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A Transplanting Method of *Laminaria japonica* Areschoug (Laminariales, Phaeophyta)

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To obtain basic data, we investigated the effect of blade length on transplants, the transplanting method of *Laminaria japonica* for creating *L. japonica* resources and the number of transplanting plates with surviving *L. japonica*. The survival rate of *L. japonica*, blade length of transplants and drag force of transplanting plates were also researched. The number of transplanting plates with surviving *L. japonica*, the survival rate and blade length of 20 cm long-initial transplants were greater than those of 1.5, 5 and 10 cm long-initial transplants in an outdoor aquarium. At the depth of 4 m in the coastal waters, the number of transplanting plates with surviving transplants, the survival rate and the blade length of 30 cm long-initial transplants were higher than those of 10 and 20 cm long-initial transplants. The drag force is calculated by cording up sporophytes of *L. japonica* into the transplanting plates under water. The drag force in the case of a 2.18 kg-weight transplanting plate and in a current speed of 0.5 $m \cdot s^{-1}$ for considering stability of the plate was 631.50 g to a concrete substratum on the seabed, 703.92 g to a shingle substratum, 788.00 g to a sand substratum, and 1018.30 g to a silt substratum. If we consider the stability and economic efficiency of the transplanting plate, the proper weight of the plate per one individual of 18.11 cm in blade width and 190.20 cm in total blade length is regarded as 508.2 g when it is calculated with the concrete substratum that shows the lowest drag force.

Key Words: drag force, *Laminaria japonica*, substrata, transplanting plate

INTRODUCTION

Macrophytes including seaweeds have been not only played an important role in the cycle of matter as the primary producers in the coastal ecosystem but also maintain primary productivity as high as those in tropical rain forests. Furthermore, they are utilized as feed for grazing animals and as spawning beds for aquatic animals. The biomass of macrophytes is about 10-50 $kg \cdot m^{-2}$, which is two to ten thousands times as much as about 0.5 $g \cdot m^{-2}$ of the biomass of phytoplankton, contributing to arresting the outbreak of the red tides (Sakai 1998).

The biomass of algae along the Korean coastal province is on the decrease due to environment change, algal feeders’ grazing, overexploitation, and marine pollution by domestic sewage and industrial wastewater, *etc*. The East Coast and Jeju-Do in Korea have been denuded due to sporadic algal whitening, thus giving rise to a decrease in fisheries resources, such as useful fishes and marine invertebrates, and also to the perishment of other marine resources. As a result, the coastal ecosystem stands on the brink of serious change (Chung *et al*. 1998).

Therefore, artificial fish reefs have been continuously installed since 1971 as part of a formation of submerged underwater vegetation. However, it will take more than three years before artificial fish reefs placed in the marine environment function well as submarine forests, because muddy sediment and barnacles attached to the surface of artificial fish reefs prevent algae from attaching onto the reefs. For example, throwing the reefs into the East Coast water near Oiyeon-do Isl. and offshore Suyu-do Isl. along the South Coast of Korea was inefficient because light transmission into the seawater decreased due to high concentrations of suspended substances and muddy sediments made algal attachment impossible. So, the function of the reefs as seaweed beds has not yet been realized (Ministry of Maritime Affairs and Fisheries

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2000). Effects of the environmental improvement method such as rock blasting, stone casting, artificial fish reef throwing and concrete application for formation of submerged underwater forests also are weak (Ha *et al.* 1998, 1999).

In Japan, the mixed use of an environmental improvement and a seed and seedling transplanting method maximized the formation of kelp forests (Taniguch 1998). Transplanting methods of seeds and seedlings, such as the sinking establishment fixing method, lower hanging method, and reverse blind method, have demerits, such as in increase of the relative difficulty of work and cost due to works in the sea.

Thus, this study was performed to obtain the baseline data on the high survival rate of transplanted *Laminaria japonica* and to improve the algal transplanting method.

MATERIALS AND METHODS

The seeding of *Laminaria japonica* was done for 20-30 minutes in September 2001, and the seedlings were cultured in an indoor aquarium until December 20, 2001 in Wando, Korea. Seeding lines were cultivated in the open sea until January 13, 2002. The sporelings were cultured to grow to 1-30 cm long in an aquarium (7 × 1.2 × 0.8 m) at the Aquaculture Research Center, Yosu National University, Korea. The seeded strings with attached sporelings (1.0-1.5 cm long) cut into 30 cm long were inserted into main ropes (Φ8). The culture condition was 43-47 $l \cdot \mathrm{min}^{-1}$ for water exchange rate, 15,000-25,000 lux at noon and 5 $l \cdot \mathrm{min}^{-1}$ of air flow rate for mixing.

A transplanting plate was manufactured by sand and cement (mixing ratio 3:1, 22W × 22L × 3H cm, 2.18 kg) and bored with three holes before drying up. After drying up, two main ropes were inserted into two holes of the plate and one rope for withdrawal was inserted in one hole. Main ropes were more than 15 cm long, and were tied by a float to always look up.

Blades (1.5, 5.0, 10.0 and 20.0 cm long) of *Laminaria japonica* were transplanted on January 14, 2002. Four seeded strings cut into 3 cm long per one transplanting plate were transplanted, and fifteen plates were thrown into an outdoor aquarium (6 × 6 × 2 m) at random.

Groups of twenty transplanting plates with transplanted blades of 10, 20 and 30 cm long were thrown randomly into the coastal water of Geumbong, Dolsan, Yosu city at the depth of 4 m on February 16, 2002. Each experiment was repeated two times.

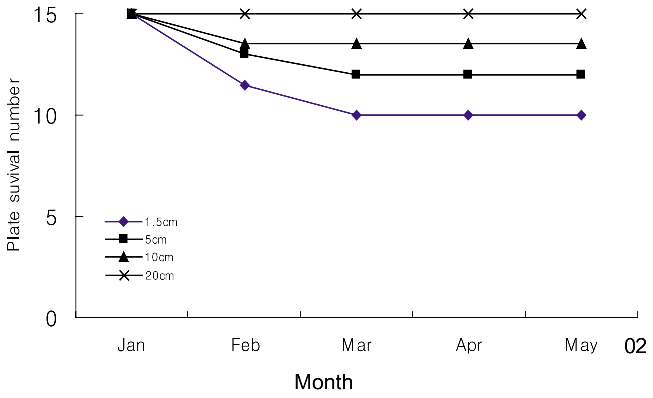

Fig. 1. The number of transplanting plates with surviving *Laminaria japonica* in the outdoor aquarium. Numerals and marks express the blade length of transplants.

The investigation was done once a month for the outdoor aquarium experiments, and on May 6, 2002 the sea experiment was finished due to the difficulty of rethrowing plates. The survival rate was calculated by dividing surviving individuals into total transplanted individuals after confirming the transplant's survival among transplanting plates threw into the outdoor aquarium (total 60 plates) and sea (total 60 plates). The total length and density of 1.5 cm long blades of transplants were observed by a universal projector and more than 5 cm long measured by a ruler. To prevent plate movement, drag force was calculated. The experiment was performed in 10 m long waterways with concrete, shingle, sand and silt substratum. The number of *L. japonica* blades on the plate that were not moved under the condition of 2.18 kg of the plate and 0.5 $\mathrm{m \cdot s^{-1}}$ of current speed was confirmed. In additon, total drag force of substratum was estimated as the value of multiplying the number of blades on the not-moved plate by mean drag force of each blade. Drag force to blades of *L. joponica* was measured by a spring balance. Because unknown drag force can move the plate, the factor of safety was multiplied as a countermeasure to an unknown drag force (Nakamura 1987).

Here,

$$S_F = \frac{W_\mu (1 - w_o / \sigma_G)}{F_o} \qquad (1)$$

where S_F is the factor of safety, W is the weight in air, is the coefficient of friction (μ between concretes = 0.75-0.95), w_o is the unit volume weight of water, σ_G is the unit volume weight of the transplanting plate, and F_o is the maximum drag force of fluid. To calculate the

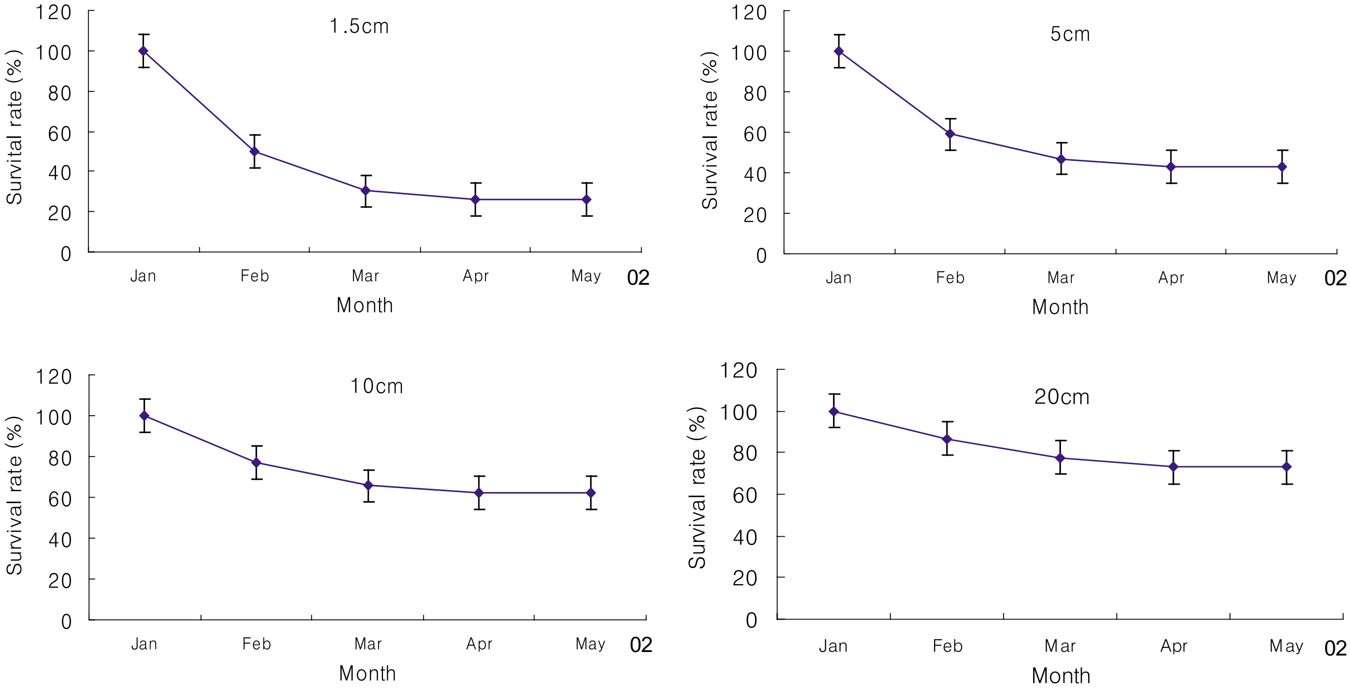

Fig. 2. The survival rate of *Laminaria japonica* after transplanting in the outdoor aquarium. Numerals express the initial blade length of transplants.

maximum static friction force of the plate and compare actual value with theoretical value, the weight was calculated as a value of weight in air minus buoyant force value. Buoyant force is equal to the weight of that body of fluid (i.e. water) which the submerged body displaces. Here,

$$B = \omega V \tag{2}$$

where B is the buoyant force, ω is the unit volume weight of water, and V is the unit volume of water. The value was confirmed as substitute weight in water obtained from the above formula for maximum static friction force. Here,

$$F = \mu W \tag{3}$$

where F is the maximum static friction force, μ is the maximum friction coefficient, and W is the weight.

RESULTS

The number of transplanting plates with surviving *Laminaria japonica* was 10 plates with 1.5 cm long blades, 12.5 plates with 5 cm long blades, 13.5 plates with 10 cm long blades, and 20 plates with 20 cm long blades after a 76-day culture in the outdoor aquarium (Fig. 1). Fig. 2 shows that long transplanting blades have a higher survival rate than short blades in blade by blade length in the growth process after transplanting. The survival rate to 111 days after transplantation and attached density per seeded strings were 26.04 ± 1.18% (5 individuals on average) and 19.2 individuals to 1.5 cm long blades of transplants, 43.12 ± 1.46% (mean 7.46 individuals) and 17.3 individuals to 5 cm long, 62.42 ± 1.57% (mean 10.01 plants) and 16.02 plants to 10 cm long, and 73.07 ± 1.91% (mean 11.40 plants) and 15.6 plants to 20 cm long. Fig. 3 shows that the growth by blade length are not distinctly different in spite of the difference in blade length of transplants. The blade length of

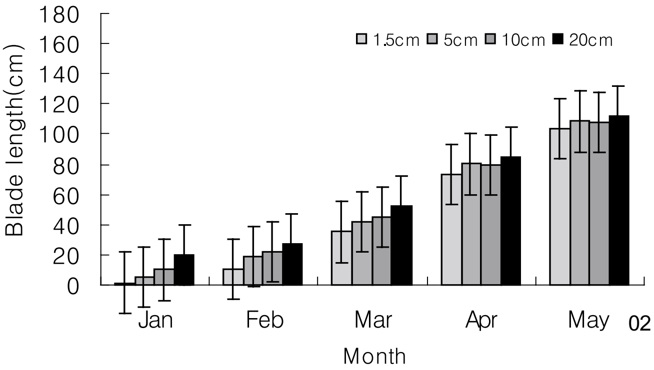

Fig. 3. The growth of *Laminaria japonica* after transplanting in the outdoor aquarium. Numerals express the initial blade length of transplants.

Table 1. The number of transplanting plates with surviving *Laminaria japonica* in the sea

BLT[1] (cm)	No. of plates	Depth (m)	No. of attached blades (mean)	SPN[2]	Survival rate(%)	TL[3] (cm)
10	20	4	15.25	11	32.78 ± 5.37	115.91
20	20	4	14.01	13	46.39 ± 6.13	125.46
30	20	4	12.06	17	67.57 ± 8.08	138.11

[1] Blade length of transplant
[2] Survival plate number
[3] Total length

Table 2. Drag force calculated by cording up sprophytes of *Laminaria japonica* onto the transplanting plates under water

Material	Plate weight (g)	Velocity $(m \cdot s^{-1})$	Blade length (cm)	Blade width (cm)	Blade weight (g)	Drag force (g)	Blade number	Total drag force (g)
Concrete	2.18	0.5	190.20	18.11	281.00	105.25	6	631.50
Shingle	2.18	0.5	180.14	17.84	201.90	100.56	7	703.92
Sand	2.18	0.5	176.75	17.55	221.00	98.50	8	788.00
Silt	2.18	0.5	176.20	17.54	206.83	101.83	10	1018.30

transplants was 103.56 ± 34.5 cm to 1.5 cm long, 104.66 ± 38.6 cm to 5 cm long, 107.60 ± 40.4 cm to 10 cm long, and 111.33 ± 42.5 cm to 20 cm long after 111 days of transplanting.

Table 1 shows the number of transplanting plates with surviving *L. japonica*, the survival rate and growth by blade length at the depth of 4 m in the coastal waters. The number of plates was 11 to 10 cm long, 13 to 20 cm long, and 17 to 30 cm long. The survival rate of blades was 32.78 ± 5.37 % (5.0 survivals among 15.25 transplants) for 10 cm long, 46.39 ± 6.13% (6.5 among 14.01) for 20 cm long, and 67.57 ± 8.08% (8.15 among 12.06) for 30 cm long. The blade length of transplants was 115.91 ± 17.80 cm for 10 cm long, 125.46 ± 16.65 cm long, and 138.11 ± 14.73 cm long.

Table 2 shows that the drag force calculated by cording up sporophytes of *L. japonica* onto the transplanting plates under water. The drag force for a 2.18 kg-weight transplanting plate in a 0.5 $m \cdot s^{-1}$ current speed was 631.50 g to a concrete substratum, 703.92 g to a shingle substratum, 788.00 g to a sand substratum, and 1018.30 g to a silt substratum.

DISCUSSION

The number of transplanting plates with surviving blades of *Laminaria japonica*, survival rate of blade, growth of blade, and the drag force of transplanting plates through the outdoor aquarium and the coastal waters experiments were investigated in this study. Schmitt and Ehrhardt (1987) reported that growth of algae was different by genetic difference, time at recruitment, and the difference of microenvironment. Kang(1999) reported that the mortality of *L. japonica* transplants was characterized by individuals of 30 cm and below of blade length. Black(1974) reported that density dependent factors did not occur from growing algae for three months. Nakahisa(1981) reported that the survival rate in artificial fish reefs for the formation of seaweed beds to prevent damage by algae feeders was two times as high as the control. Moreover, the survival rate was 30-50% after six months of seeded string transplantations. Ha *et al.*(1999) reported that the survivals were 0.1 plant $\cdot$ m^{-1} after seeded strings transplantation.

In this study, transplants perished because of density dependent factors before March. The results were very similar to the reports of Schmitt and Ehrhardt (1987), Black (1974), and Kang (1999). Individuals, however, also perished due to big diatoms and muddy sediments attached on the blades in this study. Moreover, damage by algae feeders was rarely found, differing from the report of Nakahisa (1981). It seems that young blades were protected by the inability of algae feeders to invade the aquarium and a distance of more than 16 cm between transplanting plates and blades in the outdoor experiment. In the sea experiment, the results for 10 cm transplants were similar to the reports of Nakahisa (1981) and Ha *et al.* (1999). The results for 20 and 30 cm long transplants, however, were very different from these reports, and the direct relationship between the size of transplants and surviving rate was observed.

The growth of blades by blade length showed a similar tendency after March (Fig. 3). Yotui and Nishikawa (1968) reported that the maximum growth was 4.06 $\mathrm{cm \cdot day^{-1}}$ in April. Kang (1999) reported that the growth was 2.79 cm $\mathrm{day^{-1}}$ from early March to early April, and the growth of low density was higher than high density.

The maximum growth of blades in the outdoor aquarium was 1.27 $\mathrm{cm \cdot day^{-1}}$ in March, and the blade end loss appeared in April. The mean growth was 1.30 $\mathrm{cm \cdot day^{-1}}$ in the sea experiment. Sanbonsuga (1984) reported that the growth was a sigmoid curve according to time at transplanting and differed from indigenous environmental characteristics in each sea area. It seems that the discrepancy between these results is due to growing time and indigenous environmental characteristics in each sea area according to growing time.

Friction force was not always high because drag force to plates was high due to height of total drag force of blades. Sand and silt sank due to their weight and consolidation appeared on the substratum towards pulling. So, it seems that the drag force was strong.

Considering not only the maximum static friction force but also consolidation, the value of concrete, which the total drag force was the lowest, was selected. Drag force per one blade (mean blade length 190.20 cm) was 105.25 g because drag force on 2.18 kg of concrete was 632 g, so the total blade number per one plate was six. Therefore, because drag force ranged from 632 g of the minimum to 732 ± 5 g of the maximum and drag force per one blade was 105.25 g, the total blade number per one plate was 6-7. Thus, the weight of one plate, which one blade can be fixed, can be estimated at 311-363 g.

Nakamura (1991) reported that a safety factor of 1.2 at a minimum was to add stability to unknown drag force. In this study, the safety factor was 1.4-1.6 according to formula (1). Applying a safety factor of 1.4, the plate weight per one blade was $1.4 \times 311 - 363$ g = 435.4 – 508.2 g.

To reduce error, the maximum static friction force was calculated and reconfirmed. To calculate the maximum static friction force in the water, the value of buoyant force was subtracted from plate weight in the water; so the buoyant force was calculated in the water according to formula (2). Calculating the maximum static friction force according to the formula (3) because the weight minus the buoyant force was 690 g, the maximum drag force was 636.5 g. Considering the stability and economical efficiency of the transplanting plate, the proper weight of a plate per one blade of *L. japonica* was regarded as 508. 2g at a minimum.

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