Water Chestnut (*Trapa natans*)

Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, October 2014
Revised, April 2018, May 2018
Web Version, 1/31/2019

Photo: U.S. Fish and Wildlife Service. Public domain – Government work.

1 Native Range and Status in the United States

Native Range

CABI (2018) lists *Trapa natans* as native in Albania, Algeria, Angola, Austria, Bangladesh, Belarus, Bosnia-Hercegovina, Botswana, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Guinea-Bissau, Hungary, India, Indonesia, Japan, Latvia, Malawi, Mozambique, Namibia, Pakistan, Philippines, Romania, Russian Federation, South Africa, Switzerland, Tanzania, Tunisia, Turkey, Uganda, Ukraine, Vietnam, Zambia, and Zimbabwe.

In addition to the countries listed above, GISD (2017) lists *T. natans* as native in Italy, Poland, Spain, and Sudan.

GISD (2017) lists *T. natans* as cryptogenic, established, and not invasive in Belgium, Germany, Netherlands, and Sweden.

Status in the United States

CABI (2018) lists *Trapa natans* as introduced and invasive in Connecticut, Delaware, Maryland, New Jersey, Pennsylvania, Vermont, and Virginia; and present in Massachusetts.

According to Pfingsten et al. (2018), *T. natans* has been present in Connecticut since 1998, Delaware since 1874, District of Columbia since 1895, Maryland since 1874, Massachusetts since 1874, New Hampshire since 1998, New Jersey since 2002, New York since 1884, Pennsylvania since 1977, Rhode Island since 2007, Vermont since 1942, and Virginia since 1936.

From Pfingsten et al. (2018):

"Established in Connecticut, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia."

"Extirpated from Delaware and eradicated from the District of Columbia (Carter and Rybicki 1994)."

"Reports from Kentucky and West Virginia USACE reservoirs were likely mistaken identities (L. Dodd, USACE-ERDC, pers. comm. 2017)."

From Hummel and Kiviat (2004):

"On 1 July, 1949 New York State enacted a law prohibiting transport of water chestnut. Chapter 40, §1, paragraph 170 of the Laws of New York states "No person shall plant, transport, transplant or traffic in plants of the water chestnut or in the seeds or nuts thereof nor in any manner cause the spread or growth of such plants. Any person aiding in any manner in such prohibited acts shall be deemed to have violated this section." In some cases more than 50 years passed before other states such as Maine, Minnesota, North Carolina, New Hampshire, South Carolina, Florida, and Vermont followed suit with similar noxious weed laws that specifically list *Trapa natans* as posing an ecological or economic threat. In those states it is a misdemeanor offense to possess, import, transport, sell, distribute, or cultivate the plant or plant parts except for permitted scientific or educational purposes. Persons found in violation of these restrictions are subject to fines of up to hundreds of dollars. Minnesota regulations are a preventive control measure as the plant has not yet [as of 2004] been found in that state. The National Invasive Species Act of 1996 specifically mentions *Trapa natans* as a species of concern, but imposes no restrictions or penalties on actions involving the plant, making its efficacy questionable (USDA 2003)."

"Existing laws and classifications, however, do not stop dealers of exotic plants from advertising both *T. natans* var. *natans* and *T. natans* var. *bispinosa* seeds in nationally distributed mail-order catalogs and on websites for use in garden ponds and household aquaria (Oregon Exotics 2003)."

According to USDA, NRCS (2018), *T. natans* is listed as a Class C noxious weed in Alabama; a prohibited noxious weed in Arizona; an invasive, banned species in Connecticut; a prohibited aquatic plant, Class 1 in Florida; an invasive aquatic plant in Maine and South Carolina; a prohibited species in Massachusetts; a Class A noxious weed in North Carolina; an "A" designated weed in Oregon; a quarantine species in Oregon and Washington; a plant pest in South Carolina; and a Class B noxious weed in Vermont.

Means of Introductions in the United States

From Pfingsten et al. (2018):

"Typically introduced by aquarium release, escape from ornamental ponds, hitchhiking on waterfowl, or intentional plantings. Spreads either by the rosettes detaching from their stems and floating to another area, or more often by the nuts being swept by currents or waves to other parts of the lake or river (Bickley and Cory 1955; Mirick 1996; Hummel and Kiviat 2004)."

Remarks

From Pfingsten et al. (2018):

"Unfortunately, an unrelated edible aquatic plant, *Eleocharis dulcis* (Burm.f.) Trin. ex Henschel, a sedge in the Cyperaceae, is also called water chestnut. The corm of *E. dulcis* is the familiar water chestnut, or Chinese water chestnut, sold in cans and commonly served in Chinese restaurants."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From ITIS (2018):

"Taxonomic Status:
Current Standing: accepted"

"Kingdom Plantae
Subkingdom Viridiplantae
Infrakingdom Streptophyta
Superdivision Embryophyta
Division Tracheophyta
Subdivision Spermatophytina
Class Magnoliopsida
Superorder Rosanae
Order Myrtales

Family Lythraceae
Genus *Trapa*
Species *Trapa natans* L."

Size, Weight, and Age Range

From Pfingsten et al. (2018):

"Size: up to 16 feet in stem length (Muenscher 1944)"

Environment

From CABI (2018):

"*T. natans* is found world-wide in full sun and low-energy, nutrient-rich fresh waters (Hummel and Kiviat, 2004). It is commonly found in waters with alkalinity ranging from 12 to 128 mg/L of calcium carbonate (O'Neill, 2006), and dislikes calcium-rich waters (PFAF, 2000). […] Hummel and Kiviat (2004) report that the species is found most abundantly in water around 2 m deep and in soft substrate. It also prefers slightly acidic water (PFAF, 2000), although germination can occur in water with pH ranging from 4.2 to 8.3 (Hummel and Kiviat, 2004). […] *T. natans* does not tolerate salinity; its seeds will not germinate when NaCl concentrations exceed 0.1% (Hummel and Kiviat, 2004)."

Climate/Range

From USDA-APHIS (2016):

"*Trapa natans* inhabits temperate to tropical water bodies in sluggish areas with slower water flow (Hummel and Kiviat, 2004)."

Distribution Outside the United States

Native

CABI (2018) lists *Trapa natans* as native in Albania, Algeria, Angola, Austria, Bangladesh, Belarus, Bosnia-Hercegovina, Botswana, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Guinea-Bissau, Hungary, India, Indonesia, Japan, Latvia, Malawi, Mozambique, Namibia, Pakistan, Philippines, Romania, Russian Federation, South Africa, Switzerland, Tanzania, Tunisia, Turkey, Uganda, Ukraine, Vietnam, Zambia, and Zimbabwe.

In addition to the countries listed above, GISD (2017) lists *T. natans* as native in Italy, Poland, Spain, and Sudan.

GISD (2017) lists *T. natans* as cryptogenic, established, and not invasive in Belgium, Germany, Netherlands, and Sweden.

Introduced

CABI (2018) lists *Trapa natans* as introduced and invasive in Burkina Faso and Canada; and introduced in Australia.

Means of Introduction Outside the United States

From CABI (2018):

"*T. natans* has largely been spread as a result of intentional plantings. There have been many reports of escape from cultivation, and the species was originally introduced as an ornamental (Les and Mehrhoff, 1999). […] The rough spines of the fruit make it generally unpalatable to wildlife, reducing the likelihood of the species being spread this way. Instead, seeds disperse passively, being carried by water currents as they drop to the sediment surface (Boylen et al., 2006). The spines of the fruit also allow it to spread over longer distances as a hitchhiker, when it clings to boats and gear (Hummel and Kiviat, 2004)."

"Humans may be the primary vector of transmission. *T. natans* has been historically valued as an ornamental; its escape from ornamental and botanical gardens that probably explains the invasion of the plant in the New World (Les and Mehrhoff, 1999). […] Les and Mehrhoff (1999) report observations of nuts attached to the feathers of geese, although they hypothesize that due to the size and weight of the nuts (6 g), it is unlikely that they would remain attached during prolonged flight, so although waterfowl may be a possible vector of transmission, dispersal in this manner probably only occurs over short distances."

Short Description

From CABI (2018):

"*T. natans* is an herbaceous, floating-leaf aquatic species that often grows in water around 60 cm deep (PFAF, 2000). The floating leaves are arranged in a rosette, with leathery upper leaves up to 5 cm wide and broadly rhomboid, triangular, deltoid or broadly ovate (Hummel and Kiviat, 2004). The leaves are sharply serrate, with conspicuous venation and short, stiff hairs. The species also produces submersed leaves that are strikingly morphologically different (Bitonti et al., 1996). The submersed leaves are alternate, finely divided, and can grow up to 15 cm long (Mehrhoff et al., 2003). The petioles of the floating leaves have a spongy floating section that allows for the flotation of the leaf rosette, and each stem may produce several rosettes (Hummel and Kiviat, 2004). The plant also has white flowers with four 8 mm-long petals and four green sepals. The fruit is a single-seeded horned nut-like structure, sometimes referred to as a "turbinate drupe" that develops underwater and is approximately 3 cm wide (Mehrhoff et al., 2003). Single flowers are produced in axils of floating leaves (Hummel and Kiviat, 2004). The stem of the plant is flexible, from 1 to 5 m long, nodes of the stem have slender linear roots, while the plant is anchored in the sediment by the lower roots that emerged from the propagating seed hull (Hummel and Kiviat, 2004)."

Biology

From CABI (2018):

"*T. natans* is an annual species that produces single, bisexual flowers on stalks produced from the centre of the floating rosettes. The flower has a two-chambered ovary, four stamens, four petals, and four sepals that eventually become the spines of the fruit (GBIF, 2008). The flowers

are generally pollinated by insects, but self-pollination may occur before the flower opens (Hummel and Kiviat, 2004). Once fertilized, the flower stalks droop downward, allowing the ovary to develop underwater into a nut-like barbed fruit (GBIF, 2008). The seed has two unequal cotyledons, one of which is large and starchy. Each seed produces 10 to 15 rosettes, and each rosette can give rise to up to 20 seeds (O'Neill, 2006). Seeds can remain dormant in the sediments for up to 10 years but do not tolerate dessication [sic] (Hummel and Kiviat, 2004). Vegetative reproduction is also very important to the growth and spread of the plant. The plant produces ramets that can break off and move away from the rest of the clone and survive to produce seeds. This attribute allows for extremely rapid clonal expansion, for example, a 10-fold increase was documented in 1 year in Lake Champlain (Groth et al., 1996). In fact, it has been suggested that this annual plant might act as a perennial in parts of its exotic range, mainly through rapid proliferation from clonal fragments year to year (Groth et al., 1996)."

"In spring (May in the Northeastern USA), stems bearing leaf rosettes elongate toward the surface of the water. The rosettes flourish and remain green until autumn. The plant begins to flower in early summer, and can continue to flower through to autumn (June to September in its North American range). The fruits mature mid-summer through autumn, after which they sink to the sediment when the plant begins to senesce. The plant quickly decomposes, but the seeds can stay dormant for up to 10 years. The nut overwinters in the sediment, but when water temperature rises to 12 ºC, the terminal pore begins to rot, and around 1 month later, the seed germinates (Hummel and Kiviat, 2004)."

Human Uses

From Hummel and Kiviat (2004):

"The Maglemosian people of northern Europe ate water chestnuts during the period 8000 to 6000 BC (Zvelebil 1986). This is possibly the oldest known human use of water chestnut."

"Water chestnut is valued for its nutritional and medicinal properties in modern India. The fresh nuts have a high moisture content and are in demand for quenching thirst (Mazumdar 1985). Raw *T. natans* var. *bispinosa* Roxb. nuts were commonly sold in the markets of Hong Kong, Malaya, and Thailand; however, they contain substances harmful to the alimentary canal and must be boiled to be edible (Herklots 1972). Dried water chestnuts were ground into flour and used to make various foodstuffs (Mazumdar 1985). In China water chestnut was extensively cultivated and the fruits were commonly sold in markets (Pemberton 1999). The flour and the nuts of *T. natans* var. *bispinosa* were eaten in Hong Kong at the Festival of the Full Moon (Herklots 1972). The species was used for medicine widely in Asia (Khatib 1934, Herklots 1972). Water chestnut kernels were used to treat rabies, poisonous animal bites, diarrhea, amoebic dysentery, and other conditions in the U.S.S.R. (Shishkin and Bobrov 1974)."

"In addition to serving as food for people and animals, water chestnut has been recommended for paper pulp, fertilizer, fish food, compost, and biogas fuel (i.e., methane generated from organic material via anaerobic digestion). Besha and Countryman (1980) analyzed the efficiency of anaerobic digestion of water chestnut to produce methane as a fuel for generating electricity. They estimated a potential yield of 1.16×10^{11} kJ (1.29×10^{4} MW of electricity) annually from

the 2000 ha of water chestnut in New York State, and stated that the residue after anaerobic digestion could be used as a cattle feed supplement (Besha and Countryman 1980)."

"We have heard of individual water chestnut hulls being sold in New York City, and have seen a variety of jewelry, curios, and sculpture incorporating the hulls. Bailey and Bailey (1976) stated the nuts were used in rosaries. *Trapa natans* var. *bispinosa* nuts are said to have been used in offerings to the "darker gods," and the nuts are advertised on the Internet as charms to ward off evil (Yronwode 2002)."

From CABI (2018):

"*T. natans* has also been used in a herbal mixture that has proven to provide relief from the symptoms associated with recurrent herpes genitalis and labialis (Hijikata et al., 2007).The rind of the fruit has been discovered to have antibacterial activity, and is primarily effective against gram negative bacteria (Parekh and Chanda, 2007)."

Diseases

CABI (2018) list the following pathogens for *Trapa natans*: *Athelia rolfsii*, *Bipolaris tetramera*, *Botryotinia fuckeliana*, *Cercospora* sp., and *Sclerotium hydrophilum*.

Threat to Humans

From CABI (2018):

"Additionally, the sharp spines present on the nuts can result in puncture wounds to swimmers (O'Neill, 2006). The plant may have played a role in the drowning deaths of a woman and two children in 2001 on the Hudson River (Hummel and Kiviat, 2004). Some people eat the chestnuts raw and ingest the giant intestinal fluke *Fasciolopsis buski* that is known to cause fasciolopsiasis, and the beds are known to be good breeding grounds for mosquitoes (Hummel and Kiviat, 2004)."

3 Impacts of Introductions

From Hummel and Kiviat (2004):

"Water chestnut is capable of covering nearly 100% of the water surface when conditions are favorable. High density growth results in the interception of 95% of incident sunlight, which severely affects plants beneath the water chestnut canopy, and causes shading out of submerged vascular plants and their associated microscopic flora and fauna (Winne 1950, Kiviat 1987, 1993, Groth et al. 1996). Water chestnut was considered "destructive to important submerged duck-food beds" (Martin and Uhler 1939). Displacement of submersed plants by water chestnut is believed to cause the loss of many animal species and their replacement by more tolerant, more common, and in some cases non-native species (Beaven 1955)."

"In the tidal Hudson River, water chestnut has apparently replaced water celery (*Vallisneria americana* Michx.), clasping pondweed (*Potamogeton perfoliatus* L.), introduced Eurasian watermilfoil (*Myriophyllum spicatum* L.), and other submergent plants in many areas; the only

water celery beds that thrive in the Tivoli Bays, a semi-impounded wetland of the Hudson, are where current and wave action exceed tolerance of water chestnut. Duckweeds (*Lemna minor* L., *Spirodela polyrhiza* L., *Wolffia* spp.) and filamentous algae grow among the rosettes, taking advantage of the shelter from winds and currents. Narrowleaf cattail (*Typha angustifolia* L.), pickerelweed (*Pontederia cordata* L.), and spatterdock (*Nuphar advena* Aiton f.) seem unaffected by the presence of water chestnut, which cannot compete with tall emergent species that grow above the low tide level (Kiviat 1987, 1993)."

"The coupling of decreased epiphyton abundance and low DO could be responsible for the low diversity of fish communities that inhabit water chestnut beds. Several studies have investigated species composition and abundance of fishes in water chestnut beds of the Hudson River. Most concluded that although fish do inhabit water chestnut beds, the species found in greatest abundance are common ones with wide tolerance for adverse environmental conditions that include water pollution, turbidity, and low DO (Schmidt and Kiviat 1988, Pelczarski and Schmidt 1991, Schmidt et al. 1992, Gilchrest 1998). Resident fish communities in these studies mainly consisted of fourspine stickleback (*Apeltes quadracus* [Mitchill]), juvenile banded killifish (*Fundulus diaphanus* [Lesueur]), spottail shiner (*Notropis hudsonius* [Clinton]), tessellated darter (*Etheostoma olmstedi* Storer), and the introduced common carp (*Cyprinus carpio* Linnaeus) (Schmidt and Kiviat 1988, Pelczarski and Schmidt 1991, Schmidt et al. 1992, Gilchrest 1998). These are not important sport or commercial species, but in the Hudson are important forage fishes for which water chestnut beds provide significant nurseries. Adult spottail shiners, banded killifish, and tessellated darters are not found in dense water chestnut beds, but are common in water celery beds (Schmidt and Kiviat 1988)."

From Hummel and Findlay (2006):

"We found clear differences in effects of small vs. large *Trapa* beds on dissolved oxygen thereby extending the understanding of DO effects from extremely large beds (Caraco & Cole, 2002) to plant beds more representative of the majority of sites in the Hudson."

"In general, reduced light penetration, slow water dispersal, and inhibition of gas exchange result in reduced DO levels such as the extremely low DO events (below 2.5 mg/l) observed in the large (900 000 m^2) Inbocht Bay water chestnut bed in 1999–2000 (Caraco & Cole, 2002). Our data clearly suggest there are dramatic effects on DO even for much smaller bed areas."

From CABI (2018):

"*T. natans* can have severe impacts on the environment. When compared to areas vegetated by native species, areas under *T. natans* beds experienced higher variation in (varying) dissolved oxygen (DO) levels. In a study on the Hudson River, dangerously low DO values (below 5 mg/L) occurred 51% of the time, and levels below 2.5 mg/L occurred 30% of the time, while DO below 5 mg/L never occurred in native Vallisneria beds (Caraco and Cole, 2002). These observed low levels can be lethal to fish, and consequently cause the migration of small fish from under the canopy to the edges of the beds, which in turn can cause the congregation of game fish at the edges of the beds (O'Neill, 2006)."

"Where the plant is very abundant, up to 50 rosettes can grow within 1 square metre, covering the water with up to three layers of leaves (Pemberton, 2002). The high density growth of which *T. natans* is capable can [sic] result in a decrease in light penetration. In one study that occurred in the Hudson River, only 0.5% of incident light reached a depth of 0.2 metres underneath large beds of *T. natans* (Caraco and Cole, 2002). Yet other studies report the species' general ability to intercept 95% of incident light (Hummel and Kiviat, 2004)."

"Due to the species' ability to shade out other submersed vegetation, it is generally considered a threat to biodiversity in its introduced range. The species also has an effect on epiphyton communities. In its native range, epiphyton development was shown to be significantly higher on submerged plants than on *T. natans,* while taxonomic composition of epiphytic algae, but not macroinvertebrates, was higher on *T. natans* (Cattaneo et al., 1998)."

"This plant can cause substantial nuisance to recreational users by impeding navigation and tangling fishing line. This species has little nutritional benefit for fish or waterfowl, and can have detrimental effect on native game species that utilize the area. Additionally, the sharp spines present on the nuts can result in puncture wounds to swimmers (O'Neill, 2006). The plant may have played a role in the drowning deaths of a woman and two children in 2001 on the Hudson River (Hummel and Kiviat, 2004). Some people eat the chestnuts raw and ingest the giant intestinal fluke *Fasciolopsis buski* that is known to cause fasciolopsiasis, and the beds are known to be good breeding grounds for mosquitoes (Hummel and Kiviat, 2004). However, there is evidence that the *T. natans* nuts have been consumed by humans as early as 8000 BC. Currently the nut is valued worldwide for both its nutritional value as well as its medicinal properties."

From Pfingsten et al. (2018):

"In Vermont, USA, many previously fished bays of southern Lake Champlain are now inaccessible, and floating mats of *T. natans* can create a hazard for boaters (Bove and Hunt 1997)."

"When the plant occupies a site, most recreational activities such as swimming, fishing from the shoreline, and the use of small boats are eliminated or severely impeded (Bickley and Cory 1955). The primary economic costs related to *T. natans* are associated with the costs of chemical and mechanical control efforts (Kiviat 1993)."

4 Global Distribution

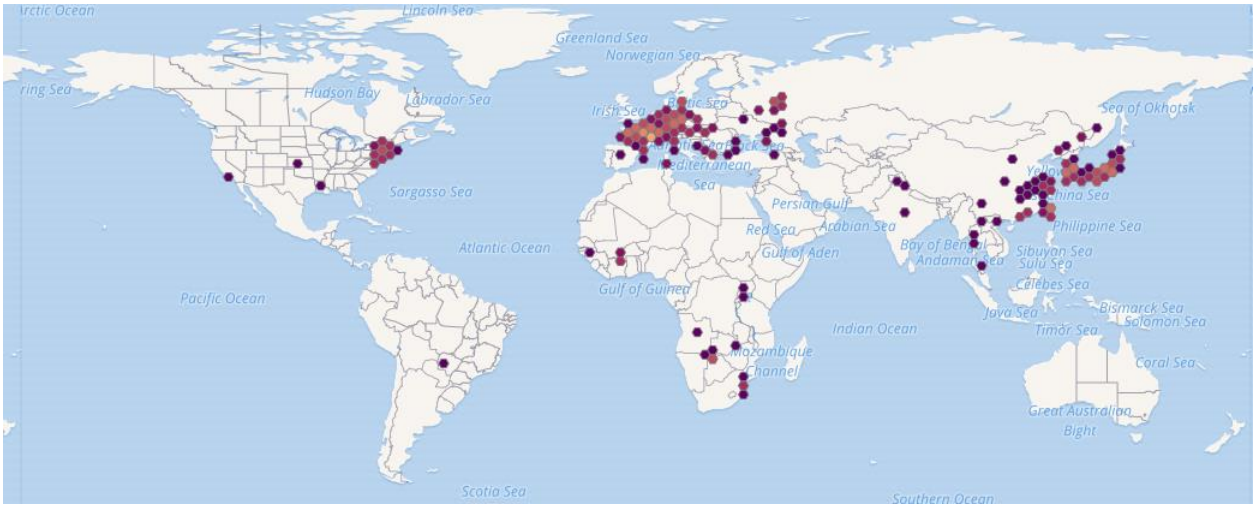

Figure 1. Known global distribution of *Trapa natans*. Map from GBIF Secretariat (2018).

The location in California is the result of a specimen collected in a supermarket (GBIF Secretariat 2018) and is not representative of an established, wild population. It was not used as a source point in the climate match.

The location in Kansas is the result of a record where the specimen may have actually been collected in South America (GBIF Secretariat 2018). Due to this discrepancy it was not used as a source point in the climate match.

The location in Louisiana is the result of a single specimen collected in 1953 (GBIF Secretariat 2018). No other source indicates an established population in Louisiana. This location was not used as a source point for the climate match.

The location in Brazil is the result of a citizen science observation (GBIF Secretariat 2018) and is not corroborated elsewhere. Insufficient information was available in the record for the author to determine if it was representative of an established wild population and was not used as a source point for the climate match.

5 Distribution Within the United States

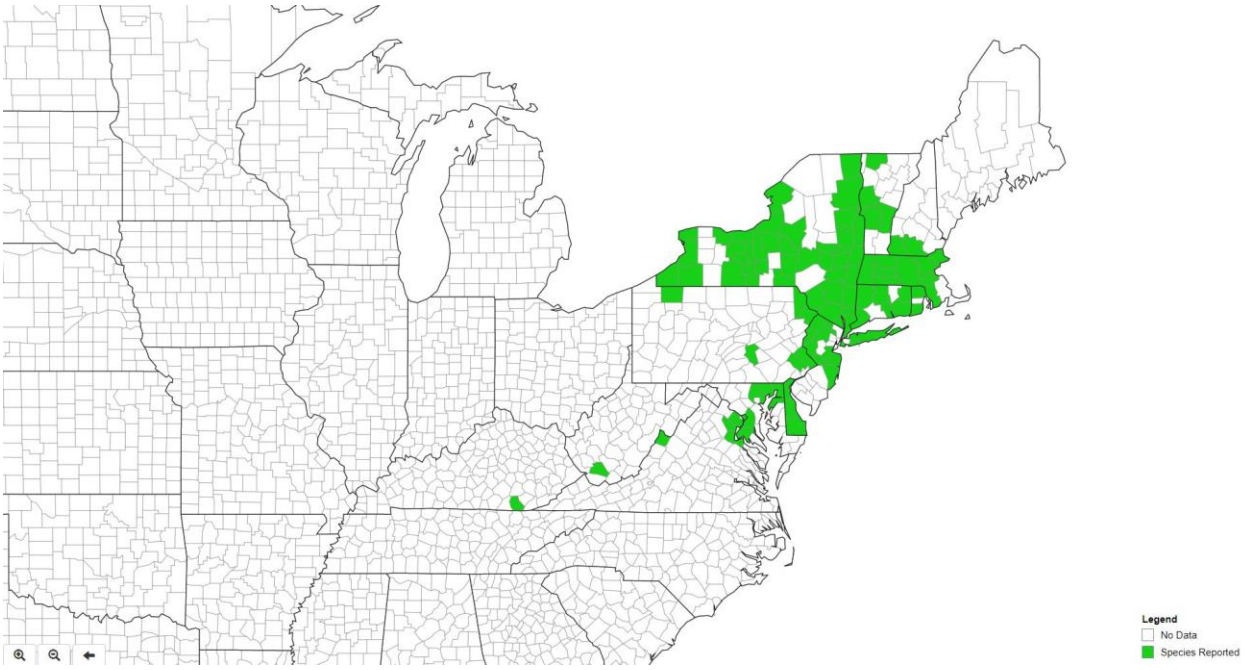

Figure 2. Known distribution of *Trapa natans* by county in the United States. Map from EDDMapS (2018).

According to Pfingsten et al. (2018), the records from Kentucky and West Virginia are most likely the result of a misidentification and were not used as source points for the climate match.

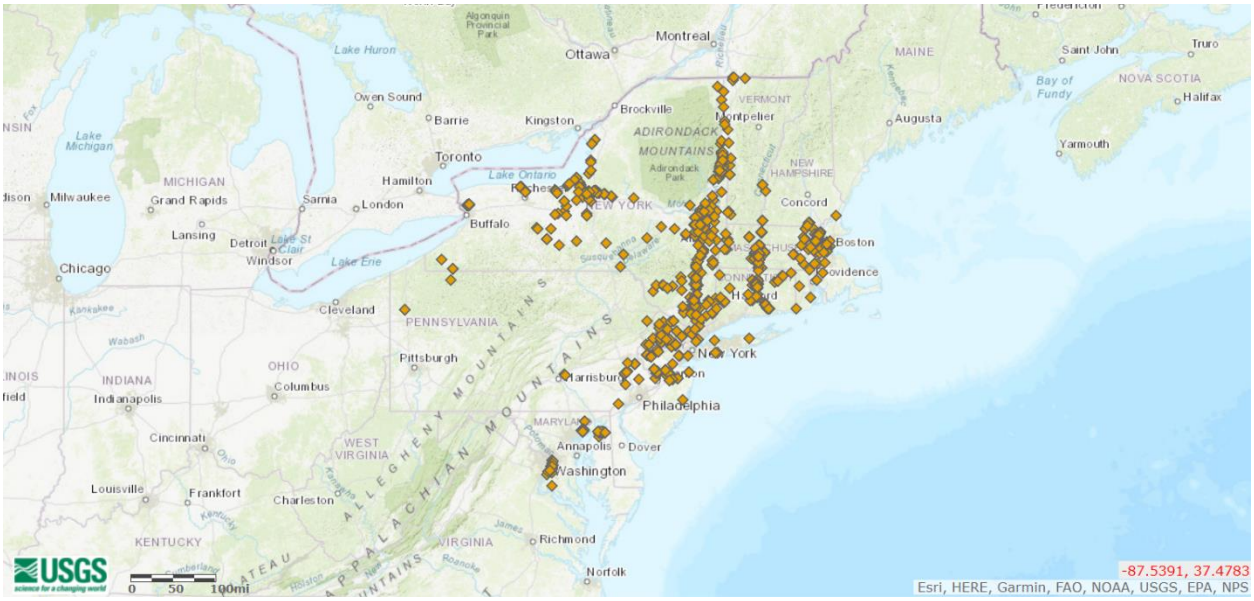

Figure 3. Known distribution of *Trapa natans* in the United States. Map from Pfingsten et al. (2018).

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Trapa natans* was high in the northeast, much of the south, mid-west, and Great Plains. It was also high in small pockets along the west coast. There were areas of low match along the west coast and in small pockets in the Great Plains. Everywhere else had a medium match. The Climate 6 score (Sanders et al. 2014; 16 climate variables; Euclidean distance) for the contiguous United States was 0.734, high. All state in the contiguous United States had high individual climate scores except Louisiana and Mississippi, which had medium scores.

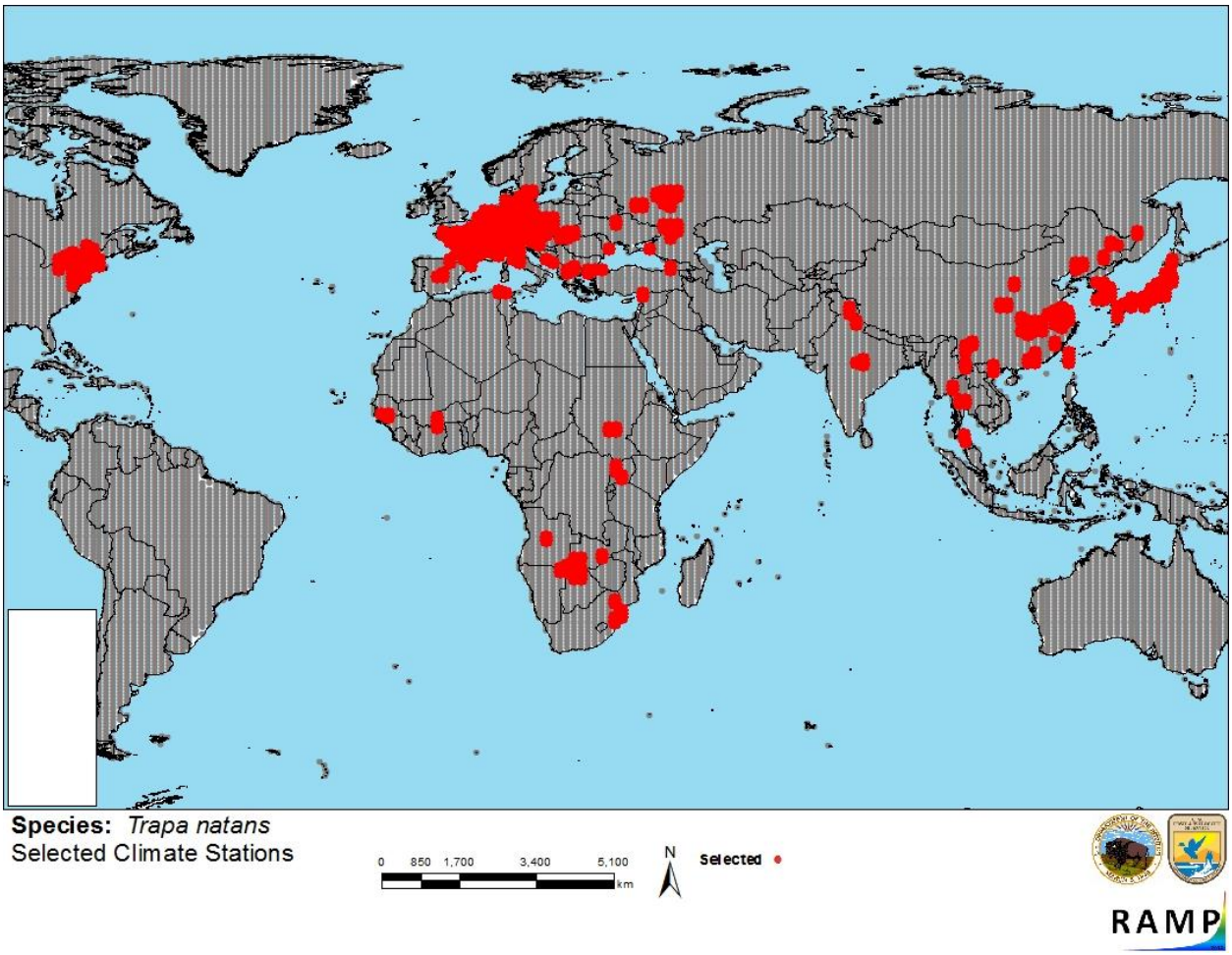

Figure 4. RAMP (Sanders et al. 2014) source map showing weather stations in North America, Europe, Asia, and Africa selected as source locations (red) and non-source locations (gray) for *Trapa natans* climate matching. Source locations from GBIF Secretariat (2018) and Pfingsten et al. (2018).

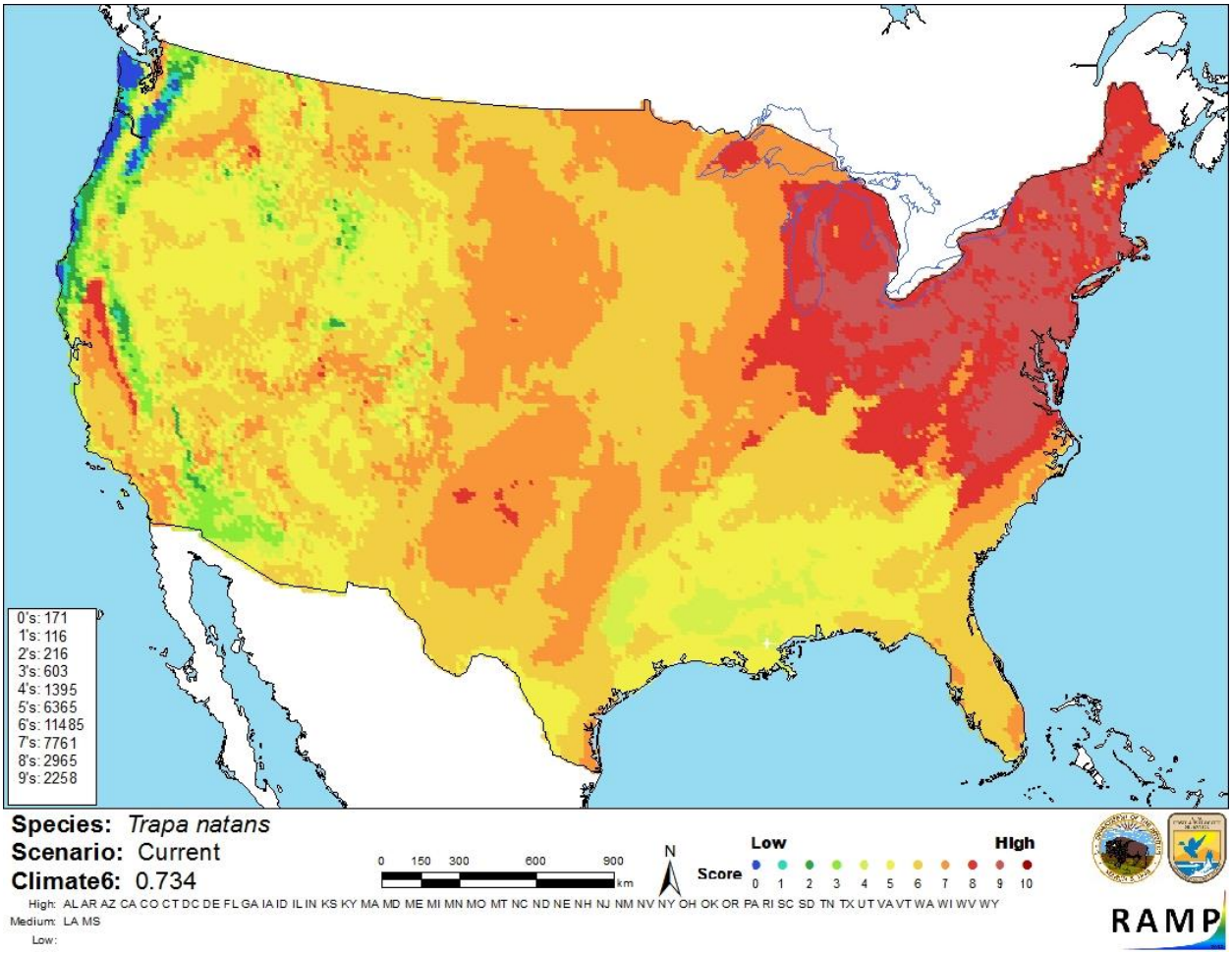

Figure 5. Map of RAMP (Sanders et al. 2014) climate matches for *Trapa natans* in the contiguous United States based on source locations reported by GBIF Secretariat (2018) and Pfingsten et al. (2018). Counts of climate match scores are tabulated on the left. 0 = Lowest match, 10 = Highest match.

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

Certainty of this assessment is high. Information on the biology, invasion history and impacts of this species is available, including some peer-reviewed literature. There is enough information available to describe the risks posed by this species.

8 Risk Assessment

Summary of Risk to the Contiguous United States

Trapa natans is an annual floating leaved aquatic plant native to large areas of Eurasia and Africa. A single plant can produce multiple floating rosettes of leaves and produce up to 20 spined nuts. *T. natans* can have a 10-fold growth rate and the nuts may be viable for up to 10 years. *T. natans* has been used as a food source for humans and domesticated animals, for medicinal purposes, and it has been proposed for industrial uses. The history of invasiveness for *T. natans* is high. It has been intentionally planted as an ornamental or food source. Impacts of this aquatic plant include the shading out and replacement of native submerged aquatic plants and severely reducing dissolved oxygen levels. Climate matching indicated the contiguous United States has a high climate match. This species is already established in parts of the Northeast. Certainty of this 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:** There are already established populations of *Trapa natans* in the Northeast.
- **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.

CABI. 2018. *Trapa natans* (water chestnut) [original text by A. Mikulyuk and M. Nault]. *In* Invasive Species Compendium. CAB International, Wallingford, U.K. Available: https://www.cabi.org/isc/datasheet/55040. (April 2018).

EDDMapS. 2018. Early Detection & Distribution Mapping System. University of Georgia, Center for Invasive Species and Ecosystem Health, Tifton, Georgia. Available: http://www.eddmaps.org/. (April 2018).

GBIF Secretariat. 2018. GBIF backbone taxonomy: *Trapa natans* L. Global Biodiversity Information Facility, Copenhagen. Available: https://www.gbif.org/species/3188757. (April 2018).

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

Hummel, M., and E. Kiviat. 2004. Review of world literature on water chestnut with implications for management in North America. Journal of Aquatic Plant Management 42:17–28.

Hummel, M., and S. Findlay. 2006. Effects of water chestnut (*Trapa natans*) beds on water chemistry in the tidal freshwater Hudson River. Hydrobiologia 559:169–181.

ITIS (Integrated Taxonomic Information System). 2018. *Trapa natans* L. Integrated Taxonomic Information System, Reston, Virginia. Available: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=27170. (April 2018).

Pfingsten, I. A., L. Cao, and L. Berent. 2018. *Trapa natans* L. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=263. (April 2018).

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

USDA-APHIS. 2016. Weed risk assessment for *Trapa natans* L. (Lytheracea) – water chestnut. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Raleigh, North Carolina.

USDA, NRCS. 2018. *Trapa natans*. The PLANTS database. National Plant Data Team, Greensboro, North Carolina. Available: https://plants.usda.gov/core/profile?symbol=TRNA. (April 2018).

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.

Bailey, L. H., and E. Z. Bailey. 1976. Hortus third: a concise dictionary of plants cultivated in the United States and Canada. Revised and expanded by the staff of the Liberty Hyde Bailey Hortorium. MacMillan Publishing, New York.

Beaven, G. F. 1955. Water chestnut threatens disaster to Maryland water areas. Maryland Tidewater News 12(1):1–2.

Besha, J. A., and W. D. Countryman. 1980. Feasibility assessment of anaerobic digestion of European water chestnuts (*Trapa natans* L.). New York State Energy Research and Development Authority, Report 80-13, Albany, New York.

Bickley, W. E., and E. N. Cory. 1955. Water caltrop in the Chesapeake Bay. Association of Southeastern Biologists Bulletin 2:27–28.

Bitonti, M. B., R. Cozza, G. Wang, M. Ruffini-Castiglione, S. Mazzuca, S. Castiglione, F. Sala, and A. M. Innocenti. 1996. Nuclear and genomic changes in floating and submerged buds and leaves of heterophyllous waterchestnut (*Trapa natans*). Physiologia Plantarum 97:21–27.

Bove, A., and T. Hunt. 1997. Water chestnut: an exotic plant invasion in Lake Champlain. Page 12 *in* N. C. Balcom, editor. Proceedings of the Second Northeast Conference on Nonindigenous Aquatic Nuisance Species, Burlington, Vermont. Connecticut Sea Grant College Program, Publication CTSG-97-02, Groton.

Boylen, C. W., L. W. Eichler, J. S. Bartkowski, and S. M. Shaver. 2006. Use of geographic information systems to monitor and predict non-native aquatic plant dispersal through north-eastern North America. Hydrobiologia 570:243–248.

Caraco, N. F., and J. J. Cole. 2002. Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. Ecological Applications 12:1496–1509.

Carter, V., and N. B. Rybicki. 1994. Invasions and declines of submersed macrophytes in the tidal Potomac River and Estuary, the Currituck Sound-Back Bay system, and the Pamlico River Estuary. Journal of Lake and Reservoir Management 10(1):39–48.

Cattaneo, A., G. Galanti, S. Gentinetta, and S. Romo. 1998. Epiphytic algae and macroinvertebrates on submerged and floating-leaved macrophytes in an Italian lake. Freshwater Biology 39:725–740.

GBIF. 2008. Global Biodiversity Information Facilities. Available: http://data.gbif.org/.

Gilchrest, W. R. 1998. A comparison of fish communities in an open and an occluded freshwater tidal wetland in the Hudson River estuary. Master's thesis. Bard College, Annandale-on-Hudson, New York.

Groth, A. T., L. Lovett-Doust, and J. Lovett-Doust. 1996. Population density and module demography in *Trapa natans* (Trapaceae), an annual, clonal aquatic macrophyte. American Journal of Botany 83:1406–1415.

Herklots, G. A. C. 1972. Vegetables in South-east Asia. George Allen and Unwin, London.

Hijikata, Y., S. Yamada, and A. Yasuhara. 2007. Herbal mixtures containing the mushroom *Ganoderma lucidum* improve recovery time in patients with herpes genitalis and labialis. Journal of Alternative and Complementary Medicine 13:985–988.

Khatib, M. H. 1934. The life history and biology of *Galerucella birmanica* Jac. (Coleoptera, Phytophaga, Chrysomelidae, Galerucinae) and the external morphology of larva and pupa, Part I. Indian Journal of Agriculture Science 5:715–732.

Kiviat, E. 1987. Water chestnut (*Trapa natans*). Pages 31–38 *in* D. J. Decker, and J. W. Enck, editors. Exotic plants with identified detrimental impacts on wildlife habitats in New York State. Cornell Cooperative Extension, Cornell University, Ithaca, New York.

Kiviat, E. 1993. Under the spreading water-chestnut. News From Hudsonia 9:1–6.

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

Martin, A. C., and F. M. Uhler. 1939. Food of game ducks in the United States and Canada. USDA Technical Bulletin 634.

Mazumdar, B. C. 1985. Water chestnut—the aquatic fruit. Agricultural Information Series 32(2):42–44.

Mehrhoff, L. J., J. A. Silander, S. A. Leicht, E. S. Mosher, and N. M. Tabak. 2003. Invasive plant atlas of New England. University of Connecticut, Storrs.

Mirick, P. G. 1996. Goose grief. Massachusetts Wildlife 46(2):15–16.

Muenscher, W. C. 1944. Aquatic plants of the United States. Comstock Publishing, and Cornell University, Ithaca, New York.

O'Neill, C. R. 2006. Water chestnut (*Trapa natans*) in the Northeast. New York Sea Grant, Invasive Species Factsheet Series 06-1, Brockport, New York.

Oregon Exotics. 2003. Available: http://www.exoticfruit.com. (July 2003).

Parekh, J., and S. Chanda. 2007. In vitro antimicrobial activity of *Trapa natans* L. fruit rind extracted in different solvents. African Journal of Biotechnology 6:766–770.

Pelczarski, K., and R. E. Schmidt. 1991. Evaluation of a pop net for sampling fishes from water-chestnut beds in the tidal Hudson River. Pages 1–33 *in* E. A. Blair, and J. R. Waldman, editors. Polgar Fellowship Reports of the Hudson River National Estuarine Research Reserve Program, 1990. Hudson River Foundation, New York.

Pemberton, R. W. 1999. Natural enemies of *Trapa* spp. in Northeast Asia and Europe. Biological Control 14:168–180.

Pemberton, R. W. 2002. Biological control of invasive plants in the eastern United States. R. Van Driesche, editor. USDA Forest Service, Publication FHTET-2002-04.

PFAF. 2000. *Trapa natans*. Plants for a Future. Available: http://www.pfaf.org/.

Schmidt, R. E., A. B. Anderson, and K. Limburg. 1992. Dynamics of larval fish populations in a Hudson River tidal marsh. Pages 458–475 *in* C. L. Smith, editor. Estuarine research in the 1980s. State University of New York Press, Albany.

Schmidt, R. E., and E. Kiviat. 1988. Communities of larval and juvenile fish associated with water-chestnut, watermilfoil and water-celery in the Tivoli Bays of the Hudson River. Report to the Hudson River Foundation, New York.

Shishkin, B. K., and E. G. Bobrov, editors. 1974. Flora of the U.S.S.R. volume XV. Malvales, Parietales, Myrtiflorae. Israel Program for Scientific Translations, Jerusalem. (English translation of original in Russian.)

USDA. 2003. [Source material did not give full citation for this reference.]

Winne, W. T. 1950. Water chestnut: a foreign menace. Bulletin to the Schools 36:230–234.

Yronwode, C. 2002. Devil pod or bat nut. Available: http://www.luckymojo.com/batnut.html. (April 2003).

Zvelebil, M. 1986. Postglacial foraging in the forests of Europe. Scientific American 254(5):104–106, 108, 110, 112, 114–115.