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Research Article

Delta arrowhead (*Sagittaria platyphylla*) in the Yangtze River: an invasive aquatic plant and the potential ecological consequences

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Abstract

The Yangtze River basin in China has one of the most highest rates of biological invasion of any freshwater ecosystem. As it is also an important agriculture, aquaculture and biodiversity hotspot, it is critical to implement early detection and rapid response, monitoring and control of new invasive species as they are discovered. This is the first report of the presence of the invasive aquatic vascular plant *Sagittaria platyphylla* in the middle and lower reaches of the Yangtze River. We propose that more research should focus on control of the aquarium trade and wetland restorations.

Key words: aquarium trade, invasion, macrophyte, wetland restoration, wetlands, first record

Introduction

Invasive species are serious threats to global biodiversity and ecosystem function (Mack et al. 2000). Freshwater ecosystems are recognized as highly susceptible to invasive species (Strayer 2010), and invasive species cause greater ecological and economic impacts in freshwater ecosystems than in terrestrial or marine ecosystems (Vilà et al. 2010). Invasive aquatic plants are of great concern because of their significant ecological and economic impacts (Wang et al. 2016).

As a result of rapid economic development, a large number of non-native aquatic organisms were introduced into China for different purposes

(including aquarium trade, aquaculture, ecological restoration, and biocontrol) (Xiong et al. 2015, 2017; Wang et al. 2016), and many of these non-native species have significant negative ecological and economic impacts (Xiong et al. 2015, 2017; Wang et al. 2016). Some regions, such as the Yangtze River, experienced a particularly high rate of invasion and establishment of self-sustaining populations of naturalized non-native aquatic species (Xiong et al. 2018). The Yangtze River is an important the biodiversity hotspot that warrants protection (Olson and Dinerstein 1998) and is one of the most important fishery and aquaculture regions in China (Wang et al. 2015). Because of this, the region is prioritized for research and conservation, especially research which focusses on the impacts and management of invasive species (Xie and Chen 1999; Xiong et al. 2018).

Delta arrowhead, *Sagittaria platyphylla* (Engelmann) J.G. Smith (Alismataceae) is a monocot native to the central and southern states of the U.S.A., that occurs in the littoral zones of ponds, lakes, and slow moving rivers and streams (Adair et al. 2012). Delta arrowhead has strong invasive characteristics, with high reproductive and dispersal capacity for both seed and vegetative structures. It also has an extended flowering season that lasts about 6 months, from summer to fall (Haynes and Hellquist 2000), producing high numbers of achenes (average 6900 per inflorescence) during its season of reproduction (Flower 2004). The achenes are light and buoyant, and readily dispersed over long distances along waterways during floods (Broadhurst and Chong 2011) and seeds are thought to be spread by water movement and animals (Santamaría 2002). The underground stem fragments and tubers of this species may be dispersed by floods and in discarded aquarium refuse and garden waste. This has facilitated the lateral spread of colonies over time (Adair et al. 2012).

Delta arrowhead is an attractive ornamental plant that has been widely marketed on a global scale (Kwong et al. 2017), leading to its introduction and establishment in multiple countries. In the past forty years, Delta arrowhead has been established in the USSR, Australia, and South Africa (Martin and Coetzee 2011; Hussner 2012; Adair et al. 2012). Delta arrowhead has also been imported to Japan, Taiwan, and Korea through the aquarium trade throughout the past thirty years, and is now considered naturalized in Indonesia (Kwong et al. 2014). Until the early 2000s, Delta arrowhead was brought into mainland China through the largely unregulated aquarium trade, along with other ornamental plants (Wang et al. 2016). Furthermore, Delta arrowhead has been widely used as an ornamental plant and in wetland restoration in China because of its wide range of tolerance to pollution and environmental stressors (Wang et al. 2016). In some invaded regions, Delta arrowhead causes significant impacts to agricultural irrigation, waterways and wetlands, particularly in the southeast of Australia (Kwong et al. 2014). It is a highly invasive and is a rapidly growing plant that forms dense monocultures of over a meter high.

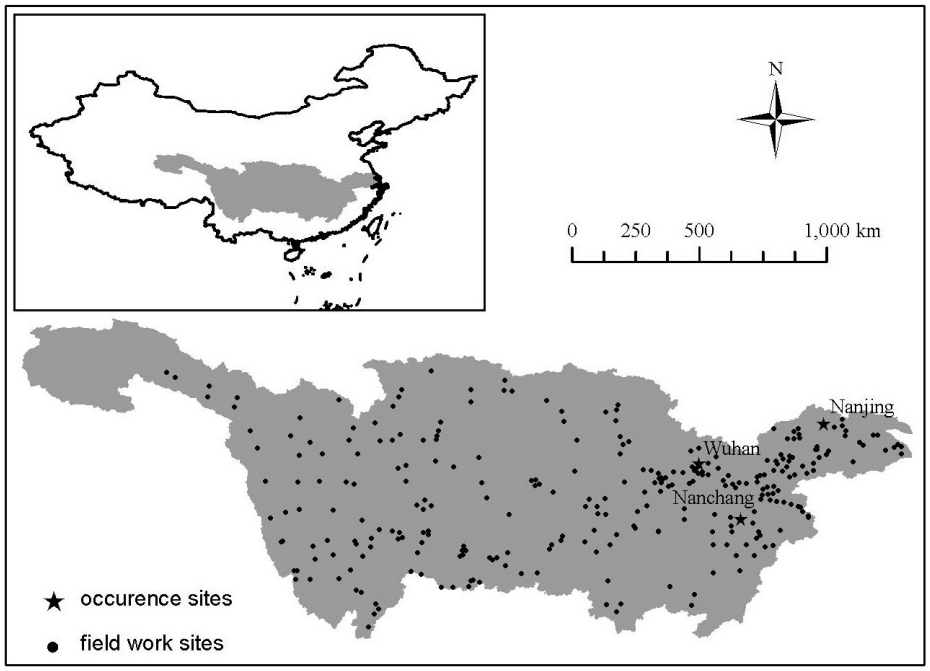

Figure 1. *Sagittaria platyphylla* sites in the Yangtze River basin.

Severe infestations block irrigation channels and drains, leading to a higher risk of flooding and damaging irrigation infrastructure. Dense monocultures of Delta arrowhead clog wetlands and waterways resulting in further deterioration of water quality, a reduction of native aquatic biodiversity and has impacts upon the safety of drinking water (Wang et al. 2016). Due to its strong invasive capabilities, wide distribution and substantial negative impacts, Delta arrowhead has been monitored and eradication plans have been implemented in Australia and some European countries (Adair et al. 2012). Delta arrowhead was listed as weed of national significance because of its invasiveness and potential impacts to the economy and the environment in 2012 (Clements et al. 2015).

To our knowledge, this study is the first record of *Sagittaria platyphylla* in the Yangtze River (Figure 1), and it provides an overview of the current distribution and potential impacts of this invader in the Yangtze River watershed. We summarize some of the biological traits of Delta arrowhead that are important in understanding the associated risks and preventing its spread.

Materials and methods

Study area

China has arguably the highest record of invasion by non-native aquatic species (Xiong et al. 2015, 2017; Wang et al. 2016), with the majority of those species occurring in the Yangtze River (Xiong et al. 2018). The Yangtze River is the largest river in China and the third largest river in the world. The length of Yangtze river is more than 6300 km, and the drainage area is about 180×10^4 km^2 (Tong and Han 1982).

Nearly 700 lakes with an area of more than 1 km^2 are distributed in the middle and lower watershed of the Yangtze River. The total surface area of the lakes is about 21 171 km^2. China's five most famous freshwater lakes (Poyang, Dongting, Taihu, Hongze and Chaohu Lakes) are located in this part of the Yangtze watershed, and it is one of the regions with the highest density of lakes in China. Due to long-term sedimentation by natural geological change, most of the lakes are characterized as shallow, with an average depth of about 2 meters or less (Wang and Du 1998).

Most of the middle and lower reaches of the Yangtze River lie in the northern subtropical zone, and a small area is within the northern margin of the mid-subtropical zone. The annual average temperature is 14–18 °C, the coldest monthly average temperature is 0–5.5 °C, the absolute minimum temperature is −20 °C, and the hottest monthly average temperature is 27–28 °C. The frost-free period is 210–270 days, and the annual precipitation is 1000–1500 mm. The climate of the middle and lower reaches of the Yangtze River is similar to the native North American region of Delta arrowhead (Guo et al. 2006; Wu et al. 2019).

Field investigation

Information about non-native aquatic species is limited in the Yangtze River, China. To further understand the distribution of non-native aquatic plant species in the Yangtze River, an investigation program (the major science and technology program for water pollution control and treatment, 2015ZX07503-005-007) has been underway since 2014. From May to September each year from 2015 to 2019, five groups of investigators (three to seven people in each group) conducted extensive geobotanical surveys in the Yangtze River, and in total of 295 sites (include rivers, lakes, marshes, reservoir, ponds, and paddies) were sampled (Figure 1). We completed a presence/absence survey to identify the occurrence of Delta arrowhead in the Yangtze River, revisiting the same sites each year, where occurrence of Delta arrowhead was identified. At each site, the community of aquatic plants was inventoried following standardized methodology and protocols for plant community inventories described by Fang et al. (2009). Basic information of sampling site (longitude, latitude, elevation, water depth and temperature), plant height, and invade area were recorded (Supplementary material Table S1), and plant specimen collection and identification were conducted according to Wu et al. (2019). For emergent plant communities, a sampling area of 2 × 2 m were used; all aquatic plants were collected, identified and reference specimens were deposited at the Herbarium of Huazhong Agriculture University.

Results

In total, 295 site were investigated (Wu et al. 2019). Delta arrowhead had successfully established naturalized populations in provinces in the middle

Figure 2. *Sagittaria platyphylla* prior to flowering. Photo by Wen Xiong.

and lower reaches of the Yangtze (Figures 1, 2, including Hubei (Provincial Capital: Wuhan), Jiangxi (Provincial Capital: Nanchang), and Jiangsu (Provincial Capital: Nanjing)). The detailed information about naturalized populations and invaded habitats are listed in Table S1. Delta arrowhead has successfully formed dense monocultures (> 50 plants m^2) in some abandoned farmland and irrigation ditches in the Yangtze River Basin (Figure 3).

Discussion

Introduction pathways and distribution

In China, the aquarium trade and ecological restoration are the two most common pathways for the introduction of invasive aquatic plants (Wang et

Figure 3. *Sagittaria platyphylla* infestation in the Yangtze River. Photo by Keyan Xiao.

al. 2016). There are currently nearly five thousand commercial outlets in China that sell arrowhead seed and corns (*Sagittaria* spp.) on the Taobao website, the largest internet market in the world (Taobao website 2019). It is very hard to identify how many stores are selling Delta arrowhead in particular, because of the difficulty in distinguishing seed and asexual propagules of different *Sagittaria* species. In spite of the lack of detailed information about the number of stores selling *Sagittaria platyphylla*, a large quantity of *Sagittaria* species were sold in all parts of the country. Delta arrowhead is also available in aquarium stores in many large cities such as Shanghai, Guangzhou, Wuhan, Nanjing, and others (Wang et al. 2016).

China has extensive wetland restorations and constructed wetlands built in the last thirty years that used Delta arrowhead as an attractive ornamental plant within them (Liu et al. 2009; Zhang et al. 2012). Besides

water parks, arrowhead is used in the constructed wetlands (Zhang et al. 2012; Wang et al. 2016). Especially in the Yangtze River, a great number of wetland parks and constructed wetland were built in the past thirty years (Zhang et al. 2012; Wang et al. 2016). Because its seeds are easily dispersed, a large number of Delta arrowhead escape and successfully establish populations in the wild.

Potential ecological and economic impacts

Due to forming dense monocultures and blocking the irrigation, Delta arrowhead is listed as highly invasive and is particularly problematic in shallow aquatic habitats within the littoral zone in the USA, Australia, South Africa (Adair et al. 2012). Delta arrowhead is a challenging and expensive plant to control, particularly in irrigation districts (Clements et al. 2015). In the Goulburn-Murray basin of Australia alone, the local government spends over 2 million AU$ for the control of this invasive species every year (Kwong et al. 2014). Therefore, the potential ecological and economic impacts of this invasive species should receive greater attention in China.

The middle and lower reaches of the Yangtze River are important grain producing areas in China (Piao et al. 2010). There are a large number of agricultural irrigation ditches in the middle and lower reaches of the Yangtze River, most of which are not cement lined (Wang et al. 2002). Making them suitable habitats for *S. platyphylla* invasion which may in turn affect agricultural practices in the region.

This study found dense monocultures of Delta arrowhead which may be replacing native wetland plants. In our investigation, we observed that alligator weed (*Alternanthera philoxeroide*s (Mart.) Griseb) (Amaranthaceae), are the main accompanying species with Delta arrowhead in site 1 (Zhangjiadashu, Wuhan), the cover of each plant is about 50% in 2017. But alligator weed were completely replaced by Delta arrowhead in 2019. Delta arrowhead may find a large number of suitable habitats and compete with indigenous species, eventually reducing native biodiversity of both flora and fauna (Adair et al. 2012; Wang et al. 2016). Most lakes in the middle and lower reaches of the Yangtze River are mesotrophic or eutrophic (Qin et al. 2013), providing adequate nutrient to promote the establishment of Delta arrowhead, making it a significant threat to native freshwater biodiversity and human well-being in the middle and lower reaches of the Yangtze River.

The Yangtze River, supports the over 40% population and economy of China, is the most agriculture and aquaculture regions in China. The invasion of Delta arrowhead may lead to a series of ecological risks such as water quality degradation, flooding and biodiversity reduction. Thus, this invasive species must be monitoring and controlled. Further research

regarding the growth, reproduction, dispersal, life-history traits, and ecological impacts of Delta arrowhead within the Yangtze River are required to ensure ecosystem health and conservation.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Summary of *Sagittaria platyphylla* in the Yangtze River.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2020/Supplements/BIR_2020_Wang_etal_SupplementaryMaterial.xlsx