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GIANT SALVINIA (*SALVINIA MOLESTA* D. S. MITCH.) IN CHINA: STATUS, IMPACT AND MANAGEMENT

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Abstract

Non-native aquatic plant species have had significant ecological and physical effects on a diversity of wetland settings in China, where non-native species are well-known for their ecological dis-placements and the changes they have caused in various wetland categories. Giant salvinia (*Salvinia molesta* D. S. Mitch.), a floating aquatic fern native to South America, is one of the most noxious invasive weeds widely introduced in tropical and subtropical regions of the world. Recently, this species has been introduced and has become widespread in south China. In this study, we review and summarize the baseline information (introduction pathway, distribution status, uses, ecological impacts, and management) available for giant salvinia in China by field investigations and literature review. Giant salvinia was first introduced in China as aquarium plant, and has established naturalized populations in 14 Provincial-level administrative regions. Now, giant salvinia become a potential threat the native biodiversity, grain production, and human health. This study provides valuable information and recommendations for managing and controlling giant salvinia in tropical and subtropical regions.

Key words: Biological invasion; Control; Farmland weed; Forage; Impact; Giant salvinia

Introduction

Global biodiversity and the health of natural ecosystems are seriously threatened by biological invasions (Barnosky *et al*., 2011; Simberloff *et al*., 2013). Freshwater ecosystems have experienced considerable biological changes that have had significantly negative economic and social impacts on the surrounding urban and rural environments, making them more susceptible to invasive species than their terrestrial and marine counterparts (Reid *et al*., 2020). In waterbodies with established populations, non-native aquatic plants alter the habitat structure, predator-prey interactions, physical and chemical characteristics, and biological background (Schultz & Dibble, 2012; Hussner *et al*., 2021). Non-native aquatic plants are drawing more and more attention from conservation biologists as they cause the direct and indirect alterations to the aquatic ecosystems they invade (Wang *et al*., 2016).

China has introduced more non-native aquatic organisms than any other countries or regions, such as USA, European Union, and ASEAN (Association of Southeast Asian Nations) (Xiong *et al*., 2015, 2017; Wang *et al*., 2016), and they established widespread feral populations in many Chinese waterbodies (Xiong *et al*., 2018, 2023a; Wang *et al*., 2021). Therein, some non-native species have caused significant negative impacts in the local environment, economy and society (Xiong *et al*., 2021, 2022, 2023b, c). Many non-native aquatic plants act as ecological engineers. They can have a profound impact on local ecosystems by introducing physical and chemical changes that alter characteristics such as water clarity, temperature, and pH (Schultz & Dibble, 2012). Non-native aquatic plants can alter nutrient cycling in water, potentially leading to eutrophication in some waterbodies (Hussner, 2012; Wang *et al*., 2016). Within aquatic communities, the presence of these non-native aquatic plants may also change the interactions between aquatic organisms. For example, they may provide new habitats and food resources, attracting the migration of some species while at the same time potentially crowding out or competing with native species (Hussner *et al*., 2021). Therefore, invasive non-native aquatic plants require our attention and management measures to mitigate their impacts on ecosystems (Hussner *et al*., 2017).

Giant salvinia (*Salvinia molesta* D.S. Mitch. 1972) (Salviniaceae) is an aquatic fern that originated in Brazil (Mitchell, 1972). It has been introduced in over sixty countries and regions on all continents except Antarctica (Anon., 2022). It is well known that this species grows rapidly and is considered one of the most noxious invasive weeds that has colonized tropical and subtropical regions

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outside of its native range (Schooler *et al*., 2011; Luque *et al*., 2013). The uncontrolled spread of giant salvinia is characterized by its ability to form dense mats covering aquatic ecosystems. This results in biodiversity decline, particularly among floating plant species, resulting in a decline of water quality, increased evapotranspiration, and economic losses (Martin *et al*., 2018). Giant salvinia was introduced in China relatively recently and has established widely distributed feral populations (Wang *et al*., 2016). Unfortunately, there is little information about its actual range or the extent of its impacts.

In this study, we (1) review and summarize the introduction pathway of giant salvinia and its distribution in China; (2) review its ecological and economic impacts; and (3) provide recommendations for the better management of this highly invasive species. It is hoped that this study will provide a baseline for the more effective management and control of non-native aquatic plants in tropical and subtropical regions of the world.

Materials and Methods

Field investigations: Over the past twenty years, we have conducted field investigations that have included all administrative areas of China using the sampling methodology described by Fang *et al*., (2009). Each sample recorded some geographic information (longitude and latitude), waterbody data (water depth and temperature), and plant community inventories.

Literature collection: We searched titles, abstracts, and reports that included the keywords "*Salvinia molesta* or giant salvinia" and "China" in selected large databases including the Web of Science (ISI, http://www.isiknowledge.com), CNKI (http://www.cnki.net), and Wanfang databases (https://www.wanfangdata.com.cn/). Information was also collected from journals and some Chinese books, such as The Checklist of the Alien Invasive Plants in China (Ma & Li, 2018) and the Invasive Alien Species China (http://www.iplant.cn/ias/, accessed April 20, 2023). The species profiles in the CABI Invasive Species Compendium and the Global Invasive Species Database (2023) were also reviewed. Detailed species descriptions of *Salvinia molesta* are found in the Jepson eFlora (https://calphotos.berkeley.edu/cgi/img_query?special=browse&where-taxon=Salvinia+molesta, accessed on June 18, 2023), and the assessment and characterization of giant salvinia are found in a diversity of government reports and gray references. Detailed geographic and other data for giant salvinia in China are presented in Fig. 1.

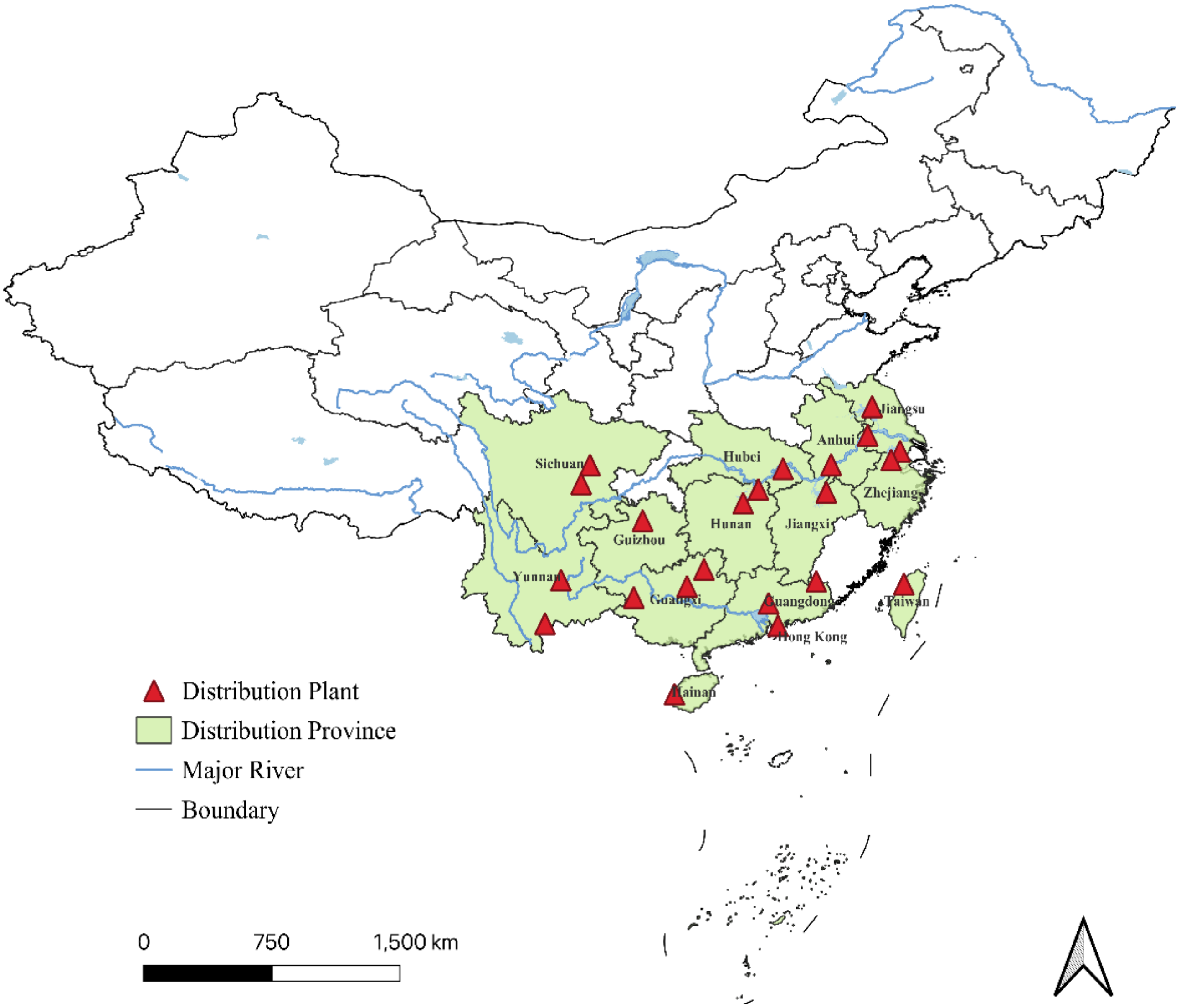

Fig. 1. distribution of giant Salvinia (*Salvinia molesta*) in China.

Results and Discussion

Distribution status and preferred habitats: Giant salvinia was first introduced in Taiwan as an aquarium plant (Zhang *et al*., 2022), the introduction pathway through which it established wild populations. According to our review of the literature and field surveys, this species has naturalized populations in 14 Provincial-level administrative regions (Provinces, Autonomous Regions, Municipalities, or special administrative zones) of China, including Anhui, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan, Yunnan, Zhejiang, Hainan, Taiwan, and Hongkong (Fig. 1). Giant salvinia generally prefers slow-moving or still-water habitats, such as paddy fields, ponds, ditches and rivers with direct sunlight exposure, and warm and nutrient-rich waterbodies (Mitchell & Tur, 1975). The optimal pH for growth and development of giant salvinia is 6.0-7.5 and the preferred water temperature is 20-30°C (Cary & Weerts, 1983). Eutrophic aquatic habitats, such as phosphate reclamation paddy fields, ditches and ponds, are particularly well-suited for its establishment and growth (Oliver, 1993).

Giant salvinia can survive for over 48 hours at temperatures as low as -3°C (Owens *et al*., 2004). It can survive and overwinter in most areas of North China (such as Henan, Hebei, Shanxi and Shaanxi). This species was commonly sold in aquarium stores in almost all large cities. Because of its ease in establishing feral populations and its high survival potential in north China (exacerbated by global warming), ongoing field surveys and monitoring are needed in this area of China.

Giant salvinia has a wide range of tolerance to salinities as high as or exceeding 20% (Harley & Mitchell, 1981). Our field investigations found that it preferred and most abundant in rivers and ponds with low salinity, such as many sites in Guangxi and Hainan (Fig. 1).

Introduction pathway and use: The aquarium trade is the most common introduction pathway for non-native aquatic plants (Padilla and Williams, 2004; Strecker *et al*., 2011; Wang *et al*., 2016). Giant salvinia was first introduced in China as an aquarium plant (Zhang *et al*., 2022), and it has been widely cultivated in China for use in aquaria. In our investigation, we observed that over 800 aquarium stores sold this species through the largest online sales platform (https://s.taobao.com/search?commend=all&ie=utf8&initiative_id=tbindexz_20170306&page=1&q=%E6%A7%90%E5%8F%B6%E8%90%8D&search_type=item&sourceId=tb.index&spm=a21bo.jianhua.201856-taobao-item.2& ssid=s5-e, accessed by 17 July 2023). Most of the online stores are located in South China (including Guangdong, Guangxi, Zhejiang, Sichuan, and Fujian,), with fewer stores located in North China (including Shandong, Hebei, Henan, Tianjin, Beijing, Liaoning and Jilin). The sites of origin of the online outlets implied this non-native species has been cultivated in these regions and has potential to escape established feral populations in these sites (Liu *et al*., 2020b).

Due to its rapid growth rate and fecundity, giant salvinia has been promoted for cultivation as a forage plant for pigs. This species has broad, thick leaves and strong root tillers, which grow in clusters after stubble leveling. Giant salvinia grows in clusters after stubble leveling with a density of 500,000-600,000 plant individuals per hectare. Freshwater weight production can reach 1000-2000 tons per hectare, over twice that of agriculturally produced alfalfa. *Salvinia molesta* is rich in nutrients, with protein comprising about 21-25%, fat approximately 4-5.5% and crude fiber around 11-15% of the total plant weight. Giant salvinia is also rich in a variety of vitamins, trace elements, and amino acids, and it has been cultivated as forage and feed for cows, sheep, pigs, rabbits, poultry and ducks. The dry production of giant salvinia can reach 30-40 tones, costing about 125-150 dollars.

Giant salvinia is highly efficient at absorbing nitrogen and phosphorus and heavy metals such as manganese, iron, zinc, and chromium (Shimada *et al*., 1988; Gupta & Devi, 1995), and it has been widely used in ecological restoration and in constructed treatment wetland projects for mines and wastewater treatment (Sukumaran, 2013; Mustafa & Hayder, 2021).

Ecological impacts: Many non-native aquatic plant species are threats to the production of Chinese grain (Wang *et al*., 2020; Xiong *et al*., 2021, 2022, 2023c, d). Giant salvinia can compete with rice (*Oryza sativa* L.) for water, nutrients and space and can affect the number of tillers in rice, which has been reported as reducing rice production by 12.5% (Azmi, 1988). Our field investigation found that giant salvinia often occurred in paddy fields and the surrounding connecting ditches of some important rice-producing area (such as Hunan, Hubei, Jiangxi, Anhui). Thus, this species is an important threat to the security of Chinese rice production. Additional giant salvinia monitoring is needed to control rice paddies in south China.

Due to its rapid growth and proliferation, giant salvinia can form thick mats over 1 meter in depth on the water surface, seriously hindering the photosynthesis of submerged plants. It inhibits the growth of native rooting-submerged plants, such as *Vallisneria natans*, *Potamogeton pectinata*, and *Potamogeton crispus* (Sculthorpe, 1967). Giant salvinia can form thick floating rafts in water (Thomas, 1981), significantly decreasing the content of CO_2 and H_2S in waterbodies (Carpenter & Lodge, 1986). This reduces the species richness and abundance of the native benthic flora and fauna, such as the submerged plants, snails, crayfish, insects and other invertebrates (McFarland *et al*., 2004).

The use of water resources and human health may be impacted by giant salvinia. Dense mats of giant salvinia provide mosquitoes and snails with a favorable oviposition habitat and refuge regions, while reducing their predation by fish, frogs, and some insects (Holm *et al*., 1977; Creagh, 1991). As a result, there is a greater chance that mosquitoes and snails will carry and spread diseases (Lounibos *et al*., 1990).

Monitoring and control: Resources such as labor, direct monetary support and equipment needed for monitoring and control of non-native species is a challenge. Ecological modeling is an effective method for predicting the distribution of non-native species (Liu *et al*., 2020a). Some research has allowed the estimation of some non-native aquatic species' distribution and dispersal trends (Zhang *et* *al*, 2014; Sui *et al*., 2016). China is the country that has the highest number of non-native aquatic species (Xiong *et al*., 2015, 2017; Wang *et al*., 2016; Yu, 2017), but efforts to study non-natives species have been restrained by a lack of knowledge of their distribution.

Unfortunately, there are few examples of successfully eradicating problematic aquatic invasive species in China, and most invasive species require ongoing treatments and effort to keep them under control (Hussner *et al*., 2017). Physical, chemical and biocontrol approaches are three of the most universally used methods for managing and curtailing non-native aquatic plants (Wang *et al*., 2016). Physical removal of giant salvinia is a continuous and ongoing method of control, but when colonization occurs, plants can reach weights of 8×10^6 kg/km^2 with rapid growth. The cost of mechanical harvesting and manual removal is much higher than that of chemical control. Use of herbicides is mentioned as an effective way to manage giant salvinia. However, it is important to use herbicides judiciously to minimize environmental impact, especially in small water bodies due to strict environmental regulations. (Wells *et al*., 1986; Nelson *et al*., 2001). The use of biological agents like the salvinia weevil (*Cyrtobagous salviniae*) is discussed by Chikwenhere & Keswani (1997). However, its effectiveness is dependent on specific environmental conditions like water temperature and nitrogen levels (Oliver, 1993). In addition, the feeding rate of the salvinia weevil is positively correlated with the nitrogen content of water bodies. When nitrogen levels in the water are low the weevil is unable to maintain a stable population, thus its density and effectiveness decline (Room, 1990). Biocontrol is not an effective management and control method to curtail the spread of giant salvinia in many regions of China. More research is needed to develop an ongoing management strategy to control and curtail further range expansion and the density of existing populations of giant salvinia in China.

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Conflict of Interest: The authors declare no competing interests.

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