Journal of Environmental Science International
23(10); 1703~1718; October 2014

pISSN: 1225-4517 eISSN: 2287-3503
http://dx.doi.org/10.5322/JESI.2014.23.10.1703

ORIGINAL ARTICLE

Study on Growth Characteristics of *Sargassum fulvellum* in the Integrated Multi-trophic Aquaculture (IMTA) System

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Abstract

An eco-friendly integrated multi-trophic aquaculture (IMTA) farming technique was developed with the goal of resolving eutrophication by excess feed and feces as fish-farming by-products. A variety of seaweed species were tried to remove inorganic nutrients produced by fish farming. However, there have been few trials to use *Sargassum fulvellum* in an IMTA system, a species with a relatively wide distribution across regions with various habitat conditions, great nutrient removal efficiency and importance for human food source and industrial purposes. In this regard, our study tried to examine feasibility of using *S. fulvellum* in an IMTA system by analyzing growth characteristics of the species in an IMTA system comprising of rockfish (*Sebastes shlegeli*), sea cucumber (*Stichopus japonocus*) and the tried *S. fulvellum* (October 2011 – November 2012). We also monitored environment conditions around the system including current speed, water temperature and inorganic nutrient level as they may affect growth of *S. fulvellum*.

S. fulvellum in the IMTA system, which were 15.72±5.67 mm long at the start of the experiment in October 2011, grew to a maximum of 1093±271.13 mm by May 2012. In September, seaweed growth was reduced to a minimum of 280±70.43 mm in length. Then, *S. fulvellum* began to grow again reaching 325±196.19 mm by November 2012. Wet weight of the seaweed was 4.01±1.89 g at the start of the experiment and reached a maximum of 109.26±34.23 g in May. The weight gradually declined to a low of 15.12±8.40 g in September 2012. Weight began to increase once more, rising to 39.27±21.69 g by November. During the experiment, the average velocity at the surface and the bottom was 6.5 cm/s and 3.4 cm/s, respectively. The water temperature ranged 5.0-23.5 ℃, which was considered suitable for growing *S. fulvellum*. Results of the study indicated no significant differences in inorganic nutrients between pre- and post-IMTA installation. It was thus concluded that *S. fulvellum* can be a suitable seaweed species to be used in an IMTA system.

Key words : IMTA, Eco-friendly aquaculture, *Sargassum fulvellum*, Growth characteristics

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Received 12 August, 2014; **Revised** 3 September, 2014;
Accepted 24 September, 2014
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1. Introduction

U.N. Food and Agriculture Organization (FAO) statistics indicate that global capture-fisheries production remained stable at around 90 million tons in the first decade (2000s) while aquaculture production rose from around 41 million tons to 83 million tons during the same period (FAO, 2012). Aquaculture production is growing by more than 10% annually and will reach 50% of world's seafood supply by 2030 (Kang et al, 2011). In South Korea, the aquaculture industry initiated mass production in the 1980s when feed organisms for larvae fish were developed (Kim et al., 2010).

Large-scale fish farms have accumulated excess feed and fish feces upon the substratum, which decompose into inorganic matter and subsequently cause eutrophication as well as poor water quality; this has led to fish diseases and pollution (Cao et al., 2007; Troell et al., 1999; Wu, 1995). According to research conducted to detect pathogens on cultured flounders in farms located on the southern coast of Korea, 60.6% of fish tested positive in the year 2005, 66.7% were positive in 2006 and 72.3% were positive in 2007 (Kim et al., 2010). The results showed that the increased level of farming wastes correlates positively to an increase in fish diseases.

An aquaculture farm that had been used for faming over a long period of time was shown to accumulate a significantly higher level of organic matter in the sediment than the surrounding area with its concentration rate reducing at a constant rate from the sediment surface to a certain depth and then remaining stable below (Kim et al., 2012). The sediment rate measured by radioisotopes was also higher in the aquaculture farm than in the overall area on the southern coast of Korea, indicating that organic matter of farming by-products plays as a significant water-borne pollutant in the sediment environment (Kim et al., 2012).

As a result, farming countries- not only South Korea, but the world over- have become more interested in eco-friendly farming (Neori et al., 2004; Wurts, 2000). Ryther et al. (1975) suggested growing seaweed in fish farms as a way to reduce or remove highly-concentrated nutrients produced by fish farming. Earlier, several studies had proven that seaweed could be successfully farmed in fish farms where feed is provided (Hernandez et al., 2002; Neori et al., 2004; Troell et al., 1999).

IMTA can be an eco-friendly type of aquaculture in which waste from fish farms is utilized as a food source for seaweed, shellfish and sea cucumbers, leading to pollution elimination (Goldman et al., 2004; Lander et al., 2004; Park et al., 2012).

As primary coastal producers, seaweed provides nurseries, habitats and food for aquatic fauna (Ohno, 1993; Watanuki and Yamamoto, 1990). In addition, seaweed contributes to a decrease in nitrogen and phosphorus levels and serves as important bio-filters (Hayashi et al., 2008; Neori et al, 2007). Existing studies have suggested that algal species such as *Sacchaarina japonica*, *Gelidium amansii*, and *Codium fragile* can be utilized in an IMTA system.

Sargassum fulvellum is regarded as a valuable species that is highly effective in absorbing nutrients and has great potential for commercialization. The *Sargassum* species can live in a wide variety of environment conditions. Deysher (1984) reported that *S. muticum* can survive in the Japanese coastal area with water temperatures ranging from 5 to 28 ℃, and Hwang et al. (2005) reported that temperature tolerance of *S. fulvellum* in the Korean southern coast ranges from 7.1 to 23.5 ℃. Along the Korean East Sea off the coast of Sokcho and Donghae, the yearly water temperatures vary from 6.86 to 26.53 ℃, and were thus considered suitable for farming *S. fulvellum* (KOEM, 2012).

Despite various potential benefits from *S. fulvellum* described above, however, there have so far been few trials that the species was employed for IMTA system. In this study, we tried to examine whether *S. fulvellum* could be used for IMTA system by analyzing growth characteristics of the species in an IMTA system. The experimental IMTA system, which was stocked with rockfish (*Sebastes shlegeli*), sea cucumber (*Stichopus japonocus*), and *S. fulvellum*, was installed at Susan harbor located in Yangyang, Gangwon province along the middle coastline of the Korean East Sea. We also monitored environment conditions around the system including current speed, water temperature and inorganic nutrient level as they may affect growth of *S. fulvellum*.

2. Material and Method

2.1 Overview of the research site

The Susan harbor (38° 04 ′ 46 ″ N, 128° 40 ′ 27 ″ E) is a government funded and administered harbor covering an area of 2,156 m^2. The bed of the harbor is formed from mud and sand. Sandy areas are inhabited by communities of seagrass. We selected an IMTA research site at depths of 7-10 m (Fig. 1).

2.2 IMTA system

A circular-type cage was adopted within the IMTA system in order to maximize effects of the integrated multi-trophic farming as well as to secure visual stability. The system was installed at depths of 7-10 m based on technical assessment for its construction and efficient farming methods. Suspended mooring using ropes and anchors was installed individually on each end of the IMTA system in order to minimize the total space occupied by the farming operation, and to prevent the system from being lost to winds and waves. The farming cage itself was divided into

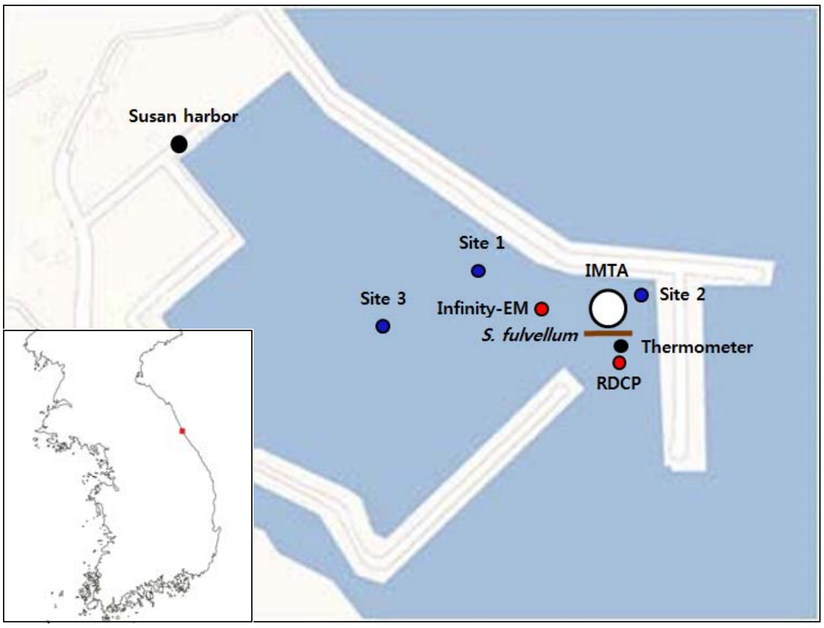

Fig. 1. Study area and site plan for current study. The IMTA system located in Susan harbor, Yangyang, Gangwon province along the middle coastline of the Korean East Sea. The hanging culture lines for *Sargassum fulvellum* were set outside of the fish cage. The wind and water current speed and direction in Susan harbor were measured using RDCP and Infinify-EM. The contents of mineral salts including NH_4^+-N, NO_2^--N, NO_3^--N, and PO_4^{3-}-P were measured at site 1, 2, and 3, respectively. Seawater temperature was also measured near *S. fulvellum* hanging culture lines.

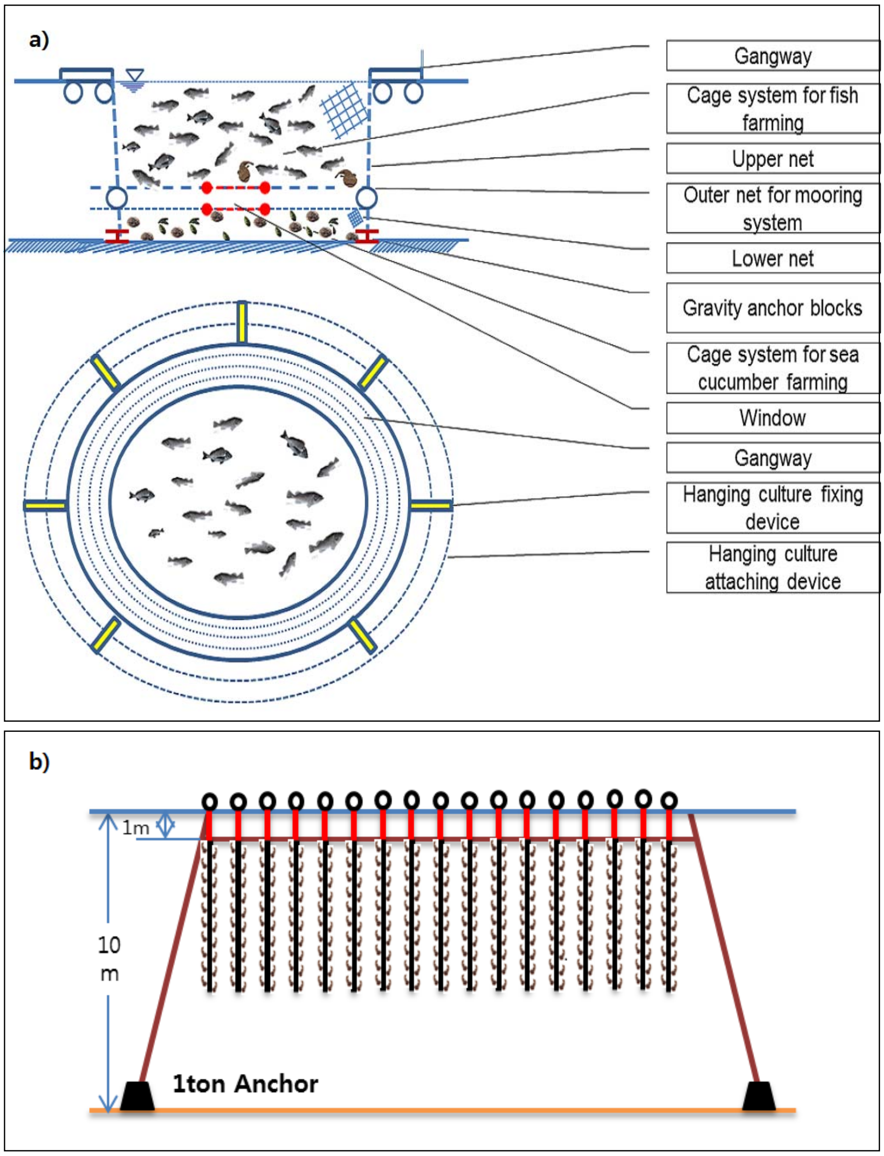

Fig. 2. IMTA model and its compartments (a) and *Sargassum fulvellum* hanging culture lines (b) used in this study.

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 excess feed utilization, the netting was flattened against the bottom of the cage area by attaching chains to its edges. By setting the hanging culture lines for *S. fulvellum* outside of the cage, the system provided the pathway to improve convenience for research and survey (Fig. 2).

2.3 Current direction and speed and water temperature in the harbor

We installed a current profiler (a Recording Doppler

Current Profiler (RDCP, 600kHz); Anderaa, Xylem Inc. Norway) to conduct continual, multi-depth monitoring of tidal-current directions and speeds at the mouth of the harbor over a period of 7 days, from May 18-25, 2012. During the same period, we also monitored surface flows by using a smaller-scale current profiler (Infinity-EM, Infinity, Japan) which was moored to a seaweed culture line vertically hanging near the farm cage. The monitoring devices were set to record measurements every 10 minutes. Wind data was obtained from the regional meteorological office in Yangyang, Korea. During the study period, water temperatures around the system were also measured (Fig. 1).

2.4 Nutrients analysis

Nutrients were analyzed pre- and post-IMTA installation (April and September 2011). Sea water was sampled at three stations both at surface (5 m under the surface) and bottom (1 m above the bottom) near the IMTA system using 5 L Niskin sampling bottle (1010-1.2, General Oceanics Inc., Florida, USA) (Fig. 1). Each of the water samples was filtered through GF/F device until 250 mL was filtered out. The filtered water was frozen at -20 ℃, transported to the laboratory and used for analysis upon being thawed. Nutrients including NH_4^+-N, NO_2^--N, and NO_3^--N were measured using an auto analyzer (QUAATRO, BRAN+LUEBBE, Hamburg, Germany) in accordance with the Marine Environ -ment Analysis Method (MLTM, 2010).

2.5 Seeding *S. fulvellum*

Seaweed seeds for the experiment were provided from a hatchery of Narae fisheries company in Jindo, South Jeolla province. Seaweed cultivation lines were cut into 3 m fragments. The seed-imbedded cultivation lines were hung vertically by attaching a 500 g weight to the end of a line. To monitor the growth, we made monthly measurements of length and wet weight. At the start of the experiment (October 16, 2011), the length of S. fulvellum was 15.72±5.67 mm. For the monthly measurement, we collected 30 samples and measured the length using a scale and vernier calipers, while the wet weight was measured using a weighing machine (MW-2N, CAS Co. Ltd., Seoul, Korea). Relative growth rates (RGR) were calculated using the following equation:

RGR (mm day^{-1} or g day^{-1}) = $(lnP_{t2}-lnP_{t1})/T_1-T_2$, where P_{t1} and P_{t2} are length or weight of *S. fulvellum* at months $T_1$and T_2.

2.6 Introduction of rockfish (*Sebastes shlegeli*)

100,000 rockfish (*Sebastes shlegeli*) with an average body weight of 8.6±3.0 g were stocked and reared in the IMTA cage, in which 10 kg extruded pellet feed (National Federation of Fisheries Cooperative Feed, Daejeon, Korea; 45% or greater crude protein, 13% or greater crude fat, 3% crude fiber, 17% crude ash and 2.7% phosphorus) were fed to juveniles from day 3 of the experiment and continuing thereafter for twice a day at 9:00 and 16:00.

2.7 Seeding *Stichopus japonocus*

22,000 juvenile sea cucumbers (*Stichopus japonocus*) were provided from a hatchery located in Namhae, Gyeongnam province. They were contained in a flow-through circular FRP tank (5 tons) indoor for 7 days to be stabilized. After being stabilized, 20,000 of the contained juveniles were moved and seeded on 4 artificial substrates (2 concrete structures and 2 PVC pipe structures) placed in the IMTA system in two stockings.

3. Result

3.1 Installation of an IMTA system

The IMTA system was designed to be operated even under the following conditions: 2.5 m wave height, 0.32 m high-tide level, 0.132 m low-tide level, 0.227 m sea-surface level, 2.5 knot current and 21 m/s wind speed (with 29.6 m/s maximum gusts). The IMTA system as a whole measured 23 m in diameter and 9 m deep. The cage net itself measured 18 m in diameter, while the fish-rearing cage was 5 m deep and sea cucumber cage was layered 3.5 m below. The floating system is supported by PE pipes and adopted a safety factor (SF=2) to be able to endure twice the loading that the IMTA is basically designed to endure (Fig. 2).

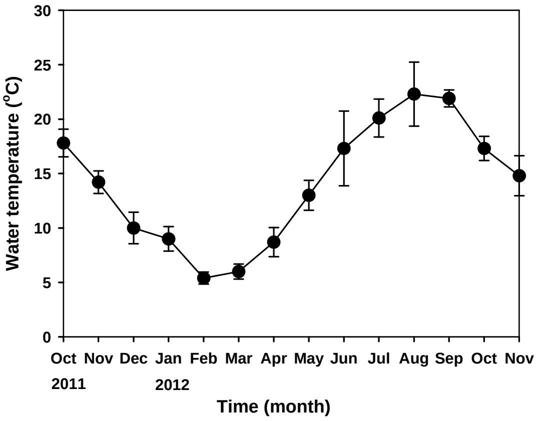

Fig. 4. Water temperature variations near *Sargassum fulvellum* hanging culture lines.

3.2 Current direction and speed and water temperature in this experimental site

Data of current speed and direction obtained from RDCP and Infinity-EM as well as wind data is shown in Fig. 3. Data was averaged for every 60 minutes and compared. According to RDCP readings of velocity at the harbor mouth, maximum instantaneous velocity at the water's surface and at the bottom was 24.8 cm/s and 10.8 cm/s, respectively. During the experiment, the average velocity at the surface and the bottom was 6.5 cm/s and 3.4 cm/s, respectively. As for direction, the current on the surface was flowing predominantly inward toward the harbor while on the bottom it was flowing predominantly outward.

According to Infinity-EM readings of velocity in the seaweed farming area outside of the IMTA system, maximum instantaneous velocity was 23.8 cm/s and the average velocity 4.7 cm/s with the current flowing predominantly in east-west direction. Comparing RDCP and Infinity-EM readings, there was a variance in current direction and speed with Infinity-EM readings 2 cm/s slower than RDCP

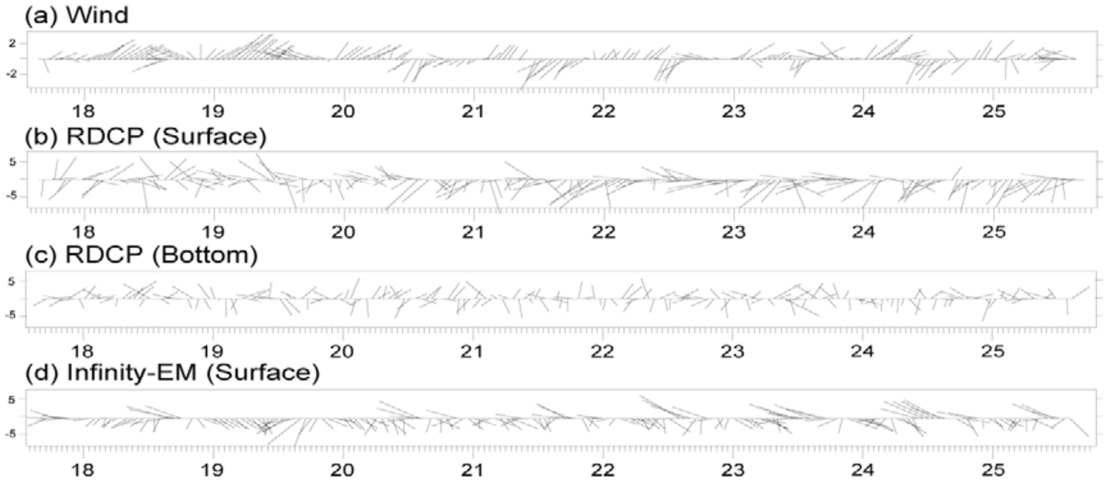

Fig. 3. Averages of wind (a) and water current speed and direction using RDCP for water surface (b) and bottom (c) and infinity of EM for water surface (d) near IMTA system (May 17th - 25th, 2012).

Table 1. Mineral salts contents in IMTA system

	Station No.	NH$_4$ - N (mg/L)		NO$_2$ - N (mg/L)		NO$_3$ - N (mg/L)		DIP (mg/L)	
		Apr	Sep	Apr	Sep	Apr	Sep	Apr	Sep
Surface	st.1	0.009	0.011	0.001	0.001	0.008	0.011	0.005	0.007
	st.2	0.014	0.014	0.001	0.001	0.016	0.015	0.004	0.007
	st.3	0.010	0.011	0.001	0.001	0.005	0.009	0.004	0.005
Bottom	st.1	0.009	0.001	0.001	0.005	0.008	-	0.001	0.003
	st.2	0.010	0.001	0.002	0.005	0.009	-	0.002	0.002
	st.3	0.010	0.011	0.001	0.001	0.008	-	0.000	0.003

- : didn't detect

readings. These variations were considered to be caused by a predominant surface flow from the mouth along the breakwater and velocity reduction against the farming structure (Fig. 3). Water temperatures within the harbor varied from 5.0 ℃ in February, 2012 to 23.5 ℃ in August, 2012 (Fig. 4).

3.3 Water quality analysis

Results of the water quality analysis (NH$_4$ - N, NO$_2$ - N, NO$_3$ - N, and DIP) at each of 3 sites in Susan harbor were shown in Table 1. At site 1, when compared to the measurements in April 2011, prior to the IMTA installation, and measurements in September 2011, post of the installation, there was no change in NO$_2$ - N concentration. Otherwise slightly increase was observed in NH$_4$ - N, NO$_2$ - N, and DIP concentration. At site 2, except that DIP concentration increased from 0.004 mg/L to 0.007 mg/L, no change was observed in others. At site 3, except that NO$_3$ - N concentration increased from 0.005 mg/L to DIP 0.009 mg/L, no change was observed in others.

3.4 Length and wet weight of *S. fulvellum*

The length of the *S. fulvellum* measured 157.20± 56.70 mm at the start of the experiment and reached a maximum of 1,093±271.13 mm by May 2012. In June, the length began to reduce due to bleaching; the *S. fulvellum* shrank to 913.42±230.93 mm and reached to a minimum of 280.70±196.19 mm by September. Algal growth revived and increased to 325.90±196.19 mm by November 2012 (Fig. 5). The wet weight measured 4.01±1.89 g at the start of the experiment, reached a maximum of 109.26±34.23 g, and then gradually decreased to a minimum of 15.12±8.40 g in September 2012. The wet weight increased once more, reaching 39.27±21.69 g by the conclusion of the experiment (Fig. 5).

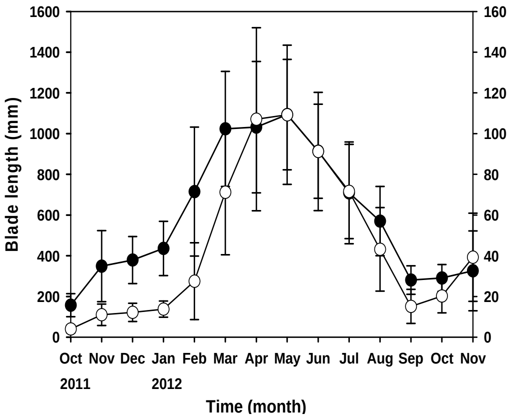

Fig. 5. Blade length (●) and blade wet weight (○) of *Sargassum fulvellum* in IMTA system.

3.5 Frequency distribution of blade length and blade wet weight of *S. fulvellum*

Seaweed lengths were mainly distributed in the 70-320 mm cultivation-measurement section and wet weights were in the 1-3 g section in October 2011. On November 7th, the lengths were extensively

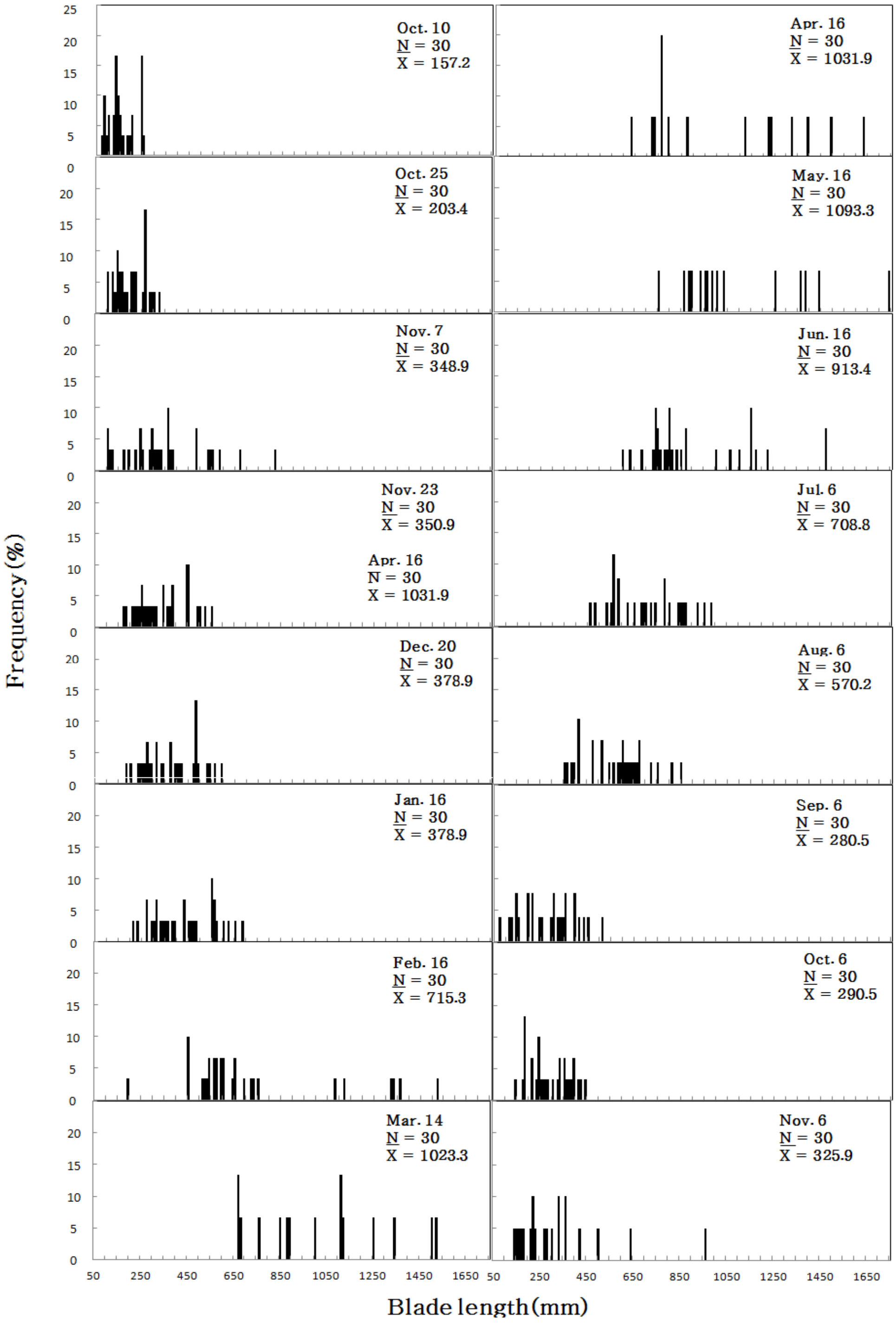

Fig. 6 (a). Frequency distribution of blade length of *Sargassum fulvellum*

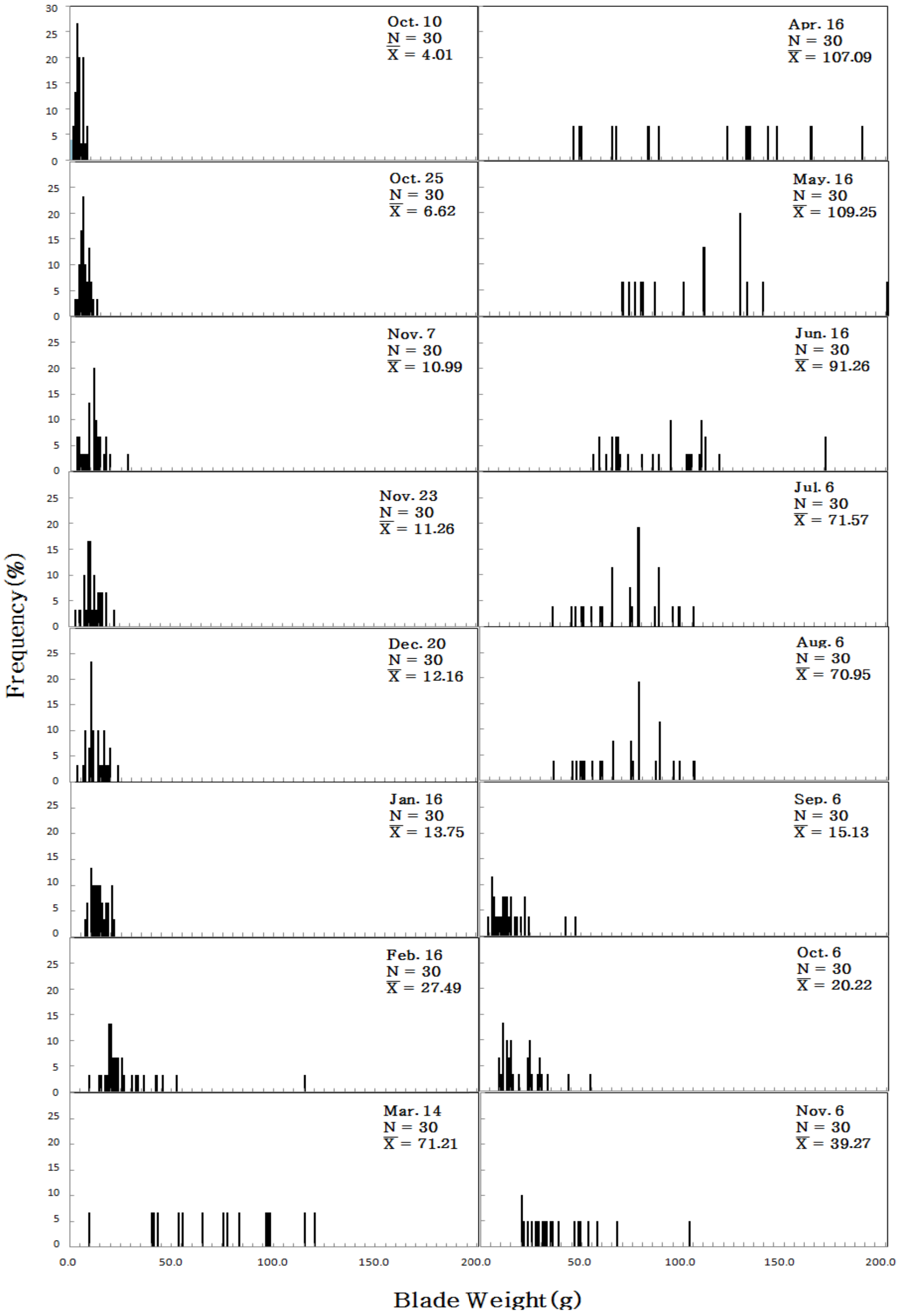

Fig. 6 (b). Frequency distribution of blade weight of *Sargassum fulvellum* distributed in the 100-820 mm section while wet weights were intensively distributed in the 3-19 g section. The distribution of lengths spanned the 170-550 mm section on November 23rd, which was a narrower range than previously observed on November 7th. The lengths were distributed in the section measuring 670-1520 mm in March 2012 and showed a similar distribution span of 630-1630 mm in April, while wet weight showed a significant difference between March (9-120g) and April (46-188g). Wet weights showed a consistent distribution frequency of 6.7% in March and April. Until May 2012, distribution ranges of lengths and wet weights were 750-1740 mm and 70-200 g, respectively, but both sectional measures showed reduced growth from June to September. In September of the same year, distribution ranges of lengths and wet weights reduced to within ranges of 70-510 mm and 4-47 g, respectively. Then, from October 2012, the two measurements started to rise once more (Fig. 6).

3.6 Relative growth rate of *S. fulvellum*

Monthly relative growth rates (RGRs) were calculated in Fig. 7 based on lengths of *S. fulvellum.* The relative growth rates from the IMTA system ranged from -9.66 to 10.27 mm/day reaching a peak of 9.31 to 10.27 mm/day in February and March 2012. In June, the rate plummeted to -6.00 mm/day due to loss of thalli, reaching -9.66 mm/day in September. In October when the water temperature decreased, thalli started to grow again with a relative growth rate of 0.34 mm/day. RGRs of the seaweed wet weight were also calculated in Fig 7. They ranged from -0.95 to 1.46 g/day with a peak of 0.46 to 1.20 g/day from February to April 2012. Particularly in March, the RGR reached a maximum of 1.46 g/day. In June, the rate decreased to -0.60 g/day and then further declined to -0.93 g/day in September. In October when the water temperature began decreasing, thalli renewed their growth with an RGR of 0.93 g/day.

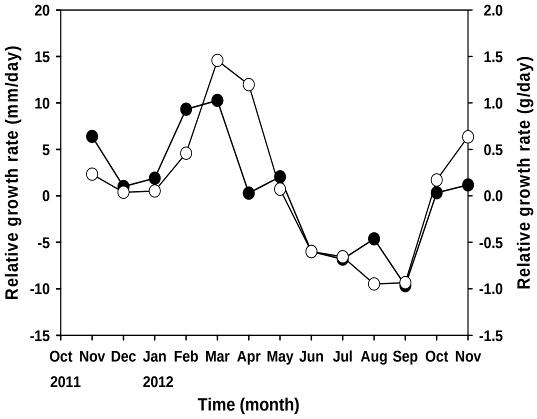

Fig. 7. Daily growth of *S. fulvellum* (●: length, ○: wet weight) in IMTA system.

4. Discussion

Aquaculture production (primarily via fish farming) has been increasing in its importance as a food source for humanity (Chopin and Yarish, 1998; Naylor et al., 2000). FAO data indicate that farming production continues increasing while capture-fishery production remains stable (FAO, 2012). Excess nutrients created from farming activities may possibly lead to eutrophication in the ecosystem (Troell et al., 1999). To address this issue, Integrated Multi-Trophic Aquaculture (IMTA) based on seaweed has been suggested globally (Buschmann et al., 2008a, c; Chopin et al., 2001, 2008; Neori et al., 2004, 2007; Troell et al., 2003).

Excess feed and feces sink onto the substratum of fish farms and decompose into inorganic matter, prompting deteriorating conditions such as lower DO levels, poor water quality and fish health and diseases (Buschmann et al., 2001; Chopin et al., 2001). The IMTA system utilizes seaweed to remove both organic and inorganic matter from excess feed and feces. This technology can provide economic benefits by removing excess nutrients and thus improving the coastal environment (Chopin et al., 2008).

Consequently, there is particular interest in worldwide for using seaweed to remove excess nutrients in the coastal environments (Buschmann et al., 2009). A number of studies tried to remove nutrients produced from fish farming using a variety of seaweed species (Hernandez et al., 2002; Troell et al., 2003; Wu et al., 1984). In reality, however, only a limited variety of species such as *Codium fragile*, *Enteromorpa intestinalis*, *Gelidium amansii*, *Gracilaria gracilis*, *G. verrucosa*, *Sacchaarina japonica*, *Porphyra yezoensis*, *Ulva rotundata* are employed in IMTA system. It is very important to consider different environmental conditions in different locations and seasons when selecting seaweed species to be used in an IMTA system.

Twenty-eight species of *Sargassum* are reported growing in Korea (Lee and Kang, 2001), among which eleven species are of commercial importance, including *Sargassum fulvellum* (Hwang et al., 2005). The species grow at water depths of 3-5 m or deeper depending upon the aquatic environment (Hwang et al., 2006). *Sargassum* thalli can grow 1-2 m and a variety of studies on *S. fulvellum* cultivation were conducted. The stripes produce primary branches with abundant spirally-arranged secondary branching. Male and female sex organs retain receptacles with those in females longer than in males (Oak et al., 2005). The perennial *Sargassum* carries out both sexual reproduction and partly vegetative propagation (Hwang et al., 2005). It is a brown alga which is used for human consumption in the southern coastal areas of mainland Korea as well as Jeju Island. *Sargassum* also provides spawning grounds for sandfish and serves as a bio-filter.

Considering its importance as food source for human consumption and nutrient absorber improving ecological condition, our study tried to adopt *S. fulvellum* in the IMTA system. We thus installed an IMTA system comprising of rockfish (*Sebastes shlegeli*), sea cucumber (*Stichopus japonocus*) and *S. fulvellum* at Susan harbor located in Yangyang, Gangwon province along the middle coastline of the Korean East Sea.

In general, seaweed growth depends on physical, chemical and biological factors, especially on conditions of light, water temperature and nutrient level (Lobban and Harrison 1994, Harrison and Hurd 2001).

We discussed the relationship between the seawater temperature and the seaweed *S. fulvellum* growth. The research site for our study at Susan harbor has wide water-temperature variations, ranging from a low of 5.4 ℃ in winter to a high of 22.3 ℃ in summer (Fig. 4). The summer temperatures presented in this study are similar to those of Hwang et al. (2005) studied at Wando, Korea. However, winter temperatures present a gap of 2 ℃ compared to the Hwang's 2005 study. In our study, growth of *S. fulvellum* was the highest in May with a measured rate of 1093.42± 271.13 mm. The lowest growth rate was experienced in June. The species started to grow again in October when the water temperature decreased. By comparison, at Wando on the southern coast of Korea, *S. fulvellum* started to grow in September when the water temperature decreased, but in May thalli were partly lost (Hwang et al., 2005). During the study at Wando, the water temperature varied from 7.1 to 23.6 ℃ with the highest recorded in September and the lowest in February.

There are also significant differences in tidal current velocity when comparing the flow rates between the outside and inside of the harbor. According to NFRDI data, velocity outside the harbor averages 50 cm/s while inside the harbor the average is barely 2 cm/s (Figure 3). The 7 day monitoring also showed that maximum instantaneous velocity at the water's surface and at the bottom was 24.8 cm/s and 10.8 cm/s, respectively. During the experiment, the average velocity at the surface and the bottom was 6.5 cm/s and 3.4 cm/s, respectively. As for direction, the current on the surface was flowing predominantly inward toward the harbor while on the bottom it was flowing predominantly outward. Hwang et al. (2007) conducted a follow-up experiment under conditions of 50 cm/s current velocity, with the substratum at depths of 15-20 m and salinity at 33.2-34.6 ‰. It is thus considered that our experiment area is very suitable for growing *S. fulvellum*.

Growth of transplanted *S. fulvellum* was recorded in Yoon et al. (2013), where it was seeded on the substratum under the waters off Jeju Island for reconstruction of the algal bed. In the study, 36-45 cm thalli planted in June grew to 100 cm in the following April. *S. fulvellum* in the IMTA system of our study showed similar growth patterns to the earlier studies mentioned above. The growth performance of *S. fulvellum* in an IMTA system is comparable to those under other farming conditions. In our study, bleaching was observed in September 2012.

Seaweed has variations in their growth, morphology and life span depending on various environmental factors such as nutrients and water temperature (Novaczek, 1980) as well as seasonal and age conditions (Maegawa, 1990; Maegawa and Kida, 1989). A study on growth of *Ecklonica cava* showed thalli were newly generated in the winter, grew wider in the following spring and thicker in the summer (Haroun et al., 1989; Yokohama et al., 1987). According to Hwang et al. (2010), after moderate level of bleaching in the summer, *S. fulvellum* grew once more in October with its branches showing a continual growth year-round. In our study, the species showed the same growth pattern as in the Hwang et al. (2010).

It is generally known that a different species of seaweed requires different levels of nutrients for its growth with different effects on its biomass (Lapointe et al., 2004; Pederson et al., 2010). It is also known that species with relatively higher growth rates require higher levels of nitrogen and phosphorus while those with relatively lower growth rates have a stronger endurance to lower levels of nitrogen and phosphorus (Pederson and Borum, 1997; Pederson et al., 2010; Martinez et al., 2012). It was reported that *Bifucaria bifurcate* had good growth performances even under a lower nitrogen condition, while *Ulva intestinalis* grew fast only under higher nitrogen level (Martinez et al., 2012). In a study on nutrient removal efficiency of *Sacchaarina japonica* (Park et al., 2012), an experiment site which reared only fish showed an increase in NH_4^+ level from 0.117±0.021 to 5.836±0.941 mg/L, however, after adding *Sacchaarina japonica* into the site in order to remove NH_4^+, the NH_4^+ level decreased to 1.642±0.121 mg/L. In the same study, PO_4^{3-} in an experiment site stocked only with fish rose from 0.440±0.000 to 0.440±0.045 mg/L, however, after adding *Sacchaarina japonica*, the PO_4^{3-} level reduced to 0.013±0.000 mg/L. It is also known that seaweed's nutrient removal efficiency (NRE) is varied depending on environment factors. NRE of *G. vermicculophylla* measured 34.4% in a static farming system while 81.6% in a flow-through system (Skriptsova and Miroshnikova, 2011). In the same context, seaweed's NRE was found to be affected by various factors including water temperature, light, salinity and nutrient level (Park et al., 2012). It was also found that NRE positively correlated with flow amount as greater flow amount increases water flow on surface of thalli, providing more nutrients (Park et al., 2012). But there are no known studies of this kind conducted on *S. fulvellum*. Further researches are needed to elucidate the relationship between physical, chemical and biological factors and nutrient removal by *S. fulvellum*.

According to MLTM (2012), nutrient conditions in waters off Yangyang, Gangwon province measured NO_3-N 0.001-0.085 mg/L, NO_2-N 0.000-0.002 mg/L, DIP 0.000-0.015 mg/L, and NH_4-N 0.004-0.026 mg/L. Our study site, Susan harbor also located in

Yangyang, showed nutrient conditions in April 2011 of NO_3-N 0.004-0.014 mg/L, NO_2-N 0.001-0.005 mg/L, DIP 0.001-0.005 mg/L, and NH_4-N 0.008-0.028 mg/L. In September 2011, the measurements were NO_3-N 0.008-0.015 mg/L, NO_2-N 0.001-0.005 mg/L, DIP 0.002-0.007 mg/L, and NH_4-N 0.001-0.014 mg/L. It was observed that water quality measurements in waters off Yangyang as well as in Susan harbor were not significantly different between in April 2011 or prior to the IMTA installation and in October 2011, post- the installation.

It is generally known that fish farming cages significantly contribute to a drastic increase in inorganic nutrients in the surrounding environment (Read and Fernandes 2003). Our study compared nutrient levels in the waters of Susan harbor pre- and post-IMTA system but showed no changes in the nutrient levels (Table 1). It can be assumed that inorganic nutrients produced from fish farming were effectively removed by the seaweed. Similar results were obtained in various earlier studies such as Buschmann et al. (1996), Neori et al. (2004) and Phang et al. (1996).

5. Conclusion

It was shown that the nutrient levels in our IMTA system were similar to or lower than those in the surrounding coastal environment by employing *S. fulvellum* to remove excess nutrients from fishing farming. Therefore we can conclude that under appropriate conditions, cultivation of *S. fulvellum* in the IMTA system can be successful. In addition, this study is the first trial in adopting *S. fulvellum* in an IMTA system. It will be needed to study further to quantitatively measure nutrient removal efficiency of *S. fulvellum* through qualitative and quantitative analysis of nutrients from fish farming.

Acknowledgement

This study was conducted with the assistance of NFRDI (Project for Fishing Village Tourism-Type IMTA Utilizing a Harbor, RP-2012-AQ-069).

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