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ORIGINAL ARTICLE

The Growth of *Mugil cephalus, Patinopecten yessoensis* and *Saccharina japonica* in the IMTA System

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Abstract

In this study, we investigated the growth of striped mullet (*Mugil cephalus*), Yesso scallop (*Patinopecten yessoensis*) and kelp (*Saccharina japonica*) farmed under the IMTA (integrated multi-trophic aquaculture) system developed by national institute of fisheries science (NIFS). The farmed striped mullets grew from an initial length and weight of 152.5±12.1 ㎜ and 41.6±7.8 g in October 2013 to 154.2±5.6 ㎜ and 47.5±8.6 g in November, 160.2±8.7 ㎜ and 55.9±9.1 g in December and 168.4±9.6 ㎜ and 58.4±8.7 g in January. The fish continued to grow and reached 190.2±9.4 ㎜ in length and 87.5±8.9 g in weight in April and 256.4±9.7 ㎜ and 156.7±6.7 g in October 2014. The daily growth rate (DGR) for total fish length was 0.015 ∼0.1 ㎜/day during the periods of fast growth and attained 0.038∼0.1 ㎜/day during February ∼ March. The kelp grew from an initial blade length and wet weight of 1.19±0.2 ㎝ and 0.0028±0.0012 g in January 2014 to 3.3±0.8 ㎝ and 2.5±0.9 g in February and 126.5±11.6 ㎝ and 107.4±22.6 g in March, after which, erosion occurred and slowed the growth. The DGRs for kelp length ranged 0.03∼1.9 ㎜/day in January 2014 and increased to 0.88∼1.9 ㎜/day during March∼April. Increasing water temperatures beginning in April lowered the DGR to 0.03 ㎜/day. Yesso scallops grew from an initial shell length, shell height and wet weight of 11.83±0.6 ㎜, 12.68±0.7 ㎜ and in September 2013 to 19.9±2.5 ㎜, 20.8±2.6 ㎜ and 0.9±0.04 g in November 2013. They continued to grow to 45.91±0.71 ㎜ in shell length, 42.55±0.8 ㎜ in shell height and 12.7±1.3 g in wet weight by May 2014 and 60.2±2.51 ㎜, 554.6±2.61 ㎜ and 24±2.70 g by October 2014. The DGRs for shell length of Yesso scallop ranged from 0.02 to 0.256 ㎜/day with higher values of 0.256∼0.27 ㎜/day during November∼December 2013 and March∼April 2014.

Key words : IMTA, Aquaculture, Growth characteristics, Environmental pollution

1. Introduction

It is widely known that fish farming releases uneaten feed, feces and excretes into the environment, which causes oxygen deficit during the nitrogen mineralization and eutrophication and thus creates a vicious circle where the poor water quality leads to lower farming productivity and lower health of farmed animals (Irisarri et al., 2015; Naylor et al., 2000; Wang et al., 2012). Thus it became more needed to develop new technologies to minimize the impacts of fish farming on the environment and secure

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eco-friendly and sustainable farming (Neori et al., 2004). A lot of efforts have so far been made by many researchers to minimize the amount of wastes released from fish farms and to utilize the farm wastes as food source for other animals from different trophic levels by developing the integrated multi-trophic aquaculture (Lander et al., 2004).

Species grown in IMTA consist of those from different trophic levels, a critical factor to reduce wastes produced from the monoculture system and make a shift to the sustainable aquaculture (Buschmann et al., 2008; Chopin et al., 2008; Naylor et al., 2000). In IMTA, seaweeds convert excretions from farmed fish or shellfish-ammonia, phosphoric acid and carbon dioxide into biomass, through which process the farm water can be reused or have lower nutrient loading into the environment (Ryther et al., 1975). It is known that shellfish which filter-feed suspended organic particles released from farmed fish help to reduce settlement of those particles on the sediment, thus reducing the environmental loading (Mao et al., 2009). Various studies on the eco-friendly aquaculture combining fish and shellfish are being carried out (Evans and Langdon, 2001; Langdon et al., 2004). Integrated Multi Trophic Aquaculture, or IMTA is an eco-friendly aquaculture technique to utilize uneaten feed and feces from fish farming as food source for seaweed, shellfish, sea cucumber, etc to reduce environmental pollution (MacDonald et al., 2011; Neori et al., 2004; Nelson et al., 2012; Park et al., 2012).

In the northern coast of China, a research on IMTA including Phaeophyceae *Saccharina japonica* and shellfish (scallop and oyster) was conducted (Fei, 2004). However, due to the erosion of *S. japonica* at warmer water temperatures in summer, temperature tolerant red algae, *Gracilariopsis lemaneiformis* has instead been used in the IMTA study (Tang et al., 2005; Zhou et al., 2006). Mao et al.(2009) identified roles of red algae *Gracilariopsis lemaneiformiss* and Farrer's scallop (*Chlamys farreri*). In this study, we conducted a comparative analysis on growth of *Patinopecten yessoensis* and Phaeophyceae species *Ecklonia cava* and *S. japonica* which utilized organic or inorganic nutrients released from the *Mugil cephalus* farming in the IMTA system developed by NIFS in an aim to understant the growth characteristics of farmed organisms in the IMTA system and their effect of imitating environmental pollution.

2. Material and Method

2.1. Overview of the study site

We conducted this study in Susan Harbor located in Yangyang-gun, Gangwon-provice of Korea. As government funded and administered fishing harbor, Susan harbor covers an area of 2,156 ㎡ and has 12 fishing vessels in the operation. The substrate in the harbor is composed of sand and mud and is regularly dredged. With depths of 7～10 m and large scaled breakwaters, the area is well protected from typhoons and swells (Fig. 1).

2.2. IMTA system

The farming cage itself was divided into two layers in order to protect sea cucumbers from farmed fish. To facilitate changing nets more easily, a separate net was installed in each of the layers. To prevent sea cucumbers from escaping and to maximize the utilization of uneaten feed and fish by-product, the netting was completely flattened against the ocean floor by attaching chains to its edges. The farming cage is a circular cage with 23 m in diameter and 9 m in depth (Fig. 2). The system was designed to farm fish inside the cage and grow shellfish and seaweeds around the cage.

2.3. *Mugil cephalus*

To understand growth characteristics of animals farmed in the IMTA system, we selected representing

Fig. 1. Maps showing site for IMTA system installation, Susan harbor, Yangyang, Gangwon on the middle east coasts of the peninsula.

fish (striped mullet, *Mugil cephalus*), shellfish (Yesso scallop, *Patinopecten yessoensis*) and seaweed (*Saccharina japnonica*) species from the east coast of Korea. We stocked in the IMTA cage 5,000 striped mullets with total length of 152.5±12.1 ㎜ and weight of 41.6±7.8 g in October 2013. We selected Soohyup Feed NO. 2 to feed the fish. The feed contains 36.0% crude protein, 6.0% crude fat, 1.0% calcium, 17.0% crude ash, 3.0% crude fabric and 2.7% phosphorus. The fish were fed twice a day with 5～7 ㎏ for each feeding. Total length and weight were monthly measured with vernier calipers and CAS MW-2N, respectively.

Fig. 2. Arrangement and placement of components and species in the IMTA system (The arrow points a facility to grow *S. japonica*).

2.4. *Saccharina japonica*

We planted *S. japoinca* in January 2014 according to the seawater flow around the IMTA cage (Fig. 2). To do this, we prepared 100 juveniles of *S. japonica* twisted on a 3 m long fiber rope, with 1.19±0.2 ㎝ in blade length and 0.0028±0.0012 g in wet weight. To investigate growth, 30 juveniles were monthly measured for length and wet weight using vernier calipers and CAS MW-2N, respectively. Daily growth rate (DGR) was calculated in the following equation;

$$\text{DGR}\ (\text{day}^{-1}) = (\text{Pt2}-\text{Pt1})/\text{T1}-\text{T2}$$

Where Pt1 and Pt2 are the length of S. japonica at months T1 and T2

2.5. *Patinopecten yessoensis*

We produced spats of *P. yessoensis* at the hatchery of East Sea Fishery Research Institute of NIFS in 2013, which were then reared at a sea farm located in waters off Jumoonjin, Gangneung-si on the east coast of Korea using hanging culture. We removed 5,000 spats from the farm to stock them in the IMTA system for our study, At the time of stocking, the average shell length was 11.83±0.6 ㎜ and the average shell height 12.68±0.7 ㎜. We placed the spats in a lantern net with 15 compartments with each compartment

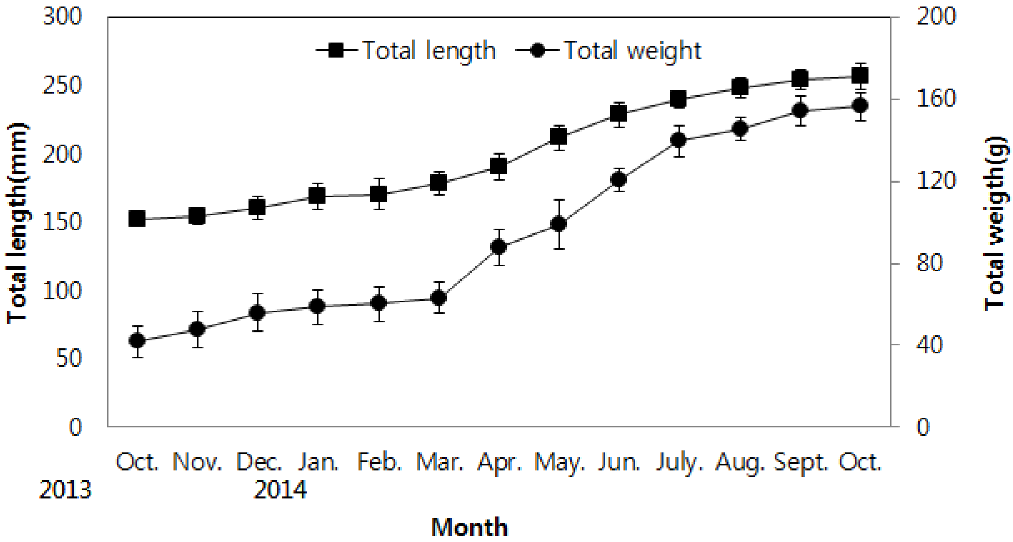

Fig. 3. Growths of total length and weight of *M. cephalus* reared in the IMTA system.

being 30 ㎝ wide and 12 ㎝ high. The shell length and height were monthly measured using vernier calipers and CAS MW-2N.

3. Results and Discussions

3.1. Growth of *M. cephalus*

Fish farming which provides significant food source for human has grown as an important industry (Chopin and Yarish, 1998; Naylor et al., 2000). South Korea has also developed a lot of fish farms, with most of its farms concentrated along the south coast. However, the intensive fish farming resulted in various problems. For example, fed by formulated or live feed, fish farms release excessive nutrients, causing eutrophication in the ecosystem (Troell et al., 1999). The IMTA system is an eco-friendly farming technique which eliminates or minimizes organic and inorganic nutrients released from uneaten feed and feces from fish farms by utilizing seaweeds and thus provides environmental and economic benefits (Chopin et al., 2008).

In our experiment, the fish grew to 154.2±5.6 ㎜ in total length and 47.5±.8.6 g in weight by November 2013 and 168.4±9.6 mm and 58.4±8.7 g by January 2014, 190.2±9.4 mm and 87.5±8.9 g by April 2014 and 256.4±9.7 mm and 156.7±6.7 g by October 2014 (Fig. 3).

3.1.1. Daily growth rate of *M. cephalus*

DGR of *M. cephalus* was obtained based on analysis of the growth results of total length and weight and is shown in Fig. 4. The total length fast grew in the IMTA with DGRs ranging 0.015～0.1 ㎜/day in general and 0.038～0.1 ㎜/day in February～March. The weight also increased fast with DGRs ranging 0.167～1.965 g/day in general and 1.965 g/day in May. The total length and weight tend to increase during the rising phase of water temperature in March to May (Fig. 4).

3.1.2. Frequency distribution of length and weight of *M. cephalus*

In October 2013, length frequency distribution occurred in a section of 11~20 ㎝ with 60% concentrated in the 16~20 ㎝ subsection. In January 2014, 75% of the length frequencies were concentrated

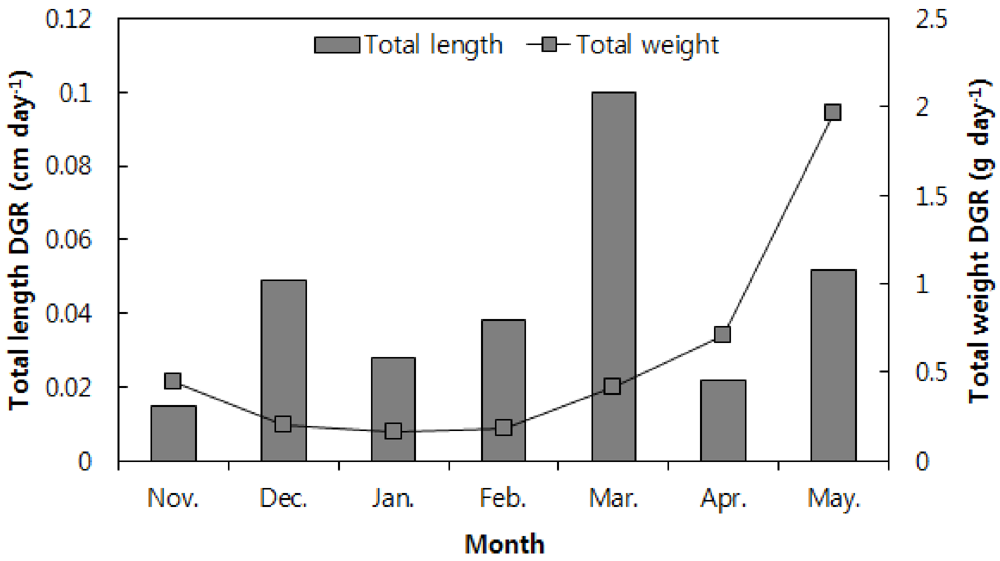

Fig. 4. Variations in DGR of the total length and weight of *M. cephalus* in the IMTA system.

in the 16~20 ㎝ section while in May 2014, 85% were distributed in the 21~25 ㎝ section. In Jun 2014, length frequencies in the 26~30 ㎝ section increased to 40%. As for weight frequency distribution, the distribution occurred in a section from 50 to 79.9 g with 50% concentrated in the 60～69.9 g subsection. In May 2014, the distribution occurred in a 100~119.9 g section and in June 2014, the distribution moved to a section from 140 to 169.9 g with 40% concentrated in the 160~169.9 g subsection (Fig. 5).

3.2. Growth of *S. japnonica*

According to a recent study, shellfish like oysters and mussels farmed in a 1ha area can remove up to 250 ㎏ nitrogen every year (Higgins et al., 2011; Kellogg et al., 2013) and the seaweeds produced from the same area are reported to remove 420 ㎏ nitrogen annually (Kim et al., 2014, 2015). Recently, the U.S. developed an IMTA application technology called "Nutrient Bioextraction", a nutrient removal technique using seaweed and shellfish. This technology is currently being applied in seriously polluted coastal waters around majoy metropolitan cities (Galimany et al., 2013; Kim et al., 2014, 2015, 2016; Rose et al., 2015). In the south coast of Korea (Gyeongnam province), 90% of the licened areas have been in farming operation for 20～30 years having worsening water quality due to accumulated fish feed and feces on the sediment under the farms. The poor water quality led to decreasing farming production with the production decreasing from its peak at 360,000 ton in 2011 to 281,000 ton in 2013.

In our experiment, *S. japonica* rapidly grew to 3.3±0.8 ㎝ in blade length and 2.5±0.9 g in wet weight in February 2014 and 125.3±9.3 ㎝ and 36.9±5.1 g in April 2014. The blade length and wet weight respectively reached 126.5±11.6 ㎝ and 107.4±22.6 g in May 2014, after which period erosion occurred causing slower growth but the wet weight remained high and the water temperatures were about 17℃ during this period (Fig. 6). Kim et al.(2007) reported that kelp transplanted in order to form marine forests grew to 179.3±40.3 ㎝ in blade length in July, when the water temperature was 19.1℃. Different from the

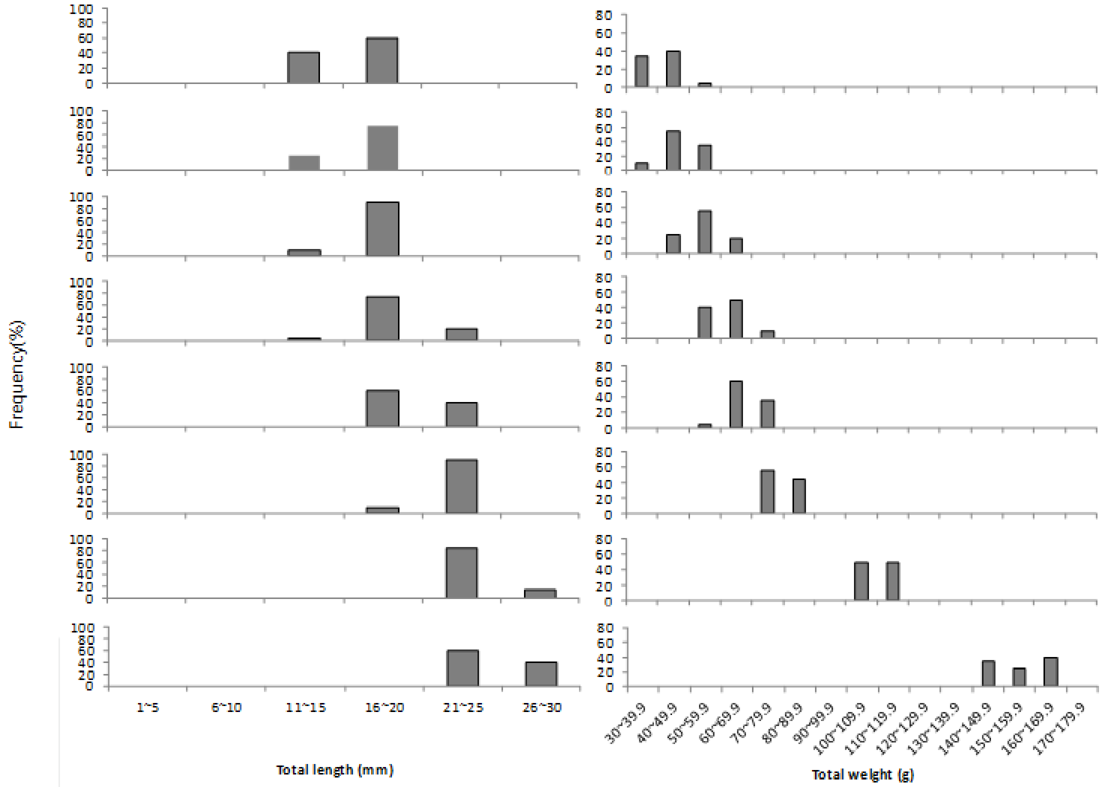

Fig. 5. Frequency distributions of the total length and weight of *M. cephalus* in the IMTA system.

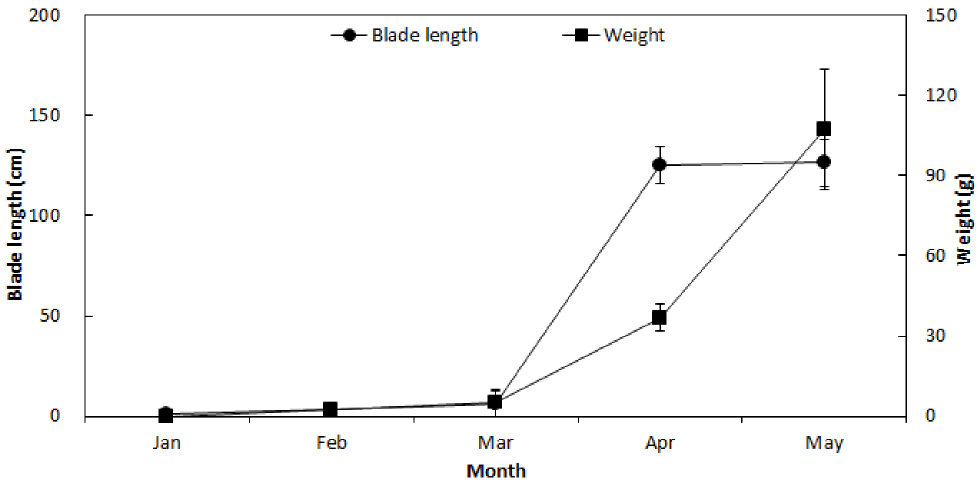

Fig. 6. Monthly growth variations of the blade length and wet weight of *S. japonica* in the IMTA system.

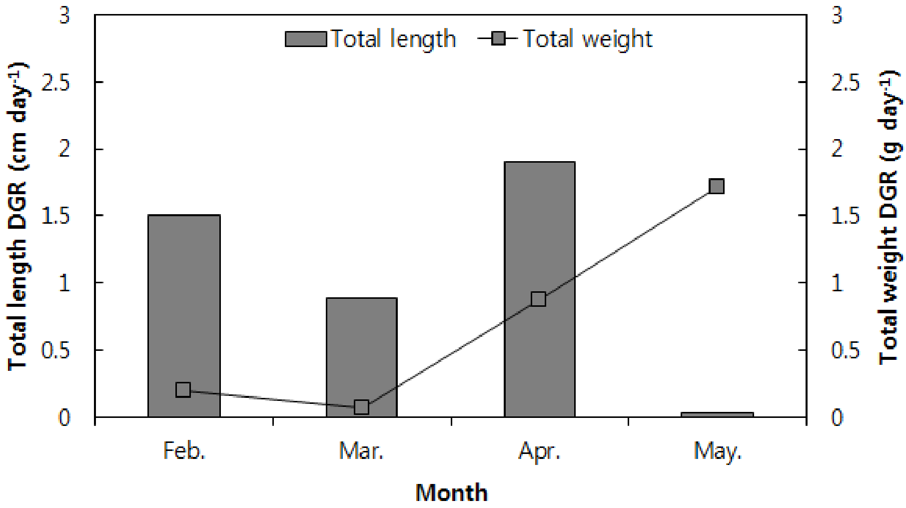

Fig. 7. Variations in DGR of the blade length and wet weight of *S. japonica* in the IMTA system.

results in Kim et al.(2007), our current study had erosion in May. This may be because that our study was conducted in harbor area while Kim et al.(2007) was done in coastal waters. Chang and Son(1993) showed that the blade length of *S. japonica* reached up to 160 ㎝ in June when the water temperature was around 15℃.

3.2.1. Daily growth rates of *S. japonica*

We obtained DGRs of *S. japonica* based on analysis of the growth results of blade length. In January 2014, DGRs ranged 0.03~1.9 ㎜/day and increased to 0.88~1.9 ㎜/day in March to April, after which period water temperature rose and DGRs declined to 0.03 ㎜/day. Kim et al.(2007) reported different DGR results for blade length with 1.05 ㎝/day in February~March and 0.28 ㎝/day in May~June. Meanwhile, wet weight had 0.07～1.72 g/day DGR during the same period. In March～May, DGRs ranged 0.07～1.72 g/day and was 1.72 g/day in April~May (Fig. 7).

3.2.2. Frequency distribution of blade length and wet weight of *S. japonica*

The initial blade length frequencies distributed in a section from 1~19.9 ㎝ with 83.3% concentrated on the subsection of 10~19.9 ㎝. In March, the distribution occurred in the section of 10~109.9 ㎝ with 20.9% concentrated on the 60~69.9 subsection. In May, the distribution spanned over a 70~219.9 ㎝ section with 15.5% concentrated in the 130~139.9 ㎝ subsection (Fig. 8). As for wet weight frequency distribution, the initial distribution occurred 100% in a 0~9.9 g section. In March, the 0~9.9 g section had 95% distribution and the other 5% occurred in a 10~19.9 g section. In May, the wet weight frequency distribution occurred in an extended section from 20~249.9 g with 9,7% occurring in the 110~119.9 subsection. Kim et al.(2007) reported that 44% of the blade length frequency distribution occurred in a 50~100 ㎝ section in February, 2013 and 16% occurred in a 200～350 ㎝ section in May. After completing the erosion phase, 84% of the blade length frequency distribution occurred in a 0～50 ㎝ section in November.

3.3. Growth of *P. yessoensis*

As large-sized shellfish species which grows in cold water. Yesso scallop, *P. yessoensis*, is mainly

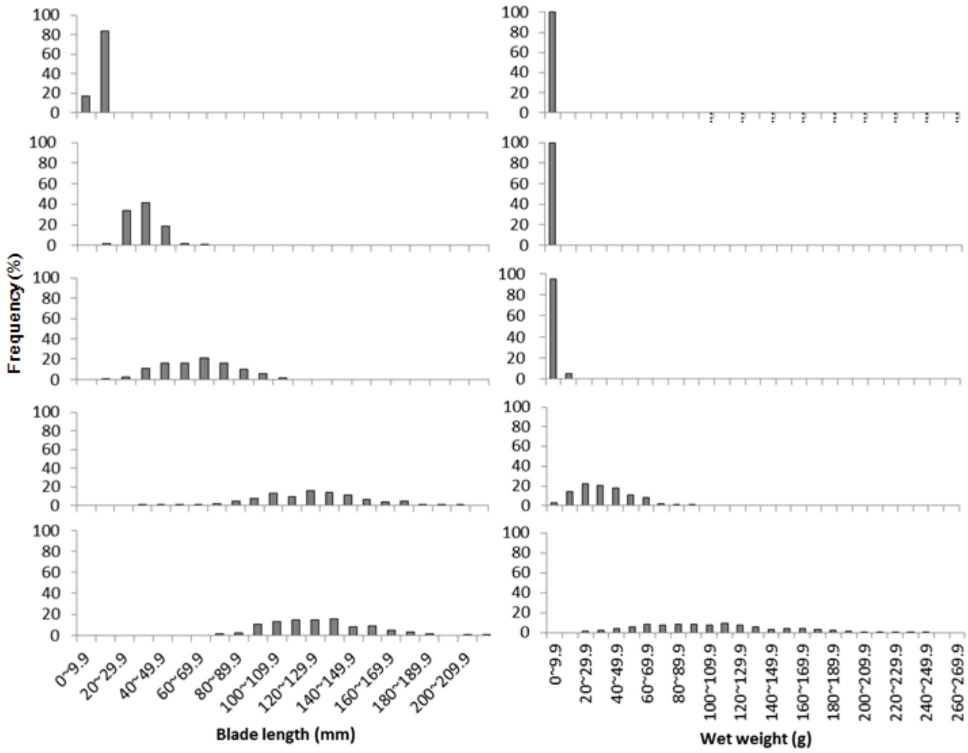

Fig. 8. Frequency distribution of blade length and wet weight of *S. japonica*.

distributed in the northern east coast of Korea and considered a commercially important shellfish (Oh et al., 2008). The Yesso scallop production reached a peak of 1,200 ton in 1997 but then the industry suffered from mass mortality in 2001 after which the production has declined reaching as low as 59 tons in 2002, but now is on the recovery with annual production of 500 tons (Kim et al., 2014a). South Korea currently imports tens of thousand tons of scallops. Yesso scallop farms are about 90% dependent on imported spats from China. The problem is that Chinese farms are also experiencing mass mortalities and lower growth and survival rates than Korean products (NIFS, 2013).

According to Kim et al.(2014a), yesso scallops grew to 12.39±1.05 ㎜ in shell length in August and 22.09±1.21 ㎜ in October, 2014. In the present study, the scallop grew to an average of 19.9±2.5 ㎜ in shell length and 20.8±2.6 ㎜ in shell height and 0.9±0.04 g in wet weight in November 2013. In January 2014, they grew to an average of 28.35±1.06 ㎜ in shell length and 28.35±1.06 ㎜ in shell height and 2.49±0.46 g in wet weight. The shell length, shell height and wet weight reached 32.1±1.95 mm, 32.12±1.75 mm, and 3.91 ±0.73 g, respectively in March, 45.91±0.71 mm, 42.55±0.8 mm and 12.7g±1.3 g in May and 60.2±2.51 mm, 54.6±2.61 mm and 24±2.70 g in October, 2014 (Fig. 9). The IMTA system used in Kim et al.(2014a) had a velocity of 4.7 ㎝/s in the system, which is significantly different from the velocity of 50 ㎝/s in the coastal area where *S. fuvellum* grows. It was analyzed that waters off Yangyang-gun, Gangwon province have

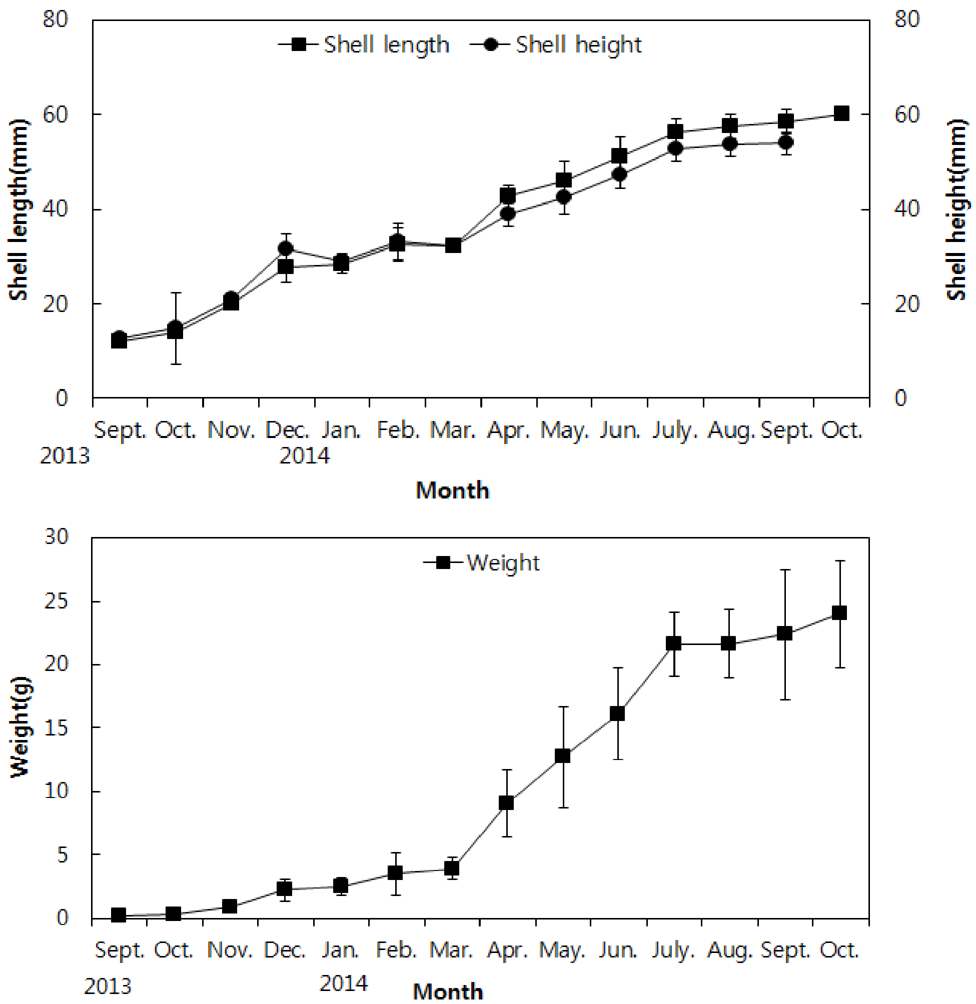

Fig. 9. Monthly growths of the shell length, shell height and wet weight of *P. yessoensis* in the IMTA system.

a nutrient profile consisting of 0.001～0.085 mg/L NO_3-N, 0.000～0.002 mg/L NO_2-N, 0.000～0.015 mg/L DIP, and 0.004～0.026 mg/L NH_4-N. The experimental area of this study has a nutrient proflie of 0.004～0.014 mg/L NO_3-N, 0.001～0.005 mg/L NO_2-N, 0.001～0.005 mg/L DIP, and 0.008～0.028 mg/L NH_4-N. This indicates that the two studies are similar in terms of nutrient composition while have significantly different velocity which is considered to have significant effect on the growth of seaweeds (Kim et al., 2014a). Along with nutrients, various environmental factors are expected to have different effects on pytoplankton populations, causing variations in growth of *S. japonica* and *P. yessoensis* (Kim et al., 2014b).

3.3.1. Daily growth rates of *P. yessoensis*

DGRs of *P. yessoensis* were obtained based on analysis of the growth results and the monthly DGRs are shown in Fig 10. The shell length showed fast

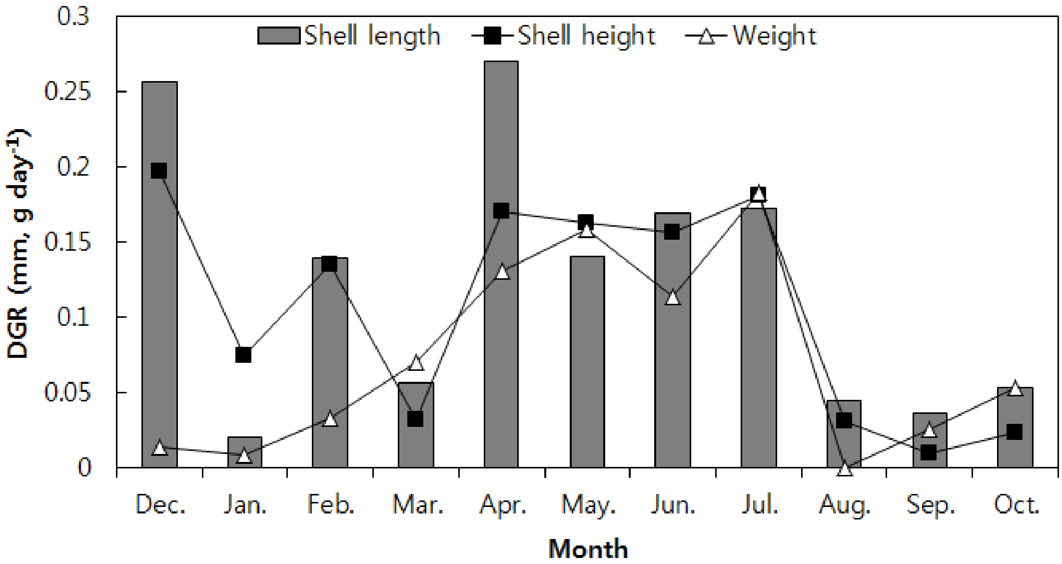

Fig. 10. Variations in DGRs of *P. yessoensis* in the IMTA system.

growth with DGRs ranging 0.02～0.256 ㎜/day in general and 0.256～0.27 ㎜/day in November～December 2013 and March～April 2014. During cold water season in December and January, the DGRs reduced to 0.02 ㎜/day. As for the shell height, the DGRs ranged 0.032～0.197 ㎜/day in general with a peak of 0.197 ㎜/day in November～December 2013 and a low in February～March 2014. The wet weight showed DGRs ranging 0.008～0.183 g/day with the lowest at 0.008 g/day in December 2013～January 2014 and the highest at 0.183 g/day in July (Fig. 10). The DGRs ranged 0.11～0.21 ㎜/day with the highest in August～September and the lowest in September～October. Populations from Gangneung-si showed a DGR range of 0.05～0.15 ㎜/day with the lowest in August～September when the Yangyang population performed the bet and the highest in May～June. Scallops farmed in IMTA showed a DGR range of 0.02～0.256 ㎜/day with fast growth of 0.256～0.25 ㎜/day in November～December 2013 and March～April 2014. In the cold water season, DGR declined to 0.02 ㎜/day in December to next January. According to Park et al.(2000), shell height DGRs were 0.247 ㎜/day for a farming density of 10 ind/㎡, 0.205 ㎜/day for 15 ind/㎡ and 0.178 ㎜/day for 100 ind/㎡ at 10 m depth. Other studies reported a DGR range of 0.05～0.14 ㎜/day (Parsons and Dadswee, 1992), indicating different results from our study.

3.3.2. Frequency distribution of shell length and wet weight of *P. yessoensis*

Shell length frequency distribution 100% occurred in a 10～29.99 ㎜ section in November 2013 and in a 19.99～39.99 ㎜ section in March 2014. The 100% distribution range moved from the section 19.99～29.99 ㎜ in November 2013 to 29.99～39.99 ㎜ in March and to the section 49.99～69.99 ㎜ in July 2014. Wet weight frequency distribution mainly occurred in a section 0～320 g. The distribution 100% occurred in the subsection of 00～9.99 g in November 2013 and March 2014 and the distribution 100% occurred in a subsection of 9.99～29.99 g in July 2014 (Fig. 11).

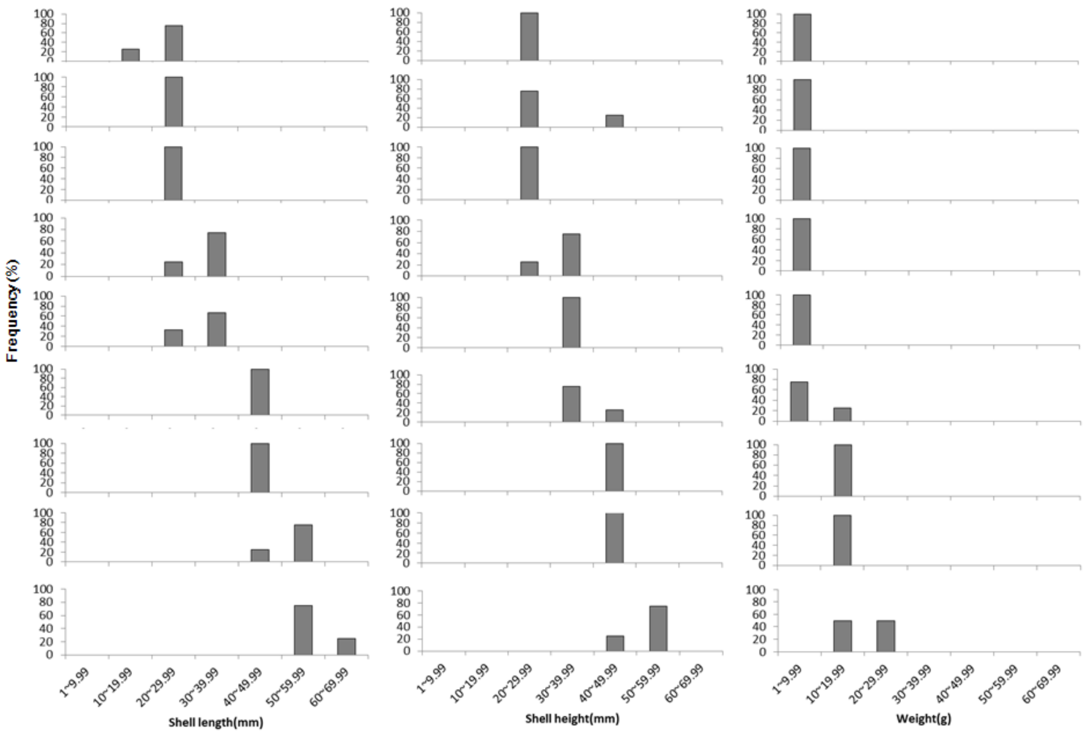

Fig. 11. Monthly frequency distributions of the shell length, shell height and wet weight of *P. yessoensis* in the IMTA system.

4. Conclusion

The farmed fish species, *M. cephalus* which discharges organic and inorganic particles grew to 256.4±9.7 ㎜ in length and 156.7±6.7 g in weight in October 2013 with DGRs ranging 0.015～0.1 ㎜/day in general and faster DGRs ranging 0.38～0.1 ㎜/day in February～March 2014. We planted seaweed species *S. japonica* to utilize the released organic and inorganic nutrients. *S. japonica* grew to 3.3±0.8 ㎝ in blade length and 2.5±0.9 g in wet weight in February and to 126.5±11.6 ㎝ in length and 107.4±22.6 g in wet weight in May 2014. The seaweed grew faster in March to April with DGRs ranging 0.88～1.9 ㎜/day. The farmed shellfish, *P. yessoensis*, grew to averages of 19.9±2.5 ㎜ in shell length, 20.8±2.6 ㎜ in shell height and 0.9±0.04 g in wet weight in November 2013 and to averages of 60.2±2.51 ㎜ in shell length, 54.6±2.61 ㎜ in shell height and 24±2.70 g in wet weight in October 2014. DGRs of shell length ranged 0.02～0.256 ㎜/day. The results showed that the farmed animals in the IMTA produced normal growth performance and their growth characteristics were found to be similar to those farmed in traditional farms according to the comparative analysis. However, *S. japonica* in the IMTA started erosion earlier. This is thought to be caused by slower water flow in the IMTA installed in the harbor compared to the environment in the coastal waters.

Acknowledgements

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