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Review article

# Cultivation of seaweed *Gracilaria* in Chinese coastal waters and its contribution to environmental improvements

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ABSTRACT

Over the past decade, the large-scale cultivation of seaweed *Gracilaria* has expanded rapidly in the Chinese coastal waters. The production of *Gracilaria* increased from 50,536 tons (t, dry weight) in 2003 to 114,722 t in 2010. The production of the seaweed ranks third only to kelps *Saccharina* (formerly referred to as *Laminaria*) and *Undaria* in China. Nan'ao located in Shantou City, Guangdong Province has been successfully developed as one of the major cultivation bases of *Gracilaria lemaneiformis* at an industrial scale in South China since 2000, and the farmed area increased by 11,538-fold from 0.13 ha in 2000 to 1500 ha in 2011. From lab-scale study to field industrial practice, it has been documented that *Gracilaria* cultivation is beneficial in environmental improvements such as mitigating eutrophication, controlling harmful algal blooms, maintaining healthy mariculture systems, and sequestrating $CO_2$. *Gracilaria* may significantly remediate contaminants in mariculture ecosystems and improve the water environment, and its cultivation provides a new approach to coastal environmental improvement in China and the world.



**Contents**



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## 1. Introduction

Approximately 1000 seaweed species globally distributed, from cold, temperate to tropical zones, are economically valuable [1]. Those seaweeds play very important roles in sustaining the biodiversity and ecological functions in marine ecosystems [2]. More than 100 species of *Gracilaria* have been described in the world, and they grow mostly in temperate, subtropical and tropical zones [3,4]. Historically, seaweeds are harvested from nature. However, seaweed cultivation has significantly grown rapidly since the early 20th century due to the continuously rising demand for food and industry. Several species of algae have been cultivated for many years, especially *Pyropia* (formerly referred to as *Porphyra*), *Saccharina* (formerly referred to as *Laminaria*), and *Nostoc* for food, *Gloipeltis* for colloidal substances and *Gracilaria* for feedstuffs and agar materials [5].

Cultivation of seaweed is one type of aquaculture. Now, aquaculture is growing fastest in the food production sector, and its average annual growth rate reached 8.3% between 1970 and 2009, compared to that of 4.9% for poultry, 2.9% for pig, and 1.8% for sheep and goats [6]. China has had the highest mariculture production in the world for over 20 years, and has remained one of the most important contributors to the world aquaculture production. For example, its mariculture production in 2010 reached 14.82 million t and accounted for 44.2% of the world's total production [7].

The rapid development of mariculture has resulted in an increasing release of nitrogen (N) and phosphorus (P) into the mariculture and its surrounding ecosystems. For example, Troell et al. [8] found that more than half of nutrients originated from marine fish culture systems, with the contribution of P, carbon (C) and N approximating 85%, 80–88% and 52–95%, respectively. Excess feed and fecal wastes of cultivated animals settle to the bottom through the water column, and then are incorporated into sediments, where the remineralization of particulate organic matter may cause an increase in dissolved inorganic nutrient concentrations. Increased discharge of organic pollutants from aquaculture farms may lead to various adverse effects to local environments, such as eutrophication, anoxia, loss of biodiversity, and coastal-water pollution [8,9].

Mixing cultivation, which incorporates seaweeds into animal mariculture systems, has long proven to be the most promising approach for mitigating the pollution of the surrounding environment by aquaculture operations. Accordingly, seaweed cultivation has been carried out for decades and has grown rapidly in China and other countries [8, 10–12]. The seaweeds cultivated at an industrial scale include many species, such as *Saccharina*, *Pyropia*, *Undaria*, and *Gracilaria* species in China.

This paper reviews the history and presents the status of *Gracilaria* cultivation, its potential environmental importance as eco-materials, and its role in maintaining healthy mariculture ecosystems in the Chinese coastal waters.

## 2. Species diversity of the genus *Gracilaria* and its distribution in China

There are more than 30 species in the genus *Gracilaria* in China [1, 13]. They distribute in the coastal waters from Liaoning in the north to Hainan in the south of China (Table 1). Species diversity of *Gracilaria* is higher in the south than in the north, and almost 50% of *Gracilaria* species are found in Guangdong and Hainan Provinces in the southern China. In the genus *Gracilaria*, the most economically important species is *Gracilaria lemaneiformis* based on the recent 10-year documentation, which contributes the most to the production of *Gracilaria* in China.

## 3. Mariculture development of seaweed *Gracilaria* and economical animals

### 3.1. Gracilaria cultivation

The artificial cultivation of *Gracilaria* began in the 1950s in China, but then the production was low. For example, the production of *Gracilaria tenuistipitata* and other *Gracilaria* species was about 500 t (fresh weight) per year in the late 1950s. By the end of the 1980s, the area for *Gracilaria* cultivation in South China reached 2000 ha, with an annual yield of 3000 t (dry weight) [1].

The cultivation history of *Gracilaria* in China may be divided into 2 stages. From the 1950s to 2000, the main cultivation species was *G. tenuistipitata*. This seaweed was cultivated mostly in ponds in small scales (just several ha), and its total production was low and not even recorded in the Chinese Statistical Yearbook of Fisheries. Starting from 2000 to 2002, the cultivation of *G. lemaneiformis* was experimentally carried out in Nan'ao, Guangdong Province. The biomass of this seaweed increased by 282-fold (from 15 g $m^{-1}$ to 4230 g $m^{-1}$) over a 155-day period, showing a much faster growth rate than *G. tenuistipitata*. Thus *G. lemaneiformis* was experimentally proven to be a good candidate for industry-scale cultivation in China. From 2003 to 2012, the cultivation

**Table 1**
The distribution of *Gracilaria* species among the Chinese coasts [1,11,13].

| Species | Distribution |
|---|---|
| *G. lemaneiformis* Bory | Shandong, Liaoning, Guangdong, Fujian |
| *G. gigas* Harvey | Guangdong, Fujian |
| *G. tenuistipitata* Zhang et Xia | Guangdong |
| *G. tenuistipitata* Var. *liui* Zhang et Xia | Guangdong, Guangxi, Hainan, Fujian, Zhejiang |
| *G. asiatica* Zhang et Xia | Chinese coast |
| *G. asiatica* Var. Zhang et Xia | Fujian, Guangdong |
| *G. chouae* Zhang et Xia | Fujian, Zhejiang |
| *G. chorda* Holmes | Hainan |
| *G. salicornia* (Ag.) Dawson | Guangdong, Hainan, Taiwan |
| *G. articulata* Chang et Xia | Hainan |
| *G. arcuata* Zanardini | Hainan |
| *G. blodgettii* Harvey | Fujian, Taiwan, Guangdong, Guangxi, Hainan |
| *G. changii* (Xia et Abbott) Abbott Zhang et Xia | Guangdong, Guangxi |
| *G. bangmeiana* Zhang et Abbott | Hainan |
| *G. bailinae* Zhang et Xia | Guangdong, Hainan |
| *G. megaspora* (Dawson) Papenfuss | Fujian |
| *G. spinulosa* (Kam) Chang et Xia | Hainan, Taiwan |
| *G. textorii* (Suring) De Toni | Liaoning, Shandong |
| *G. eucheumoides* Harvey | Taiwan, Hainan |
| *G. rubra* Chang et Xia | Hainan |
| *G. hainanensis* Chang et Xia | Hainan |
| *G. firma* Chang et Xia | Guangdong, Guangxi |
| *G. filiformis* Harvey Baily | Hainan, Taiwan |
| *G. cuneifolia* Lee et Kurogi | Hainan |
| *G. edulis* (Gmelin) Silva | – |
| *G. fanii* Xia et Pan | Guangdong |
| *G. glomerata* Zhang et Xia | Hainan |
| *G. longirostris* Zhang et Wang | Guangdong |
| *G. yinggehaiensis* Zhang et Xia | Hainan |
| *G. yamamotoi* Zhang et Xia | Hainan |
| *G. punctata* (Okamura) Yamada | Taiwan |
| *G. mixta* Abbott, Zhang et Xia | Guangdong |