Investigation and Hazard Assessment of Invasive Alien Plants on the Campus of Tongren University

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Abstract [**Objectives**] The paper was to investigate and assess the species, distribution and hazard status of invasive alien plants on the campus of Tongren University. [**Methods**] A survey was conducted using line survey method, and the risk assessment index system of invasive alien plants was established by analytic hierarchy process (AHP). [**Results**] There were 11 species of invasive alien plants on the campus of Tongren University, belonging to 8 genera and 5 families. There were 6 species of invasive alien plants belonging to Asteraceae, accounting for 54.55% of the total. In terms of the origin of invasive plants, most of them were native to North America and Europe, accounting for 27.27% of the total. In terms of harmful level, there were no high-risk invasive plants on the campus of Tongren University, but *Alternanthera philoxeroides* had the highest score and was the most harmful. [**Conclusions**] The present situation of alien plant invasion on the campus of Tongren University is closely related to the ecological environment of the campus. It is suggested to strengthen the management of campus plants, focus on the prevention and control of *A. philoxeroides*, and carry out regular investigation of invasive alien plants on campus to ensure the ecological safety of the campus.

Key words Tongren University; Invasive alien plants; Plant investigation; Analytic hierarchy process; Hazard assessment

1 Introduction

Invasive alien plants refer to the plants that, due to natural or human factors, are spread from the ecosystem of a specific region into another ecological environment to settle, reproduce and spread, and pose harm to the introduced ecological environment or the species therein[1]. Invasive alien plants often have strong ecological adaptability, reproductive capacity and transmission capacity[2]. They will not only harm the biodiversity of local populations, but also have the genes of native plants after hybridization with native species, which will strengthen the adaptability of invasive species to the new environment, thus leading to biological homogeneity[3], causing the extinction or disappearance of local organisms and causing huge economic losses[4]. In addition, invasive alien plants are a serious disturbance type, and the naturalness and integrity of the original landscape are destroyed by the formation of large area monodominant community for various reasons[5]. There are many species on the campus of Tongren University, but there are few studies on invasive alien plants, and the prevention effect is poor. Based on the field survey of invasive alien plants in Tongren University, this study established the risk assessment index system of invasive alien plants in Tongren University by using analytic hierarchy process (AHP), in order to provide basic data for the prevention and control of invasive alien plants in Tongren University and provide a basis for the construction of good ecological campus.

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2 Materials and methods

2.1 General situation of survey area Tongren University (27°47′18.05″ - 27°47′32.26″ N, 109°13′9.23″ - 109°13′35.91″ E, altitude 412.74 m) is located in Bijiang District, Tongren City, Guizhou Province, belonging to the subtropical monsoon humid climate zone, with variable temperature and more rainfall in spring, hot weather, sufficient sunlight and heavy drought in summer, faster cooling and more rainy days in autumn, and low temperature and few sunshine, scarce rain, short frost period, and long crop growth season in winter. The average annual temperature is 15 - 17 ℃, and the average annual precipitation is 1 100 - 1 300 mm. Generally, the wind speed is small, and the maximum annual average wind speed is 2.3 m/s; the average wind speed in March and July is the highest, and that in October and December is the lowest. There are both hot and cool areas, four distinct seasons, and good soil conditions. In Tongren University, the green space covers about 48% of the total area, and artificial vegetation is the major vegetation type with rich plant species[6-7].

2.2 Methods

2.2.1 Research methods. The line survey method was adopted to investigate the invasive alien plants in 9 areas of Tongren University, including teaching building, college students' innovation and entrepreneurship incubation base, training building, experimental building, administration building, Ziwei restaurant, Dangui restaurant, art building and the north gate of Tongren University (Fig. 1). The species, life forms and origin of invasive alien plants were investigated, and their habitats, individuals and communities are photographed and collected. The plant specimens were identified by the *Flora of Guizhou*[8], the *Checklist of the Chinese Invasive Plants*[9] and the Plant Photo Bank of China

(PPBC) (https://ppbc.iplant.cn), and the hazard assessment system was established by analytic hierarchy process (AHP)[10] to assess the hazards of invasive alien plants.

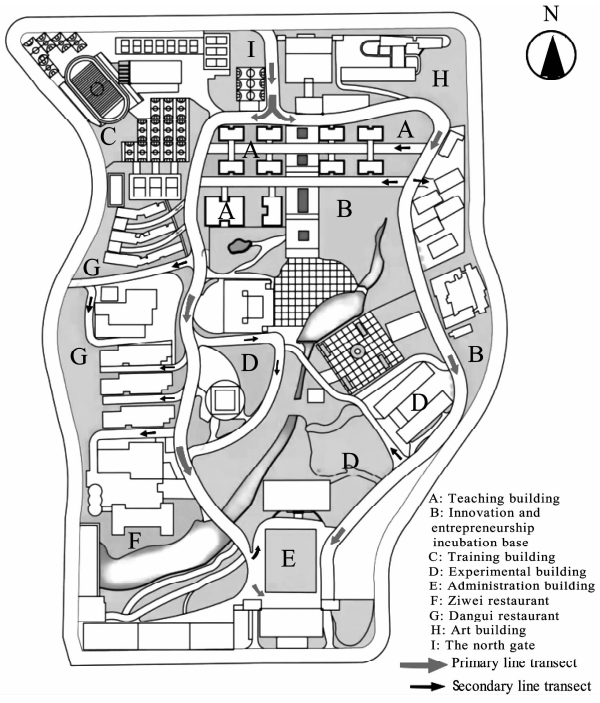

Fig. 1 Survey area of invasive alien plants in Tongren University

2.2.2 Construction of hazard assessment system. The AHP method is to take a complex multi-objective decision problem as a system, decompose the target into multiple objectives or criteria, and then decompose into several levels of multi-indicators (or factors). By solving the judgment matrix, the relative weight of each layer on the previous layer is obtained, the weight vector and feature vector are calculated, and the consistency test and total ranking are carried out, so as to determine the importance of each layer to the previous one. The overall ranking reflects the weight of each factor layer to the overall goal[11].

The assessment model is composed of target layer (A), criterion layer (B) and factor layer (C). The dimension of criterion layer consists of four aspects: invasion risk (B_1), diffusion risk (B_2), hazard and impact (B_3), and prevention and control feasibility (B_4). There are 12 main factors in the factor layer, including invasion route (C_1), number of introduced species (C_2), regulatory control situation (C_3), transmission capacity (C_4), adaptive capacity (C_5), reproductive capacity (C_6), impact on campus species diversity (C_7), impact on campus landscape (C_8), impact on ecosystem (C_9), control method and effect (C_{10}), control cost (C_{11}), and effect on native plants during control (C_{12}) (Table 1).

According to the content of factor layer in Table 1, the specific scoring standards of factor layer in the assessment model were obtained based on the risk assessment of alien plants invasion by Ou Jian *et al.*[12] (Table 2).

Table 1 Hazard assessment model of invasive plants in Tongren University

Target layer (A)	Criterion layer (B)	Factor layer (C)
Hazard assessment of invasive plants in Tongren University (A)	Invasion risk (B_1)	Invasion route (C_1)
		Number of introduced species (C_2)
		Regulatory control situation (C_3)
	Diffusion risk (B_2)	Transmission capacity (C_4)
		Adaptive capacity (C_5)
		Reproductive capacity (C_6)
	Hazard and impact (B_3)	Impact on campus species diversity (C_7)
		Impact on campus landscape (C_8)
		Impact on ecosystem (C_9)
	Prevention and control feasibility (B_4)	Control method and effect (C_{10})
		Control cost (C_{11})
		Impact on native plants during control (C_{12})

Table 2 Scoring criteria of invasive alien plants in Tongren University

Factor layer	Meaning of indicators	Scoring criteria
Invasion route (C_1)	Possibility of introduction of invasive alien plants	Artificial introduction, and no harm to the surrounding environment, 0 – 40 points; Unintentional introduction, no harm to the surrounding environment, no diffusion score, 41 – 60 points; Artificial introduction, but harmful to the surrounding environment, 61 – 80 points; Unintentional introduction, harmful to the surrounding environment, with diffusion score, 81 – 100 points
Number of introduced species (C_2)	Number of invasive alien plants introduced	Small number of introduction, 0 – 40 points; Relatively small number of introduction, 41 – 60 points; Relatively large number of introduction, 61 – 80 points; Mass introduction, 81 – 100 points

(To be continued)

(Continued)

Factor layer	Meaning of indexes	Scoring criteria
Regulatory control situation (C_3)	Control and management status of laws and regulations on invasive alien plants	There are sound regulations, and they are well managed, 0 – 40 points; There are relatively sound regulations, and they are well managed, 41 – 60 points; The corresponding regulations are not yet complete, and there are problems in management, 61 – 80 points; The corresponding regulations are not yet complete, and there are major problems in management, 81 – 100 points
Transmission capacity (C_4)	Transmission mode: 1. Wind transmission 2. Water transmission 3. Animal carrying	Can not be transmitted through the above modes, 0 – 40 points; Conforming to the above 1 transmission mode, 41 – 60 points; Conforming to the above 2 transmission modes, 61 – 80 points; Conforming to the above 3 transmission modes, 81 – 100 points
Adaptive capacity (C_5)	Whether invasive alien plants are suitable for local climatic conditions and environmental conditions	Unsuitable, unable to survive, 0 – 40 points; Unsuitable, but can grow in some places, 41 – 60 points; Suitable, with average growth, 61 – 80 points; Suitable, with fast growth, 81 – 100 points
Reproductive capacity (C_6)	Reproductive characteristics: 1. Sexual and asexual reproduction 2. Producing a lot of seeds 3. Strong vitality of seeds 4. Strong stress resistance	Exhibiting none of the above reproductive characteristics or slightly exhibiting one of the above, 0 – 40 points; Obviously exhibiting the above two reproductive characteristics, 41 – 60 points; Obviously exhibiting the above three reproductive characteristics, 61 – 80 points; Obviously exhibiting the above all reproductive characteristics, 81 – 100 points
Impact on campus species diversity (C_7)	1. Competing strongly with one of the endemic species 2. Occupying the habitat in high density 3. Being hosts to pests and diseases 4. Having allelopathy and secreting biotoxins	Showing the above one impact, 0 – 40 points; Showing the above two impacts, 41 – 60 points; Showing the above three impacts, 61 – 80 points; Showing the above all impacts, 81 – 100 points
Impact on campus landscape (C_8)	1. Damaging the ecological infrastructure of the campus 2. Changing the natural conditions of campus habitat and interfering with the natural succession of community 3. Destroying the diversity of campus landscape and affecting the beauty of campus vegetation landscape 4. Threatening biodiversity and damaging the ecological security of campus landscape	Showing the above one impact, 0 – 40 points; Showing the above two impacts, 41 – 60 points; Showing the above three impacts, 61 – 80 points; Showing the above all impacts, 81 – 100 points
Impact on ecosystem (C_9)	Impact on ecosystem processes or ecological factors: 1. Affecting microbial growth substances and nutrient circulation 2. Changing fuel composition and structure and affecting the frequency and severity of wildfires 3. Changing hydrological characteristics and affecting the available habitat space 4. Changing the local landscape by sedimentation and erosion	Showing the above one impact, 0 – 40 points; Showing the above two impacts, 41 – 60 points; Showing the above three impacts, 61 – 80 points; Showing the above all impacts, 81 – 100 points
Control method and effect (C_{10})	Specific methods and effects of controlling invasive plants	The clearing method is simple with obvious effect, and can eradicate for a long time, 0 – 40 points; The clearing method is complex with obvious effect, and can eradicate for a long time, 41 – 60 points; The clearing method is complex with unobvious effect and can not eradicate, 61 – 80 points; There is no effective control method, and the control effect is poor, 81 – 100 points
Control cost (C_{11})	Cost used in the control process	It is convenient and fast with low cost, 0 – 40 pints; It requires short-term investment of manpower and capital, 41 – 60 points; It requires a long-term investment of manpower and capital, 61 – 80 points; It causes irreversible harms and impacts that can not be restored, 81 – 100 points
Impact on native plants during control (C_{12})	Impact on native plants during control	Basically, no negative impacts on native plants, 0 – 40 points; Certain negative impacts on native plants, 41 – 60 points; Sustainable negative impacts on native plants, 61 – 80 points; Irreversible negative impacts on native plants, 81 – 100 points

2.2.3 Calculation of evaluation indicator weight value. Through the pairwise comparison of the next layer to the previous elements, the relative importance was obtained, and the judgment matrix was got. According to the 1 – 9 scale method, the relative importance was obtained and the judgment matrix was established. The maximum characteristic root λ_{max} and the corresponding eigenvector W and CI values of each judgment matrix were calculated by YAAHP software (V7.5), and $CR = CI/RI$ was used for consistency test, where CI is a consistency index; RI is a random consistency index; CR is a consistency ratio; and W_i is a weight value. When $CR < 0.10$, it can be judged that the judgment matrix has scientific consistency (Tables 3 – 7).

Table 3 Judgment matrix A – B_{1-4} and consistency test

Impact factor	B_4	B_3	B_2	B_1	W_i
B_4	1.000 0	0.500 0	0.500 0	0.333 3	0.118 8
B_3	2.000 0	1.000 0	3.000 0	0.500 0	0.296 7
B_2	2.000 0	0.333 3	1.000 0	0.500 0	0.176 3
B_1	3.000 0	2.000 0	2.000 0	1.000 0	0.408 3

Note: $\lambda_{max} = 4.166\ 1$, $CI = 0.055\ 3$, $RI = 1.000\ 0$, $CR = 0.062\ 2 < 0.1$, with reasonable weight allocation.

Table 4 Judgment matrix B_4 – C_{10-12} and consistency test

Impact factor	C_{10}	C_{11}	C_{12}	W_i
C_{10}	1.000 0	2.000 0	0.333 3	0.251 9
C_{11}	0.500 0	1.000 0	0.333 3	0.159 3
C_{12}	3.000 0	3.000 0	1.000 0	0.588 9

Note: $\lambda_{max} = 3.053\ 9$, $CI = 0.026\ 5$, $RI = 0.118\ 8$, $CR = 0.051\ 8 < 0.1$, with reasonable weight allocation.

Table 5 Judgment matrix B_3 – C_{7-9} and consistency test

Impact factor	C_7	C_9	C_8	W_i
C_7	1.000 0	2.000 0	0.333 3	0.251 9
C_9	0.500 0	1.000 0	0.333 3	0.159 3
C_8	3.000 0	3.000 0	1.000 0	0.588 9

Note: $\lambda_{max} = 3.053\ 9$, $CI = 0.027\ 0$, $RI = 0.296\ 7$, $CR = 0.051\ 8 < 0.1$, with reasonable weight allocation.

Table 6 Judgment matrix B_2 – C_{4-6} and consistency test

Impact factor	C_4	C_5	C_6	W_i
C_4	1.000 0	2.000 0	0.500 0	0.311 9
C_5	0.500 0	1.000 0	0.500 0	0.197 6
C_6	2.000 0	2.000 0	1.000 0	0.490 5

Note: $\lambda_{max} = 3.053\ 7$, $CI = 0.026\ 9$, $RI = 0.176\ 3$, $CR = 0.051\ 7 < 0.1$, with reasonable weight allocation.

Table 7 Judgment matrix B_1 – C_{1-3} and consistency test

Impact factor	C_1	C_2	C_3	W_i
C_1	1.000 0	3.000 0	2.000 0	0.524 7
C_2	0.333 3	1.000 0	0.333 3	0.141 6
C_3	0.500 0	3.000 0	1.000 0	0.333 8

Note: $\lambda_{max} = 3.053\ 8$, $CI = 0.026\ 9$, $RI = 0.408\ 3$, $CR = 0.051\ 7 < 0.1$, with reasonable weight allocation.

3 Results and analysis

3.1 Status of invasive alien plants According to the survey and statistics, there were 11 species of invasive alien plants in Tongren University, belonging to 8 genera and 5 families. There were 6 species belonging to Asteraceae, including *Erigeron annuus*, *Erigeron Canadensis*, *Bidens pilosa*, *Symphyotrichum subulatum*, *Erigeron bonariensis* and *Sonchus oleraceus*, accounting for 54.55% of the total; there were 2 species belonging to Oxalidaceae, accounting for 18.18% of the total (Table 8). As shown in Table 8, most of the invasive alien plants were native to North America and Europe, each accounting for 27.27% of the total.

Table 8 Statistics of invasive alien plants in Tongren University

Family name	Latin name	Origin	Life form
Asteraceae	*Erigeron annuus*	Brazil	Biennial herb
	Erigeron canadensis	South Africa	Annual herb
	Bidens pilosa	Tropical America	Annual herb
	Aster subulatus	West Asia and Europe	Annual herb
	Erigeron bonariensis	North America	Annual to biennial herb
	Sonchus oleraceus	North America	Annual to biennial herb
Oxalidaceae	*Oxalis pes-caprae*	Tropical America	Perennial root herb
	Oxalis corymbosa	North America	Perennial root herb
Amaranthaceae	*Alternanthera philoxeroides*	Europe	Perennial root herb
Scrophulariaceae	*Veronica persica*	Europe	Annual to biennial herb
Solanaceae	*Solanum aculeatissimum*	Brazil	Herb or subshrub

3.2 Hazard assessment analysis of invasive plants By comparing the relative importance of each element of the next layer with the previous one, the judgment matrix was established. Teachers of botany, students of forestry and landscape architecture were invited to score the factor layers according to the contents in Table 2, and the scores obtained were averaged. The score value of the factor layer was obtained by multiplying the weight of the factor layer with the score value according to the formula $V = \sum_{1}^{n} BW$ (where V is the comprehensive score; B is the factor score; W is the factor weight value; n is the number of factors). The score value of each factor layer was summed and the score value was the evaluation value of the target layer. The specific result is shown in Table 9.

Table 9 Risk assessment of invasive plant species

No.	Plant	Risk score
1	*Alternanthera philoxeroides*	61.0
2	*Bidens pilosa*	58.0
3	*Aster subulatus*	56.3
4	*Erigeron canadensis*	55.1
5	*Erigeron annuus*	54.8
6	*Erigeron bonariensis*	54.5
7	*Veronica persica*	54.3
8	*Oxalis pes-caprae*	53.9
9	*Sonchus oleraceus*	52.2
10	*Solanum aculeatissimum*	51.2
11	*Oxalis corymbosa*	48.0

As shown in Table 9, *Alternanthera philoxeroides* had the highest risk score, reaching 61.0; followed by *Bidens pilosa* (58.0), *Aster subulatus* (56.3), *Erigeron canadensis* (55.1) and *Erigeron annuus* (54.8). *A. philoxeroides* had been included in the *List of the First Batch of Invasive Alien Species in China*; *B. pi-*

losa, *A. subulatus*, *E. Canadensis* and *E. annuus* had been included in the *List of the Third Batch of Invasive Alien Species in China*.

4 Conclusions and discussion

Through the survey of invasive alien plants on the campus of Tongren University, 11 species of invasive alien plants belonging to 8 genera and 5 families were identified. According to the risk assessment system for invasive plants proposed by Zhu Shuxia *et al.* [13], if the risk score $R \geqslant 65$, the risk level is high, and it is necessary to strengthen management and control and strictly implement quarantine; if $45 \leqslant R < 65$, the risk level is intermediate, and corresponding preventive measures must be taken; if $R < 45$, the risk level is low, and it can be left alone temporarily. There were no high-risk invasive plants in the 11 invasive plants on the campus of Tongren University, indicating that Tongren University has good management and prevention of invasive plants on the campus. However, since the risk score of *A. philoxeroides* was the highest, we should focus on its prevention and control.

Artificial control, physical control, chemical control and biological control are major control methods of invasive alien plants. As the most harmful invasive plant inside and outside the campus, *A. philoxeroides* should be effectively prevented and controlled. The principle of "prevention first, comprehensive prevention and control, green prevention and control" should be adopted to control *A. philoxeroides* under the economic threshold at an appropriate cost, so as to avoid or reduce the harm caused by *A. philoxeroides* to the campus landscape and plant diversity. The technical strategy should be based on biological control, supplemented by agricultural, physical and chemical control[14]. There are two main biological control methods: natural enemy control (for example, *Agasicles hygrophila* can be used to inhibit the growth of *A. philoxeroides*), and microbial control (for example, *Fusarium* has a strong pathogenicity to *A. philoxeroides*)[15]. As for physical prevention and control, manual, mechanical eradication or salvage can be performed to dig as deep as possible, or film or ground cloth can be covered before the growth of *A. philoxeroides* in large quantities. In terms of chemical control, herbicides such as glyphosate, fluroxypyr, glufosinate-ammonium and penoxsulam can be sprayed[16].

In view of the current situation of the prevention and control of invasive alien plants on the campus of Tongren University, it is suggested to start from the following three aspects. First, the university should strengthen the publicity. The university can carry out activities to popularize the knowledge of invasive alien plants, and enhance the recognition and prevention and control awareness of teachers and students of invasive alien plants. Second, artificial control is the most traditional and simple control method of invasive alien plants at present, but the efficiency of this control method is low, so we can consider the combination of artificial control and biological control, dominated by biological control, so as to achieve better prevention and control effect of invasive alien plants. Finally, a regular survey of plants on the campus should be carried out to promptly discover and effectively prevent invasive alien plants, so as to avoid further harm to the campus ecological environment caused by their large-scale reproduction.

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