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WATERCRESS (*NASTURTIUM OFFICINALE*) IN CHINA: INTRODUCTION, CURRENT DISTRIBUTION AND ECOLOGICAL IMPACTS

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Abstract

Owing to their rapid growth, ability for dispersal and establish feral populations, and because of their detrimental ecological and economic effects, non-native aquatic plants present significant challenges in the environmental management of aquatic ecosystems. The aquatic herbaceous perennial watercress (*Nasturtium officinale*; Brassicaceae) is native to Europe, Central Asia, the Arabian Peninsula, Macronesia, north and northeast tropical Africa, which has been introduced to all continents except Antarctica. In the past century, this species was deliberately imported to China, and it has been widely cultivated for its use as both an edible leafy vegetable and as a medicinal aquatic plant. Watercress escaped from contained, cultivated sites and established feral populations in a diverse natural waterbodies. However, there is limited knowledge regarding this species in China, and insufficient scientific research and monitoring have made it difficult to control this aquatic non-native species. In this study, we describe the introduction process, present the species current distribution, and evaluate the ecological impacts of watercress by doing field research and reviewing the literature. Our research provides a valuable resource for managing the use of non-native aquatic plants.

Key words: Edible; Watercress; Invasive; Ecological impacts; Distribution

Introduction

Invasive non-native species are important biological factors that have a negative impact on the environment and ecosystem health (Simberloff *et al.*, 2013). They are also one of the main threats to the world's biodiversity, ecosystem functions, economic sustainability, sustainable development, and even human health (Molnar *et al.*, 2008; Courchamp *et al.*, 2017). In particular, non-native aquatic plants are acknowledged as ecological engineering implementors that alter biodiversity and habitat through abiotic and biotic variables (Schultz & Dibble, 2012; Hussner *et al.*, 2021). In comparison to terrestrial and marine environments, freshwater ecosystems are thought to be more susceptible to invasive species (Vilà *et al.*, 2010; Dudgeon, 2019). For local governments and environmental conservation organizations, the management and control of problematic invasive plants has become a crucial concern (Hussner, 2012; Wang *et al.*, 2016).

Over the past twenty years China has introduced more non-native aquatic species than any other country or region (Xiong *et al.*, 2015; Wang *et al.*, 2016; Xiong *et al.*, 2017). Many non-native aquatic species have become important cultivated components in aquaculture, as ornamental plants, and for food (Wang *et al.*, 2016; Xiong *et al.*, 2023a). Unfortunately, many non-native aquatic species escape into natural waterbodies and their feral populations have caused significant negative impacts in aquatic habitats and ecosystems (Xiong *et al.*, 2015; Wang *et al.*, 2016; Xiong *et al.*, 2017). Some Chinese aquatic habitats have recently experienced a very high rate of invasion, specially from 2005 to 2025, reflecting a marked increase over the past twenty years (Xiong *et al.*, 2018a; Wang *et al.*, 2021; Xiong *et al.*, 2023b). Non-native aquatic plants, such as parrot's feather (*Myriophyllum aquaticum* (Vell.) Verdc.), fanwort (*Cabomba caroliniana* A.Gray), yellow bur-head (*Limnocharis flava* (L.) Buchenau), and yellow flag (*Iris pseudacorus* L.) have established widespread feral populations and have induced many negative impacts on native biodiversity, the structure and function of aquatic habitats, human health and agricultural production (Xiong *et al.*, 2021; Xiong *et al.*, 2022; Xiong *et al.*, 2023c; Xiong *et al.*, 2023d). However, the information and data (biological traits, distribution, introduction pathway, ecological and economic impacts) about some non-native aquatic plants are very scarce, which has limited local governments, residents, and non-profit environmental organizations to identify, control, and manage these non-native species (Wang *et al.*, 2016; Wang *et al.*, 2021). Among these non-native aquatic plants, watercress (*Nasturtium officinale*) represents a particularly noteworthy case due to its dual role as a widely cultivated vegetable and a potentially invasive species.

Watercress (*Nasturtium officinale* R.Br.-Brassicaceae) an herbaceous species, is native to the eastern Mediterranean region in Europe and southwestern Asia, Central Asian, Arabian Peninsula, Macronesia, north and northeast tropical Africa (Howard & Lyon, 1952; Les & Mehrhoff, 1999). It was introduced in France and England

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in the 14th century for cultivation as an edible vegetable (Ford, 2020). This species has been imported to North America, Europe, Oceania, and Asia and has become an important edible vegetable in many countries and regions (He *et al.*, 2021). In the United States of America, watercress is recognized as a noxious and invasive plant in 46 states and it is listed as such in a number of states such as Illinois, which has placed restrictions on its cultivation and growth. Control treatments include mechanical and manual removal of the plant from habitats and the application of select herbicides including glyphosate. Since than it has been planted in East and Southwest China and it is currently the most common aquatic leaf vegetable in China (He *et al*., 2021). Watercress has been introduced in nearly all of the provincial administrative areas as a highly relished aquatic vegetable.

The purpose of this study is to (1) provide information about the introduction pathway of watercress and its present distribution in China; (2) summarize its use and ecological impacts; and (3) provide recommendations for monitoring and managing watercress in a diversity of Chinese wetland habitats.

Materials and Methods

Field investigations: From 2015 to 2022, we conducted over 30 field studies gathering comprehensive information regarding non-native aquatic plant species in China using the field methods described by Wang *et al*. (Wang *et al.*, 2020) and Xiong *et al*. (Xiong *et al*., 2021; Xiong *et al*., 2022). We recorded the location's fundamental data at each sampling site, including the longitude, latitude, elevation, water depth, temperature, and height of the invading plants. Sample data and inventories of plant communities were recorded. All watercress locations mentioned in the literature were also visited and sampled again so that their current condition could be evaluated (Supplementary material Table S1). Thus, the locations of successfully established populations of watercress are shown in Fig. 1.

Literature review: We conducted a detailed literature review and search using the terms or tem combination "watercress OR *Nasturtium officinale*" and "China" in the title, abstract, and keywords from the one English database (Anon., 2024) and one Chinese database (Anon., 2024). Additionally, we gathered data (site type, longitude, latitude, etc.) from relevant Chinese books, such as Illustrations of Alien Invasive Plants in China (Yan *et al.*, 2016) and large, comprehensive databases such as the Flora of China (Anon., 2026) (http://www.efloras.org/ florataxon.aspx?flora_id=2&taxon_id=200009627) and Anon., 2026) (http://www.iplant.cn/info/ Nasturtium% 20officinale?t=z), the (Anon., 2026 (https:// www. worldfloraonline.org/taxon/wfo-0000380323) and the (Anon., 2026) (https://powo.science.kew.org/taxon/ urn: lsid:ipni.org:names:287534-1).

Results and Discussion

Distribution and preferred habitats: Watercress was first introduced from Portugal to Guangdong Province, China in the 19th century (Lin, 2007). It quickly spread to Macau, Hongkong and regions surrounding Guangdong (Lin, 2007). According to our investigations, this species has established feral populations in 24 Provincial-level administrative regions (Provinces, Autonomous Regions, Municipalities, and special administrative zones), including Anhui, Beijing, Chongqing, Guangdong, Guangxi, Guizhou, Hebei, Henan, Heilongjiang, Hong Kong, Hubei, Jiangsu, Jiangxi, Jilin, Macau, Shanghai, Shaanxi, Shandong, Shanxi, Sichuan, Tibet, Taiwan, Xinjiang, and Yunnan (Fig. 1).

Watercress grows well in cool and humid environments, but it does not survive well and generally is not found in xeric, hot habitats. The best temperature range for it to flourish is 15-25℃, and when the temperature reaches as low as 10℃, growth stops and the leaves turn purple-red. When the air temperature is about 0℃, most individuals will not be frostbitten, but when the air temperature is higher than 30℃, the growth of watercress is weakened and the leaves become scorched and yellow (Li *et al.*, 2008). Watercress is a wetland plant most suited to growing in water, and its preferred water depth is 5-7 cm during the peak growth period. If the water is too deep the plants produce dense mats of adventitious roots, and if the water layer is too shallow, the fresh stems and leaves show aging and become spindly, affecting their yield and quality (Li *et al*., 2008). In our field investigations, ponds are the habitats most frequently inhabited by watercress, followed by wetlands, rivers, lakes, and paddy fields.

Introduction pathway and uses: Watercress is a perennial aquatic vegetable belonging to the Brassicaceae, the mustard family. It was first cultivated in Britain and France as early as the 14th century. Over time, it spread through deliberate introduction as a medicinal and food resource to America, Australia, New Zealand, Japan, and various tropical regions. In China, Guangdong Province has one of the longest cultivation histories, with the Foshan region being the first to introduce it. In the 10th year of the Qianlong reign of the Qing Dynasty (1805), Wen Ruchan documented in the "Longshan Township History" (now Shunde) that "Watercress features delicate leaves and tender roots". It grows near the coast. After winter, the stems are pruned and propagated in lotus pots. The plant is exceptionally sweet and flavorful, making it ideal for soups prepared with fatty meat." This historical record dates back nearly 200 years (Liu, 1993).

Due to its edible and medicinal values, this species was widely distributed throughout most of China in the 19th century (Lin, 2007). Watercress is a highly relished and important aquatic vegetable in China, and it has been deliberately planted in almost all Provincial-level administrative regions (Li *et al*., 2008). In our field investigations, we observed that watercress can be cultivated in a diversity of aquatic agricultural systems, including intensive farming in paddy fields and ponds, and in intensive polycultures in freshwater ponds and wetlands (aquatic vegetable-fish culture and aquatic vegetable-shrimp culture). Among the cultivated aquatic leafy vegetables in China, watercress, lotus root, water chestnut (*Trapa bispinosa*), and water morning glory (*Ipomoea aquatica* Forssk.) currently have the greatest production (Feng *et al.*, 2022). However, lotus root, water chestnut and water morning glory are mainly cultivated in south China, whereas watercress is grown in both south and north China (Wu *et al.*, 2019).

Table S1. Summary of Watercress *(Nasturtium officinale)* in China.

No.	Sampling site	Provinces, Autonomous Regions, Municipalities	Latitude, N	Longitude, E	Habitats	Major accompanying species	Year of investigation	References
1.	Suihua city	Heilongjiang	46.781669	127.010885	wetland	*Sparganium stoloniferum*	2018	Field investigation
2.	Siping city	Jilin	43.261524	124.59796	wetland	*Typha orientalis*	2018	Field investigation
3.	Zhangjiangkou city	Hebei	40.869479	114.905379	pond	*Alternanthera philoxeroides*	2019	Field investigation
4.	Baoding city	Hebei	38.78771	115.571634	pond	*Oenanthe javanica*	2019	Field investigation
5.	Tongzhou district	Beijing	39.88556	116.749672	pond	*Salvinia natans*	2010	Field investigation
6.	Taiyuan city	Shanxi	37.771305	112.518383	pond	*Stuckenia pectinata*	2015	Field investigation
7.	Weifang city	Shandong	36.617906	119.10016	pond	*Salvinia natans*	2018	Field investigation
8.	Xuchang city	Henan	34.022275	113.91629	pond	*Alternanthera philoxeroides*	2018	Field investigation
9.	Nanyang city	Henan	33.003568	112.425103	pond	*Alternanthera philoxeroides*	2019	Field investigation
10.	Ezhou city	Hubei	30.243745	114.651607	lake	*Elodea nuttallii*	2017	Field investigation
11.	Huangshi city	Hubei	30.239299	115.066894	lake	*Elodea nuttallii*	2014	Field investigation
12.	Wuhan city	Hubei	30.668593	114.219226	lake	*Lemna minor*	2008	Field investigation
13.	Kaizhou district	Chongqing	31.178229	108.494361	lake	*Alternanthera philoxeroides*	2005	Field investigation
14.	Chengdu city	Sichuan	30.401926	104.103444	pond	*Stuckenia pectinata, Potamogeton crispus*	2014	Field investigation
15.	Ankang city	Shaanxi	32.747527	108.974775	river	*Potamogeton crispus*	2011	Field investigation
16.	Qingpu district	Shanghai	31.143388	121.110738	wetland	*Salvinia natans*	2022	Field investigation
17.	Suzhou city	Jiangsu	31.242856	120.698883	lake	*Alternanthera philoxeroides*	2022	Field investigation
18.	Huzhou city	Jiangsu	30.874143	119.889833	river	*Elodea nuttallii*	2014	Field investigation
19.	Poyang county	Jiangxi	29.023437	116.602682	paddy field	*Oryza sativa*	2018	Field investigation
20.	Chaohu city	Anhui	31.639161	118.016507	paddy field	*Oryza sativa*	2007	Field investigation
21.	Bohu county	Xinjiang	41.795896	86.618035	river	*Typha orientalis*	2019	Field investigation
22.	Cuona county	Tibet	27.860986	92.019653	wetland	*Ceratophyllum demersum*	2019	Field investigation
23.	Yadong county	Tibet	27.497297	88.912051	wetland	*Hydrilla verticillata*	2005	Field investigation
24.	Kunming city	Yunnan	24.900205	102.77648	lake	*Hydrilla verticillata, Stuckenia pectinata*	2005	Field investigation
25.	Jianshui county	Yunnan	24.900205	102.77648	wetland	*Ottelia acuminata*	2005	Field investigation
26.	Pingbian county	Yunnan	23.663814	103.852578	wetland	*Ottelia acuminata*	2005	Field investigation
27.	Wanfenghu town	Guizhou	24.95378	105.046822	lake		2005	Field investigation
28.	Rongjiang county	Guizhou	25.939866	108.536271	river	*Ceratophyllum demersum, Stuckenia pectinata*	2019	Field investigation
29.	Congzuo city	Guangxi	22.34761	107.272751	wetland	*Alternanthera philoxeroides*	2019	Field investigation
30.	Qinzhou city	Guangxi	21.980494	108.595955	pond	*Alternanthera philoxeroides*	2019	Field investigation
31.	Beihai city	Guangxi	21.467111	109.191459	river	*Alternanthera philoxeroides*	2016	Field investigation
32.	Zhanjiang city	Guangdong	21.309419	110.336188	river	*Potamogeton crispus*	2016	Field investigation
33.	Yangjiang city	Guangdong	21.935677	111.890975	river	*Potamogeton crispus*	2018	Field investigation
34.	Dongguan city	Guangdong	23.075611	114.005586	pond			Field investigation
35.		Macau	22.135335	113.576304	pond			Ma and Li 2022
36.		Hongkong	22.409311	114.087404	pond			Ma and Li 2022
37.	Miaoli county	Taiwan	24.584427	120.855842	pond			Ma and Li 2022

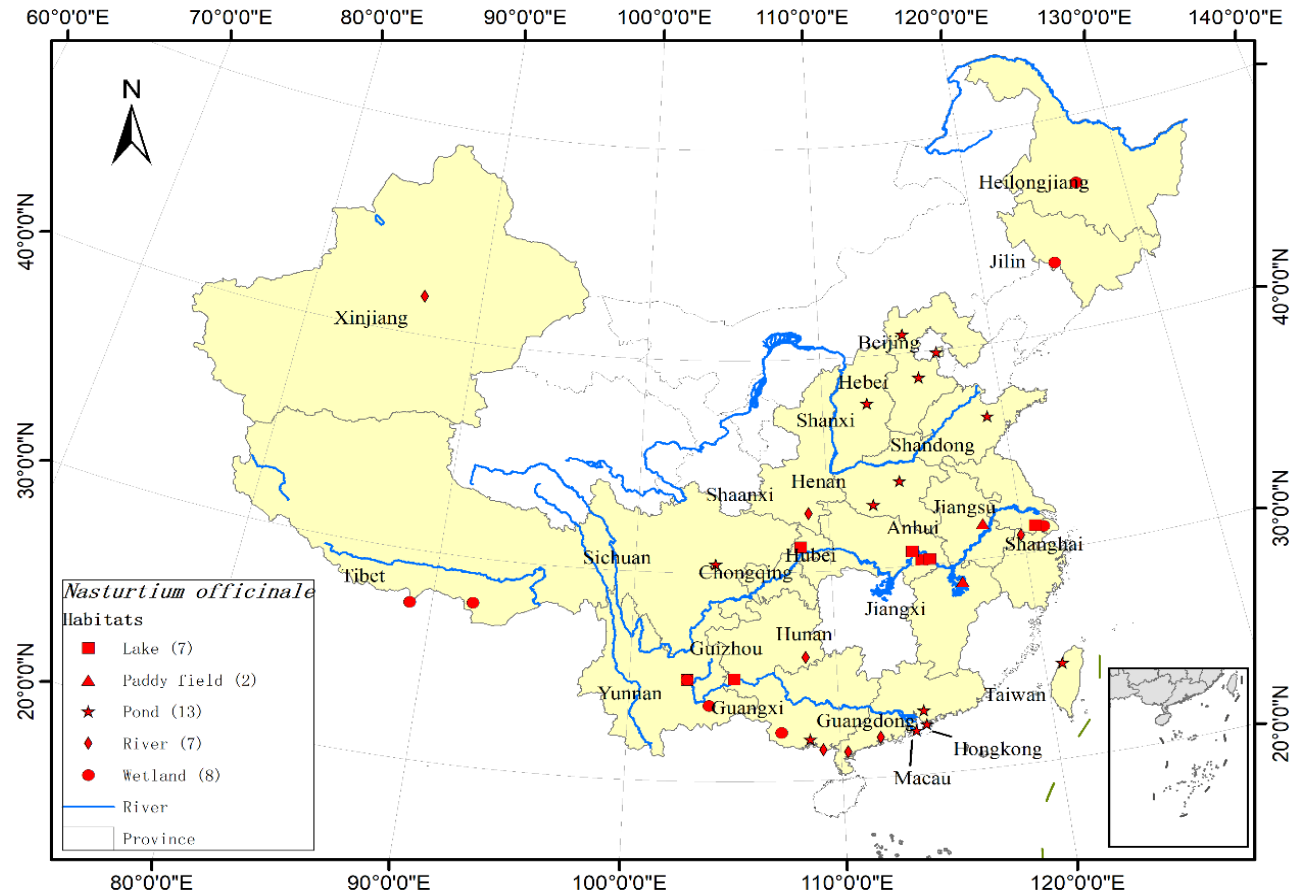

Fig. 1. The distribution of watercress (*Nasturtium officinale*) in China.

Fig. 2. Photo of watercress (*Nasturtium officinale*) in a Chinese aquatic habitat. Photo by Liang Chen.

In traditional Chinese medicine, watercress is regarded as an important medicinal plant. Recent research has shown that watercress is an effective medicine for cardiovascular diseases (Bahramikia & Yazdanparast, 2008), liver diseases (Natanzi *et al.*, 2010), cancer (Chai *et al.*, 2015), and respiratory infections (Quezada-Lázaro *et al.*, 2016). It is used as a broadly applied treatment for a wide spectrum of diseases in China.

As an effective natural approach to reducing eutrophication and pollution, many non-native aquatic plant species are widely used in wetlands to absorb and remove nutrients and inhibit the growth of algae (Xiong *et al*., 2021; Xiong *et al*., 2022; Xiong *et al*., 2023c; Xiong *et al*., 2023d). Due to its effective allelochemical inhibitory effects on *Microcystis aeruginosa* (Dai L *et al.*, 2015), watercress is widely planted in constructed and natural wetlands. Watercress polycultures with fish can decrease the nutrient content in wastewater from aquaculture production areas (Liao, 2016). Watercress has been recognized and planted as a nutrient remediation approach in many constructed treatment wetlands and other aquatic settings.

Ecological impacts: Watercress can quickly establish dense monoclonal populations which cause the decline of native biodiversity and the functioning of aquatic habitats (Fernandez-Going *et al.*, 2013). Its success as a colonizer is due to its ability to disperse and reproduce vegetatively through stem fragments, as well as its capacity for fast growth (Rejmánková, 1992). In field-based investigations, we observed that watercress has formed dense monoclonal populations, with a dry weight biomass exceeding 350 g/m^2 in Wuhan and Kunming (Fig. 2). The variety of natural aquatic plants is decreased by the thick clusters of watercress (Bergey, 2024). Unfortunately, watercress is an ecological generalist and flourishes in some biodiversity hotspots, including the Yangtze River, the Yunnan-Guizhou Plateau, and Guangdong and Guangxi areas, which support a very high biodiversity with a large number of endemic species (Xiong *et al.*, 2018b; Xiong *et al.*, 2019). We observed that watercress has replaced certain native aquatic species that are at risk of local extinction, including *Ottelia cordata* and *Najas ovolata* (both are in the Hydrocharitaceae).

Management and control: Watercress has been promulgated by the Agricultural Industry Standard of the People's Republic of China as a green food/hydroponic vegetable (NY/T 1405-2015) and as a pollution-free food. Strong environmental regulations for the cultivation of aquatic vegetables (NY 5331-2006) have been recommended by the Ministry of Agriculture and Rural Affairs of the People's Republic of China. However, the management level of farmers often falls below the recommended standards, and the means of evaluating farmers' technical performance for aquatic vegetables through quantitative indicators are often not implemented or are not in place. This results in poorly measured habitat and water quality conditions and a food product whose quality is inconsistent with the required standards.

Watercress has established widespread feral populations and has caused the decline of the native aquatic flora and fauna in a wide diversity of wetland settings throughout its worldwide introduced distribution. However, accurate information about its fine-scale distribution is scarce and incomplete. Most of the studies in China have focused on planted watercress and its commercial cultivation. A few studies conducted on a small Chinese island have reported that watercress is a low-risk invasive species at that site (Luo *et al.*, 2022). The lack of research throughout its range in China has limited ecological understanding of its impacts and also the effective management and control of this non-native and highly invasive aquatic species (Xiong *et al*., 2015; Wang *et al*., 2016). In the future, more monitoring and field-based investigations should be conducted throughout China

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