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The distribution and economic losses of alien species invasion to China

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Abstract

Invasive alien species have become one of the most serious environmental issues in the world. Data of taxon, origin, pathway, and environmental impacts of invasive alien microorganisms, invertebrates, amphibians and reptiles, fish, birds, mammals, herbs, trees, and, marine organisms in terrestrial, aquatic, and marine ecosystems of China were analyzed during 2001 and 2003, based on literature retrieval and field survey. There were 283 invasive alien species in China, and the number of species of invasive alien microorganisms, aquatic plants, terrestrial plants, aquatic invertebrates, terrestrial invertebrates, amphibians and reptiles, fish, and mammals were 19, 18, 170, 25, 33, 3, 10, and 5, respectively. The proportion of invasive alien species originated from America, Europe, Asia, Africa, and Oceania were 55.1, 21.7, 9.9, 8.1, and 0.6%, respectively. Methods for estimation of direct economic losses to agriculture, forestry, stockbreeding, fishery, road and water transportation, storage, water conservancy, environment and public facilities, and human health were established. Methods for estimation of indirect economic losses caused by invasive alien species to service functions of forest ecosystems, agricultural ecosystems, grassland ecosystems, and wetland ecosystems were also established. The total economic losses caused by invasive alien species to China were to the time of USD 14.45 billion, with direct and indirect economic losses accounting for 16.59% and 83.41% of total economic losses, respectively.

Introduction

Alien species occur outside its normal distribution. Invasive alien species establish in natural or semi-natural ecosystems or habitat, and acts as an agent of change, and threatens native biological diversity (Williamson 1996; IUCN 2000; Shine et al. 2000; McNeely et al. 2001). Invasive alien species reduces the uniqueness of regional fauna and flora, and breaks down geographical barriers that maintain global biodiversity (Lovei 1997; Fang 2000). The risks associated with the invasion of alien species are increasing, with increasingly rapid international exchange and convenient transportation (Chen and Xu 2001). Invasive alien species expedites the losses of

species and genetic biodiversity (Qiang and Cao 2001; Xie et al. 2001; Li and Xie 2002; Wan et al. 2002), destroys the structure and functions of ecosystems (Peng and Xiang 1999; Liang and Wang 2001; Zhang and Ye 2002), and causes huge economic losses (Xu and Ding 2003). For instance, invasive alien species has caused losses worth USD 138 billion to the United States (Pimentel et al. 2000). However, the data about economic losses of invasive alien species to China are not available.

Due to the lack of baseline data, knowledge, and sound control measures for invasive alien species in China, it is necessary to launch a nationwide investigation on and estimate the economic losses caused by invasive alien species, so as to grasp baseline data, identify pathways of invasion, and to put forward effective control strategies and measures.

Distribution and pathways of invasive alien species in China

An investigation of invasive alien species in China was conducted between December 2001 and October 2003, which was coordinated by Nanjing Institute of Environmental Sciences under State Environmental Protection Administration (SEPA) of China. The targets of the investigation were invasive alien micro-organisms, invertebrates, amphibians, reptiles, fish, mammals, herbs, trees, and marine organisms, which originated from other countries and established population in China. A working group was established to conduct the investigation, with professional experts on herbs from the Nanjing Agricultural University; experts on forest diseases and pests from the Nanjing Forestry University, experts on agricultural diseases and pests from the Institute of Biological Control, Chinese Academy of Agricultural Sciences, experts on oceanic species from the Third Institute of Oceanography, State Oceanic Administration, experts on fresh water fish from the Institute of Hydrobiology, Chinese Academy of Sciences, and experts on amphibians, reptiles, and mammals from the Nanjing Normal University. The investigation covered terrestrial, aquatic and marine ecosystems in China and was carried out based on literature analysis and field survey. Twenty indicators were designed for the investigation, including taxonomy, morphology, distribution, impacts, first observation, origin, invasion pathways to China, local dispersal ways, habitat, life history, and control measures, etc. Detailed information was collected for 283 invasive alien species across the country, from governmental statistics and published references (Xu et al. 2004). The data for the number of invasive alien species is as of 2000. An inventory of invasive alien species in China was developed as the result of the investigation, which is an inventory of all known recorded invasive alien species in China (Xu and Qiang 2004).

The number of invasive alien species in each category was shown in Table 1. Half of invasive alien species were terrestrial plants, other major types of invasive alien species were terrestrial invertebrates, aquatic invertebrates, microorganisms and aquatic plants.

The proportion of invasive alien species originated from America, Europe, Asia, Africa and Oceania were 55.1, 21.7, 9.9, 8.1, and 0.6%, respectively (Table 2). There is no significant difference in species composition from different regions, but half of the species were from America. This is because that species from America are more adaptable to the habitats in China.

39.6% of all invasive alien species in China were intentionally introduced; 49.3% were unintentionally introduced; nine species naturally dispersed into China, accounting for only 3.1% (Table 3). There is difference in species composition from different pathways. All invasive alien microorganisms were unintentionally introduced, through timber, seedlings, flowerpots, or soil. Fivety percent of the invasive alien plants were

Table 1. Category of invasive alien species in China.

Category	Number of species	Percent (%)
Microorganism	19	6.7
Aquatic plant	18	6.4
Terrestrial plant	170	60
Aquatic invertebrate	25	8.8
Terrestrial invertebrate	33	11.7
Amphibian and reptile	3	1.1
Fish	10	3.5
Mammal	5	1.8
Total	283	100

Table 2. Origin of invasive alien species in China.

Category	Region					
	America	Europe	Asia	Africa	Oceania	Unknown
Frequency						
Microorganism	9	4	1	0	0	5
Aquatic plant	16	1	1	1	0	5
Terrestrial plant	106	45	21	18	1	1
Aquatic invertebrate	19	13	1	0	0	0
Terrestrial invertebrate	17	5	6	4	1	4
Amphibian and reptile	3	0	0	0	0	0
Fish	6	0	1	3	0	0
Mammal	2	2	1	0	0	0
Total	178	70	32	26	2	15

Table 3. Pathways of invasive alien species in China.

Category	Intentional introduction	Unintentional introduction	Natural dispersion	Unknown
Microorganism	0	19	0	0
Aquatic plant	7	11	0	0
Terrestrial plant	88	54	8	23
Aquatic invertebrate	1	24	0	0
Terrestrial invertebrate	5	32	0	0
Amphibian and reptile	3	0	0	0
Fish	10	0	0	0
Mammal	1	3	1	0
Total	115	143	9	23

intentionally introduced as pasture, feedingstuff, ornamental plants, textile plants, medicinal plants, vegetables, or lawn plants. Twenty five percent of invasive alien animals were intentionally introduced for breeding, ornament, biological control, or through the introduction of fringe, seedling or bonsai; 76.3% of invasive alien animals invaded through commodity or transportation facility because of the failure of quarantine.

Regarding to the habitat of invasive alien species, major habitats are farmlands, accounting for 59.1%; and the other major habitats are forest ecosystems (13.7%), marine ecosystems (12.5%), and wetland ecosystems (7.2%) (Table 4).

Estimation of economic losses

The economic losses caused by invasive alien species can be divided as direct and indirect losses. Direct losses are referred to direct goods damage and practical revenue decrease to agriculture, forestry, stockbreeding, fishery, road and water transportation, storage, water conservancy, environment and public facilities, or human health. Indirect losses are referred to the losses of service function of ecosystems.

Direct economic losses

Methods for estimation of direct economic losses were developed for related industries, based on market price, opportunity cost, human resources cost, and prevention and restoration cost (Xu et al. 2004). Table 5 shows the components of losses and targets of assessment for related industries, based on all known recorded invasive alien species in China. Data were from governmental statistics and published references (Xu et al. 2004). The estimate of direct economic losses is as of 2000.

The economic loss caused by invasive alien species to eight industries in China was RMB 19847.59 million in 2000, or USD 2397.39 million (The exchange rate of USD to RMB is 8.2788). The economic losses to agriculture,

Table 4. Invasive alien species in various ecosystems of China.

Category	Farmlands	Forests	Inland waters/wetlands	Marine	Buildings
Microorganism	9	10	0	0	0
Aquatic plant	0	0	5	13	0
Terrestrial plant	162	29	1	5	17
Aquatic invertebrate	1	0	2	24	0
Terrestrial invertebrate	24	6	0	0	8
Amphibian and reptile	0	0	3	0	0
Fish	0	0	10	0	0
Mammal	2	1	3	0	0
Total	198	46	24	42	25

Table 5. Components of losses and targets of assessment for related industries.

Industries	Components of loss	Targets of assessment
Agriculture	Loss of yield, loss of quality and prevention and control costs	Loss of alien virus, pests, weeds and rats to crops, fruits and nuts
Forestry	Timber stock loss and prevention and control cost	Alien harmful virus, pests and rats
Stockbreeding	Loss of forage	Crofton weed (*Eupatorium adenophorum*)
Fishery	Loss of yield	Smooth cordgrass (*Spartina alterniflora*), common cordgrass (*Spartina anglica*) and red tide organisms
Road and water transportation	Cost of prevention and elimination, and more consumption of oil	Water hyacinth (*Eichhornia crassipes*) and alien biofouling
Storage	Loss of yield	Pea weevil (*Bruchus pisorum*) and potato tuberworm (*Phthorimaea operculella*)
Water conservancy, environment and public facilities	Cost of prevention and control, loss of value of landscapes,	Weeds and pine wood nematode (*Bursaphelenchus xylophilus*)
Human health	Loss of working time, cost of disease treatment, cost of burying the dead	Common ragweed (*Ambrosia artemisiifolia*) including giant ragweed, and Brown rat (*Rattus n. norvegicus*)

forestry, stockbreeding, fishery, transportation, storage, water conservation and public facilities, and human health account for 61.48, 11.03, 4.98, 3.08, 3.85, 0.42, 0.44, and 14.72% of total direct economic losses, respectively (Table 6). The direct economic losses caused by vegetable leaf miner (*Liriomyza sativae*), common ragweed (A*mbrosia artemisiifolia*), Brown rat (*Rattus n norvegicus*), cotton whitefly (*Bemisia tabaci*), greenhouse whitefly (*Trialeurodes vaporariorum*), Crofton weed (*Eupatorium adenophorum*) were more than RMB 1 billion.

Indirect economic losses

Methods for the assessment of indirect economic losses caused by invasive alien species to the service function of forest ecosystems, agricultural ecosystems, grassland ecosystems, and wetland ecosystems were established, respectively, based on the review of evaluation of service function of forest, agricultural, grassland, and wetland

Table 6. Losses to related industries in China caused by invasive alien species.

Industries	Economic losses (Million USD)
Agriculture	1473.99
Forestry	264.52
Stockbreeding	119.43
Fishery	73.91
Road and water transportation	92.28
Storage	10.03
Water conservancy, environment and public facilities	10.45
Human health	352.78
Total	2397.39

ecosystems and extent of damages of alien invasive species to the service function (Xu et al. 2004).

For the forest ecosystem, the impacts of invasive alien virus and pests to function were addressed, with conifer forests and broad-leafed forests treated separately due to their different ecosystem functions (Li and Xu 2005); for agricultural ecosystems, the impacts of invasive alien virus, pests, weeds, and rats to agricultural ecosystems function were addressed, with food crops, cotton, vegetables, and fruit garden ecosystems treated separately due to their different damage levels (Jian and Li 2004); the main invasive alien species that threatens grassland ecosystem function in China are crofton weed (*Eupatorium adenophorum*) and odor Eupatorium (*Eupatorium odoratum*); and the main invasive alien species that threatens wetland and marine ecosystems functions in China are alien weeds and red tide organisms (Li and Xu 2004). The ecosystem functions of inland waters, coastal and marine ecosystems are different, which should be treated separately. The losses to species and genetic diversity were not included. Data were from governmental statistics and published references.

The economic loss caused by invasive alien species to ecosystems function was RMB 99814.1 million in 2000, or USD 12056.58 million. The losses to forest, agricultural, grassland, and wetland ecosystems were USD 1959.33 million, 1404.66 million, 317.11 million, and 8375.48 million, respectively, accounting for 16.25, 11.65, 2.63 and 69.47% of total ecosystem function losses, respectively (Figure 1). The data of indirect economic losses was as of 2000.

The total economic losses caused by invasive alien species to China were RMB 119,661.69 million in 2000, or USD 14.45 billion, with direct and indirect economic losses accounting for 16.59% and 83.41% of the total economic losses, respectively. China's GDP in 2000 was approximately USD 1065.25 billion, and the economic loss caused by invasive alien species to China accounts for 1.36% of its GDP.

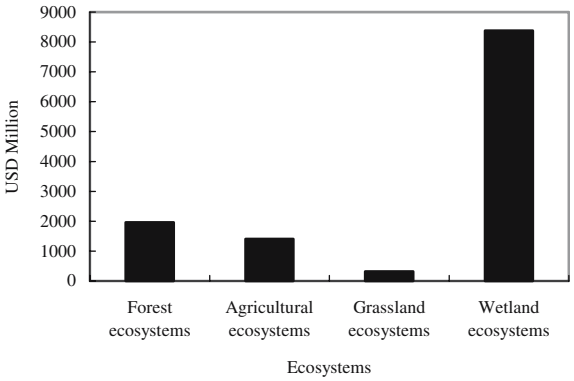

Figure 1. Indirect economic losses caused by invasive alien species to China in 2000.

Discussion

The economic loss caused by invasive alien species to the United States was USD 138 billion (Pimentel et al. 2000), accounting approximately 1.37% of US GDP. The economic loss caused by invasive alien species to the United States was 9 times of the economic losses of China, but the proportion of economic loss to national economy is similar. In the US estimate, the economic loss caused by Acquired Immune Deficiency Syndrome (AIDS) to human health was USD 6.5 billion, and the economic loss caused by alien pet cats to local birds was 14 billion US (Pimentel et al. 2000). However, these factors were not considered in China's estimate. If these factors were included, the damage of invasive alien species in China will be much more serious than in the United States.

Due to lack of comprehensive study of biological invasion in China, many parameters were difficult to obtain, which affects the accuracy and completeness of the estimate of the economic losses. There was a governmental statistics about the acreage and extent of forestry pests occurring in China, and in depth sound study on forest ecosystem service functions, thus the estimation of indirect economic losses of invasive alien species to forest ecosystems was relatively accurate. However, due to lack of study of wetland ecosystem service function in China, the indirect economic losses of invasive alien species to wetland ecosystems was estimated based on the assessment of wetland ecosystem service function in other countries and published references. The impacts of crofton weed and odor Eupatorium were only considered for grassland ecosystems, which may underestimate the economic losses.

Many institutions and individuals in China lack adequate knowledge of ecological and environmental consequences caused by invasive alien species. Some regions and departments are eager for introduction of alien species, which increases the risks of alien species invasion. For instance, half of the invasive alien plants were intentionally introduced as pasture, feedingstuff, ornamental plants, textile plants, medicinal plants, vegetables, or lawn plants. One quarter of alien invasive animals were intentionally introduced for cultivation, ornamentation, or biological control. This is because a sound risk assessment system is not established and implemented in China. The existing quarantine laws and regulations only focus on those organisms posing risk to agriculture, forestry, husbandry and fishery, and do not include those organisms that threaten eco-environment and biodiversity (Xu and Ding 2003). No specific regulation exists on the prevention, control, and eradication of invasive alien species in China. In addition, more efforts are made in the introduction of alien species, and little attention is paid on the management of introduced alien species. As a result, some alien species may escape into the natural environment from gardens and nurseries and become invasive species, which may cause potential threat to the environment.

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References

Chen LY and Xu HG (2001) Australian management strategy for invasive alien species and references available to China. Biodiversity Science 9(4): 466–471

Fang W (2000) Biological invasion and global change. In: Fang Jingyun (ed) Global Ecology Climatic Change and Ecological Response., Higher Education Press, Beijing

IUCN-The World Conservation Union (2000) IUCN Guidelines for the Prevention of Biodiversity Loss due to Biological Invasion (approved by the IUCN Council, February, 2000)

Jian LR and Li MY (2004) Indirect economic loss evaluation of biological invasion on crop-land ecosystem. Journal of Jinling Institute of Technology 20(3): 32–35

Li MY and Xu HG (2004) Valuation of indirect economic loss of alien invasive species on wetland ecosystem. Journal of Central South Forestry University 24(5): 53–56

Li MY and Xu HG (2005) Indirect economic loss evaluation of effect of alien invasive species on forest ecological system. Journal of Northwest Forestry University 20(2): 156–159

Li ZY and Xie Y (2002) Invasive Alien Species in China. China Forestry Publishing House, Beijing

Liang YB and Wang B (2001) Alien marine species and their impacts in China. Biodiversity Science 9(4): 458–465

Lovei GL (1997) Biodiversity – Global change through invasion. Nature 388: 627–628

McNeely JA, Mooney HA, Neville LE, Schei P and Waage JK (2001) A global strategy on invasive alien species. IUCN Switzerland, Gland and Cambridge, UK, in collaboration with the Global Invasive Species Programme. X + 50pp

Peng SL and Xiang YC (1999) The invasion of exotic plants and effects of ecosystems. Acta Ecologica Sinica 19(4): 560–569

Pimentel D, Lach L, Zuniga R and Morrison D (2000) Environmental and economic costs of non-indigenous species in the United States. Bioscience 50: 53–65

Qiang S and Cao XZ (2001) The harmfulness of exotic weeds in China and for their management. Biodiversity Science 9(2): 188–195

Shine C, Williams N and Gundling L (2000) A guide to designing legal and institutional frameworks on alien invasive species. IUCN, Gland, Switzerland Cambridge and Bonn. xvi + 138pp

Wan FH, Guo JY and Wang DH (2002) Alien invasive species in China: their damages and management strategies. Biodiversity Science 10(1): 119–125

Williamson M (1996) Biological Invasions. Chapman & Hall, London

Xie Y, Li ZY, William PG and Li D (2001) Invasive species in China – an overview. Biodiversity and Conservation 10(8): 1317–1341

Xu HG and Ding H (2003) Countermeasures for the prevention of invasive alien species. In: Wang DH and Fang C (eds) Conserving Biodiversity and Strengthening Nature Reserve Management, pp 128–139. China Environment Sciences Press, Beijing

Xu HG and Qiang S (2004) Inventory of Invasive Alien Species in China. China Environmental Sciences Press, Beijing,

Xu HG, Wang JM, Qiang S and Wang CY (2004) Study of Key Issues Under the Convention on Biological Diversity: Alien Species Invasion, Biosafety and Genetic Resources. Science Press, Beijing,

Zhang LY and Ye WH (2002) Community invasibility and its influencing factors. Acta Phytoecologica Sinica 26(1): 109–114