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Research Article

Yellow bur-head, *Limnocharis flava* (L.) Buchenau (Alismataceae), in China: a popular ornamental aquatic plant and a potential invasive species

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Abstract

Non-native aquatic plants are important considerations in environmental management because of their rapid growth, ability to disperse and establish feral populations quickly, and because of their negative ecological and economic impacts. Yellow bur-head (*Limnocharis flava*) is an emergent aquatic plant native to tropical and subtropical America that has been introduced primarily through the aquarium trade on all continents except Antarctica. Recently, this species has developed naturalized populations because of its widespread use in constructed wetland restoration projects and aquatic gardens. There is little information about yellow bur-head in China and the lack of scientific research and monitoring has made the management of this non-native aquatic species challenging. In this study, we review introduction pathway, current distribution, and ecological impacts caused by yellow bur-head through field surveys and a review of the literature. Yellow bur-head introduced in China as ornamental plants and spread quickly due to aquarium trade, ecological restoration. Now, this species has successfully established feral populations in 11 Provinces of south China. And this species caused significant negative impacts on native biodiversity and grain production. Thus, more attention should pay on monitoring and management of this non-native species. This study provides useful information for researchers and managers of non-native aquatic plants in China and other regions.

Key words: biodiversity conservation, distribution, horticulture, ecological impacts, macrophyte

Introduction

Global biodiversity is declining rapidly (Barnosky et al. 2011) and the impacts of biological invasions are considered to be one of the primary causes. Non-native species are significant threat to biodiversity and ecosystem function (Simberloff et al. 2013; Xiong et al. 2015). Freshwater ecosystems

are considered more sensitive to invasive species than terrestrial and marine ecosystems (Dudgeon 2019). Non-native aquatic plants can change the physical and chemical traits of waterbodies and the relationships between the environment and organisms, eventually causing ecological damage as well as having extremely negative economic impacts (Hussner et al. 2021). It has been a challenge for local governments and environmental protection organizations to administer and control non-native aquatic plants in China (Wang et al. 2016).

In recent years a great number of non-native aquatic plant species have been introduced into China for food, through the ornamental plant trade, for use in ecological restoration, and through other unintended pathways of entry (Wang et al. 2016; Yu 2017). The leaves, leaf stems, flower stalks, and young inflorescences are edible, rich in calcium, iron and vitamin A, and yellow bur-head may be grown for food. Some non-native aquatic plants have become popular species that are widely used in aquaculture, horticulture, and in ecological restoration projects (Wang et al. 2016; Xiong et al. 2022). Many researchers have reported that some non-native aquatic plants have widespread distributions and well-established feral populations in various waterbodies, and that they have caused significant economic loss in the invaded sites (Xiong et al. 2018; Wang et al. 2021). Unfortunately, there is a lack of information about the biology and ecology of many non-native aquatic plants and their established, wild populations in Chinese wetlands, making it difficult to design strategies to control and eliminate them (Wang et al. 2020; Xiong et al. 2021, 2022).

Yellow bur-head, *Limnocharis flava* (L.) Buchenau, is an emergent aquatic plant native to tropical and subtropical America, and it has become naturalized in Southern and Southeast Asia and China (Cook 1974; Holm-Nielsen and Haynes 1992). Due to its attractive triangular-shaped leaves, flower stalks and "octopus-like" inflorescences, it has become a very popular ornamental plant that is commonly used in aquatic gardens, urban greenways, and in aquaria and water features at private homes (GISD 2022). Due to its high propensity for dispersal through the production of huge seed sets (each fruit contains thousands of seeds) and asexual propagules (Brooks et al. 2008b; Karthigeyan et al. 2004), this species has become an invasive plant of great concern in Southeast Asia, Madagascar, the USA, and Australia (Brooks and Galway 2006; Abhilash et al. 2008; Brooks et al. 2008a). Since the 1990s, yellow bur-head was planted and has become well-established in the Beijing Botanical Garden (Zou and Cui 1996), and over the past 30 years it has been widely used in water gardens and wetland restoration projects (Wang et al. 2016).

The objectives of this study are (1) to summarize the pathway of yellow bur-head introduction and its distribution in China; (2) to review its ecological and economic impacts; (3) to provide recommendations for the better management of this highly invasive species.

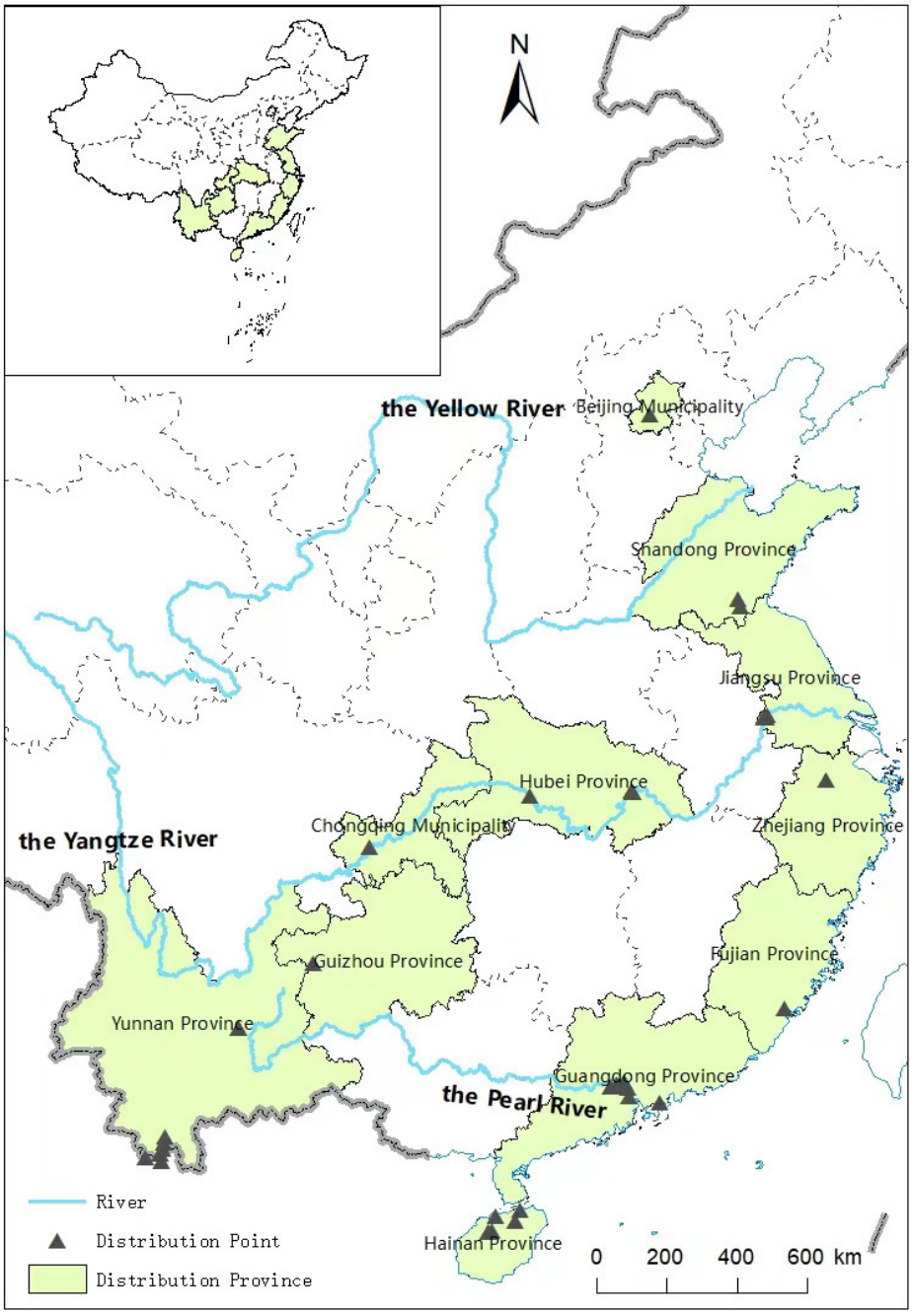

Figure 1. The distribution of yellow bur-head (*Limnocharis flava*) in China (see Supplementary material Table S1 for details).

Materials and methods

According to field studies and a review of the published literature and agency or other reports, we compiled a distribution map of yellow bur-head in China (Figure 1). We conducted over 50 field investigations and surveys to acquire information about non-native aquatic species at over 1000 sites (Wang et al. 2020; Xiong et al. 2021). For each site we developed a list of native and non-native plant species, basic geographical information (longitude, latitude, elevation), and habitat type. We conducted a literature search that contained the following combination of words "*Limnocharis*

flava" and "China" in the title, abstract, or keywords from the Web of Science (WOS, https://www.webofscience.com/wos/alldb/basic-search) and the largest Chinese information database (CNKI, http://www.cnki.net). We also collected information from relevant Chinese books, such as *Illustrations of Alien Invasive plants in China* (Yan et al. 2016).

Results and discussion

Pathways of introduction

The ornamental trade is one of the primary pathways of introduction for non-native aquatic plants (Wang et al. 2016). In 1866 yellow bur-head was first displayed and cultivated as an aquatic ornamental species in the Botanic Garden of Indonesia in Asia (Abhilash et al. 2008), it was recorded in Beijing Botanical Garden in 1989 (Zou and Cui 1996), and since the 1990s it has been widely introduced in botanical gardens throughout China (Wuhan Botanical Garden, South China Botanical Garden, and the Xishuangbanna Botanical Garden) (Zhao et al. 1999). Currently there are at least 151 botanical gardens in China and yellow bur-head is present in over 75% of them (Zhong 2020).

In the past twenty years nearly 300 national wetland parks and thousands of provincial and municipal wetland parks have been established (Pan and Zhang 2014; Xiong et al. 2022). For aesthetic and recreational enhancement, attractive aquatic plants were established in large areas and seed or asexual propagules of non-native taxa intermingled with those of others that were deliberately planted, or the non-native species were unintentionally dispersed in some other way (Xiong et al. 2021). Many city managers used attractive non-native plants like parrot's feather (*Myriophyllum aquaticum*) and fanwort (*Camboba caroliniana*) in wetland landscaping to enhance the aesthetics in waterways and created display wetlands in their cities (Xiong et al. 2021, 2022). Many communities, especially in southern China, possess or have adjacent ponds, ditches, lakes or wetlands that they plant with ornamentals such as yellow bur-head. We observed that this species is the most popular one used in wetland landscaping in large cities like Hainan, Guangdong, Jiangsu, and Hubei Provinces of southern China.

In the past forty years, most waterbodies in China have experienced eutrophication and other pollution of various types, including heavy metals (Qin et al. 2013; Zhang et al. 2015). A great number of constructed wetlands were built to absorb heavy metals and decrease nutrients (Zhang et al. 2012). Yellow bur-head has been used widely in the constructed wetlands because of its ability to absorb nitrogen and phosphorus (Chen et al. 2009). Unfortunately, many constructed wetlands have inadequate ongoing post-construction support for management. Because of the lack of ongoing oversight, yellow bur-head has escaped from many constructed wetlands and has established monospecific stands in nearby natural waterbodies (Figure 2).

Figure 2. A dense stand of yellow bur-head (*Limnocharis flava*) in a Chinese wetland. Photograph by Keyan Xiao.

Distribution and invaded habitats

Based on our literature review and field investigations, yellow bur-head has successfully established feral populations in 11 provinces, autonomous regions, or municipalities (Hainan, Guangdong, Yunnan, Guizhou, Fujian, Zhejiang, Jiangsu, Hubei, Shandong, Beijing, and Chongqing) in China (Figure 1). Our field studies show that yellow bur-head can colonize wetlands, lakes, ponds, canals and rivers (Supplementary material Table S1). It is distributed from its southernmost locality in Hainan (19.511343N; 109.498568E) to its northernmost verified site in Beijing (39.994879N; 116.221901E), thus encompassing nearly all of the north temperate monsoon climate zone. This distribution clearly illustrates that almost all regions of China are suitable and vulnerable to colonization by yellow bur-head. Habitat managers should be on the lookout for this species in all areas of China.

Potential ecological and economic impacts

Yellow bur-head reproduces both sexually through seeds and asexually by clonal or fragmentary growth. Over one thousand seeds are produced in each individual fruit and potentially over one million seeds could be generated by one yellow bur-head plant in a year (Kaul 1967; Kotalawala 1976). Yellow bur-head can also form extensive and dense monocultures. Some native endangered or endemic aquatic plants, such as *Sagittaria trifolia* and *S. sagittifolia*, have been displaced by the invasion of yellow bur-head in northwest China. The native aquatic plant species provide suitable habitats or food sources for many important native animals,

including fish, amphibians, and birds (Becker et al. 2007; Qiu et al. 2020), thus the invasion of yellow bur-head could cause a significant decline in both the native flora and fauna. We observed some sites at which yellow bur-head displaced other invasive species, such as *Eichhornia crassipes* and *Alternanthera philoxeroides*.

The safety of food sources is always one of the most important foci for the Chinese government and consumers. The large feral populations of yellow bur-head are a potential threat to rice production in China, as individual plants can grow to over 100 cm and compete with rice for nutrients, space, and light (Kotalawala 1976; Abhilash et al. 2008). Yellow bur-head clogs irrigation tanks, channels, and drainage ditches resulting in poor drainage, making the lower regions of cultivated areas unsuitable for rice farming. It also obstructs the flow of water from paddy fields during heavy rainfall, resulting in damage to rice by submersion (Karthigeyan et al. 2004). Because of these issues, yellow bur-head has become a serious threat to rice cultivation in some important rice producing areas in South China (Figure 1).

Monospecific stands of many non-native aquatic plants provide suitable oviposition habitat and refugia for mosquitos and decrease their predation by fish, insects, and birds (Xiong et al. 2021). This has increased the risk of the transmission of mosquito-borne diseases like malaria, dengue fever, and yellow fever. Therefore, non-native aquatic plants are serious threats to human health and should be quickly eradicated in and adjacent to residential areas.

Management and control recommendations

Early detection with a rapid response is the first step and is the most effective method to manage and control invasion by non-native species (Burgiel 2020; Cuthbert et al. 2022). Many researchers have conducted studies and reported new non-native aquatic plants in China (Wang et al. 2020; Xiong et al. 2021, 2022) and, unfortunately, there is a continuous pathway for new introductions through the aquarium and ornamental trades (Xiong et al. 2017; Wang et al. 2016, 2021). There is an urgent need to establish an ongoing monitoring system to identify and allow eradication of non-native species as they escape and begin to establish feral populations in China's wetlands.

Secondly, there have been many chemical, mechanical, and biological control measures that have been employed to control yellow bur-head in different regions (Brooks et al. 2008a). This species is very difficult to eradicate and to curtail its spread (Brooks et al. 2008a). Yellow bur-head has a strong tolerance to some chemical herbicides, such as 2,4-D and bensulfuron-methyl (Nakyama et al. 1999). Some researchers recommended drying and burning as the most effective method to eradicate this species

(Bahadur and Raizada 1968). Continued vigilance for new naturalized occurrences and the ongoing monitoring of existing feral populations is very important to the control and eradication of yellow bur-head.

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Authors' contribution

Conceptualization, WX and HW; methodology, WX, JL, WT; field work, WX, JL, WT, QW, YL; writing original draft preparation, WX, WT and HW; writing review and editing, WX, HW, and PAB; supervision, WX, PAB. All authors have read and agreed to the published version of the manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Location of yellow bur-head (*Limnocharis flava*) in China.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2023/Supplements/BIR_2023_Xiong_etal_SupplementaryMaterial.xlsx