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Short communication

Effects of stocking density on the cage culture of Korean rockfish (*Sebastes schlegeli*)

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ABSTRACT

To investigate the effects of stocking density on Korean rockfish culture, two rearing experiments, each including three densities and lasting 1 year, were performed. In the first experiment, the low, medium, and high stocking densities were 2.7, 3.9, and 5.6 kg/m^3, respectively; in the second experiment, the densities were 3.9, 6.4, and 8.7 kg/m^3, respectively. The temperature and salinity measured 6.9 °C–25.1 °C and 30.7–34.8 psu, respectively. The results showed that the average total lengths of the fish at low, medium, and high densities were 25.0 ± 0.1, 24.1 ± 0.2, and 23.6 ± 0.2 cm, respectively, with the fish in the low-density group growing significantly faster than those in the higher-density groups ($P < 0.05$). The daily feeding rate did not vary significantly ($P > 0.05$). The total outputs per unit area (kg/m^3) at low, medium, and high densities were 9.0, 14.2, and 18.7 kg/m^3, respectively. These two results suggest that high-density cage culture of Korean rockfish could improve economic efficiency. To ensure the stable production of Korean rockfish by cage culture, comprehensive studies on other aspects of the process such as skeletal abnormality, disease, and health are necessary.

1. Introduction

Korean rockfish, *Sebastes schlegeli*, is a well-known sedentary species found on nearshore rocky bottoms at depths of 10–100 m. The species is distributed around the coasts of Korea, Japan, and China. *S. schlegeli* exhibits the fastest growth among rockfishes, and it is an important species in Korean aquaculture alongside Olive flounder (*Paralichthys olivaceus*). Since 2001, production of this species has increased; in 2013, 23,757 tons were produced compared with 36,944 tons of flounder. Today, these two species comprise 80% of the fish culture output of Korea.

The early morphological development, growth rate and efficiency by temperature and feed rate, and larval growth of rockfish have all been previously studied (Hyun and Rho, 1996; Kusakari, 1995; Myeong et al., 1997). Although many researchers have reported seed production and physioecological results, to date, there have been few data published on Korean rockfish reared in cage culture.

In fish culture, stocking density is closely related to survival rate, growth, shape, pigmentation, health, water quality, and production (Ambrosio et al., 2008; Costa et al., 2013). Increasing the stocking density within a cage can raise the production per unit area; however, high densities may cause stress in fish, thereby affecting growth factors such as feeding efficiency, feeding rate, and digestion rate (Rowland et al., 2006), and they can have adverse effects on the culture environment by increasing the occurrence of disease (Drennan et al., 2005). As the optimal stocking density for cage culture is dependent on age, the size of fish species, and cage size, it is necessary to identify the optimum density of fish in rearing cages to produce the maximum yield with efficient management.

The aquacultural mass production of Korean rockfish in Korea became established in the early 1990s; since then, Korean rockfish, which overwinters on the southern coast, has become a representative aquacultural species in Korea. However, mass mortalities in coastal culture occur frequently due to deterioration of the coastal environment (eutrophication) and natural disasters (e.g., red tides and typhoons). In addition, production costs and stocking densities are increasing, and reductions in fish prices caused by mass imports from foreign countries have led to the deterioration of aquacultural productivity.

In this study, the optimal stocking density of cage-reared Korean rockfish was investigated with the aim of supporting the sustainable aquaculture of Korean rockfish and the enhancement of price competitiveness.

2. Materials and methods

Korean rockfish (total length, 13.1 ± 0.2 cm; body weight, 38.0 ± 3.2 g) were reared in 6.0 × 6.0 × 3.5-m wave-resistant cages near the coast of Dolsan, Yosu, Jeonnam, Korea, for 12 months. Two experiments were conducted. In the first, fish were reared for 171 days (Nov. 2010–Apr. 2011) under three stocking densities: low, 9,000 fish per cage (2.7 kg/m^3); medium, 13,000 fish per cage (3.9 kg/m^3); and high,

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18,500 fish per cage (5.6 kg/m^3). In the second experiment, fish were reared for 186 days (Apr.–Dec. 2011) at a low density of 4,000 fish per cage (3.9 kg/m^3), medium density of 7,000 fish per cage (6.4 kg/m^3), or high density of 10,000 fish per cage (8.7 kg/m^3). Each of the experiments was performed in triplicate.

The temperature ranged from 6.9 °C to 25.1 °C from November to August. The salinity level was maintained between 33 and 35 psu from November to June, showing a substantial decrease to 30 psu after July (Fig. 1). The DO level and pH measured 5.6–9.1 mg/L and 7–8, respectively.

The fish were given a commercial feed composed of 42% crude protein, 8% crude lipid, 17% ash, and 23% other ingredients. The fish were fed to satiation daily at 10:00 am, and all dead fish were recorded at that time. The amount of dissolved oxygen (DO), salinity, and pH were monitored every 2 weeks using a multiparameter water quality meter (YSI 556 MPS; YSI Inc., Yellow Springs, OH, USA). A total of 30 fish were sampled every 2 weeks, and their total lengths and body weights were measured to determine the growth rate and condition factor as follows:

$$\text{Condition factor} = \text{body weight} / \text{body length}^3 \times 100;$$

$$\text{Daily feeding rate}\ (\%) = \text{dry feed intake} \times 100 / [(\text{initial weight} + \text{final weight} + \text{dead fish weight}) \times \text{days fed} / 2;$$

$$\text{Specific growth rate}\ (\%) = (\ln \text{final weight} - \ln \text{initial weight}) / \text{days} \times 100; \text{ and}$$

$$\text{Feed efficiency}\ (\%) = (\text{wet weight gain} / \text{dry feed intake}) \times 100.$$

ANOVAs (SPSS 18.0) followed by Duncan's multiple-range tests (Duncan, 1955) were used to identify significant differences among group means.

3. Results

In the first experiment of 171 rearing days, the low-, medium-, and high-density groups started with an average total length of 13.0 ± 0.2 cm. Although the total length in the three groups continued to increase until the end of the experiment, there were no significant differences among the groups (17.8 ± 0.2, 17.8 ± 0.1, and 17.5 ± 0.1 cm, respectively; $P > 0.05$); however, the growth rate was slower at higher densities (Fig. 2). The average body weight of the fish in the three groups was 38.0 ± 3.2 g at the beginning of the experiment. The average body weight in the low-density group was 70.6 ± 3.2 g by December 30; this increase is greater than that observed in the high-density group during the same time period. By the final day of the experiment, the fish in the high-density group showed a lower body weight, 109.6 ± 2.1 g, than the fish in the other groups, which had attained weights of 121.8 ± 3.6 g (low) and 115.8 ± 2.9 g (medium) (Fig. 2).

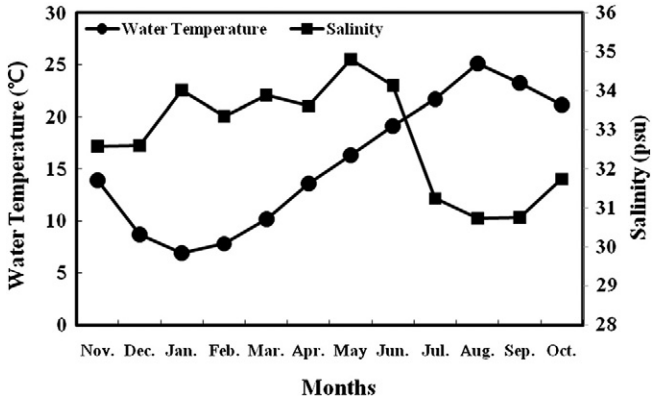

Fig. 1. Monthly changes in water temperature and salinity in the rearing cages.

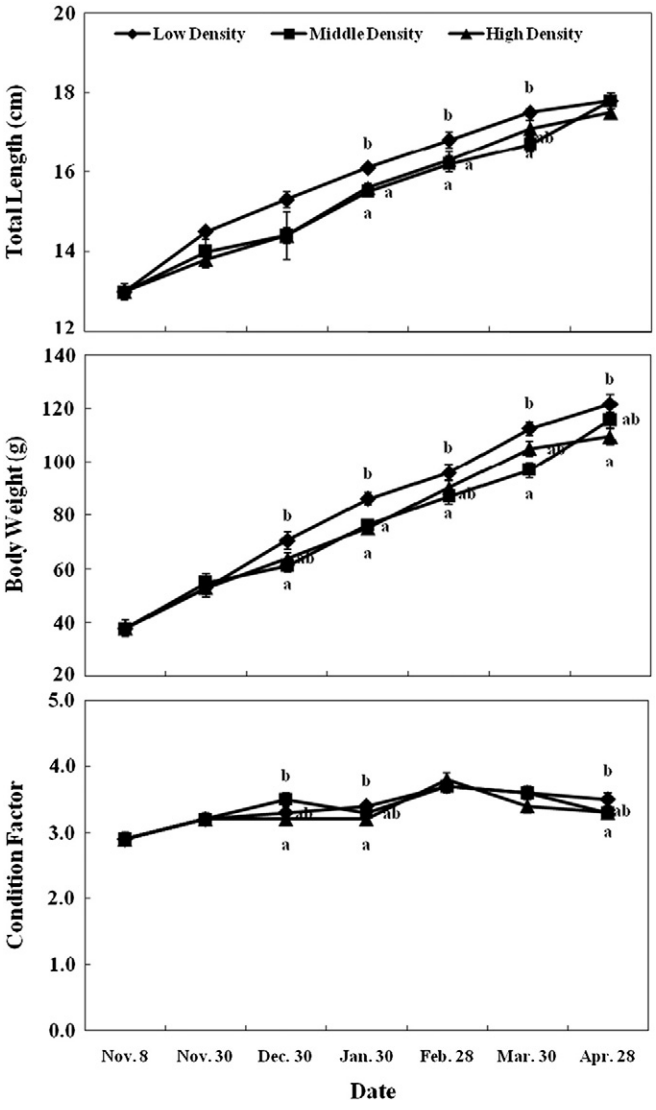

Fig. 2. Monthly changes in the total length, body weight, and condition factor of cage-cultured Korean rockfish (*S. schlegeli*) at different stocking densities during the first experiment. Low density, 2.7 kg/m^3; medium density, 3.9 kg/m^3; high density, 5.6 kg/m^3 ($P < 0.05$).

The average condition factor of the experimental fish started at 2.9 ± 0.1, reaching 3.5 ± 0.1, 3.3 ± 0.0, and 3.3 ± 0.0, respectively, in the low-, medium-, and high-density groups by the final day of the experiment (Fig. 2). The daily feeding rates of the three groups were not significantly different, at 0.58%, 0.63%, and 0.64%, respectively. The specific growth rates were 0.61%, 0.59%, and 0.57%, respectively, being lowest in the low-density group, in contrast to the daily feeding rate. In terms of feeding efficiency, the high-density group attained 88.1% and the low-density group attained 106.4%. The final survival rate was between 99.3% and 99.4%. The production per unit area (kg/m^3) measured 8.7, 11.9, and 16.0 kg/m^3, respectively (Table 1).

In the second experiment of 186 rearing days, the low-, medium-, and high-density groups started at average total lengths of 17.8 ± 0.2, 17.8 ± 0.1, and 17.5 ± 0.1 cm, respectively, and had attained respective lengths of 25.0 ± 0.1, 24.1 ± 0.2, and 23.6 ± 0.2 cm by the end of the experimental period (Fig. 3). The low-density group exhibited significantly faster growth than the medium- and high-density groups ($P < 0.05$). The low-density group also showed a significantly greater increase in body weight, at 296.8 ± 5.4 g, compared to the medium- and high-density groups, at 271.6 ± 5.8 and 253.8 ± 5.8 g, respectively ($P < 0.05$).