Annual Life Cycle and Productivity of the Brown Alga
*Sargassum yezoense*
off the Coast of the Oshika Peninsula, Japan

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Abstract: The annual life cycle and productivity of the brown alga *Sargassum yezoense* (Yamada) Yoshida et T. Konno (Sargassaceae, Fucales) were investigated in populations at Tomari-hama on the Oshika Peninsula from May 1997 to November 1998. The annual life cycle was characterized by the following three stages: 1) germination period during August to November, when the standing crop and length of main branches were at minimum and the main branches < 10 cm in length increased in number, 2) the growth period during October or December to June, when the standing crop increased due to elongation of the main branches, and the ratio of dry to wet weight decreased, 3) the reproductive maturation period occurred during June to August, when the larger-sized main branches (>10 cm) matured in sequence. The annual net production estimated by the stratified clip technique was 903.9 g/m². Since the productive structure of *S. yezoense* is similar to that of grass type, of which standing crop is much at lower strata of the thalli by sufficient light, it is suggested that this alga maintains its population by an immediate colonization of juveniles throughout the year into gaps formed after older thalli are lost.

Keywords: Annual life cycle; Growth; Maturation; Productivity; *Sargassum yezoense*

Introduction

The large, perennial brown alga *Sargassum yezoense* (Sargassaceae, Fucales) is found in the northern Pacific Ocean from the Oshika Peninsula in Miyagi Prefecture to Hokkaido and in the Sea of Japan from the Goto Islands to Hokkaido. The alga forms the dominant population in the subtidal zone at 0 to 2 m depth off the Pacific coast in Tohoku, and is considered to play an important role as a primary producer, just as the large brown alga *Eisenia bicyclis* does at depths >2 m where it forms the dominant population. The detailed ecological characteristics of *E. bicyclis*, such as age and growth, annual life cycle and productivity of individuals in each age group, annual net production of the population, mechanism of population maintenance, annual fluctuations and the succession leading to formation of the climax have been obtained. However, there have been no ecological studies on this species.

Populations dominated by the Fucales are called "Garamoba" in Japanese and play important ecological roles as habitats and breeding niches of many marine species including commercial valuable fish. Among these algae, the annual life cycle and net production of the large annual, *S. horneri*, and the large perennials, *S. patens*, *S. macrocarpum* and *S. confusum*, have been studied. Their productivities are much higher than those of tropical forests.

The aim of the present study was to elucidate the annual life cycle of *S. yezoense* and to estimate the annual net production of the population. In addition we also considered how the population is maintained.
Materials and Methods

Monthly or bimonthly investigations were carried out in beds of *Sargassum yezoense* at depths of 1 to 2 m in subtidal zones off the coast of Tomari-hama (38°14'N, 141°31'E) along the Oshika Peninsula from June 1997 to November 1998. Four 50×50-cm quadrats were placed randomly within the algal population and all individuals with a holdfast were collected using a knife. This alga sprouts many branches from the disk-like holdfasts, which cover the sea bottom and form lump-like perennial stipes. It is therefore impossible to identify any one individual in a dense *S. yezoense* population, so each main branch was measured and observed. The number, length and total wet weight of main branches collected in each quadrat were measured and the occurrence of receptacles was observed. In the case of main branches <10 cm long, their total wet weight was measured after counting. In this study no new main branches germinated from fertilized eggs nor perennial stipes were distinguished.

The basal parts of the main branches removed from the holdfasts and stipes in each quadrat were aligned and cut into 10-cm sections from the base to the top. Each part was then dried in a hot-air convection oven approximately at 90°C and the dry weight was recorded when it had reached a stable value. These data provides the vertical distribution of the standing crop involving the productive structures for calculation. And annual net production was calculated from the total amount of loss estimated by monthly or bimonthly changes in productive structures. This method is the ‘stratified clip’ technique, which is widely used for terrestrial herbaceous plants, resembles to the Fucales in forming thalli by apical growth and pneumatocysts. We followed Taniguchi and Yamada and Taniguchi and Yamada, who estimated annual net production of *S. horneri*, *S. patens* and *S. macrocarpum* using this method. Annual net production was also estimated by the method of Boysen-Jensen.

The surface water temperature of the sea was measured by the Miyagi Prefecture Fisheries Research and Development Center during the period of study; the average values for 1966-1995 were also obtained at Enoshima (38°24'N, 141°36'E) near the study site.

Results

Water temperature

The seasonal water temperature during this study was similar to the average during the period 1966-1995, apart from December, and the deviation from the average was about 1°C (Fig. 1).

Growth, density and maturation

Seasonal changes in the standing crop of the total dry weight of four 50×50 cm quadrats, the ratio of dry to wet weight as a indicator of thickening, average length of main branches of 200 individuals in sequence from the largest one and the density of main branches (number of individuals/m²) are shown in Fig. 2. The standing crop decreased from 1192.2 g/m² in June 1997 to 210.2 g/m² in November, then gradually increased and reached a maximum of 805.7 g/m² in June 1998, and again decreased to a minimum of 146.4 g/m² in September. The ratio of dry to wet weight remained at approximately 0.20, but rose to 0.29 in November 1997, when the stand-

![Fig. 1. Seasonal variations in surface water temperature in 1997 and 1998, and average values during the period 1966 and 1995 at Enoshima near the study site.](image-url)
Fig. 2. Seasonal changes in standing crop (solid lines A) and the ratio of dry to wet weight (dotted lines, A), average length and the standard deviations (vertical bars) of main branch (B), and density of main branches (C) of Sargassum yezoense. Average length of main branches was calculated by 200 individuals in order from the largest one.

Fig. 3. Seasonal changes in density of main branches of Sargassum yezoense at length intervals of 10 cm. Filled charts represent the main branches with receptacles.

The length of main branches changed seasonally corresponding to the standing crop, reaching a maximum of 64.7 cm in June 1997 and shortening to a minimum of 10.4 cm in November. After their gradual elongation until May 1998, the length was around 40 cm until August and shortened to a minimum in September. The density varied markedly in all seasons, ranging from 1,425 to 2,777 individuals/m². Peak values occurred in June and December 1997, April 1998 and August 1998. The seasonal pattern of changes in density also differed among the population in 1997 and 1998.

To examine seasonal changes in the length of the main branch in detail, seasonal changes in the number of main branches divided at 10-cm intervals and the occurrence of receptacles is shown in Fig. 3. Main branches with all size classes from <10 to >40 cm long occurred from July to August 1997. The main branches <10 cm long decreased in August and attained a maximum of 2,377 individuals in November. The number then decreased sharply to 911 individuals in January 1998 and increased to 1,082 individuals in April, but had decreased to 812 individuals by May. They then gradually increased to 1,609 in August and 1,666 in September. Thus germination was from late summer to autumn when the water temperature rose to a maximum and then declined. A small peak was associated with the occurrence of germination in spring. The main branches 10-20 cm long decreased sharply to 5 in November, then increased from December and attained a maximum of 617 individuals in March 1998 corresponding to decrease in the branches <10 cm. The number decreased to 269 individuals in June and again increased to 400 individuals on August. The branches >20 cm disappeared in November. Those 20-30 cm long increased later than those 10-20 cm long and reached a maximum of 527 individuals in August 1998. The branches 30-40 cm long increased from March to May 1998 much later than those 20-30 cm long, while decreasing slightly in June and August. Branches over 40 cm long were found again in April 1998 and had slightly increased by August. The number of <
10 cm long branches decreased from September to November, whereas those 10-20 cm long increased. This successive changes in each length of main branched shows that the growth period was during October or November to June and also in summer. Maturation was found in June and August 1997 and 1998 in the main branches greater than 10 cm long, being more pronounced in the longer branches, and in August than in June. Therefore, maturation occurred in June to August, when the water temperature rose to a maximum. The main branches had already started to die-back during maturation and were renewed in autumn, when the water temperature fell.

Productive structure
Seasonal changes in the productive structure of the *S. yezoense* population are shown in Fig. 4. The standing crop was higher in the lower strata than in the upper strata. In November 1997, there were only branches less than 10 cm long, due to the disappearance of longer ones. There was then a gradual formation of the upper strata and an increase in the standing crop of both strata until June 1998. There were losses of 27 g, 31.7 g and 3.6 g from the lowest stratum (< 10 cm) during December 1997 to January 1998, April to May, and May to June, respectively. There was also a loss of 434.9 g from the strata >10 cm during June to August 1998. The standing crop of the main branches remaining in September was 146.4 g. The total loss during one year from November 1977 was 757.5 g/m². This duration between both minimum standing crop represents an annual life cycle. The annual net production was 903.9 g/m², thus adding 146.4 g/m² to the standing crop in September.

Discussion

Annual life cycle
The annual life cycle of *S. yezoense* was characterized by the three stages, germination, growth and reproductive maturation from the seasonal changes in biomass, length and density of main branches (Fig. 2), and their density at length intervals of 10 cm (Fig. 3). The germination, growth and reproductive maturation period of *S. yezoense* were during August to November, October or December to June, and June to August, respectively. The maturation period in Oshoro Bay, Hokkaido is during middle July to middle August the same as that in this study20). Similarly, *S. confusum*17), *S. patens*15), *S. macrocarpum*15) and *S. horneri*14) mature during late spring to summer and elongate during winter to spring as found in *S. yezoense*.

Annual net production
The standing crop of the *S. yezoense* population decreased to a minimum in November after the old main branches had died-back in summer 1997 (Fig. 2A) and main branches 10 < cm long dominated the great part of the population (Fig. 3). Then, the standing crop increased, corresponding to elongation of the main branches and reached a maximum of 805.7 g/m² in June and again decreased in September due to their die-back (Figs. 2A, 3). Therefore, the annual cycle of
the *S. yezoense* population off the coast of Tomarihama was determined during the period from November 1997 to September 1998 and annual net production was estimated to be 903.9 g/m². Using the method of Boysen-Jensen\(^1\), production was estimated to 893.9 g/m², which was based on the total loss of 88.2 g/m² until June and the seasonal maximum standing crop of 805.7 g/m² in June. This value approximates that estimated by the stratified clip technique.

Values for the annual net production in wet weight of the large annual alga *Sargassum horneri* (Fucales)\(^1\) and the large perennial alga *Eisenia bicyclis* (Laminariales)\(^7\) convert to about 4.3 kg/m² and 4.0 kg/m² dry weight, respectively, based on a dry to wet ratio of 0.2\(^{15}\). Values for the dry weight of the large perennial algae *S. patens*, *S. macrocarpum*\(^15\), *S. confusum*\(^17\) and *Laminaria angustata*\(^21\) are about 5.5 kg/m², 8.2 kg/m², 0.95 kg/m² and 1.3 kg/m², respectively. Annual net production of *S. yezoense* was less than that of these five larger species. The ratio of annual net production to seasonal maximum standing crop of *S. yezoense* was 1.1, which is the same as the value of 1.1 for *S. horneri*\(^1\) and *S. confusum*\(^17\), 1.4 for *S. patens*\(^20\) and 1.2 or 1.4 for *S. macrocarpum*\(^5,16\).

**Mechanism of population maintenance**

The productive structure of *S. yezoense*, which is similar to that of grasses\(^18\), showed the highest standing crop in the lowest stratum, with decreasing values towards the upper stratum throughout the year (Fig. 4). It is possible that sufficient sunlight reaches a low strata of thallus. Accordingly, it is considered that the juveniles immediately colonize to the gaps where older thalli are lost throughout the year as found in grass type. In the low stratum of the *S. yezoense* population there were more than 800 individuals/m² of main branches < 10 cm long at all seasons (Fig. 3). This shows that new plants colonized throughout the year and utilized any gap in the upper stratum. It has been already reported that populations of *Eisenia bicyclis*\(^5,10\) and *Ecklonia cava*\(^22\) are maintained by gap regeneration similar to a terrestrial forest. While the germination period of *E. bicyclis* and *E. cava* is fixed seasonally, it is considered that *S. yezoense* regenerates its population by main branches < 10 cm long growing throughout the year. Therefore, this alga shows a productive structure similar to terrestrial grasses and maintains its population by gap regeneration responding to a lack of upper stratum, as new main branches were found in April 1997 (Fig. 3)

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**References**

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宮城県牡鹿半島沿岸における褐藻エゾノネジモクの
生活年周期と生産力

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1997年6月から1998年11月に、宮城県牡鹿半島泊浜沿岸潮下帯の褐藻エゾノネジモク群落の生活年周期と生産力を調べた。生活年周期は、8月から11月かけて、枯死脱落にともない現存量と主枝長が年間最低となるのに対して、10 cm 未満の主枝が増加する発芽期、10月より12月から6月にかけて、現存量の上昇と主枝の伸長ならびに乾重量/湿重量の比が低下する伸長期、そして、6月から8月にかけて、10 cm 以上の主枝で長い順から集中的に成熟する成熟期の3期に分けられた。年間総生産量は層別刈り取り法によって903.9 g/m²と推定された。エゾノネジモク群落は、光の到達によって下層の現存量が大きいイネ科草本型生産構造を示すので、上層の欠如に対し、季節を問わず発芽して速やかにギャップを埋めて群落を維持すると考えられた。