Bull. Korean Fish. Soc. 27(4), 390~396, 1994

韓水誌, 27(4), 390~396, 1994

Age and Growth of *Ecklonia stolonifera* Okamura in Pusan Bay, Korea

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Age and growth of *Ecklonia stolonifera* Okamura were investigated by random quadrate sampling method at monthly intervals from February 1993 to January 1994 in Pusan Bay, southeastern coast of Korea. The size of various parts of the collected plants was periodically measured individually. An allometric relationship was established according to the total length, blade length, stipe length, stipe diameter and weight of frond. Each age group was divided according to the range of stipe length by the allometric relation.

The population of *E. stolonifera* consisted of five age groups; 1 year (41.5%), 2 years (25.9%), 3 years (21.1%), 4 years (7.8%) and 5 years (3.5%). During a year, biomass of the population increased drastically from May to September, but gradually decreased from October to January. Zoosporangial sori were observed on blades of three or more years old, from October to December. New populations were formed by zoospores, developed on shoots of three or more years old, and also they were vegetatively formed from stoloniferous haptera on two or more year old mother thalli.

Introduction

Ecklonia stolonifera Okamura is widely distributed along the eastern and southern coasts of Korea (Kang, 1966). This species usually grows in the subtidal zone, 2~10 *m* deep, along the coast. The species, which is one of the major primary producers in shallow water (Druehl *et al.*, 1977), plays an important role both ecologically in the coastal ecosystem and economically in the fisheries production. Therefore, considerable knowledge has been accumulated on its distribution, growth and population structures from an ecological point of view.

Recently, several studies on its ecology (Notoya, 1984, 1985, 1986, 1987; Notoya and Aruga, 1990), zoospore germination (Notoya and Asuke, 1983) and nuclear divisions (Yabu and Notoya, 1985) were reported. However, little attention has been paid to population dynamics. The study of population dynamics is of great importantance, not only for the ecological field but also for fisheries and commercial field in order to provide fundamental data for management and conservation of marine bioresources.

E. stolonifera is perennial algae, and its populations are maintained by alternating each age group. Therefore, it is necessary to establish the age structure, growth pattern and maturation period of *E. stolonifera* population.

The present study has been undertaken to determine the age structure of *E. stolonifera* populations, with seasonal fluctuation of growth, and ma-

turation period for twelve months. By analyzing these data, it could be revealed factors controlling recruitment of *E. stolonifera* populations.

Materials and Methods

The study site was located off Pusan Bay, southeastern coast of Korea (Fig. 1), where the sublittoral substratum consisted mainly of rocks suitable for kelp communities. *E. stolonifera, Sargassum horneri* and *S. ringgoldianum* were the major components of the sublittoral vegetation. *E. stolonifera* usually grew in water deeper than 2~8 *m*.

The samples were taken at monthly intervals from February 1993 to January 1994. Samples were collected by random quadrat (50×50 *cm*) at 2~8 *m* depths through scuba diving. It was assumed that more than 30 individuals were large enough to estimate the parameters in an unbiased manner (Elliott, 1977).

The sizes of various parts of the collected plants were measured for each type of plant and sampling period. An allometric relationship was established between the total length, blade length, stipe length, stipe diameter and weight of frond. Each age group was divided according to the range of stipe length by the allometric relation (Maegawa and Kida, 1984).

The formation of zoosporangial sori on the blade was checked for each population of plants of various sizes.

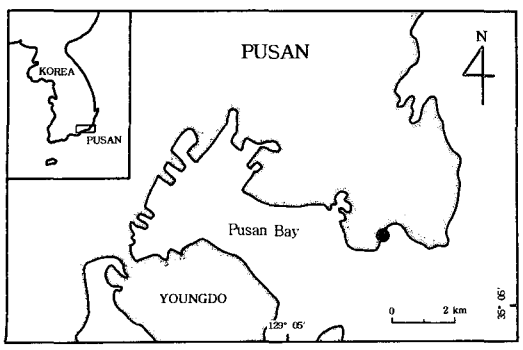

Fig 1. A map showing the sampling site in Pusan Bay, Korea.

Results

The *Ecklonia stolonifera* population was composed of fronds of various age groups. According to the range of stipe length by the allometric relation, each age group was divided into 1 to 5 years age groups (Fig. 2). The average stipe length of respective size group clearly corresponded to the stipe length of *E. stolonifera*, the age of which was determined from the stoloniferous rhizoid system (Notoya, 1986).

Numbers of samples and various parameters at different age groups of *E. stolonifera* are shown in Table 1. Distributions of the shoot age of *E. stolonifera* are shown as five age groups; 1 year (41.5%), 2 years (25.9%), 3 years (21.1%), 4 years (7.8%) and 5 years (3.5%). One-year old shoots showed the highest frequency. The average stipe length values from the five age groups were estimated at 2.5, 6.5, 11.3, 14.9 and 16.8 *cm*, respectively.

Frequency distribution of total length, blade length, stipe length and stipe diameter of *E. stolonifera* populations during the investigation period are shown in Fig. 3. The data indicafe that small size classes were recorded over the whole year. Figure 4 showed relationships between total length, blade length, stipe length and stipe diameter in *E. stolonifera* shoots to the age groups. This relationship between age (X) and growth (total length, blade length, stipe length and stipe diameter; Y) was expressed by the formula $Y=16.194X+6.24$($r=0.93$), $Y=13.712X+1.632$($r=0.95$), $Y=4.876X-0.902$($r=0.97$) and $Y=1.652X+0.194$($r=0.99$). Each parameter increased with the age of shoots.

During the investigation period, water temperature and biomass fluctuations are shown in Fig. 5. Water temperature increased until September, 19 93, and then decreased greatly in October, 1993. The variations of biomass showed dependency on the water temperature. The thalli number and biomass of the population showed a high peak from May to September and a low from October to January. The maximum biomass for *E. stolonifera* was recorded in September.

Formation of zoosporangial sori in *E. stolonifera* was observed on blades more than three years old, during from October to December (Fig. 6).

Discussion

In temperate waters, the most striking and highly productive members of the benthic flora are the laminarian algae (North, 1971; Mann, 1973; Kain, 1979). *Ecklonia stolonifera* was included in the warm-current species even though it belongs to the *Laminariales*. Dn the southeastern coast of Korea, *E. stolonifera* showed the same population pattern as has been reported in other Japanese localities (Notoya, 1984, 1985, 1986, 1987).

There were obvious regular patterns over most of the population parameters during the experimental period. The oldest *E. stoloifera* frond was revealed as six years old at the Tanosawa coast in Aomori Prefecture (Notoya, 1986). Meanwhile, Notoya and Aruga (1990) reported its life span was five years. In the present study, the age of the oldest frond was also five years (Fig. 2).

A characteristic feature of the size distribution was that the highest frequency of length was found in the smallest size class even during the resting season (Fig. 3). The higher frequency in the smaller size classed is probably due to the fact that the individuals recruited consistently during this season.

Werner and Caswell (1977) compared the performance of size-and age-based models for a population of teasel, in which they found that the size-based model was more accurate, even though the transition probabilities were derived from the same population. Obviously, the accuracy of age determination was reduced in the oldest plants but nevertheless, the method is much better than that using other morphological measurements, because diameter and length of stipe can be increased appreciably without formation of age rings for every year. That is, each parameter increased with the age of shoots. In the present study, the correlation between blade length and stipe (length and diameter) showed significant differences(Fig. 4). Stipe size was a good indication of age up to at least 6 years.

The thalli number and biomass of the population showed a high peak from May to September whereas there was a low from October to January (Fig. 5). The loss of biomass in winter was due to regeneration rates being unable to compensate for thallus maturation and loss of tissue. The loss of biomass due to the intrinsic death rate would be significant, because the death rate was concentrated

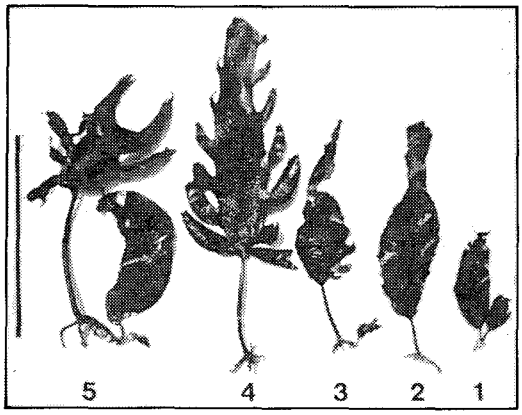

Fig 2. The morphology of age groups (1~5 years) in *Ecklonia stolonifera* in Pusan Bay, Korea. Scale bar is 30*cm*.

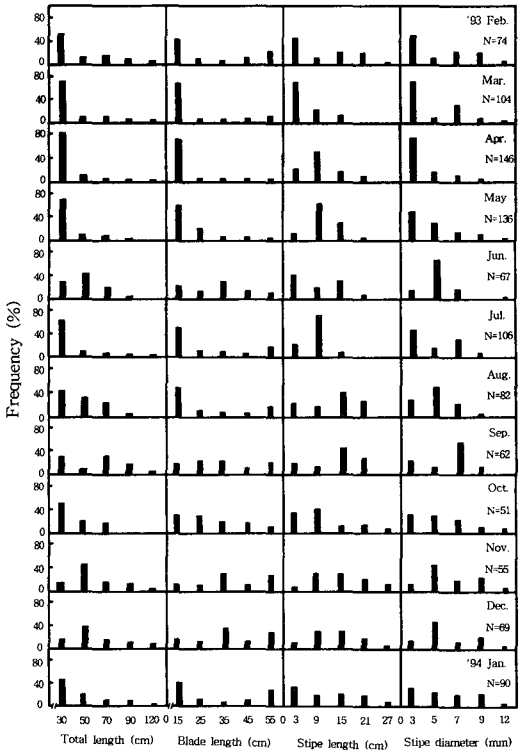

Fig 3. Frequency distribution for total length, blade length, stipe length and stipe diameter of *Ecklonia stolonifera* populations.

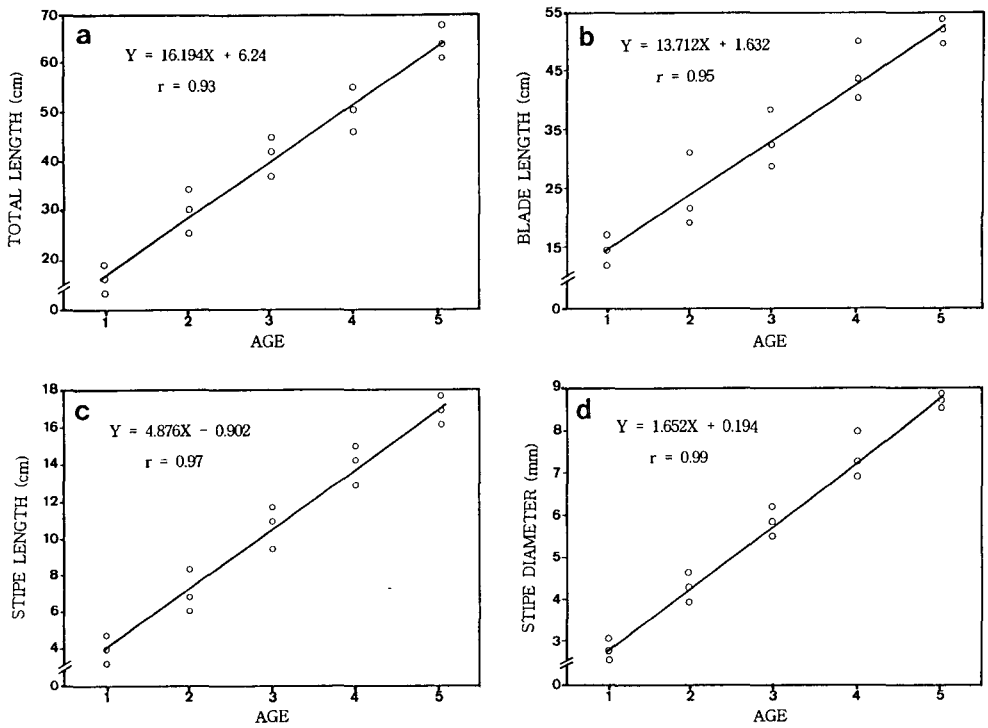

Fig 4. Relationships of parameters to the age of *Ecklonia stolonifera*. a, Relationships of total length to age; b, relationships of blade length to age; c, relationships of stipe length to age; d, relationships of stipe diameter to age.

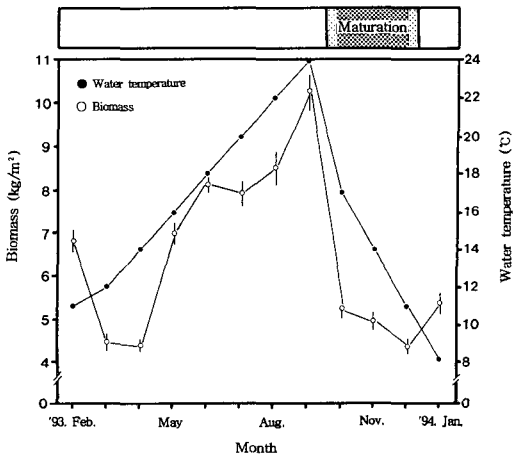

Fig 5. Maturation period, biomass fluctuations and water temperature during the investigation period measured at Pusan Bay, Korea.

largely on the small size classes by weight, if the mortality followed an exponential pattern. The growth occurred during the preceeding and warmer months, hence warmer water temperatures were probably not detrimental to adult *E. stolonifera* thalli. The lower water temperatures may have triggered the onset of fertility, with the resulting release of zoospores, gametophyte growth and a decline in the standing crop. The cool water temperatures was more favourable for gametophte growth and development, and also the observed life history indicated an adaptation taking advantage of these favourable conditions. In addition, Novaczek (1980) has suggested that the seasonal variations in growth rate of sporophyte of *E. radiata* in the field, although no doubt influenced also by nutrients, and water temperature and perhaps by endogenous rhythms, appeared to follow the variation in light.

The first sorus formation was observed on blades of three or more years old, in October 1993, as in the report of Notoya and Aruga (1990). This

Table 1. Number of samples and various parameters at different age groups in *Ecklonia stolonifera*

Parameters	Age group				
	1	2	3	4	5
Number of samples	270 (41.5%)	270 (25.9%)	220 (21.1%)	82 (7.8%)	37 (3.5%)
Blade length (*cm*)	8.7 ± 3.4	25.8 ± 10.2	41.6 ± 13.2	43.1 ± 11.3	47.3 ± 12.9
Stipe length (*cm*)	2.5 ± 0.9	6.5 ± 2.1	11.3 ± 3.1	14.9 ± 5.9	16.8 ± 8.7
Stipe diameter (*mm*)	2.1 ± 0.5	4.1 ± 1.2	6.1 ± 1.0	7.5 ± 2.5	8.9 ± 3.8
Frond weight (*g*)	2.5 ± 1.1	11.7 ± 3.2	35.7 ± 15.4	50.9 ± 20.1	69.5 ± 24.7

suggests that onset of reproduction was dependent upon plant age and size. In populations, the smallest reproductive plant had a stipe length of ca.10 *cm* and diameter of ca. 5 *mm*(Table 1). Our results are in good agreement with findings of Notoya and Aruga (1990). According to these authors, zoosporangial sori were observed on blades longer than 18 cm and broader than 7 *cm* in shoots more than three years old.

The data obtained by Iwahashi (1971) could be serve as an important parameter for indicating the survival rate of the natural *E. cava* bed. Survival rates, however, may fluctuate depending on the population densities and environmental conditions. In this report, four different mortality coefficients(0.4, 0.5, 0.7 and 0.9) were observed in estimating the stipe weight per recruit. In the estimation, each year class was assumed to recruit 1.75 year after the development of young sporophytes. These data indicate that the potential production of both stipe and blade reached its maximum in the second year class.

In this study, one-year-old shoots showed the highest frequency(41.5%). There was a high peak in numbers of plants in the smallest size class and a broad lower peak in the largest size calss, with relatively few plants of intermediate size. The presence of a maximum peak in the smallest size classes during the growing season suggested that there was a continuous recruitment. The highest frequency of weight which appeared in the smallest size classes from January to March reflected decayed individuals persistently remaining over the dormancy period(Koh *et al.*, 1993).

In the recruitment of *Ecklonia stolonifera*, there were two methods of multiplication. One was sexual reproduction by egg germination. That is, when *E. stolonifera* becames three or more years old, zoospores were formed. The zoospores served to form new populations through sexual propaga-

Fig 6. Formation of zoosporangial sori on blades of *Ecklonia stolonifera*. Arrow indicates the sori of dark part.

tion by gametophytes. Then in the field, plants comprised of a membranous acuminate blade 8~10 *mm* long supported by a stipe of 1 *mm* length and 0.5 *mm* diameter, attached by a basal pad surmounted by branching haptera. Meanwhile, the other new plants were formed by new shoots from perennial stolons and also grew by perennation from the stems of plants of more than two years old. When first visible in the field, the newest haptera, distinguished by their pale colour and smooth surface, separated, along with the attached portion of stipe, from older tissues. Both methods of multiplication by young sporophyte recruits appeared in winter and spring, respectively.

More data on the structure and the fluctuations in parameters of giant kelp (*E. stolonifera*) populations are needed for a more formal treatment of the subject.

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Received April 22, 1994
Accepted July 2, 1994

부산만 인근 해역 곰피 (*Ecklonia stolonifera* Okamura)의 생장과 연령조성

박찬선 · 황은경 · 이수정 · 노경환 · 손철현
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1993년 2월부터 1994년 1월 사이에 부산만 외양 용호동 일대에 분포하는 곰피 군락의 생장과 연령조성을 조사하였다. 채집된 엽체는 각 개체별 전장, 엽장, 경상부(Stipe)길이, 경상부 직경 및 체중을 측정하였다. 포복지에서 영양생장한 개체는 포복지의 생장 방향에 따라 연차적으로 출현하였다. 연령군과 체장, 경상부 길이, 경상부 직경 및 엽상부 길이와의 상관관계는 모두 높게 나타났고, 그중 경상부 직경과의 상관관계가 가장 높은 $Y=1.652\times0.194$ $r=0.99$ 였다. 조사지역내 곰피의 연령조성은 1년생 41.5%, 2년생 25.9%, 3년생 21.1%, 4년생 7.8% 및 5년생 3.5%로 나타났다. 각 연령군별 경상부 길이는 1년생 2.5 *cm*, 2년생 6.5 *cm*, 3년생 11.3 *cm*, 4년생 14.9 *cm* 및 5년생 16.8 *cm*으로 나타났다. 조사기간 동안 생체량 변동은 4월에 4.2 kg/m^2로 최소치를 보였으나 5월부터 증가하기 시작하여 9월에 10.5 kg/m^2으로 최고치를 나타내었으며, 10월에는 5.2 kg/m^2으로 다시 감소하였다. 자낭반의 형성은 3년생 이상의 엽체부터 관찰되었으며 성숙의 주성기는 10월부터 12월로 나타났다.