Carolina Fanwort (*Cabomba caroliniana*)

Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, March 2015
Revised, January 2018
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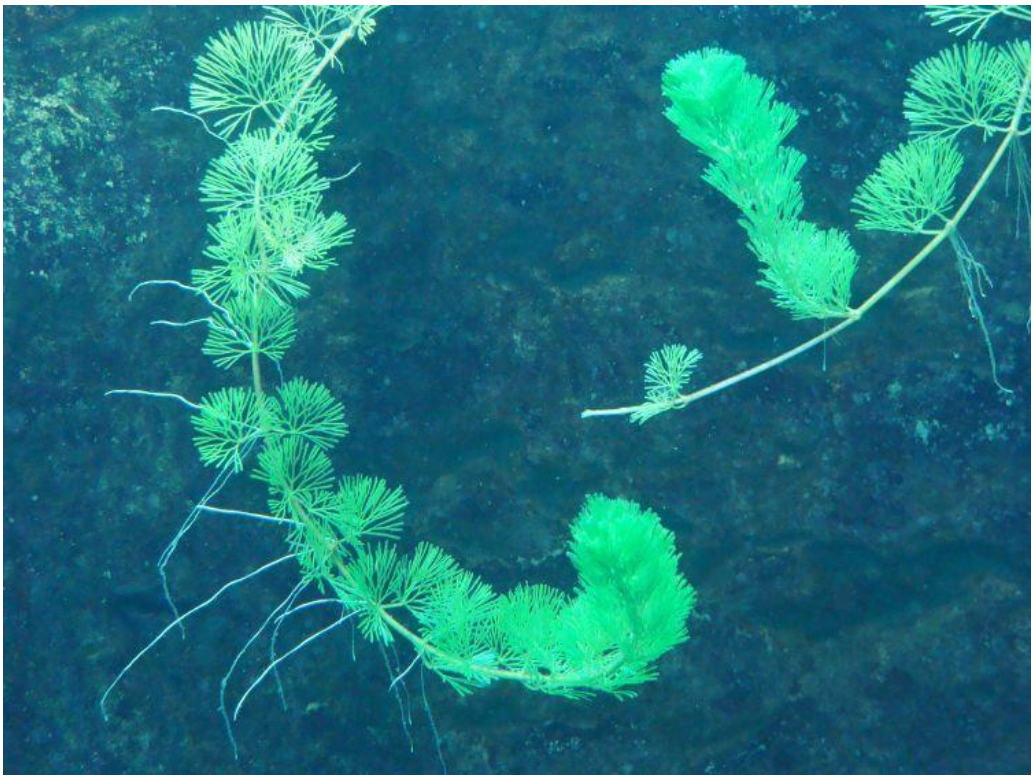

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1 Native Range and Status in the United States

Native Range

From CABI (2018):

"*C. caroliniana* is native to subtropical temperate areas of northeastern and southeastern America (Zhang et al., 2003). It is fairly common from Texas to Florida, Massachusetts to Kansas in the USA, and occurs in southern Brazil, Paraguay, Uruguay, and northeastern Argentina in South America (Washington State Department of Ecology, 2008). The species has

two varieties with different distributions. The purple-flowered variety *C. caroliniana* var. *caroliniana* occurs in the southeastern USA, while yellow-flowered *C. caroliniana* var. *flavida* occurs in South America."

From Larson et al. (2018):

"*Cabomba caroliniana* A. Gray is native to southern Brazil, Paraguay, Uruguay, northeast Argentina, southern and eastern USA."

From Wilson et al. (2007):

"In the United States fanwort has been marketed for use in both aquaria and garden ponds since at least the late 1800s, resulting in its repeated introduction and subsequent naturalization outside its original range (Les and Mehrhoff 1999)."

Status in the United States

Sources differ on the native or invasive status of *Cabomba caroliniana* in individual states (CABI 2018; Larson et al. 2018), and one source reports that it may not be native to the United States, but instead introduced a few centuries before European colonization (Wilson et al. 2007).

CABI (2018) lists *Cabomba caroliniana* as introduced in California, Connecticut, Delaware, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Oregon, Rhode Island, and Washington; native in Arkansas, Florida, Georgia, North Carolina, and South Carolina; and present but with no indication of introduced or native status in Alabama, District of Columbia, Hawaii, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maine, Maryland, Mississippi, Missouri, Oklahoma, Pennsylvania, Tennessee, Texas, Vermont, and Virginia.

From CABI (2018):

"People in the water garden industry grow plants in Florida, Australia and Asia for distribution and sale to Europe and other parts of the USA (ISSG, 2008)."

USDA, NRCS (2018) list *Cabomba caroliniana* as extirpated in Indiana, Threatened in Kentucky, a Q list weed in California, invasive and banned in Connecticut, an invasive aquatic plant in Maine, prohibited in Massachusetts, a Class A noxious weed in Vermont, and a Class B noxious weed and wetland and aquatic weed quarantine species in Washington.

From Larson et al. (2018):

"Native range in USA: Connecticut, Massachusetts, New Hampshire, Rhode Island, Alabama, Arkansas, District of Columbia, Florida, Illinois, Indiana, Kentucky, Louisiana, Maryland, Michigan, Mississippi, Missouri, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Virgina [sic]"

"Great Lakes region: The first sighting in the Great Lakes drainage was in the Lake Michigan drainage in 1935. Reported from IL, IN, MI, NY, OH, PA and Ontario.

Other US Reports: Ala., Ark., Conn., D.C., Fla., Ga., Ky., La., Md., Mass., Miss., Mo., N.H., N.J., N.C., Okla., Oreg., R.I., S.C., Tenn., Tex., Va"

From Wilson et al. (2007):

"In the United States fanwort has been marketed for use in both aquaria and garden ponds since at least the late 1800s, resulting in its repeated introduction and subsequent naturalization outside its original range (Les and Mehrhoff 1999)."

"It is also generally considered native to the south-eastern United States, although Mackey and Swarbrick (1997) concluded that the disjunct nature of this range suggests that the plant originated in South America and was introduced and naturalized in the United States some time ago."

"In the United States, fanwort is generally considered native in the southeast, although it has been suggested that it may have been a very early introduction from South America (Mackey and Swarbrick 1997) (see Section 4 [in source material]). Believed to have been present in the United States since before European settlement (1400s) (Les and Mehrhoff 1999), it was known from the turn of the (20th) century as occurring from Texas to southern Florida, north to Missouri and east to North Carolina (Chapman 1897; Small 1903). In the 1950s, Fassett (1953) described a northward expansion of this range, including southern Illinois, northern Kentucky, Virginia to New York, southern Connecticut and Massachusetts, and an isolated occurrence in southern Michigan, where it was discovered in 1935 (Hanes 1938; Voss 1985; Mills et al. 1993). A review of herbaria in the 1970s added new specimen locations from Oklahoma and Kansas (Sanders 1979)."

Means of Introductions in the United States

From Swearingen and Bargeron (2016):

"It is believed the introduction of *Cabomba caroliniana* outside of its native range is a result of improper disposal of aquarium contents."

From Larson et al. (2018):

"Means of Introduction: 1935, release from aquarium in Lake Michigan drainage (U.S. EPA 2008). Fanwort stems become brittle in late summer, which causes the plant to break apart, facilitating its distribution and invasion of new waterbodies. It produces seed but vegetative reproduction seems to be its main vehicle for spreading to new waters. Large numbers of plants are sent from Florida to the rest of the U.S. for commercial use. Fanwort is also grown commercially in Asia for export to Europe and other parts of the world. Small-scale, local cultivation occurs in some area and aquarists (aquarium release or escape) are probably responsible for some introductions."

Remarks

From CABI (2018):

"With regards to the species *C. caroliniana*, there are two varieties. In parts of the southeastern United States, the existence of a purple-tinted flower leads botanists to treat this population as variety *C. caroliniana* var. *caroliniana* whereas South American plants having yellow flowers are treated as variety *C. caroliniana* var. *flavida* Ørgaard (Flora of North America, 1993+). However, many synonyms exist for *C. caroliniana* var. *caroliniana*, including *C. caroliniana* var. *pulcherrima*, *C. australis*, and *C. pulcherrima* (USDA-ARS, 2008)."

From Wilson et al. (2007):

"No hybrids involving fanwort are reported in the literature. Within the genus *Cabomba*, it is possible that *C. haynesii* is of hybrid origin, as its distribution and several of its characteristics seem to be intermediate between *C. palaeformis* and *C. furcata*, and its fruit and seed set are comparatively low (Ørgaard 1991). However, this remains uncertain, and no other reports of hybridization were found (Ørgaard 1991; Mackey and Swarbrick 1997)."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From ITIS (2018):

"Kingdom Plantae
Subkingdom Viridiplantae
Infrakingdom Streptophyta
Superdivision Embryophyta
Division Tracheophyta
Subdivision Spermatophytina
Class Magnoliopsida
Superorder Nymphaeanae
Order Nymphaeales
Family Cabombaceae
Genus *Cabomba*
Species *Cabomba caroliniana* A. Gray"

"Taxonomic Status:
Current Standing: accepted"

Size, Weight, and Age Range

From Swearingen and Bargeron (2016):

"[…] with stems up to 6.5 ft. (2 m) long."

From Larson et al. (2018):

"Mature plant size is approximately 12-31 inches or more (30-80 cm or more) and may grow up to 10m long (Wilson et al. 2007)."

Environment

From GISD (2018):

"It grows well in high nutrient environments with low pH, but in more alkaline waters it tends to lose its leaves (Australian Department of Environment and Heritage, 2003). High calcium levels inhibit growth and unlike other aquatic weeds, cabomba can grow well in turbid water (Australian Department of Environment and Heritage, 2003). It prefers […] with a [water] temperature range of 13-27ºC but can survive when the surface of the water body is frozen (Australian Department of Environment and Heritage 2003)."

From CABI (2018):

"It can grow in water with pH from 5.7-9.2, is highly tolerant of anaerobic conditions and can survive in high alkalinity water (USDA-NRCS, 2008) and/or water with high turbidity. Growth is highest at medium turbidities, but the plant still thrives in high-turbidity water, and moderate-to-high turbidity water facilitates the production of adventitious roots (Mackey, 1996)."

"In China, Yu et al. (2004) report finding *C. caroliniana* typically in waters with pH 6.19-7.51, total nitrogen 0.14-3.27 mg/L, total phosphorus 0.044-0.838 mg/L and dissolved oxygen from 1.23-7.32 mg/L."

From Wilson et al. (2007):

"It is estimated that water temperatures at the bottom of the lake would remain at about 4°C during the winter, with reduced light penetration depending on the thickness of surface ice and snow. The physiological mechanisms by which this tropical plant has been able to adapt to the conditions in Canadian waters are unknown"

Climate/Range

From CABI (2018):

"*C. caroliniana* is native to subtropical temperate areas […]"

From Wilson et al. (2007):

"Warm, humid climates with rain throughout the year and a mean annual [air] temperature of 15–18°C are most suitable for fanwort (Ørgaard 1991; Mackey and Swarbrick 1997). Its optimal [air] temperature range is reported as 13–27°C, although it can withstand [air] temperatures of less than 0°C."

"Populations in Kasshabog Lake survive a mean annual temperature of 6°C (Ontario Ministry of the Environment 1979), on the southern edge of the Canadian shield where average daily minimum air temperatures in the winter months fall between –10°C and –15°C (Department of Energy, Mines and Resources 1974)."

Distribution Outside the United States

Native

Part of the native range of *Cabomba caroliniana* occurs within the United States. See Section 1 for a description of the complete native range.

From CABI (2018):

"*C. caroliniana* […] occurs in southern Brazil, Paraguay, Uruguay, and northeastern Argentina in South America (Washington State Department of Ecology, 2008). The species has two varieties with different distributions. The purple-flowered variety *C. caroliniana* var. *caroliniana* occurs in the southeastern USA, while yellow-flowered *C. caroliniana* var. *flavida* occurs in South America."

From Larson et al. (2018):

"*Cabomba caroliniana* A. Gray is native to southern Brazil, Paraguay, Uruguay, northeast Argentina, […]."

Introduced

GISD (2018) lists *Cabomba caroliniana* as introduced to Australia, Canada, China, India, Japan, Malaysia, New Guinea, and Peru.

CABI (2018) lists *Cabomba caroliniana* as introduced and invasive in China (Jiangsu, Shanghai, and Zhejiang), and Japan (Honshu province); as introduced in India, Malaysia, Canada (Ontario), UK (England and Wales), Australia (Northern Territory, New South Wales, Queensland, and Victoria), and Papua New Guinea.

CABI (2018) lists *Cabomba caroliniana* as present but with no indication of introduced or native status in Mexico, Bolivia, Belgium, France, Hungary, Netherlands, New Caledonia, and New Zealand.

DAISIE (2018) lists *Cabomba caroliniana* as alien and established in Belgium, Great Britain, and Sweden, and as alien and status unknown in England, Scotland, and Sweden.

NOBANIS (2018) lists *Cabomba caroliniana* as established in Austria and Sweden but its invasiveness status is not known in either country. It is established and invasive in Denmark and Netherlands.

Hussner (2012) lists *Cabomba caroliniana* as introduced in Belgium, England, Germany, Hungary, the Netherlands, Scotland, and Sweden.

From GISD (2018):

"This lake [Lake Macdonald, Australia] has been infested with cabomba for about ten years and 75% of its surface area (about 180 hectares) is covered by the weed [Australian Department of Environment and Heritage 2003]."

From Biosecurity Queensland (2018):

"This species is not yet widely naturalised, and is currently found mainly in the coastal districts of eastern Australia. It is most common in water bodies in south-eastern Queensland and northern Queensland, but is also becoming common in eastern New South Wales. Also recorded in Victoria (e.g. near Dollar in South Gippsland, near Lake Benalla and in Lake Nagambie) and the Northern Territory (i.e. at Marlow Lagoon in Palmerston and along the Darwin River, approximately 40 km south of Darwin)."

From Anđelković et al. (2016):

"*Cabomba caroliniana* is an alien species which was registered in Serbia for the first time in 2008 (Vukov et al. 2013) in a Vrbas-Bezdan canal of the main irrigation canal network of Serbia. It was subsequently recorded in several new localities, all of them along the different sections of the canal network of the Hydrosystem Danube-Tisa-Danube, in Vojvodina Province […]."

Means of Introduction Outside the United States

From GISD (2018):

"The infestation at Marlow Lagoon near Darwin is thought to have started by someone emptying an aquarium (complete with coloured rocks) into the lagoon [Australian Department of Environment and Heritage 2003]."

From CABI (2018):

"*C. caroliniana* spreads largely through activities related to the aquarium trade. The species is widely available from aquarium plant distributors and has long been recommended for use in aquarium gardening."

"Because of its value to the aquarium industry, the plant is often intentionally cultivated both in its native and adventive range, where it is harvested for sale and distribution worldwide. It is suspected that at least some of the invasive populations in Queensland, Australia were intentional introductions related to the aquarium trade (Mackey, 1996). Additionally, the same qualities that make this plant attractive as an aquarium plant may also lead people to plant it in outdoor water gardens, posing a risk for release and population expansion."

Short Description

From GISD (2006):

"*C. caroliniana* is fully submerged except for occasional floating leaves and emergent flowers (Australian Department of the Environment and Heritage 2003). The roots grow on the bottom of water bodies and the stems can reach the surface. Parts of the plant can survive free-floating for six to eight weeks. It is a perennial, growing from short rhizomes with fibrous roots. The branched stems can grow up to 10m long and are scattered with white or reddish-brown hairs. The underwater leaves are divided into fine branches, resulting in a feathery fan-like appearance. These leaves are about 5cm across and secrete a gelatinous mucous which covers the submerged parts of the plant. The floating leaves, however, are small, diamond-shaped, entire, and borne on the flowering branches. The solitary flowers are less than 2cm across and range in colour from white to pale yellow and may also include a pink or purplish tinge. The flowers emerge on stalks from the tips of the stems (Australian Department of Environment and Heritage, 2003)."

From Biosecurity Queensland (2018):

"The branching stems are slender (i.e. 1-2 mm thick), rounded, covered in small whitish or reddish-brown hairs, and grow up to 10 m long. The stems and underwater (i.e. submerged) leaves are covered with a thin jelly-like (i.e. gelatinous) coating.

Two totally different types of leaves (i.e. dimorphic leaves) may be found on this species. The underwater (i.e. submerged) leaves (3-7 cm long) are oppositely arranged, or sometimes arranged in whorls, and are divided several times (i.e. deeply dissected). These fine divisions give the leaves a feathery, fan-shaped, appearance. A few floating leaves are sometimes present (i.e. on or just above the water surface). These are smaller (up to 20 mm long), narrowly oval or elongated (i.e. elliptic or lanceolate) in shape, with entire margins. The underwater (i.e. submerged) leaves usually have stalks (i.e. petioles) up to 30 mm long, however the uppermost submerged leaves may be stalkless (i.e. sessile). The floating leaves have stalks (i.e. petioles) 20-50 mm long that are attached to the undersides of the leaf blades (i.e. the leaves are peltate)."

"The small flowers (6-20 mm across) are borne just above the water surface. They are white or cream in colour, sometimes with a pinkish tinge at the tips, and have a yellow centre. Each flower has six 'petals' (i.e. tepals or perianth segments), which are actually three petals and three sepals (4-12 mm long) that closely resemble each other, and six yellow stamens (about 4 mm long). These flowers are borne singly (i.e. they are solitary) on short stalks (i.e. pedicels) 10-40 mm long that are produced in the upper leaf forks (i.e. axils). Most flowering occurs during summer and autumn.

The fruit consists of two to four, bottle-shaped, leathery segments (4-7 mm long), each containing 1-3 seeds. Seeds are oval (i.e. ellipsoid) in shape (1.5-3 mm long and 1-1.5 mm wide), turn brown as they mature, and are covered in a jelly-like (i.e. gelatinous) slime. However, seeds are rarely, if ever, produced by plants growing in Australia."

Biology

From GISD (2018):

"Cabomba is sensitive to drying out and requires permanent shallow water, usually less than 3 metres (but up to 10 metres) deep (Australian Department of the Environment and Heritage 2003). It grows rooted in the mud of stagnant to slow flowing water including streams, and smaller rivers (The Washington State Department of Ecology, 2003). It also grows in ponds, lakes, reservoirs, sloughs, ditches, and canals (The Washington State Department of Ecology, 2003)."

"It can respond to wide fluctuations in water depths and is a water column feeder that grows well in silty substrate and exhibits reduced vigour in hard substrates (Australian Department of Environment and Heritage, 2003). It may be found in streams, small rivers, ponds, lakes, reservoirs, sloughs, ditches and canals. Growth of 50mm a day has been reported in Lake Macdonald in Queensland, Australia."

From CABI (2018):

"*C. caroliniana* is a perennial species that produces solitary hypogenous flowers […]. The flowers are usually pollinated by small, nectar-seeking flies (Schneider et al., 2003). Flowers are bisexual and often self-pollinated (ISSG, 2008). However, vegetative reproduction is probably the most important means of spread. The plant produces rhizomes which can easily break into fragments. Fragments can be transported both actively and passively to new areas. A fragment can regenerate into a full plant as long as it bears at least one pair of leaves (Peconic Estuary Program, 2006)."

"The plant flowers during the summer months of May to September in the southeastern United States although the plant generally self-pollinates and field germination rates are low (ISSG, 2008). In fact, the plant doesn't produce seed in the northern parts of its range, but multiplies clonally and spreads quickly by stem fragmentation. At the end of the growing season, the stems become defoliated, brittle and hard (Mackey, 1996). These turion-like stems produced at the end of the growing season can break free and remain green at the sediment surface and help the plant to over-winter under adverse conditions (Wilson et al., 2007). Defoliated stem fragments can remain buried in mud under ice, and will regrow starting in April (Mackey, 1996). North of Queensland in Australia, *C. caroliniana* flowers throughout the year, while in southern Queensland, the plant may overwinter and sexual reproduction has not been documented (Mackey, 1996). In the summer in southeastern Queensland, buoyant stems up to 6 m long can grow at 5 cm per day. In the same region in July and August, the stems lose buoyancy and fragment on the soil surface. After the winter months, these fragments will re-root and grow into new plants. In mild winters, dieback may not be observed (Mackey, 1996)."

Human Uses

From Biosecurity Queensland (2018):

"Cabomba (*Cabomba caroliniana*) was deliberately cultivated as an aquarium and pond plant in the past. However, it is now illegal to grow or sell this species in Australia and it should no longer be present in cultivation."

From CABI (2018):

"It is very commonly used as an aquarium plant due to its attractive flowers and finely dissected leaves, probably contributing to its introduction and spread. People in the water garden industry grow plants in Florida, Australia and Asia for distribution and sale to Europe and other parts of the USA (ISSG, 2008)."

"It is one of the most popular aquarium plants available from distributors."

"In Australia, trade of *C. caroliniana* is a $300,000 per year business. *C. caroliniana* is also used in reclamation activities, primarily to remove lead from contaminated water supplies. Lead removal by *C. caroliniana* was 80-90% efficient at lead concentrations of one and 10 mg/L after 12-15 days of exposure (Yaowakhan et al., 2005)."

From NIES (2018):

"Release of this species is prohibited in Aichi Prefecture, Japan]."

Diseases

From Wilson et al. (2007):

"Several phytoparasitic nematodes have been reported from fanwort samples collected in Florida (*Aphelenchoides fragariae* Ritzema-Bos, *Criconemoides* sp., *Dolichodorus* sp., *Hemicriconemoides* sp., *Hirschmanniella caudacrena* Sher and *Tylenchus* sp.), as well as the free-living nematodes *Actinolaimus* sp., *Mesodorylaimus* sp. and *Michonchus* sp. (Esser 1985). The free-living nematodes *Dorylaimus* spp., *Rhabditis* spp., and *Mononchus* spp. have also been reported from aquarium samples of fanwort from Malaysia (Revilla et al. 1991), though Mackey and Swarbrick (1997) point out that these genera are commonly found on many aquatic plants. The polyphagous snail *Marisa cornuarietis* L. was observed feeding on unidentified *Cabomba* species in laboratory tests in Puerto Rico (Ferguson and Butler 1966)."

Threat to Humans

From CABI (2018):

"This species can also reduce swimming access and potentially cause human health safety issues (Mackey, 1996)."

3 Impacts of Introductions

From Hogsden et al. (2007):

"Our findings show that the structure and composition of biological communities in dense beds of *Cabomba caroliniana* differ from those found in native macrophyte beds in Kasshabog Lake. We have documented significant differences between *C. caroliniana* and native beds for underwater light conditions, macrophyte equitability, epiphytic algae biomass, and macroinvertebrate biomass and abundance."

"Macroinvertebrate biomass was significantly higher in natives beds ($p = 0.008$; […]), while species diversity ($p = 0.55$; […]) and equitability ($p = 0.23$; […]) did not differ between macrophyte beds. Community composition was similar between *C. caroliniana* and native beds. Of the eleven families identified, all were found in both macrophyte bed types, except *Gammarus*, which was only found on native plants. Total abundance was substantially higher in *C. caroliniana* beds, owing to high densities of coenagrionids and chironomids ($p = 0.023$; […]). In fact, mean overall abundance and the abundance of chironomids, coenagrionids, and hepatgeniid mayflies were all significantly higher in *C. caroliniana* beds ($p < 0.05$). The increased abundance of some predators (e.g., odonates, chironomids) in *C. caroliniana* beds contributed to significantly more invertebrates being found, despite greater biomass being recorded in native beds. This could suggest that *C. caroliniana* beds are providing new habitats for some predacious macroinvertebrates. Finely dissected leaves and complex architectures are known to provide superior habitats for invertebrates (Dvorak and Best 1982)"

From GISD (2018):

"At Marlow Lagoon more than $400,000 was spent initially trying to control the weed without eradicating it [Australian Department of Environment and Heritage 2003]."

"*C. caroliniana* is an extremely persistent and competitive plant. Under suitable environmental conditions it forms dense stands and crowds out previously well-established plants. Once established, this plant can clog drainage canals and freshwater streams interfering with recreational, agricultural, and aesthetic uses (The Washington State Department of Ecology 2003)."

"In Austrailia Cabomba is regarded as a \"Weed of National Significance\". It is one of the worst weeds in Australia because of its invasiveness, potential for spread, and economic and environmental impacts. It is choking waterways along Australia's east coast (Australian Department of the Environment and Heritage 2003). It is extremely persistent and can take over a water body, excluding native plant species. It can also have an impact on native animals - in northern Queensland platypus and water rat numbers are lower in infested creeks (Australian Department of the Environment and Heritage 2003)."

"Cabomba's dense mass of underwater stems and leaves provide a hazard for recreational water users (Australian Department of the Environment and Heritage 2003). When this vegetation dies off, decomposition causes dramatic oxygen reductions and foul smelling water."

From CABI (2018):

"Zhang et al. (2003) report *C. caroliniana* presents a significant threat to *Ottelia alismoides*, a once common species that is seldom seen after the introduction of *C. caroliniana*."

"*C. caroliniana* is an economic asset given its heavy trade in the aquarium industry. In Australia, even despite its declared status, the plant is still traded by northern growers, although its economic value is less than AUS $10,000 annually (Mackey, 1996). The economic costs of this species can be quite substantial. Infestations increase the colour of potable water, thus increasing the cost of treatment up to AUS $50 per mega litre. Dense populations can interfere with recreational activities and matted vegetation can decrease aesthetic value, resulting in a decrease in tourist dollars. For example, commercial fishing camps in the USA have been forced to close or have had incomes severely impacted and private camp owners have closed due to heavy infestations (Mackey, 1996). Economic losses are probably less severe in Australia, where natural lakes are fewer, although decreased amenity values, health risks and safety issues still threaten significant economic impacts (Mackey, 1996)."

"This plant is extremely productive, and can be a nuisance even in its native range (Hanlon et al., 2000). In Queensland, *C. caroliniana* have been shown to negatively impact water quality. The winter dieback that occurs in harsher areas of its range can cause substantial nutrient release, especially manganese pulses. This sudden manganese release can impact the manganese cycle and impact water quality. Additionally dense stands can cause water loss through seepage and overflow, thus impacting hydrological regimes (Mackey, 1996). Compared with native macrophyte beds, light is significantly attenuated under *C. caroliniana* beds (Hogsden et al., 2007)."

"The impacts of *C. caroliniana* on biodiversity have been widely reported in the literature. It has a different ecological niche than most other aquatic plants, thus impacting native species (Zhang et al., 2003). *C. caroliniana* populations are often associated with areas with decreased species diversity (Cao et al., 2006). Hogsden et al. (2007) showed that while native macrophytes could be found in *C. caroliniana* beds, their abundance was both low and uneven. They also found that epiphytic algae is more commonly present on *C. caroliniana* plants, and although the community composition of macroinvertebrates was not different from native plants, *C. caroliniana* plants supported higher abundances of macroinvertebrates. An additional study found that species composition and species number were greater in sites without *C. caroliniana* (Ding et al., 2007)."

"While *C. caroliniana* has high social value as an aquarium plant, in natural systems the plant can cause substantial nuisance to recreational users by impeding navigation, tangling fishing line and wrapping motor propellers. Thick vegetation can also decrease aesthetic value. This species can also reduce swimming access and potentially cause human health safety issues (Mackey, 1996)."

From Zhang et al. (2003):

"Second, invasive fanwort has become a problem for human activities in some areas. For example, it is now found in the parks of famous scenic spots such as Donghu Lake, Shaoxing, Zhejiang, and restricts human recreational activities."

From Wilson et al. (2007):

"Fanwort populations in Canada have been shown to grow as virtual monocultures in several bays of Kasshabog Lake near Peterborough, Ontario, where they reach densities of more than 200 plants m^{-2} (500 shoots m^{-2}) (Noël 2004) […]. These dense stands reduce the light available through the water column and reduce the diversity of native plant species (Noël 2004). This corresponds with reports from the United States, where fanwort populations in New Hampshire form dense, uniform beds in the littoral zones of lakes and displace native plant species (Sheldon 1994). In Australia, extensive fanwort infestations in Queensland have been shown to displace almost all other submerged vegetation, including established native species (Mackey and Swarbrick 1997). Likewise, in China, fanwort is reported to have become the dominant aquatic species where it occurs in Jiangsu and Zhejiang provinces, within 10 yr [years] of its first introduction (Zhung et al. 2003)."

"In the United States, Sanders (1979) reported that a fanwort infestation in one lake in Louisiana caused several commercial fishing camps to close, while others faced a reduced income."

4 Global Distribution

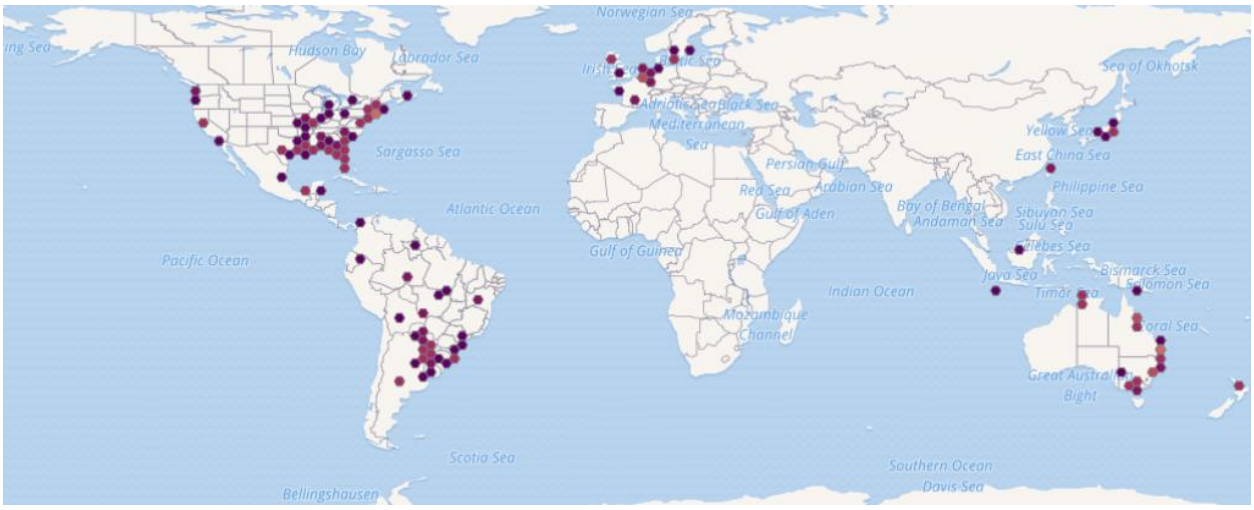

Figure 1. Known global distribution of *Cabomba caroliniana*. Map from GBIF Secretariat (2018).

Figure 2. Known global distribution of *Cabomba caroliniana* in India. Map from India Biodiversity Portal (2018).

Additional locations in Serbia are given by Anđelković et al. (2016); additional locations in China are given by Zhang et al. (2003).

5 Distribution Within the United States

Figure 3. Known distribution of *Cabomba caroliniana* in the United States. The light orange shading indicates the assumed native range of *C. carolinana* within the contiguous United States. Map from Larson et al. (2018).

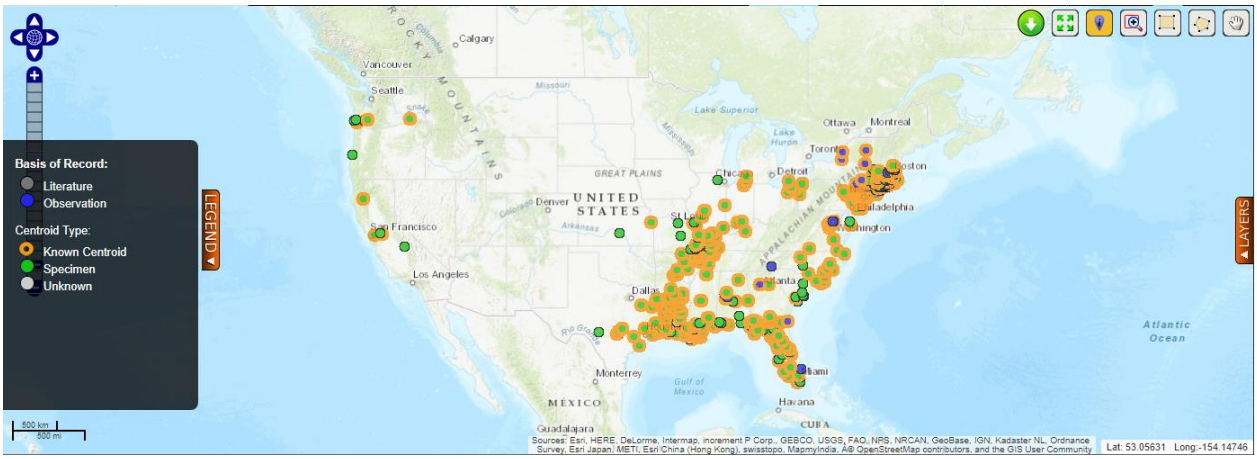

Figure 4. Known distribution of *Cabomba caroliniana* in the United States. Map from BISON (2018).

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Cabomba caroliniana* was high for the eastern half of the contiguous United States and along the west coast. The match was medium in the upper Midwest, Great Plains south through the non-coastal areas of the southwest. There were very small pockets of low match in the Great Plains, southwest, and areas of Oregon and Washington. The Climate 6 score (Sanders et al. 2014; 16 climate variables; Euclidean distance) for the contiguous United States was 0.768, high. All states had individually high climate scores except for North Dakota and Wyoming, which had medium scores.

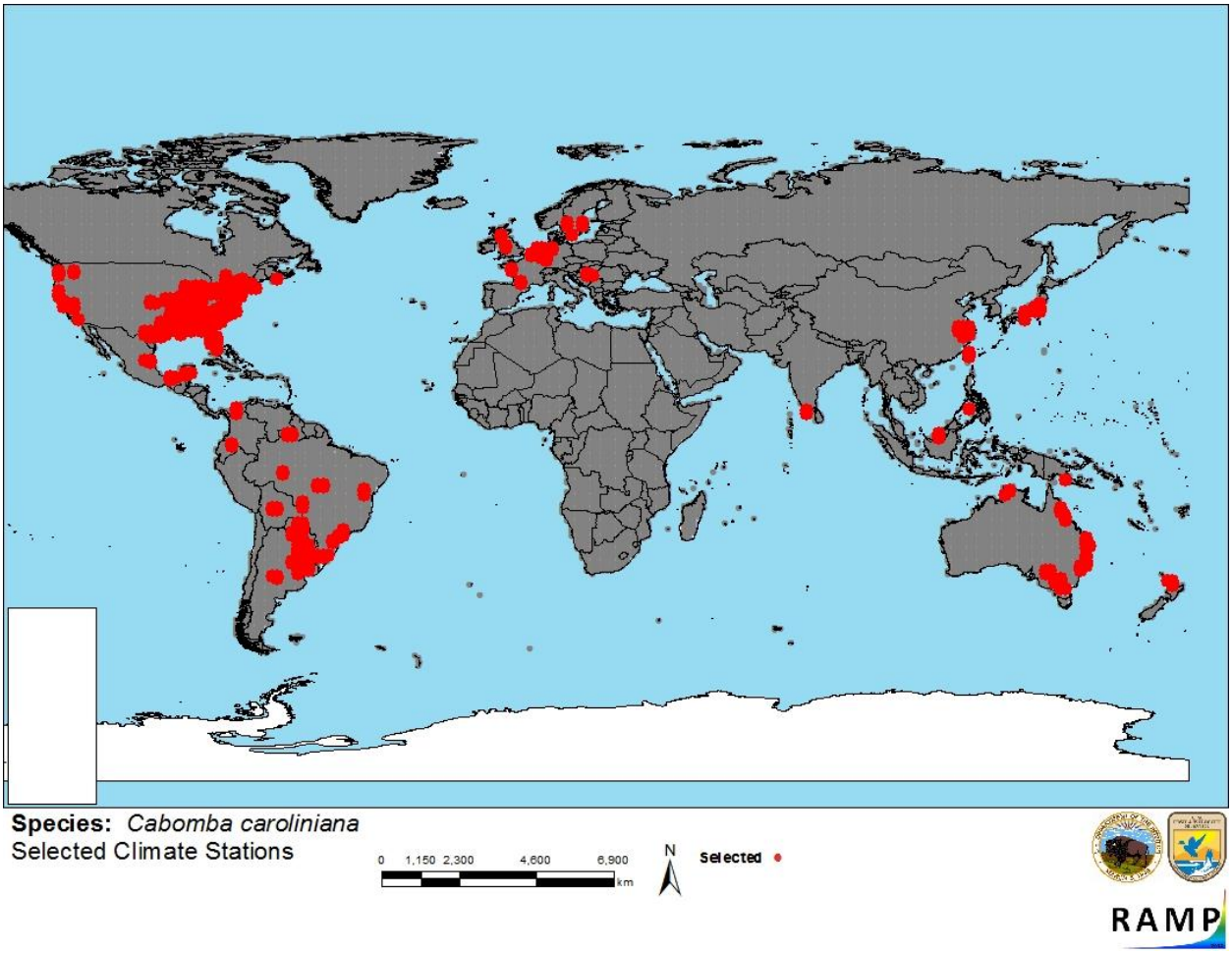

Figure 5. RAMP (Sanders et al. 2014) source map showing weather stations selected as source locations (red) and non-source locations (gray) for *Cabomba caroliniana* climate matching. Source locations from Zhang et al. (2003), Anđelković et al. (2016), BISON (2018), GBIF Secretariat (2018), India Biodiversity Portal (2018), and Larson et al. (2018).

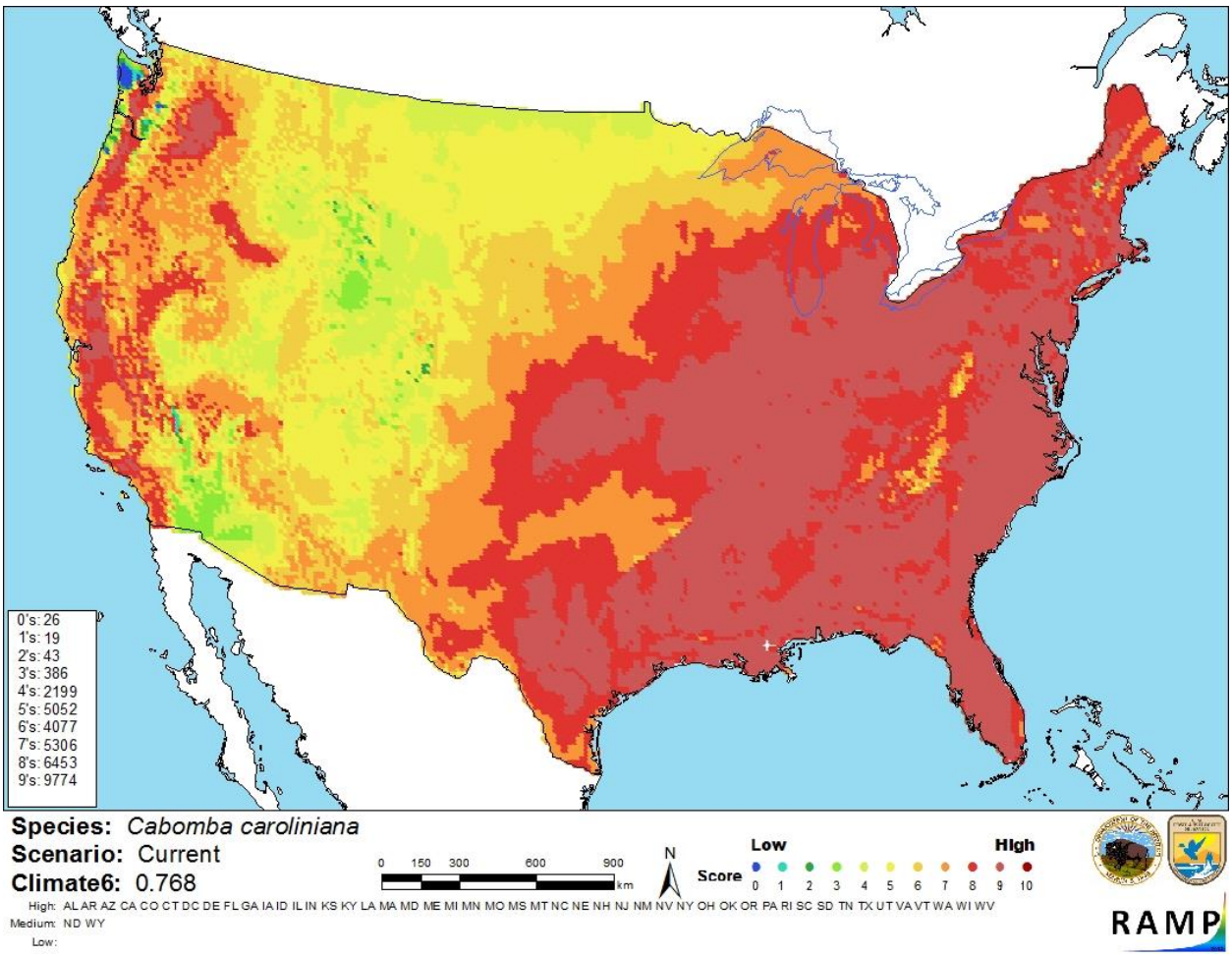

Figure 6. Map of RAMP (Sanders et al. 2014) climate matches for *Cabomba caroliniana* in the contiguous United States based on source locations reported by Zhang et al. (2003), Anđelković et al. (2016), BISON (2018), GBIF Secretariat (2018), India Biodiversity Portal (2018), and Larson et al. (2018). 0 = Lowest match, 10 = Highest match.

The High, Medium, and Low Climate match Categories are based on the following table:

Climate 6: Proportion of (Sum of Climate Scores 6-10) / (Sum of total Climate Scores)	Climate Match Category
0.000≤X≤0.005	Low
0.005<X<0.103	Medium
≥0.103	High

7 Certainty of Assessment

The certainty of assessment for *Cabomba caroliniana* is high. Information on the biology, invasion history and impacts of this species is readily available. Most information, including that for impacts of introductions is sourced from peer-reviewed literature.

8 Risk Assessment

Summary of Risk to the Contiguous United States

Cabomba caroliniana may be native to southern portions of the contiguous United States, and populations of this species are established in many other parts of the country. The species has spread worldwide for use as an aquarium plant and subsequently has been introduced in areas of North America, Europe, Asia, and Oceania. The history of invasiveness for *C. caroliniana* is high. There are demonstrated adverse ecological and economic impacts of those introductions. Climate matching indicated the contiguous United States has a high climate match. The certainty of assessment is high. The overall risk assessment category is high.

Assessment Elements

- **History of Invasiveness (Sec. 3): High**
- **Climate Match (Sec. 6): High**
- **Certainty of Assessment (Sec. 7): High**
- **Remarks/Important additional information:** *C. caroliniana* may be native to southern portions of the contiguous United States and populations of this species are established in much of the country.
- **Overall Risk Assessment Category: High**

9 References

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 10.

Anđelković, A. A., M. M. Živković, D. Lj. Cvijanović, M. Z. Novković, D. P. Marisavljević, D. M. Pavlović, and S. B.Radulović. 2016. The contemporary records of aquatic plants invasion through the Danubian floodplain corridor in Serbia. Aquatic Invasions 11(4):381–395.

Biosecurity Queensland. 2018. Weeds of Australia: *Cabomba caroliniana.* Available: http://keyserver.lucidcentral.org/weeds/data/media/Html/cabomba_caroliniana.htm. (January 2018).

BISON. 2018. Biodiversity Information Serving Our Nation (BISON). U.S. Geological Survey. Available: https://bison.usgs.gov. (January 2018).

CABI. 2018. *Cabomba caroliniana* (Carolina fanwort) [original text by A. Mikulyuk and M. Nault]. *In* Invasive Species Compendium. CAB International, Wallingford, U.K. Available: https://www.cabi.org/isc/datasheet/107743. (January 2018).

DAISIE European Invasive Alien Species Gateway. 2018. *Cabomba caroliniana*. Available: http://www.europe-aliens.org/speciesFactsheet.do?speciesId=535#. (January 2018).

GBIF Secretariat. 2018. GBIF backbone taxonomy: *Cabomba caroliniana* A. Gray. Global Biodiversity Information Facility, Copenhagen. Available: https://www.gbif.org/species/2882443. (January 2018).

GISD (Global Invasive Species Database). 2017. Species profile: *Cabomba caroliniana.* Invasive Species Specialist Group, Gland, Switzerland. Available: http://www.iucngisd.org/gisd/speciesname/Cabomba+caroliniana. (January 2018).

Hogsden, K. L., E. P. S. Sager, and T. C. Hutchinson. 2007. The impacts of the non-native macrophyte *Cabomba caroliniana* on littoral biota of Kasshabog Lake, Ontario. Journal of Great Lakes Research 33(2):497–504.

Hussner, A. 2012. Alien aquatic plant species in European countries. Weed Research 52:297–306.

India Biodiversity Portal. No date. *Cabomba caroliniana* A. Gray. India Biodiversity Portal, species page. Available: http://indiabiodiversity.org/species/show/264155. (January 2018).

ITIS (Integrated Taxonomic Information System). 2018. *Cambomba caroliniana* A. Gray. Integrated Taxonomic Information System, Reston, Virginia. Available: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=18408. (January 2018).

Larson, J., L. Cao, L. Berent, and S. Iott. 2018. *Cabomba caroliniana* A. Gray. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=231. (January 2018).

NIES (National Institute for Environmental Studies). 2018. *Cabomba caroliniana*. *In* Invasive species of Japan. National Research and Development Agency, National Institute for Environmental Studies, Tsukuba, Japan. Available: http://www.nies.go.jp/biodiversity/invasive/DB/detail/80070e.html. (January 2018).

NOBANIS. 2018. *Cabomba caroliniana*. Available: https://www.nobanis.org/species-info/?taxaId=9773. (January 2018).

Sanders, S., C. Castiglione, and M. Hoff. 2014. Risk assessment mapping program: RAMP. U.S. Fish and Wildlife Service.

Swearingen, J., and C. Bargeron. 2016. Invasive Plant Atlas of the United States. University of Georgia Center for Invasive Species and Ecosystem Health. Available: http://www.invasiveplantatlas.org/. (January 2018).

USDA, NRCS. 2018. *Cabomba caroliniana*. The PLANTS database. National Plant Data Team, Greensboro, North Carolina. Available: https://plants.usda.gov/core/profile?symbol=CACA. (January 2018).

Wilson, C. E., S. J. Darbyshire, and R. Jones. 2007. The biology of invasive alien plants in Canada. 7. *Cabomba caroliniana* A. Gray. Canadian Journal of Plant Science 87(3):615–638.

Zhang, X., Y. Zhong, and J. Chen. 2003. Fanwort in eastern China: an invasive aquatic plant and potential ecological consequences. AMBIO: A Journal of the Human Environment 32(2):158–159.

10 References Quoted But Not Accessed

Note: The following references are cited within quoted text within this ERSS, but were not accessed for its preparation. They are included here to provide the reader with more information.

Australian Department of the Environment and Heritage. 2003. *Cabomba* (*Cabomba caroliniana*). Weeds of national significance: weed management guide. Department of the Environment and Heritage and the CRC for Australian Weed Management.

Cao, P., M. Yu, X. Jin, and B. Ding. 2006. Studies on niche characteristics and interspecific association of main populations in submerged communities invaded by *Cabomba caroliniana*. Journal of Zheijiang University Agriculture and Life Sciences 32(3):334–340.

Chapman, A. W. 1897. Flora of the southern United States: containing an abridged description of the flowering plants and ferns of Tennessee, North and South Carolina, Georgia, Alabama, Mississippi, and Florida, 3rd edition. American Book Company, New York.

Department of Energy, Mines and Resources. 1974. National atlas of Canada, 4th edition. The MacMillan Company of Canada, Toronto.

Ding, B., X. Jin, M. Yu, J. Yu, H. Shen, and Y. Wang. 2007. Impact to native species by invading subaqueous plant *Cabomba caroliniana*. Oceanologia et Limnologia Sinica 38(4):336–342.

Dvorak, J., and E. P. H. Best. 1982. Macro-invertebrate communities associated with the macrophytes of Lake Vechten: structural and functional relationships. Hydrobiologia 95:115–126.

Esser, R. D. 1985. A survey of the phytoparasitic nematodes associated with aquatic macrophytes in Florida. Proceedings – Soil and Crop Science Society of Florida 44:150–155.

Fassett, N. C. 1953. A monograph of *Cabomba*. Castanea 18:116–128.

Ferguson, F. F., and J. M. Butler. 1966. Ecology of *Marisa* and its potential as an agent for the elimination of aquatic weeds in Puerto Rico. Proceedings of the 19th Southern Weeds Conference 1966:454–455.

Flora of North America. 1997. Flora of North America North of Mexico, volume 3. New York and London.

Hanes, C. R. 1938. Additions to the flora of Michigan. Papers of the Michigan Academy of Science 23:135–139.

Hanlon, S. G., M. V. Hoyer, C. E. Cichra, and D. E. Canfield. 2000. Evaluation of macrophyte control in 30 Florida lakes using triploid grass carp. Journal of Aquatic Plant Management 38:48–54.

ISSG. 2008. [Source material did not give full citation for this reference.]

Les, D. H., and L. J. Mehrhoff. 1999. Introduction of nonindigenous aquatic vascular plants in Southern New England: a historical perspective. Biological Invasions 1(2/3):281–300.

Mackey, A. P. 1996. Cabomba (*Cabomba* spp.). Pest status review series - Land Protection Branch. Queensland Government Department of Natural Resources and Mines, Australia.

Mackey, A. P., and J. T. Swarbrick. 1997. The biology of Australian weeds 32. *Cabomba caroliniana* Gray. Plant Protection Quarterly 12:154–165.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. Journal of Great Lakes Research 19:1–54.

Noël, J. 2004. Growth, reproduction and control of an invasive plant, *Cabomba caroliniana* in Kasshabog Lake, Ontario and its potential dispersal. Master's thesis. Trent University, Peterborough, Canada.

Ontario Ministry of the Environment. 1979. Water quality survey of lakes in the Seven Links Planning Area, Peterborough County, field survey 1978. Parts 1 & 2. Ontario Ministry of the Environment, Technical Support Section, Central Region, Canada.

Ørgaard, M. 1991. The genus *Cabomba* (Cabombaceae) – a taxonomic study. Nordic Journal of Botany 11:179–203.

Peconic Estuary Program. 2006. Fanwort *Cabomba caroliniana*. Invasive Species in the Peconics. Peconic Estuary Program, Yaphank, New York.

Revilla, E. P., S. S. Sastroutomo, and M. A. A. Rahim. 1991. Survey on aquarium plants of quarantine importance and their associated nematodes. Biotrop (Bogor, Indonesia), Special Publication 40:205–215.

Sanders, D. R. 1979. The ecology of *Cabomba caroliniana*. Pages 133–146 *in* E. O. Gangstad, editor. Weed control for public health applications. CRC Press, Boca Raton, Florida.

Schneider, E. L., S. C. Tucker, and P. S. Williamson. 2003. Floral development in the Nymphaeales. International Journal of Plant Science 164(5 Supplement):5279–5292.

Sheldon, S. P. 1994. Invasions and declines of submersed macrophytes in New England, with particular reference to Vermont Lakes and herbivorous invertebrates in New England. Lake Reservoir Management 10:13–17.

Small, J. K. 1903. Flora of the southeastern United States. J. K. Small, New York.

U.S. EPA (U. S. Environmental Protection Agency). 2008. Predicting future introductions of nonindigenous species to the Great Lakes. U.S. Environmental Agency, Washington D.C.

USDA-ARS. 2008. Germplasm Resources Information Network (GRIN). National Germplasm Resources Laboratory, Beltsville, Maryland.

USDA-NRCS, 2008. The PLANTS Database. National Plant Data Center, Baton Rouge, Louisiana.

Voss, E. G. 1985. Michigan flora. A guide to the identification and occurrence of the native and naturalized seed-plants of the state. Part II. Dicots (Saururaceae–Cornaceae). Cranbrook Inst. Sci. Bull. 59.

Vukov, D., T. Jurca, M. Rućando, R. Igić, and B. Miljanović. 2013. *Cabomba caroliniana* A. Gray 1837: a new, alien and potentially invasive species in Serbia. Archives of Biological Sciences 65:1515–1520.

Washington State Department of Ecology. 2003. Technical information about *Cabomba caroliniana* (Fanwort). Water Quality Program: Non-Native Freshwater Plants.

Washington State Department of Ecology. 2008. Technical information about *Cabomba caroliniana* (Fanwort). Non-Native Freshwater Plants. Available: http://www.ecy.wa.gov/programs/wq/plants/weeds/.

Yaowakhan, P., M. Kruatrachue, P. Pokethitiyook, and V. Soonthornsarathool. 2005. Removal of lead using some aquatic macrophytes. Bulletin of Environmental Contamination and Toxicology 75(4):723–730.

Yu, M., B. Ding, J. Yu, X. Jin, H. Zhou, and W. Ye. 2004. Basic characteristics of submerged plant communities invaded by *Cabomba caroliniana* and its habitat in China. Acta Phytoecologica Sinica 28(2):231–239.

Zhung, X., Y. Zhong, and J. Chen. 2003. Fanwort in eastern China: an invasive aquatic plant and potential ecological consequences. Ambio 32:158–159.