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Ecological and Economic Impacts of Alien Invasive Yellow Flag (*Iris pseudacorus* L.) in China

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Abstract: Non-native aquatic plants can alter the physiochemical condition of habitats and can have negative ecological and economic impacts. Thus, understanding the characteristics of non-native aquatic plant species is important as a foundation for the conservation of biodiversity and environmental management. The yellow flag (*Iris pseudacorus*) is an emergent aquatic plant native to Africa, northwest Asia, and Europe that has been introduced through the aquarium trade to all continents except Antarctica. This species has recently been brought into China and it has established large and widespread naturalized populations causing serious ecological and environmental problems. Unfortunately, information about the yellow flag in China is very scarce. We summarize the introduction pathways, current distribution, and ecological impacts of the yellow flag through field surveys and a review of the literature. We hope that this study can provide useful information for researchers and wetland managers involved with non-native emergent plants in China and other regions.

Keywords: biodiversity conservation; freshwater habitats; ornamental trade; ecological impacts; risk; management

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1. Introduction

Global aquatic biodiversity has decreased significantly in the past half century [1] and invasion by non-native species is one of the primary pressures driving the global biodiversity crisis [2]. Freshwater ecosystems are recognized as being more sensitive to invasive species than other ecosystems [3,4]. In recent years, many non-native aquatic plants, such as fanwort (*Cabomba caroliniana*), parrot's feather (*Myrioophyllum aquaticum*), and water hyacinth (*Eichhornia crassipes*), have been introduced in many diverse areas in China and have had negative ecological impacts and caused enormous economic losses [5–7]. Thus, gaining information about naturalized non-native aquatic plants is urgent for conservation biologists and environmental managers [8].

China is among the countries with the highest number of non-native aquatic plant species [8,9]. A great number were used in aquaculture, horticulture, ecological restoration or for other purposes [6–8,10]. Freshwater ecosystems in China provide a diversity of habitats and support a high biodiversity [11–13]. Many non-native aquatic plants have widespread and established large areas of wild populations in some waterbodies, and eventually, cause significantly negative ecological impacts [14,15]. For example, some non-native plant species form dense monospecific mats displacing native aquatic plants by decreasing light [6,7,10]. Reviews of invasion characteristics and their consequences in China have been conducted for *Cabomba caroliniana* and *Myriophyllum aquaticum* [6,7],

non-native floating-leaved plants, such as *Hydrocleys nymphoides* [16], and non-native free-floating plants, such as *Eichhornia crassipes* [17]. Nevertheless, the data-base and current information of non-native emergent plants in China are very limited [10].

The yellow flag, *Iris pseudacorus* (Linnaeus, 1753) (Iridaceae), is a perennial herb that is an emergent aquatic plant native to Africa, northwest Asia, and Europe [18]. It is a very popular ornamental species used in aquatic and wetland horticulture, and it has been introduced in all continents except Antarctica. Due to its ease in dispersal of its seed and asexual propagules [19,20], it has become a problematic invasive plant in Canada, USA, Argentina, Chile, Uruguay, South Africa, Japan, Australia, and New Zealand [21–27]. In China, it has been widely used in water gardens and wetland restoration projects over the past 40 years [8]. Nonetheless, there is scarce information about this non-native emergent plant species in China. Therefore, this study was carried out to: (1) Summarize the yellow flag's pathways of introduction and its current distribution in China; (2) Review its ecological and economic impacts and; (3) Provide management recommendations for better controlling this aggressive and widespread non-native aquatic plant.

2. Materials and Methods

Over the past 20 years, we conducted more than 50 field surveys at over 1000 sites to acquire information regarding non-native aquatic plants [6,10]. At each site, we recorded a species inventory (non-native and accompanying native plant species), basic geographical information (longitude and latitude), and habitat type (such as river, lake, pond, reservoir, or channel). We conducted a literature search that contained the following combination of words "*Iris pseudacorus*" and "China" in the title, abstract, or keywords in the Web of Science (WOS, https://www.webofscience.com/wos/alldb/basic-search; accessed on 1 January 2023) and the largest Chinese information database, CNKI (CNKI, http://www.cnki.net, accessed on 1 January 2023). Information was also included from some Chinese books, such as *Illustrations of Alien Invasive Plants in China* [28]. Based upon field investigations and a review of the literature, we compiled a distribution map of naturalized yellow flag populations in China (Figure 1).

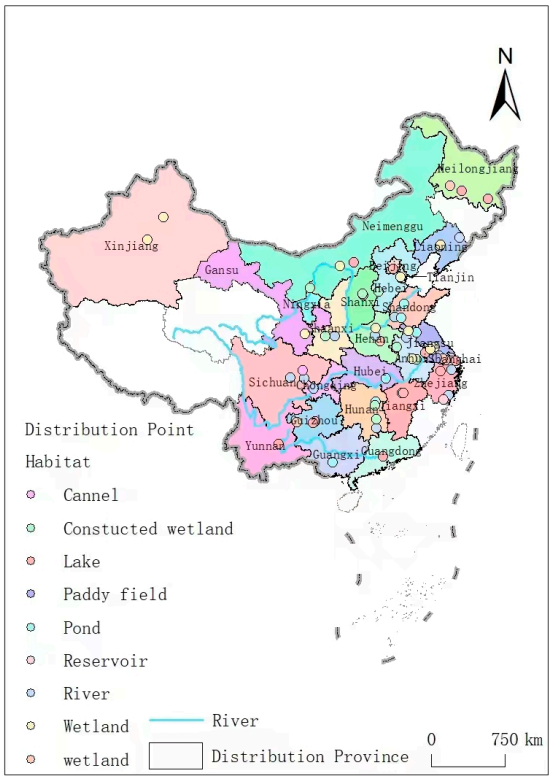

Figure 1. Distribution of yellow flag (*Iris pseudacorus*) in China.

3. Introduction Pathways

China's economy and its standard of living have increase rapidly in the past forty years. A great number of gardens, wetland-based parks, and waterfront landscape approaches and strategies have been established to provide an aesthetic and healthy living environment for local residents [6–8]. The yellow flag is one of the most popular ornamental emergent plants because of its attractive yellow flowers, rapid growth, high sexual (hundreds of seeds per plant are produced annually) and asexual propagation capabilities (vegetative, clonal proliferation through rhizomes), and its low cost of maintenance [29,30]. The yellow flag has been widely planted in wetlands, lakes, and ponds in almost all big cities because of its beautiful and aesthetic contributions to urban wetland landscapes. Particularly in south China, many communities possess ponds, streams, or ditches linked to rivers or lakes, and we observed this species to be the most planted species in waterfront landscaping in large cities, such as Shanghai, Guangzhou, Nanjing, and Wuhan.

Eutrophication and pollution with heavy metals has occurred in many Chinese wetlands during the past forty years [31–33]. The number and surface area of wetlands under construction have increased rapidly during the past three decades [34]. The yellow flag was widely planted in constructed wetlands in China because of its ability to absorb nitrogen, phosphorus, and heavy metals [35–38]. Like many other ornamental plants, the yellow flag manages to spread from the constructed wetlands and established feral populations in many waterbodies (Figure 2).

Figure 2. A population of yellow flags (*Iris pseudacorus*) in a Chinese wetland. Photo by Keyan Xiao.

In the past twenty years, efforts to restore farmland to forest, grassland, and lakes were undertaken to protect the natural environment in China [39]. The yellow flag spreads quickly in abandoned farmlands because of its drifting seed capsules, or clonally through its rhizomes. Differing from most other aquatic plants, seed dispersal is important to the spread and colonization ability of the yellow flag [20]. Each plant can produce over 600 viable seeds that can be transported by hydrochory for long distances [24]. It can quickly form dense monospecific stands through subterranean clonally propagating rhizomes [19]. The yellow flag flourishes in wetlands adjacent to lakes, abandoned farmland, and ponds [22].

4. Distribution and Habitats

Based upon the results of our review of the literature and field investigations, we have determined that the yellow flag has successfully established a feral population in 26 provinces, autonomous regions, and municipalities (Anhui, Beijing, Chongqing, Gansu, Guangdong, Guangxi, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Liaoning, Ningxia, Shaanxi, Shandong, Shanghai, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, and Zhejiang) in China (Figure 1). Our field studies indicate that the yellow flag can colonize and establish populations in natural wetlands, rivers, lakes, ponds, constructed wetlands, paddy fields, canals, and reservoirs. It is distributed from its southernmost site in Guangxi (22.848737 N, 108.303638 E) to its northernmost occurrence in Heilongjiang (45.847358 N, 126.574381 E), reflecting a broad range of climatic conditions, from north temperate monsoon climate to drought climatic condition. This distribution clearly shows that almost all regions of China are vulnerable to colonization by the yellow flag. Additional monitoring efforts are needed in all of China.

5. Potential Ecological and Economic Impacts

Yellow flag rhizomes were commonly used as medicine in the past, as they are a powerful cathartic, but due to their extremely acrid taste, they are no longer commonly utilized as a medicine. An infusion of it has been found to be effective in medicating diarrhea, and it is reputed to be of value in treating dysmenorrhea and leukorrhea. Thus, this species has been used as traditional medicine in some invasive regions, especially by the poor in remote areas.

Due to its high dispersal and colonization abilities and its rapid growth [20], the yellow flag proliferated extensively and also formed intensive monoculture patches displacing the native plant assemblages in many wetlands (Figure 2). Some native endangered or endemic aquatic plants, such as *Ranalisma rostratum* and *Sparganium minimum*, were out-competed by the yellow flag in northwest China. In south China, the yellow flag is widespread and displaces many native emergent aquatic plants, such as *Typha orientalis*, *Eleocharis dulcis*, *Oenanthe javanica*, and *Zizania latifolia*. Natural wetlands provide suitable habitats or food sources for many important species of native fauna, including birds, fish, and mammals [40], and the invasion of the yellow flag has likely been one of the primary causes of the significant decline of the natural wetland flora and fauna [22].

The areas with the greatest establishment of feral populations and distribution of the yellow flag (Figure 1) are also the most important paddy-producing areas. Similar to *Sagittaria platyphylla* [10], dense monospecific stands of yellow flag block water flow in irrigation ditches and drainage channels, reducing grain production in many major grain-growing areas. Because of its high environmental tolerance (a diversity of substrates, wide range of PH, desiccation, and salinity), the yellow flag has successfully invaded some non-urban areas (such as Xinjiang). Because the yellow flag has high glycoside levels, it can cause gastroenteritis in livestock and skin irritation in humans [20]. Thus, the invasion of this species is a potential threat to the development of animal husbandry and human health in farmland, focusing upon livestock production.

6. Management and Control Recommendations

Early detection followed by a swift response are the most effective measures for controlling and eradicating non-native species [41,42]. New technologies, such as environmental DNA and remote sensing, have been applied in monitoring the occurrence and distribution of various non-native plants [43,44]. Especially in the northern pastoral area and southern farmland, this species established widespread feral populations and occupies large area of wetland habitats. Remote sensing can quickly detect large areas of plant community and is widely used in environmental monitoring [44]. However, this measure needs more funding and professional expertise of remote sensing. Lack of adequate funding and professional specialists are the main bottleneck in governmental and research-based monitoring of non-native species. Greater cooperation and collaboration

between researchers, professional institutions, and the educated public are fundamental and urgently needed to better manage non-native species. Many aquatic plants are sold by network outlets in China [6,7], providing an unregulated and easily accessed source of non-native material. The monitoring of the trade of non-native species through the internet is another avenue needed to control their unregulated use.

Central themes in recommended management strategies include integrated management, including using manual removal or mowing followed by chemical treatments. Caution should be used if pulling out this plant by hand because it can cause skin irritation. Seed pods should be removed to help control population expansion, and small infestations should be dug up along with their entire rhizome root system. Chopping machines or devices may be utilized for large stands, and burning can be considered where conditions allow. Biocontrol has been regarded as an effective measure for the control of some non-native species (such as *E. crassipes* and *E. nuttallii*); however, there has been little research as to the efficacy of using native biocontrol approaches to curtail the growth of the yellow flag.

Public education about the risks and consequences of invasions by non-native species is very important to their control [45]. Unfortunately, the primary focus regarding the yellow flag has been upon its benefits (such as improving aquaculture, beautiful landscaping, and ecological restoration) and there has been insufficient funding supporting its monitoring and management [8,46]. Measures addressing the risks and advantages of using various management, as well as an enhancement of public education about them (books, websites, and brochures), their discussion in higher education (undergraduate courses and other means of reaching students), and through additional professional training about the yellow flag for the civil, agricultural, and environmental engineers.

The timing and methods of eradication are very important in controlling the further establishment of feral populations and in restricting the spread of non-native aquatic plants. For example, the yellow flag can produce a great number of viable seeds that survive for a long period in mud or water [24]. Eradication should be conducted prior to the flowering season [20], and subterranean rhizomes should be completely removed to avoid re-establishing wild populations of yellow flag. It is very difficult to completely eradicate non-native aquatic species once they are established [47]. New technologies, such as exposure to hot water or aquatic disinfectants and desiccation, have been applied to control and eradicate non-native aquatic plants [48–50]. However, more research is needed to find the most effective means of yellow flag eradication in China. As suggested by the experiences of North America with naturalized yellow flags, the research areas that are needed include the mechanisms of yellow flag invasion, its spread in different community types, and a better understanding of the roles of competition and shading in affecting the growth, survival, and reproduction of the yellow flag. In conclusion, we call researchers to conduct more research on remote sensing and image interpretation, as well as the chemistry, biology, and hydrology of the yellow flag.

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