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Effects of Temperature on Survival and Growth of Three Juvenile Abalone *Haliotis sieboldii, Haliotis discus* and *Haliotis discus hannai*

Hyowon KIM · Min-min JUNG · Jun-Wook HUR* · Kyoung-Ho KANG†

(National Institute of Fishery Science · *Bio-Monitoring Center · †Chonnam National University)

온도조건별 전복 치패(3종) *Haliotis sieboldii, Haliotis discus* 및 *Haliotis discus hannai*의 성장과 생존율

김효원 · 정민민 · 허준욱* · 강경호†

(국립수산과학원 · *생물모니터링센터 · †전남대학교)

Abstract

Effects of sustained temperature on survival and growth of juvenile abalone of *Haliotis sieboldii, Haliotis discus* and *Haliotis discus hannai* were investigated in present study. Young abalone from a single spawning were reared in laboratory for five moths. The experiments were conducted at 7, 14, 21 and 28 °C. The shell length and total weight of abalone in each treatment were recorded monthly during the experiments. The results showed that there was no significant deference in survival rate among three species regardless of water temperature except that *H. sieboldii* and *H. discus* had significant low survival rates (45.6 % and 23.3 % respectively) at 28 °C ($p < 0.05$). Temperature had significant influence on gross growth rates of juvenile abalone ($p < 0.05$). All these three species showed highest growth rate at 21 °C and lowest growth rate at 7 °C. The results also indicated that the optimal species at 7, 21 °C were H. discus, H. discus hannai respectively. At 14 °C both *H. sieboldii* and H. discus could be successfully cultured. At 28 °C the H. discus hannai was the best one because of the low survival rates of *H. sieboldii* and H. discus.

Key word : Abalone, *Haliotis sieboldii, Haliotis discus, Haliotis discus hannai,* Water temperature effect

Ⅰ. Introduction

Temperature is considered to be one of the most important physical factors influencing marine organisms, and the biological effects of temperature are complex and wide-ranging (Ponce-Palafox et al., 1997). Temperature also maintains direct relationships with survival and growth, as well as other whole-body functions involved in the energy metabolism of invertebrates(Prosser, 1991).

Abalones are thermoconformers whose body temperature varies according to their surrounding environment, therefore temperature is considered as a primary factor governing the physiological processes of this poikilotherm. Approximately 70 marine species of abalone are widely distributed

† Corresponding author : 061-659-7165, mobidic@chonnam.ac.kr

from cool temperate to tropical regions (Lindberg, 1992), and therefore the tolerance range and optimal temperature conditions for survival and growth are species-specific and depend on evolutionary adaptations (García-Esquivel et al., 2007). Among marine abalones, six species are distributed along the coasts of Korean peninsula including *H. diversicolor supertexta*, *H. diversicolor diversicolor*, *H. discus hannai*, *H. discus*, *H. sieboldii*, and *H. gigantea*. And the artificial cultures of *H. sieboldii*, *H. discus* and *H. discus hannai* have been performed and developed rapidly.

From an aquacultural perspective, the knowledge of temperature effects on survival and growth of abalone is essential to the management of both fisheries and aquaculture, and this understanding especially facilitates farm site selection in thermally optimal areas(Hecht, 1994) and optimal species selection. For most abalone farms which are located on-land, they can adjust the rearing temperature to optimize the growth rates of the abalone, so the farmer must know the optimal temperature for growth and survival (Steinarsson & Imsland, 2003). For the farms which were no ability to adjust the temperature due to cost reason, the farmer must choose the abalone species which is suitable to local temperature.

The influences of temperature on the physiology (Braid et al., 2005; Baldwin et al., 2007), survival and growth (Nie et al., 1996; Britz et al., 1997; Díaz et al., 2000; Steinarsson & Imsland, 2003; García-Esquivel et al., 2007) of abalones have been widely documented, but the effects of sustained temperature on survival and growth of abalone *H. sieboldii*, *H. discus* and *H. discus hannai* during relatively long rearing periods under culture conditions reminds unknowns.

The aim of the present study was to evaluate the chronic effects of temperature on survival and growth of *H. sieboldii*, *H. discus* and *H. discus hannai*, with a view to determine the optimal temperature for each species which would help to maximize production and to provide reasonable suggestion to farm site and species selection.

Ⅱ. Materials and Methods

The experiments were conducted at 7, 14, 21 and 28 °C over 5 months. Young abalone of *H. sieboldii* (11.05± 0.95 mm, 0.145±0.135 g), *H. discus* (10.5±0.85 mm, 0.13±0.035 g) and *H. discus hannai* (10.35±1.25 mm, 0.145±0.065 g) from a single spawning respectively were obtained from a commercial hatchery and reared in tanks in laboratory in Jeju Island, South Korea according to Britz et al.(1997) with major modifications. Abalones were stocked at a rate of 60 animals per 75 L tank, and all tanks were continuously aerated. Each tank was cleaned twice a week and two thirds of the water replaced with fresh member-filtered seawater with pH 8.2 and salinity 35. Temperatures of 7, 14 and 28 °C were maintained constant in constant temperature units, and temperature of the laboratory was maintained at 21 °C by means of an air conditioner. Three replicates were used for each temperature. The abalones were reared in constantly darkness with light only being turned on during feeding, surveillance and measurements.

To ensure that the growth of abalones would not be limited by feed availability, the abalone were fed with artificial feeds (Nihon Nosan Kogyo, Yokohama, Japan) at a rate of approximately 4 % of body weight per day, which was well in excess of requirements. Every day uneaten feed was removed from the tanks at 20:00 h and replaced with fresh feed.

Monthly measurements of shell length and weight of all abalone were made. Before measurement, excess water was drained from the batches of abalone by suspending them in a nylon net bag over a sink for five minutes (Britz et al., 1997). Shell length was measured along the longest axis of the shell to ±0.01 mm using electric digital callipers. Weight was recorded to ±0.02 mm with an electronic balance. The buckets were checked daily to identify and remove any dead organism.

Survival rate (SR) was estimated as: where Ni and Nf are the number of live organisms present at time 0 and at time t, respectively.

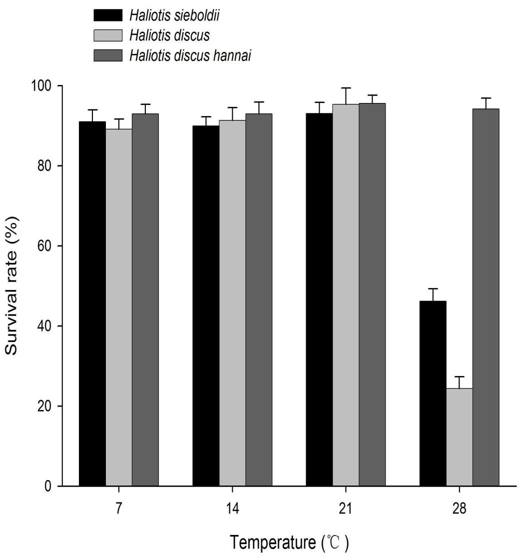
Specific growth rate (SGR) and gross growth rate (GGR) were estimated according to Hopkins (1992) and García-Esquivel et al.(2007) as: where Wf and Wi are the final and initial weight (mg) or size (㎛) of the organisms, and t is the time elapsed between both measurements.

Triplicate length and weight data were pooled if they did not differ significantly. Data from experiments were subjected to one-way analysis of variance and Tukey's range test. Significance of differences was defined as P<0.05 in all cases. Statistics were performed using the statistical software SPSS for Windows.

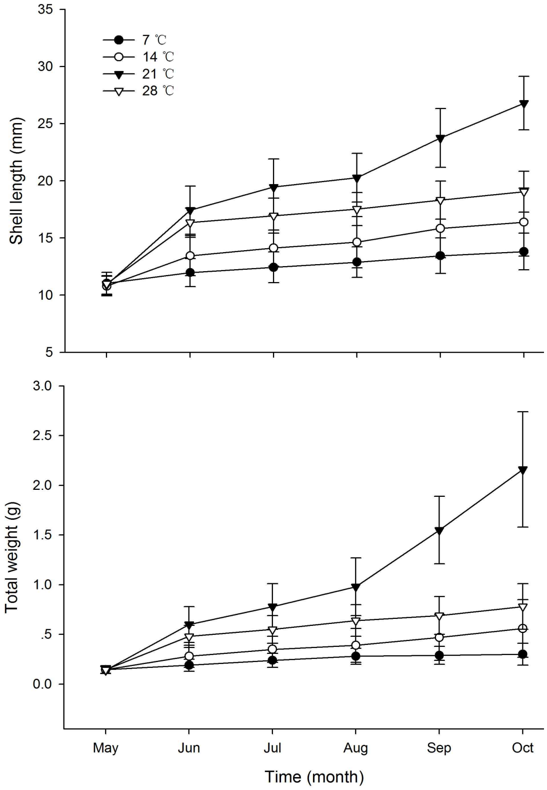
Ⅲ. Results

1. Effects of temperature on survival and growth of *H. sieboldii* ([Figs. 1 & 2])

For *H. sieboldii*, the survival rates were 94.4 %, 92.2 %, 95.6 % and 45.6 % in 7, 14, 21 and 28 °C treatments respectively. Abalone increased their shell length and body weight in every treatment from the fist month of the experiment. In 21 °C the abalone showed the best growth tendency, and in 28 °C the abalone showed a slower growth, while in 7 and 14 °C the abalone exhibited poor growth during five months. Abalone from 21 °C were about 41 % lager and 177 % heavier at the end of the experiment than those reared at 28 °C, and 64 % lager and 286 % heavier than those reared at 14 °C, as well as 94 % lager and 720 % heavier than those reared at 7 °C. Temperature showed significant effects on shell and weight growth rates. Organisms in the 21 °C treatment attained the highest gross growth rate (GGR, 106±10.2 ㎛ d^{-1}, 14±3.7 mg d^{-1}) and specific growth rate (SGR, 0.60±0.07 % d-1 for shell length, 1.82±0.19 % d^{-1} for total weight), while the lowest GGR (18±4.3 ㎛ d^{-1}, 1±0.5 mg d^{-1}) and SGR (0.14±0.03 % d^{-1} for shell length, 0.48±0.07 % d^{-1} for total weight) was observed at the 7 °C treatments.



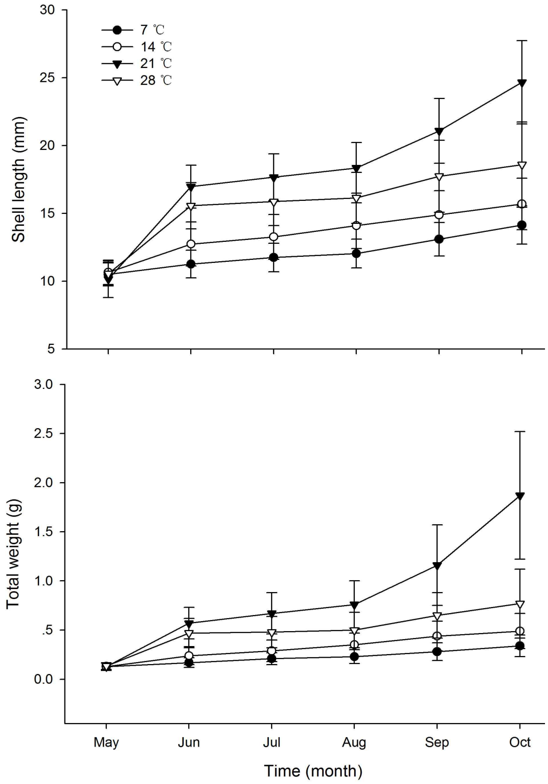
[Fig. 1] Survival rates of juvenile abalone *Haliotis sieboldii, Haliotis discus and Haliotis discus hannai* at different temperatures.



[Fig. 2] Growth curves of juvenile abalone, *Haliotis sieboldii* at different temperatures.

2. Effects of temperature on survival and growth of *H. discus* ([Figs. 1 & 3])

For *H. discus*, the survival rates were 93.3 %, 91.1 %, 98.8 % and 23.3 % in 7, 14, 21 and 28 °C treatments respectively and showed a similar growth tendency to *H. sieboldii*. Abalone from 21 °C were about 33 % lager and 142 % heavier at the end of the experiment than those reared at 28 °C, and 57 % lager and 280 % heavier than those reared at 14 °C, as well as 74 % lager and 450 % heavier than those reared at 7 °C. Temperature showed significant effects on shell and weight growth rates. Organisms in the 21 °C treatment attained the highest GGR (97±11.5 μm d^{-1}, 12±4.1 mg d^{-1}) and SGR (0.59±0.05 % d^{-1} for shell length, 1.78±0.19 % d^{-1} for total weight), while the lowest GGR (24±3.7 μm d^{-1}, 1±0.5 mg d^{-1}) and SGR (0.20±0.03 % d^{-1} for shell length, 0.64±0.08 % d^{-1} for total weight) were observed at the 7 °C treatments.



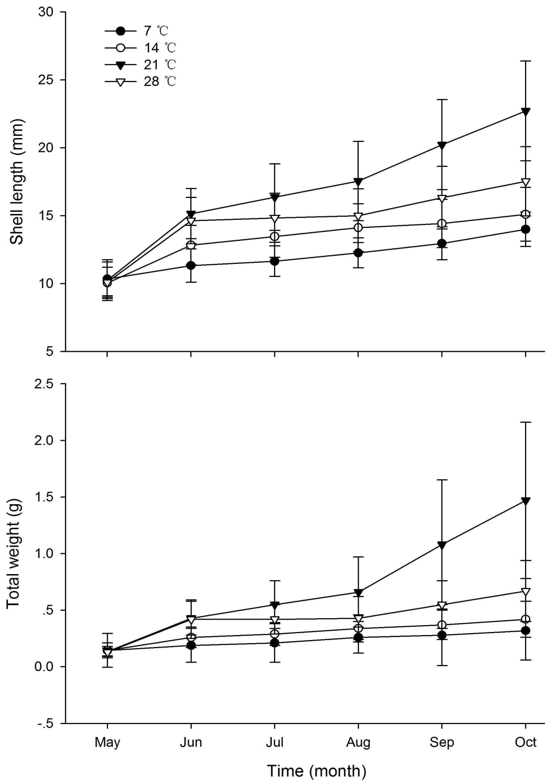
[Fig. 3] Growth curves of juvenile abalone, *Haliotis discus* at different temperatures.

3. Effects of temperature on survival and growth of *H. discus hannai* ([Figs. 1 & 4])

For *H. sieboldii*, the survival rates were 96.6%, 94.4%, 97.7 % and 90.0% in 7, 14, 21 and 28 °C treatments and showed a similar growth tendency to *H. sieboldii* and *H. discus*. Abalone from 21 °C were about 30 % lager and 119 % heavier at the end of the experiment than those reared at 28 °C, and 50 % lager and 250 % heavier than those reared at 14 °C, as well as 62 % lager and 350 % heavier than those reared at 7 °C. Temperature showed significant effects on shell and weight growth rates. Organisms in the 21 °C treatment attained the highest GGR (83±14.5 μm d^{-1}, 9±4.3 mg d^{-1}) and SGR (0.53±0.06 % d^{-1} for shell length, 1.59±0.18 % d^{-1} for total weight), while the lowest GGR(24±0.1 μm d^{-1}, 1±0.2 mg d^{-1}) and SGR(0.20± 0.01 % d^{-1} for shell length, 0.52±0.03 % d^{-1} for total weight) were observed in the 7 °C treatments.

4. Effect comparison of specific temperature on GGR of different juvenile abalones (<Table 1> & [Fig. 5])

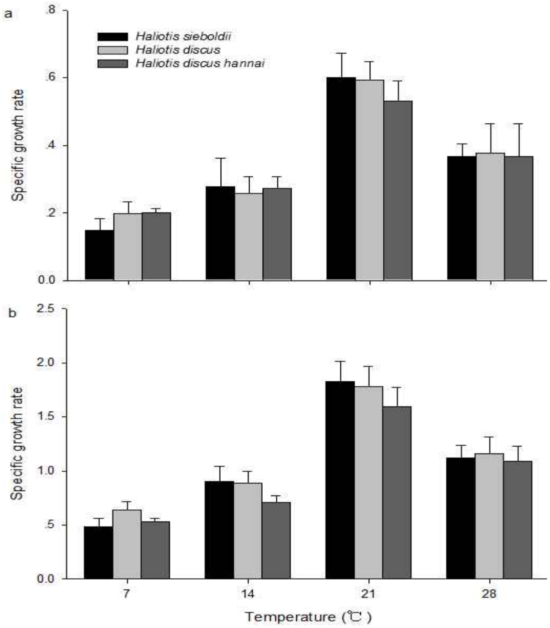
Temperature had significant influences on GGR and SGR of juvenile abalone, but different juvenile abalones showed various responses to specific temperature. At 7 °C the *H. sieboldii* had the lowest GGR and *H. discus* had the highest GGR. At 14 °C *H. discus hannai* had the lowest GGR, while there was no significant difference between *H. sieboldii* and *H. discus.*
At 21 °C the GGR among three species were significantly different, and the *H. discus hannai* had the highest GGR and *H. sieboldii* had the lowest GGR. At 28 °C there was no significant difference among the samples.



[Fig. 4] Growth curves of juvenile abalone, *Haliotis discus hannai* at different temperatures.

<Table 1> Gross growth rate (GGR) exhibited by juvenile abalones of *Haliotis sieboldii, Haliotis discus and Haliotis discus hannai* at different temperatures

	Haliotis sieboldii		*Haliotis discus*		*Haliotis discus hannai*	
	GGR (μm d^{-1})	GGR (mg d^{-1})	GGR (μm d^{-1})	GGR (mg d^{-1})	GGR (μm d^{-1})	GGR (mg d^{-1})
7°C	18±4.3	1±0.5	24±3.7	1±0.5	24±0.1	1±0.2
14°C	37±14.2	3±1.7	34±6.7	2±0.9	34±5.5	2±0.6
21°C	106±10.2	14±3.7	97±11.5	12±4.1	83±14.5	9±4.3
28°C	54±5.2	4±1.2	54±15.3	4±2.1	50±9.7	4±1.6



[Fig. 5] Specific growth rate (SGR) exhibited by juvenile abalones of *Haliotis sieboldii, Haliotis discus and Haliotis discus hannai* at different temperatures. (a): SGR for shell lengths; (b): SGR for total weights.

Ⅳ. Discussion

1. The optimal temperature for each abalone species

The physiological process of abalone was significantly affected by ambient temperature, and the effects are species specific. This study confirmed this viewpoint and clearly showed the how the survival and growth rate of *H. sieboldii*, *H. discus* and *H. discus hannai* depended on temperature. The temperature was the most important modifier of energy metabolism and previous study also indicated that temperature significant influenced the feed consumption and feed-conversion ratio(Britz et al., 1997). So in fact, the variation of growth is a compositive result of the action of many physiological factors together.

The results of growth and survival obtained from present study differed from the results reported by García-Esquivel et al.(2007). In their study, no increase of shell length or body weight was observed during the first month of the experiment, and the survival rate was lower than those in present study. It may be attributable to the adaptation of theses three abalones to the diets used in the experiments. The relative high survival rate may be attributable to the good water quality in Jeju Island. In another study (no published), abalone *H. sieboldii*, *H. dicsus* and *H. discus hannai*, which were cultured at nature water temperature (range from 17 to 21 °C) during five months in Jeju Island, showed near 100 % survival rates and high GGR (64-92 $\mu m\ d^{-1}$, 6-11 mg d^{-1}).

The organisms at 28 °C treatments showed a relative higher growth rate than organisms reared at 7 and 14 °C treatments. But organisms from the 28 °C treatments showed gradually obvious sighs of withering syndrome, this is similar to the previous study on green abalone, *Haliotis fulgens*(García-Esquivel et al., 2007) and could explain the low survival rate in this treatment. But no deeper investigation was conducted in this study for this phenomenon. Organisms at 7 and 14 °C treatments also showed slower growth, but they maintained relatively higher percent survival.

All of these three species showed highest growth rate at 21 °C and lowest growth rate at 7 °C, so the abalone farms can adjust the rearing temperature to optimize the growth rates of the abalone.

2. The optimal species for each temperature

Although all of these three species showed highest growth rate at 21 °C and lowest growth rate at 7 °C, the responses of each species to specific temperature were various. These results indicated that the optimal species at 7, 21 °C were *H. discus* and *H. discus hannai* respectively. At 14 °C both *H. sieboldii* and *H.* discus could be successfully cultured. At 28 °C the *H. discus hannai* was the best one because of the low survival rates of *H. sieboldii* and *H. discus*. For the farms which were no ability to adjust the temperature, the farmer can choose the abalone species according to both local temperature and the data obtained from this study.

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