Studies on the artificial cultivation and propagation of giant kelp (*Macrocystis pyrifera*)

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Introduction

For the purpose of developing a useful seaweed resource, giant kelp (*Macrocystis pyrifera*) was introduced from Mexico into China in August–September, 1978. Since then, a series of studies has been made, including investigations on experimental ecology and techniques for cultivation and propagation of this species in natural beds. The present paper is an integrative and brief introduction to our recent work.

Selection of sea area for cultivation

Giant kelp is a cold-water seaweed. As has been reported, the upper temperature limit for sporophytic survival ranges from 20 to 25 °C. However, most of the Chinese coastal waters, where conditions appear favorable for culturing giant kelp, often attain temperature of over 20 °C in summer. Therefore we chose Qingdao (36°05′N), Lidao (36°50′N), Huangcheng Island (38°20′N) and Dalian (38°45′N), all situated in northern China, as trial areas to determine whether *M. pyrifera* is able to survive the summer in these waters (Table 1).

As shown in Table 1, when the water temperature in the trial areas was higher than 23 °C, the survival rate of *M. pyrifera* became very low, and thalli began to rot (Fig. 1) and were washed away by the current. The longer the exposure to these high temperatures, the more severe the decay. From these observations, it seems probable that in Chinese coastal waters, 23 °C is the upper temperature limit for survival of *M. pyrifera*.

We also have observed the following in situ: (1) Tolerance of high temperature in *M. pyrifera* varies among plants of different ages and among parts of the same plant. The older a plant or tissue is, the less it will tolerate high temperatures. Also, vegetative blades have less tolerance than sporophylls. (2) Decay of thalli varies with the depth of water where they dwell. Plants growing in shallower water decay badly because they are encrusted by bryozoa or other epiphytes. (3) Current velocity is an important factor in survival. Although the water temperature was the same, plants in more swiftly moving water survived better than those in slow currents.

Through two years' observation of the four sites, we consider that the Huangcheng Island is the best for cultivation of giant kelp.

Studies on experimental ecology

It is necessary to obtain information about the influence of water temperature and light intensity on vegetative growth and development, for a large-scale cultivation of juvenile sporophytes of giant kelp. Accordingly, we have observed the effects of these two factors on gametophytes.

The exprimental method used in this study was similar to that for *Laminaria*. Sporophylls were collected from mature *Macrocystis* plants, washed, allowed to dry in the shade and then immersed in sterilized sea water. Zoospore release was thus obtained and the zoospores were allowed to settle on microscope slides which were then transferred into dishes containing enriched and sterilized sea water, and cultured at different temperatures and light

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Table 1. Summer temperatures and effect on survival of *Macrocystis pyrifera* sporophytes in different coastal areas of China.

Area	Range of temperature July to Sept. (°C)	Days over 23 °C	Total number of plants	Plants surviving	Survival rate (%)
Qingdao	20.5–27.0	75	900	0	0
Lidao	20.0–24.0	15	4 000	12	0.3
Dalian	20.0–24.0	14	600	14	2.3
Huangcheng	14.6–23.0	0	600	588	98

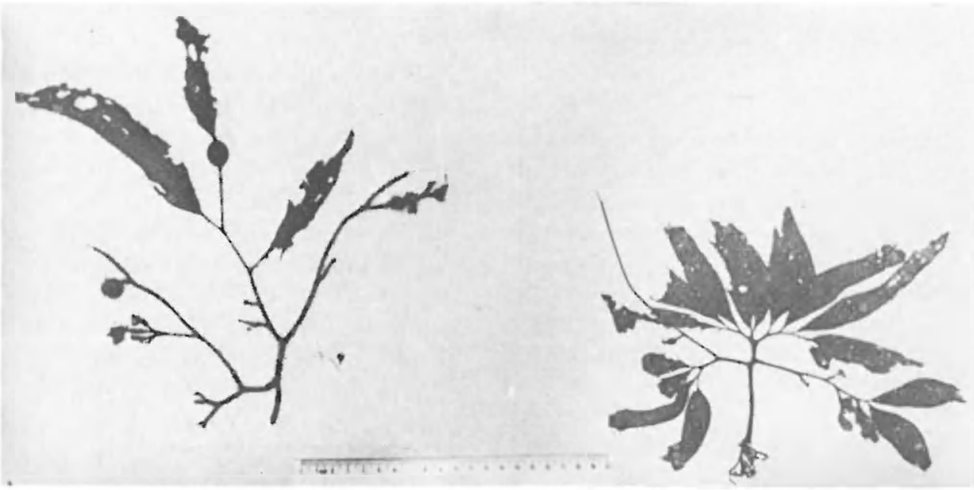

Fig. 1. Decayed thalli of *Macrocystis pyrifera* after exposure to temperatures higher than 23 °C.

intensities. The enriched seawater was renewed every week. Growth rate was determined by measuring the diameter of the primary cell of female gametophytes, and the stage of fertility of male and female gametophytes was indicated by percentage of females forming zygotes (Figs. 2, 3).

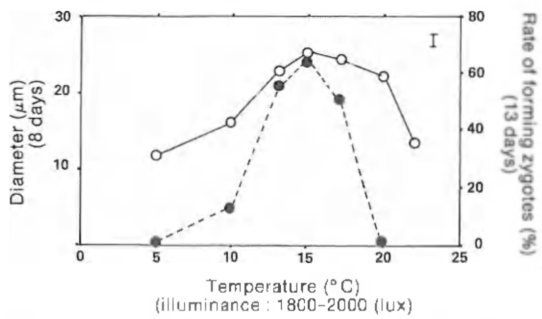

Fig. 2. Rates of growth and zygote formation in female gametophytes of *Macrocystis pyrifera* 8 and 13 days old, respectively, under various temperatures. Open circles (○): diameter of primary cells (n = 20). Vertical bar in upper right corner indicates least significant range of 5%). Solid circles (●) : percentage of plants forming zygotes.

Figure 2 shows, of the temperature range examined in the experiment, the optimal temperature for growth of female gametophytes was from 13 to 17 °C. The gametophytes grew better at the upper limit of the optimum temperature range than at the lower limit. Although the temperature range of 13–17 °C was also optimal for fertility of female gametophytes, the lower limits of the range were slightly more conductive to fertilization than the

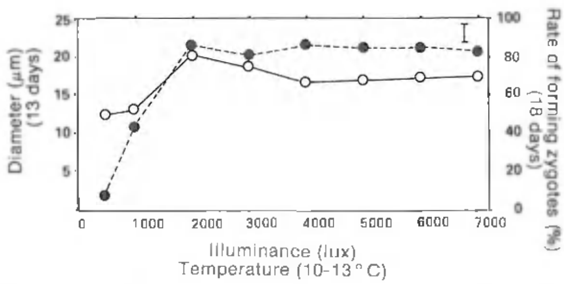

Fig. 3. Rates of growth and zygote formation in female gametophytes of *Macrocystis pyrifera* 13 and 18 days old, respectively, under various intensities of illumination. Symbols as in Fig. 2.

upper limits. In fact, the reproduction of gametophytes was totally inhibited when the water temperature was higher than 20 °C.

The influence of light intensity on vegetative growth and fertility is shown in Figure 3. Illuminance of 2 000–3 000 lux was optimal for growth and development of gametophytes, but illuminance as high as 7 000 lux did not inhibit growth or zygote formation. A lower illuminance, however, such as 500 lux, obviously delayed the development of gametophytes.

The results described above provide some useful information for sporeling cultivation. A large number of gametophytes employed in our experiments are now cultured as seed stock at such temperature and light optima.

Studies on techniques of cultivation and propagation

Cultivation of sporelings. To obtain a great number of sporelings of the giant kelp for use in the experiments on artificial cultivation and propagation, we have cultured two types of sporelings, summer sporelings and autumn sporelings. The procedure followed in culturing the former is as follows: Initially, juvenile sporelings are cultured indoors. When the temperature of the sea is optimal and the sporelings reach a length of 10 mm, they are transferred into the sea. The experience accumulated in culturing sporelings of *Laminaria japonica* indicates that one of the important factors to consider is placing sporelings at the appropriate depth, where they normally dwell. Therefore, we monitored and measured growth rates of *M. pyrifera* sporelings at different depths (Table 2).

Table 2 obviously indicates that, although the giant kelp can be found on the sea bed at depths of 20–30 m, artificially cultured sporelings on floating rafts grow better in shallower than in deeper water, in our trial sea areas. The shallower the water in which sporelings grow, the higher the growth rate will be. During the growing period of 42 days, the average length of sporelings planted at 1- and 2-m

Table 2. Comparison of growth rates of *Macrocystis pyrifera* sporelings at different depths (Huangcheng Island).

Depth (m)	28.X.82	12.XI.82		8.XII.82	
	x length* (mm)	x length (mm)	Rate (%)	x length (mm)	Rate (%)
1	10.6	28.6	170	152.8	434
2	10.2	29.0	184	122.8	413
3	9.3	23.6	154	79.2	236
3.5	8.0	26.6	233	76.4	187
4.5	8.6	19.2	123	–	–
5.5	10.8	18.8	74	45.5	141

* n = 10

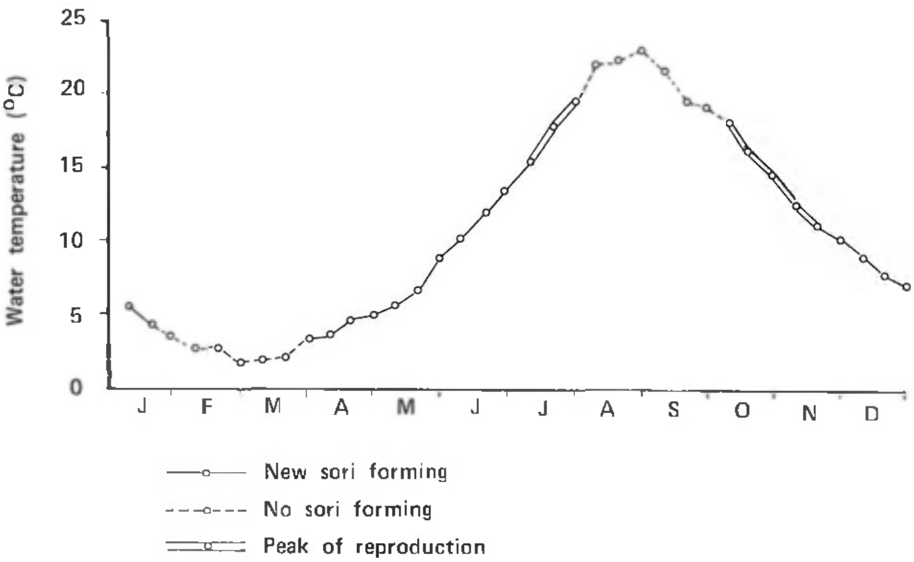

Fig. 4. Reproductive periodicity in *Macrocystis pyrifera* in raft cultivation, China.

depths increased 14- and 12-fold, respectively. As long as the sporelings are cultured at an appropriate depth, it will be possible to reduce the time required for culturing sporelings in the sea.

Autumn sporelings are cultivated entirely in the sea. The spores are collected in October, utilizing stones, bamboo strips and plastic ropes as substrates. After spore collection, these substrates are hung beneath floating rafts. In our experiments, there were many sporelings on stones and bamboo strips, but nearly none on plastic ropes. The growth of autumn sporelings was similar to that of summer sporelings, showing the highest growth rate at a depth of 1–2 m.

Parent plants, comprising one-, two-, and three-year-olds, provide mature sporophylls and are cultured on floating rafts. Through continual observation for three years, we have found that a great number of mature sporophylls appear in mid- to late July (summer) and in early October to late November (autumn). There is a longer reproductive period in autumn. In summer, when the water temperature exceeds 19.5 °C, no mature sori are found, so it is considered probable that the upper temperature limit for sporulation is at 19–20 °C (Fig. 4).

Methods of cultivation and propagation. Since 1979, three methods (viz., floating raft, casting stone with sporelings, and submerged floating rope) have been tried at Qingdao, Lidao, Dalian and Huangcheng Island.

Floating raft was a method similar to that used in *Laminaria* culture. There were two types of cultivation, suspending and flattening. The merits of floating rafts are that it is easy to observe and manage the cultured plants, but more materials are needed and the cost is higher than for other methods. It is therefore not suitable for large-scale production, and is presently utilized only in breeding sporelings and in stock-keeping.

Casting stone was an attempt to propagate *M. pyrifera* on the sea bed. In this method, stones served as substrates to which spores adhered and then grew into sporelings, or sporelings were tied by hand to the stone. Such stones were cast into a suitable sea bed, and surrounded with nets to protect juvenile plants from grazing by sea urchins. The results of the experiments are very inconclusive because the nets were inadequate to prevent urchins invading and seriously damaging the seaweeds.

Submerged floating rope involved inserting two wooden piles into the sea bed, between which were strung plastic ropes on which sporelings were fastened. Three hundred sporelings, each 70 cm long, were planted on these ropes at Huangcheng Island in August, 1980. By the end of the year, they were up to 20 m long, and the survival rate was estimated at 100%. In May, 1982, the culture area was expanded to about 0.8 ha (12 mu). After four months, the average length of these seaweeds was 13 m, compared with the initial average length of 2.2 m.

The cultivation experiments show that the last method is the best one, very simple to operate and efficient in preventing damage by sea urchins.

Conclusion

Since the introduction of giant kelp into China, the technical problems in artificial cultivation have been preliminarily solved, thus providing a basis for more extensive cultivation of this species.

The trials will be continued on a larger scale at Huangcheng Island. The main targets are to improve culture methods further and validate their economic effects. If it is considered reasonable, giant kelp cultivation will be extended to other coastal areas. It is also planned to breed new strains or to introduce heat-tolerant strains in order to expand potential culture areas.

It has been found that in the trial sea areas, either the germination or growth of sporophytes of *M. pyrifera* are limited by factors such as water temperature, light intensity and type of substratum. Based on the results obtained, we are led to the conclusion that it seems impossible for giant kelp to block channels or otherwise become a nuisance due to natural overpropagation in the sea.