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Techniques for the restoration of *Sargassum* beds on barren grounds

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Abstract : On barren grounds formed after deforestation, supply of propagules is often limited due to the long distance from existing seaweed beds. However, drifting thalli of *Sargassum* can reproduce and introduce embryos even on barren grounds. In order to investigate whether drifting *Sargassum* can effectively supply embryos, the abundance and fecundity were investigated in thalli entangled around floating ropes of a set net in western Wakasa Bay, in the Sea of Japan. Biomass of the entangled drifting *Sargassum* was the highest in late May. Drifting thalli of *Sargassum patens* and *S. macrocarpum* were found to release comparable numbers of embryos to those growing in seaweed beds. The following year, an artificial reef was deployed in the same area, and floating ropes were installed above the artificial reef to entrap drifting *Sargassum*. Six month later, the percent cover of *Sargassum* on the top of the artificial reef was higher around the floating ropes, suggesting that this setup facilitated the effective supply of *Sargassum* embryos. In addition, novel techniques to culture *Sargassum* seedlings were developed. The seedlings can be cultured freely in a transparent aquarium with strong bubbling. It is easy to adjust the density of seedlings in accordance with their size, avoiding density-dependent mortality and growth suppression. We also developed two techniques to fix seedlings to some setups or to the seabed. These techniques using seedling production and aquaculture can be applied for the recovery of *Sargassum* beds on barren grounds.
Key words : *Sargassum*, drifting seaweed, seaweed aquaculture, seedling production, trap

Introduction

Seaweed forests have important roles in primary production and providing nursery grounds, now decreasing along the coasts of Japan. We are trying to generate seaweed forests (particularly *Sargassum*) using drifting thalli and seedling production techniques, which have been developed over the course of artificial reef construction and seaweed aquaculture. This paper introduces these techniques.

Use of drifting seaweed

On barren grounds formed after deforestation, supply of propagules is often limited due to the long distance from existing seaweed beds in the surrounding area. The dispersal ability of *Sargassum* embryos is rather limited compared to that of kelp (Kendrick and Walker, 1991; Reed *et al.*, 1988). However, drifting seaweed of *Sargassum* is able to transport embryos over a long distance. We used drifting seaweed to enhance the supply of embryos onto an artificial reef. This study consists of a preliminary survey and an application for artificial reef construction.

Preliminary survey

For the preliminary survey, the biomass and fecundity of drifting seaweed were investigated. To clarify temporal changes in biomass, drifting seaweed entangled around floating ropes of a set net in western Wakasa Bay, in the Sea of Japan, was investigated on a bi-weekly basis from early May to late July 2005 (Yatsuya *et al.,* 2006). Biomass

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was highest in late May (Fig. 1), reaching to 1.3 kg (wet wt.) per meter of floating rope. Among these seaweeds, *Sargassum patens* and *S. macrocarpum* were dominant (Fig. 1).

Therefore, the fecundity of these species was examined with respect to the difference between drifting thalli and that attached on the substrata in a *Sargassum* bed. Drifting and attached seaweeds were collected within an area of 1 km, and 1.5 kg of thalli was stored in a tank with running seawater. After one week, the numbers of embryos released from the thalli were counted under a microscope.

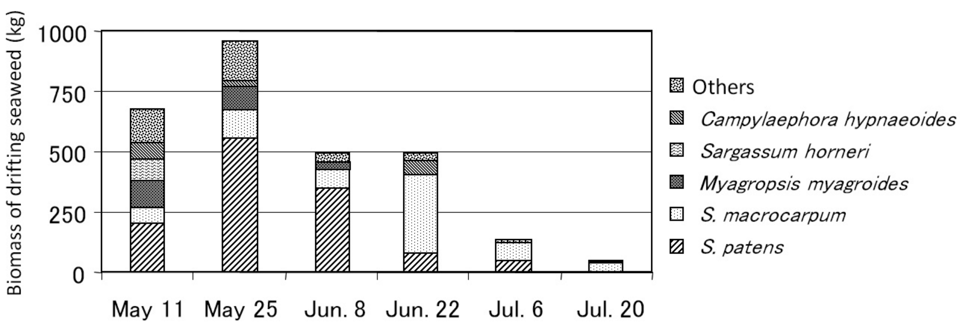

Fig. 1. Biomass of drifting seaweed entangled around floating ropes of a set net in western Wakasa Bay, the Sea of Japan.

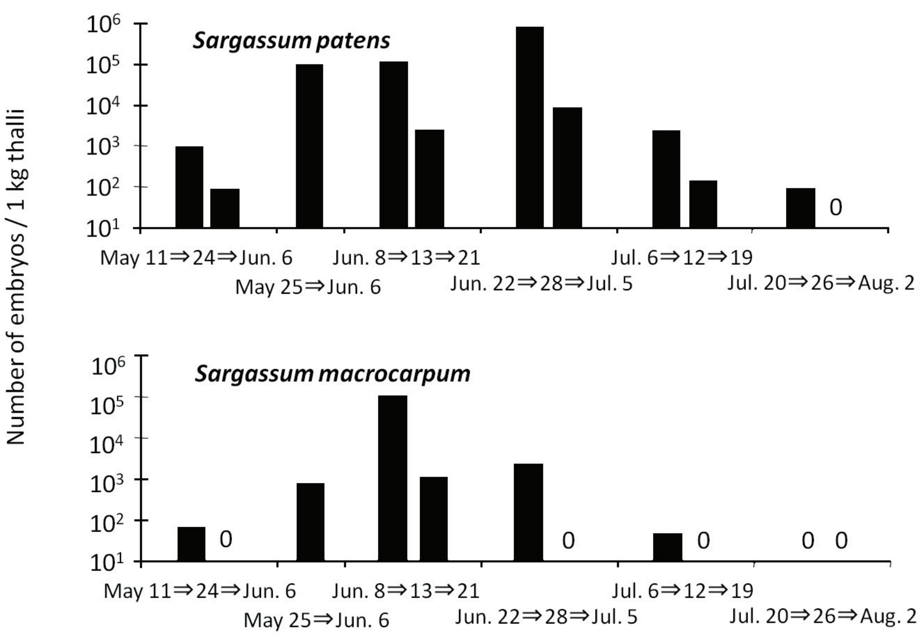

Fig. 2. The number of embryos released from 1 kg of drifting seaweed. N.D. indicates no data.

Sargassum patens and *S. macrocarpum* released at maximum 770,000 and 100,000 embryos per kg of drifting thalli, respectively (Fig. 2). These figures were equal to or higher than those of attached seaweed, suggesting that drifting was comparable to attached seaweed in regard to the number of released embryos.

Application for artificial reef construction

In March of the following year, 7,000 m^2 of artificial reef on a sandy seabed was deployed in the same area investigated in the previous year. It seemed to receive few *Sargassum* embryos due to the lack of a wild *Sargassum* forest in the surrounding area. From April to July, floating ropes were positioned above the artificial reef to entrap drifting *Sargassum* thalli and supply embryos. Since the abundance of drifting *Sargassum* in this year was lower than expected, we collected drifting thalli around the area and manually tied it to the floating ropes.

Six month after construction, the percent cover of *Sargassum* was investigated along a transect line perpendicular to the floating ropes. The cover of *Sargassum* was higher around the floating ropes (Fig. 3), suggesting that this setup effectively supplied *Sargassum* embryos from drifting thalli of *Sargassum* (Yatsuya *et al.*, 2008). This technique was also applied for the restoration of seaweed beds on barren areas around Kyusyu Island.

Seedling production

Seaweed growing in its natural environment shows higher mortality in its early life stage (Chapman, 1984). However, seedling production on land and subsequent transplantation into the sea could reduce the risk of mortality. Therefore, methods of effective seedling production and transplantation into the sea should be developed.

How to cultivate *Sargassum* seedlings

To date, seedlings of *Sargassum* are usually planted on the surface of a hard substratum. These seedlings suffer from density-dependent mortality

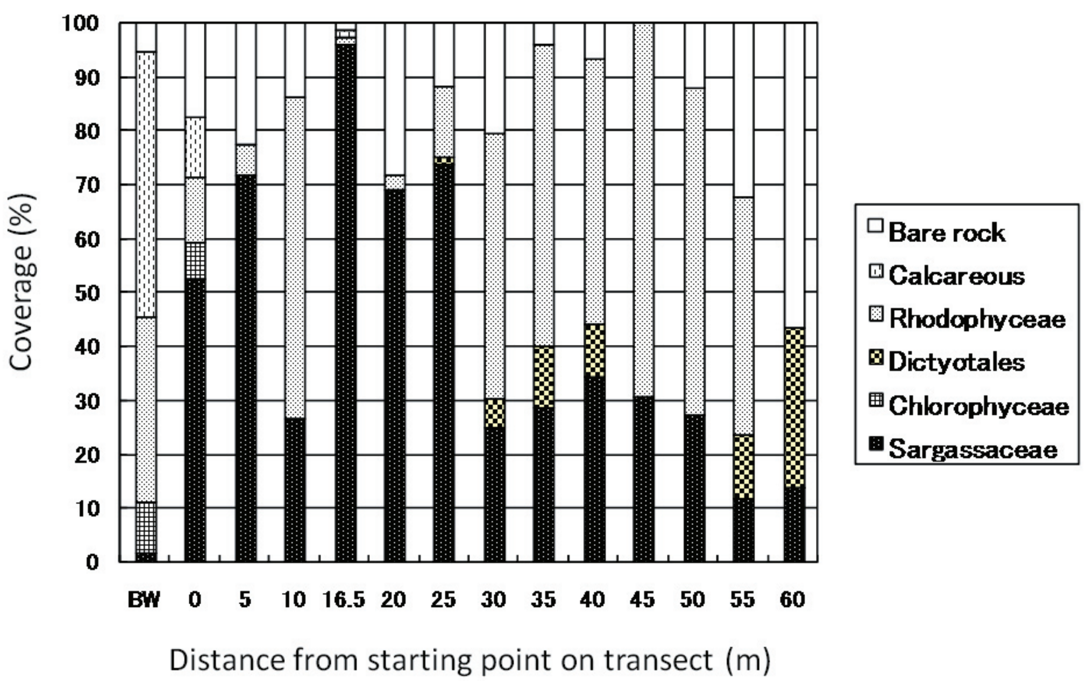

Fig. 3. Percent cover of seaweeds along a transect line on an artificial reef. The floating rope, which trapped drifting seaweed, was installed at 16.5m. BW indicates the foundation of a breakwater along the shallower edge of the artificial reef.

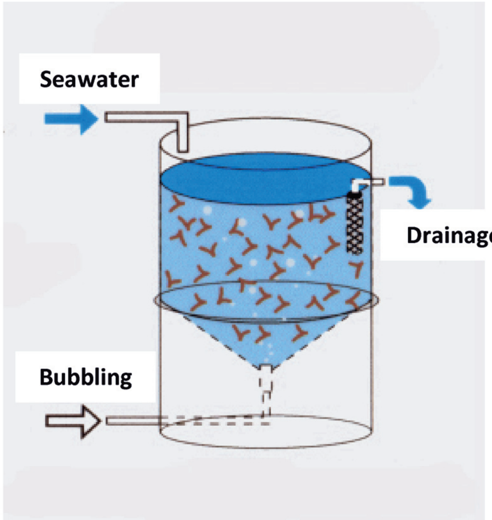

Fig. 4. Schematic drawing of the free culture method.

when they grow and become crowded. We found that *Sargassum* seedlings could be cultured freely in a transparent aquarium with a constant inflow of seawater and strong aeration (Fig. 4). Using this method, it is easy to adjust the density of seedlings in accordance with their size, avoiding density-dependent mortality and growth suppression.

The growth and survival rate of small seedlings with one leaf were compared using two culture methods: one involved free culture in an aquarium, and the other planting on a hard substratum. Both the growth and survival rates of seedlings were higher using the free culture method (Table 1). The density of seedlings also had a significant effect on the growth and mortality rates. The lower the seedling density, the better the growth and survival rates. This new culture method has been applied for seedlings of *Sargassum fulvellum*, *S. horneri,* and *S. patens*.

How to fix seedlings of *Sargassum* in the sea

In this section, two techniques of how to fix *Sargassum* seedlings in the sea are reported. The first method uses a net to which the seedlings are fixed. Each primary branch of the seedling is inserted through the mesh of a net. Then, the net is rolled to encircle the basal part of the seedling, protruding most of the primary branch. The size of the net is usually 5 m long and 20 cm wide and stretched mesh size is 4 cm. Seedlings weve fixed every 10 cm on the net. This line is suspended horizontally at a depth of 1 to 2 m. At this time, the average length of seedlings is more than 20 cm. The seedlings grow from autumn through winter, achieving a length of more than 1 m during the reproductive season in spring of the following year. These thalli are expected to release masses of embryos into the surrounding area (Fig. 5a).

Secondly, we use a tiny substratum attached to seedlings which is cultured freely in an aquarium. The substratum is made of a kind of plastic whose density (i.e., specific gravity) is nearly equal to that of the seawater. The dimensions of the substratum are 1.0 x 1.5 x 1.0 cm. *Sargassum* embryos were sown on the surface of the substratum and cultured in a tank with slowly running filtered seawater for two months. After that, the seedlings growing on the substratum were cultured freely in the same

Table 1. Growth and survival rates of *Sargassum fulvellum* seedlings at various densities using the two culture methods

Method	Cultured freely in aquarium				Planted on a hard substratum
Density of seedlings	25 ind./L	50 ind./L	100 ind./L	200 ind./L	7.5 ind./cm^2
Growth rate* (mg/day)	0.28	0.17	0.14	0.06	0.07
Survival rate (%)	75	79	64	49	20

* Growth rate = $(W_t - W_0)/t$,
where W_t and W_0 are the mean weights of a seedling at t days later and the start of the experiment, respectively. t is the experimental period (days)

(a) (b)

Fig. 5. *Sargassum fulvellum* fully grown in the reproductive period (a), and *Sargassum* seedlings growing a tiny to substratum are fixed in various ways (b).

way in the method mentioned above. When the seedlings were transplanted in the sea, the tiny substrata with seedlings are fixed to some setups or to the seabed in various ways. They can be attached to a rock or concrete block on the sea bottom, or tied to a rope suspended at the target depth (Fig. 5b). This technique made it possible to transplant smaller seedlings which could not be fixed by a mesh net. Therefore, we have been able to culture *Sargassum* seedlings in any season with physically and/or chemically favorable conditions and a lower grazing pressure. These techniques using seedling production and aquaculture can be applied for the recovery of seaweed beds on barren grounds.

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