Research Article

Distribution and impacts of invasive parrot's feather (*Myriophyllum aquaticum*) in China

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Abstract

Invasive plants have caused significant negative ecological and economic impacts throughout the world. Parrot's feather (*Myriophyllum aquaticum*) is an aquatic plant introduced from South America to South Africa, USA, Europe, New Zealand through the aquarium trade. It was recently brought to China where naturalized populations have become widespread. However, there is little information about the status, distribution, and the ecological and economic impacts of parrot's feather which is critical to the Chinese government and environmental managers. We summarized introduction pathway, current distribution, and ecological impacts of parrot's feather by field investigations and literature review. Our study could provide significant references for the management of non-native aquatic plants in China.

Key words: aquarium trade, aquatic plants, biological invasion, ecological impacts, wetland restoration

Introduction

Invasive species are considered to be one of the main biological threats to the ecosystem (Simberloff et al. 2013). Research has shown that invasive species caused higher ecological and economic impacts in aquatic environments than in terrestrial environments (Vilà et al. 2010). Invasive aquatic plants in particular, have had a great negative impact on biodiversity and ecosystem functioning (Brundu 2015). Thus, more attention should be

dedicated to studying and controlling these invasive aquatic plants (Wang et al. 2016).

In recent years, China has become one of the countries most seriously threatened by a great number of invasive aquatic plant species (Xiong et al. 2015, 2017; Wang et al. 2016). Some waterbodies have an exceptionally high introduction rate by invasive species (Xiong et al. 2018; Wang et al. 2020b), such as Delta arrowhead (*Sagittaria platyphylla* (Engelm.) J.G. Sm., 1894) and water hyacinth (*Eichhornia crassipes* (Mart.) Solms, 1883), which have caused great regional ecological and economic losses (Lu et al. 2007; Wang et al. 2020a).

Parrot's feather, *Myriophyllum aquaticum* (Vell.) Verdc. 1973 (Haloragaceae) is a rooted emergent plant native to the Amazon River in South America, that typically grows in freshwater streams, ponds, lakes, rivers and canals (Sutton 1985). Parrot's feather is dioecious, but the males are very rare in the field even in its native range (Sutton 1985). In invaded areas, parrot's feather populations are primarily female and depend on asexual reproduction which promote increasing their distribution (Xie et al. 2013, 2018). Asexual propagules (fragments and rhizomes) of parrot's feather have the potential to spread for several months and can rapidly extend their distribution by kilometers during periods of clonal dispersal (Wersal and Madsen 2011; Xie et al. 2013). These asexual propagules draw nutrients from the water column through adventitious roots. Once the adventitious roots become attached to benthic sediments, these propagules can establish high density, monospecific stands because of their rapid growth (Hussner et al. 2009; Xie et al. 2010).

This species was introduced into the global aquarium trade during the 20th century (Thiébaut 2007). At first, it was not recognized as a noxious weed in the USA as it only reduced water movement in rivers and canals extending flood duration and intensity (Timmons and Klingman 1958). Researchers gradually realized the magnitude of other negative impacts including a decline in water quality, the formation of dense monoculture populations that impede water flow, and its competition and displacement of native aquatic plants. Because of these negative impacts, parrot's feather was identified as an important invasive aquatic plant in Europe, USA and South Africa (Hussner et al. 2009; Wersal and Madsen 2011). In the past 20 years, this species was introduced and sold as one of the primary aquarium plant species in China (Wang et al. 2016). Unfortunately, there is little information about this species as a naturalized plant in Chinese wetlands.

The objective of this study is to summarize introduction pathway, biological traits, current distribution and potential impacts of parrot's feather in China. We hope that this study will help environmental managers to better understand and manage invasive species introduced via the aquarium trade to China.

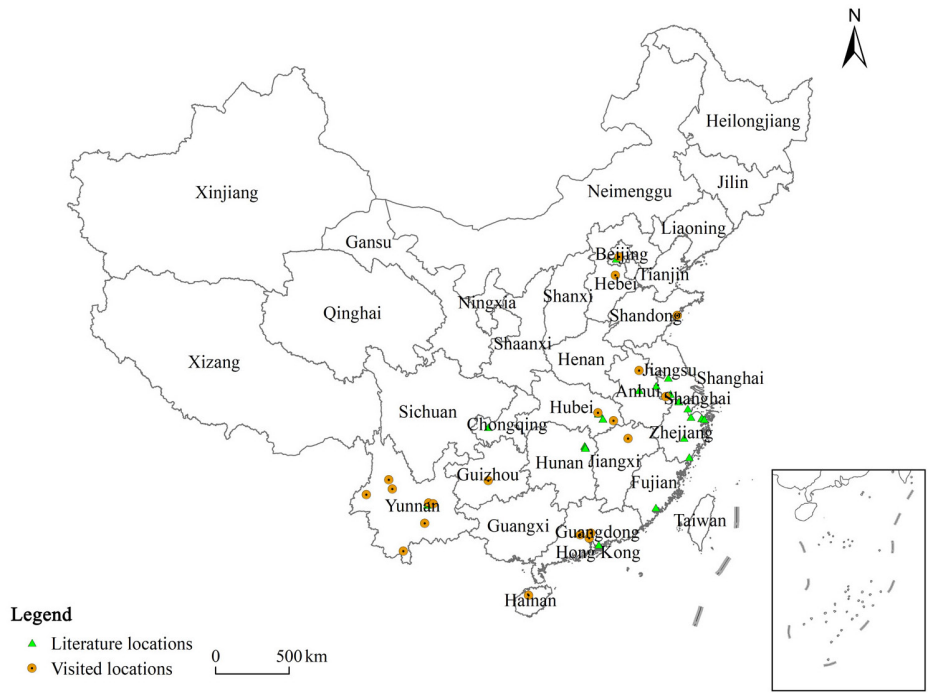

Figure 1. Locations of parrot's feather in China.

Materials and methods

Literature collection

We conducted a literature search that contained the following combination of words "*Myriophyllum aquaticum*" and "China" in the title, abstract, or keywords from the Thomson Institute for Scientific Information (ISI, http://www.isiknowledge.com) and CNKI (http://www.cnki.net). We also collected information from some Chinese books, such as *Illustrations of Alien Invasive plants in China* (Yan et al. 2016).

Field investigation

To acquire detailed information about non-native aquatic plant species in China, we carried out over 30 field investigations from 2015 to 2019, using the field methodology described by Wang et al. (2020a). At each sampling site, we recorded basic information such as the longitude, latitude, elevation, water depth, temperature, and plant height in the invaded area. The sampling and plant community inventories were recorded using the protocol described by Fang et al. (2009). We also revisited all sites of parrot's feather reported in the literature (Supplementary material Table S1). Based on our field investigations and literature review, we compiled the first distribution map of the parrot's feather in China.

Results and discussion

Distribution

According to our field surveys and reports in the literature, parrot's feather clearly has a broad distribution in South China (Figure 1). Parrot's feather

was successful in establishing flourishing populations in 14 Provinces, Autonomous Regions or Municipalities (Anhui, Beijing, Chongqing, Fujian, Guangdong, Guizhou, Hainan, Hebei, Hubei, Hunan, Jiangsu, Shandong, Yunnan, Zhejiang; Figure 1). Field surveys verified that parrot's feather occurred in all sites of literature records. Lakes are the most frequent ecosystems inhabited by the parrot's feather (20), followed by wetlands (17), rivers (16), and ponds (6). According to our field investigation, parrot's feather generally occurs in shallow (0.3–1.2 m), slow-moving or still water (river, wetland, pond, lake), and forms dense vegetation with other aquatic plants (Table S1). It reaches the northernmost point in Beijing Olympic Park (39.916058°N; 116.154992°E), where climate is typical of north temperate monsoon climate. The results indicate that most regions of China are at high risk of being invaded by parrot's feather. Although there are no records of parrot's feather having successfully established in some regions of South China, such as Guangxi, Sichuan and others, these results do not necessarily indicate that it has never colonized these regions (Figure 1). Due to the paucity of study and reports, occurrences may not simply have been observed and recorded.

Introduction pathways

Along with rapid economic growth and improvement in the quality of life over the past forty years, domestic aquaria has become an important form of recreation in China (Xiong et al. 2015). At present, the aquarium trade is the most frequent pathway for the introduction of invasive aquatic plants in China (Wang et al. 2016; Yu 2017). Parrot's feather is a very popular aquarium plant in China because of its rapid growth, attractive and feathery shape, its low cost and maintenance requirements, and because of the ease in getting viable plant material. There are over 300 commercial outlets in China that sell parrot's feather on the Taobao website, the largest internet market of the world (Taobao website 2020), and it is sold in almost all large cities of China. We observed parrot's feather marketed in aquarium stores in Wuhan, Lhasa, Zhanjiang, Nanjing and Shanghai.

Eutrophication of waters is a significant environmental problem in China (Qin et al. 2013). Many aquatic plants have been used in wetland restorations to absorb nutrients and control algae blooms. Parrot's feather is an excellent plant for use in constructed wetlands due to its high and rapid rate of nitrogen and phosphorus removal (Wang et al. 2018; Tan et al. 2019). Over the past 30 years, the area of constructed wetlands has increased rapidly in China (Zhang et al. 2012), and parrot's feather has been widely planted in these wetlands (Wang et al. 2016), particularly in southern China (Zhang et al. 2012). Inevitably, parrot's feather has escaped and established wild populations in southern China (Figure 1), a problem that is still occurring (Wang et al. 2016; Yu 2017).

Figure 2. Naturalized parrot's feather in Chinese wetlands (Yunnan and Beijing). (A) Population of parrot's feather (*Myriophyllum aquaticum*). (B) A community dominated by parrot's feather and alligator weed (*Alternanthera philoxeroides*). Photographs by Keyan Xiao.

In the past forty years, there has been a significant decrease in aquatic vegetation in most lakes in China (Zhang et al. 2017). For the protection of lake environments and the restoration of a lacustrine ecological functions, many aquatic vegetation restoration projects were carried out in Chinese lakes. For example, the research team of Te Cao (Institute of Hydrobiology, Chinese Academy of Sciences) conducted a 10-year aquatic vegetation restoration project in Erhai lake in Yunan, China (IHB website 2020). In Erhai Lake, we observed that fragments of parrot's feather were intermingled with other aquatic plants used for aquatic vegetation restoration. Parrot's feather successfully colonized and became the dominant species in Erhai Lake, threatening nature restored sites (Figure 2). Due to the large quantity

of asexual propagules and its high dispersal potential (Xie et al. 2013, 2018), parrot's feather has successfully established feral populations in many other lakes including Taihu, Liangzi, Dianchi Lake (Figure 1; Table S1).

Recently, China became the most important aquaculture producer worldwide (Wang et al. 2015). Parrot's feather was widely artificially planted in many aquaculture ponds to provide habitat for some important aquaculture edible species, such as the North American red swamp crayfish (*Procambarus clarkii* Girard, 1852), and to decrease predation by birds (Hou 2018). Because of farming, parrot's feather has become widely distributed in many ponds and canals, especially in the most important red swamp crayfish production areas, like Hubei, Hunan, Jiangxi, Anhui, and Jiangsu (Table S1).

Ecological and potential economic impacts

Parrot's feather is a species with a characteristically rapid growth. The vertical shoots emerge rapidly from the surface water and can occlude open areas (Wersal and Madesen 2011). This species forms dense monospecific stands that can reduce the submersed native plants because of its dense canopy blocking sunlight and reducing oxygen exchange (Stiers et al. 2011). In this study, we observed that parrot's feather formed dense monospecific stands replacing native aquatic plants in many invaded sites. For example, the dense cover of parrot's feather has displaced the native endangered submersed plant (*Ottelia acuminata* (Gagnep.) Dandy, 1934) in Erhai Lake. Parrot's feather can also alter macroinvertebrate composition and can cause significant ecological alteration in the detrital community (Stiers et al. 2011; Stiers and Triest 2017). Most of the regions colonized by parrot's feather had originally very high native biodiversity (He et al. 2020; Wang et al. 2020a) that is now seriously threatened by parrot's feather. In many locations in China, parrot's feather has displaced other strong competitors, such as Eurasian watermilfoil (*Myriophyllum spicatum* L., 1753), alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb., 1879), and water chestnut (*Trapa bispinosa* Roxb., 1814) (Figure 2). Parrot's feather seems therefore to have a potential competitive advantage over native communities in China.

The invasion of some non-native species can facilitate the establishment of other non-natives (Simberloff and Von Holle 1999). For example, researchers found that non-native aquatic plants (*A. philoxeroides*) provide good habitat and refugia to non-native mosquitofish (*Gambusia affinis* Baird & Girard, 1853) and facilitate invasion of mosquitofish (Xiong et al. 2019). In our investigation, we observed that also the parrot's feather hosts mosquitofish and the two species are jointly invading many habitats in southern China (Cheng et al. 2018; Xiong et al. 2019). This is likely because the dense monospecific mats provided by parrot's feather can hide mosquitofish from birds and other predators.

Our previous study (Xiong et al. 2008) verified enemy release hypothesis. A widely distributed native herbivore snail (*Radix plicatula* Benson, 1842,

Lymnaeidae) prefers native plant species (such as *M. spicatum*) over non-native aquatic plants (such as *M. aquaticum*). This preference causes non-native aquatic plants to have a potential competitive advantage over its native competitors, displace native plants, and finally establish single superior communities.

Impacts to human health and activities

Parrot's feather can affect human health and the utilization of water resources. Dense mats of parrot's feather provide suitable oviposition habitat and refuge areas for mosquitos and at the same time decrease their predation by fish (Orr and Resh 1989), This increases the risk of mosquitoes carrying and transmitting disease.

Parrot's feather forms dense monocultures in many canals and ditches, which influences irrigation pumping and water distribution for agricultural purposes. This has a negative impact on crop production, especially in the most important grain producing area of China, like in the middle and lower reaches of the Yangtze River, where parrot's feather and other invasive exotic aquatic plants have become a significant threat to agricultural production (Wang et al. 2020a). Parrot's feather has been widely used in constructed wetlands to improve water quality (Wang et al. 2018), but its dense mat-like stands impede water movement and pose challenges also to drinking water supplies in some invaded regions (Jacot-Guillarmod 1977). Parrot's feather decreases, in fact, water quality due to large detrital deposits. Unregulated parrot's feather populations are a significant threat to drinking water in some invaded regions.

In conclusion, parrot's feather has successfully established extensive naturalized populations in southern China (Figure 1). This is especially critical in some important economic and agricultural regions (such as in the middle and lower reaches of Yangtze River), where parrot's feather has established many feral populations in various waterbodies. The invasion threatens native biodiversity, drinking water safety, agriculture irrigation and mosquito-borne diseases. Therefore, a better monitoring, research and control are necessary to prevent further spreading.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Summary of *Myriophyllum aquaticum* in China.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2021/Supplements/BIR_2021_Xiong_etal_SupplementaryMaterial.xlsx