Bioremediation of Nutrient Enriched Waters by the Rhodophyte *Gracilaria lemaneiformis* in China

Yufeng Yang[1], Fang Jin[1] & Charles Yarish[2]
1 College of Life Science and Technology, Jinan University, Guangzhou 510632, China
2 Department of Ecology & Evolutionary Biology, The University of Connecticut, Stamford, CT 06901-2315, USA

Abstract

Cultivation of the rhodophyte, *Gracilaria*, has rapidly expanded in China over the past decade. The principal species being cultured is *G. lemaneiformis*. It grows very well in the coastal waters of Guangdong, Guangxi, Fujian, Zhejiang, Jiangsu, Shanghai, Shandong and Liaoning provinces. The highest specific growth rate (SPG) reaches up to 13.9%/d in Jiaozhou Bay, Shandong Province. In 24 h laboratory experiments, the seaweed was able to remove 68.44% NH_4-N, 23.03% NO_3-N, and 13.04% NO_2-N. The concentrations of NH_4-N decreased 85.53 % and 69.45%, and the concentrations of PO_4-P decreased 65.97 % and 26.74% in mesocosms with *Gracilaria* after experiments of 23 days and 40 days, respectively. *G. lemaneiformis* is very effective in decreasing N and P loadings. The seaweed significantly inhibited the growth of phytoplankton in other mesocosm experiments. Large scale *G. lemaneiformis* cultivation can be an effective means of improving water quality conditions and promoting a more sustainable finfish mariculture industry in China.

1. Introduction

The genus *Gracilaria* is one of the most important economically important seaweeds because of its ability to be aquacultured, produce high yields, nutrient removal capabilities, and a source of agar which is a commercially valuable phycocolloid (Liu et al., 1997; Fei et al., 1998; Fei, 2004; Yang et al., 2006).

In China, more than 30 species of *Gracilaria* have been recorded but *G. lemaneiformis*, is the most important species in the genus. In 2007, *Gracilaria* production reached 99,451 t. The culture of *Gracilaria* is the fourth most important economic seaweed in China.

In general, 52-95% of nitrogen and 85% of phosphorus of fish feeds for marine fish culture systems may be lost into the environment through waste, fish excretion and the production of faeces. This level of waste can easily induce harmful algal blooms and eutrophication problems (Wu, 1995). To improve the water quality in nearshore waters that are being impacted by land-based and open water finfish culture, *Gracilaria* cultivation is being encouraged by provincial authorities (Fei, 2004; Yang et al., 2004; 2006; Zhou, 2006).

2. Growth Rate & Cultivation of *Gracilaria*

A series of experiments showed that specific growth rates of *Gracilaria lemaneiformis* was very high in Nanao (Guandong Province)and Jiaozhou Bay (Shandong Province; Table 1). In one series of experiments in Jiaozhou Bay, the biomass of *G. lemaneiformis* increased from 50g/m to 775 g/m (fresh weight) after 28 days, with specific growth rate (SGR) of 13.9%/day (Yang et al., 2006).

Table 1. Comparison of the specific growth rates (SGR) of *G. lemaneiformis* in Chinese coastal waters

Site	Growth Period	SGR (%/day)	References
Nanao	17 Nov – 20 Dec, 2001	11.71	Yang et al., 2006
Jiaozhou Bay	2– 30 Oct, 2001	13.90	Yang et al., 2006
Jiaozhou Bay	13 Jun-12 Jul, 2004	11.30	Zhou et al., 2006

Nanao is an island county of Guangdong Province with a population of about 70,000. Of these, about 5,000 people are now engaged in the cultivation of *Gracilaria*. Nanao Island has seen a very recent rapid increase in *Gracilaria* cultivation. The area of cultivation rose from 0.06 ha in 1999 to 800 ha in 2006. In this area seaweed production increased to over 40,000 tons per year. In other areas of China, cultivation of *Gracilaria* has also expanded with total production reaching 99,451 t in 2007 (Table 2).

Table 2. Large-scale cultivation experiments of *Gracilaria* in Chinese coastal waters

Years	Sites
1988- 2009	Zhanjiang, Guangdong
1999-2009	Shantou, Guangdong
2000-2009	Putian, Fujian
2000-2009	Jiaozhou Bay, Shandong
2001-2009	Liangyungang, Jiangsu
2002-	Dalian, Liaoning
2005-2007	Beihai, Guangxi
2003-2009	Xiangshangang, Zhejiang
2005-2009	Shanghai


Gracilaria Cultivation


Gracilaria Harvest

3. Bioremediation Role

3.1 Increase DO

Seventeen visits were made to Shenao mariculture area, in Nanao, Guangdong Province between November 17 and December 13, 2002. The results showed that DO was the highest in the cages with *Gracilaria*, second highest in the surrounding sea water (outside the cages), and lowest in the cages with fish (Fig. 1). A 12 day mesocosm (1 m^3) experiment carried out in 2005 (December 9-21) demonstrated that the concentrations of DO were always higher in the mesocosms with *Gracilaria* (red color) than ones without it (white color) (Fig. 2). The results demonstrated that cultivation of *Gracilaria* is very effective in improving DO levels in mariculture areas.

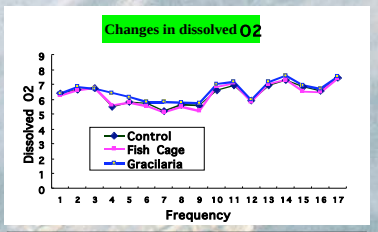

Fig. 1. Comparison of DO in the cages with fish, the cages with *Gracilaria*, and in natural sea water between 17 November and 13 December, 2002.

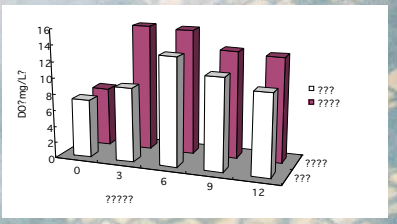

Fig. 2. Comparison of DO in the mesocosms with (red) and without (white) *Gracilaria*

3.2 Biofilter

Mesocosm experiments demonstrated that *G. lemaneiformis* can effectively remove inorganic nutrients from seawater. Yang et al (2006) found that concentrations of NH_4-N decreased by 85.53% and 69.45%, and that concentrations of PO_4-P decreased by 65.97% and 26.74% in the mesocosms with *Gracilaria*. In mesocosm experiments, *Gracilaria* removed 68.44% of NH_4-N, 23.03% of NO_2-N and 13.04% of NO_2-N over a 24 hour period (Table 3). The maximum uptake rates of NO_3-N, NH_4-N, and PO_4-P by *G. lichenoides* were 55.88, 35.17 and 3.106 umol/g/h, respectively; the corresponding rates for *G. lemaneiformis* were 53.17, 32.24 and 3.064 umol/g/h, respectively (Xu et al., 2007). These studies confirm that *Gracilaria* species are good candidates for nutrient removal.

Table 3. Effects of *Gracilaria* on nutrient concentrations (μ mol/L) in 24 h mesocosm experiments.

	NH^{4+}	NO^{3-}	NO^{2-}	DIN
Without *Gracilaria*	9.38±3.39	1.78±0.30	0.69±0.08	11.85±3.53
With *Gracilaria* (after 24 h)	2.96±0.99	1.37±0.45	0.60±0.12	4.94±1.55
Percentage (%) of Removing nutrient	68.44	23.03	13.04	58.31

3.3 Decrease in densities of microalgae

In the 12 day mesocosm experiments demonstrated that *G. lemaneiformis* negatively impacted microalgae growth . The densities of phytoplankton increased from 3.017*10⁴ to 105.5*10⁴ cell/L in the mesocosms without *Gracilaria*. In mesocosms with *Gracilaria*, densities only increased from 2.387*10⁴ to 26.5*10⁴cell/L. The densities of phytoplankton were always lower in the mesocosm with *Gracilaria* (Fig. 3) . Recent research demonstrates that this seaweed has potential algicidal effects on microalgal bloom species including *Alexandrium tamarense, Amphidinium carterae, Skeletonema costatum, Chaetoceros curvisetus, Scrippsiella trochoidea* and *Prorocentrum donghaiense* (Liu et al.,2006; Wang et al., 2007). Large scale cultivation of *Gracilaria* may be an effective ecological strategy in the control of harmful algal bloom species in Chinese coastal waters.

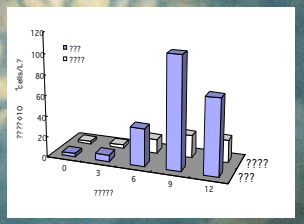

Fig. 3. Comparison on total phytoplankton densities in the mesocosms with (white) and without *Gracilaria* (blue).

Conclusions

The rapid development of mariculture in China has produced serious environmental problems such eutrophication, hypoxia and high frequency harmful algal blooms including red tide events.

Large scale cultivation of *Gracilaria* – appears to decrease coastal eutrophication, increase DO concentrations, and controls harmful algal bloom species (including red tide blooming species) in mariculture areas.

Large-scale cultivation of *Gracilaria* could be an effective bioremediation strategy in maintaining the water quality in and around finfish aquaculture areas in China.

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