MARINE PLANT AQUACULTURE

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Summary

Marine plant aquaculture, which supplied nearly 6 300 000 tons of fresh products in 1995 and provided a turnover of US$8.2 billion, ranked second to freshwater fish in aquacutural production and was first in marine production, with 45% of total tonnage. Three types of culture can be distinguished: (i) that used for seeding of microscopic elements of the reproduction cycle, e.g. *Laminaria japonica* (4 000 000 tons harvested in China in 1996), *Porphyra* (760 000 tons) or *Undaria* (370 000 tons); (ii) that based on the use of cuttings placed directly in the marine environment, *e.g. Kappaphycus alvarezii* and *Eucheuma denticulatum* (500 000 tons); and (iii) that using cuttings in land facilities, *e.g. Chondrus crispus* As knowledge about the biology and composition of marine plants improves, new cultures will develop, such as those intended for cosmetic (*Asparagopsis*) or pharmaceutical uses (*Padina*).

1. Foreword

The cultivation of marine plants began when man was obliged to increase available natural production. The pioneers were probably Japanese peasants who some two centuries ago consumed the Rhodobiont *Porphyra tenera*. They noted that this species was much more prolific (but unusable) in insalubrious than salubrious areas and decided to place branches in the waters of insalubrious areas to obtain good seeding before immersing them in salubrious areas for harvesting and consumption.The initial concern was to augment the natural populations. Subsequently, a greater demand for marine food plants, in conjunction with accumulated knowledge about their biology and the marine environment, led to the gradual development from 1960 of an increasingly organized and productive aquaculture, both in quantitative and qualitative terms.

In 1996, this source of aquaculture produced 6 272 000 tons (wet weight), *i.e.* more than 80% of the 8 017 458 tons used in the world. Compared to aquaculture worldwide, estimated at 25 366 600 tons for a turnover of US$43 billion, it ranked second in tonnage (26%) and turnover (19.9% or US$8.2 billion) after freshwater fish. In terms of marine aquaculture alone, which supplied 14 129 000 tons of fresh products, marine plants accounted for 45%, far more than mollusks (31%), diadromous fish (10.1%), crustaceans (8.5%), and sea fish (4.2%). This application is also the most economic one for energy since plants obtain their own nutrients from the sea.

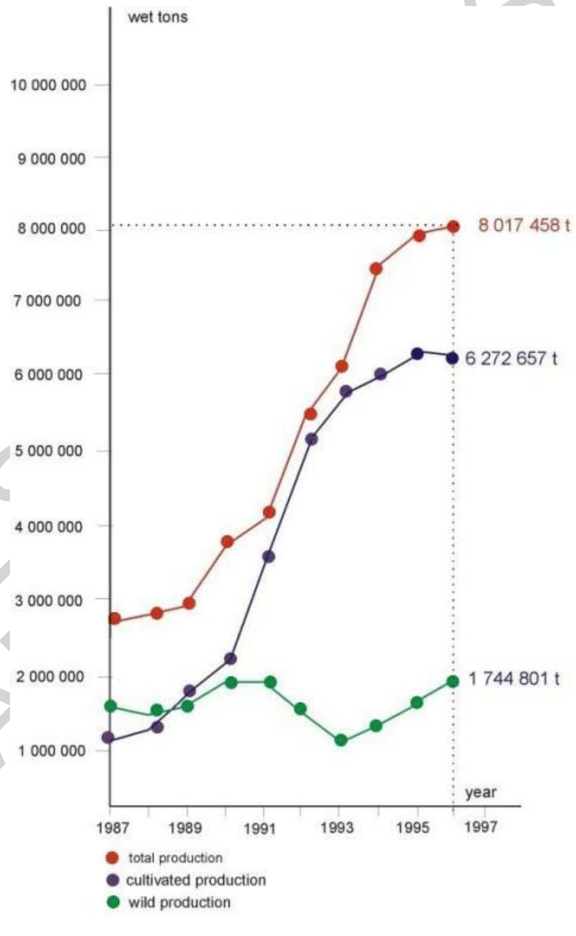

Figure 1. Developments in marine plant production by aquaculture. Aquaculture of marine plants began with the cultivation of *Porphyra* in Japan at the beginning of the 20th century, was followed by the cultivation of *Laminaria japonica* in China around 1950, and has intensified especially since 1980. After a very rapid development from 1980 to 1985, the total tonnage has become stable, although the number of species produced is increasing.

This source initially provided only marine plants for use as food, with most of the tonnage (see Figure 1) going into direct human consumption (5,246,751 tons in 1996).

In addition to increasing the quantity significantly, the objective was to improve the quality and the conformity with standards in order to facilitate sale on the food market.

This application rapidly became profitable since plants for food were sold at one hundred times the price of those used as phycocolloids, providing appreciable production gains and a higher turnover than for colloid plants (Figure 2).

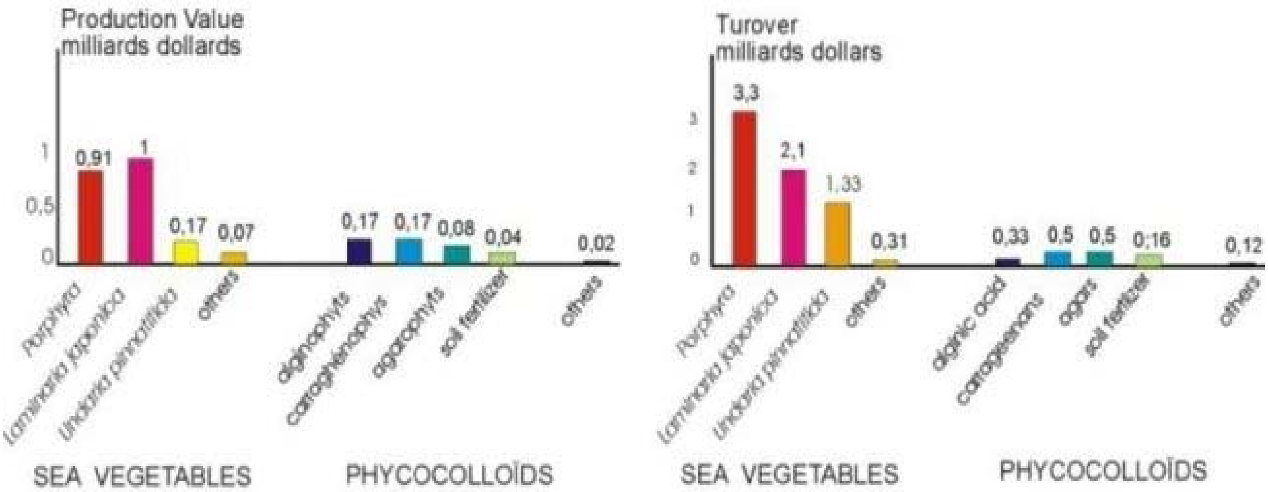

Figure 2. Impact of marine plant aquaculture. The two-histograms allows comparison of production gains (US$2.25 billion in total) and the turnover produced by marine plant aquaculture (US$8.2 billion). The part intended for human consumption is much more remunerative than that for phycocolloid extraction.

Since 1963, this approach has been applied to Californian populations of *Macrocystis pyrifera*, which have thus been reconstituted, and since 1975 to carrageenophytes (*Eucheuma*, *Kappaphycus*) and the agarophyte *Gracilaria* in countries where labor costs are still low (Southeast Asia, Chile).

Plant aquaculture can be classified according to three parameters (see Figure 3):

- The purpose (extraction of agars, carrageenans or alginic acid; food uses; etc)
- The seed type (cell from the reproduction cycle or cuttings)
- The production structures (only on land, only in the sea, or both on land [germination] and in the sea [development])

This table (Figure 3) shows the existence of three main types of seeding methods from:

- Elements of the reproduction cycle
- Cuttings (only in the sea)
- Cuttings (only on land)

AIM	SEEDING		
	spores, gametes or zygotes	cuttings	
Alginic acid	*Macrocystis* *Laminaria j*		
Agars		*Gracilaria g* *gracilaria v*	
Carrageenans		*Eucheuma* *Kappaphycus* *Betaphycus*	*Chondrus*
Sea vegetables	*Laminaria j* *Porphyra* *Undaria* *Monostroma* *Ulva* *Enteromorpha* *Cladosiphon*	Caulerpa Hizikia	*Spirulina* *Chlorella*
Cosmetics Pharmocology		*Padina* *Odontella* *Asparagopsis*	
Colouring			*Porphyridium*
food for aquaculture			*Chaetoceros* *Tetraselmis* *T iso*
TECHNICS	sea and nursery	only in sea	only in tanks

Figure 3. Classification of marine plant cultivation according to three parameters: purpose, seeding mode and the technique used. The most advanced methods often make use of elements of the reproduction cycle, but require a land facility to control this seeding.

2. Seeding with Elements from the Reproduction Cycle: The Example of *Laminaria japonica*

This technique requires a perfect understanding of the reproduction mode and the parameters involved. The development phase and harvesting take place in the sea, but seeding is performed on land, consisting in the production of very many seedlings subsequently attached to cord supports and placed in the sea.

Thus, land facilities are needed to carry out the reproduction cycle and obtain massive emission of reproductive elements (spores, gametes or zygotes). This land phase is carefully controlled and independent of the factors present in the marine environment. It requires skilled labor (scientists), whereas fishermen can carry out operations in the sea.

Laminaria japonica, known as Kombu on the trade market, is a good example of the application of this technique since it is the marine plant with the highest production in the world (just over 4 000 000 tons in 1996.

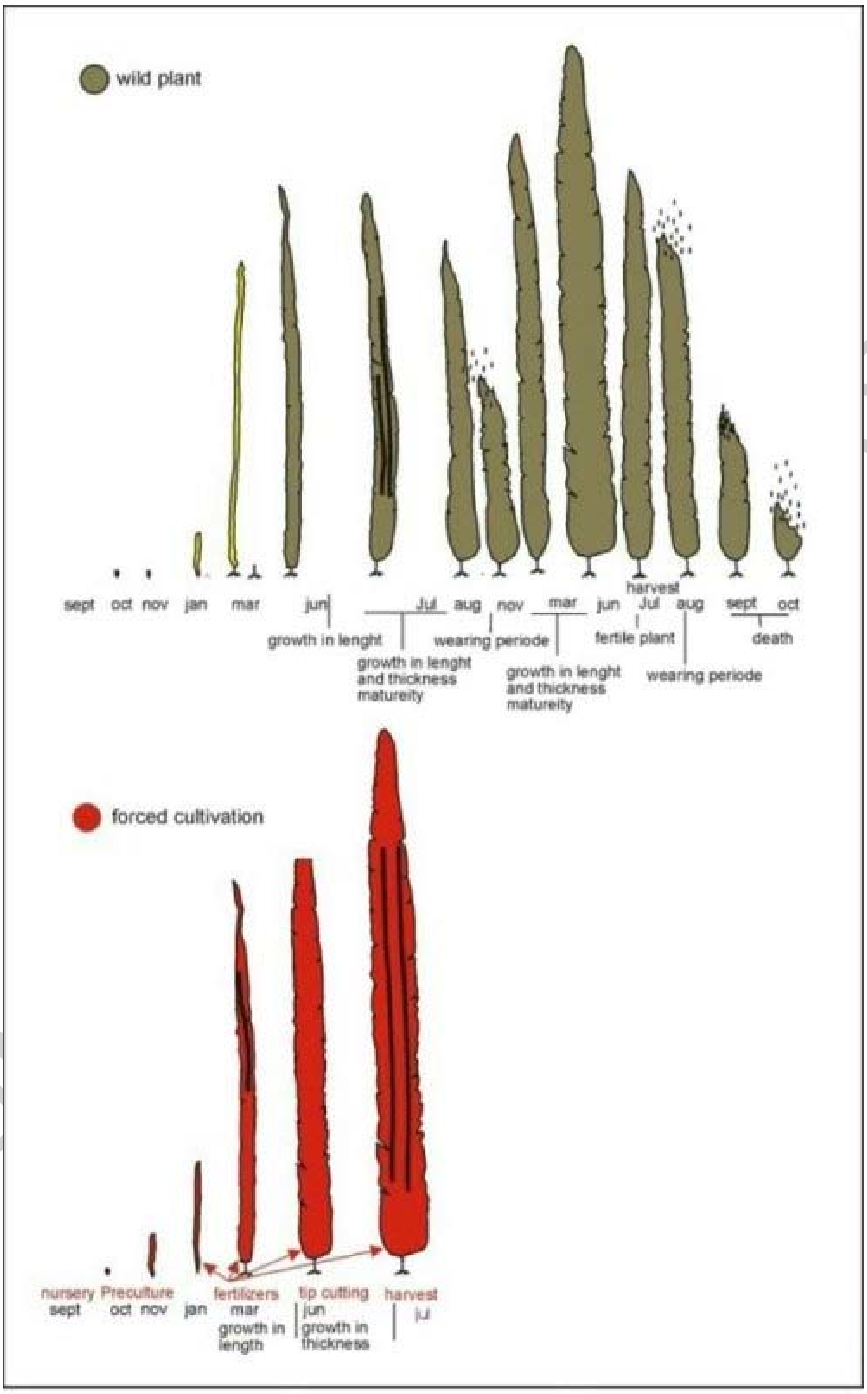

Figure 4. Life of *Laminaria japonica*. Above: the natural life: harvesting can only be performed after 24 months. Below as a result of pre-cultivation, use of fertilizers, tip-cutting, and optimal positioning of the plants relative to lighting, accelerated growth allows harvesting after 8 months.

Theoretically, the wild stock is not found below 36° north latitude since the gametophytes do not tolerate temperatures above 18°C, whereas the sporophyte is more resistant. Accordingly, the production of gametophytes and seedlings on land has allowed the development of cultures in the sea down to 25° north latitude, precisely in areas naturally rich in nutriments.

The wild plant (Figure 4) can only be harvested after 20 to 24 months. By the so-called "forced" cultivation method now used in China, Japan and Korea, the interval has been reduced to 8 months. Everything is done at each stage to speed up plant growth. This approach saves time; economizes on the surface area needed, and improves quality.

The "forced cultivation" method for *Laminaria japonica* is based on the two-phase reproduction cycle typical of Laminariaceae: the first macroscopic phase consists of a lamina 4 to 6 m long, and the second is a microscopic filament (gametophyte):

- **The collectors**: These are artificial supports to which the spores will attach. They consist of a network of small coconut fiber cords (diameter: 5 mm) carefully washed to remove any toxicity.
- **Release and attachment of spores**: The fronds are taken to the laboratory where they are carefully dried with a cotton pad in sterile seawater to remove as many epiphytes (organisms living on the lamina) as possible. The fronds are then left overnight in darkness at a cool temperature (10°C) where they begin to undergo dehydration.

The next morning, the frond is immersed in seawater (12°C) in bright light. In China, this seawater is contained in large cement tanks (3×1, 5×1, 2 m) where some 200 to 250 corded collectors are suspended. Once the plants are in contact with the water, the sporocysts all open together, each releasing about 60 spores (small cells with two lateral flagella). The water then turns slightly brown because of the multitude of spores. The spores attach to the cords and lose their flagella. Experience has shown that complete seeding takes about 45 min.

2.1 Growth in a Seeding Facility (see Figure 5)

The collectors are then placed in a large tank containing seawater enriched with ammonium nitrate and potassium phosphate.

The reproduction cycle develops on the cords: germination of the spores into gametophytes, production of gametes, fecundation-yielding zygotes, and germination of zygotes into seedlings. Seedlings 1 to 2 mm high need to be available by September. To slow growth, light intensity can be reduced by placing curtains at the windows to speed up growth, additional lighting can be provided by fluorescent lamps and more nutrients can be given.

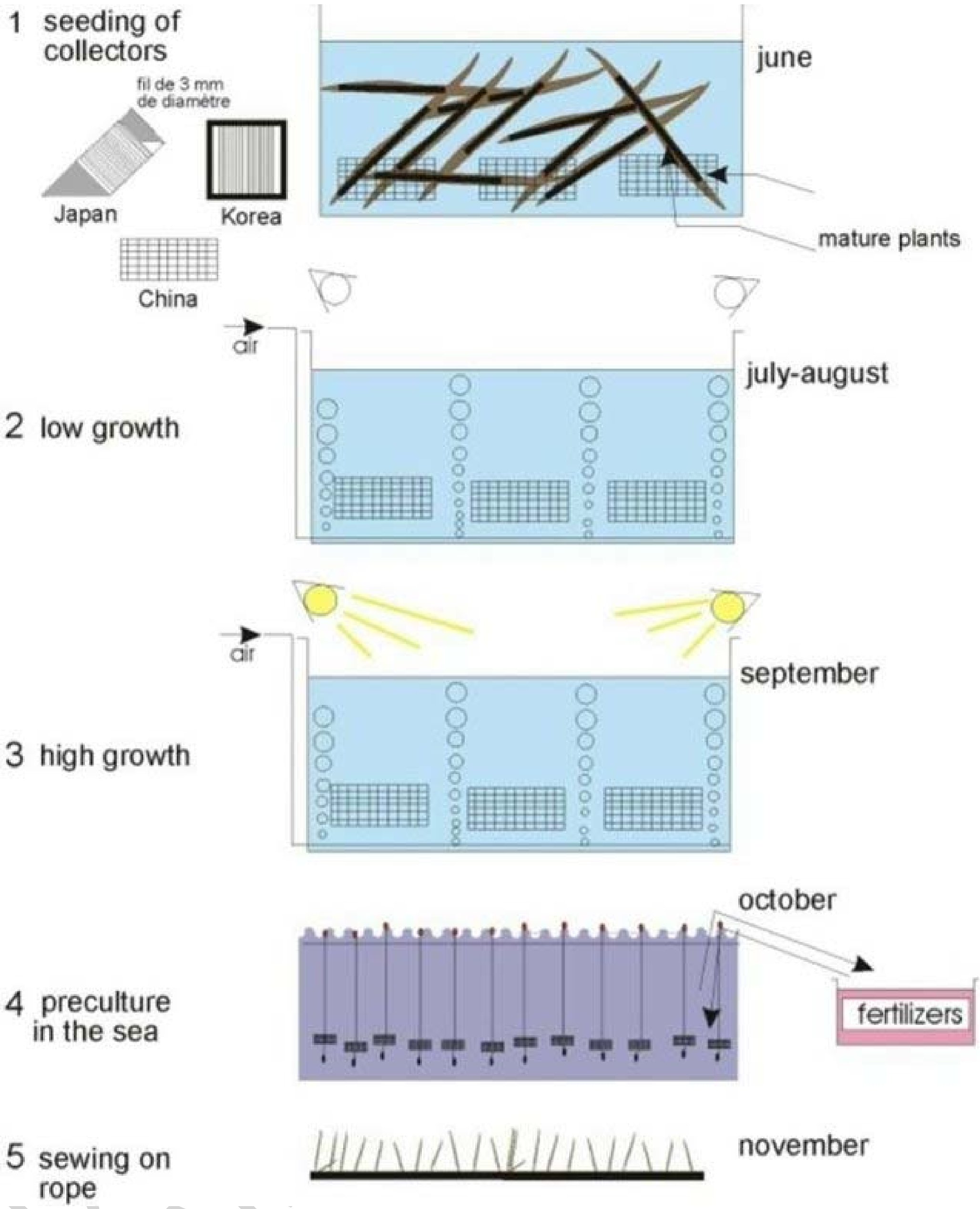

Figure 5. Cultivation of *Laminaria japonica*. The germination phase provides seedlings 20 to 25 cm long, which can thus benefit from rapid winter growth.

2.2 Pre-cultivation

The pre-cultivation step consists in suspending the collectors in the sea, so that the seedlings can gradually adapt to the conditions of the marine environment. A calm area should be chosen (generally protected by islands or shoals) and at a depth (usually 4 m) not subject to undertow and intense light. These conditions are maintained until November.

Throughout this period, the collectors are raised each week to eliminate any sediment and remove any undesirable species. Each collector is soaked in an ammonium nitrate-enriched solution for 10 to 15 min. The seedlings store this fertilizer, which allows them to accelerate their growth. At the end of October or the beginning of November, the seedlings measure 20 to 25 cm in length, whereas without fertilizer they would not yet have reached 5 cm.

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Biographical Sketch

Rene Perez graduated in 1963 from Montpellier University, France, with his D. Sc. Biology and Oceanography, has finished during 1968 his PhD Natural Science in Caen University, France. He received the title of Doctor for his thesis on exploitation, cultivation and uses of marine seaweeds. He was Chief of the seaweed laboratory of I.S.T.P.M (Institut Scientifique et Technique des Pêches Maritimes, France) from 1965 to 1981, and chief of the Aquaculture plant laboratory of IFREMER (Institut Français de Recherches pour l'Exploitation de la Mer, France) from 1982 and 1990. He is now in charge of the biology, physiology, cultivation of macro-seaweeds used for extraction or human consumption in the laboratory Production and Biotechnologies des algues (IFREMER). He is the author of two books, *La Culture Des Algues Dans Le Monde* published by IFREMER, in 1990, *Ces Algues Qui Nous Entourent* published by IFREMER in 1997.