【Review】

Alien plant invasion in water systems in Shanghai, China

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Abstract

Biological invasion is one of the most three critical environmental problems in the world. Biotas in water system are always changing rapidly because of being weak at invasion resistant. In this paper, two typical invasive plant species in water systems in Shanghai was discussed. (1) *Eichhornia crassipes*, in freshwater system, whose invasion process, invasion mechanism, harm, and control strategies were elucidated; (2) *Spartina alterniflora*, in estuarine water system, whose transplanting in Chongming East Beach of Shanghai causes large controversy, was recognized as a critical invasive species. The current idea for these two plant species and some suggestions on study and control of biological invasion were discussed.

Key words: biological control, invasion, invasive species, Shanghai, water system

1. Introduction

The loss of biodiversity and the radical changes in the ecological status of native species caused by biological invasion are attracting unprecedented attention in the world. Species introductions and invasions are always due to human activities; for example, people introduce nonindigenous species through agriculture, forestry, gardening, horticulture, and traffic (Malakoff, 1999; McKinney & Lockwood, 1999; Edward, 2001; Shea & Chesson, 2002; Ambrogi & Savini, 2003). Biological invasions threaten native ecosystems, especially biodiversity, because invasive species always out-compete the local species. Therefore declining biodiversity at regional and global scale may result in a homogenized biosphere (McKinney & Lockwood, 1999). Biological invasions also result in vast economic cost, e.g., in the United States, there are about 50,000 foreign species, and some major invasive species cause environmental damages and losses more than $138 billion per year (Pimentel et al., 2000). The number of invasive species is usually more in the area with more intensity of global trade. As a result, studies on the pathway, i.e., how given species are introduced from their origins and become invasive species, are increasing. For example, ballast water has been recognized as a remarkable vector for introductions of alien species to the aquatic systems in marine or estuarine areas (Mooney, 1999; Wasson et al., 2001; Elliott, 2003). Shanghai, as the biggest city in China, with the third biggest container port in the world, won its fast urbanization in the recent decades, is now facing a serious status of biological invasion: the number of angiosperm species in Shanghai is 890, among which 57.4% (511 species) are nonindigenous species (Li et al., 2001). In Shanghai's water systems, the most critical invasive plant species are water hyacinth (*Eichhornia crassipes*), *Alternanthera philoxeroides*, *Cabomba caroliniana*, *Ambrosia artemisiifolia*, and *Spartina alterniflora* (Wang et al., 1996; Li et al., 2001). Declining native biodiversity and huge economic loss has been made by infestation of these invasive species. In this paper, control and management of some of these invasive species will be discussed.

2. Water Systems in Shanghai

Shanghai is a typical coastal city, lying in the east of China. It covers a total area of 6340.5 km^2, among which 22.5% is natural wetlands **(Fig. 1)**. (1) The Huangpu River, dissecting the city into two, is the major water supply for more than 16 million citizens; (2) Lake Dianshan, origin of the Huangpu River, is the major drinking water resource for the city; (3) Chongming East Beach (Chongming Island), lying in the east of the city, is an important wetland of the local ecosystem, which was specified as Nature Reserve for Birds in 1999; furthermore, it was valued as an internationally important wetland in "Ramsar Convention" in 2001; (4) Shanghai port is the biggest international seaport in the mainland of China; in 2000, it became the third biggest seaport in the world.

According to Costanza's ecosystem services calculating formula (Costanza et al., 1997), the total value of ecosystem services is $7.3X10^9 per year for the whole ecosystem in Shanghai, among which more than 97% was provided by estuaries and lakes/rivers (Zhao et al., unpublished). Therefore, the water systems play an important role in the whole ecosystem services in Shanghai.

Moyle (1996) reported that freshwater and estuarine biotas are changing rapidly worldwide and all aquatic systems are invasible. Water systems in Shanghai get no exception. In this study, two typical

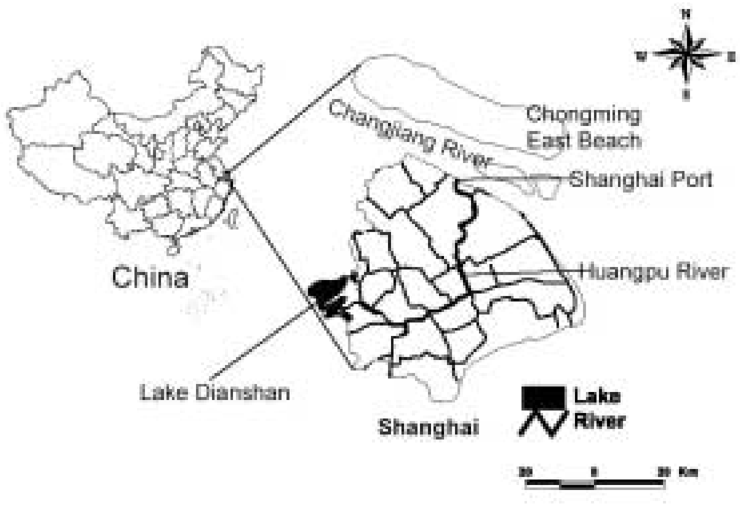

Fig. 1. Water systems in Shanghai

invasive aquatic plant species will be discussed: *E. crassipes* in the fresh water system; and *S. alterniflora* in the estuarine water system.

3. *Eichhornia crassipes* (Water hyacinth)

Eichhornia crassipes (Mart.) Solms, Pontederiaceae **(Fig. 2)** is native to the Amazon River, which is a famous invasive species of many countries, and is recognized as one of the top-ten weeds in the world (Julien, 2000; Kathiresan, 2000). *E. crassipes* was introduced to China in 1900s as a kind of feed for live stocks, and then was transplanted by people in different water areas. In 1990s it was initially reported that there was a water hyacinth explosion in Lake Dianchi in Yunnan Province (Ding, 2000). At that time, some scientists predicted that probably there would be a nationwide water hyacinth ecological disaster in the near future. Now, the prediction is fulfilling, almost all of the provinces in south part of China are afflicted by this weed (**Fig. 3**).

3.1 Invasion process of water hyacinth in Shanghai

At the beginning, *E. crassipes* was utilized as feed for live stocks and poultries in China, which became popular and was transplanted in many places until 1970s. During that period, water hyacinth was introduced to Shanghai. At that time, many Shanghai farmers' standard of living was low, so water hyacinth was welcomed as a cost saving feed. Therefore, this plant was transplanted in many kinds of water areas, such as ponds, lakes, channels, and streams where it can grow well. In addition, it can purify industrial effluent by taking up metals and toxic materials from wastewater for their metabolic use (Kim & Kim, 2000; Singhal & Rai, 2003). Furthermore, attracted by its splendid blooming, people transplanted it in some parks and gardens as a landscape plant. However from 1980s, the Shanghai's urbanization boomed increasing living standards, which led to decrease in the number of farmers who

Fig. 2. Eichhornia crassipies, Water hyacinth

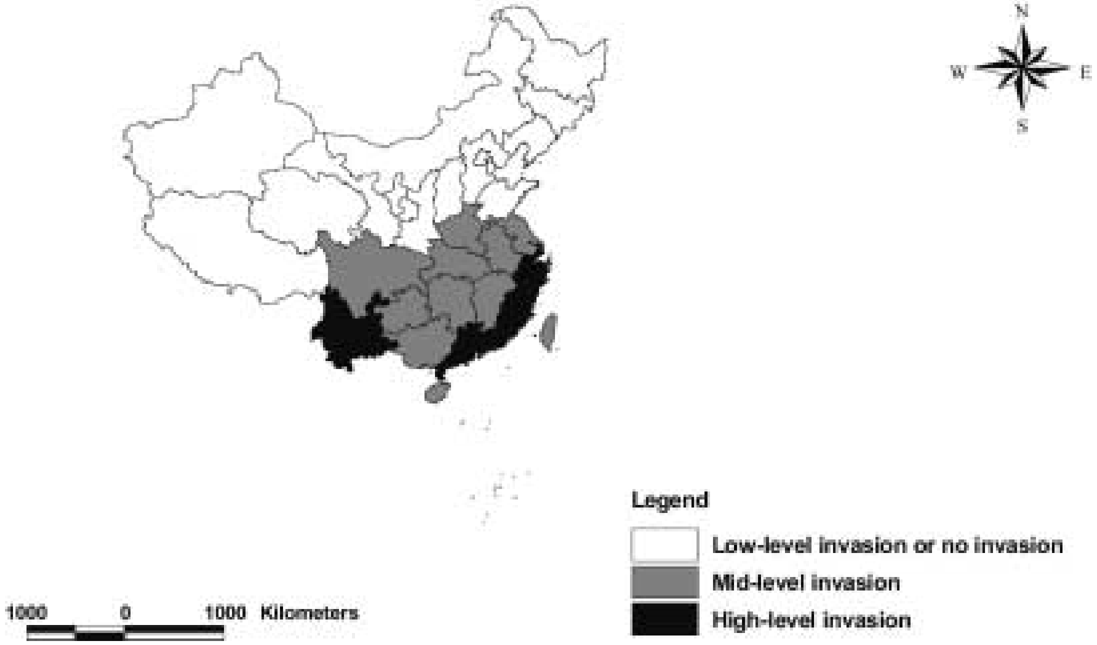

Fig. 3. Distribution of *Eichhornia crassipes* in China

utilized water hyacinth. Furthermore, during the urbanization process, water systems in Shanghai were polluted (esp. eutrophication in Huangpu River and its tributaries). Polluted water resulted in collapse of aquatic ecosystems in many places; however it did not affect the living of water hyacinth. Contrarily, to some extent, the eutrophicated water stimulated the growth of water hyacinth.

3.2 Mechanism of the water hyacinth explosion in water systems in Shanghai

The explosion was due to two aspects: biological characteristics of this plant (invasiveness), and invasibility of the habitat. a) Biological characteristics of the weed: (1) light tolerant, grows well in tropical and temperature regions (27-30℃ is the best temperature for its growth); (2) generates fast. In appropriate circumstances, water hyacinth can reproduce a new ramet by clonal growth (i.e., vegetative propagation) every 5 days, which can survive by itself after separation from the maternal plant; water hyacinth also has sexual propagation, one inflorescence can produce about 300 seeds, which bourgeon in the water and grow into new plants. With the clonal growth and sexual propagation, the number of water hyacinth can increase exponentially; (3) water hyacinth always grows in rivers, lakes, or ponds, and it can float easily and diffuse anywhere in water systems; (4) high tolerance, it can grow in environment with low water quality (such as industrial waste water); (5) high rivalrousness, water hyacinth acts as a "green mat" on water surface, defying other plant species below which gradually die out lacking photosynthesis.

b) Invasibility of the habitat: (1) Eutrophication. The Huangpu River runs through Shanghai city with a population of more than 16 million, and it has to receive almost all of the waste water in the city. This results in a high level of eutrophication in the water system. (2) Lacking of local biodiversity. Fast urbanization in the recent decades in Shanghai brought high economic growth with modernized buildings of concrete footings. These factors result in rarity and extinction of many native species, which make up the flimsy native ecosystem with little invasion resistant. Therefore, nonindigenous species with high tolerance of such environments can invade easily.

3.3 Eco-loss of water hyacinth and its potential harm to society in Shanghai

Infestation of water hyacinth has caused dramatic ecological and economic loss, and it may potentially harm the society.

(1) Destruction of ecosystem structures, and decrease ecological services. Invasive plants influence environments in many ways; the main aspect concerns the biodiversity and ecological services of local ecosystems. For example, in Lake Dianchi, Yunnan Province, water hyacinth covered almost all over the lake with an area of 1000ha, and many local aquatic plants and animals tend to disappear. The number of water plant species at Caohai, Lake Dianchi has fallen from 16 in 1960, 8 in 1970, 5 in 1980, to 3 in 1990 (Ding et al., 2000). However, until now, there is no statistical data about the harm of water hyacinth to native biodiversity and ecological services in water systems in Shanghai. According to our field work in the recent years, it can be found that water hyacinth mono-specific populations covered the river in many places. The high density green mats decrease the deliquescent oxygen in the water, therefore other plants in the aquatic ecosystem lack light and oxygen; furthermore, the remnants of water hyacinth rot in the water——which make the water quality worse in the river.

(2) Economic loss. Firstly, local government has spent much on the salvage of this weed in the past decades. In 1975, workers salvaged only about 0.5 tons water hyacinth in Shanghai; however, in 1995, 50t/d; in 2001, 250t/d (sometimes more than 400t/d); Secondly, the flourishing water hyacinth always jams the river way and ports, which results in economic loss.

(3) Potential harm to society. Shanghai is the biggest city of China, the “green mat” floating through the city with plastic bags and foams will surely be galling for a healthy city landscape. In addition, water hyacinth may provide convenience for breeding of harmful pathogens, mosquitoes and flies. It was reported that the water hyacinths on Lake Victoria increased the incidence of snail- and mosquito borne diseases which affected millions of people (Mooney, 1999).

3.4 Current control of water hyacinth in Shanghai

Great effort has been made in trying to eradicate water hyacinth in the Huangpu River and its tributaries. However, the “green mats” still flourish every year. So far, the main method to control water hyacinth is by manual or mechanical salvage. Special scoop nets and boats are equipped for salvage by environmental sanitation workers. In other countries suffered with water hyacinth, biological control and chemical control are applied and there are some successful experiences (Hill et al., 1999; Malakoff, 1999; Babu et al., 2003). *E. crassipes* was once successfully controlled by two weevils, *Neochetina bruchi* and *N. eichhorniae*, and one moth, *Niphograpta albiguttalis* (Malakoff, 1999; Julien, 2000). In China, some experiments and releases of *N. eichhorniae and N. bruchi* have also been done in Zhejiang and Fujian Province. The weevils greatly suppressed the plants around the release areas (Ding et al., 2000). However, the tests and release in Shanghai is still absent.

4. *Spartina alterniflora* (Smooth cordgrass)

Spartina alterniflora Loisel., Gramineae **(Fig. 4)** is native to the East and Gulf Coasts of North America (Maricle & Lee, 2002). In the last century, *S. alterniflora* and another cordgrass *S. anglica* have been introduced throughout Europe, North America, Australia, and Asia based on their value to coastal engineering and agriculture (Maricle & Lee, 2002). The cordgrass is a perennial intertidal plant which can dramatically alter the ecology and structure of estuaries (Kriwoken & Hedge, 2000). Its dense rhizome-root networks act as a trap for silt and mud in open mudflows. Its ability to produce fertile seed, extensive rhizomal networks and prolific vegetative growth has allowed it to spread rapidly in estuarine mudflats it was introduced.

Due to its value of sediment accretion and mitigating of shoreline erosion, *S. alterniflora* was intentionally introduced to Jiangsu Province, in 1979. At that time, it was welcomed by people in coastal regions. Soon, in the beginning of 1980s it was introduced to Fujian Province. Since saline and anoxic estuarine conditions are often uninhabitable by other plants, the cordgrass flourished and spread rapidly along the coast and estuaries. Now *S. alterniflora* can be found in almost all part of east coast of China.

In the recent years, *S. alterniflora* was introduced to Chongming East Beach, east part of Shanghai. Workers are employed to plant *S. alterniflora* in the beach. The planting of cordgrass in Chongming East Beach has provoked a variety of responses **(Table 1)**. In some situations *Spartina* is welcomed and valued; to the contrary, some people consider the cordgrass to be a critical invasive plant, i.e., a pest. Why the nonindigenous *Spartina* becomes such an intractable matter? Some officials in local government prefer to reclaiming land more rapidly from Chongming East Beach. The beach locates in the mouth of the Yangtze River, which increases continuously by the alluvial materials from the whole

Fig. 4. *Spartina alterniflora* infestation in Chongming East Beach, Shanghai

Table 1. Potential positive and negative impacts associated with *Spartina alterniflora* infestation in Shanghai

	Positive impacts	Negative impacts
Economics	Sediment accretion makes new land more rapidly	Fishery reduction, e.g., output reduction of seashells and crabs
Ecology	Increase in estuarine organic productivity by *Spartina* detritus	Infestations dramatically alters intertidal habitat having significant impact on native ecosystems
Tourism/ recreation	Visual improvement by replacing the brown mudflats with green meadows	Beach sediments change into annoying slush, making inconvenience for entry and bird observation on the beach
Society	Providing employment by transplanting *Spartina*	Wide green meadow may offer hiding place for criminals; death and panic caused by tidewater when working in the wide and slushy meadow
Geomorphology/ Engineering	Reclaiming land and mitigating coastal erosion	Changing hydrodynamics and topography in the intertidal area

Yangtze River. From 1990 to 2000, Chongming East Beach has expanded eastward about 5.9 Km, almost 0.6 Km/year (Zhao et al., unpublished). Then, the new land on the beach has been enclosed by levees in 1990, 1997, and 2000 respectively. Therefore, rapid sediment accretion of *Spartina* made it welcomed by some people, and especially by land agents. To the contrary, some other people, mainly scientists and some residents, set themselves against planting *Spartina* grasses in the beach. They proclaim that this cordgrass is a troublesome invasive species, which will probably cause terrible havoc to native fauna and flora communities. The ecological disaster made by *Spartina* spp. in Fujian Province and other countries are cited for supplement. For example, in Fujian Province of China and Willapa Bay in the USA, many local crabs, shells, fishes have been asphyxiated by the cordgrass (Grevstad et al., 2003). Furthermore, local environmental office in Fujian Province confirmed that many mangrove patches disappeared and were replaced with cordgrass. The scientists against *Spartina* plantation are afraid of its infestation on the beach and its striking spreading speed. However, few correlative studies about the invasion of *Spartina* have been brought out in China. Li and his colleagues (Li, 2003, personal communication) discovered that *S. alterniflora* in Chongming East Beach had great impact on a local plant species, *Scirpus mariqueter*, which is the predominant plant species in the beach before introductions of *Spartina*. Crucially, *S. mariqueter* is the main food resource for many bird species, one of which is *Grus monacha*, living only in part of China and Japan, is one of the endangered bird species listed in the IUCN Red List (Jing et al., 2002; Ma et al., 2003).

5. Discussion

5.1 Control strategies of invasive species in water systems in Shanghai

1) Water hyacinth. In the recent years, the local government has tried to reduce the waste water and improve the water-purify system, however, this did not mitigate the infestation of water hyacinth. Water

hyacinths have been salvaged by special machines or scoop nets in Huangpu River in Shanghai City (i.e. downstream). In fact, salvage is not an effective way to eradicate or control water hyacinth. Countless water hyacinths in the downstream of the Huangpu River didn't occur locally, indeed they came from the upstream and tributaries and then went and generate together, forming green mats in the whole water system. Therefore, salvage on the downstream can be called a “Terminal Management Mode”. Furthermore, there is only inefficient management and cooperation on the control and management of the whole water system. The workers who salvage water hyacinths now are old with only poor salaries; until now there is no special organization or office to manage and control the ecological problems of the whole water system. In the past the water systems were always managed by administrative border. Since there have been some successful cases to control water hyacinth with its natural predators, and it is always considered that biological control is more effective than manual or mechanical control on invasive species on a large scale. Thus a new series of control strategy should be developed. Here are some suggestion for the control of water hyacinth in the water systems in Shanghai: (1) in-depth research of this plant species, especially its ecological behaviors, e.g., relationship between water hyacinth and its habitat (water quality, hydrodynamics, and so on). This kind of research will supply useful information for control actions; (2) replace the terminal management with an integrative control strategy. That is, “giving priority to biological control, combining with mechanical salvage”. In China, *Neochetina bruchi* and *N. eichhorniae* have been developed as biocontrol agents for water hyacinth in some places, not including Shanghai. Therefore, it is time to look for potential biological control agents from its natural enemies. It is possibly not difficult to find an appropriate candidate since water hyacinth has been successfully controlled in Zhejiang Province, neighbor of Shanghai, and has almost the same biomes as Shanghai.

2) *S. alterniflora*. In March, 2003, *S. alterniflora* and *E. crassipes* are prescribed as especially serious invasive species in China (totally 16 species, 9 plant species and 7 animal species) by Ministry of Environment of China. This is the first time that invasive species are promulgated by department of central government. Even so, it seems that the controversy on *Spartina* will not stop in the near future. So far the control of invasive *Spartina* grasses is only few, the mechanical way is almost impossible to eradicate this plant because of its dense growth and rhizome-roots. As for its biological control, to date only a delphacid planthopper *Prokelisia marginata* was introduced into Willapa Bay as a biological control agent (Grevstad et al., 2003). Therefore, the most important thing now we should do is to find out the invasion process and impacts of *Spartina*, instead of large number of critics on newspapers which are common at present. Afterwards, assessment and control of this invasive species is likely to be advanced.

5.2 GIS and remote sensing application in monitoring and predicting invasive species

Generally, studies on biological invasion focus on community or ecosystem scale. Biological invasions are always described as a regional or national wide problem as it was referred to; however, relatively large scale research on biological invasion is almost absent. As nowadays the Geological Information System (GIS) and Remote Sensing (RS) has been applied in many ecological fields, especially in landscape ecology. GIS and remote sensing (e.g., satellite imagery and airborne photographs) can act as a convenient tool for monitoring the real time geographical condition, depicting and predicting the invasion process, and then a following GIS database can give support to scientists and decisionmakers. Therefore, scientists and special technicians can know exactly the invasion condition, and bring forward some appropriate control strategies; even they also can evaluate and compare different control strategies on a landscape scale during the control process.

5.3 Some ecological and social concerns on biological invasion

Species in an evolutionary new or young ecosystem might have lower competitive abilities than potentially invaders which probably have had a longer time to adapt to such kind of environment. Chongming East Beach, whose area increases every year, might be quite weak at resisting invasion. Therefore, *Spartina* grasses with high invasiveness can spread rapidly and become the predominant species in the beach. For water hyacinth, it can be concluded that this invader is a better resource exploiter than native aquatic species. Eutrophied water in a city ecosystem may be quite hard for native plant species to survive, thereby, water hyacinth which can grow well under such kind of conditions won its first prize in the competition.

Ecological communities are rarely saturated with species (Moyle & Light, 1996); this also makes biological invasion a global problem. Studies on prediction and control methodology of bioinvasions are the key points in invasion biology in the recent years. According with the whole invasion process, some suggestion on how to control and manage biological invasion can be addressed as: (1) prevention invasions in the first place, e.g., detect strictly at customers, refresh ballast water before entering a port, introduce nonindigenous species carefully, etc; (2) eradication of invasive populations when they are young or newly established, because it costs little. However, detection and consciousness on potential harm of these invasions are generally ambiguous; (3) integrated control of established populations with mechanical, chemical (e.g., application of herbicides) and biological control. For those established and flourishing invasive species populations, it is difficult and also sometimes risky to eradicate them. Why risky? Since the invasive species may have dominated the ecosystems for a period of time and new biological relationship may have formed between the invaders and some other native species. Eradication of these invaders might destroy this kind of relationship and result in detrimental impacts on native species. In addition, because the invaders have been a member of the ecosystem, along with eradication of the invaders, blank niche will form and probably be invaded by some other new nonindigenous species. Therefore, to deal with the established invasive species populations, there are two relatively safe ways, one of them is to control the invaders at an appropriate level, and another one is to eradicate them and then restore the weak ecosystem with other noninvasive native species.

In fact, to study or control bioinvasions is not only scientists' duty but everyone's concern. Every person has the responsibility to avoid introducing and diffusing of invasive species. Therefore, a wide-spread teaching or publication on the harm and prevention of invasive species should be launched.

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References

Ambrogi, A. O., and Savini, D. (2003), Biological invasions as a component of global change in stressed marine ecosystems, *Marine Pollution Bulletin,* 46, 542-551.

Babu, R. M., et al. (2003), Bioassay of the potentiality of *Alternaria alternata* (Fr.) keissler as a bioherbicide to control water hyacinth and other aquatic weeds, *Crop Protection*, In press.

Costanza, R., et al. (1997), The value of the world's ecosystem services and natural capital, *Nature*, 387, 253-260.

Ding, J. Q., et al. (2000), Water hyacinth in China: its distribution, problems and control status, *Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, Beijing, China.* pp29-32.

Edward, B. B. (2001), A note on the economics of biological invasions. *Ecological Economics,* 39, 197-202.

Elliott, M. (2003), Biological pollutants and biological pollution–an increasing cause for concern, *Marine Pollution Bulletin*, 46, 275-280.

Grevstad, F. S., et al. (2003), Biological control of *Spartina alterniflora* in Willapa Bay, Washington using the planthopper *Prokelisia marginata*: agent specificity and early results, *Biological Control*, 27, 32-42.

Hill, M. P., et al. (1999), Life history and laboratory host range of *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae), a new natural enemy released on water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub.) (Pontederiaceae) in South Africa, *Biological Control,* 14, 127-133.

Jing, K., et al. (2002), Primary research on the characteristics of feeding sites of *Grus monacha* in the east tide flat of Chongming, *Zoological Research,* 23(1), 84-88 (In Chinese).

Julien, M. H. (2000), Biological control of water hyacinth with arthropods: a review to 2000, *Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, Beijing, China.* pp 8-20.

Kathiresan, R. M., (2000), Allelopathic potential of native plants against water hyacinth, *Crop Protection,* 19, 705-708.

Kim, Y. C., and Kim, W. J. (2000), Roles of water hyacinths and their roots for reducing algal concentration in the effluent from waste stabilization ponds, *Water Research,* 34(13), 3285-3294.

Kriwoken, L. K., and Hedge, P. (2000), Exotic species and estuaries: managing Spartina anglica in Tasmania, Australia, *Ocean & Coastal Management,* 43, 573-584.

Li, B., et al. (2001), Perspectives on general trends of plant invasions with special reference to alien weed flora of Shanghai, *Biodiversity Science,* 9(4), 446-457 (In Chinese).

Ma, Z. J., et al. (2003), Effects of tidewater on the feeding ecology of hooded crane (*Grus monacha*) and conservation of their wintering habitats at Chongming Dongtan, China, *Ecological Research,* 18(3), 321-329.

Malakoff, D. (1999), Biological control: fighting fire with fire, *Science,* 285(5435), 1841-1843.

Maricle, B. R., and Lee, R. W. (2002), Aerenchyma development and oxygen transport in the estuarine cordgrasses *Spartina alterniflora* and *S. anglica, Aquatic Botany,* 74, 109-120.

McKinney, M. L., and Lockwood, J. L. (1999), Biotic homogenization: a few winners replacing many losers in the next mass extinction, *TREE,* 14(11), 450-453.

Mooney, H. A. (1999), Species without frontiers, *Nature,* 397, 665-666.

Moyle, P. B., and Light T. (1996), Biological invasions of fresh water: empirical rules and assembly theory. *Biological Conservation,* 78, 149-161.

Pimentel, D., et al. (2000), Environmental and economic costs of non-indigenous species in the United States, *BioScience,* 50(1), 53-65.

Shea, K., and Chesson, P. (2002), Community ecology theory as a framework for biological invasions, *TREE*, 17(4), 170-176.

Singhal, V., and Rai, J. P. N. (2003), Biogas production from water hyacinth and channel grass used for phytoremediation of industrial effluents, *Bioresource Technology*, 86, 221-225.

Wang, S., et al. (1996), *Conservation of Chinese Biodiversity* (2). Beijing, China Environmental Science Press. pp 91-151 (In Chinese).

Wasson, K., et al. (2001), Biological invasions of estuaries without international shipping: the importance of intraregional transport, *Biological Conservation*, 102, 143-153.

Zhao, B., et al. Estimating the service values of wetlands in Shanghai. Wetland (In reviewing).

Zhao B., et al. (2003), Wise exploitation of newly growing land resources: an assessment on land-use change of Chongming Island using GIS, *Chinese Geographical Science*, 13 (2), 134-141.