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The positive and negative effects of exotic *Spartina alterniflora* in China

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ABSTRACT

Spartina alterniflora is a perennial salt marsh grass native to the Atlantic and Gulf Coasts of North America. Recognized for its effects of diminishing strong tide even storms and accelerating sediment deposition, *S. alterniflora* was introduced into China in 1979. Now the artificial vegetation of *Spartina* has expanded to around 50 000 h m² along the east coast of China due to its strong capability of propagating by seeds and rhizome fragments. Although it was listed among 16 harmful exotic species in China 3 years ago, we need to evaluate its positive and negative effects in the coastal region of China objectively. This paper reviews some major positive effects of *S. alterniflora* in China, e.g. being a dominant primary producer, buffering against tides, accelerating accretion and reclamation, absorbing nutrients and digesting pollutants, as well as some major negative effects, e.g. occupying the niche of local species, altering the mudflat habitat, changing and even diminishing biodiversity, and damaging the aquaculture in the tidal land. In addition, its biomaterial uses and biological substitution as a means of ecological regulation is also discussed.

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1. Introduction

Salt marshes are generally considered as being among the most productive ecosystems in the world (Mitsch and Gosselink, 1993). Their harsh environments are known to be the important mechanism influencing plant succession. The habitats are highly structured environmentally and they can provide a gradient of environmental conditions from extremely inundated and saline to relatively mesic (Cantero et al., 1998). Habitat complexity, such as the chemical and hydrophysical characteristics of soils, flooding, monotonic gradient, may directly affect associated vegetation (Davy and Costa, 1992). In the meantime, marsh vegetation plays an important role in trophic ecology of coastal region. Plant species diversity and community production of salt marshes have been positively correlated with soil nutrient availability (Theodose and Roths, 1999).

Spartina alterniflora is a perennial salt marsh grass native to the Atlantic and Gulf coasts of north America. The plant disperses by seeds and rhizome fragments, forming small tussocks initially forming small tussocks and then covering the eventual elevation of intertidal habitats. It always primarily invades bare intertidal mudflats. *S. alterniflora* has been introduced throughout Europe, Australia and Asia in efforts to prevent shoreline erosion (Maricle and Lee, 2002), to accelerate land formation, and to restore degraded wetlands from oil pollution (Lin and Mendelssohn, 1998) during the last centuries. Recently, worldwide debate about this species has arisen. On one hand, *S. alterniflora* is a competent pioneer and serves a series of functions in coastal ecosystem. On the other hand, its rapid spread on tidal lands has made it a dreaded invader, and has drawn strong protest and objection.

Recognized for its conspicuous effect of diminishing strong tide and accelerating sediment deposition, *S. alterniflora* was

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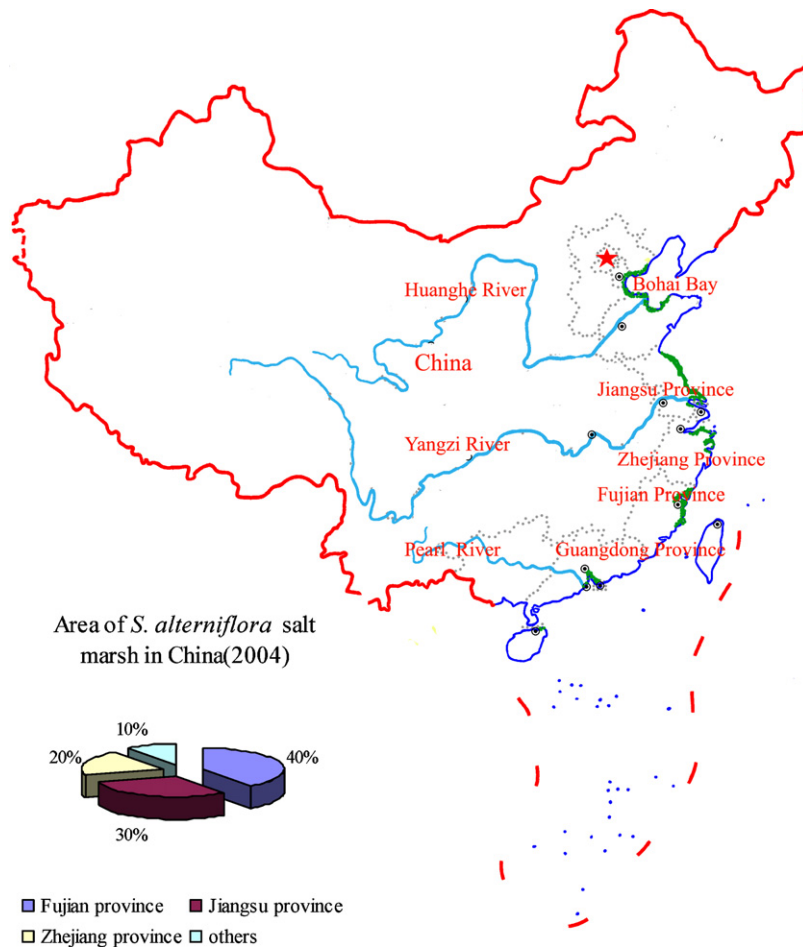


Fig. 1 – Distribution of *Spartina alterniflora* salt marsh in China. The green block represents *S. alterniflora* salt marsh.

introduced into China by Nanjing University in 1979. With artificial transplantation and natural dispersing, *S. alterniflora* is now distributed in nine of the 14 coastal provinces in East and South China. It reaches Zhuhai in southwest (N22°17', E113°33') and Huludao in northeast (N38°56', E121°35'), spanning from the tropics to the temperate zone. Now in the coastal region of China, *S. alterniflora* has expanded to around 50 000 h m², with more than 20 000 h m² distributed in Fujian Province, about 15 000 h m² distributed in North Jiangsu, about 10 000 h m² distributed in Zhejiang, and the majority of the other 5000 h m² distributed in the estuary of Yangtze River, Yellow River Delta, Bohai coastal region according to our investigation (Fig. 1; Liu et al., 2007; Wang et al., 2008).

S. alterniflora grows well in China. Its stiffly erect stems, with 11 nodes each, reach more than 2.0 m tall and 1.2 cm in diameter. Its leaves reach about 50 cm long and 2 cm wide. And its inflorescence is spike-like, about 30 cm long. Clones of *S. alterniflora* in most temperate areas of East China flower prolifically but set few seeds, while in subtropical and tropic areas they have high rates of viable seed set. Each newly planted seedling brings up 10–100 shoots in a year, and a mature plantation normally has the stable density of 490 shoots m⁻² on average. It produces 2600 g m⁻² dry overground biomass each year, and keeps its underground biomass almost stably at 3000–3600 g m⁻², with about

500 g m⁻² new roots replacing its old ones every year (Qin and Chung, 1992).

After its initial transplantation to the intertidal land of North Jiangsu, China, *S. alterniflora* merged into the local salt marsh system gradually, and exhibited distinct zonation patterns associated with elevation and frequency of tidal inundation. The lower border of the marsh is dominated by the exotic *S. alterniflora*, while the upper border is dominated by *Suaeda heteroptera*, and area in between is dominated by *Phragmites australis* or other graminoids such as *Aeluropus littoralis* and *Zmperata cylindrica*. The situation in Zhejiang and Fujian is different from Jiangsu. In Zhejiang and Fujian, *S. alterniflora* invaded the tidal land, grew and dispersed with high speed, and eventually covered all mudflats in 4–5 years. Of course, local people have gained much benefit from prevention of erosion, buffering against storm and pollution and reclamation of tidal lands. However, this specific *Spartina* vegetation changed the ecosystem structure and biodiversity, occupied the niche of native species, and even completely displaced them. These negative effects took place mostly on the aquaculture farms of coastal regions and have brought severe economic loss.

These different functional divergences directed our interest to review the positive effects as well as negative effects of *S. alterniflora* in China. In addition, its biomaterial uses and

Table 1 – Seasonal dynamics of *S. alterniflora* vegetation growth in coastal region of North Jiangsu

	Density (individual plant m ⁻²)	Average height (cm)	Above-ground biomass (g m ⁻²)	Below-ground biomass (g m ⁻²)
Apr.	200.2	36.1	376.4	459.2
Jul.	106.7	104.3	1871.0	1491.0
Oct.	117.0	145.9	2593.3	1654.6
Dec.	111.0	142.9	2093.3	1154.6
Net primary production (NPP g(dw) m ⁻² yr ⁻¹)			3412.4	

biological substitution as a means of ecological regulation will also be discussed.

2. Positive effects of *S. alterniflora*

2.1. Dominant primary producer

Carbon cycling is one of the elementary nutrient flows in wetlands, and wetlands are main regulators of CO₂, the main component of the greenhouse gases. *S. alterniflora* is a C₄ plant whose ratio of photosynthesis to respiration is much greater than 1 (Mallott et al., 1975; Long et al., 1975; Pomeroy and Wiegert, 1981), and the effect of photosynthesis and productivity of this is a valuable index for assessing its ecological function. By our field determination of the grass primary productivity and the soil organic carbon content of local salt marshes in the coastal region of North Jiangsu, we can estimate the carbon fixation capacity of *S. alterniflora* and its contribution to the greenhouse gases in coastal areas of China.

S. alterniflora flourished in the intertidal land and adapted well to local environmental conditions. The seasonal dynamics of *S. alterniflora* vegetation growth is shown in Table 1. In the fall, stems became steady and the vegetation reached the apical height. No difference in stem density was detected between fall and winter before withering and being rushed away by high tides. In spring and summer, higher stem densities were observed due to sprouting of new seedlings. The biomass of *S. alterniflora* in October was larger than in other months, showing that the material storage was the highest in fall. Moreover, the net primary production (NPP) of *S. alterniflora* was estimated to be 3412.4 g(dw) m⁻² yr⁻¹, which is fairly large.

The accumulation of CO₂ in the atmosphere and its greenhouse effect are of great interest to scientists all over the world. Although the forest is the largest system to digest CO₂ on our planet, its area has declined due to more and more construction demand for timber. The salt marsh, as well as the mangrove, is one of the most productive ecosystems and should be considered a major assimilator of CO₂ on earth. So the role of *S. alterniflora* vegetation in fixing CO₂ and mitigating the green house effect could not be ignored. The CO₂ fixation due to *S. alterniflora* vegetation was estimated by the following equation (Liu et al., 2007):

$$\text{CO}_2 \text{ yr}^{-1} = \frac{\text{NPP} \times A}{0.614},$$

where CO₂ yr⁻¹ (kg) is the CO₂ fixed by the *S. alterniflora* salt marsh per year, NPP is the net annual primary production (NPP) of *S. alterniflora* salt marsh, A is the area of *S. alterniflora* salt marsh, and 0.614 the transformation coefficient from CO₂ to the net primary productivity.

The total net primary production (TNPP) of the *S. alterniflora* salt marsh in China increased from 18 186 tons in 1981 to 1 706 126 ton in 2004 (see Table 2), and CO₂ fixed by the *S. alterniflora* vegetation per year increased from 29 619 ton to 2 778 707 tons.

2.2. Buffering against storm tides

Preventing seashore bank and shoreline erosion from storm tides was the first aim of introducing *S. alterniflora* to China. There are 18 000 km of coastline and 9997 km of seashore bank in China, and 40% of the Chinese population live and 60% of GDP of China are produced within 300 km from the shoreline. From July to September each year, the coastline in China suffers severely from the Pacific storm tide. Except for 15 000 h m² of mangroves in South China, most of the intertidal lands were naked before *S. alterniflora* was introduced. Billions of RMB (Chinese yuan) were spent each year on repairing dikes in such areas.

In the past 26 years, *S. alterniflora* proved itself to be an excellent guard along the coast. A famous case was from Ouhai County of Zhejiang Province, where the 5th typhoon invaded in 1990. Ouhai County of the province had two districts attacked by typhoon with the maximum tide height of 6.27 m. One was Yongqiang and the other was Linkundao. In front of the bank in Yongqiang there was 2000–3000-m broad mudflat without any macrophytes, while in front of the Linkundao bank there was 2000–4000-m broad salt marsh with 100–300-m broad *S. alterniflora* vegetation toward sea. When the 5th storm came, huge waves rushed over the bank of Yongqiang and completely destroyed it. The Linkundao bank was intact, and only sprays of waves reached the dike (Lu and Wu, 1996). Another proof of the function of *S. alterniflora* was from Wenzhou City, Zhejiang Province. When the 17th strong typhoon attacked the whole seashore in 1994 with the average

Table 2 – CO₂ fixation by *S. alterniflora* vegetation in China

Year	Area (× 10 ² h m ²)	TNPP (ton yr ⁻¹)	CO ₂ fixation (ton yr ⁻¹)
1981 China (Fujian)	5.33 ^a	18 186	29 619
2004 Fujian	200 ^a	682 472	1 111 518
Jiangsu	150 ^b	511 800	833 550
Zhejiang	100 ^a	341 236	555 759
Others	50 ^a	170 618	277 879
2004 China	500 ^c	1 706 126	2 778 707

^a Qin's investigation.

^b Liu et al. (2007).

^c Wang et al. (2008).



Fig. 2 – The sea dike without *S. alterniflora* vegetation in front was crushed (left) and the sea dike with *S. alterniflora* vegetation in front was saved (right) in Dongtang district of Wenzhou City, China when the 17th strong typhoon attacked the whole seashore in 1994. Photographs: L. Min.

tide height of 7 m and the maximum tide height of 10–11 m, huge waves washed over most of the banks, 70% of the dams in the city were crushed (Fig. 2), and thousands of residents had to leave home. However, some dikes were intact, because in front of them *S. alterniflora* vegetation developed well. For example, in the Dongtang district of Yancheng, 15 km of dike experienced baptism of typhoon and stayed intact due to the 200 m broad *S. alterniflora* vegetation in front (Fig. 2). Nearly 10 million RMB each year for repairing the damaged dike were saved during the last 15 years due to *S. alterniflora*'s ability to buffer against storm tides in Zhejiang province.

2.3. Accelerating accretion and reclamation

The idea of using *Spartina* grass for accelerating land formation was came from Holland. As a matter of fact, the first species tried for this purpose in China was *Spartina anglica* Hubbard, which was introduced from England in 1963. Because this species grew rather dwarfish in China, it was eventually replaced by *S. alterniflora*. The Yellow River, Yangtze River and Zhujiang River are three main rivers in China, which has 3.9% of the flux in the world. Large amount of sand, which account for 10% of this kind, were transported to the sea from these rivers, and this makes a rich source for land development. Bruno and Kennedy (2000) reported that beds of *S. alterniflora* could reduce mean water velocity by 50% and maximum velocity by nearly an order of magnitude. The rigid, densely packed stems decrease the rate of tidal flow, causing suspended sediment to precipitate while dense root mats trap sediment. As a result, large amounts of sediment from river or sea accumulated on the beach.

Rates of accretion of *S. alterniflora* of a 490 year old marsh in Boston, Massachusetts, reached 61 cm in 100 years, but due to a 30 cm subsidence a net 31 cm was obtained. A deteriorating Barataria Bay marsh, in Louisiana with 27 cm net accretion in 100 years and a 45 cm net for a stable marsh in Four League Bay have been cited (Mitsch and Gosselink, 2000). In a new report from Chung et al. (2004), on the tidal land of Dongtai County, Jiangsu Province, the largest radiated alluvion in Asia, results of 56 measurements taken over 3.4 years, of the *S. alterniflora*

plantings, showed that accretion was greater than for the control: 52.1 cm versus 10.5 cm and 48.5 cm versus 16.9 cm were calculated. By our recent investigation there has been around 10 000 h m² of newly formed land reclaimed from the grass accretion in Yancheng City, Jiangsu, during 2002–2004. It is obvious that the efficiency of land formation by *S. alterniflora* is much higher than what has been reported by other countries.

It is very necessary for China to reclaim new land from accreted seashore mudflats since it has 13 hundred million people and an annual reduction of 400 000–50 000 h m² of arable land now. In addition, the accelerating accretion of *S. alterniflora* in sea-level rising worldwide should be of concern, for example, both 52.1 and 48.5 cm exceeded expected rise in sea-level worldwide was predicted to be 18.0 cm by the year 2030, and 46.0 cm by 2100 respectively (Myers, 1993).

2.4. Absorbing nutrients and digesting pollutants

The common knowledge about absorption, transformation and decomposition of heavy metals and other organic pollutants via *Spartina* vegetation can be used in water quality improvement (Qin and Chung, 1989). Thus construction of *Spartina* plantation to treat N, P, heavy metals and some other toxic materials was proposed (Tanner et al., 1998; Qi et al., 1999). Moreover, *Spartina* wetlands could play a role in the disposal of pollution from aquaculture and petroleum production (Hubbard et al., 1999; Lindau et al., 1999; Lin and Mendelssohn, 1998). The experiment of Liu and Tian (2002) showed that *S. alterniflora* had significant potential for cleaning sewage, and the digestion rates of TP and NH₃-N were 32.1% and 38.3% respectively. Thus *S. alterniflora* salt marshes can be used to clean eutrophic sea water.

N and P dynamics in the *S. alterniflora* salt marsh of Jiangsu in 2002–2003 showed its huge carrying capacity of nutrients. The total N content in *S. alterniflora* sediment was observed to be higher in any period and position of the salt marsh than that in the mudflat (Fig. 3-I). The trend of N content in *S. alterniflora* sediment went down seaward, but the change in different seasons was not regular. In the mudflat habitat, no difference of total N content was detected seaward and over time. Con-

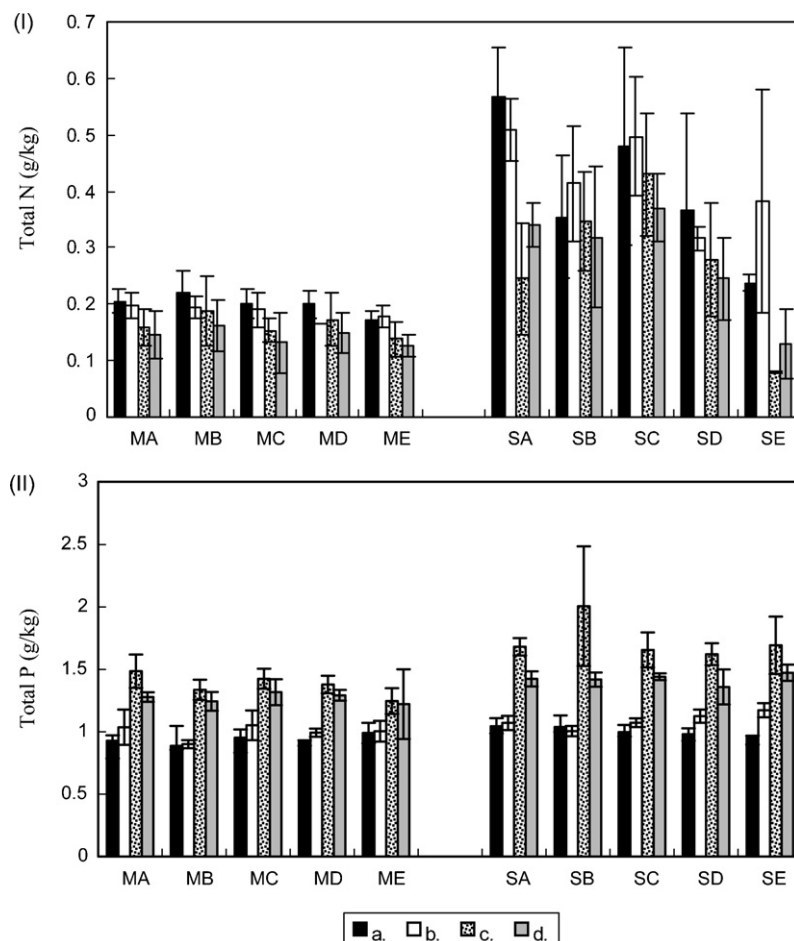


Fig. 3 – Total N and P changes in sediment of *Spartina* salt marsh (S) and mudflat (M) along seaward orientation during different seasons (a. Oct.; b. Dec.; c. Apr.; d. July; A, B, C, D, E are along seaward orientation).

Note: for the method of sampling and analysis, see Zhou et al. (2008).

cerning total P content in sediment, Fig. 3-II shows that it went up over seasons in both habitats. Furthermore, the habitat of *S. alterniflora* got higher P content, although the difference was not significant in some seasons. Furthermore, we also found that the organic matter content in *S. alterniflora* salt marsh sediment of Jiangsu was also higher than that in the mudflat, and the seasonal fluctuation was similar to N (Fig. 4). It shows that the *S. alterniflora* salt marsh has a higher capacity of nutrient transformation and favorable soil structure than bare flats.

3. Negative effects of *S. alterniflora*

3.1. Changing landscape by rapid propagation and expansion

S. alterniflora was accused of competing with native salt marsh vegetation, even modifying the native gene bank (*S. alterniflora* was brought to Europe and Pacific coastline of America, and hybridized with local *Spartina* species), threatening regional biodiversity and richness, and decreasing ecosystem stability (Washington Sea Grant Program, 2000). Its high production and rapid propagation caused the widespread invasion of the exotic, including in

China, and has become the focus of attention in recent years.

Besides the mangrove, which is distributed only in several southern coastal provinces, very few native salt marsh macrophytes could grow and create large vegetation on coastal tidal

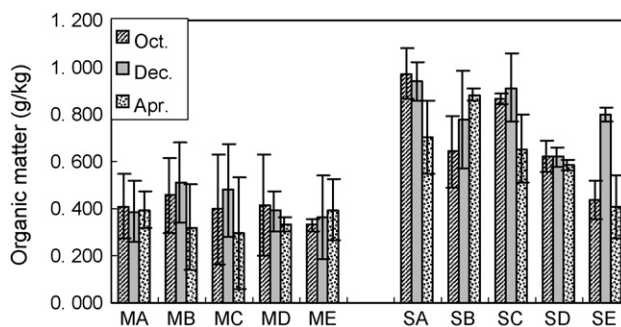


Fig. 4 – Organic matter content (g kg^{-1}) in sediment of *S. alterniflora* salt marsh (S) and mudflat (M) along seaward orientation during different seasons (A, B, C, D, E are along seaward orientation).

Note: for the method of sampling and analysis, see Zhou et al. (2008).

Table 3 – Comparison of biodiversity indexes of macrobenthos between salt marsh of *S. alterniflora* (S) and mudflat (M)

Biodiversity indexes	Salt marsh of <i>S. alterniflora</i> (S)				Mudflat (M)			
	Oct.	Dec.	Apr.	Jul.	Oct.	Dec.	Apr.	Jul.
Shannon index	1.536	1.267	1.499	1.536	2.571	1.693	2.603	1.745
Simpson index	4.115	3.236	3.205	4.032	10.562	3.610	9.259	3.717
Margalef index	0.837	0.560	0.908	0.793	2.447	1.723	3.146	2.670
Pileou average	0.790	0.914	0.721	0.790	0.908	0.771	0.855	0.549
Richness	7	4	8	7	17	9	21	24
Total number	144	41	209	190	93	25	82	392

Note: for the method of sampling and analysis, see Zhou et al. (2007).

land in China. *Suaeda*, which inhabits intertidal land, can usually form huge vegetation of “Red Beach” vegetation at the estuary of Liaohe, the Delta of Yellow River, and Yancheng coastline, and draw a lot of people for sight-seeing. But when *S. alterniflora* was transplanted to these areas, the landscape was changed. *S. alterniflora* spread very fast and eventually dominated intertidal land, although it was mainly distributed on the middle part of intertidal land. It elevated the mudflat with accelerating accretion, modified the usual pattern of distribution and succession of native vegetation, and eventually changed the landscape of “Red Beach” landscape.

The 2 years' community densities of three ecotypes of *S. alterniflora* (introduced from North Carolina, Georgia and Florida) were 683, 448 and 352 m⁻² respectively in Luoyuan Bay of Fujian Province (Qin et al., 1985). The average biomass (of aboveground part and belowground part) of mature *S. alterniflora* community (introduced from North Carolina, 7 years) at the eroded Delta of Old Yellow River was 2657 and 3517 g m⁻² (dw) respectively (Qin and Chung, 1992). In addition to seed reproduction, *S. alterniflora* shot up from its rhizomes very quickly. In our experiment in Guangxi Province, after transplantation for three months its stem height increased from 10–20 to 150–190 cm, the seedling number from 2–3 to 220–350, and the grass patch spread out 0.8–1.2 m (Cao and Chen, 1997). In the Dongtai coastal region of Jiangsu, a *S. alterniflora* marsh was surprising because its width of 1.1 km and cover of 70% formed within only 9 years (Chung et al., 2004). TM satellite images and field work showed its area in different years: 2240 h m² in 1993, 3880 h m² in 1995, 7520 h m² in 1997, 13 640 h m² in 1999, and 16 230 h km² in 2001 (Zhang, personal communication, 2004).

3.2. Biodiversity change

The assessment of the effect of *S. alterniflora* on biodiversity is summarized in Table 3. The biodiversity indexes of macrobenthos in salt marsh of *S. alterniflora* were less than those in the mudflat in every season. The richness and majority of macrobenthos in the salt marsh of *S. alterniflora* in the winter were the lowest, but increased with the coming of the growing season. Although species richness of macrobenthos in *S. alterniflora* marsh was lower, the biomass was higher, and especially single species biomass was large. There were more species of macrobenthos on the mudflat, especially some mollusks (Fig. 5). Some of mollusk, especially shellfish, had to migrate to the mudflat outside of the *S. alterniflora* marsh since

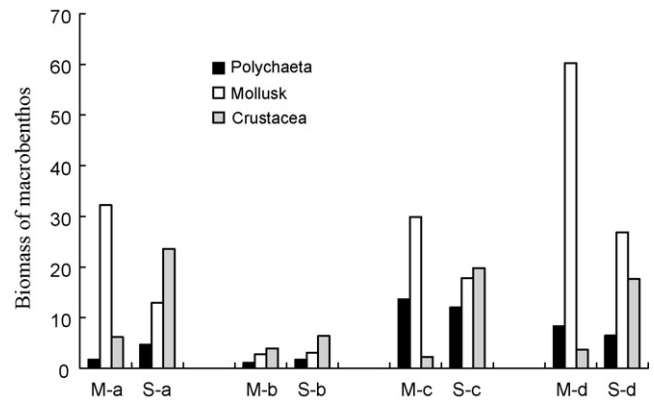


Fig. 5 – The biomass of macrobenthos in salt marsh of *S. alterniflora* (S) and mudflat (M) in different seasons (a. Oct., b. Dec., c. Apr., d. Jul.). Resource: Zhou et al. (2007).

the exotic grass occupied their original niche and forced them to do so (Fig. 6).

3.3. Other negative effects

Although the hybridization of *S. alterniflora* with local species was reported in the Pacific coastal region of America and UK (Ayres et al., 1999; Thompson, 1991), the same case has not been found in China, because there was no local species of *Spartina* species originally. In Jiangsu province the accelerating accretion of *S. alterniflora* could disturb the normal distribution



Fig. 6 – Shellfish migrated to the mudflat outside of *S. alterniflora* marsh in Yancheng City, China. Photograph: P. Zuo.



Fig. 7 – *S. alterniflora* invaded the fringe of scrubby mangrove and competed with the latter in Zhangjiang estuary, Fujian Province. Photograph: W. Wang.

and succession of native vegetation, change the microgeography of salt marsh. For example, in some places the “Red Beach” landscape of *Suaeda* disappeared and was replaced by mosaic patches of *Suaeda* and *S. alterniflora*. In Fujian Province *S. alterniflora* invaded the fringe of scrubby mangrove and competed with the latter (Fig. 7).

4. Ecological regulation of *S. alterniflora*

Considering the positive and negative effects of *S. alterniflora*, we prefer to take measures of ecological regulation based on its integrative use and biological substitution, rather than eradicate and kill the exotic invader with some extreme methods including herbicides. It is nearly impossible to eradicate a species in its favorite habitat entirely. An old Chinese saying states that “it cannot be burned to death and it will tiller when spring comes”. Furthermore, when you use herbicides to kill it you will pay high prices not only economically but also environmentally.

4.1. Integrative use

Due to the high nutrient content in *S. alterniflora* shoot, 11.85% crude protein, 2.26% fat, 27.1% cellulose, 0.235% calcium,

0.191% phosphorus, and various amino acid, vitamin, and trace elements, its fodder use for stockbreeding has been studied in China for many years. For example, Xiapu Agricultural Bureau in Fujian Province used *S. alterniflora* dry meal to feed 185 000 pigs each year. With the grass meal replacing 6% traditional fodder, the county can save 3.5 million kg traditional fodder and 2.1 million RMB (Qin and Zheng, 1998). A decrease in mortality from 8.33% to 2.00% in sample chickens eating *Spartina* fodder was reported (Zheng and Xu, 1994). In another study, feeding fur-producing rabbits with 30% *Spartina* meal obtained 5.29% more fur than the control (Wang et al., 1996). A demonstrating 1333 h m² farm land with *S. alterniflora* and alfalfa has been set up in Haixing County, Hebei Province, with livestock capacity of 149 000 sheep (Lin and Li, 1999).

Clamworm is a segmented burrowing marine worm of the genus *Nereis*, commonly used as bait for fishing. The worms can rarely be found on Chinese coastal beaches, but are prolific in *Spartina* marsh in which the fresh product of clamworm reaches 2311 kg h m⁻² yr⁻¹. This “rich philanthropist” could offer more than 100 Yuan profit each day to each local farmer who dug it along the Jiangsu and Zhejiang coastline. Income of collecting clamworm is three times more than the average level in local areas, drawing a lot of coastal farmers’ attention to salt marsh.

Living on the ecotone between terrestrial and oceanic ecosystems, *S. alterniflora* contains not only rich nutrients as mentioned above, but also high content of submetabolic materials, e.g. flavonoids, vitamins, etc. which benefit human health. According to principles of ecological engineering, we invented “Biomineral Liquid” extracted from *S. alterniflora* and produced a series of green health food, such as “Weduo Beer” (with multi-trace elements), “*Spartina* Capsule for Lipid Falling”, etc. All these formulated the important loops of *Spartina* ecological engineering and favored its hierarchical utilization (Qin et al., 1998).

4.2. Biological substitution

In natural conditions no species has been found to substitute *S. alterniflora* in subtropical and temperate intertidal zones in China. However, this situation could be changed via modifying the microgeomorphic and hydrological regime of salt marsh. The natural vegetation succession of coastal wetland occurs



Fig. 8 – The local *Phragmites* community are growing quickly in the cofferdamed salt marsh of *S. alterniflora* of North Jiangsu (left). The *Phragmites* community substituted for *S. alterniflora* in the cofferdamed salt marsh of North Jiangsu (right). Photographs: H. Cai.

according to the gradient change of elevation, tide strength and salinity in the habitat. When natural or artificial disturbances take place above variables could experience a dramatic change, and the normal vegetation succession could make a turn, even biological substitution could happen. For example, in *S. alterniflora* marsh of North Jiangsu where we constructed a rotund cofferdamed area with 55 h m², tides and sea water were obstructed, rain water was accumulated and the salinity of the soil solution decreased in the cofferdamed area, resulting in fast growth of the native *Phragmites* community and substitution for *S. alterniflora* to the end (Fig. 8). Now this new cofferdamed *Phragmites* wetland draws a lot of waterfowl and the indexes related to biodiversity and others will be determined.

5. Conclusion

The positive and negative effects of *S. alterniflora* on the salt marsh environment in the coastal region of China are due to its prominent resistance to extreme tidal conditions, great primary production and strong propagation capability. Its primary production is very high and could be a dominant contributor in the salt marsh to fix CO₂ and alleviate the greenhouse effect. In the past 26 years, *S. alterniflora* has been identified as an excellent guard buffering against storm tides, accelerating accretion and reclamation, absorbing nutrients and digesting pollutants, while it could occupy the niche of local species, alter the mudflat habitat, change and even diminish biodiversity, damage the aquaculture in the tidal land, etc. Considering the positive and negative effects of *S. alterniflora*, we prefer to take ecological regulation based on its integrative use and biological substitution, rather than eradicate and kill the exotic invader with some extreme methods including herbicides.

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