

Rapid Communication**Large-flowered waterweed *Egeria densa* Planchon, 1849: a highly invasive aquatic species in China**

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OPEN ACCESS**Abstract**

Non-native aquatic plants are regarded as serious threats to aquatic biodiversity and ecosystem health. Large-flowered, or Brazilian waterweed (*Egeria densa* Planchon, 1849) is a submerged aquatic plant native to South America that has been introduced to all continents except Antarctica primarily because of its popularity in the aquarium trade. *E. densa* was brought into China after 2000, and it has become one of the most popular aquatic plants used in China's burgeoning aquarium trade. It is one of many non-native aquatic species whose plasticity and thermal tolerance have buffered them from global warming impacts. This has allowed the establishment of feral populations that have caused significant negative impacts in China. Information about introduction pathways, distribution, and the ecological impacts of non-native species, such as *E. densa* has been very limited in China. This knowledge gap has hindered their effective management. Here we provide an updated distribution of *E. densa* in China from summarized literature data and our comprehensive field study. Furthermore, an overview of ecological impacts, and control or eradication approaches that have been used to manage and curtail the spread of large-flowered waterweed is presented.

Key words: aquarium, biodiversity, biological invasions, freshwater ecosystems, ecological impacts, aquatic weed

Introduction

Biological invasion by non-native species is recognized as one of the most serious threats to global biodiversity and ecosystem function (Mack et al. 2000; Santos et al. 2011; Simberloff et al. 2013; Mayfield et al. 2021). Freshwater ecosystems are highly susceptible to invasive aquatic species

(Strayer 2010), and invasive aquatic species cause greater ecological and economic impacts on freshwater ecosystems than in their terrestrial and marine counterparts (Vilà et al. 2010). Non-native aquatic plants can alter hydrological conditions, the physical and chemical characteristics of the aquatic settings in which they occur, and the relationships of different biological groups within them, frequently displacing native species and reducing overall biodiversity (Hussner et al. 2021). Because of this ongoing problem, invasive aquatic species and their control have increasingly become a focus of research in freshwater ecosystems (Wang et al. 2016).

Concomitant with its rapid economic development, in the past fifty years China has experienced the ongoing introduction of a great number of non-native aquatic species for a diversity of purposes including the aquarium trade, aquaculture, food production, ecological restoration, and biological control (Xiong et al. 2015, 2017; Wang et al. 2016). Many wetlands in China have experienced a particularly high rate of invasion, colonization and the establishment of feral populations by non-native aquatic species (Xiong et al. 2018a, b; Wang et al. 2021). Some invasive aquatic plants such as delta arrowhead (*Sagittaria platyphylla* (Engelm.) J.G.Sm.) and parrot's feather (*Myriophyllum aquaticum* (Vell.) Verdc.) change the ecosystem structure of the sites they invade and have caused great ecological damage and economic losses (Wang et al. 2020; Xiong et al. 2021). The rapid expansion of non-native aquatic plants and the damage they incur is recognized as an issue of serious concern, and there is an increasing research focus on such species (Wang et al. 2016, 2020). Unfortunately, information about some non-native aquatic plants is very scarce and has limited their control and management.

Large-flowered waterweed (*Egeria densa* Planchon, 1849; Hydrocharitaceae), also known as Brazilian waterweed or *Egeria* waterweed, is a submerged perennial monocotyledonous dioecious plant that is native to eastern South America, specifically Brazil, Uruguay and Argentina (Gillard et al. 2017). It has become a very popular aquarium species and has established populations in the wild in many temperate regions of the World, including North America (Les and Mehrhoff 1999), South America (Yarrow et al. 2009), Oceania (Roberts et al. 1999), Africa (Coetzee et al. 2011), Europe (Hussner 2012) and Asia (Haramoto and Ikusima 1988). *Egeria densa* is recognized as a problematic invasive species by the International Union for the Conservation of Nature (Gillard et al. 2017). It has been well-studied in the United States, where it is recognized as a highly invasive species found in 37 out of 50 states, and is present in ponds, lakes and rivers in most of North America (Caudill et al. 2019). *Egeria densa* was introduced into China within the past twenty-five years as a very popular aquarium species (Wang et al. 2016), but there has been little information about its feral distribution and impacts in China's wetlands.

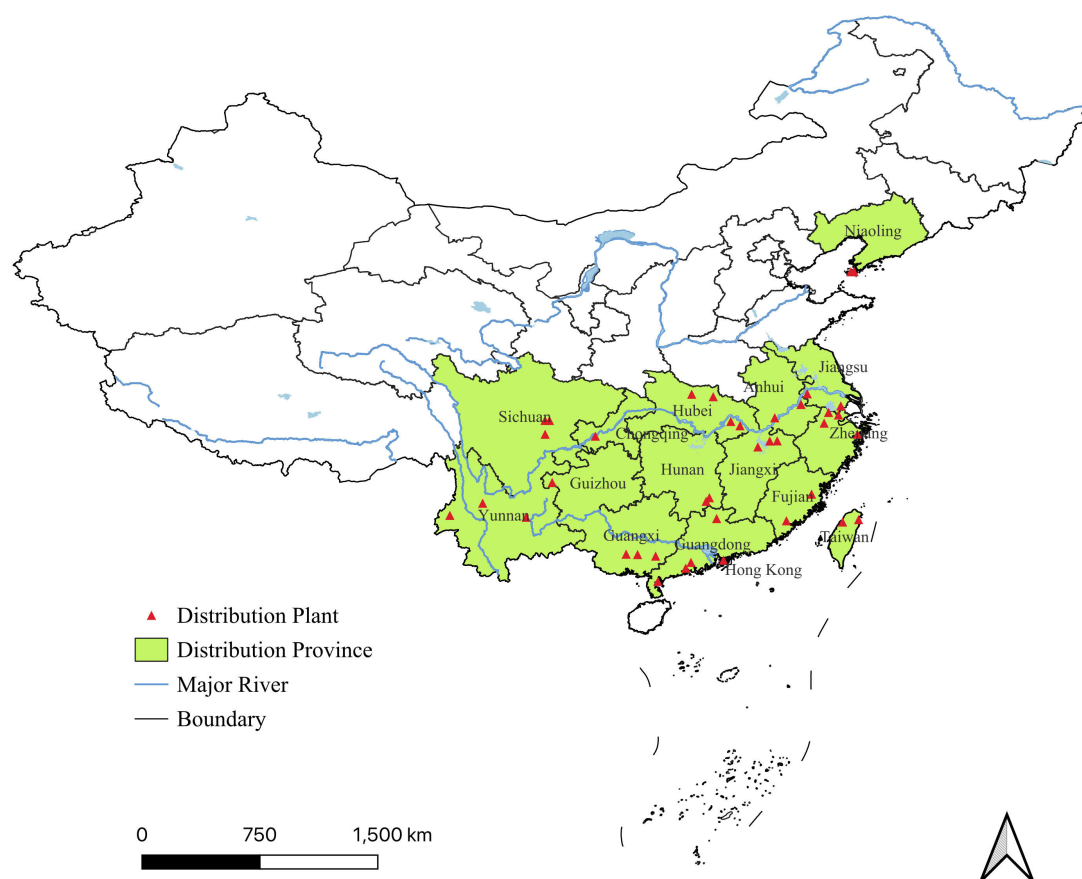


Figure 1. The distribution of large-flowered waterweed (*Egeria densa*) in China.

The purpose of this study is to provide an updated distribution of *E. densa* in China and an overview of biological traits and the ecological and economic impacts of the species in China. We hope that this study can provide basic information about this species and other invasive aquatic plants, and that it will help government and environmental protection organizations in better managing *E. densa* and other problematic aquatic non-native species.

Materials and methods

To gather distribution data for non-native aquatic species, we conducted over 50 field investigations including over 1000 sites (including rivers, lakes, marshes, reservoir, ponds, and paddy field) primarily between May and August from 2003 to 2022 (Wang et al. 2020; Xiong et al. 2021, 2022, 2023a). We recorded the coordinates of each site (WGS84 coordinate system) and habitat type at sites where *E. densa* occurred (Supplementary material Table S1). Meanwhile, we searched the literature using the terms “large-flowered waterweed” and “China” in the title, abstract, and keywords from one English database (Web of Science 2023) and two large Chinese databases (CNKI 2023; Wanfang 2023). We also collected information from Chinese books and reports, such as *Alien Aquatic Plants and Animals in China* (Li et al. 2007). We summarized a distribution map (Figure 1) of *E. densa* in China based on field investigation and a review of the literature.

Results and discussion

Morphological traits and feral population

Egeria densa is a submerged rooted perennial weedy plant that occurs in lentic and slow-moving freshwater habitats of less than two meters in depth including ditches, sloughs, canals, rivers, ponds, lakes, reservoirs and some lotic habitats, especially at sites with nutrient-enriched sediments (Yarrow et al. 2009). The genus *Egeria* is monocotyledonous, and includes three South American species. It grows quickly, and its stems are about 2–3 mm thick and can reach 40–200 cm in length, but it commonly occurs in submerged mats in which individual plants are less than 100 cm long (Figure 1). Stems of *E. densa* are cylindrical and normally have four cauline leaves organized in close whorls, making it easily distinguished from similar aquatic species (Rimac et al. 2018).

The morphology of *Egeria* species is very similar to that of the other genera in the Hydrocharitaceae. However, *Elodea* species have three leaves arranged in a whorl, *Hydrilla* species have five or six leaves (the highest number is eight) in whorls, and *Lagarosiphon* species have three or four leaves in alternate spirals or as pseudo-whorls. It has been recently reported that *E. densa* has five or six leaves per node in Australia and Ireland (Csurhes et al. 2008; Millane and Caffrey 2014). *Egeria densa* is dioecious and only males plants occur in its introduced regions (Toussaint and Bedouet 2005). In China, sexual reproduction and the production of seed have not been observed in the field during our field investigations.

Once established in the wild, *E. densa* has the propensity to rapidly build large populations and spread because of its ability to proliferate from fragments (Kuntz et al. 2014; Thiébaud et al. 2016). Research has shown that fragments survive for long periods and continuously produce new individuals (Crane et al. 2019). In some regions of China farmers cultivate this species from fragments to provide food and habitat for introduced red swamp crayfish (*Procambarus clarkii* Girard, 1852) and Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards, 1853). *Egeria densa*'s propensity to develop apical branches quickly in low light circumstances allows it to outcompete native macrophyte species and establish thick subsurface mats (Caudill et al. 2019). In our field surveys, we found that an individual can develop two or even three separate plants during one month.

Introduction pathways

Egeria densa was originally introduced in China as an aquatic aquarium plant over thirty years ago (Wang et al. 2016). This species is morphologically very similar to water thyme (*Hydrilla verticillata*) and other waterweed species (*Elodea nuttallii* and *Elodea canadensis*), but is much more resilient and easier to grow and thus is extremely popular among aquarium hobbyists. We found that it is sold in pet and aquarium stores in almost all large cities, including Wuhan, Nanjing, Shanghai, and Guangzhou (Wang et al.

2016, 2021). *Egeria densa* is sold in over 100 stores in Taobao, which is the largest online trade platform in the world (Taobao 2023).

Over the past twenty years, China has become the largest aquaculture producer in the world (FAO 2022). Many non-native species are widely promoted and farmed throughout China for a diversity of uses in most cultivated regions, including the Yangtze and Pearl River basins (Lin et al. 2015; Xiong et al. 2015). Because of its rapid proliferation and ease of maintenance, *E. densa* has been widely planted in aquaculture ponds to provide suitable habitats and forage for red swamp crayfish (Xiong et al. 2022), a highly invasive North American crustacean species, which was brought to China for aquacultural purposes and has reached very high production levels (2,633,595 tons in 2021, *unpublished data*).

In the past forty years, eutrophication has become one of the most serious environmental problems in Chinese wetlands (Qin et al. 2013; Zhang et al. 2015). A great number of artificial wetlands was constructed in China serving as waste water treatment to decrease nitrogen, phosphorus, and heavy metals (Liu et al. 2008; Zhang et al. 2012). Many non-native aquatic plants, such as parrot's feather, fanwort, and yellow bur-head were widely used in these wetlands because of their rapid growth and the fact that they are inexpensive (Xiong et al. 2021, 2022, 2023a). Inevitably, some individuals escaped because of the lack of appropriate management, and thus have unintentionally spread into the wild anthropogenically (Wang et al. 2016).

The urbanization level and population in China have increased rapidly during the past twenty years (Tan et al. 2016). Along with rapid economic growth and an improvement in the quality of life in China, there has been an influx of ornamental plants, including many novel non-native plants that have been used in created landscapes. Many non-native aquatic plant species were deliberately introduced into urban wetland parks and riverfront landscapes in large cities (Xiong et al. 2021, 2022, 2023a). *Egeria densa* was widely used because of its fast growth and the ease of maintaining it. Our field studies found that it was planted in parks, courtyard landscaping, and riverfront enhancements in Wuhan, Nanjing, Guangzhou, and other large cities (Wang et al. 2016).

Distribution and suitable habitats

According to our field investigations (39 sites), a review of the literature, iNaturalist reports (<https://www.inaturalist.org/places/china?q=Egeria%2Bdensa>), Herbarium collections, and other databases, *E. densa* has been recorded in over 16 Provinces, Autonomous Regions, Municipalities or Special Administrative Regions of China (Anhui, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Hongkong, Jiangsu, Jiangxi, Liaoning, Sichuan, Taiwan, Yunnan, Zhejiang). As previously discussed, it prefers shallow (< 2 m, mainly 0.4–1.5 m), lentic and slow-flowing rivers, lakes,



Figure 2. Monospecific stand of large-flowered waterweed (*Egeria densa*) in Hubei, China.

ponds, reservoirs, and wetlands. It is primarily distributed in South China with numerous localities in Guangdong, Guangxi, Hunan and Hubei Provinces (Xiong et al. 2019). Some researchers have reported that this species only survives in waterbodies with temperatures of 3–35 °C (Yarrow et al. 2009), which are primarily distributed in South China (such as Guangdong, Guangxi, Yunnan). However, we have confirmed that it has reached the northernmost point (pond habitat) in the Liaoning Province (38.933295°N; 121.517855°E, WGS84). It may be that the observed range extension was facilitated by global warming, as was already suggested for several other non-native species, which have extended their distributions to higher latitudes as additional suitable habitats become available (Gunderson and Stillman 2015).

In our field surveys, we verified that this species most frequently occurs in rivers, followed by ditches, ponds, lakes, and reservoirs (Table S1). We also observed that it was present and formed dense monospecific stands in some brackish water habitats, such as the estuary of the Jianjiang River in the Guangdong Provinces (Xiong et al. 2019).

Ecological impacts

Due to *E. densa*'s propensity to disperse and proliferate from stem fragments as well as its capacity for rapid growth and colonization (Thiébaud et al. 2016), dense monoclonal populations can arise very quickly, altering native biodiversity and aquatic ecosystem functions (Lacet et al. 2019). In North America, the dense underwater mats formed by *Egeria* prevent water flow, thus interfering with irrigation systems, hydroelectric facilities, boating and other water-based recreation, and urban water supplies. *Egeria densa* displaces native aquatic vegetation, changes ecological relationships, and alters the physical and chemical functioning of aquatic ecosystems (DiTomaso et al.

2013). Concern has been expressed in the United States regarding the potential invasion of shallow water restoration sites by *Egeria* such as those in the Sacramento-San Joaquin Delta (Durand et al. 2016). In the field locations we investigated, the species formed dense mats with about 200 plants per square meter in Wuhan, Suzhou, and other locations (Figure 2). The Yangtze River Basin is a major component of *E. densa*'s distribution, which poses a serious threat to this valuable ecosystem. The Yangtze River is one of the world's 200 priority ecoregions for conservation, is an important habitat for many endemic species, and sustains a high level of native aquatic biodiversity (Olson and Dinerstein 1998), as well as native species that are in danger of extinction, such as *Najas oguraensis* Miki, *Utricularia punctata* Wallich ex A. Candolle, and *Ottelia cordata* (Wall.) Dandy (Yu et al. 1998).

South China is one of the most important areas in China concerning agricultural production and aquaculture (Piao et al. 2010). We observed dense populations of *E. densa* blocking the channels in grain production areas of Jiangxi, Hunan, and Jiangsu, which could have a detrimental impact on the yield. This was already demonstrated for other non-native aquatic plants, as well as for *E. densa* (Xiong et al. 2021, 2022), whose dense monoclonal populations impact the water flow in agricultural canals and ditches and the overall production.

Underwater mats of *E. densa* reduce light penetration, can physically displace native species, and reduce dissolved oxygen from the water column at night, which has resulted in fish kills due to the nocturnal respiration of high densities of plants (CAIP 2023).

Management and control

Early detection and eradication of small populations during the invasion process is the most effective control measure because once a feral population becomes established it is very difficult to completely remove all of the plants and plant fragments (Donaldson and Cooke 2016; Wang et al. 2016). Numerous researchers have reported non-native species in different wetlands in China (e.g. Xiong et al. 2015, 2017, 2018b, 2023b; Wang et al. 2016, 2021), but there is a lack of a comprehensive monitoring network for non-native species and information about invasiveness and distribution is scarce. Thus, field research and surveys, monitoring of aquarium retail and online sales, as well as citizen reporting, must all be a part of the preliminary detection network for non-native species. Researchers, environmental protection organizations, local governments and residents can work together in this effort. There is an urgent need for regulations governing the introduction, trade, and management of non-native aquatic species that pose a direct threat to China's aquatic environments.

Citizen science efforts, including platforms such as iNaturalist to record species occurrences, are among the most effective tools for the early detection of non-native species and the identification of new feral population localities.

Education is an important predictor of the volunteers' ability to correctly identify non-native species (Delaney et al. 2007), but identifications can be enhanced when accurate and georeferenced photographs are submitted. Although more and more researchers are focusing on non-native species (Qiu and Chen 2009), only a few universities offer courses on biological invasions in China. Due to insufficient number of taxonomists and unfamiliarity of novel non-native taxa, the identification of non-native species is a serious problem (Engel et al. 2021), although iNaturalist and similar programs are helpful. As an example of the need for taxonomic expertise, researchers spent over a year seeking taxonomists to identify a new non-native aquatic plant, delta arrowhead (*Sagittaria platyphylla*) (Wang et al. 2020). At present, about 499 non-native aquatic plants have been introduced into China (Wang et al. 2016; Yu 2017). Courses in the identification of non-native aquatic plants are needed in universities, institutes and community education centres.

In the United States and elsewhere, the introduction of triploid (sterile) grass carp (*Ctenopharyngodon idella*) is an inexpensive control method that currently exists for *E. densa* eradication, as well as other problematic aquatic plants. Grass carp consumes 20 to 100 per cent of their body weight in aquatic vegetation daily and can live for twenty years (Stanley 1974). Even though introduced grass carp are sterile and cannot reproduce, problems can arise from overstocking so careful planning and research are needed before implementing this method in China. Mechanical removal is another method that has been used to control *E. densa*. This approach involves hand or machine pulling and cutting mats, and even dredging invaded sites. It is difficult to accomplish mechanical removal without leaving fragments that could re-establish the species at a removal site, and there is also a risk of producing far more plant fragments which will spread downstream. Seasonally dewatering impacted areas can also eradicate the invasive species, though it clearly has negative impacts on the broader aquatic community (Hussner et al. 2017). Chemical control has included a wide diversity of treatments that can only be utilized carefully and as directed for the specific chemical employed, as they can damage other organisms in the aquatic ecosystem. These include using branched-chain amino acid inhibitors (penoxsulam), pigment synthesis inhibitors (fluridone), contact photosynthetic inhibitors (diquat) inorganic herbicides (chelated copper), and non-herbicidal chemicals dyes or colorants (DiTomaso et al. 2013). However, prevention of the introduction and subsequent population establishment is much more efficient than eradication after the species has already established and become naturalized or invasive.

Various new technologies such as Environmental DNA, remote sensing, and machine learning of artificial intelligence have been widely used in identifying and monitoring of non-native species and areas occupied by them (Tréguier et al. 2014; Vaz et al. 2018; Novoa et al. 2020; Feng et al. 2022). There is a need for additional skilled and trained technical personnel to implement these and other management strategies, additional financial

support for management and control efforts, and cooperation among different technical teams in the practical application of these and other new techniques. This should be a cooperative and unified effort by local governments, citizens, universities, and environmental protection NGOs (non-governmental organizations).

Author's contribution

Conceptualization, WX, WT, and ZW; methodology, WX, DX, QW, YL, WT; field work, WX, DX, QW, YL, HS, QG, KX, KX, WT, HW; writing original draft preparation, WX, WT and HW; writing review and editing, WX, HW, YW, and PAB; supervision, WX, PAB.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Summary of large flowered waterweed (*Egeria densa*) in China.

This material is available as part of online article from:

http://www.reabic.net/journals/bir/2024/Supplements/BIR_2024_Xiong_et_al_SupplementaryMaterial.xlsx