent competition for space. Stocking densities in the plastic cage would make it difficult for abalone at the bottom of the stack to move, thus affecting their growth and survival rate even though there are optimum stocking densities (Jarayabhand *et al*., 1995).

The mean shell lengths, wet body weights (Figures 1 and 2) monthly growth and survival rates (Figure 3) of abalone reared in plastic cages with different stocking densities were significantly different after six months of the grow-out period.

A previous experiment also indicated that abalone stocked at low densities appeared to have higher growth and survival rates than those stocked at higher densities. There were significant differences in abalone length and weight, and also in survival when taken over different time periods. After culture for six months, there were significant differences in shell length and in weight of abalone grown at a stocking density of 40 pcs/cage and also of 60 pcs/cage in comparison with the two stocking densities of 80 and 100 pcs/cage.

The present study showed sustained growth of *H. asinina* throughout the experiment, implying the eminent suitability of stocking densities of 40-60 pcs/cage to provide adequate growth for tropical abalone culture. The high stocking densities of 80-100 pcs/cage in the grow-out period appeared to be unsuitable for tropical abalone culture.

At high stocking densities, abalone may have more difficulty moving out from cover to reach food due to interference with each other. This may have affected their feeding and living conditions, growth and survival rate (Huchette *et al*., 2003).

Another important factor that may affect abalone growth is the high stocking density. Since stocking density was carried out over extended time periods, the abalone at higher densities received higher loads of *G. verrucosa* as feed, which could lead to dissolved oxygen competition and restricted water movement within the plastic cage. The growth of abalone is inhibited by increased levels of metabolic wastes, disease and reduced dissolved oxygen (Jarayabhand and Paphavasist, 1996; Takami *et al*., 1997). A high water exchange rate is important to maintain water quality as stocking densities increase (Steinarsson and Albert, 2003).

The highest survival rate was at a

stocking density of 60 pcs/cage (78.2%) followed by 40, 80 and 100 pcs/cage with a survival rate of 68.7, 59.5 and 47.2%, respectively. Abalone at stocking densities of 40 and 60 pcs/cage (68.7 and 78.2%, respectively) had higher survival rates than those stocked at high densities of 80-100 pcs/cage (59.5 and 47.2%, respectively). The results show that the plastic cages set in the tank were appropriate for culturing tropical abalone. The high growth rate of *H. asinina* achieved in the study shows its strong potential for culture. Economic analysis will be important to help determine the optimum stocking density to maximize the production schedule and market potential.

Growth and survival rate with different initial size of abalone

The growth and survival rate of abalone depends on initial size, season (temperature) and density (Pirker and Schiel, 1993; Capinpin *et al*., 1998). Initial size is a major factor affecting the growth and survival rates of gastropods.

Variations in growth and survival rates as a result of different initial sizes of abalone are known to be sensitive to a number of environmental and physiological influences and to food selection (Webb *et al*., 2004; Lloyd and Bates, 2008).

During the grow-out period of abalone offer important information to our own were interested in the growth that can be achieved at different seasons and initial size of development abalone (Kawamura *et al.,* 1995; Degnan *et al*., 2001). The current study produced high growth (Figures 4 and 5) even with a large initial size and after culturing for six months.

The data showed that *H. asinina* fed on *G. verrucosa* and cultured in plastic cages can reach sizes of 34-37 mm shell length in six months from initial size groups of 4-5, 7-8 and 10-11 mm.

Generally, the growth of abalone was higher in smaller and faster-growing juveniles than in larger abalone. Average monthly growth increments were calculated from measurements over the six months. The average daily growth (L) for 180 days (Dn=180) in the shell length of the group initially 4-5mm with a density of 60 pcs/cage was 0.04 mm/day and the increase in weight (W) was 2.21 g/day, which were greater than for either the group initially 7-8 mm (L=0.02 mm/day, W=0.55 g/day) or the group initially 10-11 mm (L=0.01 mm/day, W=0.33 g/day).

The growth of the group initially 4-5 mm with a density of 60 pcs/cage varied more than in the groups initially 7-8 and 10-11 mm over the six months of culturing, but the survival rate was lower. The survival rate of the groups initially 10-11, 7-8 and 4-5 mm were in descending magnitude 82, 64.8 and 46.2%, respectively. Partitioning of the data on the interaction of the period and initial size showed that the initial size of the individual abalone affected their growth. The group initially 4-5 mm had a survival rate (46.2%) that was lower, because during the first month of culture, not enough diatoms were available for this smaller initial size.

The study demonstrated that some abalone had a low initial survival rate, such as those in the initial size group of 4-5mm. It is therefore possible that the growth potential of the abalone in the present study may have been affected by the higher survival rate in the abalone with an initial size of 10-11 mm. Nevertheless, since the abalone all had similar growth histories, it can be argued that the results correctly demonstrate how an optimum initial size and growth potential are related to the shell length of the abalone.

The FCR values differed based on the overall average initial size of abalone with the group initially 4-5, 7-8 and 10-11 mm having FCR values of 12.6, 11.3 and 13.2, respectively. Thus the group with the largest initial size of 10-11 mm had the highest FCR value (13.2).

In the present experiment, *H asinina* with initial size groups of 4-5, 7-8 and 10-11 mm

attained a final size length of 34, 35 and 37 mm, respectively. The results of the plastic cage experiment showed that *H. asinina* with initial size ranges of 4-5, 7-8 and 10-11 mm and stocked at 60 pcs/cage attained a harvest survival rate of 46.2, 64.8 and 82%, respectively with FCR values reaching 12.6, 11.3 and 13.2, respectively, during the six-month grow-out period.

CONCLUSION

The tropical donkey-ear abalone *H. asinina* should be stocked at densities from 40-60 pcs/cage to achieve a better survival rate, for grow-out rearing in suspended plastic cages measuring 30 × 40 × 30 cm.

Initial size is a major factor affecting the growth of gastropods. The average daily growth (L) for 180 days (Dn=180) in the shell length of the group initially 4-5mm with a density of 60 pcs/cage was 0.04 mm/day and the increase in weight (W) was 2.21 g/day, which were greater than for either the group initially 7-8 mm (L=0.02 mm/day, W=0.55 g/day) or the group initially 10-11 mm (L=0.01 mm/day, W=0.33 g/day). Comparisons showed that the highest survival rate between groups was achieved with 60 pcs/cage. The survival rates of groups initially10-11 mm was higher than the survival rate in groups initially 7-8 mm and 4-5 mm with descending values of 82, 64.83 and 46.16%, respectively.

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