Water Spangles (*Salvinia minima*)

A Technical Review of Distribution, Ecology, Impacts, and Management

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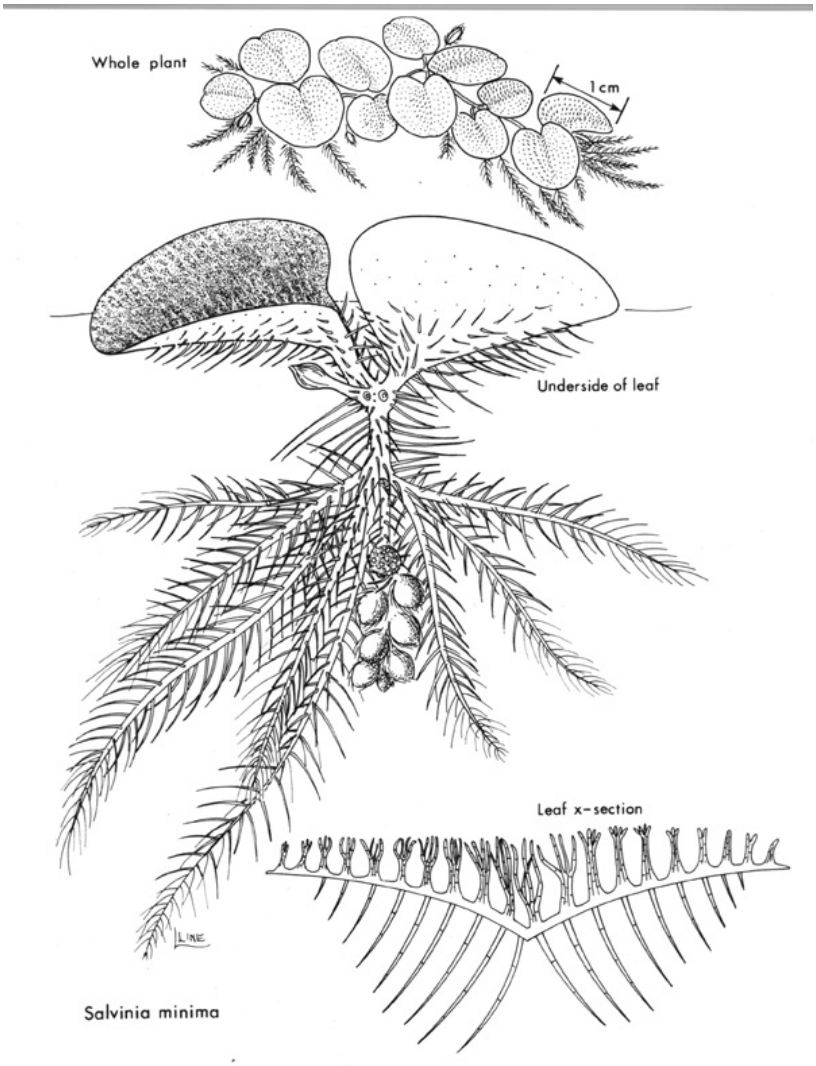

Salvinia minima

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Water Spangles, (*Salvinia minima*): A Technical Review of Distribution, Ecology, Impacts, and Management

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This literature review was commissioned by the nonprofit Centre for Agricultural Bioscience International (CAB International; http://www.cabi.org/index.asp) as part of a larger invasive species compendium. We completed eight literature reviews for the project, and due to the large number of requests for this information, we have decided to make the reviews available as DNR miscellaneous publications. Species reviewed include:

- Carolina fanwort (*Cabomba caroliniana*) – [PUB-SS-1047 2009]
- European frog-bit (*Hydrocharis morsus-ranae*) – [PUB-SS-1048 2009]
- Indian swampweed (*Hygrophila polysperma*) – [PUB-SS-1049 2009]
- African elodea (*Lagarosiphon major*) – [PUB-SS-1050 2009]
- Yellow floating heart (*Nymphoides peltata*) – [PUB-SS-1051 2009]
- Curly leaf pondweed (*Potamogeton crispus*) – [PUB-SS-1052 2009]
- Water spangles (*Salvinia minima*) – [PUB-SS-1053 2009]
- Water chestnut (*Trapa natans*) – [PUB-SS-1054 2009]

In completing the literature reviews, we preferentially consulted the peer-reviewed primary literature and supplemented the reviews with secondary sources where necessary. The outline for the reviews is identical for each species and was provided as part of the CAB International commissioning. This effort compliments work conducted during the development of the WDNR's proposed invasive species identification, classification and control rule; a more exhaustive list of species and accompanying literature review summaries can be found on the DNR website at: http://dnr.wi.gov/invasives/

Identity

Taxonomy and Nomenclature

The heterosporous fern clade, of which *Salvinia minima* is a part, contains two families, Marsileaceae and Salviniaceae. These water ferns are the only group of heterosporous plants to have evolved heterospory after the Paleozoic. The group evolved and then diversified at the same time as flowering plants (Nagalingum et al., 2006). The family Salviniaceae is monogeneric, and includes ten species of *Salvinia*, all of which are highly morphologically similar (USDA-NRCS, 2008; Jacono et al., 2001). The names *Salvinia auriculata* Aublet and *Salvinia natans* (Linnaeus) Allioni and *Salvinia rotundifolia* Willdenow have been misapplied to *Salvinia minima* in several sources, and *S. auriculata* is occasionally erroneously listed as synonymous (Flora of North America Editorial Committee, eds., 1994+).

Summary of Invasiveness

Salvinia minima is a very productive free-floating, non-rooted aquatic fern native to South and Central America. Introduced to Southern Florida in 1926 (Jacono, 2003), the

plant is degrading wetland ecosystems in several states (Tipping and Center, 2005). *S. minima* has an extremely high reproductive potential: the plants can rapidly colonize bodies of water, forming thick mats that displace native species, impact water quality, impede recreational activities, and clog waterways and irrigation channels (Rayachhetry et al., 2002). Salvinia is also resistant to desiccation, allowing it to be transported long distances out of water (ISSG, 2006). The species can act as an annual, dying back when temperatures decrease and causing harmful nutrient pulses and dissolved oxygen crashes (Dickinson and Miller, 1998).

Distribution, Introduction, and Spread

Distribution

Salvinia minima occurs in lakes, riparian zones, water courses, wetlands and pools (ISSG, 2006) in warm temperate areas (Jacono et al., 2001). The species is common and wide-ranging from southern Mexico to northern Argentina and Brazil; however, the natural range in Argentina cannot be accurately determined due to the frequency of use in the water garden and aquarium trade (Jacono, 2003). The species is native to South America but is now established in the southern United States (Tipping and Center, 2005). These aquatic ferns have invaded drainage basins in Texas, Louisiana, Alabama, Arizona, California, Florida, Georgia, Hawaii, Mississippi, North Carolina and Oklahoma (Rayachhetry et al., 2002). The species grows best in slow-moving or still water and can tolerate salinity levels up to 7 ppt (ISSG, 2006).

Risk of Introduction

People commonly grow *Salvinia spp.* in aquaria and water gardens. Consequently, the plant has been distributed through related activities (Haynes and Jacono, 2000). Salvinia is still readily available in the aquaculture industry for direct purchase or can be included as a hitchhiker (ISSG, 2006). Since the species spreads not only clonally but also by spores, ship ballast water that contains spores can spread the plant internationally (ISSG, 2006). The earliest collection in North America was made around 1930 and was likely the result of ballast discharge of contaminated water in the St. Johns River near Jacksonville (ISSG, 2006). Plants were then documented in wide ranging locations across Florida and Georgia, which were likely the result of independent introductions (Jacono et al., 2001).

Biology and Ecology

Description

S. minima is a deep green, free-floating, rootless, aquatic fern (ISSG, 2006). Stems can be up to 6 cm and leaves are from 1-1.5 cm long and almost round to elliptic. They are obtuse or notched at the apex and round to heart-shaped at the base. The upper surfaces of the fronds are covered with stiff hairs, with 4 separated branches. The under surfaces of the leaves are brown and pubescent with slender and unbranched hairs (Flora of North America Editorial Committee, 1993+). The stiff hairs on the fronds serve to trap air, thus providing buoyancy (Dickinson and Miller, 1998). Obscure veins are areolate and do not quite reach to the leaf edges. Sporocarps occur in groups of 4-8 with up to 25 megasporangia (Flora of North America Editorial Committee, 1993+).

Similarities to Other Species

All *Salvinia* species have stems with many multicellular hairs, leaves are horizontally spreading; floating leaves are green and pubescent. Sporocarps are borne on structures

resembling cymes or on submerged leaves. Though the species resemble each other quite significantly, they can be distinguished from other floating leaf species by the unique upper side of the floating leaf (Flora of North America Editorial Committee, 1993+). Distinguishing among the various species in the *Salvinia* genus is difficult, and requires recognizing the differences in spore placement and leaf shape (Jacono, 2003).

Habitat
S. minima occurs in still or slow-moving water in tropical and warm temperate area of North and South America (Tipping and Center, 2005). It prefers the shallow backwaters in bayous, lakes and ponds, low-energy streams, oxbows, ditches, swamps and marshes (Jacono, 2003). It occurs frequently in waters with high organic content (UFL-IFAS, 2002), and typically inhabits water bodies with salinity levels as high as 4-7ppt (Jacono, 2003). Salvinia, due to its interesting morphology, is a popular aquarium and water gardening plant, it can grow fairly well in small, artificially constructed ponds (USACE-ERDC, 2002).

Genetics
The taxonomy of the genus *Salvinia* is relatively straightforward. The genus contains approximately 10 closely-related species in the monogeneric family Salviniacea. De la Sota and Cassa de Pazos (2001) report that the species *S. minima* has two distinct cytotypes: 2n=4x=36 and 2n=6x=54. The first population occurred in Brazil, and the second in Argentina. In its adventive range, genetic distances range to .48, which are high for an introduced, vegetatively reproducing plant (Madeira et al., 2003).

Reproductive Biology
S. minima reproduces vegetatively. Branching and fragmentation of rhizomes leads to the production of a high number of daughter plants (Jacono, 2003) The stiff hairs on the surface of the leaf helps to slow the desiccation of the plant, thus allowing it to spread long distances out of water (Jacono, 2003). Members of the genus occasionally reproduce via spores produced in sporocarps (USACE-ERDC, 2002), but fertile specimens are so rarely reported that the species is essentially considered sterile (Flora of North America Editorial Committee, 1993+).

Physiology and Phenology
High rates of vegetative reproduction occur throughout the growing season. Lateral buds are found deeply imbedded in the stem, and will also lie dormant during dry and cold periods, sprouting when warmer temperatures occur. Additionally, rhizome fragments can also lie dormant in vegetation until favorable growing conditions return (ISSG, 2006). Dickinson and Miller (1998) showed that the competitive effects of *Salvinia minima* varied with the seasons, the plant took over the surface area during the summer but grew only very slowly in the fall, when its competitive effects were minimal.

Associations
Few reports of this species' associates and the corresponding strength of those associations exist in the literature. One field study on the competitive ability of floating leaf species reports *S. minima* from a habitat that also supports the other floating-leaf species *Azolla caroliniana, Spirodella punctata, Wolffia* spp*., Wolffiella* spp. and *Lemna* spp. This same habitat also supports *Typha*, *Sparganium americanum, Hydrocotyle ranunculoides, Myriophyllum* spp. and *Bidens laevis* (Dickinson and Miller, 1998).

Environmental Requirements
S. minima can grow in a wide variety of aquatic habitats, but does best in those with a high organic content (UFL-IFAS, 2002). It is also most frequently found in still and slow-moving water. Phytoremediation investigations suggest that *S. minima* be grown at a pH of 5.0 or 6.0 and with a maximum initial ammonium-nitrogen concentration of 70 mg/L (Olguin et al., 2007). The species is sensitive to high salinity; coastal populations in Texas are sometimes only found during the winter months, when salinity decreases to around 4-7ppt (Jacono, 2003).

Movement and Dispersal

Natural Dispersal
S. minima spreads vegetatively, is free-floating and highly capable of passive transmission by water movement.

Vector Transmission
The discharge of ship ballast water contaminated with spores may explain the initial introduction of *S. minima* outside of its native range (ISSG, 2006). However, since the plant is largely sterile, spread of spores may prove less of a threat than vegetative spread. Its resistance to desiccation provided by the stiff leaf hairs means it is easily transported on boating and other recreational equipment, humans and wildlife. *S. minima* can hitchhike between waterbodies over long distances on boats, trailers, alligators, turtles and dogs (Jacono, 2003).

Accidental Introduction
People report seeing *S. minima* transported on boats, trailers, and dogs. The ability of this plant to act as a hitchhiker makes it an excellent candidate for accidental introduction (ISSG. 2006). It is also occasionally included as a contaminant in aquaculture mailings (ISSG, 2006).

Intentional Introduction
S. minima is an important plant in the water garden industry. It is widely available for purchase, and people may intentionally plant the species in areas where it may escape to natural environments (ISSG, 2006).

Natural Enemies
Several herbivorous insects are reported from field surveys. The semi-aquatic grasshopper *Paulinia acuminata* oviposits on *Salvinia* fronds and has shown promise in the biological control of *S. molesta* (Julien et al., 2002). The curculionid *Neohydronomus affinis* which occurs naturally as a predator of water lettuce will also feed and oviposit on *S. minima*. A weevil species (*Cyrtobagous salvinia*) similarly uses populations of *S. minima* for food and during reproduction (Tipping and Center 2005). In fact, the weevil is found widely in Florida, but in no other states in *Salvinia*'s adventive range, which may explain the higher nuisance levels reported from other states (Jacono et al., 2001).

Impacts

Economic Impact
This species is capable of an extremely high growth rate. In its adventive range the plants can rapidly colonize bodies of water, forming thick mats that displace native species, impact water quality, impede recreational activities, clog waterways, water

intakes and irrigation channels; it can also interfere with power generation, and decrease the integrity of fisheries (Rayachhetry et al., 2002; Jacono, 2003). All of these factors present some economic impacts that can be severe, although specific studies that quantify the economic damage are lacking.

Social Impact
This plant can cause substantial nuisance to recreational users by impeding navigation and tangling fishing line. *Salvinia minima* is capable of extremely dense growth, creating mats as thick as 20 to 25 cm. (Jacono, 2003). This species can reduce swimming access, founder livestock, and stimulate unsightly, possibly toxic, algal blooms. In Louisiana, the plants occur in a thick mat almost entirely covering a waterway with area 19.3 km x 110 m. These thick mats clog waterways, irrigation channels, affect power generation and block water intakes (Jacono, 2003)

Impact on Habitat
The introduction of *S. minima* poses a significant threat to aquatic systems in the southern areas of the United States (Jacono et al., 2001). This species is highly productive during the summer, but quickly dies back as soon as temperatures decrease (Dickinson and Miller 1998). The sudden pulse of decaying organic matter can cause nutrient pulses and dissolved oxygen crashes that can result in fish kills and algae blooms. Additionaly, colonies of *Salvinia minima* can grow very densely, such that they shade light from valuable native submerged aquatic plant species (USACE-ERDC, 2002; ISSG, 2006). *S. minima* is extremely competitive and can displace native vegetation and result in a decrease in food and habitat available for other native organisms (ISSG, 2006).

Impact on Biodiversity
S. minima grows densely and can outcompete native plant species (ISSG, 2006), which likely corresponds to a decrease in local biodiversity. The plant is highly competitive among other free-floating species. A competition study specifically showed that *S. minima* had negative effects on the change in cover of the species *Azolla caroliniana* and *Spirodela punctata* (Dickinson and Miller, 1998). In Louisiana, native *Lemna* species were completely replaced by *S. minima* (ISSG, 2005).

Management

Economic Value
S. minima has successfully been used in water reclamation activities. It has been used quite often in the treatment of water contaminated with lead, cadmium, as well as for treating high-strength synthetic organic wastewater (Olguin et al., 2007; Olguin et al., 2005; Outridge and Hutchinson, 1991).

Social Benefit
Salvinia minima has been used industrially in the phytoremediation of water contaminated with heavy metals and organic waste (Olguin et al., 2007; Olguin et al., 2005; Outridge and Hutchinson, 1991).

Invasive Species Management

Prevention
The vegetative propagules of this species are very easy to spread. Therefore, educational programs are usually necessary to decrease this form of human-mediated spread. Teaching users how to clean equipment in a way that decreases the chance of transmission is one way to lessen the impact of the human vector. Several states have legislated the regulation of the purchase, transportation, and introduction of this species.

Detection and Inspection Methods
S. minima is a floating species, which makes it easier to identify than most submerged aquatic vegetation. Volunteer monitors should be trained on the identity and habit of this potential invader.

Rapid Response
If a population is removed relatively quickly, it may be possible to prevent population establishment.

Public Awareness
Numerous educational campaigns have been directed at informing the public about the danger of aquatic invasive species. States in which *S. minima* is particularly problematic commonly distribute informational materials about its identity as well as how to report new invasions. Other educational campaigns have been directed toward informing the public about how to clean equipment in order to prevent the movement of invasive species.

Eradication
There are reports of successful eradication of *Salvinia molesta* (Miller and Wilson 1989, HI DLNR 2004), but to our knowledge, no similar reports exist for *S. minima.*

Cultural Control and Sanitary Measures
Fragments, ramets, rhizomes and plants are easily transportable and are resistant to desiccation. Thus, it is extremely important to decrease the instances of accidental introduction by addressing humans as a vector. By establishing guidelines on how to properly clean equipment, dispose of water, and identify target plants, it is likely that instances of accidental transportation and release will be fewer.

Physical and Mechanical Control
Mechanical harvesting may be used to control small populations of *S. minima*. Otherwise, as the plant is intolerant of salinity levels above 7ppt, salt water from the Gulf is often allowed to flow into bayous along coastal sites in North America. Water drawdown to a level at which stranded plants will dry out and freeze provides effective control and nuisance relief (Jacono, 2003).

Movement Control
Barriers and screens and booms have shown some ability to control the spread of local populations but require significant maintenance and clearing to be truly effective (ISSG, 2006). Since plants can spread via fragments, much attention has been given to decrease human-mediated dispersal. The plant is on a number of state noxious lists. Some states have put in place legislation to regulate the sale, transportation and introduction of *S. minima.*

Chemical Control
Glyphosate and trifluralin have been found to be highly lethal to *S. minima* (although trifluralin is a known human health hazard), and 2,4-D significantly inhibits growth (Santos and Banzatto, 1998). Repeated treatments of diquat and fluridone have also been found to control *S. minima* successfully (ISSG 2006). According to McKinney and Durocher, the dense hairs covering the fronds may reduce herbicide absorption for foliar applications (cited in ISSG 2006).

Biological Control
The weevil *Cyrtobagous salviniae* has proven to be an effective natural predator in, as well as outside of, the native range of *S. minima*. In the United States, the weevil is found abundantly in Florida, where the species is less of a nuisance compared to the areas to which the weevil has not been introduced (Madeira et al., 2003). Of the currently explored species, the weevil show the most promise as a biological control agent, as no barriers seem to exist barring the introduction of the weevil beyond Florida (Madeira et al., 2003).

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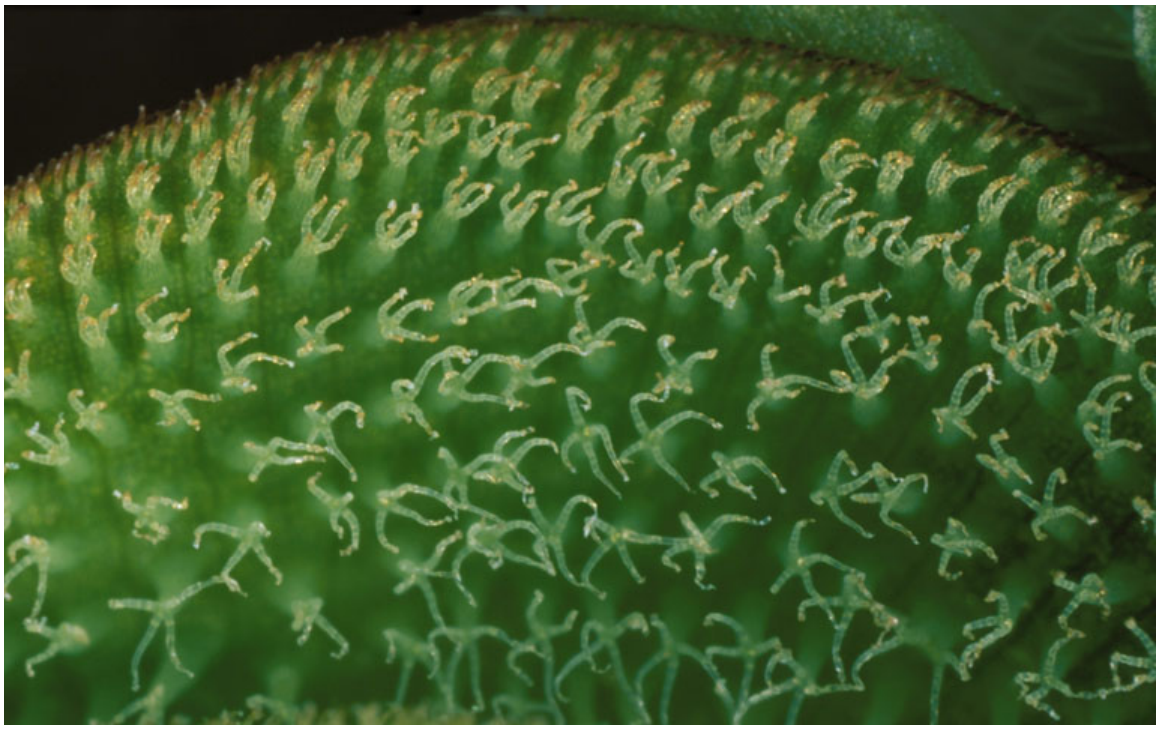

Salvinia minima
Underside of leaf, unbranched hairs

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