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Overview on seagrasses and related research in China*

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Abstract Seagrass research in China is still in its infancy. Even though there has been progress recently, there is still a great deal of research needed to gain a better understanding of seagrass. In this article we review and discuss the advances in seagrass research in China from two aspects: (1) seagrass species and their distribution; (2) seagrass research in China, including studies on their taxonomy, ecology, photosynthesis, applications in aquaculture, salt-tolerance mechanisms and other research topics. A total of 18 seagrass species belonging to 8 genera are distributed in nine provinces and regions in China (including Hong Kong and Taiwan), as well as the Xisha and Nansha Archipelagos. They can be divided into two groups: a North China Group and a South China Group. Based on the seagrass distribution, the Chinese mainland coast can be divided into three sections: North China Seagrass Coast, Middle China Seagrass Coast, and South China Seagrass Coast. Ecological studies include research on seagrass communities, nutrient cycling in seagrass ecosystems, genetic diversity, pollution ecology and research in the key regions of Shandong, Guangdong, Guangxi, and Hainan. Seagrass species and their locations, community structure, ecological evaluation, epiphytes, ecological functions and threats in the key regions are also summarized. Other studies have focused on remote sensing of seagrass, threatened seagrass species of China, and pollen morphology of *Halophila ovalis*.

Keyword: seagrass; seagrass meadow; marine ecosystem; China

1 INTRODUCTION

Seagrasses, defined as flowing plants growing in shallow marine environments, formed an ecological group and not a taxonomical group (Kou et al., 2000). Seagrasses grow in the shallow marine and estuary environments of all the world's continents except Antarctica. Seagrass distribution in the world was divided into ten regions: North Pacific (Japan to Baja), Chile, North Atlantic, The Caribbean, Southwest Atlantic Region, Mediterranean Region, Southeast Atlantic Region, South Africa Region, Indo-Pacific Region and South Australia Region (Short et al., 2001). The primary food of animals such as manatees, dugongs, green sea turtles, and critical habitat for thousands of other animals and plants species, seagrasses were also considered one of the most important shallow-marine ecosystems for humans since they play an important role in fishery production (Green et al., 2003). It was estimated that global Seagrass area was 170 000 km^2 (Green et al., 2003). Some 247 protected sites were known to include seagrass ecosystems, and two in China.

The first published record of seagrasses in China was that of Miki (1932), who described new species in Japan and reported localities in the Chinese territory. Other reports of the wider distribution of Japanese species by Miki (1933, 1934) brought the total number of species recorded from China to six. In the 1970s, some data on seagrasses from the Hong Kong region were published (den Hartog, 1970; Hodgkiss et al., 1978a, b). The seagrass species and their distribution in China were recorded in a number of books (Institute of Botany, Guangdong, 1977; Zheng, 1990; Fang, 1992, 2004; Institute of Botany, the Chinese Academy of Sciences, 2002; Wu et al., 2004; Ye, 2005) and, more recently the data on the

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seagrasses of China updated (Wu et al., 2004.). From 1979 to 1993, Mr. Yang Zongdai and several other scholars systemically studied Chinese seagrasses, including their taxonomy (Yang et al., 1983; den Hartog et al., 1990; Yang et al., 1993), morphology (Yang et al., 1983; Yang et al., 1993), distribution (Yang, 1979; Yang, 1985), ecology (Yang et al., 1981, 1984; Yang, 1982) and applications in aquaculture (Ren et al., 1991). Following the death of Yang Zongdai, in the subsequent seven years there were only six publications on Chinese seagrasses (Ma et al., 1994; Gao et al., 1995a, b; Victor et al., 1996; Liu et al., 1998; Yu et al., 1998). However, since the turn of the century, many scholars have studied different aspects of seagrass biology, including their distribution (Fan et al., 2007a), morphology (Sun et al., 2002), salt-tolerance mechanisms (Ye et al., 2002a, b), photosynthesis (Wang et al., 2004; Fan et al., 2007b), and ecology (Huang et al., 2006a; Han et al., 2007a,b; Huang et al., 2007a). However, Chinese seagrasses remain poorly known and much additional research is required.

In this paper, species, distribution, biology and ecology of seagrasses in China had been reviewed in order to accelerate seagrass researches in China and introduce the results to the world.

2 SEAGRASS SPECIES AND DISTRIBUTION IN CHINA

According to taxonomic publications (den Hartog et al., 1990; Yang, 1993; Huang, 1994; Lin et al., 1999; Zhao et al.,. 1999; Morton et al., 2001; Shen et al., 2002; Fan et al., 2004; Yip et al., 2006; Lin, 2006; Huang et al., 2007b), a total of 18 seagrass species belonging to 8 genera are distributed in 9 provinces and regions in China (including Hong Kong and Taiwan), as well as the Xisha and Nansha Archipelagos (Table 1)[2]. Only one species, *Zostera japonica*, occurs in both North China and South China. Seagrass diversity is distinctly higher in South China (7 genera, 12 species) than in North China (two genera, 7 species) (Table 1). Therefore, the 18 seagrass species can be divided into two geographic groups: 1) North China Group, including (nos. 1–7) in Table 1, belonging to the North Pacific Region of the global seagrass distribution, and 2) South China Group (species no. 3 and nos. 8–18), belonging to the Indo-Pacific Region of the global seagrass distribution (Short et al., 2001).

It is notable that seagrass species are not recorded from coastal middle China in Jiangsu and Zhejiang Provinces (although some seagrasses occur on Zhejiang's islands), because the seawater transparency is too low for seagrass survival (Yang et al., 1981). It is implicated that the Chinese mainland coast can be divided into three sections: North China Seagrass Coast, Middle China Seagrass Coast and South China Seagrass Coast.

3 SEAGRASS MORPHOLOGIC TAXONOMY

Yang et al. (1983) utilized three numerical methods to clarify the taxonomy of seagrasses and selected 10 characters (ligulate leaves, distribution, presence/absence of tannins, monopodial or sympodial branching, herbaceous or woody habit, anthotaxy, concurrence of the leaf and leaf sheath, rhizome thickness, blade profile, and pollination mode) for a cladistic analysis of twelve genera. These authors subdivided seagrasses into five families, namely Zosteraceae (*Zostera*, *Phyllospadix* and *Halodule*), Thalassiaceae (*Thalassia* and *Halophila*), Amphibolisaceae (*Amphibolis*, *Thalassodendron*, and *Heterozostera*), Posidoniaceae (*Posidonia*, *Cymodocea*, and *Syringodium*) and Enhalusaceae (*Enhalus*). Yang et al. (1993) also utilized cladistic methods to revise the taxonomy and reconstruct a phylogeny of seagrasses using the same 10 characters. The same five families and 12 genera were recognized but the classification of the genera was revised as follows: Zosteraceae (*Zostera* and *Phyllospadix*), Thalassiaceae (*Thalassia* and *Halophila*), Amphibolisaceae (*Amphibolis*, *Thalassodendron*, *Heterozostera*, and *Syringodium*), Posidoniaceae (*Posidonia*, *Halodule*, and *Cymodocea*) and Enhalusaceae (*Enhalus*).

den Hartog et al. (1990) surveyed Chinese seagrasses and only listed 15 species. These authors recognized only two families. Potamogetonaceae (subfamilies Zosteroideae and Cymodoceoideae) was represented by 10 species (*Zostera marina, Zostera caespitosa, Zostera japonica, Phyllospadix iwatensis, Halodule uninervis, Halodule pinifolia, Syringodium isoetifolium, Cymodocea rotundata, Cymodocea serrulata* and *Thalassodendron ciliatum*) and the Hydrocharitaceae (subfamilies Vallisnerioideae, Thalassioideae and Halophiloideae) by five species (*Enhalus acoroides, Thalassia hemprichii, Halophila ovalis, Halophila decipiens* and *Halophila beccarii*).

[2] *Posidonia australis* Hooker f. and *Thalassodendron ciliatum* (Forskål) den Hartog were recorded in China (Wu et al., 2004; Hartog et al., 1990). However the sample was perfectly identified.Therefore, *Posidonia australis* and *Thalassodendron ciliatum* were not mentioned in this paper.

Table 1 Species and distribution of Chinese seagrasses

Species	Province or region	Geographical portion
Zostera marina L.	Liaoning, Hebei and Shandong	North China
Zostera caespitosa Miki	Liaoning, Hebei and Shandong	North China
Zostera japonica Ascherson & Graebner	Liaoning, Hebei, Shandong, Fujian, Taiwan, Guangdong, Hong Kong, Guangxi and Hainan	North and South China
Zostera caulescens Miki	Liaoning	North China
Zostera asiatica Miki	Liaoning	North China
Phyllospadix iwatensis Makino	Liaoning, Hebei and Shandong	North China
Phyllospadix japonicus Makino	Liaoning, Hebei and Shandong	North China
Syringodium isoetifolium (Ascherson) Dandy	Taiwan, Guangdong and Guangxi	South China
Halodule uninervis (Forskål) Ascherson	Taiwan, Guangdong, Guangxi and Hainan	South China
Halodule pinifolia (Miki) den Hartog	Taiwan, Guangdong, Guangxi and Hainan	South China
Cymodocea rotundata Ehrenberg & Hemprich ex Ascherson	Taiwan, Guangdong and Hainan	South China
Cymodocea serrulata (R. Brown) Ascherson	Taiwan and Hainan	South China
Enhalus acoroides (L. f.) Royle	Hainan	South China
Thalassia hemprichii (Ehrenberg) Ascherson	Taiwan, Guangdong, Hainan and Xisha Archipelago	South China
Halophila ovalis (R. Brown) Hooker *f.*	Taiwan, Guangdong, Hong Kong, Guangxi, Hainan and Xisha Archipelago	South China
Halophila minor (Zollinger) den Hartog	Guangdong, Hong Kong, Guangxi, Hainan, Xisha Archipelago	South China
Halophila decipiens Ostenfeld	Taiwan, and Hainan	South China
Halophila beccarii Ascherson	Taiwan, Guangdong, Guangxi, Hong Kong, Hainan and Xisha Archipelago	South China

Halophila ovalis was represented by 2 subspecies (*Halophila ovalis* ssp. *ovalis* and *Halophila ovalis* ssp. *pesudovalis*). The authors also presented a key to the species based on vegetative and generative characteristics (leaf, root, shoot, rhizome and flower).

Seagrasses are represented by twelve genera which have been classified in four families (Zosteraceae, Posidoniaceae, Cymodoceaceae, and Hydrocharitaceae). Zosteraceae includes three genena (*Zostera*, *Phyllospadix*, and *Heterozostera*); Posidoniaceae one genus (*Posidonia*); Cymodoceaceae five genena (*Cymodocea*, *Halodule*, *Syringodium*, *Amphibolis*, and *Thalassodendron*); Hydrocharitaceae three genena (*Enhalus*, *Thalassia*, and *Halophila*). (Kuo et al., 2001)

4 SEAGRASS ECOLOGY

4.1 Seagrass communities

Yang et al. (1981) studied seagrass communities in Qingdao, Shandong Province, which belong to the platyphyllous eelgrass ecobiomorphism. The algae growing epiphytically on the leaves of eelgrass (*Zostera*) and surfgrass (*Phyllospadix*) were *Heteroderma zostericola*, species of *Eromorpha*, *Ectocarpus*, *Polysiphonia* and *Ceramium* and several benthic diatoms. Several bryozoans also grow epiphytically on the leaf of eelgrass, for example, *Electra tenella*, *Microporella orientalis*, *Tubulipora flabellaris*, and *Bugula californica*. Polychaetes of the zoobenthos inhabit the seagrass meadow, including *Typosyllis fasciata*, *Typosyllis adamantens kurilensis*, *Exogone gemmifera*, *Exogone gemmifera*, *Brania clavata*, *Sphaerosyllis porifera* and *Polyophthalmus pictus*. Sessile seashells and shellfishes, natant shellfishes and fish larva were also members of this community.

4.2 Pollution ecology

Huang et al. (2007a) studied the shoot morphology, shoot density, biomass and nutrient contents in different tissues of the dominant species *Enhalus acoroides* in seagrass meadows in Xincun Bay, Hainan Island, and discussed the effects of nutrient loading of seawater and sediment-poor water on *Enhalus acoroides*. The results showed that: (1) there were significant differences between sampling sites in shoot morphology (leaf length, leaf width and shoot weight), shoot density and above-ground biomass of *Enhalus acoroides*, and these three factors were negatively correlated with the dissolved inorganic nitrogen (DIN) contents of seawater and sediment-pore water; (2) there was a significant difference between the total nitrogen (TN) and total phosphorus contents of *Enhalus acoroides* at three sampling sites; (3) the TN contents of *Enhalus acoroides* were positively correlated with the DIN concentrations of seawater and sediment-pore water at their respective sampling sites; (4) the epiphyte biomass per unit area of *Enhalus acoroides* leaves increased significantly with increasing nitrogen loading in the water column; and (5) the cage culture-derived nutrient loading was a potential cause for the decline of seagrass and degeneration of seagrass meadows in the cage-culture area of Xincun Bay.

4.3 Research in key regions

4.3.1 Qingdao, Shandong Province

In Qingdao, seagrass meadows are widespread, and are located at Jianggezhuang, Hongshiai, and Huangdao on the west coast of Jiaozhou Bay, at Shuangpu, Nügukou and Lunkou on the east coast of Jiaozhou Bay, at Xuejiadao in the mouth of Jiaozhou Bay, and at Damaidao and Shilaoren. Rocky coasts, where the wave impact is high, for example, the seagrass meadows of Jianggezhuang and the subtidal zone of Damaidao and Taipingjiao, are the main habitats of the surfgrass, *Phyllospadix iwatensis*, whose biomass and annual productivity were 1851 g/m^2 and 696 gC/m^2, respectively (Yang et al., 1981). *Zostera caespitosa*, whose biomass and annual productivity were 1 150 g/m^2 and 432 gC/m^2, respectively, grew from the mouth of Jiaozhou Bay to the submarine tidal flat of Zhanqiao. *Zostera marina* inhabited the inner bay from Huangdao to Hongshiya and was the dominant species in the wide tidal flat of Jiaozhou Bay; the biomass and annual productivity of this species were 1 500 g/m^2 and 564 gC/m^2, respectively (Yang et al., 1981). The annual biomass output of the epiorganisms was 20 g/m^2 (Yang et al., 1984). The coverage of seagrass in the intertidal zone and subtidal zone was more than 75%, but that on the mud or sand beach of the intertidal zone was less than 45% (Yang et al., 1981).

The epiorganisms in the seagrass meadow of Qingdao, which were divided into algae, microalgae, animals and bacteria, comprised 69 alga species, 25 polychaete species, 1 gephyrea species, 1 echiuran species, 3 brachiopod species, 108 mollusc species, 39 crustacean species, and 12 echinoderm species (Yang et al., 1984).

4.3.2 Guangdong Province

Seagrass meadows in Guangdong Province occur in Liusha Bay of Leizhou Peninsula, Donghai Island of Zhanjiang and Hailing Island of Yangjiang (Table 2). *Halophila ovalis* is the dominant species and distributes consecutively, accounting for more than 98% of the spatial area of seagrass meadows in Liusha Bay (Huang et al., 2006a).

4.3.3 Guangxi Zhuang Autonomous Region

Seagrass meadows in the Guangxi Zhuang Autonomous Region are distributed mainly in areas near Hepu, Beihai and Pearl Bay, Fangchenggang (Huang et al., 2006a).

4.3.3.1 Hepu, Beihai

4.3.3.1.1 Species, distribution and community structure

According to historical surveys, seven representative seagrass meadows occurred in Hepu (Table 3; Deng, 2002; Huang et al., 2006a). Seagrass species inhabiting Hepu seagrass meadows were *Zostera japonica*, *Halophila ovalis*, *Halodule uninervis*, and *Halophila beccarii*, which grew on the tidal flat of the intertidal zone and the clay-like and arenaceous part of the subtidal zone (Deng, 2002). The wet weight (WW) and dry weight (DW) of *Halophila ovalis* were 1 965.0 g/m^2 and 25.5 g/m^2, respectively, and the WW/DW ratio was 7.7 (Huang et al., 2006a).

4.3.3.1.2 Ecological evaluation

According to monitoring data from surveys of the Guangxi coastal fishing ecology and environment from 2001 to 2004, Ma et al. (2007) assessed the environmental quality of seawater in Guangxi Hepu National Natural Reserve for dugongs and found that the seawater was polluted by Zn, Cu and Pb (Table 4).

Based on the condition of Hepu seagrass meadows, Fang Jingwei (Deng, 2002) instituted a hierarchical

Table 2 Area, species, biomass, shoot density (SD), shoot productivity (SP) and leaf productivity (LP) of seagrass meadows in Guangdong, China (Huang et al., 2006a)

Location	Area (km^2)	Species	WW(g/m^2)	DW (g/m^2)	WW/ DW	SD(shoots/m)	SP(mg/shoot/h)	LP(mg/m/d)
Liusha Bay	9.	*Halophila ovalis*	189.5	25.7	7.4	5958	0.011424	1633.541
	–	*Halodule uninervis*	92.7	18.8	5.1	66	0.576900	913.810
Donghai Island	0.09	*Halophila beccarii*	–	–	–	–	–	–
Hailing Island	0.01	*Halophila ovalis*	–	–	–	–	–	–

DW: dry weight; WW: wet weight; –: No analysis

Table 3 Distribution, area and community structure of seven seagrass meadows in Hepu (Deng, 2002)

No.	Latitude and longitude (center)	Area (×10^{-2} km^2)						Community structure
		1987	1994	1999	2000	2001	2003	
1	21°29.00′N, 109°42.65′E	200	20	13	133	14	225	*Halophila ovalis*, solitary
2	21°32.12′N, 109°37.20′E	–	33	13	133	0.2	40	*Halophila ovalis*, solitary
3	21°28.67′N, 109°40.27′E	–	47	2.7	2.0	0.1	10	*Zostera japonica* and *Halophila ovalis*, conjunct; *Zostera japonica*, dominant
4	21°29.72′N, 109°41.03′E	–	–	–	–	13	18	*Zostera japonica* and *Halophila beccarii*, conjunct; *Zostera japonica*, dominant
5	21°27.65′N, 109°45.62′E	–	133	1.3	20	3.3	45	*Halophila ovalis*, *Halodule uninervis* and *Zostera japonica*, conjunct; *Halophila ovalis*, dominant
6	21°28.35′N, 109°42.00′E	–	27	13	33	3.3	47	*Zostera japonica*, solitary
7	21°35.08′N, 109°40.01′E	47	17	10	30	5.3	200	*Halophila ovalis*, *H. uninervis* and *Zostera japonica*, conjunct; *Halophila ovalis*, dominant

Table 4 Concentrations of pollutants in sea water in spring and autumn during 2001–2004 at Guangxi Hepu National Nature Reserve for dugongs and single factor assessment (Ma et al., 2007)

	Concentration (mg/L)			Assessment		
Item	Low	High	Mean	Pollution index	Mean	Quality status
Dissolved oxygen	5.95	9.58	7.73	1.08–0.90	0.08	Very good
Chemical oxygen demand	0.74	1.64	1.06	0.37–0.82	0.53	Good
Inorganic nitrogen	0.00	0.129	0.037	0–0.65	0.19	Very good
Inorganic phosphorus	0.00	0.023	0.005	0–1.53	0.33	Very good
Cu	0.00	0.045	0.008	0–9.00	1.50	Bad
Pb	0.00	0.035	0.006	0–35.00	5.8	Very bad
Zn	0.00	0.060	0.019	0–3.00	0.95	Normal
Cd	0.00	0.001	0.0002	0–1.00	0.20	Very good
pH	7.50	8.28	8.06	0.33–0.85	0.71	Good
Oil	0.00	0.05	0.014	0–1.00	0.28	Very good

evaluation standard for ecological importance, and evaluated the ecological importance of Hepu seagrass meadows.

Based on local research, statistical analyses and previous research results, Han et al. (2007a) analyzed the main services of the Hepu seagrass ecosystem, including fisheries, nutrient cycling, scientific research, protection of the coast from erosion, climate regulation, biodiversity maintenance, cultural value et al. Ecological and economic methods were used to evaluate the economic value of seagrasses in Hepu, including the market evaluation method, contingent evaluation method, carbon and tax method, benefit transfer method and expert survey method. The total service value of the Hepu seagrass ecosystem was found to be about 6 290 RMB/km^2 in 2005. Among these services, the indirect-use value was the main contributor, which was 4 470 RMB/km^2, accounting for 71% of the total value. The non-use value was 1 540 RMB/km^2, accounting for 24.5% of the total value. The direct-use value was the lowest contributor (only 284 RMB/km^2), accounting for only 4.5% of the total value. Primarily based on local statistics from 1980 to 2005, Han et al. (2007b) also employed basic theories of eco-economics to estimate the service value loss caused by human activities. The evaluation index system included food production, atmospheric regulation, ecosystem nutrient circulation, water purification, biodiversity maintenance, and scientific research functions. The total service value loss was 3.465 795×10^8 RMB from 1980 to 2005, and the loss ratio reached 72%. The direct-use value increased by 4.452 88×10^7 RMB, while the indirect-use value loss was 3.911 083×10^8 RMB, with the loss ratio accounting for 82% from 1980 to 2005, providing evidence for an increasing intensity of human exploitation.

4.3.3.1.3 Epiphytes[3]

In July 2004, staff of the South China Sea Institute of Oceanology, CAS surveyed the Hepu seagrass meadows and concluded that the Hepu seagrass meadows were among the largest seagrass meadows

[3] Chen Y N. 2004. The ecosystem and sustaining use of Guangxi Hepu seagrass meadow. Collected Papers of the Theory of Scientific Development and Circular Economy. (in Chinese with English abstract)

in China and contained very high biodiversity. The data showed that: (1) the content of marine heterotrophic bacteria and oil-degrading bacteria were 3.5×10^2 cells/L and 200 ind./L; (2) the seagrass meadows contained 48 phytoplankton species, for which the mean biomass was 8.28×10^6 ind./m^3; (3) the seagrass meadows contained 51 zooplankton species, for which the mean biomass was 44.93 mg/m^3; they contained 201 determinative benthos species, of which the mean biomass and mean density were 949.68 g/m^2 and 1 757 ind./m^2; (4) regarding the nekton, the seagrass meadows provided habitat for 223 fish species, representing 16 orders and 77 families; 16 cephalopod species, comprising two orders and four families; and 20 crustacean species belonging to four families

4.3.3.1.4 Seagrass functions

Seagrasses are the primary food source for the internationally rare marine mammal *Dugong dugon*. In the vicinity of Hepu seagrass meadows are two marine reserves: the Guangxi Hepu National Natural Reserve for Dugongs, the only reserve for dugongs in China, and the Shankou Natural Reserve for Mangroves in Guangxi. The dugong relishes foraging in and inhabiting seagrass meadows. Therefore, the distribution of dugongs is reliant on the distribution and productivity of seagrasses. In addition, both of the reserves listed above are the habitat of *Sousa chinensis*, a national first-class rare animal, and *Neophocaena phcaenoides*, a national second-class rare animal (Deng, 2004).

Hepu seagrass meadows contribute to local economic development, providing demotic income and a seafood source. The high biodiversity and productivity of Hepu seagrass meadows provide excellent natural conditions for fishing (Deng, 2004).

The Hepu seagrass ecosystem is a habitat and food source for animals. Seagrass ecosystem has complex community structures, which provides an ideal habitat for many organisms (feeding, shelter and concealment, and reproduction) (Deng, 2004).

Similar to the terrestrial soil, Hepu seagrass meadows have been termed the ‘filter’ and ‘air conditioner’ for seawater. Seagrasses can absorb seawater impurities and filter suspended sediments from the water, which greatly improves seawater transparency and regulates seawater quality in the intertidal zone. Seagrasses also affect seawater temperature and thereby stabilize the ecosystem (Deng, 2004).

Finally, the seagrass meadow is a natural barrier for the beach and coastline. Seagrass meadows weaken wave and ocean current energy, creating a region of reduced energy on the leeward side, which helps to stabilize sediments, safeguard the beach and coastline, and prohibit or minimize coastal erosion. Consequently, seagrass meadows, along with coral reefs and mangroves, represent ‘safeguards’ for the coastline (Deng, 2004).

4.3.3.1.5 Threats

According to the surveys of Deng (2002), Huang et al. (2006a), Lan et al. (2006) and Li et al. (2007), seagrass meadows in Hepu are facing serious threats, because local people have neglected the importance of protecting seagrass meadows. Destruction to the seagrass by Human Activity is in Table 5. Frequent anthropogenic disturbance and damage has severe impacts, which are often irreversible (Deng, 2002; Huang et al., 2006a).

The seagrass ecosystem is affected by a number of natural factors, for example, the increase in seawater temperature, typhoons, the sediment cover, the changing natural habitat (for example, tide, nutrients, heavy metal and organic contaminant) and seashell propagation, which invade and inhabit the seagrass environment. These natural disturbances are not terminally destructive, and the seagrass ecosystem can quickly recover from them.

4.3.3.2 Pearl Bay

The dominant seagrass species in Pearl Bay, is *Zostera japonica*, with less frequent *Halophila beccarii*. The total area of the seagrass meadow is about 150 hm^2. The WW and DW of *Zostera japonica* is 449.0 g/m^2 and 66.4 g/m^2, respectively, and the WW/DW ratio is 6.8 (Huang et al., 2006a).

4.3.4 Hainan Province

Seagrass meadows in Hainan Province occur in Li’an Bay (Table 6), Xincun Bay, Longwan Bay and Sanya Bay (Table 7). Seagrass meadows in Li’an Bay grow in water 0–3 m deep around the lagoon. The basal substrate is sand-mud. The dominant species is *Enhalus acoroides* and the total distribution area of *Halophila ovalis* is less than 10%. In Xincun Bay, seagrass meadows are distributed mainly in the south of the lagoon, and the basal material is sand-mud. Similarly, the dominant species is *Enhalus acoroides*, and the total area of *Halodule uninervis* is less than 8%. In Longwan Bay, seagrass meadows are distributed in belts at the inner margins of the coral reef platform. The bottom material in Longwan Bay and Sanya Bay is fine sand (Huang et al., 2006a).

Table 5 Impacts of human activities on seagrass meadows (Huang, 2006; Deng, 2002)

Human activity	Impact
Building shrimp ponds and marine engineering	Conversion of seagrass meadows into shrimp ponds, decreasing the photosynthetic capacity of seagrasses
Digging and raking of sandworms and shells	Reduction of sediment and destruction of seagrass roots and stems
Catching shrimps and fishes by poison, electricity and explosives	Trampling of seagrasses and uprooting or severing of seagrass roots and stems
Pitching stakes to cultivate oysters	Occupation of land, alteration of habitat
Dredging channels	Decreasing the photosynthetic capacity of seagrass
Pollution from land and sea	Destruction of a suitable environment for seagrass

Table 6 Species, biomass, shoot density (SD), shoot productivity (SP) and leaf productivity (LP) of a seagrass meadow (area 320 hm^2) in Li'an Bay, Hainan, China (Huang et al., 2006a)

Species	WW (g/m^2)	DW(g/m^2)	WW/ DW	SD($shoots/m^2$)	SP(mg/shoot/h)	LP($mg/m^2/d$)
Enhalus acoroides	4 660.0	1 094.8	4.3			
Thalassia hemprichii	11 357.0	1 146.8	9.9	1 508	0.112 539	4 073.011
Cymodocea rotundata	2 041.0	365.3	5.9	2 027	0.059 692	2 903.896
Halodule uninervis	990.0	225.3	4.4			
Halophila ovalis	416.0	52.8	7.9			

DW: dry weight; WW: wet weight.

Table 7 Area and species of seagrass meadows in other bays of Hainan, China (Huang et al., 2006a)

Location	Area (km^2)	Species
Li'an Bay	3.2	*Enhalus acoroides*; *Thalassia hemprichii*; *Cymodocea rotundata*; *Halodule uninervis*; *Halophila ovalis*
Xincun Bay	2	*Enhalus acoroides*; *Thalassia hemprichii*; *Cymodocea rotundata*; *Halodule uninervis*
Longwan Bay	2	*Enhalus acoroides*; *Thalassia hemprichii*; *Halophila ovalis*
Sanya Bay	0.01	*Enhalus acoroides*; *Thalassia hemprichii*

4.4 Application of stable isotope analysis to seagrass ecology research

Huang et al. (2006b) summarized the theoretical basis and progress in for the application of stable isotope analysis to seagrass ecology research over the last 20 years, and discussed the prospects for stable isotope data analysis, the application of stable isotope analysis to seagrass pollution ecology and the use of seagrass δ^{15} N for establishing a eutrophication indicator system in the nearshore area.

4.5 Seagrass biomass and primary production research

Xu et al. (2007) reviewed the progress in seagrass biomass and primary production research. The variation in seagrass primary production and biomass is determined by abiotic factors such as irradiance level, inorganic carbon supply, nutrient availability, water temperature, salinity, water velocity, iron deficiency and pollutants. Herbivorous animals and the interaction with epiphytes are the most important biotic factors affecting the biomass and primary production of seagrasses. In general, the abiotic factors display optimal ranges for seagrass growth while the biotic factors have double faced effects. Further research should be focused on development of research methods and comparative analysis based on larger spatial and temporal scales.

5 SEAGRASS PHOTOSYNTHESIS

Ma et al. (1994) used chloroplasts isolated from *Zostera marina* collected in summer and autumn of 1992 at Huiquan Bay, Qingdao, Shandong Province to study the relationship between the change in Mg^{2+}-induced Chl *a* fluorescence and Mg^{2+}-induced thylakoid surface charge alteration in chloroplasts. The increase in Mg^{2+}-induced Chl *a* fluorescence intensity from photosystem (PS) II was closely correlated with the decreased Mg^{2+}-induced electric charge density on the outer surface of the thylakoid. These experimental results demonstrated that the regulatory effect of the cation on excitation energy distribution between the two photosystems is controlled by the electrostatic property of the thylakoid surface in the chloroplasts of *Zostera marina*.

Gao et al. (1995a, b) investigated the interrelations between thylakoid polypeptide components and Mg^{2+}-induced Chl *a* fluorescence and thylakoid surface charge changes in *Zostera marina* chloroplasts treated with Ca^{2+} and trypsin. It was confirmed that the increase in Mg^{2+}-induced PS II fluorescence intensity was closely related to the decrease in Mg^{2+}-induced surface charge density of the thylakoid membrane in untreated chloroplasts. Removal of the 32–34 kD polypeptides on the thylakoid surface by Ca^{2+} extraction of the chloroplast did not affect the Mg^{2+}-induced phenomenon. If the Ca^{2+}-treated chloroplast was further digested by trypsin to remove the 26 kD polypeptide on the membrane surface, the Mg^{2+}-induced phenomenon disappeared completely. These results clearly indicated that the 26 kD polypeptide on the thylakoid surface was the specific activity site of the cation that induced these two correlated phenomena in *Zostera marina* chloroplasts. The mechanism by which the cation had a regulatory effect on excitation energy distribution between PS II and PS I was controlled by the electrostatic property of the thylakoid surface.

Wang et al. (2004) disaggregated *Zostera marina* by supersonication and isolated fractions by sucrose density gradient centrifugation. The absorption, fluorescence emission, and excitation spectra of the fractions were measured to study the spectral characteristics of these pigment-protein complexes and the 2,6-dichlorophenol-indolphenol (DCIP) photoreduction activity of each complex to identify PS II particles. The data showed that CP3, with DCIP photoreduction activity of 34.27 μE/(mg chl h), and P4, with DCIP of 7.29 μE/(mg chl h), were PS II complexes, which was further confirmed from the P_{680} differential spectrum. Determination of the P_{700} differential spectrum confirmed that CP5 had an absorption peak at wavelength 695 nm, suggesting that CP5 was a PS I complex. In comparison with the P_{700} absorption of continental higher plants, there was a 5 nm blue shift. All results indicated that PS II with photoreduction activity and PS I complexes could be successfully isolated by sucrose density gradient centrifugation at 20% and 40% sucrose densities, respectively.

Fan et al. (2007b) reviewed seagrass photosynthesis. Seagrass photosynthesis is impacted by factors such as light, temperature, inorganic carbon and salinity, of which light and inorganic carbon are the most common restricting factors. Seagrasses are capable of acquiring HCO_3^- as a source of inorganic carbon because of the shortage of inorganic carbon in seawater. Less available light radiation also restricts the photosynthetic rate. Global climate change and human activities will influence the succession of seagrass meadows through their impact on environmental elements such as temperature and radiation.

6 APPLICATIONS IN AQUACULTURE

Ren et al. (1991) transplanted *Zostera marina* into shrimp (*Peaaeus chinensis*) ponds. *Zostera marina* formed seagrass meadows in the shrimp ponds. The shrimps are able to swim and graze freely in the seagrass meadows and to rest under the algal forests at noon, which is an essential environmental condition for shrimps to grow in culture ponds. The quality of shrimps grown in eelgrass ponds is superior to that of ponds lacking eelgrass. The outputs and economic benefits of shrimps could be raised by 26.6% and 190.5%, respectively.

Liu et al. (2006) transplanted *Zostera marina* into sea cucumber ponds. The authors found that *Zostera marina* can grow in most sea cucumber ponds. Sea cucumbers aestivate half-a-month later and revive half-a-month sooner than those in control ponds lacking *Zostera marina*. In the presence of *Zostera marina* the longevity of sea cucumbers is almost 35% higher than that of the control.

7 SALT-TOLERANCE MECHANISMS

Ye et al. (2002a) reviewed and discussed advances in research on *Zostera marina* from five aspects: (1) morphological and anatomical characteristics, (2) basic physiology, (3) salt-tolerance mechanisms, (4) possible growth-limiting factors, and (5) questions and expectations. These authors (Ye et al., 2002b) determined the activities of two enzymes extracted from the leaves, the photosynthesis rates and some physiological data of *Zostera marina* under a salinity gradient (100%, 150%, 200%, and 300% artificial seawater [ASW]) *in vitro*. Under increased salinity (concentrated seawater), Na^+, Cl^-, malondialdehyde and glucose contents and the osmotic potentials (absolute value) in the leaves increase with elevated medium salinity, but both K^+ and free amino acid (mainly proline) contents decrease. The activity of malate dehydrogenase from the leaves under a salinity gradient showed the following ranking: 100% ASW > 150% ASW > 200% ASW.

Phosphoenolpyruvate carboxylase (PEPC) extracts from the 100% and 200% ASW-treated plants show similar activities (both insensitive to salinity) under the salinity gradient *in vitro*, but the activity of PEPC from plants treated with 150% ASW is dependent on salinity. Whether the plant is stressed at 150% ASW and can tolerate a higher salinity than that of seawater needs to be studied further. In the meantime, the data does not agree with the opinion that adaptation of eelgrass to seawater salinity is partly achieved by the insensitivity to salinity of some metabolic enzymes. It could be inferred that lack of transpiration might be an important aspect of the plant's tolerance to seawater salinity.

Ye et al. (2003) also determined the contents of various organic and inorganic osmotica in the leaves, shoots and roots of *Zostera marina* and calculated their contributions to the osmotic adjustment to seawater. Na^+ and K^+ were the most important inorganic osmotica, and dissolved sugars and free amino acids were the most important organic osmotica for the plant to realize osmotic adjustment in seawater. Ion x-ray microanalysis indicated that vacuoles in the mesophyll cells were the main sites in leaves to accumulate toxic ions. In addition, the study indicated that ion compartmentalization between lead epidermal cells and mesophyll cells are crucial for the plant to avoid accumulation of toxic ions in photosynthetic cells.

8 OTHER RESEARCH

8.1 Progress in remote sensing of seagrasses

Yang (2007) reviewed the multi- and hyper-spectral remote sensing of seagrasses in shallow coastal water, and domestic seagrass and bio-optical model studies, and also discussed the research tendency in future.

8.2 Study of threatened seagrass species of China

Based on the types of threatened species put forward by International Union for Conservation of Nature and Natural Resources (IUCN, Lucas et al., 1978), Yu et al. (1998) summarized the seagrasses species of China (Table 8) into four types as follows: endangered species, vulnerable species, rare species, indeterminate species (without enough evidential data), and also discussed the factors affecting these threatened species.

8.3 Pollen morphology of Halophila ovalis

Sun et al. (2002) examined the pollen morphology of *Halophila ovalis* from Sanya, Hainan Province, with light microscopy (LM), scanning electron microscopy (SEM) and transmission electron microscopy. The pollen grains are subellipsoidal in shape and monosulcate. Under LM, the ornamentation of the exine is granular. Under SEM, the pollen exine is spinulous, and the ultra-short spinules are 0.2 μm long. The spinule apex is obtuse or acute. The pollen surface bears scattered granules.

9 CONCLUSION

Between 1977 and 2007, 16 books, 38 articles and five conference papers on Chinese seagrasses were published. Ten books are focused on the taxonomy, morphology and distribution of Chinese seagrasses, and the remaining books cover the ecology of Chinese seagrasses. However, no professional guide to Chinese seagrasses has been published. The subject of 22 (57.9%) articles is the taxonomy, morphology, distribution and ecology of Chinese seagrasses. Five articles are on seagrass photosynthesis, three on salt-tolerance mechanisms, two on applications in aquaculture, and six on other research topics. Five conference papers are on the

Table 8 Threatened seagrass species in China (Yu et al., 1998; Lucas et al., 1978)

Conservation status	Species	Threat
Endangered Species	*Cymodocea rotundata*	Continually occurring threats
Vulnerable Species	*Zostera asiatica*	Severe destruction of habitats or excessive disturbance
	Zostera japonica	Severe destruction of habitats or excessive disturbance
	Enhalus acoroides	Environmental stress
	Thalassia hemprichii	Environmental stress
	Halophila minor	Environmental stress
Rare Species	*Zostera caespitosa*	Sparse distribution and reproductive isolation
	Halodule uninervis	Sparse distribution and reproductive isolation
Indeterminate Species	*Zostera marina*	Marine pollution
	Phyllospadix iwatensis	Marine pollution
	Phyllospadix japonica	Marine pollution
	Halodule pinifolia	Marine pollution
	Halophila ovalis	Marine pollution

taxonomy, morphology, distribution and ecology of Chinese seagrasses.

Research on Chinese seagrasses is still at an early stage. Moreover, current research has several deficiencies: (1) the lack of continuity of research projects; (2) few seagrass species and seagrass meadows have been well studied; (3) the research depth is inadequate; (4) the absence of a Chinese professional book on seagrasses is a deterrent to scholars and students; (5) more aspects of seagrass biology need to be studied; (6) and there is a notable paucity of research into seagrass restoration.

To improve seagrass researches in China, further researches are required on seagrass investigation, biology of more seagrass species, ecosystem function of seagrass meadows, the environmental factors influencing distribution and abundance and, especially, seagrass restoration researches (Han et al., 2008). Meanwhile, publishing of relevant book, personnel education establishment of seagrass research institutes and more seagrass protection sites should been done in future.

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