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Structure and Function of Submarine Forest 2. Population Dynamics of *Ecklonia stolonifera* as a Submarine Forest-Forming Component

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The population dynamics of *Ecklonia stolonifera* was investigated at Tongyeong coastal area in the South Sea of Korea. The blade length and width, stipe length and diameter, mean total length and mean weight were measured from randomly collected fifty individuals in every month. The plants in Tongyeong population were relatively bigger than those of Busan Korea and Aomori Japan in terms of their blade length and width. The population biomass was low in winter and high in spring and summer. The sporangial sori were found from August to December but prominent in September and October. About 90 % of the Tongyeong population was consisted of one- and two-year old plants and the zoosporangial sori were observed mostly in two-year old plants. It was different from the results of Busan and Aomori population in which the zoosporangial sori were observed from the plants older than three years. The new populations were developed from the zoospores of two-year old plants and their generation time was relatively shorter than those of Busan and Aomori.

Key Words: *Ecklonia stolonifera*, population dynamics, submarine forest

INTRODUCTION

The submarine forest is very important in the structure and function of the subtidal ecosystem like the terrestrial forest. The marine plants that form the submarine forest belong to several benthic marine algae of Laminariales and Fucales and seagrass such as *Phyllospadix* and *Zostera*. Recently, the public concern on the submarine forest and its composing species has been increased because of its ecological function. The submarine forest plays the roles of spawning and nursery ground for coastal fishes, purifies the eutrophicated water by absorbing the nutrients such as nitrogen and phosphorus, and provides resources such as bioactive materials that are recently spotlighted (Hayashida 1984; Yoo *et al.* 2001; Seo and Yoo 2003; Yoo 2003).

Ecklonia stolonifera, a benthic marine alga, is distributed in the subtidal zone down to 30m deep and usually grows at 2-10 m depth (Notoya and Aruga 1990; Park *et al.* 1994). The mixed populations of age one to six are found together because it is perennial species. It is, therefore, indispensable to correctly assess the population structure such as the growth pattern, age structure, and maturation period in order to understand this population. Some studies have been conducted on its characteristics of *E. stolonifera* population (Notoya 1984, 1987), formation of sporangial sori (Notoya and Aruga 1990), zoospore germination (Notoya and Asuke 1983), and nuclear division (Yabu and Notoya 1985) in Japan, whereas there was only one study on the population growth in Busan, Korea (Park *et al.* 1994).

This study has been conducted to get the phenological characteristics of *E. stolonifera* population for the evaluation of its bioresource potential at Tongyeong subtidal rocky shore. Because this species is one of major algae that form the submarine forest (Druehl *et al.* 1977) and an economic seaweed used for food and industry as well (Oh *et al.* 1990). In addition other *E. stolonifera* populations of different locations were also compared.

MATERIALS AND METHODS

This study was conducted by scuba diving at the 5-8m depth of the subtidal zone at Cheockpo-ri, Sanyang-eup, Tongyeong-shi (128° 25’0”E, 34° 45’0”N) in every month.

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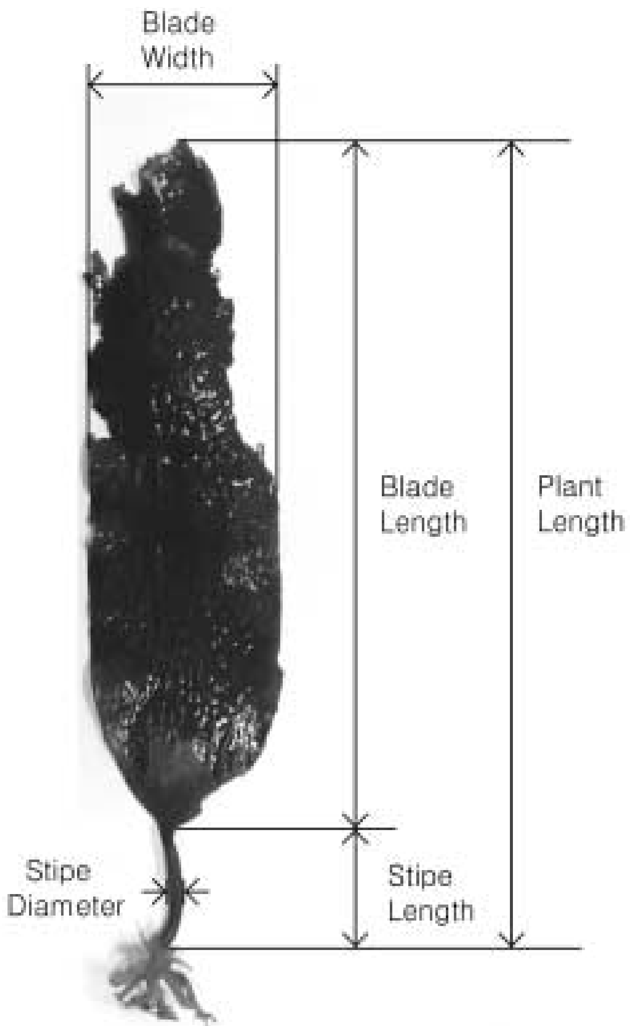

Fig. 1. Illustration of *Ecklonia stolonifera* shoot showing parameters measured.

More than 50 individuals of *Ecklonia stolonifera* plants were randomly collected (Elliott 1977; Barbour *et al.* 1987). The collected samples were transported to the laboratory, and the blade length and width, stipe length and diameter and total length and fresh weight were measured (Fig. 1). Fronds that formed the sporangial sori were counted as a relative frequency of sporangial sori. The frequency distributions of the blade length, plant weight, stipe length and stipe diameter were grouped in a class interval of 20 cm, 30 g, 5 cm, and 1 mm, respectively. Ten plants were randomly selected and estimated their age by the growth ring from the cross-sectioned stipe. The population age class was estimated by using the formula $Y = 1.652X \times 0.194$ (X: age, Y: stipe diameter) (Park *et al.* 1994). The monthly temperatures of Tongyeong shore were used from the National Fisheries Research and Development Institute data (Anon 2002).

RESULTS

The range of water temperatures of Tongyeong shore where *Ecklonia stolonifera* plants grew were between 7.7°C at lowest in January and 26°C at highest in August (Fig. 2E). The changes of the blade length and width of *E. stolonifera* population were shown in Fig. 2A. The monthly mean blade lengths were within the range of 45.2-96.5 cm and generally relatively long blades were found from March to July. The monthly mean blade width was 28.6 cm at the widest in March and 13.7 cm at the narrowest in November. The variation of stipe length was smaller than that of the blade length. It was 11.9 cm at the longest in June and 4.3 cm at the shortest in February. The change of stipe diameters did not related with that of stipe length (Fig. 2B). The mean total length and mean weight are shown in Fig. 2C. The mean total lengths were within the range of 49.9-104.5 cm, the longest in November and shortest in May. Generally, plants weighed heaviest in July and lightest in November. *E. stolonifera* formed the sporangial sori from August to December, and the composition of plants with sporangial sori was 78.0% in September and 16.0% in December (Fig. 2D).

Histograms of the grouped frequency distribution for blade length, plant weight, and stipe length and diameter of the present population are shown in Fig. 3. In the monthly variation of the frequency distribution of the blade length, any young plants smaller than 30 cm did not appear from January to July, whereas plants of 10-130 cm long appeared from September to December. The plants larger than 70 cm appeared in high proportion from March to July. The blade length increased up to the maximum length in May, so plants larger than 110cm were of 30% in the total population in this month (Fig. 3A). For the frequency distribution based on the total plant weight, plants under 90 g accounted for high proportion from November to February, while plants over 90 g began to increase from March and accounted for high proportion from May to July. During this period, plants over 210g accounted for 10% in May and June and 20% in July (Fig. 3B). The frequency distribution based on the stipe length is shown in Fig 3C. There was not any plant of which stipe length was longer than 15 cm from November to March. The stipe length, however, began to increase after then, and showed highest values in August and September. The frequency distribution based on the stipe diameter is

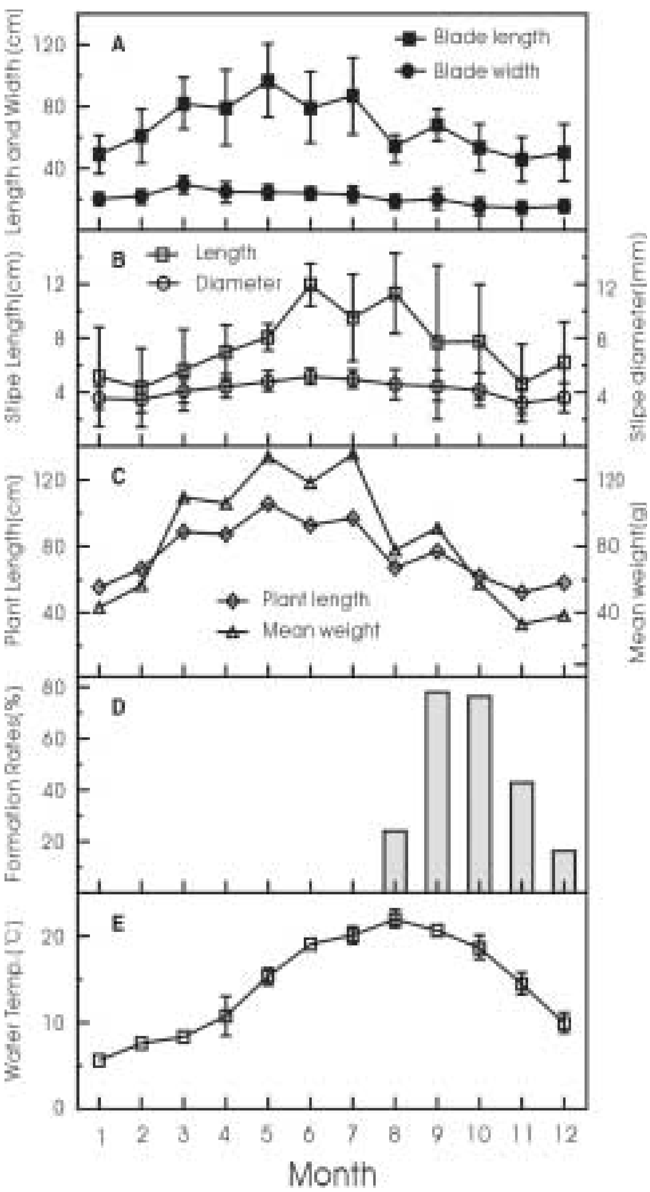

Fig. 2. Monthly variation of blade length and width (A), stipe length and diameter (B), total length and weight of the plants (C), formation rate of sporangial sori (D) for *Ecklonia stolonifera* population, and water temperature of Tongyeong (E).

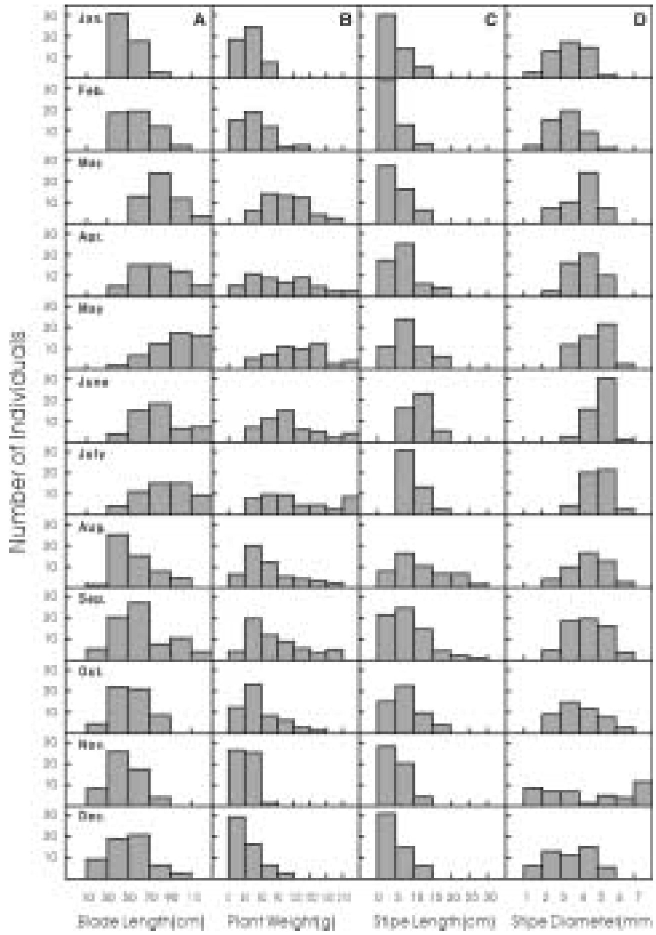

Fig. 3. Frequency distribution for total length (A) and weight of the plats (B) and stipe length (C) and diameter (D) in *Ecklonia stolonifera* population.

shown in Fig 3D. The plant of which stipe diameter is over 5 mm showed higher frequency distribution from May to November. The plants of which stipe diameter was larger than 6 mm accounted for relatively high proportion in November. The results of growth ring indicated that the two-year old plants were account for 90-95%, and the plants over three-year old were 5-10% and plants older than three-year old were rarely observed. These results were coincided with the estimation from the relation formula of age and stipe (Park *et al.* 1994).

DISCUSSION

In the coast of Korea, *Ecklonia stolonifera* is distributed from Keumho Islands of South Sea through to Wolseong of East Sea and in Ulleungdo and Chujado Island. Especially, its distribution has been intensively reported from Geojedo Island through to Yeongil Bay (Kang 1965, 1966; Kim *et al.* 1994; Koh *et al.* 1994; Lee and Kang 2001). Kang (1966) and Lee and Boo (1981) reported its distribution in Ulleungdo Island. Other studies of Lee (1991), Lee (1994), and Kim *et al.* (1996) did not report its occurrence at 31 stations of East Sea area from Daezin to Gijang and in Ulleungdo and Dockdo Island. Therefore, the distribution limits of *E. stolonifera* should be identified.

Laminarian algae produce larger amount of biomass than any other benthic marine algae (Mann 1973; Kain 1979). *E. stolonifera* is one of the laminarian algae.

Generally it is distributed in the warm water area, which is different from the location of the other members of Laminariaceae (Kang and Koh 1977; Park *et al.* 1994).

The population ecology of *E. stolonifera* has been reported by Notoya (1984, 1985, 1986, 1987) and Park *et al.* (1994). Compared with these studies, the blade length and width of the Tongyeong population were much longer and wider than the blade of the population investigated at Busan of Korea (Park *et al.* 1994) and Aomori of Japan (Notoya and Aruga 1990).

Total length and weight of *E. stolonifera* frond decreased after August possibly due to thallus shedding. The sporangial sori began to be formed in August when the thallus began to shed, and the maximal formation of the sporangial sori was found in September and October. After release of zoospores plants were rapidly disintegrated. Finally in December, only 16.0% of the total population had the sporangial sori.

Comparing with the reports that such formation was made in November (Notoya 1984) and in October-December (Park *et al.* 1994), plants in Tongyeong population formed the sporangial sori for the longer period than those of Busan and Aomori. On the other hand, the vegetative growth of plants in Tongyeong population mainly occurred from March to July and it was different from the reports by Park *et al.* (1994) from May to September and from February to July by Notoya (1984). Based on the frequency distribution of the blade length, stipe length and plant weight, small plants seemed abundant from September to February. It was speculated that young plants were newly recruited after shedding of thallus in this season (Notoya 1984).

Notoya and Aruga (1984) reported that the ratios of blade length to width and stipe length to diameter increased, as plants grew older. Park *et al.* (1994) reported that the correlation coefficient between stipe diameter and age was the highest among these parameters. Tongyeong population mostly consisted of the two years old plants and their stipe diameter was smaller than 6 mm. Notoya (1986) reported that the one and two years old plants accounted for 64.0%, whereas Park *et al.* (1994) reported 67.4%. They also reported that the plants above three years old formed zoosporangial sori and released zoospores developed into the new population. About 90% of Tongyeong population, however, consisted of the plants younger than two years old and the zoosporangial sori were observed mostly from the two-year old plants. Therefore, the population dynamics of *E. stolonifera* in Tongyeong was different from those of Busan and Aomori.

All these results indicated that individual plants of *E. stolonifera* population in Tonyeong are bigger and heavier than those of Busan and Aomori. Duration of the plants' sporangial sori formation was relatively longer, and the plant groups younger than two years old accounted for high proportion in the population age class distribution. Based on these factors, it is thought that Tongyeong population has its own unique physio-ecological characters. Generally, *E. stolonifera* population consists of the plants aged from one to six. Tongyeong population, however, consists of the plants aged under two, which indicates that it has the relatively shorter generation time.

It is speculated that the high proportion of young generation in Tongyeong population as seen above was related with the environmental factors of this area. There are numerous aqua-farms of fish and shellfish from which waste nutrients were discharged in large quantities. In addition yellow loess also has been intensively scattered around net pens for the red tide control in summer (Kim *et al.* 2000). These suspended solids including the wasted nutrients, yellow loess directly and/or indirectly affected the ecology of the neighboring benthic algal community. The introduced suspended solids increased the turbidity of the seawater, settled down to form the film on the plants' blade. It might also disturb the settlement of the algal spores on the substratum and smother other organisms in the sediment. Therefore, the plants of *E. stolonifera* population in Tongyeong might change its survival strategy to spend more energy for reproduction than vegetative growth to overcome the unusual environment of high nutrients and turbidity. So it was speculated that the age distribution of Tongyeong area was skewed to younger generation after all. Further long-term studies on the population structure and dynamics of other algal species are required to define differences of the effects of introduced factors from the normal variations in the natural populations.

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