コンブのバイオマス生産における収量の把握と栽培条件の評価

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Productivity Estimation and Evaluation of the Cultivation Factors in Biomass Production of *Laminaria*

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Abstract : Effect of spacing of culture ropes and cultivation density on the growth of blades and on the yield in *Laminaria diabolica* Miyabe was studied off Rausu, Hokkido from December 1983 to August 1984. Length, width and weight of blades from wide spacing of ropes showed higher values than those from close spacing. The largest yield was obtained with density ca. 90 plants/m and ca. 155 plants/m at 1m and 3m culture rope intervals respectively. The maximum yield in one year old *Laminaria diabolica* was ca. 18 kg/m and 24 kg/m for 1m and 3m culture rope intervals, respectively. Effects of intermittent harvesting on the total yield were studied. Data were obtained by culturing blade cuttings off at 50, 30 and 10 cm distance from the base of blade in spring. The total harvest of plants cut off at less than 30 cm from the blade base showed lower value than those of uncut plants. Such cutting treatment is not acceptable for biomass production in *Laminaria diabolica.*

Introduction

The Ministry of Agriculture, Forestry and Fisheries of the Japan National Government has begun to encourage technical inovation in utilization of the continuously renewable, large scale biomass from land and the sea. This program is called the "Biomass Conversion Project (BCP)". Large brown algae were selected as a source of marine biomass in the project. Large algae such as *Larinaria* and *Undaria* are cultivated and used mainly for human food in Japan, but in the future they must be utilized as materials for many purposes[1~3].

Cultivation of algae in the sea is attractive because of the large amount of available space that offers excellent potential for the production of vast quantities of renewable biomass. As the first step of the research program for algal production, experiment was designed to make accurate productivity estimation and to evaluate limiting factors in mass cultivation of *Laminaria*.

Materials and Methods

For this experiment, mature plants of *Laminaria diabolica* Miyabe were collected from wild populations at Rausu, Nemuro Prov., Hokkaido in September 1983. Juvenile plants used in this experiment were prepared in the laboratory by the same methods described fully in the prior paper[4]. When juvenile plants raised on the culture strings reached 5−10 mm lengths in October 1983, they were outplanted to the cultivation apparatus (20m × 50m) off Rausu for the field experiments.

The seedling string was fixed along a 3m culture rope (hereafter called 0 cm interval), or the string was cut into 3 cm segments that were inserted at 10 and 30 cm intervals along a 3m culture rope. By this method, plant clusters were grown at settled intervals. Culture ropes with seedling

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strings were tied at 1m or 3m intervals so as to hang down from the main horizontal ropes. The method of outplanting was the same as that described in the above cited paper[4].

From October 1983 to March 1984 the main horizontal ropes were adjusted at a depth 10m below the sea surface in order to avoid the problem of sea-ice. During the remainder of the growing season the ropes were adjusted to float at a depth 1−2m below the sea surface.

Effects of the spacing (in another words intraspecific competition) on the blade characteristics and on the yield were determined comparing the mean values of blade characteristics and the average amount of plant produced per unit length of culture rope. The data for effect of spring hervest on the yield were obtained by the cultivation of the blade after it was cut off at 50, 30 and 10 cm distance from the base of blade in May 1984.

Results

1. Effects of cultivation spacing on the growth of *Laminaria*

The mean values of blade characteristics together with their 95% confidence limit, in different cultivation spacing of ropes and clusters are given in Table 1 and 2. The length, width, blade form and weight of blade from wide spacing within culture rope showed higher values than those from close spacing within culture rope in both May and August. And the mean plant weight declined rectilinearly by increasing total number of plants per unit length of culture rope (Fig. 1 & 2).

These data indicate that the growth of the plants decreased with decreasing spacing along the culture ropes and increasing the plant density on the culture rope. And the mean values of blade characteristics such as length, width and weight cultivated on the 3m intervals ropes always showed higher values than those cultivated on the 1m intervals rope (Table 1 & 2). This indicate that spacing between culture ropes also has effects to the growth of plants. Effects of density on the blade characteristics grown until August was slightly greater than those grown until May (cf. Fig. 1 & 2).

2. Effects of cultivation density on the yield of *Laminaria*

For the convenience, the total plant weight per unit length of culture ropes was used as unit for the"yield". In this paper, the yields were calculated from the average plant weight and the total number of plants grown on the unit length of the culture rope presented in Fig. 3. Against the same density, yield showed higher values in the plants cultivated on the rope settled at 3m intervals than those cultivated on the rope settled at 1m intervals.

The yield increased with increasing density. The largest yield was obtained with the density ca. 90 plants/m and ca. 155 plants/m at 1m and 3m culture rope intervals, respectively. Beyond which further increase in density resulted in decreased yield (Fig. 3). The maximum yield was estimated to 17.58 kg/m and 23.95 kg/m for 1m and 3m culture rope intervals, respectively. However increased rope spacing means decreasing the yield per unit length of culture with accompaning risk of decreases in yield per unit area of culture apparatus.

3. Effect of cutting off on the growth of blade and yield of *Laminaria*

Laminaria blade increase in length is by intercalary growth. This means that the basal part is the most important feature of *Laminaria* blade for future growth. As a result, when the distal part of blade is cut off, the basal part of blade will continue to grow normally.

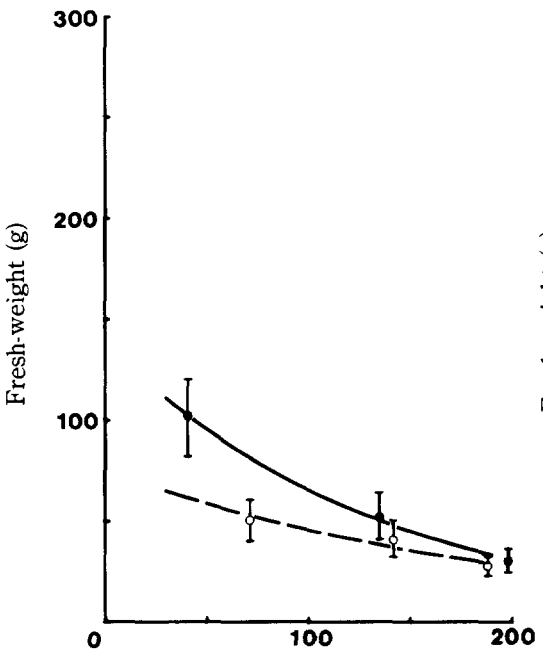

Fig. 1. Fresh- weight of *Laminaria diabolica* in relation to the density on the rope cultivated from Dec. 1983 to May 1984. Vertical bars shows ± 95 % confidence of mean values plotted. The equation of regression is *ln* W = -0.0057 D + 4.3295 for the plants cultivated on the rope at 1m intervals (bottom curve), and *ln* W = -0.0075 D + 4.9360 for those at 3m intervals (upper curve). Data from Table 1.

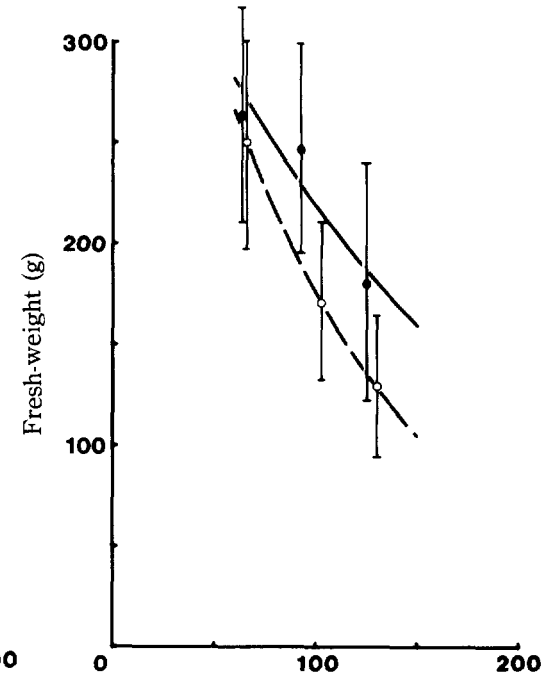

Fig. 2. Fresh-weight of *Laminaria diabolica* in relation to the density on the rope cultivated from Dec. 1983 to Aug. 1984. Vertical bars shows ± 95 % confidence limit of mean values plotted. The equation of regression is *ln* W = -0.0137 D + 6.2056 for the plants cultivated on the rope at 1m intervals (bottom curve), and *ln* W = -0.0063 D + 6.0226 for those at 3m intervals (upper curve). Data from Table 2.

Table 1. Mean and 95% confidence limit of the blade characteristic of *Laminaria diabolica* cultivated from Dec. 1983 to May 1984 off Rausu, Nemuro Prov., Hokkaido.

Spacing ropes	Spacing clusters	N	Blade length (L) (cm)	Blade width (W) (cm)	Blade from (L/W)	Blade weight (g)
1m	0cm	57	95.27± 8.74	6.94± 0.68	13.97± 0.80	27.64± 6.94
1m	10cm	47	96.58±10.15	9.10± 0.94	10.80± 0.60	40.97± 9.04
1m	30cm	85	110.04± 9.16	10.30± 0.81	10.80± 0.41	50.07± 8.98
3m	0cm	60	87.01± 8.82	7.66± 0.72	11.52± 0.57	30.66± 7.71
3m	10cm	57	102.77±11.23	11.04± 2.11	10.27± 0.34	52.64±12.36
3m	30cm	46	143.28±16.41	13.96± 1.40	10.22± 0.55	101.00±20.76

Table 2. Mean and 95% confidence limit of the blade characteristic of *Laminaria diabolica* cultivated from Dec. 1983 to Aug. 1984 off Rausu, Nemuro Prov., Hokkaido.

Spacing ropes	Spacing clusters	N	Blade length (L) (cm)	Blade width (W) (cm)	Blade from (L/W)	Blade weight (g)
1m	0cm	26	93.76±12.84	16.31± 2.30	5.99± 0.55	128.46±36.59
1m	10cm	31	101.20±11.28	20.13± 2.52	5.19± 0.34	171.00±40.48
1m	30cm	20	130.77±14.64	20.88± 2.45	6.37± 0.67	249.50±24.25
3m	0cm	25	117.62±17.22	16.67± 2.37	7.11± 0.40	180.32±60.33
3m	10cm	28	124.23±16.22	21.36± 2.36	5.88± 0.41	246.96±52.52
3m	30cm	39	138.12±14.30	23.66± 2.45	5.95± 0.29	263.46±54.50

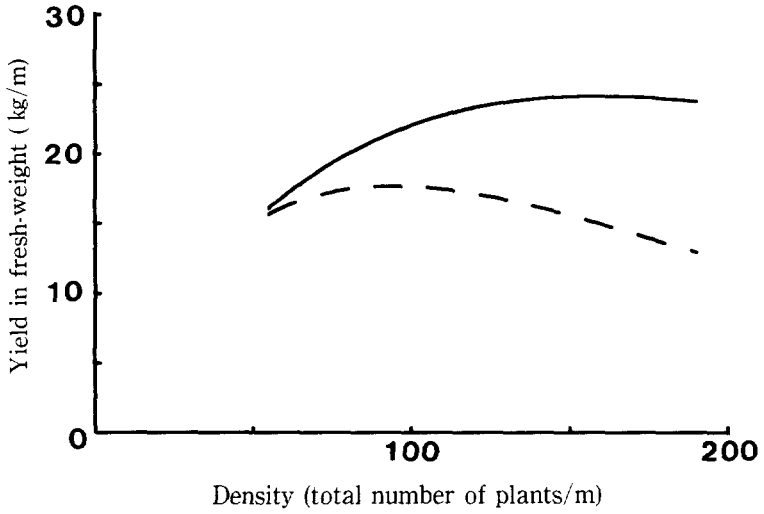

Fig. 3. Simulated relationship between the yield and density in August 1984. Computation based on the data shown in Fig. 2. Bottom curve : 1m intervals. Upper cerve : 3m intervals.

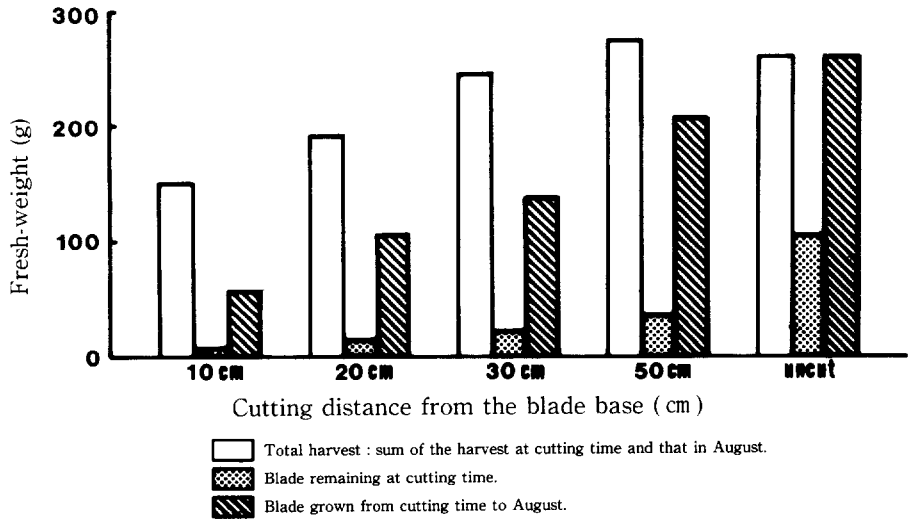

Fig.4. Effect of cutting distance from the blade base on the harvest in *Larinaria diabolica* cultivated off Rausu, Hokkaido from May (cutting time) to Aug. 1984.

In this experiment cuttings were made in May when blades had attained almost the maximum length and deterioration of distal portion of the blades had become noticeable. At cutting time the average harvest per plant was 65.8g, 81.0g, 86.9g, 94.0g and 0g for the plants trimmed off at 50 cm, 30 cm, 20 cm and 10 cm from blade base and uncut plants, respectively.

During more than 100 days in the growing period from May to August the blade weight increased. Average blade weight at the final harvest time of the first year in August was 223.2g, 141.1g, 105.6g, 58.4g and 263.4g for the plants trimmed at 50 cm, 30 cm, 20 cm and 10 cm from blade base and uncut plants, respectively. This means that total realistic harvest per plant was 289.0g, 222.1g, 192.5g, 152.4g and 263.4g for the plants trimmed off at 50 cm, 30 cm, 20 cm and 10 cm from blade base and uncut, respectively (Fig. 4). Total harvest of uncut plants showed higher value than the trimmed plants except the plants trimmed off at 50 cm from the blade base. And the plants trimmed off at 50 cm from the blade base did not show remarkably higher value compared to the uncut plant.

Discussion

From the literature, the yield in total fresh weight of plants produced on the unit length of culture ropes can be 3.6 kg/m to 166.2 kg/m[5] in laminariaceous plants. The high yields, were from *Laminaria japonica* grown on the isolated vertical culture rope[5]. The variation in the yield was caused mainly by the cultivation conditions and species selected for cultivation[5].

In this experiment, it was demonstrated that the total number of plants per unit length of the culture rope and spacing between culture ropes were the key factors controlling difference in certain characteristics of blade in *Laminaria diabolica*. Plant size decreased with an increase in plant density. Thus, yield was substantially affected by changes in the cultivation density. The largest yield was obtained with a density of ca. 90 plants/m and ca. 155 plants/m at 1m and 3m intervals of culture ropes, respectively. The maximum yield was estimated at 17.58 kg/m and 23.95 kg/m for

1m and 3m intervals, respectively. With further increase in density there was a decrease in yield.

In laminariaceous plants, blade length increase takes place by intercalary growth[6]. This means that the basal part is most important for growth, while the upper part contributes to the absorption of nutrients and photosynthesis. As a result, when the blade is trimmed off at less than a certain distasce from the blade base, the amount of elongation will decrease. The cutting effects studied indicate that trimming off remaining less than 30 cm from the base of blade has severe effects for the growth and the total harvest. We conclude that the cutting treatment in spring is not acceptable at least for biomass production by *Laminaria diabolica*.

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