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Research Article

Growth rates of *Haliotis rufescens* and *Haliotis discus hannai* in tank culture systems in southern Chile (41.5ºS)

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ABSTRACT. The increased activity of aquaculture in Chile involves cultivation of salmonids, oysters mussels and other species such, and to a lesser extent species such as red abalone (*Haliotis rufescens*) and Japanese abalone (*Haliotis discus hannai*). The aim of this study was to evaluate the growth rate of *Haliotis rufescens* and *Haliotis discus hannai* fed with different pellet based diets with *Macrocystis* sp. and *Ulva* sp., grown in ponds for 13 months. The results for both species denoted that there was an increase in length and biomass during experimental period, existing low growth rates during the austral winter (July-September) and increase during the austral summer (December-January). Results are consistent with descriptions of literature that there is high rate of growth during the summer and using diet of brown algae. From the economic standpoint abalone farming would be an economically viable activity for local aquaculture, considering the water quality and food requirements.

Keywords: abalone, *Haliotis rufescens*, *Haliotis discus hannai*, growth rate, aquaculture.

Tasas de crecimiento de *Haliotis rufescens* y *Haliotis discus hannai* en cultivos en estanques en el sur de Chile (41,5°S)

RESUMEN. El incremento de las actividades de acuicultura en Chile involucra principalmente cultivo de salmónidos, ostiones, algas, mitílidos y otras especies, y en menor escala especies como los abalones rojo (*Haliotis rufescens*) y japonés (*Haliotis discus hannai*). El objetivo del presente estudio fue evaluar el crecimiento de *Haliotis rufescens* y *Haliotis discus hannai* alimentados con diferentes dietas a base de pellet *Macrocystis* sp. y *Ulva* sp., cultivados en estanques durante 13 meses. Los resultados para ambas especies denotaron que hubo incremento en longitud y biomasa durante el periodo experimental, existiendo bajas tasas de crecimiento durante invierno austral (julio-septiembre) e incremento durante el verano austral (diciembre-enero). Los resultados concuerdan con las descripciones de la literatura en que hay altas tasas de crecimiento durante el verano usando dieta a base de algas pardas. Desde el punto de vista económico el cultivo de abalones sería una actividad económicamente viable para la acuicultura local, si se considera los requerimientos de calidad de agua y alimentación.

Palabras clave: abalón, *Haliotis rufescens*, *Haliotis discus hannai*, tasa de crecimiento, acuicultura.

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INTRODUCTION

The growth of commercial aquaculture over the last two decades has led Chile to become the world's second biggest salmon producer, fact for which it is well known in the world aquaculture industry. However, along with the production of salmon species, the culture of molluscs and algae contribute to the overall aquaculture production of the country, and it is an emerging niche being developed through several projects involving the private sector, the academy and the Chilean government. Within the group of relevant, non-salmon cultures that are presently being developed in Chile are the red and Japanese abalone (*Haliotis rufescens* and *Haliotis discus hannai*, respectively), which had an overall production of 304 ton in 2006, equivalent to FOB US$ 6.8 million in exports (Flores & Leal, 2007). The abalone is characterized for being a gourmet and niche product which is consumed primarily in Asian countries. The supply of abalone is led by Australia and China, which together account for 60% of the world supply. China, Hong Kong and Japan, on the other hand, account for 80% of the world demand for abalone. Current prices have reached US$ 24.3 for frozen or refrigerated product and US$ 29.2 for live product (Flores & Leal, 2007), reflecting the fact that world market demands are not being met.

The red abalone is naturally distributed along the east coast of the Pacific Ocean from Sunset Bay, Oregon USA to El Rosario Baja California, México (Guzmán del Próo, 1992) between the intertidal zone and down to a depth of 20 m (Cox, 1962). It is the largest species of abalone thus far described, with shell lengths over 27 cm and weights above 1.7 kg (Hahn, 1989). The Japanese abalone, on the other hand, is distributed along the coastal waters of East Asia, where it is a significantly valuable and popular fisheries resource (Li *et al.,* 2004).

The culture of abalone in Chile began in the 1980s with the introduction of the red and Japanese abalone. At present there are 25 centres dedicated to the culture of abalones in Chile, of which 65% are located in southern Chile (40-42ºS), 25% in central-northern Chile (30-32ºS) and a remaining 10% distributed between Chile's central area (32-34ºS) and the country's most northern area (27-29ºS). The production of these 25 centres is estimated to reach 3000 ton yr^{-1} in 2010.

Recent studies of the red abalone have investigated the size-dependency of optimal growth temperatures (Steinarsson & Imsland, 2003), the survival of the red abalone under different varying environmental factors (Braid *et al.,* 2005), and its preferred temperature and critical thermal maxima (Díaz *et al.,* 2000). Research on the Japanese abalone, on the other hand, has focused on a wide range of issues regarding culture related aspects of its biology (Kawamura *et al.,* 1995; Mai *et al.*, 1996; Nie *et al.*, 1996; Takami *et al.*, 1997, 2002; Mai, 1998; Tan *et al.*, 2001; Li *et al.*, 2004; Park *et al.*, 2008). In this study, we assessed weight and shell length growth rates of *H. rufescens* and *H. discus hannai* under controlled conditions in an experimental station located in southern Chile (41.5ºS, 72.45ºW) during a 13 month trial period (January 2000-January 2001). To our knowledge, this is the first study reporting growth rates of *H. rufescens* and *H. discus hannai* throughout a year long trial. The range of size classes used in the experiment, on the other hand, can be considered to mimic the growth of a discrete generation of cultured abalones until their commercial harvest size. Our results provide useful information for further technical and economical pre-feasibility studies for the commercial culture of these two species in regions with rainy maritime climates.

MATERIALS AND METHODS

Abalone selection and culture system

A total of 150 abalones of each species were used for the trials. The abalones were obtained from the northern Catholic University of Coquimbo (Japanese abalone) and from the company Semillas Marinas S.A. (red abalone). For each species, the abalones were grouped in five size classes as described in Table 1.

The culture system used in the growth trials employed small containers made out of a mesh of high density polyethylene which had tablets in its interior that served as a fixation substrate for abalones. The containers were placed inside two circular tanks with a capacity of 800 L each. A total of 15 containers were placed inside each tank, each one of which had 10 individual abalones. Three replicates were considered for each size class. Continuous water flow and aeration was provided to the tanks. Conditions were maintained identical in the tanks containing the Japanese and red abalone size classes throughout the entire experimentation period.

Culture management and sampling

Japanese and red abalones were fed twice a week with two types of algae (*Macrocystis* sp. and *Ulva* sp.) and algae pellets provided by the Universidad Católica del Norte to Coquimbo. All groups were fed in excess and the surplus of algae and dead individuals were removed. Simultaneously, containers and tanks were cleaned and the temperature of each tank was measured and registered. All abalones were weighed and measured at the beginning of the experiment and then repeatedly once a month (all individuals for each size group and species) from January 2000-January 2001. All abalones were kept under a natural dark/light cycle and water temperature regime, mean temperature during studied period is mentioned in Fig. 1.

Data analysis

Weight and length data recorded during the 13 month trial period for each species and size class was analyzed using descriptive statistics, regression analysis and inferential statistics. Time-series plots were used to visually compare average weight and length gain per month, regression analysis was performed to determine the growth pattern in weight and length of each size class during the 13 month trial

Table 1. Size classes of red and Japanese abalone used in the experiment. All classes had three replicates.

Size	Japanese abalone	Red abalone
Class 1: 15-25 mm	3 groups of 10 individuals	3 groups of 10 individuals
Class 2: 25-35 mm	3 groups of 10 individuals	3 groups of 10 individuals
Class 3: 35-45 mm	3 groups of 10 individuals	3 groups of 10 individuals
Class 4: 45-55 mm	3 groups of 10 individuals	3 groups of 10 individuals
Class 5: 55-65 mm	3 groups of 10 individuals	3 groups of 10 individuals

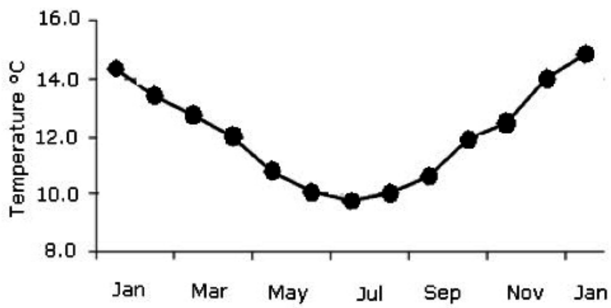

Figure 1. Mean temperature in culture system during studied period.

period. One-way ANOVA were used to assess statistically significant differences between weight and length growth rates among size classes in each species (Zar, 1996). The assumption of normality was checked using the Anderson-Darling normality test along with P-P and Q-Q plots of the empirical cumulative distribution function, and observed values versus the corresponding normal distribution. Weight growth rates for the red and Japanese abalone and length growth rate data for the Japanese abalone was log(x+1) transformed prior to the ANOVA. Bar graphs of weight and length gain per month averaged over the 13 month period were also used to visually compare the magnitude of the difference in growth rates in each size class and between both species. All analysis was performed using Microsoft Excel spreadsheets and XL-STAT version 7.1.

RESULTS

Red abalone (*Haliotis rufescens*)

Fig. 1 and Fig. 2 show time-series plots of monthly averaged growth rates (g month^{-1} and mm month^{-1}, respectively) for the red and Japanese abalone in each of the five size classes studied (Table 1). The red abalone exhibits a consistent weight growth peak in the month of October (austral spring), right after a depressed weight growth rate in the month of September (end of austral winter) (Fig. 2). This weight growth peak is consistent across all five size classes studied. A secondary and earlier peak appears to occur during the austral winter, which can be seen to have occurred in July for size classes 1 and 3 and very markedly in May for size classes 4 and 5 (Fig. 2). Both weight growth peaks (*i.e.*, austral winter and austral spring peaks) increase in magnitude with size class for the red abalone (*e.g.*, the marked October growth peak increases from 2.2 g month^{-1} in size class 1 to 14 g month^{-1} in size class 5, representing a six-fold increase). An austral winter and austral spring peak can also be seen in length growth rates for the red abalone (Fig. 3) and they are also consistent across all five size classes. The austral winter length growth peak occurred in May for size classes 1, 2, 4 and 5 and in June for size class 3. The magnitude of the difference between the austral winter and austral spring growth peak for length, however, is not as marked as it is in weight growth peaks (Figs. 2, 3). Indeed, in size class 2 and 5 the May growth peak is greater than the October peak, and thus a principal and secondary growth peak cannot be distinguished (Fig. 3). In contrast to what is seen in Fig. 1, the austral winter and austral spring length growth peaks does not increase consistently from size class 1 to size class 5 (Fig. 3).

All size classes of red abalone exhibited significant linear trends in their weight and length growth pattern throughout the trial period (Figs. 4, 5). Weight growth rates can also be seen to increase from size class 1 to size class 5. The slope of the regression line increases consistently from 0.78 in size class 1 to 5.15 in size class 5. The size-dependency of weight growth rates in the red abalone is statistically significant (one-way ANOVA; $P < 0.0001$), and it can be graphically seen in Fig. 6. Length growth rates in the red abalone, on the other hand, did not show size-dependency. The slope of the regression line does not increase consistently from size class 1 to size class 5 (Fig. 5), and the ANOVA was not statistically significant ($P = 0.417$, Fig. 6).

Both weight and length growth rates in the red abalone were depressed for a one-month period during

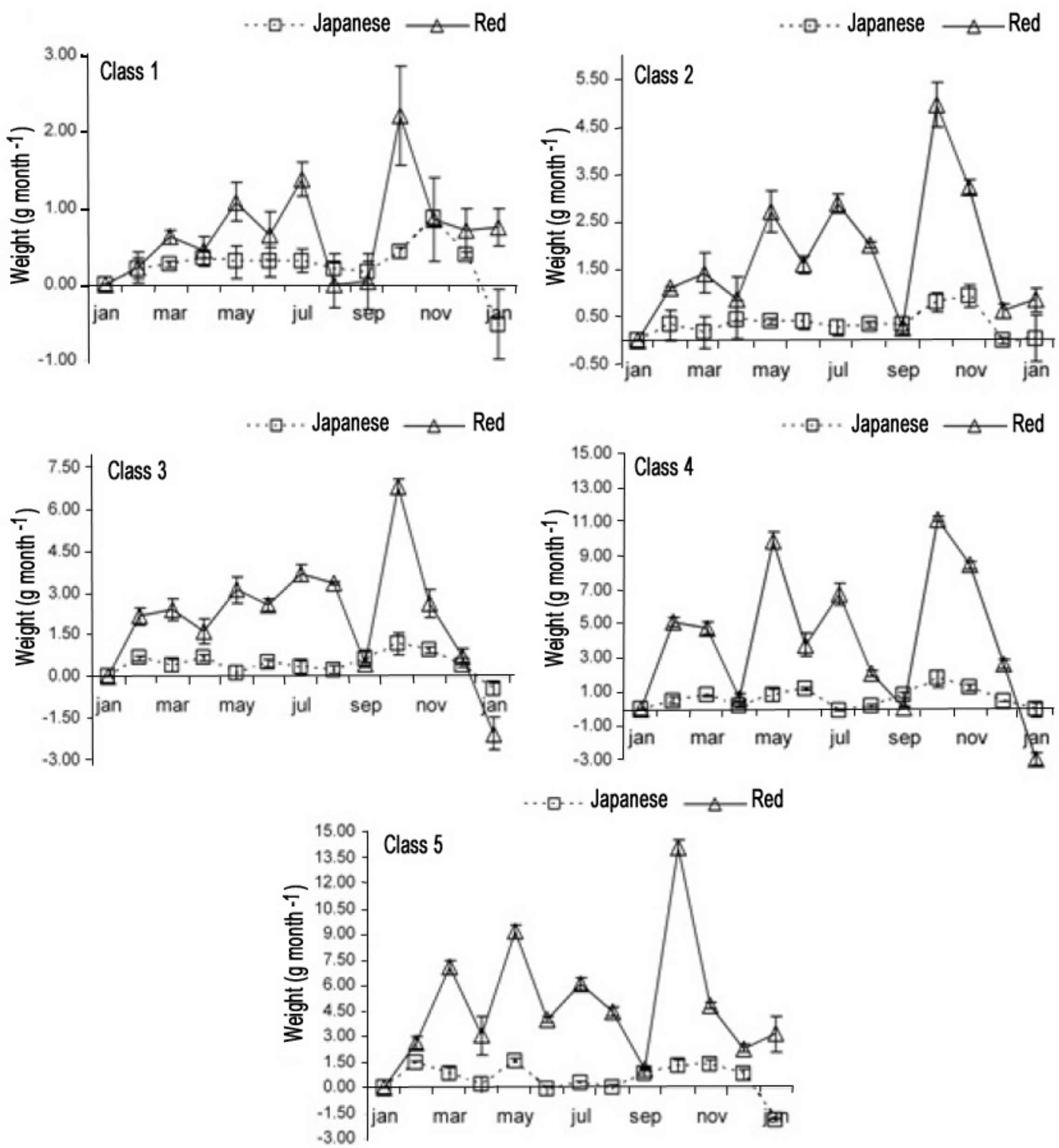

Figure 2. Time series plots of monthly averaged weight growth rates for the red and Japanese abalone in each size class.

the austral winter. This occurred most notably in the month of September for all size classes (Figs. 4, 5) and included the month of August (*i.e.*, two-month depressed growth period) in size classes 1 and 4 for weight growth rates (Fig. 4). After this depressed growth period, weight and length growth rates increased significantly in the month of October, during which they peaked in the red abalone (Figs. 2, 3). At the end of the experimentation period (*i.e.*, January), red abalones in size classes 3, 4 and 5 can be seen to have lost weight with respect to the previous month (Fig. 4).

Japanese abalone (*Haliotis discus hannai*)

The Japanese abalone, although having significantly lower weight and length growth rates than the red abalone in our study, presents a somewhat similar growth pattern to that of the red abalone (Figs. 2, 3). Weight growth rates in the Japanese abalone have a peak in the austral spring, which occurred in November for size classes 1 and 2 and in the month of October in size classes 3 and 4. This austral summer weight growth peak, however, is not evident in size class 5. Neither is the austral winter weight growth peak in any of the five size classes so clearly seen in

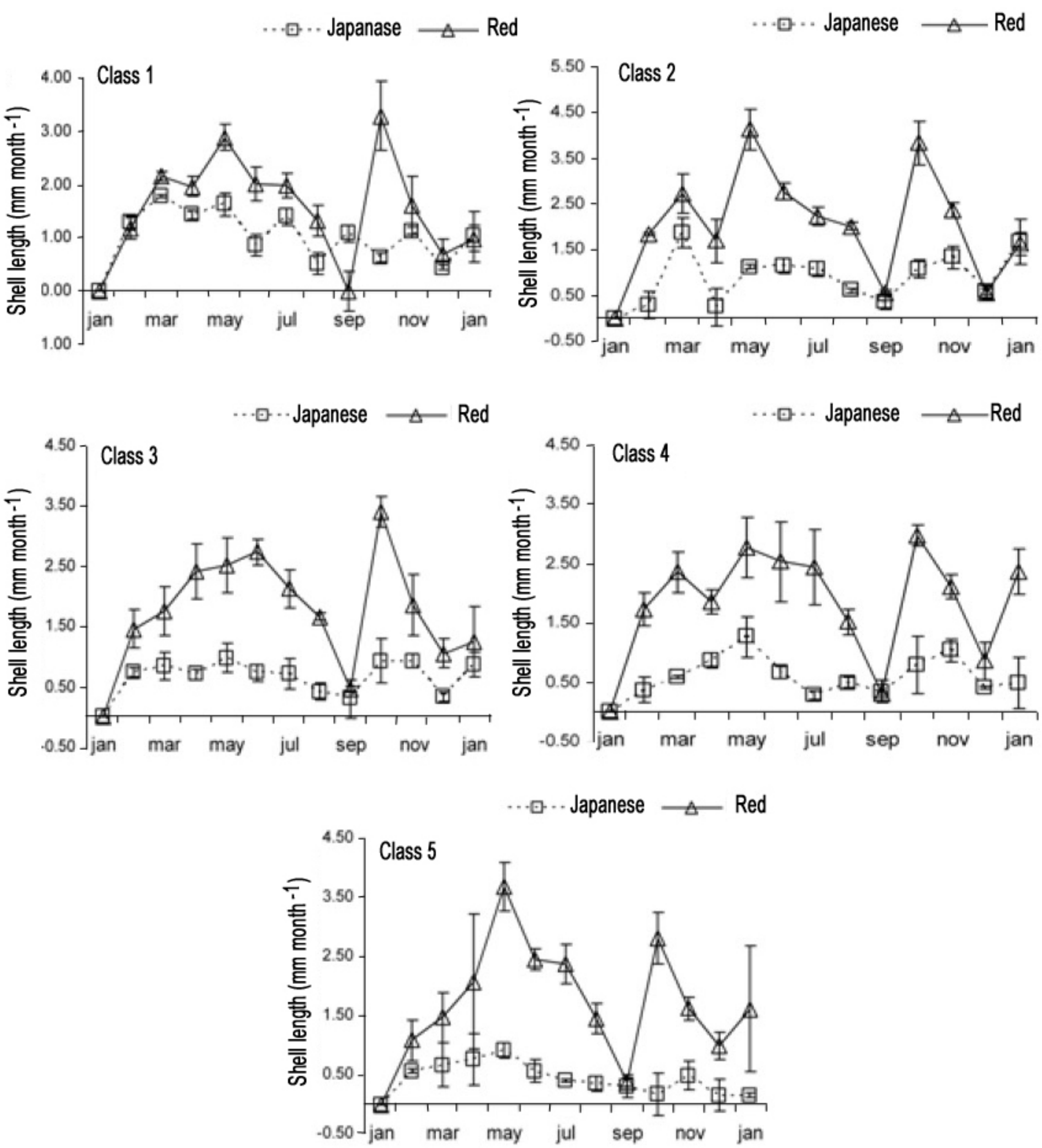

Figure 3. Time series plots of monthly averaged shell length growth rates for the red and Japanese abalone in each size class.

the red abalone (Fig. 2). The magnitude of the austral spring weight growth peak, however, increases consistently from size class 1 to size class 4 from 0.84 to 1.80 g month^{-1}, following a similar trend to that observed in the red abalone (Fig. 2). Length growth rates in the Japanese abalone, on the other hand, exhibit two characteristic growth peaks similar to those observed in the red abalone (Fig. 3). All size classes present an austral spring growth peak, which occurred in November for size classes 1, 2, 4 and 5 and in October for size class 3, and an earlier peak which occurred in late austral summer in size classes 1 and 2 (*i.e.*, March) and in austral autumn in size classes 3, 4 and 5 (*i.e.*, May) (Fig. 3). In the Japanese abalone, the early length growth peak is greater in magnitude than the austral spring length growth peak, in contrast to the red abalone, where both growth peaks appear to have similar magnitude throughout the size classes.

The Japanese abalone exhibited significant linear trends in its weight and length growth pattern throughout the trial period (Figs. 4, 5). The size

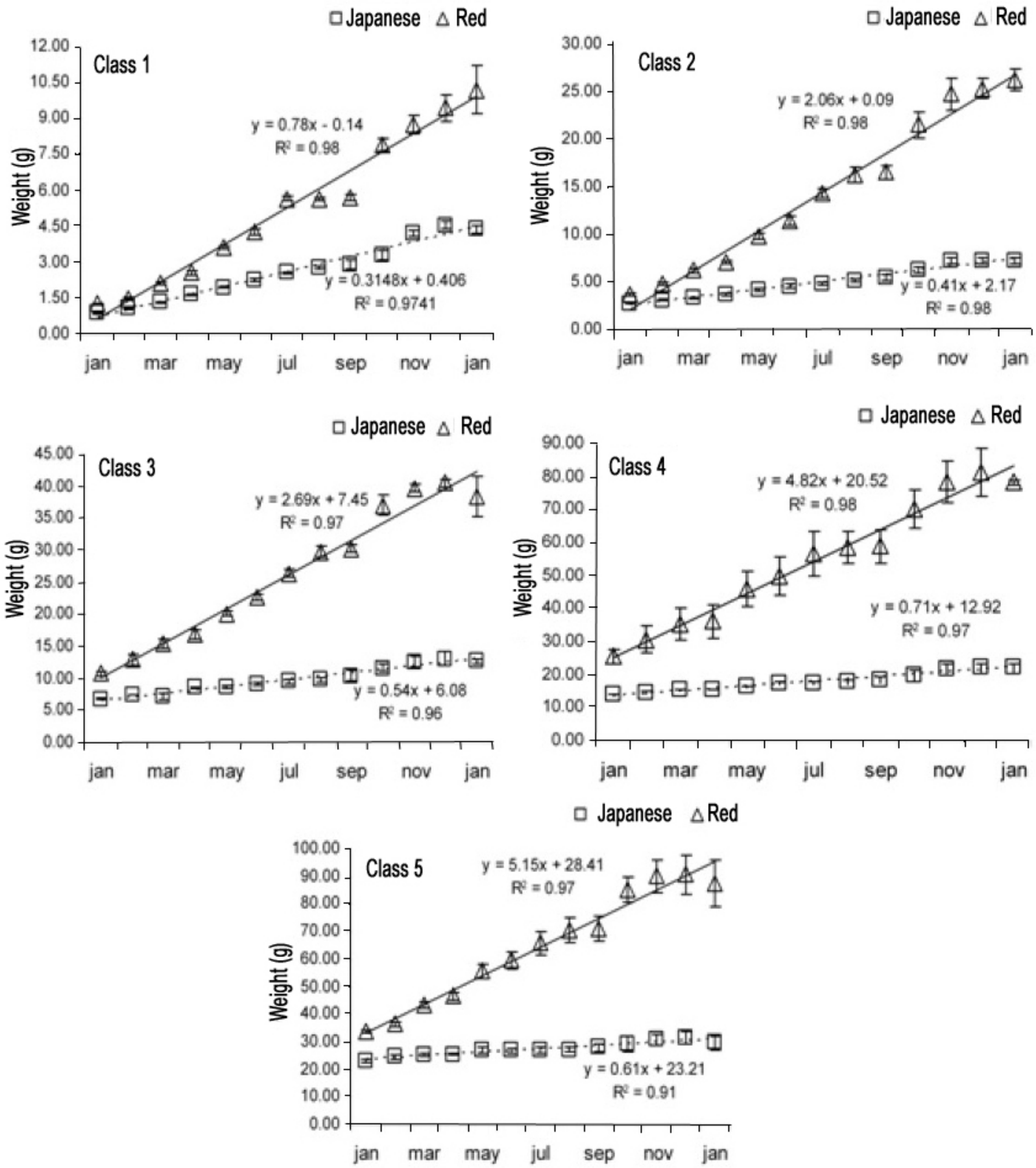

Figure 4. Linear regression plots of weight increase throughout the experimentation period for the red and Japanese abalone in each size class.

dependency of weight growth rates in the Japanese abalone was not statistically significant (one-way ANOVA, $P = 0.112$) and it can be graphically seen in Fig. 6. Length growth rates in the Japanese abalone, on the other hand, show statistically significant size-dependency (one-way ANOVA, $P < 0.0001$; Fig. 6). The slope of the regression line (Fig. 5) can be seen to decrease consistently from size class 1 to size class 5. Unlike the red abalone, the Japanese abalone does not exhibit clear signs of depressed growth rates for any particular months during the trial period (Figs. 4, 5).

DISCUSSION

The results exposed in the present paper denote that both abalone species studied have two peak growths in southern winter and summer. These results agree with descriptions of Diaz *et al.* (2000), who indicated that *H. rufescens* has an optimal growth at 18ºC that would explain the results obtained in the present paper about the optimal growth in southern summer. The results of Qi *et al.* (2010), denoted that the abalone *H. discus*

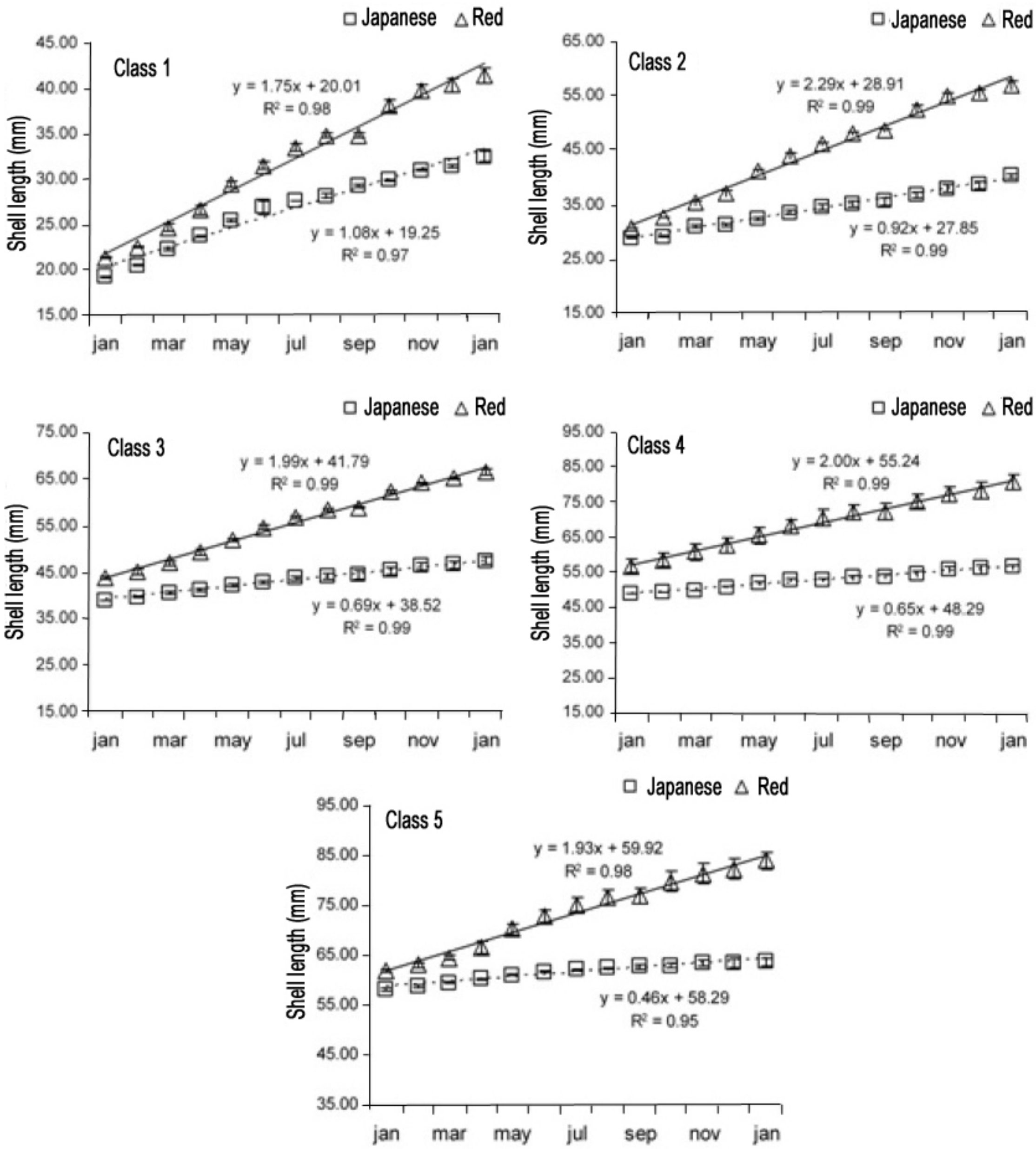

Figure 5. Linear regression plots of shell length increase throughout the experimentation period for the red and Japanese abalone in each size class.

hannai cultured under different diets based in *Gracilaria lamaeniformis*, *Laminaria japonica* and *Sargassum pallidum* as individual diet component and a mixture of these algae, denoted that the optimal growth were observed in diets of algae mixture. In another hand, Steinarsson & Imsland (2003) described high growth rates in *H. rufescens* with mixture diet based on *Laminaria digitata* and the red seaweed *Palmaria palmata* at mean temperature of 18ºC. Also, for *Haliotis tuberculata coccinea* obtained optimal growth rates with a mixture of red seaweeds, and this study give more emphasis in protein and carbohydrate components for obtain optimal growth (Fermin & Mae-Buen, 2002; Vieira *et al.,* 2005). These results agree with the natural diet of *Haliotis* genus of Mexican Pacific coast that included mainly red algae (Guzmán del Próo *et al.*, 2003).

Nevertheless, Park *et al.* (2008), obtained optimal growth of *H discus hannai* that were feed with brown algae such as *L. japonica* and *Undaria pinatifida* in a recirculating ongrowing system. Similar result as observed for the same species that was cultured and

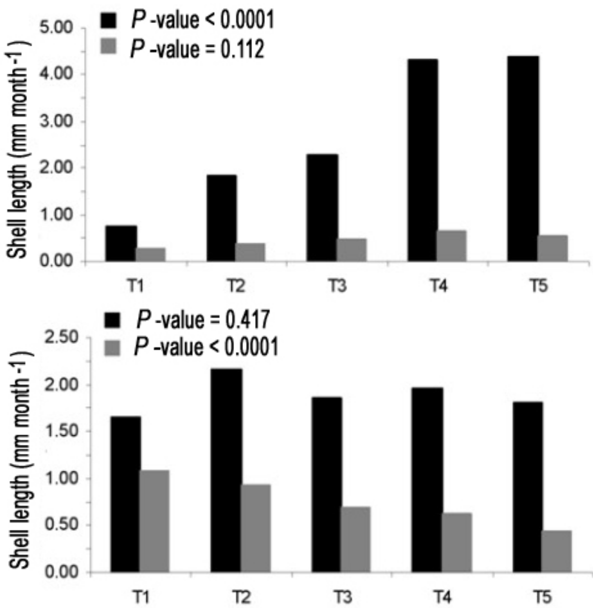

Figure 6. Weight and shell length growth rates for the red and Japanese abalone in each size class averaged over the 13 month trial period. *P*-values correspond to one-way ANOVA to asses size-dependency of growth rates (α = 0.05).

feed with the brown seaweed *Eisenia bicyclis* (Uki, 1981) and *U. pinnatifida* (Momma & Sato; 1970; FAO, 1990). These results would be explained due to the presence of alginate in brown seaweeds that are important for micronutrient assimilations (Lee, 2004; Moriyama *et al.,* 2009). Those results would explain the results of the present study about high growth rates due the diet based on *Macrocystis* sp. and *Ulva* sp.

Soria & Zúñiga (1998), did the first descriptions about ongrowing of *H. discus hannai* that is possible fron a technical and economical standpoint. These results agree with Zúñiga (2010), who described that *H. discus hannai* culture is very rentable on an economical standpoint in central and southern Chile, considering the advantages, such as water quality and food availability, that generate fast growth rates with high efficiency. If we integrate the results of the present study, and the antecedent of high growth rated when brown seaweed is used, the abalone culture in Chile would be possible and viable on an economical standpoint.

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