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# A risk assessment system for alien plant bio-invasion in Xiamen, China

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**Abstract**

Bio-invasion has caused serious ecosystem damage and enormous economic losses in China, and it has been the greatest factor to island bio-diversity reduction. Xiamen, as an important seaport with a relatively high conservation value, is particularly vulnerable to bio-invasion for its typical island ecosystem as well as frequent human-made disturbance. As a result of field surveys, literature review, and consultation with experts, a list of 67 alien plants identified as major invaders (12 species) and emerging invaders (55 species) in Xiamen has been compiled. Based on the analysis of the current situation of bio-invasion in Xiamen, a risk assessment system for alien plant invasion has been designed using a ranking system and an analytic hierarchy process. The system consists of 17 secondary indices, grouped into 6 primary indices reflecting the different stages in the bio-invasion process: introduction, establishment, dispersion, current range, infestation, and artificial control. Biogeographical, ecological, and experience-linked aspects of the species as well as artificial disturbance were taken into account in the index selection and criterion development. The system was then validated (and worked well) using fifty well-known alien plant species as candidates. Appropriate recommendations are proposed to help local policy-makers prioritize their decisions on such alien plants.

**Key words**: bio-invasion; invasive species; alien plants; risk assessment

## Introduction

Bio-invasion has threatened native bio-diversity and ecosystem service functions all over the world, and its significance as a global environmental issue has been widely recognized. China's natural ecosystems, like those in most parts of the world, are under threat from invasive species. According to the research report of a National Key Project aimed at invasive species in China, up to 283 species have invaded China and cause direct and indirect economic losses as high as 14.985 billion US dollars per year (Xu *et al*., 2004). In China, some policies and laws referring to the management of alien species have been brought into effect. However, China has not yet enacted a special law or set up a comprehensive system to regulate the risk management of invasive alien species. Prevention of bio-invasion currently mainly relies on quarantine measures which primarily focus on agriculture and forestry protection rather than ecosystem conservation and bio-diversity protection. Under this circumstance, a number of researchers have drawn attention to the risk assessment of pests and alien plant species. Most of these studies are primarily agricultural in scope (Fan and Zhao, 1997; Ji, 1994; Jiang *et al*., 1994; Li and Qin, 1998), nevertheless, some workers have established risk assessment of alien species in terms of ecosystem conservation and bio-diversity protection (Xiang *et al*., 2002; Xu *et al*.., 2004). For the local decision-makers, these case studies mainly could provide the framework and methodology but do not offer practical tools for the local management of alien species. There are still very few cases of risk assessment for bio-invasion at the local scale in China.

Xiamen (117°53′–118°25′E and 24°24′–24°55′N), situated at the estuary of the Jiulongjiang River along the southeast coast of Fujian Province, China. comprises Xiamen Island proper, Gulangyu Islet and the coastal part along the north bank of the Jiulongjiang River (Fig.1). It is particularly vulnerable to bio-invasion for its typical island ecosystem, frequent human-made disturbance and southern subtropical climate which provides favorable conditions for a wide range of tropical and subtropical plants. The problems associated with alien plant invasion are escalating rapidly in Xiamen. Some plant invaders are already well-established. Several are recently introduced, or have entered a phase of rapid population growth. Serious impacts of the plant invaders on ecosystem and landscape value have attracted the local government's attention in recent years. The Xiamen Environmental Protection By-law in 2004 clearly states that an environmental impact assessment must be performed under the supervision of the competent authorities before the introduction of alien species. However, there is no sufficient information concerning alien plants presented in Xiamen and no protocols are available for the local government to identify those

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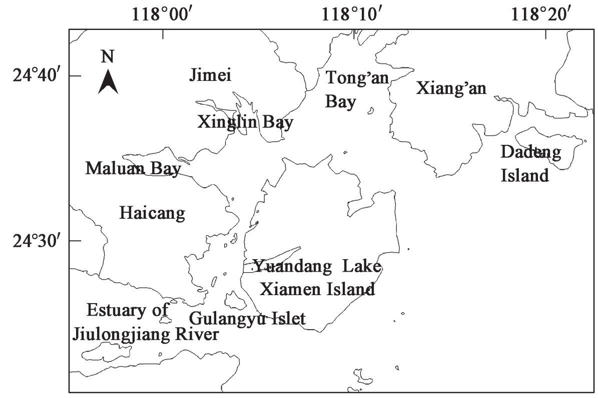


**Fig. 1** Map of Xiamen, China.

species that have a high-risk of introduction and are most problematic in terms of intervention measures. Therefore, it is important to make it clear that how many alien plant species have already invaded or would pose a potential threat in the future. Moreover, a practical risk assessment system for bio-invasion prevention and control is urgently needed.

As for the local decision-makers, preventive measures ideally consist of two parts: the prevention of entry of one species; and the restriction of spread and reduction of actual or potential impacts once the species is present (Zamora *et al*., 1989; Westbrooks, 1991). Several screening systems for predicting the potential effects of invasive species before their introduction to a given region have been devised to address the former task, such as: the Weed Risk Assessment (WRA) system in Australian (Pheloung *et al*., 1999); the exotic plants rating system in central Europe (Weber and Gut, 2004); the woody plants risk screening system in South Africa (Tucker and Richardson, 1995) and North America (Reichard and Hamilton, 1997), and others (Copp *et al*., 2005; Greenslade, 2002; Smallwood and Salmon, 1992; Daehler and Carino, 1999). For the latter one, a risk prioritizing system is required to help direct limited resources to countermeasures against those species already present in an area (e.g., Robertson *et al*., 2003; Nel *et al*., 2004; Hiebert, 1997; Hiebert and Stubbendieck, 1993; Kolar and Lodge, 2002). Most of these cases have provided useful references for designing an alien plant risk assessment system in Xiamen.

In this article, our attempt to compile a list of alien plants identified as major invaders and emerging invaders in Xiamen is reported, and a risk assessment system proper for Xiamen is proposed to meet the requirements of the policy-makers in preventing the introduction of high-risk species and the management of established alien species.

# 1 Materials and methods

## 1.1 Approach

Field surveys of alien plant species in Xiamen were conducted from February 2005 to October 2006, totally 12 times. The survey areas include human-made habitats (e.g., urban park, farmland, road-side), and natural or semi-natural communities (e.g., suburban forest, coastal zone, unmanned islet). In addition to field surveys, literature review (Li and Xie, 2002; Chen, 2005; Workgroup of Fujian Province Local Flora, 1995; Huang, 2006), internet/agency database search (ETF/CCICED, 2002), was made to compile the list of alien plants identified as major invaders and emerging invaders in Xiamen. Major invaders refer to those invasive alien species that are well-established, and which already have a substantial impact on natural or semi-natural ecosystems. Emerging invaders currently have less influence, but have attributes and potentially suitable habitats that could result in increased range and consequences in the next few decades (Nel *et al.*, 2004). Both categories include alien species that are already established in Xiamen.

In the case studies concerning prevention of bio-invasion, various approaches have been applied quantitatively and qualitatively, such as a broad-scale climate matching procedure (Mgidi *et al*., 2006), derivation of a black list with available quantitative data (Nel *et al*., 2004), quantitative risk assessment by Discriminant Analysis (DA) and Categorical and Regression Tree Analysis (CART) (Kolar and Lodge, 2002; Reichard and Hamilton, 1997), according to Tucker and Richardson (1995), multiple logistic regressions (Scott and Panetta, 1993), ranking systems (Weber and Gut, 2004; Hiebert and Stubbendieck, 1993; Robertson *et al*., 2003; Hiebert, 1997), and a set of questions or criteria integrated with a scoring system similar to ranking system (Pheloung *et al*., 1999; Greenslade, 2002; Copp *et al*., 2005). Among the various approaches, the ranking system provides users with a tool to sort exotic plant species based on their present level of impact and their innate ability to become a pest (Hiebert and Stubbendieck, 1993). In this study, a ranking system consisting of a set of criteria and scoring system was chosen to develop the risk assessment system, as it is simple, easy to perform, and appropriate for the intended purpose.

As a popular multiple criteria decision-making tool, the analytic hierarchy process (AHP) provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances (Saaty, 1990; Omkarprasad and Sushil, 2006), and so we used the AHP to determine the weights of indices in the ranking system.

## 1.2 Risk assessment system design

It has been recognized that the success of a bio-invasion results from a complicated chain of processes, which generally includes the stages of introduction, establishment, dispersion, and final infestation (i.e., becoming a pest) (Xu *et al*., 2003). This viewpoint has formed the rationale of our approach. According to the stages of the invasion process, we designed the risk assessment system of six primary indices (Appendix). Although artificial control is not a component of the invasion process, but it is the human terminal response to the invasion, therefore, the index of feasibility of control should be regarded as an inseparable part of the risk assessment system.

When establishing the secondary indices and their respective detailed criteria, biogeographical, ecological, and experience-linked aspects of the species as well as artificial disturbance in each of the stage of the invasion process were all taken into account. We also consulted those criteria mainly used for weed risk assessment and decision-making tool for prioritizing alien species in bio-invasion management (Hiebert and Stubbendieck, 1993; Tucker and Richardson, 1995; Pheloung *et al*., 1999; Robertson *et al*., 2003; Weber and Gut, 2004; Xu *et al*., 2004). Such indices and detailed criteria have been selected deliberately under the constraints of data availability and ease-of-use considerations to be more appropriate to alien plant species impacts on Xiamen natural environments.

### 1.3 Scoring system

The weight of primary indices and secondary indices in the scoring system was defined using the AHP approach (Weber, 1993; Zeng *et al*., 2007; Tan, 2002). Each of the primary indices was allocated with a weight on a percentage basis, and a certain portion of the weight under each primary index was allocated to the subdivided secondary indices. The sum by adding up all the values was 100. The 17 secondary indices were assessed further, each with a series of detailed criteria from which only one positive option was chosen. Finally, the whole weight or only a portion of the weight of the secondary index value was allocated to the target plant species (Appendix). For example, the primary weight for the primary index, "1 Probability of introduction", is 15%, and the weight allocated to the top secondary index 1.1 "Probability of intentional introduction", is 4%. If the plant was unlikely to be introduced this factor is given 0, might be introduced intentionally it is given a factor of 2, but an intentional introduction is proved, a full weight of the index is allocated, namely 4.

Through this evaluation process, all the primary and secondary indices for a specific alien plant can be summed to obtain a numerical value or score. The resulting summed scores allow the target species to be ranked in order of their invasion risk. Having consulted the ranking of risk assessment for the alien plants in China and other countries (Daehler *et al*., 2004; Pheloung *et al.*, 1999; Tucker and Richardson, 1995; Weber and Gut, 2004; Xu *et al.*, 2004), the ranking of risk for alien plant assessment in Xiamen is given in Table 1. Depending on the score of the risk assessment (100 is the worst case), action recommendations can be made.

### 1.4 System validation

We validated the risk assessment system by testing a set of well-known invasive plant species. The information used for the risk assessment process mainly came from the primary literature through database search using the Science Direct, the Springer link Database and the Chinese Journal Full-text Database, prepared by the China Academic Journals Electronic Publishing House, and the World Wide Web (using search engines and on-line databases such as, ISSG/IUCN-SSC, 2000; ETF/CCICEO, 2002; USDA-APHIS, 1999).

## 2 Results

### 2.1 List of alien plants

We identified 67 alien plants as either major invaders (12 species) or emerging invaders (55 species) in Xiamen (Table 2).

Among the 12 major invasive alien plants in Table 2, three species already have badly impacts in Xiamen, namely *Macfadyena unguis-cati*, *Spartina alterniflora*, and *Eichhornia crassipes*. These three most invasive species have cost a great deal each year in manpower and material resources in keeping them under control.

### 2.2 Result of the system validation

The complete risk assessment system for alien plant bio-invasion is set out in Appendix. Forty-three alien plants (including 12 major invaders and 31 emerging invaders) which have different impacts in Xiamen from Table 2, together with 7 alien species from adjacent regions which are considered the most likely to be introduced into Xiamen, were chosen as candidates for the system validation. Because the range and impact of all the species were identified in the field surveys and the desk work, and they represented various degrees of potential invasion, they were the most appropriate candidates to test and validate the risk assessment system. The results are shown in Table 3, where the species are listed in order of decreasing scores.

## 3 Discussion

The reliability of the total risk score (and hence of the rank) is clearly dependent on the quality of the available data and the experience of the assessor. As is the case with most assessment tools, application of the system is limited due to the lack of ecological data for plant species. Several ranking systems allow only some of the criteria to be considered due either to a genuine lack of, or access to, reliable data, but sometimes may result in an unusually high or low score and rankings for individual species in practice (Pheloung *et al*., 1999; Greenslade, 2002; Robertson *et al*., 2003). The proposed risk assessment

**Table 1** Ranking of the risk for alien plant assessment and recommended responses to the assessed risk in Xiamen, China

| Rank interval | Rank of risk | Recommended response for management |
|---|---|---|
| 0–39 | Acceptable | Allow introduction or existence |
| 40–59 | Requires further research | Represents moderate risk, need to gain relevant information and take some measures for prevention and supervision |
| 60–100 | Unacceptable | Represents a great risk, forbid introduction or must be put under control |

**Table 2** List of alien plants by family and number of species identified as major invaders and emerging invaders in Xiamen, China

| Family | No. of species | Common name | Species name | |
|---|---|---|---|---|
| Piperaceae | 1 | Shiny Peperomia | *Peperomia pellucida* | E |
| Urticaceae | 1 | Artillery Plant | *Pilea microphylla* | E |
| Chenopodiaceae | 1 | Mexican Tea | *Chenopodium ambrosioides* | E |
| | | Alligator Weed | *Alternanthera philoxeroides* | M |
| Amaranthaceae | 4 | Spinyflower | *Alternanthera pungens* | E |
| | | Thorny Amaranth | *Amaranthus spinosus* | E |
| | | Green Amaranth | *Amaranthus viridis* | E |
| Nyctaginaceae | 1 | Four O'clock | *Mirabilis jalapa* | E |
| Basellaceae | 1 | Madeira Vine | *Anredera cordifolia* | M |
| Brassicaceae | 2 | Swine Wart Cress | *Coronopus didymus* | E |
| | | Poor-man's pepper | *Lepidium virginicum* | E |
| Leguminosae | 4 | Wattle | *Acacia farnesiana* | E |
| | | White Popinac | *Leucaena leucocephala* | E |
| | | White Sweetclover | *Melilotus albus* | E |
| | | Humble Plant | *Mimosa pudica* | E |
| Oxalidaceae | 1 | Violet Woodsorrel | *Oxalis corymbosa* | E |
| Euphorbiaceae | 2 | Garden Spurge | *Euphorbia hirta* | E |
| | | Castorbean | *Ricinus communis* | E |
| Malvaceae | 2 | Venice Mallow | *Hibiscus trionum* | E |
| | | Coromadel | *Malvastrum coromandelianum* | E |
| Sterculiaceae | 1 | Florida Waltheria | *Waltheria indica* | E |
| Passifloraceae | 1 | Weed Passion Flower | *Passiflora foetida* | E |
| Cactaceae | 2 | Pest Pear Opuntia | *stricta var. dillenii* | E |
| | | Prickly Pear | *Opuntia monacantha* | E |
| Apiaceae | 1 | Wild Celery | *Apium leptophyllum* | E |
| Convolvulaceae | 2 | Five Fingered Morning Glory | *Ipomoea cairica* | M |
| | | Common Morning Glory | *Ipomoea purpurea* | M |
| Verbenaceae | 2 | Common Lantana | *Lantana camara* | M |
| | | Jamaica Falsevalerian | *Stachytarpheta jamaicensis* | E |
| Labiatae | 1 | Wild Spikenard | *Hyptis suaveolens* | E |
| Solanaceae | 3 | Common Thorn apple | *Datura stramonium* | E |
| | | Wild Tobacco | *Solanum erianthum* | E |
| | | Wild Tomato | *Solanum torvum* | E |
| Scrophulariaceae | 3 | Sweet Broom | *Scoparia dulcis* | E |
| | | Persian Speedwell | *Veronica persica* | E |
| | | Field Speedwell | *Veronica polita* | E |
| Bignoniaceae | 1 | Cat's Claw Vine | *Macfadyena unguis-cati* | M |
| Asteraceae/Compositae | 16 | Mexican Ageratum | *Ageratum conyzoides* | E |
| | | Saltmarsh Aster | *Aster subulatus* | E |
| | | Railway Beggarticks | *Bidens pilosa* | E |
| | | Asthmaweed | *Conyza bonariensis* | E |
| | | Horseweed | *Conyza Canadensis* | E |
| | | Guernsey Fleabane | *Conyza sumatrensis* | E |
| | | Hawksbeard Velvetplant | *Crassocephalum crepidioides* | E |
| | | Praxelis | *Eupatorium catarium* | M |
| | | Gallant Soldier | *Galinsoga parviflora* | E |
| | | Guayule | *Parthenium hysterophorus* | M |
| | | Camomileleaf Soliva | *Soliva anthemifolia* | E |
| | | Procumbent Tridax | *Tridax procumbens* | E |
| | | Singapore Daisy | *Wedelia trilobata* | M |
| | | Eastern Daisy Fleabane | *Erigeron annuus* | E |
| | | Ragweed | *Ambrosia artemisiifolia* | E |
| | | Mexican Sunflower | *Tithonia rotundifolia* | M |
| Poaceae (nom. alt. Gramineae) | 10 | Wild Oat | *Avena fatua* | E |
| | | Tropical Carpetgrass | *Axonopus compressus* | E |
| | | Bear Grass | *Cenchrus echinatus* | E |
| | | Torpedo Grass | *Panicum repens* | E |
| | | Johnson Grass | *Sorghum halepense* | E |
| | | Indian Goosegrass | *Eleusine indica* | E |
| | | Palm Grass | *Setaria palmifolia* | E |
| | | Smooth Cord-Grass | *Spartina alterniflora* | M |
| | | Vetiver Grass | *Vetiveria zizanioides* | E |
| | | Hilo Grass | *Paspalum conjugatum* | E |
| Araceae | 1 | Water Lettuce | *Pistia stratiotes* | E |
| Pontederiaceae | 1 | Water Hyacinth | *Eichhornia crassipes* | M |
| Rubiaceae | 1 | Buttonweed | *Spermacoce latifolia* | E |
| Phytolaccaceae | 1 | Pokeberry | *Phytolacca americana* | E |
| Total | 67 | | | |

M: major invader; E; merging invader.

system is designed to use biogeographical and ecological indices and criteria that relevant data can be fairly easy to obtain. Therefore as an integrated system, all the indices should be used to calculate the total score for a species in our system, and it would be more complex, if not impossible, to design a system that would be capable of taking only certain criteria into account. In addition, since our system is designed to be performed at the local scale, the list of candidate species will almost certainly be different from the list at national scale and the influence of information gap may be less significant. Although the obtaining reliable data and information for all indices and all species is almost impossible, the consequences of missing data need to be considered when evaluating the final ranked list of alien plants. This can be done by examining the index and criterion scores for those species that are ranked unusually high or low. This ranking system provides a tool for investigation in bio-invasion management. Despite the potential weaknesses, the risk assessment system appears to have delivered credible results (Table 3) which accord with the actual hazards caused by these plants basically. Among the 31 species which had values of 60 or above and ranked as unacceptable, all the 12 major invaders were in the top 21 species and with values over 65. Of the seven species which gained values above 80, the three most invasive plants in Xiamen and the notorious invasive weed *Mikania micrantha* were the top four invaders. Considering both its strong invasive attributes and the catastrophic ecological consequences caused in the neighboring Guangdong Province, any form of introduction of *Mikania micrantha* should be denied or should be under rigorous inspection against its escape from control. *Solidago canadensis*, which is widespread and invasive in the areas of the Changjiang River Dalta, was ranked fifth. It should be pay special attention to preventing its re-introduction in the trade and horticulture activities. It used to be cultivated in Xiamen as an ornamental flower and was wiped out in 2005. Since *Lantana camara*, *Wedelia trilobata*, *Leucaena leucocephala*, and *Acacia farnesiana* have already been introduced into Xiamen and planted widely, we propose their replacement by other urban vegetation plants upon considering the high risk associated with these species, and timely efforts must be made to eradicate isolated infestations.

We also noticed that several alien plants identified as emerging invader gained a relatively high risk value, and some of them, such as *Sorghum halepense*, *Ambrosia artemisiifolia*, *Panicum repens*, *Leucaena leucocephala*, *Opuntia monacantha*, and *Pistia stratiotes* gained a value even higher than some major invaders. These species share some common features. They all had a successful invasion history in other areas in China, have some strong invasive attributes and would cause a massive impact when they formed an infestation. However, in Xiamen, such species currently have a restricted geographic distribution and show lower influence. Therefore high scores of these species may be attributed to indices such as reproductive ability, dispersal potential, and (potential) hazard and

**Table 3** Risk assessment of 50 alien plant species

| Species name | Risk value | Family | Species name | Risk value | Family |
|---|---|---|---|---|---|
| Risk rank of unacceptable, 60–100 | | | Risk rank of requires further research, 40–59 | | |
| *Macfadyena unguis-cati* | 86 | M | *Avena fatua* | 59 | E |
| *Mikania micrantha* | 86 | I | *Chenopodium ambrosioides* | 59 | E |
| *Spartina alterniflora* | 85 | M | *Alternanthera pungens* | 57 | E |
| *Eichhornia crassipes* | 84 | M | *Axonopus compressus* | 57 | E |
| *Solidago canadensis* | 83 | I | *Bidens pilosa* | 54 | E |
| *Alternanthera philoxeroides* | 83 | M | *Mimosa pudica* | 54 | E |
| *Lantana camara* | 82 | M | *Duranta repens* | 54 | I |
| *Sorghum halepense* | 79 | E | *Solanum erianthum* | 52 | E |
| *Wedelia trilobata* | 77 | M | *Panicum maximum* | 52 | I |
| *Ambrosia artemisiifolia* | 76 | E | *Solanum torvum* | 51 | E |
| *Anredera cordifolia* | 74 | M | *Passiflora foetida* | 49 | E |
| *Panicum repens* | 73 | E | *Vetiveria zizanioides* | 44 | E |
| *Leucaena leucocephala* | 71 | E | *Peperomia pellucida* | 43 | E |
| *Opuntia monacantha* | 70 | E | *Hyptis suaveolens* | 42 | E |
| *Tithonia rotundifolia* | 70 | M | *Sonneratia apetala* | 41 | I |
| *Ipomoea cairica* | 70 | M | Risk rank of acceptable, 0–39 | | |
| *Pistia stratiotes* | 69 | E | *Setaria palmifolia* | 39 | E |
| *Parthenium hysterophorus* | 68 | M | *Mirabilis jalapa* | 38 | E |
| *Ipomoea purpurea* | 67 | M | *Pilea microphylla* | 38 | E |
| *Opuntia dillenii* | 67 | E | *Laguncularia racemosa* | 36 | I |
| *Eupatorium catarium* | 66 | M | | | |
| *Ageratum conyzoides* | 65 | E | | | |
| *Lantana montevidensis* | 64 | I | | | |
| *Conyza canadensis* | 63 | E | | | |
| *Ricinus communis* | 63 | E | | | |
| *Paspalum conjugatum* | 63 | E | | | |
| *Acacia farnesiana* | 62 | E | | | |
| *Eleusine indica* | 62 | E | | | |
| *Oxalis coxymbosa* | 61 | E | | | |
| *Cenchrus echinatus* | 60 | E | | | |
| *Veronica persica* | 60 | E | | | |

M: major invader; E: merging invader; I: the species which is not present but considered most likely to be introduced into Xiamen.

impact. This indicates that the risk assessment system to a certain extent plays an early warning function.

This assessment system has been applied in practice since March, 2007 when a program of restoration for the mangrove forest along the Tong'an Bay was proposed by the local government. Two species of mangrove, *Sonneratia apetala* and *Laguncularia racemosa*, which were planned to be introduced, were assessed against the criteria of this system by researchers from Xiamen Institute of Environmental Protection. Based on the results in Table 3, some preventive measures can be taken in the introduction activities. It was the first attempt on bio-invasion risk assessment for introduced alien plants in Xiamen and this attempt changes the situation whereby no practical tool was available for use in the management of alien plants. Since it takes a relatively long time before central government can enact special laws and form a complete system for the regulation of the risk management of bio-invasion, and because preventing the introduction of high-risk species currently relies mainly on quarantine measures, we propose that a regulation aiming at management of alien species should be put into effect by the local government. As one of the most important components, the risk assessment of bio-invasion could be incorporated into the process of Environment Impact Assessment, which has gained great success in the environmental management in China.

## 4 Conclusions

On the basis of two years research, it has been made clear how many alien plant species have invaded Xiamen or pose a potential threat of invasion in the future. The list presented in this paper provides decision-makers with a basis for the management of alien plants. Meanwhile we have developed an alien plant risk assessment system adapted for the Xiamen area. Using 50 well-known species, the proposed risk assessment system has been tested, and works well. Obviously, the ranking of plant species based on a prioritization score is valid only for a limited period, because the status of these plants may change due to successful intervention strategies, changes in legislation, introduction of new species, or population increases of certain plants (Mclaren *et al*., 1998). However, the risk assessment system should be of great help to decision-makers in the management of alien species.

By modifying some secondary indices and related detailed criteria appropriately, such an assessment system could be customized to be more widely applicable for the risk assessment of plant invasions in other regions. However, this system is still incomplete and no doubt the criteria under each index require modification and refinement in the future. Since the outcome of any validation depends on the number and kind of species tested (Weber and Gut, 2004), its practicability must be evaluated by future work involved in the practical management of invasive plants.

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## Appendix

The risk assessment system for alien plant bio-invasion in Xiamen. This system involves six primary and seventeen secondary indices and the detailed criteria, together with the numerical value given to a positive answer to a criterion. Each of the indices was allocated with a weight on a percentage basis shown in the following bracket.

**1 Probability of introduction (15%)**

**1.1 Probability of intentional introduction (4%)**

Unlikely to be introduced intentionally 0

Can be introduced intentionally 2

There is some proof that it has previously been introduced intentionally 4

**1.2 Probability of unintentional introduction (3%)**

Unlikely to be introduced unintentionally 1

Can be introduced by tools of transportation 2

Can be introduced easily by tools of transportation and/or there is some proof that it has been introduced unintentionally 3

**1.3 Present supervision of introduction (4%)**

In the list of the targets of the present quarantine system and an integrated control program, and measures can prevent its introduction very well 1

In the list of quarantine targets for control, not too difficult to quarantine and can be intercepted under current supervision 2

Not in the list of quarantine targets for control, there are some difficulties in quarantine but can be intercepted under current supervision 3

Not in the list of targets for control, allowed to be introduced under current supervision 4

**1.4 Frequency and number of introductions (4%)**

Introduced once or in limited frequency, and the quantity per time is small 1

Introduced with limited frequency with a large quantity per time, or frequently with little quantity per time 2

Introduced many times and with large quantity per time 4

**2 Probability of establishment (15%)**

**2.1 Species adapted to Xiamen climate and environment (5%)**

(Annual averages in climate: temperature is 21°C, range from 1.5 to 38.5°C, precipitation is about 1,200 mm, mainly in the rainy season from May to August, acid rain frequency is 78.8%, humidity is 78%. The major soil type is lateritic red earth, secondary types are paddy soil, coastal solonchak, and a few red earth, and aeolian soil)

Unsuitable, cannot establish*
Relatively suitable 3
Suitable 5

**2.2 Reproductive ability and characteristics (10%)**

(1) Mode of reproduction: reproduces readily by both vegetative propagation and seeds or spores; (2) reproduces more than once yearly and has a relatively long period of blooming and fruiting; (3) produces a large number of seeds, greater than or equal to 1,000 seeds or spores per plant annually; (4) grows more rapidly to reproductive maturity than most plants of its life form; (5) grows by spreading rhizomes or stolons that may root at nodes; fragments capable of dispersing and subsequently generating a new plant; (6) can establish in a poor environment and is resistant to poor soil; (7) seeds or spores can survive in a poor environment: seeds remain viable in the soil for more than one year; (8) others

Has none of these characteristics or weakly exhibits only one or two 1
Exhibits one of the characteristics 2
Exhibits two of the characteristics 4
Exhibits three of the characteristics 6
Exhibits four of the characteristics 8
Exhibits over four of the characteristics 10

**3 Dispersal potential (15%)**

**3.1 Dispersal mechanism and distance of range: (7%)**

(1) By wind; (2) by water; (3) by animals; (4) by transport (e.g., vehicles)

Cannot make use of these media for dispersal and long-distance dispersal seldom or never occurs 1
Can make use of one of these media for dispersal and has relatively long-distance dispersal capabilities 3
Can make use of two of these media for dispersal and has relatively long-distance dispersal capabilities 5
Can make use of more than two of these media for dispersal and frequently expands over long-distance 7

**3.2 Trend of dispersion (5%)**

Its potential habitat is small 1
There are some suitable habitats or similar habitats invaded elsewhere in Xiamen 3
There are a large number of suitable habitats or similar habitats invaded elsewhere in Xiamen 5

**3.3 Natural enemies (3%)**

An effective natural enemy exists 0
A natural enemy exists but effect is insignificant 2
No natural enemy 3

**4 History of invasion and type of potential invasion (10%)**

**4.1 History of invasion at home and abroad (6%)**

No history of invasion in other areas 1
There are some reports of its invasion in China or other countries 4
There are some reports of its invasion in China and other countries 6

**4.2 Type of potential invasion (4%)**

Annual plant 1
Biennial plant, herbage or vine 2
Perennial plant, of American origin, herbage or vine 4
Others 0

**4[a] Circumstances of current range (10%)**

**4.1[a] Current range size in region (6%)**

Isolated or spotty range in region 1
Has invaded more than 300 $m^2$ 4
Widespread in region, at least in accord with the criteria below: 6
(a) Collectively adds up to at least 4,000 $m^2$
(b) Five infestations of at least 300 $m^2$ each
(c) Five infestations that each cover an entire localized community
(d) More than five infestations some of which are at least 300 $m^2$ or cover entire localized communities.

**4.2[a] Proportion of current range where the species caused negative impact (4%)**

Impacts occur in < 5% of the species' current generalized range in region 1
Impacts occur in 5%–20% of the species' current generalized range in region 2
Impacts occur in 21%–50% of the species' current generalized range in region 3
Impacts occur in >50% of the species' current generalized range in region 4

**5 (Potential) Hazard and impact (30%)**

**5.1 Impact on ecosystem processes and system-wide parameters (10%)**

(1) Increase in fire occurrence, frequency, and intensity in local area; (2) geomorphological changes caused by erosion and sedimentation; (3) hydrological regime changes and reduced available aquatic habitats caused by rapid transpiration; (4) impact on availability of nutrients and minerals, e.g. the species is a nitrogen fixer and causes a change of soil nitrogen; (5) cause system-wide reduction in light availability; (6) change in salinity, minerals, alkalinity, or pH; (7) others

No perceivable impact on ecosystem processes and system-wide parameters 0
Mild influence on ecosystem processes and system-wide parameters, exhibits weakly one or two of the impacts on ecosystem processes 4
Strongly exhibits impact on one ecosystem process 7
Significantly exhibits impact on two ecosystem processes 8
Strongly exhibits impact on more than two ecosystem processes, causes major, possibly irreversible, alteration or disruption of ecosystem processes and system-wide parameters. 10

**5.2 Impact on native plant or animal species (10%)**

(1) Strongly out-competes a particular native species; (2) produces spines, thorns, burrs, or is toxic to animals; (3) produces chemical substance to inhibit the germination

or growth of other plants; (4) climbing or smothering growth habit; (5) hybridizes with a particular native species (especially with precious species); (6) hosts a disease or pest which causes damage; (7) other

Exhibits one or two of these impacts weakly, little or no impact on particular native species 1

Exhibits one impact and occasional impact on a particular species 3

Exhibits two impacts and significant impact on a particular species (e.g., has negative impacts on about 50% of the individuals of a native species) 6

Exhibits three impacts and significant impact on a particular species (e.g., has negative impacts on about 50% of the individuals of a native species) 8

Exhibits more than three impacts and significant impact on a particular species (e.g., has negative impacts on more than 50% of the individuals of native species) 10

**5.3 Impact on economy and other aspects (10%)**

(1) Local agriculture, forestry or fishing; (2) ecological community structure, causes alteration of original ecological function; (3) availability of soil, wetland, or other resources; (4) destruction of original landscape and causes damage to sites of importance to tourism; (5) impacts human health; (6) others

Little or without impact on local economy and other aspects 1

Weak impact on one aspect 4

Significant impact on one aspect 6

Significant impact on two aspects 8

Significant impact on more than two aspects 10

**6 Feasibility of control (15%)**

**6.1 Measure and effect of control (5%)**

Effective methods for permanent eradication of invasive species 1

Effective methods for temporary control of invasive species 3

No effective methods to control or eradicate invasive species 5

**6.2 Cost and time commitment of restoration (5%)**

Quick process of control with low cost 1

Requires short-term man-power and funding, time for control or restoration needs at least one year 2

Requires a great deal of man-power and funding short-term, time for control or restoration requires less than five years 3

Requires a great deal of man-power and funding long-term, time for control or restoration needs more than five years 4

The damage and impact are irreversible 5

**6.3 Impact of control on native species (5%)**

Little or no impact of control on native species 0

Moderate impact of control on native species 3

Continuous and severe impact of control on native species 5

[a] If the target of assessment is an invasive plant which has caused measurable visual impact in the local area, the fourth primary index is "Circumstances of current range"; however, if the target is an alien plant which would pose a potential threat, the category "History of invasion and type of potential invasion" is the choice.

* Directly gains the risk ranks of acceptable.

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