STUDY OF SPECIES DISTRIBUTION AND HARM CAUSED BY INVASIVE ALIEN PLANTS IN THE UPPER REACHES OF THE XIANGJIANG RIVER

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(Received 16th May 2025; accepted 10th Jul 2025)

Abstract. The aim of this study was to investigate the species distribution and potential hazards in the upper reaches of the Xiangjiang River to provide a basis for the formulation of more scientific and effective management strategies. The invasive plants in the upper reaches of the Xiangjiang River were investigated through field studies and statistics, and the dominant species were determined. The most severe species in the upper reaches of the Xiangjiang River were comprehensively evaluated to better formulate prevention and control strategies. A total of 83 alien invasive plants belonging to 28 families were found in the upper reaches of the Xiangjiang River. Among the invasive plants, Asteraceae, Amaranthaceae, Poaceae, Euphorbiaceae, and Leguminosae were the dominant families. The distribution of invasive plants was the most extensive in Quanzhou County. The community structure of invasive plants in the upper reaches of the Xiangjiang River is relatively simple, and the main species are annual herbaceous plants. Among these invasive plants, 49 species were introduced artificially, and 34 species were unintentionally introduced. Fifty-four species (65.06%) of these plants originated from America. Among the invasive alien plants, 13 were identified as seriously hazardous, 29 as highly hazardous, 26 as generally hazardous, and 15 as mildly hazardous. For 17 sample plants, the coverage of most plants exceeded 70%. The importance value of Eichhornia crassipes, Erigeron sumatrensis, and Solidago canadensis in the community reached 100%, suggesting that long-term monitoring of their growth is needed. The natural conditions in the upper reaches of the Xiangjiang River provide a suitable environment for the growth of invasive alien plants. It is necessary to strengthen the monitoring and control of invasive alien plants to protect the health and stability of the ecosystem in this region.
Keywords: *invasive species, watershed, classification, hierarchy, distribution characteristics, prevention and control*

Introduction

Plant invasion refers to the process in which plants spread from their original habitats to new environments through natural or human means, causing economic losses or ecological disasters in biodiversity in invaded areas, agricultural and forestry production, and human health. Successful plant invasions often involve plants occupying the living space and resources of native plants, ultimately replacing the latter and disrupting ecosystems, leading to a reduction in biodiversity (Hu et al., 2024). The process of plant invasion includes the introduction and colonization of alien species, which may be brought to new regions through human activities (such as horticultural introduction, agricultural planting, etc.) or natural routes (such as wind and water, etc.) (Yang et al., 2024). Most of the major invasive species in China originate from human factors. Invasive species have strong adaptability to the environment and climate and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_97199738

exhibit relatively easy reproduction methods, making it easier to form dominant populations and causing severe harm to local agricultural production and the environment. Therefore, in agricultural production, it is necessary to strengthen the monitoring of invasive plants to provide scientific evidence for integrated prevention and utilization (Du et al., 2016, 2023; Peng et al., 2008).

The Xiangjiang River is considered the mother river in Hunan Province, as it is the largest river in Hunan Province. With rapid economic development, the number of invasive plants in this region is also increasing rapidly, and the resulting damage area is gradually expanding (Meng and Chen, 2020). Therefore, to protect the biodiversity of the Xiangjiang River Basin, it is necessary to control invasive plants effectively in this region. Moreover, the rich plant resources in the Xiangjiang River Basin are highly important for the protection of Xiangjiang River ecology and support the environmental protection and management of the river. The upper reaches of the Xiangjiang River constitute an essential part of the Xiangjiang River Basin and include parts of eastern Hunan, southern Hunan, and northern Guangxi. The two basins are as follows: the eastern source, which ranges from Lansi County to Qiyang City, covering 515 kilometers; the western source, which ranges from Xingan County to Qiyang City, spanning 431 kilometers. The soil types within the basin are diverse and include red soil, yellow soil, and mountainous soil; the precipitation distribution in the upper reaches of the Xiangjiang River is uneven, with climate characteristics influenced mainly by monsoons (Chu, 2023). Summer (May-September) is the season with the most precipitation, whereas winter (November-March of the following year) is relatively dry; the upper reaches of the Xiangjiang River possess abundant ecological resources, including forests, lakes, wetlands, mountains, and grasslands, among other ecosystems, which host a wide variety of plant species. The superior natural conditions provide an extremely favorable environment for the growth and reproduction of invasive plants.

Researchers have studied invasive plants in Hunan and some parts of Guangxi to varying degrees. In the 2007–2017 survey, researchers investigated the distribution of invasive plants in various regions of Hunan (Shen et al., 2007; Peng et al., 2017). It has been reported that invasive plants in local areas have certain impacts on ecology, greening, and farmland; for example, *Ageratina adenophora*, a highly invasive and malignant plant, poses a severe threat to China's agricultural and animal husbandry production because of its own biological characteristics, undermining biodiversity and even disrupting local ecosystems (Ma and Bai, 2004). Invasive alien species also have a significant impact on urban park green spaces in Changde City (Tu et al., 2024). The invasive plant *Phalaris minor* severely harms wheat and other cereal crops, severely threatening their growth (Xu et al., 2015). Du Yun et al. investigated invasive plants and biodiversity in the Yuanjiang River Basin and Dongting Lake and reported similar findings (Du et al., 2017, 2020). The ecological environment of some waters has been damaged by invasive plants. In 2022, Wan Zixue and others conducted a survey on invasive plants in the Hunan region of the Yangtze River Economic Belt (Wan et al., 2022). In 2024, Teng Kaipeng et al. investigated the Beibu Gulf region of Guangxi (Teng et al., 2024). These studies revealed a total of 150 species from 38 families of invasive plants. The above literature discussed the basic distribution, origin, and introduction routes of invasive plants in Hunan and Guangxi.

A review of the literature revealed no research data currently available on invasive alien plants in the Xiangjiang River Basin. Additionally, no comprehensive and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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systematic processing of plot data has been conducted for invasive alien plants in parts of Hunan and Guangxi, and the importance values or impacts of severely harmful invasive plants on the environment have not been calculated. Information about the species and biological characteristics of invasive alien plants is crucial for understanding the richness of such plants in different regions and formulating relevant management measures (Pyšek and Richardson, 2006; Khuroo et al., 2012; Wang et al., 2017). Therefore, it is necessary to study the species distribution and potential hazards of invasive plants in the upper reaches of the Xiangjiang River (Chen, 2022). To understand the current situation of invasive plants in the upper reaches of the Xiangjiang River, appropriate management measures should be taken (Xu et al., 202).

Survey site and method

Survey site

The upper reaches of the Xiangjiang River begin in Lansi County, Hunan Province, and Xing County, Guangxi Zhuang Autonomous Region, and then converge at Pingdao Island in Lingling District, Yongzhou City, Hunan Province. The upstream section from the source of the Xiangjiang River in Lansi County, Hunan Province, to Qiyang City, is 515 km long; the upstream section from the source of the Xiangjiang River in Xing County, Guangxi Zhuang Autonomous Region, to Qiyang City is 431 km long.

Random sampling surveys were conducted between 08 March 2023 and 31 August 2024 at 32 sites in 13 counties and districts along the upper reaches of the Xiangjiang River, including Lanshan County, Jianghua County, Dao County, Shuangpai County, Dongan County, Lingling District, Lengshuitan District, Qiyang City, Jiangyong County, Xintian County, Ningyuan County, Quanzhou County, and Xingan County, for a total of 54 samples, as depicted in *Figure 1*.

Investigation methods

Field investigation method

Field investigations were carried out using measurement data and photographs to investigate and analyze the distribution of invasive plant species, the introduction and spread of routes, and the degree of damage caused by invasive plants.

Statistical methods

Two to four points in each county or district of the upper reaches of the Xiangjiang River were randomly selected, with a distance greater than 10 km between each point. Since most invasive plants are herbaceous, quadrat surveys were conducted in 1 m × 1 m grids for the dominant species in each area, and one representative sample from the overall population was selected. In the quadrat survey, the population was divided into several nonoverlapping subpopulations or layers, and samples were randomly drawn from each subpopulation. The primary goal of this method is to ensure that the distribution of certain specific characteristics in the sample is similar to that of the population, thereby obtaining accurate estimates. Quadrat surveys can increase sample representativeness, reduce sampling error, and better account for the variations among different subpopulations within a population.

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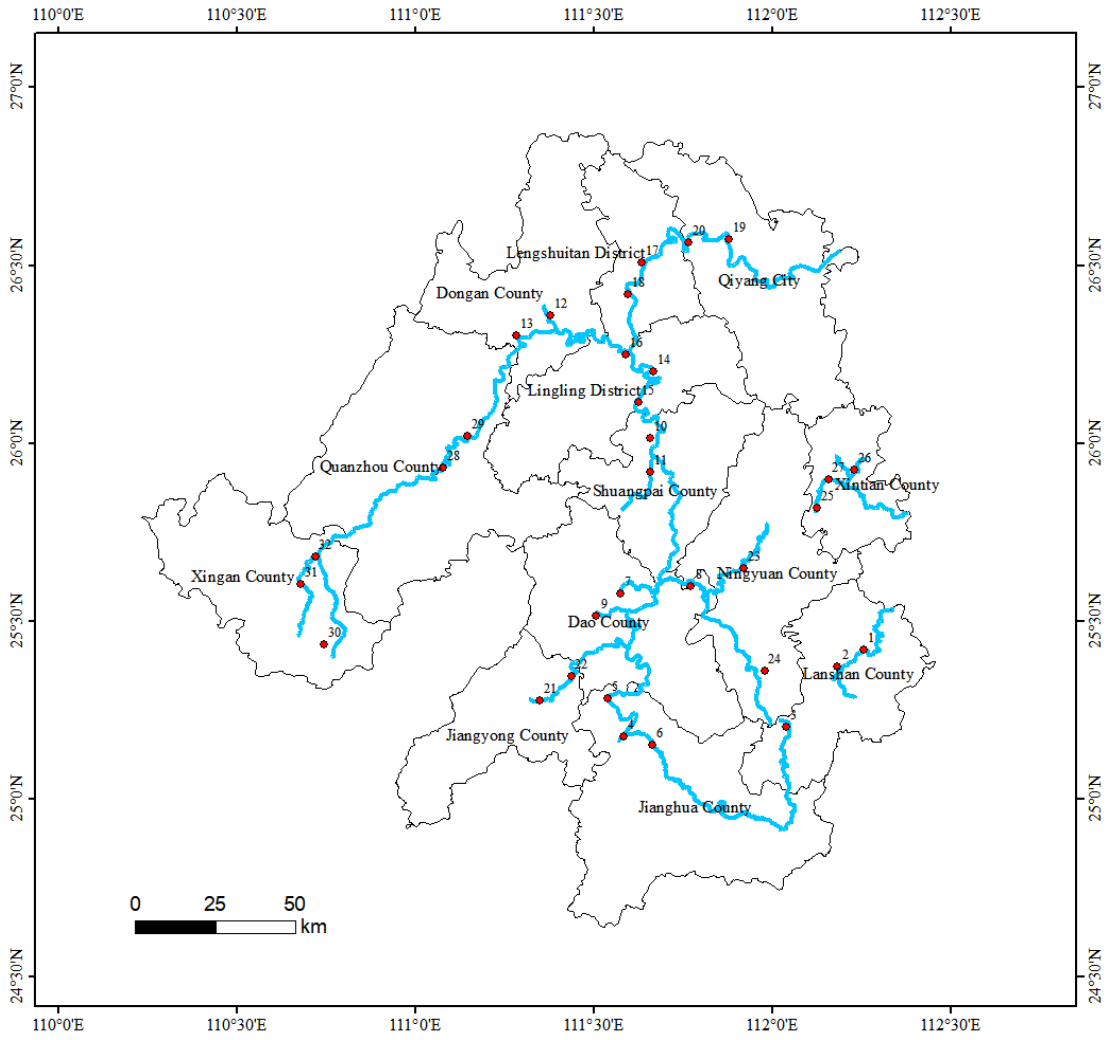

1 Leijialing Village
2 Dulong Road
3 Xiang River Source in Lanshan County
4 Jianghua Shutianhe National Wetland Park
5 Shangzhai Cave
6 Centianhe Avenue
7 Dao County Party School
8 Jiang Family
9 Lianxi Hometown
10 Dalu Kou Village
11 Yongshui Road
12 Liushi Town Village
13 Lv Budou Village
14 Lingjiaotang Town
15 Lingjiao Xie Family
16 Taojiang Road Liuping Village Committee
17 Siqu Tian Village Qili Ping
18 Liu Zhong Road
19 Tianma Road
20 Sanjia Village
21 Yongming River National Wetland Park
22 Shangjiangwei Town
23 Xinche Village
24 Shun Emperor's Mausoleum
25 Long Family Courtyard
26 Longquan Street S323
27 Xingquan Village
28 Leigongling National Mine Park
29 Sangui Village
30 Xiang River Source in Xingan County
31 Lingqu Canal
32 Shizitang
Tributaries of thr Xiangjiang
Township Border

Figure 1. *Random distribution of the survey results for the counties and urban areas in the upper reaches of the Xiangjiang River*

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Statistical evaluation

Data preprocessing: Variables with a missing data rate of more than 10% were deleted, and extreme values were identified and eliminated through box plots.

Descriptive statistics: Descriptive statistical analysis was carried out on the collected data of plant height, density, canopy cover and cushion thickness, etc., and statistical quantities such as the mean value and frequency were calculated to understand the trend of the data and provide a basis for further analysis (Peng et al., 2009).

Quality control: To ensure the quality of the data, three or more sample plots were measured and recorded in each plot. To reduce data error, 20% of all sample plots were repeated, and the species list of the two records met the requirement of consistency higher than 90%.

Analysis method

GIS (Geographic Information System): A GIS enables the collection, storage, management, processing, analysis, display, and description of geographical data. When combined with ArcGIS, the visualization and analysis of spatial data could be achieved along with precise mapping, providing intuitive and reliable spatial information support for this investigation of the upper reaches of the Xiangjiang River (Liu and Niu, 2002).

Classification of invasive plant hazards

The field observations of exotic invasive plants in the upper reaches of the Xiangjiang River, in combination with the "Catalog of Invasive Alien Plants in China" (Ma and Li, 2018) and the data regarding the ecological characteristics, botanical classifications, origins, damage situations, and invasion ranges of these plants, revealed four categories of exotic invasive plants surveyed in the field: "I" for seriously hazardous, "II" for highly hazardous, "III" for generally hazardous, and "IV" for mildly hazardous.

Data calculation

Farmland weed calculation formula:

- Relative coverage (abbreviated as RC) refers to the percentage cover of a certain wild plant (weed) in the community to the sum of the covers of all plants; RC (%) = (the cover of a certain weed/the sum of the covers of various weeds) ×100.
- Relative height (RH) refers to the ratio of the height of a certain wild plant (weed) in the sample field to the height of crops in the sample field; RH (%) = (height of a certain weed/height of crops) × 100.
- Field frequency (abbreviated as F) refers to the percentage of field numbers in which a certain field wild plant (weed) appears in the surveyed field; F (%) = (the number of fields in which weeds appear/total number of surveyed fields) × 100.
- Product advantage degree MDR MDR (%) = (relative height × relative cover) × 100.
- Important value (abbreviated as IV) MDK (%) = (MDR of a certain weed/sum of MDR of all major plants in the community) × 100; an importance value of ≥10% indicated important weed, ≥1% indicated major weed, and <1% indicated secondary weed (Xiang et al., 2021).

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Results and analysis

Composition and distribution of invasive plant species in the upper reaches of the Xiangjiang River

Species of invasive plants in the upper reaches of the Xiangjiang River

The eastern source flows through Lansi County, Jiangyong County, Dao County, Ningyuan County, Xintian County, Shuangpai County, and Lingling District. The western source flows through Xing County, Quanzhou County, Dong County, and Lingling District. A comparison and analysis of the distributions of invasive plant species in the upper reaches of the Hunan and Guangxi watersheds revealed seven dominant invasive plant species in the upper reaches of Hunan: *Alternanthera philoxeroides*, *Eleusine indica*, *Erigeron sumatrensis*, *Bidens pilosa, Symphyotrichum subulatum*, *Phytolacca americana,* and *Sida acuta*. In the upper reaches of Guangxi, eight species were dominant: *Sida acuta*, *Bidens bipinnata*, *Erigeron sumatrensis*, *Alternanthera philoxeroides*, *Erigeron annuus*, *Symphyotrichum subulatum*, *Ipomoea triloba*, and *Paspalum distichum*.

Through field investigations of the species distribution of invasive plants in the upper reaches of the Xiangjiang River and an analysis of the literature (Zeng et al., 2022), the upper reaches of the Xiangjiang River Basin were preliminarily identified as having invasive alien plants. There were 83 species belonging to 28 families, as shown in *Table 1*. Among the invasive plants, the families with the greatest number of species were Asteraceae, Amaranthaceae, Poaceae, Euphorbiaceae, and Leguminosae, which comprised 19, 9, 8, 6, and 6 species, respectively, accounting for 22.89%, 10.84%, 9.64%, 7.23%, and 7.23% of the total number of invasive plant species. This was followed by the Solanaceae and Convolvulaceae families, each with 4 species; Onagraceae, with 3 species; Malvaceae, Basellaceae, Apiaceae, and Brassicaceae, each with 2 species; and one other species, as shown in *Figure 2*.

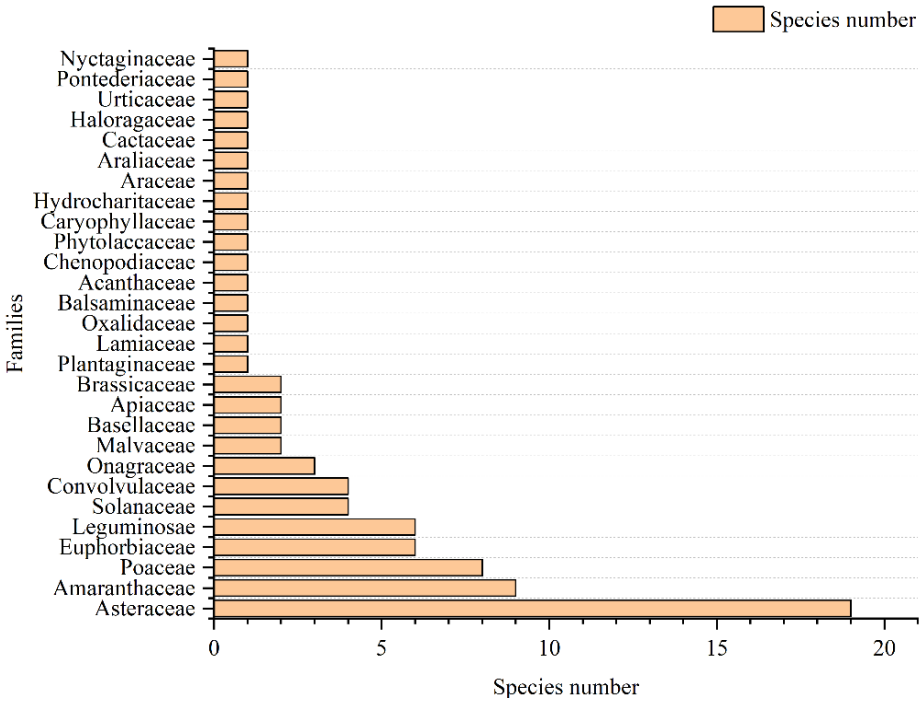

Figure 2. *Number of invasive alien plant species in the upper reaches of the Xiangjiang River*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Distribution of invasive plant species in the upper reaches of the Xiangjiang River

According to the survey and statistics, there are 83 species and 28 families of invasive alien plants in the upper reaches of the Xiangjiang River, among which 66 species are sparsely distributed and 17 species are widely distributed, as shown in *Schedule 1*. In all the counties and districts, 36 invasive alien plant species belonged to 18 families, accounting for 64.29% of the total number of families. Qiyang City and Dao County had 43 and 42 species, respectively, belonging to 17 families, accounting for 60.71% of the total number of families. Lingling District had 37 species and 16 families, accounting for 57.14% of the total number of families. Lansi County and Shuangpai County had 38 and 36 species, respectively, all belonging to 15 families, accounting for 53.57% of the total number of families. Jianghua County and Xing County had 41 and 31 species, respectively, belonging to 14 families, accounting for 50.00% of the total number of families. Dong County and Lengshuitan District had 38 and 31 species, respectively, belonging to 13 families, accounting for 46.43% of the total number of families. Ningyuan County and Xintian County had 28 and 32 species, respectively, belonging to 12 families, accounting for 42.86% of the total number of families. Jiangyong County had 21 species belonging to 10 families, accounting for 35.71% of the total number of families. These data showed that the most common distribution of invasive alien plant families and genera was in Quanzhou County, which could, therefore, suffer from greater potential hazards from plant invasions, as shown in *Figure 3*.

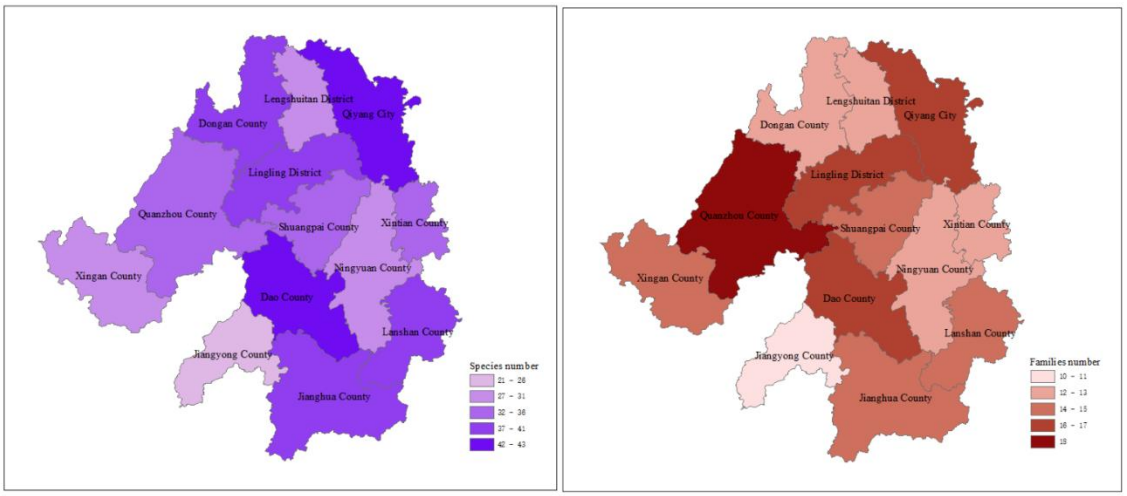

Figure 3. *Distribution of exotic invasive plants in the upper reaches of the Xiangjiang River*

Community structure of invasive alien plants in the upper reaches of the Xiangjiang River

The investigation results revealed that the planar structure of invasive alien plants in the upper reaches of the Xiangjiang River was generally simple, such as the widespread growth of *Eichhornia crassipes*, *Alternanthera philoxeroides*, and *Erigeron annuus*. Moreover, there are two-species planar structures, for example, two *Alternanthera philoxeroides* in *Paspalum distichum*. The vertical structure of the invasive alien plants in the Xiangjiang River was essentially a single-layer structure, such as *Eichhornia*

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crassipes, *Erigeron sumatrensis*, and *Solidago canadensis*, with the relative height and cover reaching 100% each, with no other plants growing within their range, indicating absolute growth dominance. Two-layer structures, such as upper layer *Celosia argentea* + lower layer *Ipomoea triloba*, are less common.

Schedule 1. *Species of alien invasive organisms in the upper reaches of the Xiangjiang River*

Serial number	Family	Latin name	Distribution	Frequency
1	Phytolaccaceae	*Phytolacca americana* L.	Wide distribution	78.13%
2	Amaranthaceae	*Amaranthus blitum* L.	Low distribution	6.25%
3	Amaranthaceae	*Amaranthus spinosus* L.	Low distribution	6.25%
4	Amaranthaceae	*Amaranthus retroflexus* L.	Low distribution	50.00%
5	Amaranthaceae	*Amaranthus hybridus* L.	Low distribution	6.25%
6	Amaranthaceae	*Amaranthus viridis* L.	Low distribution	43.75%
7	Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb.	Wide distribution	100.00%
8	Amaranthaceae	*Bassia scoparia* (L.) A. J. Scott	Low distribution	12.50%
9	Amaranthaceae	*Celosia argentea* L.	Low distribution	43.75%
10	Amaranthaceae	*Chenopodium ficifolium* Sm.	Low distribution	28.13%
11	Brassicaceae	*Lepidium virginicum* Linnaeus	Low distribution	46.88%
12	Brassicaceae	*Nasturtium officinale* R. Br	Low distribution	9.38%
13	Chenopodiaceae	*Dysphania ambrosioides* (Linnaeus) Mosyakin & Clemants	Low distribution	15.63%
14	Fabaceae	*Medicago polymorpha* L.	Low distribution	3.13%
15	Fabaceae	*Melilotus suaveolens* Ledebour	Low distribution	37.50%
16	Fabaceae	*Robinia pseudoacacia* L.	Low distribution	6.25%
17	Fabaceae	*Sesbania cannabina* (Retz.) Poir.	Low distribution	34.38%
18	Fabaceae	*Senna tora* (L.) Roxb.	Low distribution	6.25%
19	Fabaceae	*Trifolium repens* L.	Low distribution	9.38%
20	Asteraceae	*Ambrosia artemisiifolia* L.	Low distribution	3.13%
21	Asteraceae	*Ageratum conyzoides* L.	Wide distribution	71.88%
22	Asteraceae	*Bidens bipinnata* L.	Wide distribution	93.75%
23	Asteraceae	*Bidens pilosa* L.	Wide distribution	68.75%
24	Asteraceae	*Cosmos bipinnatus* Cav.	Low distribution	9.38%
25	Asteraceae	*Crassocephalum crepidioides* (Benth.) S. Moore	Low distribution	25.00%
26	Asteraceae	*Erigeron annuus* (L.) Pers.	Wide distribution	84.38%
27	Asteraceae	*Erigeron sumatrensis* Retz.	Wide distribution	93.75%
28	Asteraceae	*Erigeron canadensis* L.	Wide distribution	84.38%
29	Asteraceae	*Eclipta prostrata* (L.) L.	Wide distribution	68.75%
30	Asteraceae	*Galinsoga parviflora* Cav.	Low distribution	3.13%
31	Asteraceae	*Helianthus tuberosus* L.	Low distribution	6.25%
32	Asteraceae	*Lactuca indica* L.	Low distribution	12.50%
33	Asteraceae	*Solidago canadensis* L.	Low distribution	12.50%
34	Asteraceae	Sonchus oleraceus L.	Low distribution	34.38%
35	Asteraceae	*Sphagneticola calendulacea* (Linnaeus) Pruski	Low distribution	3.13%
36	Asteraceae	*Symphyotrichum subulatum* (Michx.) G.L. Nesom	Wide distribution	87.50%
37	Asteraceae	*Xanthium strumarium* L.	Wide distribution	68.75%
38	Asteraceae	*Zinnia elegans* Jacq.	Low distribution	6.25%
39	Convolvulaceae	*Cuscuta chinensis* Lam.	Low distribution	28.13%
40	Convolvulaceae	*Ipomoea triloba* L.	Wide distribution	81.25%
41	Convolvulaceae	*Ipomoea purpurea* Lam.	Low distribution	6.25%
42	Convolvulaceae	*Ipomoea purpurea* (L.) Roth	Low distribution	46.88%
43	Apiaceae	*Cyclospermum leptophyllum* (Persoon) Sprague ex Britton & P. Wilson	Wide distribution	68.75%
44	Apiaceae	*Daucus carota* L.	Low distribution	37.50%
45	Euphorbiaceae	*Euphorbia heterophylla* L.	Low distribution	3.13%
46	Euphorbiaceae	*Euphorbia maculata* L.	Low distribution	40.63%

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Serial number	Family	Latin name	Distribution	Frequency
47	Euphorbiaceae	*Euphorbia humifusa* Willd. ex Schltdl.	Low distribution	3.13%
48	Euphorbiaceae	*Euphorbia hirta* L.	Low distribution	53.13%
49	Euphorbiaceae	*Euphorbia hypericifolia* L.	Low distribution	9.38%
50	Euphorbiaceae	*Ricinus communis* L.	Low distribution	6.25%
51	Solanaceae	*Alkekengi officinarum* Moench	Low distribution	21.88%
52	Solanaceae	*Nicandra physalodes* (L.) Gaertner	Low distribution	12.50%
53	Solanaceae	*Physalis angulata* L.	Low distribution	3.13%
54	Solanaceae	*Physalis philadelphica* Lamarck	Low distribution	12.50%
55	Oxalidaceae	*Oxalis corymbosa* DC.	Low distribution	15.63%
56	Urticaceae	*Pilea microphylla* (L.) Liebm.	Low distribution	3.13%
57	Malvaceae	*Abutilon theophrasti* Medicus	Low distribution	3.13%
58	Malvaceae	*Sida acuta* Burm. F.	wide distribution	87.50%
59	Acanthaceae	*Ruellia simplex* C. Wright	Low distribution	6.25%
60	Onagraceae	*Ludwigia hyssopifolia* (G. Don) Exell	Low distribution	25.00%
61	Onagraceae	*Ludwigia adscendens* (L.) Hara	Low distribution	6.25%
62	Onagraceae	*Oenothera laciniata* Hill.	Low distribution	3.13%
63	Basellaceae	*Anredera cordifolia* (Ten.) Steenis	Low distribution	3.13%
64	Basellaceae	*Basella alba* L.	Low distribution	9.38%
65	Plantaginaceae	*Plantago virginica* L.	Wide distribution	68.75%
66	Lamiaceae	*Ocimum gratissimum* L.	Low distribution	3.13%
67	Balsaminaceae	*Impatiens balsamina* L.	Low distribution	3.13%
68	Haloragaceae	*Myriophyllum aquaticum* (Vell.) Verdc.	Low distribution	3.13%
69	Caryophyllaceae	*Cerastium arvense subsp. strictum* Gaudin	Low distribution	3.13%
70	Araliaceae	*Hydrocotyle verticillata* Thunb.	Low distribution	12.50%
71	Cactaceae	*Opuntia dillenii* (Ker Gawl.) Haw.	Low distribution	3.13%
72	Nyctaginaceae	*Mirabilis jalapa* L.	Low distribution	21.88%
73	Poaceae	*Avena fatua* L.	Low distribution	12.50%
74	Poaceae	*Eleusine indica* (L.) Gaertn.	wide distribution	90.63%
75	Poaceae	*Lolium multiflorum* Lam.	Low distribution	28.13%
76	Poaceae	*Pseudosorghum fasciculare* (Roxburgh) A. Camus	Low distribution	6.25%
77	Poaceae	*Paspalum conjugatum* Bergius	Low distribution	9.38%
78	Poaceae	*Paspalum distichum* Linnaeus	Wide distribution	78.13%
79	Poaceae	*Panicum repens* L.	Low distribution	6.25%
80	Poaceae	*Sorghum sudanense* (Piper) Stapf	Low distribution	3.13%
81	Araceae	*Pistia stratiotes* L.	Low distribution	6.25%
82	Hydrocharitaceae	*Elodea canadensis* Michx.	Low distribution	3.13%
83	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solme	Low distribution	28.13%

"I" for seriously hazardous, "II" for highly hazardous, "III" for generally hazardous, and "IV" for mildly hazardous

Life forms of invasive plants in the upper reaches of the Xiangjiang River

In the upper reaches of the Xiangjiang River, there were 51 species of annual herbaceous plants belonging to 16 families, accounting for 61.45% of the total number of species; 25 species of perennial herbaceous plants from 16 families, accounting for 30.12% of the total number of species; 4 species of perennial aquatic herbaceous plants from 4 families, accounting for 4.82% of the total number of species; 2 species of shrubs from 2 families, accounting for 2.41% of the total number of species; and 1 species of trees from 1 family, accounting for 1.20% of the total number of species. As shown in *Figure 4,* herbaceous plants have stronger invasive capabilities and cause greater damage to local ecosystems (Nan et al., 2023; Wang, 2012; Wang et al., 2021).

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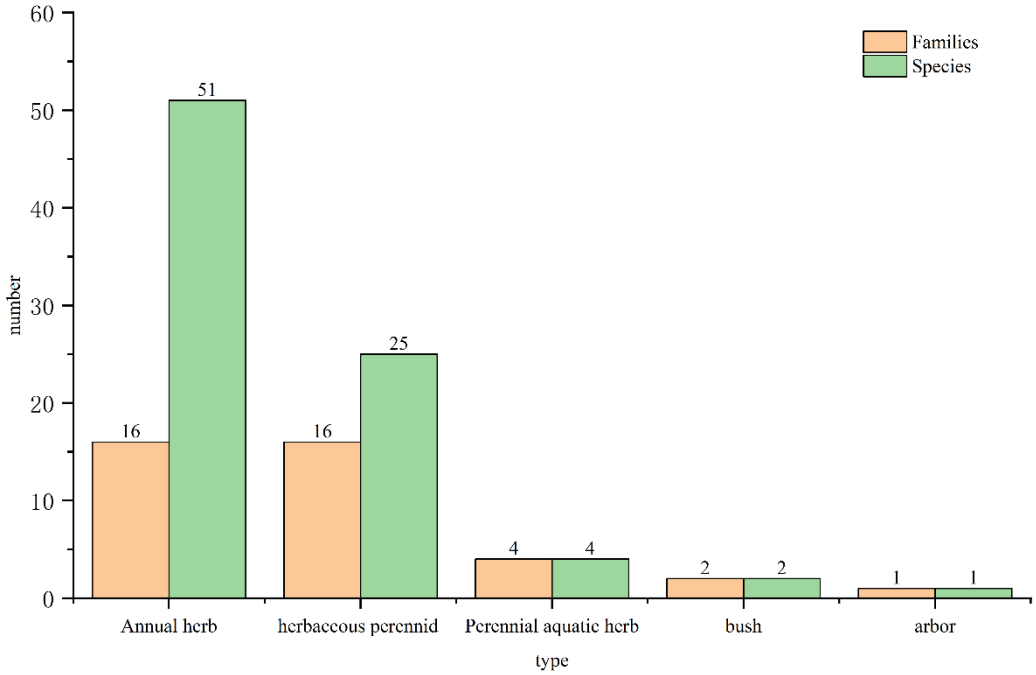

Figure 4. *Life patterns of invasive alien plants in the upper reaches of the Xiangjiang River*

Origins and introduction routes of invasive plants in the upper reaches of the Xiangjiang River

Analysis of the origins of invasive plants in the upper reaches of the Xiangjiang River

According to the classification method of origin reported in previous studies (Qi and Xu, 2006; Zhang et al., 2023), among the 83 invasive plant species in the upper reaches of the Xiangjiang River, 54 species originated from America, accounting for 65.06% of the total number of species. The remaining species included 14 from Asia, accounting for 16.87% of the total number of species; 10 from Europe, accounting for 12.05% of the total number of species; 4 from Africa, accounting for 4.82% of the total number of species; and 1 from Oceania, accounting for 1.20% of the total number of species. These findings indicate that plants from America are more likely to invade the upper reaches of the Xiangjiang River. Within the global flora, discontinuous distributions between North American and East Asian flora were common. Therefore, during the process of introducing plants, particular attention should be given to plants from America, and their adaptability and invasiveness in the upper reaches of the Xiangjiang River should be strictly evaluated. If any plant species with a natural persistence capability over the years are discovered, they should be introduced and utilized with caution, as shown in *Figure 5*.

Introduction routes of the invasive plants in the upper reaches of the Xiangjiang River

As shown in *Figure 6,* the analysis of the introduction routes of invasive alien plants in the upper reaches of the Xiangjiang River revealed that invasive species were mainly introduced intentionally, totaling 49 species, accounting for 59.04% of the total number of species. The intentionally introduced invasive species are primarily ornamental flowers, landscaping plants, medicinal herbs, vegetables, and forage grasses with certain

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economic value. Unintentionally introduced species included *Ambrosia artemisiifolia*, *Avena fatua*, and *Pseudosorghum fasciculare*, among which 34 species accounted for 40.96% of the total number of species. These species are often brought into the region inadvertently through grain transportation and trade. Additionally, some invasive seeds spread more easily, are carried by wind, and are naturally dispersed into areas from neighboring provinces.

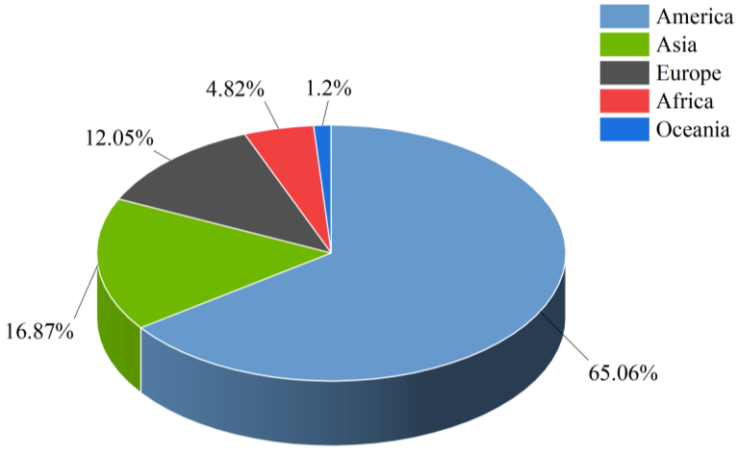

Figure 5. *Origins of invasive alien plants in the upper reaches of the Xiangjiang River*

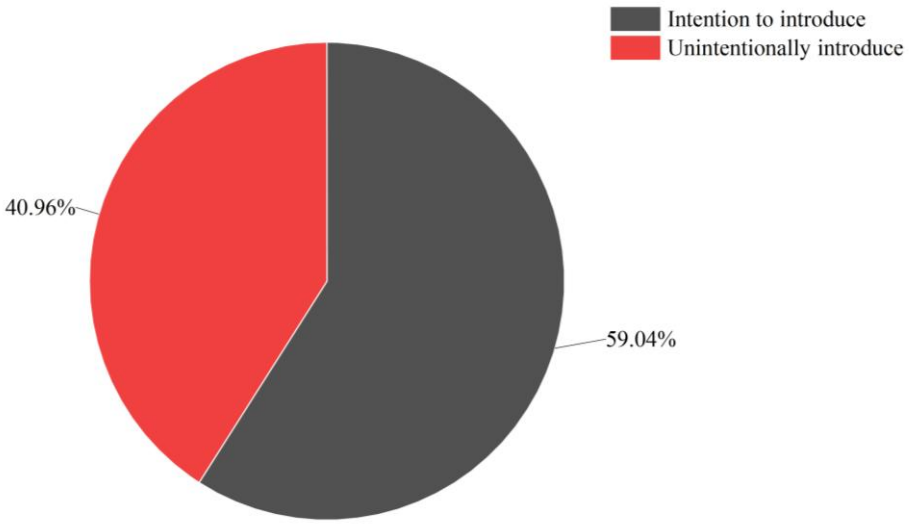

Figure 6. *Introduction routes of invasive alien plants in the upper reaches of the Xiangjiang River*

Harm and evaluation of invasive plants in the upper reaches of the Xiangjiang River

Classification of the hazard level of invasive plants in the upper reaches of the Xiangjiang River

As shown in *Figure 7,* among the invasive plant species found in the upstream region of the Xiangjiang River, there were 13 species with a severity level of I, accounting for 15.66% of the total number of invasive plants, 29 species with a severity level of II,

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accounting for 34.94% of the total number of invasive plants, 26 species with a severity level of III, and 15 species with a severity level of IV, accounting for 18.07% of the total number of invasive plants. Among these, 81.93% of the species had invasion severity levels of I to III, indicating that the invasive plants in the upper reaches of the Xiangjiang River could pose significant threats.

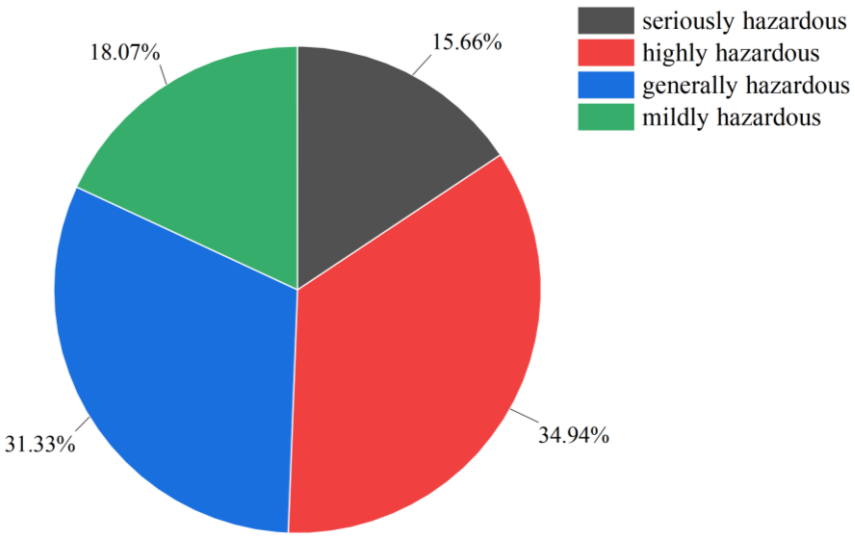

Figure 7. *Hazard levels of invasive alien plants in the upper reaches of the Xiangjiang River*

The degree of harm caused by invasive plants in the upper reaches of the Xiangjiang River

As shown in *Table 1,* through the plant analysis of 17 of the 83 invasive alien plants in the upper reaches of the Xiangjiang River, 14 had a relative coverage of more than 70%, accounting for 82.35%, whereas 3 species had a relative cover density below 70%, accounting for 17.65% of all species. The relative cover density indicates the dominance of a species within the community; high dominance can lead to the suppression or disappearance of other species, thereby reducing community diversity and stability. Invasive plants in the upper reaches of the Xiangjiang River are highly aggressive, necessitating enhanced control and eradication of the severely affected species. For example, during this investigation, extensive coverage of *Alternanthera philoxeroides* was discovered on Dulong Road in Lanshan County and Tianma Road in Qiyang City, with cover areas of 57 m^2 and 80 m^2, respectively, and both regions had a canopy density of 100%, precluding the existence of other plant species. This weed is robust, thrives in both aquatic and terrestrial environments, and reproduces rapidly, resulting in severe ecological disruption, waterway obstruction, health threats, and reduced crop yields (Xu, 2011; Zhang and Chen, 2005). Sampling conducted on Yongshui Road in Shuangpai County, Tianma Road in Qiyang City, and Liushiting village in Dong'an County of Yongzhou City revealed varying degrees of coverage by *Bidens bipinnata*, with areas of 30 m^2, 200 m^2, and 260 m^2, respectively. These plants can reach 128 cm in height and achieve a canopy density of 92%. Owing to its numerous branches and strong reproductive capabilities, *Bidens pilosa* often invades dry farmlands and orchards, displacing native plants and damaging economic crops. *Erigeron canadensis* was found to cover areas of 103 m^2, 300 m^2, 121 m^2, and 600 m^2

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DOI: http://dx.doi.org/10.15666/aeer/2305_97199738

during consecutive surveys of Chentianhe National Wetland Park in Jianghua County, Lianxi Hometown in Daoxian County, Jiangjia in Daoxian County, and Lingjiaotang Town in Lingling District, respectively. With an average plant height of up to 156 cm and a relative canopy density of 78.41%, *Erigeron canadensis* grows rapidly, competes for resources, and significantly affects the growth of other plants. *Erigeron annuus* possesses strong reproductive and invasive abilities, commonly occurs on hillsides and fields, and is widely distributed in various upstream regions of the Xiangjiang River. Large areas of *Erigeron annuus* were observed growing in Xingquan Village and Longjia Compound in Xintian County, with a canopy density of up to 85% and vigorous growth. The above locations are shown in *Figure 1*.

Table 1. *Species analysis of invasive alien plants in the upper reaches of the Xiangjiang River*

Species	Field density (stock/m^2)	Height or pad thickness (cm)	Frequency (%)	Relative altitude (%)	Relative coverage (%)	Product dominance degree (%)	Sum of product dominance of main plants (%)	Important value (%)
Pontederia crassipes	80	52	28.13	100	100	100	100	100
Erigeron sumatrensis	10	233	93.75	100	100	100	100	100
Solidago canadensis	26	172	12.50	100	100	100	100	100
Daucus carota	20	152	37.50	37.39	93.18	34.84	35.87	97.13
Euphorbia hirta	91	34	53.13	49.36	88.67	43.77	45.68	95.82
Melilotus suaveolens	13	130	37.50	39.42	92.14	36.32	38.56	94.19
Xanthium strumarium	8	100	68.75	59.42	95.63	56.82	61.32	92.66
Bidens alba	72	103	68.75	69.82	87.3	60.95	67.83	88.46
Alternanthera philoxeroides	121	62	100	90.26	96.98	87.53	99.48	87.99
Paspalum distichum	317	54	78.13	65.21	93.27	60.82	69.70	87.26
Phytolacca americana	11	100	78.13	41.37	77.22	31.95	36.99	86.37
Erigeron annuus	19	120	84.38	73.50	88.81	65.28	79.25	82.37
Ageratum conyzoides	52	57	71.88	54.96	61.87	34.00	41.89	81.16
Sesbania cannabina	44	163	34.38	37.89	68.54	25.97	33.23	78.15
Ipomoea triloba	5	26	81.25	46.27	85.34	39.49	51.29	76.80
Erigeron canadensis	25	156	84.38	54.11	78.41	42.42	60.62	69.98
Bidens pilosa	20	128	93.75	30.95	68.97	21.35	32.06	66.59

The importance value of each of the 17 species in the quadrat was above 65%, with three species having an importance value of 100%, accounting for 17.65% of all the species. These three species are *Eichhornia crassipes*, *Erigeron sumatrensis*, and *Solidago canadensis*. *Eichhornia crassipes* often forms a single dominant community in habitats such as rivers, ditches, and ponds. Originally introduced as an ornamental species, it was later promoted as pig feed but has now become a rampant weed. A survey of Yongshui Road in Shuangpai County upstream of the Xiangjiang River revealed that the coverage area was 300 m^2. With respect to the area of *Eichhornia crassipes*, 3000 m^2 was determined at the source of the Xiangjiang River in Xing County. In the area of *Eichhornia crassipes*, the degree of canopy coverage was as high as 100%, and no other plants survived. The cover hinders water flow, destroys water quality, consumes dissolved oxygen, blocks river channels, leads to the spread of pests and diseases, and seriously affects the ecological environment and aquatic biological safety (Si, 2021; He, 2023). In this survey, a 20 m^2 cover area was found beside Geely car no. 570 Fengcheng Road, Yaoshan County, Jianghua County. The average height of *Erigeron sumatrensis* is 233 cm, and the canopy degree is 87%. The plant is tall and

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DOI: http://dx.doi.org/10.15666/aeer/2305_97199738

vigorous, which poses a threat to agriculture, biodiversity, and ecological composition (Guo et al., 2022). *Solidago canadensis* (Zhang et al., 2023; Du et al., 2023), which originated in North America, has strong reproductive capacity, fast propagation speed, obvious growth advantages, and broad adaptability. It competes with surrounding plants for sunlight and fertilizer until other plants die, thus posing a serious threat to biodiversity. In this survey, the coverage area in Lianxi, Daoxian County, was found to be 62 m^2. The average height was as high as 181 cm, with a canopy cover of 100%. There were almost no associated plants around it. On both sides of the S323 Highway in Xintian County, within a range of nearly 200 m, *Solidago canadensis* was distributed, tall and dense. As shown in the table, these three invasive alien plants had the highest relative importance and the greatest impact on the community. Moreover, plants have a single community composition and population structure within their habitat, severely affecting the growth of other organisms in the area, and their invasion trends need close monitoring. The above locations are shown in *Figure 1*.

Discussion and conclusion

Current situation of invasive alien plants

This survey revealed that 83 species of invasive alien plants belonging to 28 families exist in the upper reaches of the Xiangjiang River. Compared with the existing research findings on invasive alien plants in parts of Hunan and Guangxi, both similarities and differences were revealed in this study. The main differences were as follows: (1) In the upper reaches of the Xiangjiang River in Guangxi, there are 61 species of invasive alien plants, which contrasts with the findings of Tang Saichun et al. from Guangxi, who reported a range of 180–200 species (Tang et al., 2023). The number of invasive plants is relatively low, mainly because the survey covered a relatively small area in Guangxi. (2) In this survey, there were 76 species of invasive plants in the upper reaches of the Xiangjiang River in Hunan Province, which is similar to Liu Le's results from his investigation of invasive alien plant species in southern Hunan, which included 91 species. This is primarily because the upper reaches of the Xiangjiang River are located in southern Hunan but do not include areas such as Rucheng County, Jiahe County, and Guidong County in Chenzhou (Liu, 2016).

Characteristics of invasive plants

The most severe threat from invasive plants in the upper reaches of the Xiangjiang River is from the Asteraceae family, with 19 species, accounting for 22.89%. Among these, particularly harmful plants include *Solidago canadensis*, *Erigeron canadensis*, and *Erigeron sumatrensis*. The primary reasons are that Asteraceae plants exhibit strong adaptability to the environment and climate, spread quickly over long distances, and reproduce easily, making them highly likely to form dominant populations (Xiao et al., 2021; Wang et al., 2017), which poses significant threats to local agricultural production and the environment. Statistical analysis of invasive alien plant species in various counties revealed that the most diverse families and genera of invasive alien plants are found throughout the prefecture. This may be related to the geographical location of the prefecture, which is situated at the border between Guangxi Province and Hunan Province, where prevention and control efforts are relatively limited. The climate is suitable, and trade activities are frequent, increasing the risk of human-mediated spread (Ding, 2008).

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An analysis of the community structure of invasive alien plants in the upper reaches of the Xiangjiang River revealed that invasive alien plants compete with or occupy the ecological niches of local species; squeeze out local plants; and change the structure or function of the population, community, or ecosystem, leading to the singularity or degradation of the ecosystem and damaging or polluting the ecological environment (Li, 2022). Reducing crop yield, affecting the quality of agricultural products, increasing the cost of prevention and control, etc. (Ma, 2022), can cause enormous economic losses. It is evident that invasive alien plants severely damage the ecological environment and threaten biodiversity. This survey revealed that the number and proportion of annual herbaceous plants are significantly greater than those of other types in this region, possibly due to their more evolved nature compared with other species, shorter growth cycles, and greater adaptability to the environment. Among these, annual herbaceous plants can complete their life cycle rapidly within months, have a high seed set rate, and produce smaller seeds that are easy to disperse, making it easier for the plants to spread and form dominant populations; thus, herbaceous plants are more likely to establish invasive dominance than perennial plants are (Shi et al., 2017; Song et al., 2023; Wu et al., 2021). The results of the surveys conducted in the Changsha, Zhuzhou, and Tanxiang areas of Hunan Province are the same as those reported by Yan (2024). Therefore, strengthening the monitoring and control of annual herbaceous plants is important.

Sources of invasive plants

The analysis of the origin of invasive plants in the upper reaches of the Xiangjiang River revealed that most of these plants originated in America, with 54 species accounting for 65.06% of all species, which is consistent with the findings of other related studies (Zhang et al., 2010; Huang et al., 2011). Therefore, it is necessary to strengthen the monitoring of the aforementioned types of plants in agricultural production activities. Statistical analysis of the introduction routes of invasive alien plants in the Xiangjiang River revealed that most of these plants were intentionally introduced into the region. In terms of survey areas, there are more species of invasive alien plants in residential areas than in non-residential areas, with a higher frequency of occurrence of the former, and the invasive plants along roadsides are mostly distributed in strips. This may be related to human activities, as the primary mode of spread for invasive alien plants is seed dispersal, which is facilitated by human activity. Some invasive alien plants reproduce through seeds and rhizomes, with underground roots extending laterally, rapidly occupying and destroying the existing vegetation and encroaching on the living space of other plants, leading to their death. Once these plants take root and multiply extensively in new environments, they can cause irreversible damage to local ecosystems and biodiversity. The strong root systems and reproductive capabilities of these plants also make their eradication challenging. These plants include *Solidago canadensis*, *Eichhornia crassipes*, and *Alternanthera philoxeroides* (Li, 2019). Therefore, preventing and controlling such invasive alien species is important. Strict supervision and prevention measures should be taken to prevent their further spread and harm.

Harm caused by invasive alien plants

Current situation of damage

Data analysis of 17 plots of invasive plants revealed that most plants had a canopy cover of more than 70%, with *Eichhornia crassipes*, *Erigeron sumatrensis*, and

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Solidago canadensis having an importance value of 100% in the community, indicating that these plants pose the most severe threat to the ecosystem. This classification aligns with the "List of Invasive Plants in China" for plants classified as the most harmful. According to the statistical analysis of the biological characteristics, growth conditions, and damage levels of invasive plants in the Xiangjiang River, the frequency of occurrence of severely damaging invasive plants is high for species such as *Alternanthera philoxeroides*, *Bidens bipinnata*, *Bidens pilosa*, *Erigeron annuus*, *Erigeron sumatrensis*, and *Erigeron canadensis*. Moreover, *Solidago canadensis, Eichhornia crassipes*, and *Ambrosia artemisiifolia pose* significant economic and ecological threats, requiring various monitoring and control measures. Although less harmful plants, such as *Ocimum gratissimum*, *Helianthus tuberosus*, and *Nasturtium officinale,* are invasive, they present a relatively low risk of damage if they are developed and utilized reasonably.

Integrated prevention and control of invasive species

For the prevention and control of *Alternanthera philoxeroides*, strategies could include the introduction of specific natural enemy insects, such as *Agasicles hygrophila* (Fu et al., 2007). For the control of *Bidens pilosa* and *Bidens alba*, the use of parasitic plants and vine plants to curb their spread could be considered, with the objective of reducing their population density (Shang and Zhu, 2019). Simultaneously, efforts should be intensified to protect and restore native plant diversity by increasing the level of species diversity in ecosystems, thereby increasing the system's resistance stability and naturally inhibiting the spread of exotic invasive plants.

In terms of chemical control, low-toxicity, highly efficient, and environmentally friendly herbicides should be carefully selected and applied, especially for exotic species such as *Solidago canadensis* and *Pontederia crassipes*, which are difficult to control effectively through physical or biological means. When chemical control measures are implemented, it is imperative to adhere strictly to usage norms and standards to avoid adverse impacts on non-target biological populations and the environment. Regular evaluations of pesticide effectiveness should be conducted, with timely adjustments in pesticide strategies.

Limitations and prospects

The rapid spread and proliferation of invasive alien plants in the upper reaches of the Xiangjiang River pose significant threats to local natural ecosystems and the economy. The significance of this survey lies in its integration of field investigations and literature reviews, which collectively identified new invasive species in Hunan Province for the first time, including *Sphagneticola calendulacea* and *Anredera cordifolia*. While these non-native species disrupt the ecological balance through resource competition and alterations to the soil structure, it is critical to note that not all identified invasive species exhibit the capacity to hybridize with native flora. Hybridization risks, where present, may introduce genetic pollution, further threatening the stability of local biodiversity. Given these multifaceted threats, the prevention and control of invasive alien species are imperative. To safeguard ecological security, a long-term monitoring mechanism must be established. This system should prioritize early detection of invasive species, particularly those with hybridization potential, and implement targeted mitigation strategies to curb their spread and associated ecological and economic damage (Sun et al., 2016).

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This study is the first systematic and comprehensive survey of invasive alien plants in the upper reaches of the Xiangjiang River, clarifies the distribution, quantity, and impact of invasive species in this basin, and provides a basis for formulating more scientific and effective management strategies. However, it has the following shortcomings:

(1) The growth cycles of invasive alien plants differ, and the invasion of plants is a dynamic process. It is necessary to carry out long-term monitoring and analysis to fully understand the process of invasion to provide an effective basis for systematic institutional prevention and control policies.

(2) The spread and influence of invasive alien species are global, and the lower reaches of the Xiangjiang River also face potential risks. On the basis of the results of the investigation of invasive alien plants in the upper reaches of the Xiangjiang River, more research on the lower reaches of the Xiangjiang River is needed.

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