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EVALUATION OF GROWTH AND SURVIVAL OF JUVENILES OF THE JAPANESE ABALONE *HALIOTIS DISCUS HANNAI* IN TWO CULTURE SYSTEMS SUSPENDED IN TANKS

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ABSTRACT Growth and survival of the Japanese abalone *Haliotis discus hannai* were studied over a six-month period at the Center for Abalone Production, Universidad Católica del Norte, Coquimbo, Chile. Cultures were carried out in lantern and basket nets suspended in seawater tanks having a constant flow of fresh seawater from La Herradura Bay. A total of 900 juveniles were observed, starting with individuals having an average length of 20 mm. The abalone juveniles were fed with two species of macroalgae, half of which was Gracilaria chilensis, and the other was half Ulva sp (mass basis), fed *ad libitum*. Artificial pelletized food was fed as a supplement, at a rate of 2% of the body mass of the abalones daily. Water quality in the cultures was monitored twice daily, included water temperature, pH, dissolved oxygen, and water flow rate. The average survival of the abalones at the termination of the experimental period was 96.2% in the lantern nets, and 94.6% in the culture baskets, although these differences were not statistically significant ($P > 0.05$; nested ANOVA). The highest mean specific growth rates were obtained in the lantern net systems with rates of 0.34% per day in length and 1.02% per day in weight; comparative values for the basket systems were 0.31% per day and 0.86% per day. Higher growth rates for weight and length of the shell were obtained in the lantern systems than in the basket culture systems. An analysis of covariance of values for growth in weight and length of the abalones showed significant differences between results from the lantern and basket systems ($P < 0.05$). Based on the results of the study, the lantern systems should be considered as an interesting alternative for the culture of *Haliotis discus hannai* both in land-based cultures, and at sea, because they have a larger carrying capacity for abalones compared with the baskets in the culture tanks and only occupy one third of the water column space. The lantern nets not only provided the best growth, but were also more economical, and easier to handle than the baskets.

KEY WORDS: *Haliotis discus hannai*, juveniles, growth and survival, tank culture, Chile

INTRODUCTION

World production of cultured abalone has undergone a progressive increase from 689 tons in 1989 to 8,696 tons in 2002 (Gordon & Cook 2001); production in Chile has followed this trend. The two species cultivated in Chile include the green abalone *Haliotis discus hannai* and the red abalone *Haliotis rufencens;* production of these species was, respectively, 8 and 128 tons in 2003 and 1 and 342 tons, respectively in 2005 (Sernapesca 2005). Abalone culture has been one of the major growth industries in aquaculture in Chile in recent years as part of a trend toward diversification in this area by introducing the cultivation of new species.

This activity is relatively new to Chile, being initiated in the late 1970s with introductions of the California red abalone *H. rufescens* (Viviani 1981). In 1997 FONDEF project 1102 was approved for the initiation of the mass culture of the green abalone *H. discus hannai*, of interest to private enterprise, because this species is highly valued in the Japanese and other world markets.

Until recently the green abalone had been cultured in land-based tanks, until the recent authorization on January 2005 for culture of the green and red abalone in open circuit tanks except between the latitudes of 26°03′30″ and 30°20′00,″ where the systems are presently required to be closed circuit.

Introduction of the Japanese abalone has been somewhat difficult technically, requiring extensive efforts both in hatcheries and in conditioning of broodstock. The production of this species at each culture center has mainly been carried out in long rectangular fiberglass ''raceway'' type culture tanks similar to those used in Japan. A series of innovations and/or modifications have been introduced to abalone culture systems at the abalone production center at UCN and at some Chilean private companies. Some methods have been adapted from advances in other countries, mostly as applied to other species of abalone. There has been little published on the comparative culture technologies among different species of abalone, probably because of the proprietary nature of the abalone culture industry. Muller (1999) compared refuge systems used on a pilot scale with red abalone, and Morey (1998) reported on three different hydraulic systems used for the culture of green abalone, suggesting that the water supply, when entering from the upper part of the tank, was more advantageous than when entering from the bottom or the end of the tank. In the present study we used a raceway tank with water entering the bottom, which seemed more advantageous in conjunction with the use of basket and modified lantern-type refuges. An ideal system for the culture of abalone juveniles should provide sufficient surface area for use by the abalone, free access to food, minimum contact between the animals and fecal matter, adequate flows of seawater and aeration, and a minimum of handling (Hahn 1989).

Abalone production systems need to optimize the related factors of water quality, production technology, type and size of cages and culture tanks, abalone size, and quality and quantity of food (Hooker & Morse 1985, Fallú 1991, Le Touche et al. 1993, Mercer et al. 1993, Mai et al. 1994).

The present study is a contribution to the development in Chile of culture technology for growout of the green abalone. Data was obtained on the efficiencies of two culture configurations presently in use (basket and lantern nets) with regard

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growth and survival of juvenile abalone, which are critical factors in mass abalone culture. These data are part of the requirements of FONDEF project DOI 1141, which financed the development of new technologies for tank culture of the green abalone.

MATERIALS AND METHODS

Juvenile Production

A total of 900 juveniles *H. discus hannai* nine months in age, from a single cohort produced in February 2000 at the UCN abalone production center were used in this study. The mean length of these abalone was 20 ± 1.02 mm, and mean weight 1.23 ± 0.09 g.

Experimental Design

Growth of this abalone was compared using two types of culture systems, one using modified scallop culture lantern nets, and the other a basket system. The lantern nets included three "floors," and had overall dimensions of 60 cm in height and 50 cm in diameter. The walls of the lantern nets were made of "netlon" plastic screening having a mesh opening of 0.4 cm, and the floors were made of rigid plastic garden screen with a mesh opening of 0.6 cm. Each floor of the lantern net included a conical-shaped refuge made of black polyethylene 18 cm in height by 50 cm in diameter. The refuges were perforated by six orifices of 5 cm in diameter to facilitate the movement of the abalone throughout the system (Fig. 1).

The baskets were rectangular and made of 0.6 cm mesh garden screening; each measured 85 × 85 × 40 cm and supported by an internal framework of 25 mm PVC tubing. Each basket contained three cylindrical black polyethylene refuges 30 cm. in height and 37 cm. in diameter, having 11 semicircular orifices 8 cm. in diameter (Fig. 2).

The present experiments used a total of three lantern systems and three baskets, distributed randomly within a seawater tank (below) in which they all were exposed to the same water flow conditions.

Characteristics of the Tanks

The holding tank for the culture systems was a fiberglass raceway-type, 10 m 0 in length, 1 m in width, and 0.65 m in height. The volume of the tank was about 5.0 m^3. Inflowing water entered at one end of the tank, and was distributed throughout the tank through 40 mm PVC tubing on the bottom of the tank; the bottom tubing had ten 80 cm transverse extensions at 90° to the main tubes, perforated by 2-mm holes at 5-cm intervals.

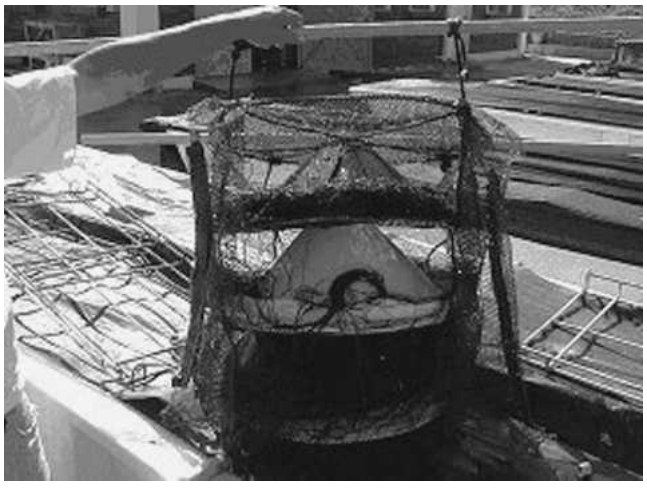

Figure 1. Culture of abalone juveniles in three-floored lantern nets suspended in raceway tanks.

Figure 2. Culture of abalone juveniles in three-floored cylinders in raceway tanks.

Overflow from the tank was arranged from a standpipe at the opposite end of the inflow. Seawater used for the culture was pumped directly from La Herradura Bay, and filtered though a battery of 25-μm bag filters (Fig. 3).

Aeration of the raceway tank was effected using 25-mm PVC tubing with 1-mm perforations every 5 cm. Aeration was provided from the bottom and one side of the tank to create a maximum of water circulation. The tank was shaded by agricultural shade cloth with 80% light blocking capacity.

Feeding

The juvenile abalone were fed *ad libitum*, with equal parts in mass of the macroalgae *Gracilaria chilensis* and an *Ulva sp*. Feeding was done once a week. The macroalgal feeding was supplemented by feeding with artificial pellets provided by the UCN abalone production center, at a rate of 2% of the abalone body weight, two times weekly. Macroalgal food was replaced weekly, and feeding of the pellets coincided with twice-weekly tank cleaning.

Cleaning

Cleaning of the entire raceway tank was effected twice weekly as stated previously. All the refuges were removed from the lantern nets and baskets and thoroughly rinsed with fresh seawater from a low-pressure hose. Remaining organic matter was removed from the bottom of the raceway by siphoning off. Total cleaning of the raceway was done once a month, removing all water and scrubbing the tank with plastic brush to remove all possible food and fecal remains. Disinfection was effected using 10% HCl and freshwater under pressure to dislodge any remaining organic matter.

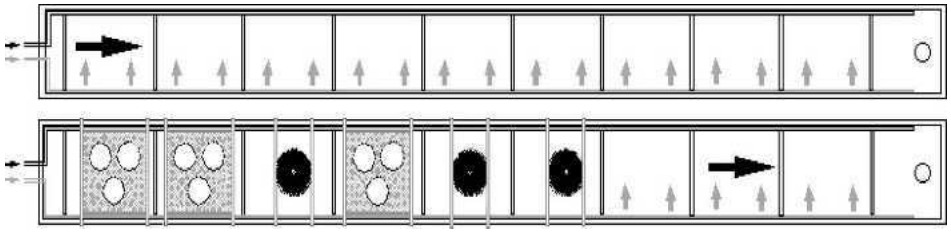

Figure 3. Distribution of water and airflow to lantern and cylinder culture systems in raceway tanks. Upper tank = side view, Lower tank = floor view. Black arrow = water flow; Gray arrow = airflow. Lantern net = dark circle; cylinders on basket = three white circles.

Sampling

The experiment ran November 2000 to May 2001. A total of 30 abalones were obtained from each replica of each system, with care to obtain 10 individuals from the floor of each system. Because there were three replicates, a subtotal of 90 individuals was sampled from each of the two different culture systems, giving a grand total of 180 abalones obtained in this sampling. The abalones were dislodged with the use of a small spatula with care taken to avoid injury to the individuals. Maximum shell length of each individual was measured to ±0.01 mm with a calliper. The drained wet weight of each specimen was obtained to nearest 0.01 g using an Ohaus'' XL-410 semianalytical electronic balance.

Measurement of Physical and Chemical Variables

Temperature and dissolved oxygen in the raceway tank were taken twice daily at 10:00 and 16:00 h, respectively, using a Sper Scientific oxygenometer. (±0.4 mg/L O_2; ±1°C) Measurements were taken throughout the tank (head, center, outflow end), and at different depths (surface, midwater, and bottom). The pH was determined twice daily using an Aqua-tecno model Ph-Testr2 Waterproof meter. Water flow rate was determined by back calculation from times determined to fill a 20 L bucket. Ammonium was determined using an Eco-Systems brand colorimetric test kit. The following formula (Uki 1989) was applied to determine if the levels of dissolved oxygen were adequate for the abalone:

$$R = M \times W^b \times A^T$$

where R = range of oxygen consumption by the abalones (mLO_2/animal/h.) for *H. discus hannai*, W = body weight (g) and T = water temperature (°C). The values M = 0.0210, b = 0.8025 and A = 1.0963 are constants.

The supply of water to the tanks was determined by:

$$Q = n \times R_{WT}/S_T(1 - 10^{-2}a)$$

where Q = water flow (L/h), n = number of animals, R_{WT} = oxygen consumption (mLO_2/animal/h) per body weight of abalones W(g) at a given water temperature T (°C), S_T = dissolved oxygen in seawater (mLO_2*l* agua de mar) at a given water temperature T (°C), a = rate of oxygen saturation (%) in the tank.

Data Analysis

The homocedesticity of the variances was determined using the Hartley test and the normality of the data was checked using the Kolmogorov-Smirnov-Lilliefors test (Sokal & Rohlf 1995).

Survival

This was determined by census of individual through each stage of the culture, expressed as a percentage using the following formula:

$$\therefore \%S = \left(\frac{Ma}{Ni}\right) \times 100 \text{ (Ricker 1979)}$$

where

Ma = Accumulated mortality,

Ni = Initial number of abalone.

Growth

Data collected in samplings for lengths and weights were used to calculate growth rates of both variables in terms of daily growth rate (DGR) and specific growth rates(SGR) after Ricker (1979).

Daily growth rate (DGR) =

$$DGR(um/d) = \frac{(Lf - Li)}{T} \cdot 1000$$

$$DGR(mg/d) = \frac{(Wf - Wi)}{T} \cdot 1000$$

Specific growth rate (SGR) =

$$SGR(\%/d) = \frac{(\ln Lf - \ln Li)}{T} \cdot 100$$

$$SGR(\%/d) = \frac{(\ln Wf - \ln Wi)}{T} \cdot 100$$

where:

Li, Wi = Initial shell length (mm) or initial weight (g).

T = time between measurements (d).

ln = natural log.

The increase in length was determined from the difference between the final length and the initial length of the abalone.

The increase in weight was determined from the difference between the final weight and the initial weight of the abalone.

Comparisons of survival between the lantern nets and baskets were made using a nested analysis of variance (ANOVA) after making an arcsine transformation of the percentage data.

A covariance analysis (ANCOVA) was applied for comparisons of increases in length and weight to minimize the effects of differences in body size during the experiment. In all cases when

the null hypothesis was rejected we applied the Tukey multiple comparison test to determine the levels of differences among mean values (Zar 1996). The alpha value assigned to all tests was ≤ 0.05 for accepting tests as significant.

RESULTS

The temperature range in the seawater in the holding tank ranged between 19.2°C and 15.7°C, with the highest values observed during January and February (16.6–18.4°C). The monthly average pH ranged from 8.0–8.2, with extremes of 8.6 and 7.9. Dissolved oxygen in the water remained above 5.0 mg/L throughout the experiment, with monthly averages of 5.7–6.0 mg/L, and extremes of 6.7–5.1 mg/L. The average percentage of oxygen saturation in the water throughout the entire experiment was 74.1%, with a maximum of 86.9% and a minimum of 63.1%. Ammonium concentrations were always below 0.1 mg/L. Water flow through the tanks ranged between 13 and 80 L/min., with the highest average flow of 50 L/min. occurring in April and lowest in November with 20.2 L/min.

Following Uki (1989) we used the extreme temperature values occurring during the experiment, as well as using the lowest values found for oxygen saturation and water flow rate.

$$R = 0.021 \times 8^{0.8025} \times 1.0963^{19.2} = 0.651 \text{ mLO}_2/\text{animal/h}.$$

The water supply required through a given tank is calculated from the following expression:

$$Q = n \times R_{WT}/S_T(1 - 10^{-2}a)$$

Based on the preceding, Q = 900 abalones × 0.651 mLO_2/animal/h/5.45 (1 – 0.87) = 827 L/h. This value is higher than the lowest mean value obtained in November, with 20.2 L/min (1212 L/h). Based on this result we concluded that the abalones experienced optimal conditions of oxygen concentration and water flow during the experiment.

Survival

The average percent survival for *H. discus hannai* was 96.2% in the lantern systems and 94.6% in the basket systems. At the end of the experiment during May 2001, the highest survival (97.3%) was observed in the lanterns, whereas the lowest occurred in the baskets (93.3%).

The analysis of variance showed no significant differences between the two culture methods ($P = 0.498$), and no significant differences among the replicates ($P = 0.845$) (Table 1).

TABLE 1.

Nested parametric analysis of variance (ANOVA) of survival of abalones in the different culture systems.

Source	Sum of Squares	Gl	Mean of Squares	F test	P
System	8.896	1	8.896	0.468	0.498
Groups (System)	26.294	4	6.573	0.346	0.845
Error	684.032	36	19.001		

$F_{0.05}$ (1,36) = 4.11.
$F_{0.05}$ (4,36) = 2.64.

Growth

At the beginning of the experiment, the mean length of abalone in the lantern nets was 21.01 ± 1.80 mm and the average weight was 1.25 ± 0.32 g.

In the baskets, the average length was 20.44 ± 1.90 mm and the weight 1.21 ± 0.33 g.

The daily growth rate in length (DGR) was higher during the earlier part of the experiment, with mean percentage values of 108.3 μm/dayay for the lantern nets and 104.3 μm/day for the baskets. Later, and approaching the end of the experiment, these values dropped to 83.09 μm/day for the lanterns and 74.01 μm/day for the baskets (Fig. 4).

Significant differences in DGR (length) were detected in growth in shell length between the two culture systems ($P = 0.000$), and between the replicates ($P = 000$) Table 2a.

The DGR over the entire experiment was 101.13 μm/day in the lantern nets and 83.17 μm/day in the baskets. During the first 45 days the DGR in weight of the juveniles had mean values of 21.33 mg/day for the lanterns and 20.4 mg/day for the baskets. These values subsequently increased between January and February, later declining during the latter months of the experiment. Significant differences were detected in the DGR (weight) between the lantern and basket systems ($P = 0.000$), and between the replicates ($P = 000$) Table 2b.

The DGR in weight over the entire experiment was 36.34 mg/day in the lanterns and 24.79 in the baskets (Fig. 5).

Over the first 45 days of the experiment the SGR in length was 0.45%/day for the lanterns and 0.48%/day for the baskets, these values slowly dropped to 0.22%/day at the end of the experiment in both culture systems (Fig. 6). The specific growth rate (SGR) in shell length over the entire experimental period was 0.34%/day in the lanterns, and 0.31%/day in the baskets.

The SGR in weight had comparatively higher values during the first month of the experiment, with percentages nearly identical between the two culture systems (lanterns 1.27%/day, baskets 1.26%/day). These rates dropped toward the end of the experiment to 0.57 and 0.48%/day, respectively. The SGR in weight over the entire period of the study were 1.02%/day for the lanterns and 0.86%/day for the baskets. (Fig. 7)

In conclusion, during 180 days in culture, the juvenile abalone increased in shell length by 18.2 mm and in weight by 6.54 g. in the lantern nets (Fig. 8). In the baskets they increased by 14.97 mm and 4.46 g. At the end of the experiment, as shown

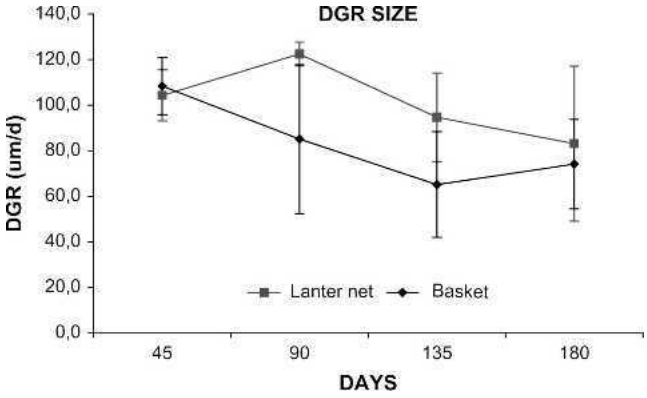

Figure 4. Daily growth rate in length (TCD) of abalones cultured in both systems.

TABLE 2a.

Analysis of covariance (ANCOVA) for growth in length of *Haliotis discus hannai*.

Source	Sum of Squares	Gl	Mean of Squares	F test	P
Months	1130,632	1	1130,632	62,029	0,000
Treatment	13752,41	3	4584,137	251,496	0,000
Interaction M/T	321,334	3	107,111	5,876	0,001
Error	12977,954	712	18,227		

$F_{0.05}$ (1712) = 3.84.
$F_{0.05}$ (3712) = 2.61.

by the ANCOVA, the differences observed in lengths and weights of the abalone in the two culture systems were significant ($P = 0.000$), and thus the growth increments in length and weight, under all conditions tested, were somewhat better in the lantern nets than in the basket systems. (Fig. 9).

DISCUSSION

The results showed no significant differences in survival between the two culture systems presently tested. This rate of survival was higher than that cited by Hahn (1989) for the same species and similar sizes, which ranged between 60 and 90%, but were similar to the 97% survival reported by Poblete (2000) who worked over periods of 6 and 12 mo, respectively.

Cartagena (2001), working with *H. discus hannai* in relatively small baskets (30 × 15 × 15 cm) obtained survival rates of 91.7% and 96.7% with 18 and 24 mm abalone, in a period of 5.5 mo. Mercer et al. (1993) also worked with the green abalone, obtaining survival rates of 84% to 95%, in a period of eight months. We attribute our high rates of survival in part to our minimization of the degree of handling of the animals during the experiment, in accord with Le Touche et al. (1993) who attribute higher mortality rates to higher degrees of handling. Uki (1989) reported that abalone stopped feeding for one or more days after being handled. Another factor explaining our higher rates of survival was probably related to the configurations of the culture baskets used by various authors. In many cases, these systems keep the abalone in the upper layers of water in the holding tanks (15–20 cm), which coincides with a low degree of water interchange within the baskets, because the water in the tanks tends to follow a path of least resistance between the bottom of the tank and the floors of the cages.

TABLE 2b.

Analysis of covariance (ANCOVA) for growth in weight of *Haliotis discus hannai*.

Source	Sum of Squares	Gl	Mean of Squares	F	P
Months	209,828	1	209,828	71,977	0,000
Treatment	2143,016	3	714,339	245,037	0,000
Interaction M/T	108,436	3	36,145	12,399	0,000
Error	2075,639	712	2,915		

$F_{0.05}$ (1712) = 3.84.
$F_{0.05}$ (3712) = 2.61.

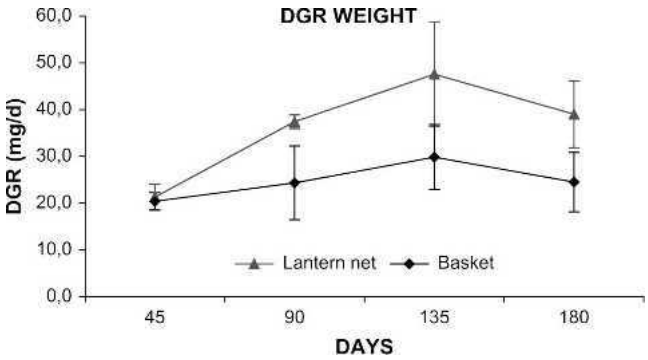

Figure 5. Daily growth rate in weight (TCD) of abalones cultured in both systems.

Different positions of water supply within the interiors of the raceway tanks produce different circulation patterns and even potential "dead zones" low in oxygen (Morey 1998), which may affect the carrying capacities of the systems (Uki 1989). The survival rates cited for some of the above authors were obtained with small, laboratory-sized systems, which did not simulate the larger, production-size systems tested during the present research, because smaller systems are less likely to suffer from water circulation problems.

Growth

Growth in abalone is the result of the complex interaction of environmental factors (T°C, O_2, photoperiod, density), and proper diet (Stuart & Brown 1994). The low pH in the system appears to be an important factor, which affects attraction to and palatability of the diet to the abalone, which may have irregular feeding habits, and are probably highly sensitive to environmental and physiological factors (Rivero & Viana 1996, Sakata & Ino 1992). Nevertheless, in this study the pH ranged from 8.0–8.2, with extremes of 8.6 and 7.9.

Water temperature is a highly important factor with regard to metabolic rate and energy use in abalone. The growth rates of *H. discus hannai* are highest when they are cultured between 15°C and 20°C (Imai 1977, Sakai 1962). In the present study, this water temperature range was maintained for five months of the study but decreased during the last month from 15°C to 12.6°C, reflected by decreases in length and weight of the

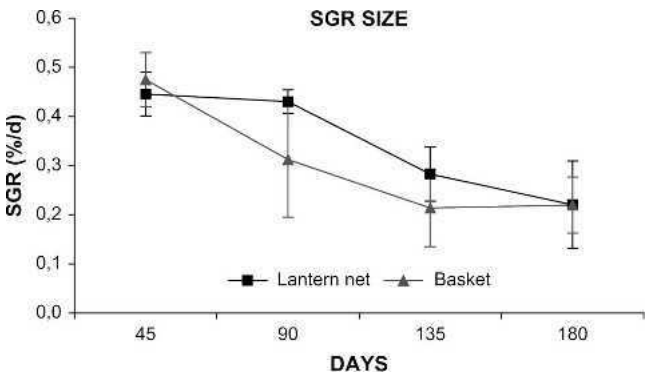

Figure 6. Specific growth in length (TEC) of abalones cultured in both systems.

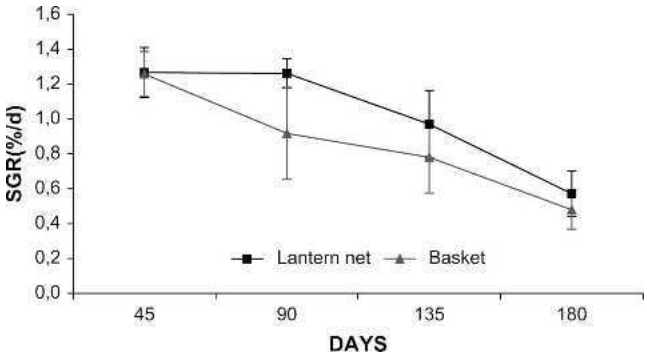

Figure 7. Specific growth in weight (TEC) of the abalones cultured in both systems.

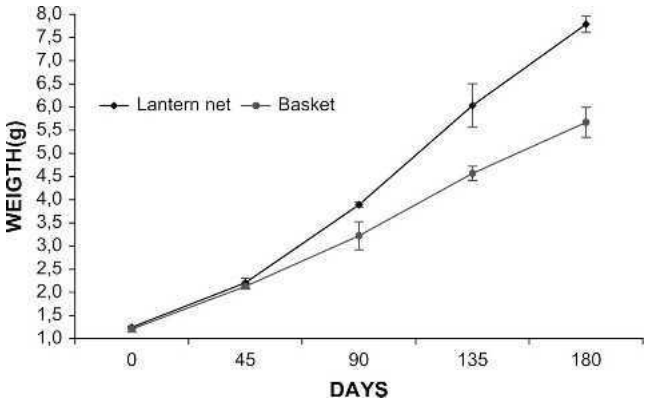

Figure 9. Growth in weight (g) of *Haliotis discus hannai* from de November 21, 2000 to May 21, 2001.

abalone population. The highest rates of growth in the abalone were observed in the summer months, when the temperature reached 19.2°C (January and February), later followed by a minimum temperature of 12.6°C in May. Martinez (1987) suggested that temperature was the main factor regulating abalone growth, because their metabolic rates are temperature-dependent. The abalone feed at lower rates during the winter, thus lowering their metabolic rates and energy requirements (Lopez et al. 1998).

Ammonium reduces the growth and increases mortality in abalones of various species at concentrations above 3.16 mg/L (Kasturi et al. 2006, Cheng et al. 2004, Sylvain et al. 2003); in the present study, ammonium values always remained below 0.1 mg/L.

The oxygen consumption by *H. discus hannai* increases exponentially in relation to water temperature (Uki & Kikuchi 1975). Oxygen consumption at night increases by 20% compared with the daytime oxygen consumption, probably because of increased movement during the day, accompanied by food consumption. Our present results suggested that the abalones in the present experiment were always subjected to optimal oxygen and water flow conditions.

The type feeding given to test abalone prior growth experiments may influence the outcome of the experiments in relation the experimental design, duration, and individual variation in growth of the abalone (Mai et al. 1994). We assumed this was not a factor in the present experiment, because we had fed the test abalone a diet similar to the one given them over the experimental period, and they showed no lag in growth at the beginning of the experiment. The test abalone also had been conditioned to their new refuges for two weeks prior to initiation of the experiment.

The results of the present experimentation were not limited by temperature and oxygen conditions within the culture, as these were, except for the temperature in one winter month, within normal limits favorable to the growth of *H. discus hannai*. There were however some uncontrolled variations in water flow, which varied form 0.22–1.33 L/sec. because of technical difficulties in our hydraulic system. Lowered water flow through the system could lower the rate of feeding by the abalone (Shepherd & Steinberg 1992).

Uki & Watanabe (1991), reported a growth rate in weight for 20–30 mm *H. discus hannai* fed on *Ulva sp.* as 0.71%/day, representing a value lower than our average ranges of 1.02%/day in lanterns, and & 0.86%/day in baskets. This difference may reflect differences in temperature between these two results, because the yearly variations in temperature on the Japanese coast are between 5°C and 20°C, and lower than those of our tanks.

Our growth values, as presented in the results section, were higher than those presented by Estay (1999) for the same species at sizes of 15–17 mm, which were fed on an artificial diet. Hoshikawa et al. (1998), obtained growth values near our rates in cultures of hybrids between *Haliotis kamtschatkana* and *Haliotis discus hannai*, with daily growth rates between 72 and 129.6 μm/day. Our rates were also comparable to those of Uki (1989), who worked with 24.3 mm (mean size) *H. discus hannai juveniles*, obtaining growth rates as high as 104 μm/day.

Our specific growth rates of near 0.5%/day (length) and 1.3%/day (weight) for both lanterns and baskets were higher than the maximum values obtained by Corazani & Illanes (1998) of 0.26%/day in length and 0.89%/day in weight of 20 mm *H. discus hannai* fed with various diets. Their comparably lower results were probably caused by the fact that the research was preliminary, using small cage systems, which provided poor water circulation for the abalone.

The results obtained by Sepulveda (1998) were somewhat higher than our SGR results for length and weight, but this may be due his study of 10-mm abalone where the growth may have a greater slope in its early phase. Our growth rates were almost

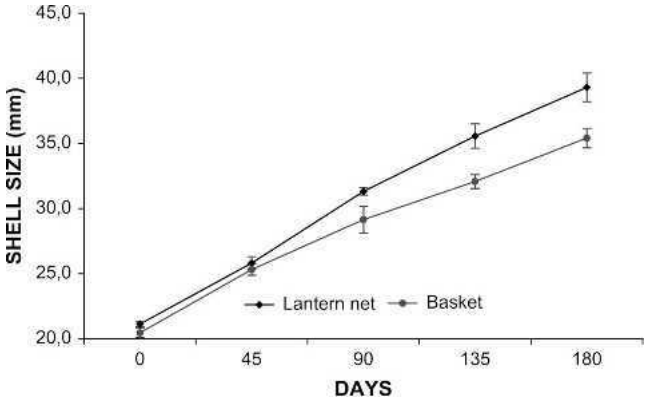

Figure 8. Growth in length (mm) of *Haliotis discus hannai* from November 21, 2000 to May 21, 2001.

the same as those obtained by Riquelme (2000) with *H. discus hannai* using varied photoperiods. Poblete (2000) found somewhat lower growth rates when feeding this abalone species with *Lessonia trabeculata*.

The raceway tank used in our experiment had more rapid water velocity over the bottom than near the surface, and local losses in pressure because of the use of injectors (Morey 1998). The configuration of our experiment was such that there was more water flow through the lantern net systems, because they occupied a large portion of the water column, whereas the water in the raceway passed above and below the basket systems. Lower amounts of after circulation through the basket systems may help explain the lower rates of growth in these systems.

We assume that our lantern system was favorable to the growth of the juvenile abalone based on the highly favorable protection from light offered by the conical refuges, which provided extensive shaded space. Exposure of young abalone to light may be a highly stressful factor interfering with growth (Fallú 1991), even lowering survival rates. The refuges in our basket systems appeared to be suboptimal, however, as the abalone were observed to congregate in certain areas of the refuges during the day, potentially interfering with their growth caused by the high local densities.

The present comparative results suggest that the lantern net system be considered as an interesting alternative for tank cultures of *H. discus hannai*, as they increase the carrying capacity of the culture because they occupy only one third of the water column within the tanks and provide more surface area than the basket systems. Lantern net culture could also be introduced for cultures in the sea, particularly in regions of northern Chile where workers and administrators have had experience in scallop cultures using lantern nets suspended from long lines. A drawback to this culture is, however, the high rate of fouling in northern Chile, which tends to slow water circulation through the nets, and introduces labor costs in handling and cleaning operations.

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