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The past, present and future of phycology in China

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Abstract

Algae have been part of Chinese life for thousands of years. They are widely used as food and have been cited in Chinese literature as early as 2500 years ago. However, formal taxonomic studies on Chinese algae were initiated by foreign scientists only about 200 years ago, and by Chinese phycologists only about 90 years ago. This paper summarizes the history of modern phycological studies on Chinese algae and provides an overview of the achievements of phycological studies by Chinese scientists, especially on algal taxonomy, morphology, genetics, ecology and environmental research, physiology, biotechnology, algal culture, applied phycology and space phycology, in the last century. Recent development in phycological research focuses on algal floristic and molecular systematics, algal molecular biotechnology, applied phycology including micro and macroalgal cultivation and algal product development, and the roles of algae in environmental pollution control. These areas will also be the main focuses of Chinese phycological research in the foreseeable future.

Introduction

Although phycology, the study of algae, was started in the west, the earliest bibliographic record of the algae appeared in an old Chinese book *Shijing* (Poem Classic), at least 2500 years ago. This paper reviews only contributions to Chinese phycology.

Reports on taxonomy of Chinese algae by foreign scientists

Modern study of the algae started about 200 years ago by Dawson Turner (1809) on a Chinese alga, *Fucus tenax* Turner (= *Gloiopeltis tenax* (Turner) Decaisne), a silk sizing seaweed. In the last century six other scientists had dealt with Chinese seaweeds, including C. Agardh (1820), Montagne (1840), J. Agardh (1848, 1879), Kuetzing (1849), Martens (1866) and Debeaux (1875). In the present century, there were at least 14 foreign scientists interested in Chinese seaweeds, including Gepp (1904), Cotton (1915), Grunow (1915, 1916), Ariga (1919), Collins (1919), Reinbold (1919), Cowdry (1922), Howe (1924, 1934), Tilden (1929), Yamada (1925, 1950), Okamura (1931, 1936), Setchell (1931a, b; 1933, 1935, 1936), Grubb (1932) and Noda (1971).

The first report on Chinese fresh water algae was undoubtedly that by the French scientist P. Petit who published a paper on Ningbo algae in 1880. Borge published in 1899 a collection of freshwater algae by the Russian military officer N.-M. Przewalski from North and Northwest China and determined by K. Maximoviz. The German scientists, E. Lemmerman and H. Schauinland, reported their collection of Asian algae and algae from Jinjiang to Zhenjiang in 1899, 1901, 1907. The Russian P.K. Kozov collected algal specimens from Mongolia and Tibet in 1899-1901, and the lists were published in 1907 by C.S. Mereshkowsky. The American scientist N.G. Gee published a series of papers on Zhejiang and Jiangsu algae in 1919 and 1926. The French L. Vaillant and C. Gaudichaud collected some fresh water algae at Macau in 1836–1837; these algae were reported in 1844–1846 by C. Montagne. The famous Swedish explorer A. Sven Hedin visited China six times and collected some algae which were later published by F. Hustedh in 1922, W. Wille in 1930 and Borge in 1934. Another famous explorer, the Austrian H. Handel-Mazzetie came to China in 1913 and had also collected some algae which were studied and published by H.Skuja in his Symbolla Sinica in 1937. Other investigators were J.E. Tilden in 1920, Okada in 1932 and 1936, K. Negora in 1940, 1941, 1943 and 1953, Mashiko in 1951 and M. Noda in 1963 and 1971. This brief discussion on the reports of foreign scientists on Chinese fresh-water algae is extracted from a report on the history of systematic classification of Chinese freshwater algae by Professors Bi, Hu and Liu (Bi et al., 2001) containing the necessary references.

Modern study of phycology by Chinese scientists

Modern study of phycology by Chinese scientists was undoubtedly initiated by C.S. Chien (Professor Qian Chong Shu) who published a physiology paper in 1917 on 'Peculiar Effects of Barium, Strontium and Cesium on *Spirogyra*' (Chien, 1917). Professor H.H. Chung came back to China after some years of postgraduate study at Harvard University in U.S. Apparently, he took a course on algae at the Woods Hole Marine Biology Laboratory in the early twenties and became interested in phycology. In his trip to the vicinity of Xiamen and other places in Fujian, Guizhou and Hubei Provinces, he collected not only vascular plant specimens but also algal specimens including seaweeds and freshwater algae. He did not study the algal specimens himself but sent them to Dr N.L. Gardner of U.S. He even taught a course on algology at Xiamen University in 1929 in which I had the opportunity to attend.

Taxonomic phycology

The first Chinese to study taxonomic phycology in China is Wang Chu-Chia (Prof. Wang Zhi-Jia) who published his first paper in 1930 (Wang, 1930), and altogether 12 papers. The next one is Li Liang-Ching (Dr L.C. Li) who published in 1932 an abstract of his dissertation of Doctor's degree (Li, 1932), and altogether 29 papers. The third phycologist is C.K. Tseng (Dr Zeng Cheng-Kui) who published his first phycological paper in 1933 (Tseng, 1933), and altogether, to date, 344 papers, of which 97 concerned taxonomy and resources, and edited 12 books. The fourth phycologist is Jao Chin-Chih (Dr Rao Qin-Zhi) who published his first paper on Chinese phycology in 1935 (Jao, 1934), and altogether 76 phycological papers and edited two books. The fifth phycologist is Nie Dashu (Prof. Ni Da-Shu), a protozoologist turning to a Dinophyta phycologist and published his first paper in 1934 (Wang & Nie, 1934), and altogether 12 papers. Professor Nie eventually became the first Chinese specialist on aquatic animal diseases. The sixth phycologist is Chin Teh-Chiang (Prof. Jin De-Xiang) who was originally a zoologist and after obtaining M.Sc. at Lingnan University in 1935 became interested in phytoplankton; he published his first phycological paper in 1937 (Chin, 1937) and studied diatoms ever since, publishing 65 papers and four books. The seventh phycologist is Chu Hao-Ran (Zhu Hao-Ran), a former student of Dr Jao who published his first paper in 1944 (Chu, 1944), and altogether 40 papers and one book. The eighth phycologist is Ley Shang-Hao (Prof. Li Shang-Hao), also a former student of Dr Jao, published his first phycological paper in 1944 (Ley, 1944), and altogether 9 papers and one book.

The above eight phycologists, including three marine and five freshwater phycologists, were practically the few scientists devoted to the study of algae before 1949 who continued their studies of taxonomic phycology after 1949. After the establishment of the People's Republic of China, the Chinese people especially people of the coastal provinces, pay more attention to the algae and a few universities even offer courses in phycology. Many scientists are involved in the study of different phases of algae. In taxonomic study of the algae, we may mention just a few, such as Profs Chiang Young-Ming of Taiwan and Fan Kung-Chu of mainland China, both students of the late Dr George Papenfuss of U.S., Profs Zheng Bo-Lin, Zhang Jun-Fu, Xia Bangmei and Lu Baoren, students of Dr C.K. Tseng, Prof. Bi Lie-Jiao, a student of Dr C.C. Jao.

As is in the other botanical and zoological sciences, taxonomy always preceeds other sciences. A total of 40 000 specimens of marine algae and 30 000 specimens of freshwater algae have been collected respectively by the Institute of Oceanology and Institute of Hydrobiology of the Chinese Academy of Sciences (CAS) alone. The publication of the Cryptogamic Floras of China started in the seventies, consisting of five floras (1) Marine algal flora, (2) Fresh water algal flora, (3) Fungal flora, (4) Lichen flora and (5) Mosses and Liverworts flora. The algal flora was split into two because persons involved and collecting methods in these studies are different from one another. In the marine algal flora (Flora Algarum Marinarum Sinicarum) two volumes have been published: Vol. 2, Rhodophyta, No. 5 Ahnfeltiales, Gigartinales and Rhodymeniales by Xia & Zhang (1999) describing 17 families, 40 genera and 104 species; and Vol. 3, Phaeophyta No. 2 Fucales by Tseng & Lu (1999) describing 3 families, 6 genera and 141 species. Two more volumes on Ceramiales (Rhodophyta) by Zheng Bo-Lin et al. and on Centricae (Bacillarophyta) by Guo Yu-Jie are in the process of editing and will be ready for printing soon. In the fresh water algal flora (Flora Algarum Sinicarum Aqua Dulcis) six volumes have already been published: Vol. 1, Zygnemataceae by C.C. Jao (1986); Vol. 2, Chroococcophyceae by H.R. Chu (1991); Vol. 3, Charophyta by Han Fushan & Li Yaoying (1994); Vol. 4, Centric diatoms by Qi Yuzao (1995); Vol. 5, Ulothricales, Ulvales, Chaetophorales, Trentepohliales and Sphaeropleales by Li Shang-Hao & Bi Lie-Jiao (1998); and Vol. 6, Euglenophyta by Shi Zhixin (1999). Two more volumes are in the process of being edited, and will be ready for printing soon.

Basic study on morphology, ecology and physiology of the algae

Algal morphology

Tseng & Chang (1954, 1955) started their investigation on the life history of *Porphyra tenera* Kjellman in early 1952, independent of Kurogi of Japan and solved the problem of the 'seed' of *Porphyra* in its cultivation. This they called 'conchospore' which has been followed by most phycologists. In the eighties, Tseng & Sun (1989) studied the chromosome numbers of the *Conchocelis* stage of *Porphyra* and the alternation of the nuclear phases and chromosome numbers. They revealed the astonishing phenomenon that meiosis occurs in the germinating conchospores (Tseng & Sun, 1989).

Algal ecology

The most difficult job in algal ecology takes place in marine expeditions. One has to collect the specimens of phytoplankton by special devices, to analyze the collected specimens, to identify them and to write out reports. Algal ecological work actually started in 1954 when we initiated fishery expedition under the ichthyologist Professor Zhang Xiao-Wei and the ecological group was led by Dr Zhu Shup-Ping with Guo Yu-Jie as his assistant. The population was analyzed and the ecological characteristics of the dominated species decided. This was followed by national oceanological expeditions (1958–1962), coastal zones and beaches investigation (1981–1986), islands investigation (1990–1992), and Xisha and Nansha Islands expeditions (1980–1999). In these studies, Guo was in charge of the phytoplankton study. She contributed a paper on the primary productivity and phytoplankton of the Kuroshio (Y.J. Guo, 1991). She believed that the Kuroshio area was one of the unproductive regions in the world oceans, although it was a little more productive than the regions near the Equator. In a study of the characteristics of phytoplankton distribution in the Yellow Sea, Guo & Zhang (1996) pointed out that the horizontal and vertical distribution patterns of the phytoplankton in the Yellow Sea in May and September in 1992 were similar but the average abundance and species number of phytoplankton in September were higher than those in May. Diatoms dominated the 142 species of phytoplankton identified.

Since the seventies, our scientists paid special attention to marine pollution ecology, especially the ecology of red tides. On the ecological dynamics of the red tide, it was found that between *Noctiluca scintillans* (Macartney) Ehrenberg and *Skeletonema costatum* (Grev.) Cleve, *Prorocentrum minimum* (Pavilard) Schiller and *Skeletonema*, there was in existence a definite interspecific competition and that the appearance of different red tides was related to the N/P ratio (Zou, 1999). Investigation on the poisonous substance present in shellfish may indicate the distribution of the poisonous algae (Zhou et al., 1999).

Gymnodinium mikimotoi Miyake *et* Kominami *ex* Oda was one of the principal red tide organisms in the red tide occurring in Hong Kong and Guangdong Province, resulting in the death of many aquaculture fish in 1998 (Qi et al., 2004). An investigation was conducted by Jinan University on the mechanism of this Dinophyte on the fish and found out that this Dinophyte can cause swelling on the upper skin tissue of the fish gills. This resulted in the complete obstruction of the gills, leading to the death of the fish.

Algal physiology

In the early forties when C.K. Tseng worked on a special agar project, he initiated a study of the photosynthesis of *Gelidium cartilagineum* (L.) Gaillon and published a paper in 1946 (Tseng & Sweeney, 1946). In the sixties a study was made on the pigment system and photosynthesis of *Porphyra yezoensis* Ueda (Zhou et al., 1966). Unfortunately the researches had to stop in late 1966 because of the so-called 'Cultural Revolution'. The work was resumed in 1973, and a comparative study of the spectrum absorption of some species of green, brown and red seaweeds was made and published in 1974 (Zhou et al., 1974). A series of papers on comparative photosynthesis of benthic seaweeds was published by Tseng et al. (1980, 1981a, b). The discovery of *Prochloron* in the Xisha (Paracel) Islands (Zeng et al., 1982), led us to discussion on the evolution of photosynthetic organisms (Tseng & Zhou, 1983a, b; 1984).

Algal genetics

Talking about algal genetics, we must pay due respect to the late Prof. T.C. Fang (Fang Zong-Xi), the founder of this science in China. Fang was trained as a human geneticist in England and returned to China in 1950. In 1953, he accepted the invitation of Shandong University, then in Qingdao, and joined the staff. Later in 1959 when the Shandong University moved to Jinan, he stayed and joined the staff of Shandong College of Oceanography. He was invited by the Institute of Oceanology, CAS, to be a part-time research fellow and in charge of genetic research. He used the cultivated *Laminaria* as the main subject for genetic research. In 1959, the principal problems of the cultivation of *Laminaria japonica* Aresch. had been solved and large-scale cultivation had just started. The problems concerning genetics of the *Laminaria* became significant. The *Laminaria* employed is the wild natural population, rather than selected strains. However, *Laminaria* has sexual reproduction. In the spore collecting process, two or more plants were used. The resulting sporophytes were a mix of those from hybridization and those from a single plant self-fertilization. Fang made an experiment with both and showed that hybrid sporophytes exhibited a two times faster in growth in area than those obtained from self fertilization (Fang & Jiang, 1962).

From 1959–1984, Fang and his students at the Institute of Oceanology, CAS and the Shandong College of Oceanology conducted 25 years of genetical research on *Laminaria* and later also on *Undaria*. On the conviction that the cultivated *Laminaria* is a hybrid, they employed self-fertilization to produce a few new strains of *Laminaria*, such as the broad leaf strain 'Haiqing No. 1', the long leaf strain 'Haiqing No. 2', and the thick leaf strain 'Haiqing No. 3'. They obtained clones of male and female gametophytes and discovered that parthenogenetically developed female gametophytes gave rise to female sporophytes which produced zoospores that grew to become female sporophytes (Fang & Dai, 1984).

The Shandong College of Oceanography, in cooperation with Rongcheng *Laminaria* Seedling Station and Rongcheng Aquaculture Station, used a selected female gametophyte to cross with the male gametophyte from a thick frond sporophyte and obtained a new strain called 'Danhai No. 1' which gave a higher yield and better quality than the best variety used in cultivation at that time (Fang et al., 1983). In 1981, Fang and his group employed the hybrid between the female haploid clone No. 10 and the male haploid cell introduced from Hokkaido, Japan. A new strain was obtained, the 'Danza No. 10', which was estimated to increase the yield by 30% (Fang et al., 1985). The bountiful *Laminaria* harvest became a reality and this must be partially credited to Prof. Fang.

Studies on microalgae, biotechnology and space phycology

Microalgae

In the fifties, the investigation on feeding marine juvenile aquatic animals with some microalgae such as *Tetraselmis*, *Phaeodactylum*, *Pavlova* was carried out. The animal growers were provided with the seeds of these algae and instructions for their cultivation. In the early sixties, cultivation of the freshwater alga *Chlorella* sp. in large scale was tried but failed. In the eighties, the brine alga *Dunaliella* was started to be cultivated in large scale and *Dunaliella* cultivation is now an established industry (Guo, 1991). In the seventh five-year plan, one of the problems was to decrease the dependence of aquaculture on imported fish protein. It was decided to study three microalgae because of their high protein contents, namely, *Dunaliella*, *Anabaena* and *Spirulina*. It was found that *Spirulina* gave the best and most proteinaceous products. It was further found that *Spirulina* is an excellent health food for humans (Wu et al., 1993). During the following years, there had been a *Spirulina* 'fever' in Chinese society and more than 100 enterprises were involved in *Spirulina* production. There are now still quite a few enterprises producing tablets for human consumption (Liang et al., 2004).

Biotechnology

Biotechnology has been effected in marine algae in the following six categories: (1) In hybridization technique, hybrids of *Laminaria japonica* have been obtained. (2) In cellular and protoplast technique, cultivation of *Porphyra haitanensis* Chang *et* Zheng has been effected with vegetative cell; growth of isolated seaweed protoplast of *Ulva*, *Enteromorpha*, *Monostroma*, *Porphyra* and *Chondrus* has been obtained. (3) Algal immobilization technique has been attempted for seedstock and seedling production. (4) In tissue culture technique, tissue cultures of *Laminaria japonica* and *Undaria pinnatifida* (Harv.) Sur. have been effected. (5) In processing of natural products, including bioactive substances, some work on anti-tumor and anti-radiation effect of marine algae has been done and the hypolipodermis medicine PSS from *Laminaria japonica* has been awarded golden medal in the 15th International Fair of Invention in Yugoslavia. (6) In biotechnology industry, we have promoted mass cultivation of *Dunaliella* for the β-carotene and that of *Spirulina* for its high protein content (Tseng & Qin, 1991).

Space phycology

Space biology is quite a new thing in China, especially space phycology for which we have to thank the Institute of Hydrobiology, Chinese Academy of Sciences. A good discussion of this research is found in Liu et al. (2001). In the Chinese Journal of Space Science, Vol. 17, supplement 1997, several papers were published by Prof. Y.D. Liu and his colleagues. In there, Prof. Liu and his colleagues summarized the interesting points about microgravity biology, space physiology, cell culture and tissue engineering, space exploitation and some details concerning gravisensing (Hu & Liu, 1997a, b; Song et al., 1997). They found in the flight experiment that in *Chlorella pyrenoidosa* Chick the number of pyrenoides conspicuously diminished and in *Anabaena* its fat body significantly decreased in size. Their experiments on *Anabaena oryza* Fritsch strains retrieved from space flight and reflight indicated two types of biological responses, the recoverable phenotype responses and the heritable genotype responses (Hu et al., 1996; Hu & Liu, 1997c). Their study of a strain of the microalga *Anabaena* carried in the retrievable canister for 15 days showed that the growth rate of the alga was slower than that of the ground control (Hu et al., 1997). In another experiment, nine species of algae were flown in space for eight or fifteen days, then retrieved and analyzed in the laboratory (Hu & Liu, 1997b). The results indicated that the algae have a strong adaptability to space environment. Cytological observation on *Anabaena siamensis* Antarikanonda after space flight showed obvious difference between the space flight and the ground control samples (Chen et al., 1997). The possible mechanisms of responses of *Dunaliella salina* (Dunal) Teodoresco to simulated microgravity showed the plasma membrane to be the most direct site of paraperception and a theoretical model for micro-gravi-sensing, transduction and responses of the organism was proposed (Hu & Liu, 1997d).

Applied studies on cultivation of seaweeds and the seaweed industry

Cultivation of algae

Cultivation of seaweeds by traditional methods, to the knowledge of the author, dealing with *Gloiopeltis* and *Porphyra* has been in existence in China for several hundred years. Modern methods of cultivation are, however, only about forty something years old. Rafts in various forms are generally applied. Three kinds of methods are practiced.

Zoospores method, the Laminaria *type of mariculture*

The zoospores of *Laminaria* or *Undaria* are collected and cultured. *Laminaria japonica* is a cold temperate alga and can survive in summer water temperature of 20–25 °C, but cannot survive in temperature above 25 °C for a long time. We have devised a summer sporeling method in which zoospores are collected in early June, the gametophyte and young sporophyte stages pass the hot summer in cooled rooms of 10 °C, and the young sporophytes are taken out to the sea in Autumn when water temperature gets down to 20 °C. The summer sporeling method is very suitable for cultivation of cold temperate plants in warm temperate or even subtropical regions (Tseng et al., 1955; Tseng, 1981).

Conchospore method, the Porphyra *type of mariculture*

This is especially applicable for the cultivation of purple laver, *Porphyra* spp. The leafy *Porphyra* is the object of cultivation. Carpospores from *Porphyra* are planted on mollusc shells in late Spring. The carpospores will penetrate into the shell and develop the filamentous sporophyte stage – the *conchocelis* stage. This will eventually give rise to conchospores which upon germination will grow to become the leafy *Porphyra* (Tseng & Chang, 1955; Tseng, 1981). The filamentous thalli of *Bangia fusco-purpurea* (Dillw.) Lyngb. are also cultivated by this method.

Vegetative multiplication method, the Betaphycus *type of mariculture*

This is applicable to quite a few species of seaweeds beside *Betaphycus*, such as *Gracilaria*, *Kappaphycus* and *Hizikia* (= *Sargassum fusiforme* (Harv.) Setch.). Carpospores of *Gracilaria lemaneiformis* (Bory) Daws. upon germination will give rise to a callous like structure which will have to take about half a year to grow up to become young sporelings and another half year to grow to become an adult plant. For practical purposes, the growth rate is too slow. In the vegetative multiplication method, cuttings of *Gracilaria* are planted on raft during the best season for their growth and they grow to 100–200 times their original thallus in weight in one season. In the case of *Gelidium* and *Hizikia*, very young plants are employed.

Fertilizer application and Laminaria *transplantation to the south*

In the cultivation of *Laminaria*, a method of applying fertilizer in the open sea was devised (Tseng et al., 1955b). Southward transplantation of *Laminaria* to Zhejiang and Fujian Provinces of the East China Sea, which is subtropical in nature has been conducted with success (Tseng, 1958). With the help of the summer sporeling method, the height of the hot summer temperature and the duration of hot summer are not of major concerns. Rather, it is the length of the winter and spring seasons that is important, i.e. whether the seasons are long enough to effect growth of the plant to market size. By this way, the cold temperate *Laminaria japonica* is now maricultured in warm temperate and subtropical regions such as Zhejiang and Fujian (Tseng, 1981).

Current algal cultivation industry

At present two species each of *Porphyra* and *Gracilaria*, and one species each of the following: *Bangia*, *Gelidium*, *Kappaphycus*, *Betaphycus*, *Laminaria*, *Undaria* and *Hizikia* (= *Sargassum fusiforme*) are under cultivation by the above methods of mariculture.

There is also a small microalgae cultivation industry, a *Dunaliella* and a *Spirulina* mariculture industry. The *Dunaliella* culture group is located in Tanggu, Tianjin, a part of the Salt Research Institute, which received funding from the United Nation Development Programme (UNDP). This produces β-carotene present in the cells in as much as 6% of the dry weight (Guo, 1991). The *Spirulina* culture group is located in Sanya, Hainan Province in south China. It belongs to the South China Sea Institute of Oceanology. *Spirulina* is well known for its protein contents, 60–70% of the plants in dry weight (Wu et al., 1993). There are about 50 *Spirulina* culture groups in China, mostly freshwater, producing altogether less than 1000 tons of *Spirulina* powder per year.

Marine algal industry

At present China has an alginate industry composed of a few factories and employing *Laminaria japonica* as the principal raw material. The alginate was used as a substitute for starch grains in sizing cotton fibers in Qingdao and a small factory was built for the production of sodium alginate. It is now popularly employed in textile industry and produced about 8000–10 000 tons of the alginate annually. The industry was initiated in the early fifties employing wild *Sargassum confusum* Ag. as the raw material (Tseng & Ji, 1962). In a few years resources of the raw material were practically depleted. So the industry had to turn to the cultivated *Laminaria*, which is more expensive but dependable as a raw material.

China has a small agar industry dating back to the thirties. There has been a small agar factory in Qingdao employing *Gelidium amansii* (Lamx.) Lamx. as the raw material. There are now a few small factories in Fujian Province employing over-mature thalli of *Porphyra haitanensis* as raw materials and a few small factories in Guangdong and Hainan Provinces employing *Gracilaria tenuistipetata* var. *liui* Zhang *et* Xia as raw material. Total annual production of agar at present is only a few hundred tons.

China has also a small carrageenan industry with a small factory in Hainan. For many years this factory employed locally produced *Betaphycus gelatinum* (Esper) Doty as the raw material and produced a product called ‘agar’ in the market. It is actually a carrageenan instead of an agar. The annual production is also a few hundred tons.

The future of Chinese phycology

Taxonomy and floristic study

Chinese phycology has started rather late in the 1930s. Compilation of Chinese algal floras, although planned in the early seventies, did not get the actual publication started until the eighties. The first volume, Tomus 1 of Floras Algarum Sinicarum Aqua Dulcis, Zygnemataceae is by Dr Chin-Chih Jao. At present, six volumes have been published in this series. In the Flora Algarum Marinarum Sinicarum two volumes have been published. Four volumes of these two series have just finished compilation and are in the process of being edited. Fourteen more volumes in these two series of algal floras will be compiled in the next few years. Preparation for the other algal groups, mostly microscopic and uncommon species, will follow. Studies on soil algae, desert algae, snow algae and hot spring algae should be encouraged.

Ecological study

Phytoplankton in terms of nannoplankton and the smaller picoplankton have received careful studies for the last forty something years. A few years ago, Dr Jiao Nian-Zhi found the picoplankton *Prochlorella* in the Pacific. This picoplankton was found in great quantity below 100 m of sea water. Recently it was also found in the South China Sea. We are actually unaware taxonomically just how many genera and species of Prochlorophyte there are. The only way to find out is to keep on investigating. But it will involve a lot of expenses for ship times and instrumentations. Survey of deep lakes should also be taken. I believe we shall find similar picoplankton. Since the seventies, algal ecological study in terms of the environment has become more and more important.

China's marine environment has been troubled more and more with red tides and ways and means to predict and prevent the occurrence of red tides are becoming more and more important. We must protect our seas from pollution. In the fifties when we promoted cultivation of seaweeds, we had to fertilize our seas because there was then a very low N and P content. But now with the advance of animal aquaculture, the N and P contents in seawater have risen greatly. It is therefore suggested that large perennial seaweeds should be planted to help absorb these excess nutrients and large scale cultivation of seaweeds could be carried out for the same purpose to protect the environment (Fei & Tseng, 2003). With the development of space technique, space phycology must be emphasized.

Biotechnology study

Emphasis should be laid on molecular biotechnology of seaweeds, referring to the biotechnology on identification, modification, production and utilization of seaweed molecules, not only manipulating macromolecules such as DNA, RNA and proteins, but also dealing with low molecular weight compounds such as secondary metabolites. Studies on molecular genetic labeling techniques and genetic engineering should be made (see Qin et al., 2004).

Comparative photosynthesis and evolution

Photosynthetic pigments of the algae are much more complicated than those of the seed plants, especially the phycoerythrin and phycocyanin, which are not found in the seed plants. Comparative photosynthesis of the algae with different photosynthetic pigments will show many things, especially the course of evolution. It is therefore suggested that studies on comparative photosynthesis should be continued.

Cultivation of algae

It may be said that modern seaweed cultivation has started in China in the early fifties when raft cultivation and the summer sporeling method of *Laminaria japonica* cultivation were initiated, making the *Laminaria* cultivation an important successful industry. In some years, just the *Laminaria* industry alone reached an annual production of over three millions tons, fresh weight. The method currently employed is basically that of the fifties with some small changes. For instance, in the cultivation of the summer sporelings, big green houses are still in use, and the zoospores are collected by numerous *Laminaria* fronds of one or several strains dumped together. We firmly believe that biotchnology should be applied to the cultivation of *Laminaria* sporelings and changes of the method be applied.

The *Porphyra* cultivation, thanks to Professor Fei Xiu-Geng, who holds a few patents in *Porphyra* cultivation method and has collected about 20 species from different parts of the world and more than 100 strains in his culture room, our *Porphyra* cultivation has been modernized to some extent. We believe that application of modern biotechnology can further modernize our *Porphyra* cultivation method.

In the present method of cultivation of *Gracilaria lemaneiformis,* the favorable growth temperature of 12–22 °C necessitates the storage of the seaweed during unfavorable season in low temperature room. Its growth is, however, best in the southern provinces probably because of higher concentration of nutrients elements, although its home in China is up north in Qingdao. We believe that by mean of modern biotechnology, we shall be able to improve our current farming method.

Hizikia (=*Sargassum fusiforme*) is now cultivated by transplants of young plants. The method has to be modernized because the current method consumes too much raw materials, depleting the natural resources.

At present, we cultivate nine genera and 11 species of seaweeds. There are a few more algae that deserve cultivation. For instance, *Caloglossa leprieurii* (Mont.) J. Ag., the famous antihelmintic *Zhegucai*, is in need of cultivation. *Gloiopeltis furcata* Post. *et* Rupr. and *G. tenax* (Turn.) J. Ag. are excellent silk sizing materials and the first algae to e cultivated in China. Modern cultivation method should be applied. So far, cultivation of freshwater algae is limited to a few microalgae, especially *Spirulina*. There is a demand on the market to have more 'Facai', *Nostoc commune* var. *flagelliformis* (Berkeley *et* Curtis) Bornet & Flahault. I hope that our freshwater algologist will see to it that *Facai* will be cultivated in the near future.

Algal industry

There is at present an alginate industry with producing ability of 13 000 tons of alginate annually. Its quality is, however, inferior to that of the American product and some improvement is needed. Our agar industry is in need of good raw materials. Recently, *Gracilaria lemaneiformis*, which gives a good agar, has been subjected to cultivation. We expect to have a good agar industry. Our carrageenan industry depends on *Betaphycus gelatinum* which produces a product called 'agar' for a long time but is actually a beta-carrageenan. We just began to cultivate *Kappaphycus alvarezii* (Doty) Doty *ex* Silva and the production of Kappa-carrageenan will be expected.

PSS and FPS are the two medicines now made from extract of *Laminaria japonica*. We believe there are many more bioactive substances in this group of lower plants, especially the microalgae. A few health food products are in the process of production. There is a great number of interesting and valuable compounds in the microalgae, not only the marine but also the freshwater microalgae, waiting to be developed (see Liang et al., 2004).

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