Sagittaria australis

Southern Arrowhead

Alismataceae

Sagittaria australis courtesy R. W. Smith, Lady Bird Johnson Wildflower Center

***Sagittaria australis* Rare Plant Profile**

New Jersey Department of Environmental Protection
State Parks, Forests & Historic Sites
State Forest Fire Service & Forestry
Office of Natural Lands Management
New Jersey Natural Heritage Program

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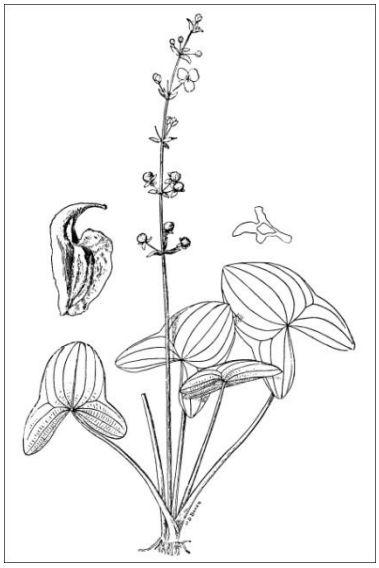
Life History

Sagittaria australis (Southern Arrowhead) is a perennial aquatic herb in the water-plantain family. The basal leaves are held above the water on sturdy petioles that are 19–85 cm long and distinctly five-winged, and the large leaf blades are broadly arrow-shaped with backward-pointing lobes. The stout scape of the inflorescence may reach up to a meter in height and bears 5–12 whorls of flowers. Each whorl includes three flowers and three basal bracts which are lance shaped and have a somewhat papery appearance. *S. australis* plants are monoecious (having separate male and female flowers) and the whorls of male (staminate) flowers are situated above those of the female (pistillate) flowers. The flowers are up to 3 cm wide and have three white petals, three spreading or downwardly curved sepals, and numerous stamens or pistils. In fruit, the pedicels are spreading or ascending. The fruits are a dense conglomeration of one-seeded achenes that form a spiny ball 1–2.2 cm in diameter. Individual achenes are flat, winged, glandless, and have an erect beak 0.7–1.7 mm long with a recurved tip. (See Britton and Brown 1913, Fernald 1950, Fassett 1957, Beal et al. 1982, Gleason and Cronquist 1991, Block and Rhoads 2011, Spaulding et al. 2019, Haynes and Hellquist 2020).



Left: Illustration from Mohr (1901). Center and Right: Photos by Dwayne Estes, 2001.

Sagittaria australis reproduces vegetatively via lateral stems (stolons) and corms (Haynes and Hellquist 2020). During the late summer months *Sagittaria* plants produce one or more white stolons, each of which terminates in a storage organ topped with a bud (corm) that is suitable for surviving the winter, and the downward-curving tips of the stolons press the corms into the mud (Arber 1920). The stolons usually decay by winter (Arber 1920), although some may persist longer (Rogers 1983). When spring arrives the corms develops into new plants (Arber 1920). *Sagittaria australis* can bloom from June through October (Haynes and Hellquist 2020, Weakley 2022). In the northern part of its range the species is likely to flower between late July and early September (Rhoads and Block 2007) and mature fruits can often be found in late September and October (NJNHP 2022).

Ten additional kinds of *Sagittaria* may be found in New Jersey (Kartesz 2015) but *S. australis* is most likely to be confused with other species that have predominately arrow-shaped leaves such as *S. cuneata*, *S. engelmanniana*, and *S. latifolia*. Mature achenes are helpful in distinguishing the plants: Those of *S. latifolia* have beaks that are perpendicular rather than erect, and resinous glands are present on those of *S. cuneata* and *S. engelmanniana*. When plants are still in flower the sharply-winged petioles can help to identify *Sagittaria australis*, and some characteristics of the floral bracts may also be helpful in making a species determination (Beal et al. 1982).

Emerson et al. (1999) found that iron-oxidizing bacteria are sometimes present in the root zone of *Sagittaria australis* plants, coating the roots with a rusty precipitate known as Fe-plaque. The coating may serve as a barrier to oxygen loss or to the uptake of contaminants (Hansel et al. 2001, Pi et al. 2010), and the bacteria might also play a role in the cycling of nutrients (Emerson et al. 1999).

Pollinator Dynamics

As with other plants in the Alismataceae, *Sagittaria* species are self-compatible (Rogers 1983, Haynes et al. 1998, Les 2020). Nevertheless, *Sagittaria* flowers are showy, secrete nectar, and typically attract a broad array of pollinators that may include various species of bees, wasps, flies, beetles, and butterflies (Rogers 1983, Les 2020). Muenchow and Delesalle (1994) reported that *S. australis* flowers were pollinated by an assortment of generalist bees, with the most frequent visitors including *Lasioglossum*, *Ceratina*, *Augochlora*, and *Bombus* species.

Haynes et al. (1998) remarked that flowers in the water-plantain family often open mid-morning and close in the afternoon, and Muenchow and Delesalle (1994) noted that the flowers of *Sagittaria australis* only remained open for a day. Due to its clonal reproduction Southern Arrowhead can form large stands (Rogers 1983), which likely enhances the visibility of the floral display. Muenchow and Delesalle (1992, 1994) found that the lowest (pistillate) flowers on any given plant were the first to bloom, often opening together, but the staminate flowers did not all open at once: While an average inflorescence contained 16–21 male flowers usually only four or five were in bloom simultaneously. In *S. australis*, the staminate flowers are larger than the pistillate ones (Delph 1996) and it has been demonstrated that larger *Sagittaria* flowers are more attractive to pollinators (Glaettli and Barrett 2008). While the showier male flowers may initially draw insects to the plants, once the pollinators arrive it is more energy-efficient for them to continue foraging locally (Ohashi and Yahara 2001) and the bees observed on *S. australis* by Muenchow and Delesalle (1994) visited both male and female flowers. Because of their clumped distribution the flowers of clonal plants are more likely to be fertilized with closely related pollen (Vallejo-Marín et al. 2010), but self-pollination does not appear to affect seed quality in *Sagittaria australis* (Baskin and Baskin 2015).

Seed Dispersal and Establishment

A female *Sagittaria* flower has numerous pistils, sometimes as many as 1500 or more (Haynes and Hellquist 2020), and seed production in the genus is generally high (Les 2020). Although

the winged achenes of *S. australis* may occasionally be moved by wind they are primarily adapted for water dispersal. *Sagittaria* propagules are resistant to wetting and the seeds have been known to float for months while retaining viability (Arber 1920, Rogers 1983). The curved stylar beaks on *S. australis* achenes could also facilitate attachment to birds or mammals for longer dispersal distances (Haynes et al. 1998, Rogers 1983). Some species of *Sagittaria* can be dispersed by fish (Pollux 2011). The achenes may also be eaten by waterfowl (USDA NRCS 2000), and although that is somewhat rare when it does occur it can be a significant event with several hundred seeds being consumed in a single feeding period (Les 2020). Some vegetative dispersal of stolons and corms, or even entire plants, may also take place (Rogers 1983).

Sagittaria seeds have a hard inner coat that delays germination until the protective layer becomes cracked or decayed (Crocker 1907, Arber 1920). Under normal circumstances plants in the genus are slow to germinate, often taking two years, and *S. latifolia* seeds are sometimes said to need various stratification regimes (USDA NRCS 2000, Northwest Meadowscapes 2022). However, experimental work has indicated that a period of dormancy is not an absolute requirement and *Sagittaria* seeds can germinate rapidly in some situations (Crocker 1907, Leck and Simpson 1993). Seed banking has been documented in *Sagittaria*, and *S. latifolia* was characterized as a species that can maintain some presence in a seed bank even after large portions of its propagules have been depleted (Leck and Simpson 1993). Grabowski (2001) discussed propagation methodology for several wetland plant species and indicated that *Sagittaria australis* requires a saturated substrate in order to germinate and establish. No studies of *S. australis* germination under natural circumstances were found, but it is possible that the seeds can also sprout underwater as they often do in other *Sagittaria* species (Arber 1920, Leck and Graveline 1979, Sarneel et al. 2014, USDA NRCS 2000, Northwest Meadowscapes 2022). Once *Sagittaria* seeds have germinated the seedlings usually have a good chance of successful establishment (USDA NRCS 2000). Although mycorrhizae have been documented in *S. latifolia* (Wang and Qiu 2006) they were not noted by Emerson et al. (1999) during their study of *S. australis* roots.

Habitat

Sagittaria australis grows in a variety of wet habitats at elevations from 1–300 meters above sea level (Haynes and Hellquist 2020). The species is a generalist in terms of canopy openness: Work by Szakacs (2020 and Szakacs et al. 2022) showed that *S. australis* had no significant habitat preference relative to shade classes. Robinson (1956) recorded a water pH of 6.9 at two *S. australis* sites in Tennessee, and range-wide the species is known to tolerate conditions that vary from slightly acidic to slightly basic (Haynes and Hellquist 2020). However, a continuously wet substrate appears to be necessary—Luken and Thieret (2001) reported that Southern Arrowhead grew profusely on frequently flooded portions of a lake shoreline but was absent from mud flats and sites that were not frequently flooded.

Throughout its range, *Sagittaria australis* has been found growing in the shallow waters of marshes, swamps, bogs, backwater pools, and floodplain meadows, as well as along the margins of rivers, lakes, and ponds (Silberhorn 1970, Rhoads and Block 2007, Block and Rhoads 2011, Weakley et al. 2022). It has also colonized the emergent zones of artificial water bodies

including reservoirs (Luken and Bezold 2000, Thompson and Fleming 2004) and a ponded area created by seepage from underground quarrying (Thompson et al. 2005). At suitable sites *S. australis* can become locally abundant (Robinson 1956).

In New Jersey the habitats of extant *S. australis* populations include both swampy woods and a more open, herb-dominated seepage area, while some historical occurrences were associated with brooks, ponds, bogs, and marshy river shores (NJNHP 2022). Vermont's sole colony of Southern Arrowhead is somewhat unusual in that it is confined to an alluvial mid-river island where the plants are sometimes exposed to strong currents or subject to rapid inundation (Gilman et al. 2020). The authors noted that the Vermont population had persisted at the site for at least four years despite its exposure to a high-energy environment.

Wetland Indicator Status

Sagittaria australis is an obligate wetland species, meaning that it almost always occurs in wetlands (U. S. Army Corps of Engineers 2020).

USDA Plants Code (USDA, NRCS 2022)

SAAU2

Coefficient of Conservatism (Walz et al. 2018)

CoC = 7. Criteria for a value of 6 to 8: Native with a narrow range of ecological tolerances and typically associated with a stable community (Faber-Langendoen 2018).

Distribution and Range

The global range of *Sagittaria australis* is restricted to the eastern and central United States (POWO 2022). The map in Figure 1 depicts the extent of *S. australis* in the North America.

The USDA PLANTS Database (2022) shows records of *Sagittaria australis* in five New Jersey counties: Burlington, Cape May, Middlesex, Monmouth, and Somerset (Figure 2). *S. australis* has also been collected in Gloucester, Hunterdon, and Mercer counties (Mid-Atlantic Herbaria 2022). The data include historic observations and do not reflect the current distribution of the species.

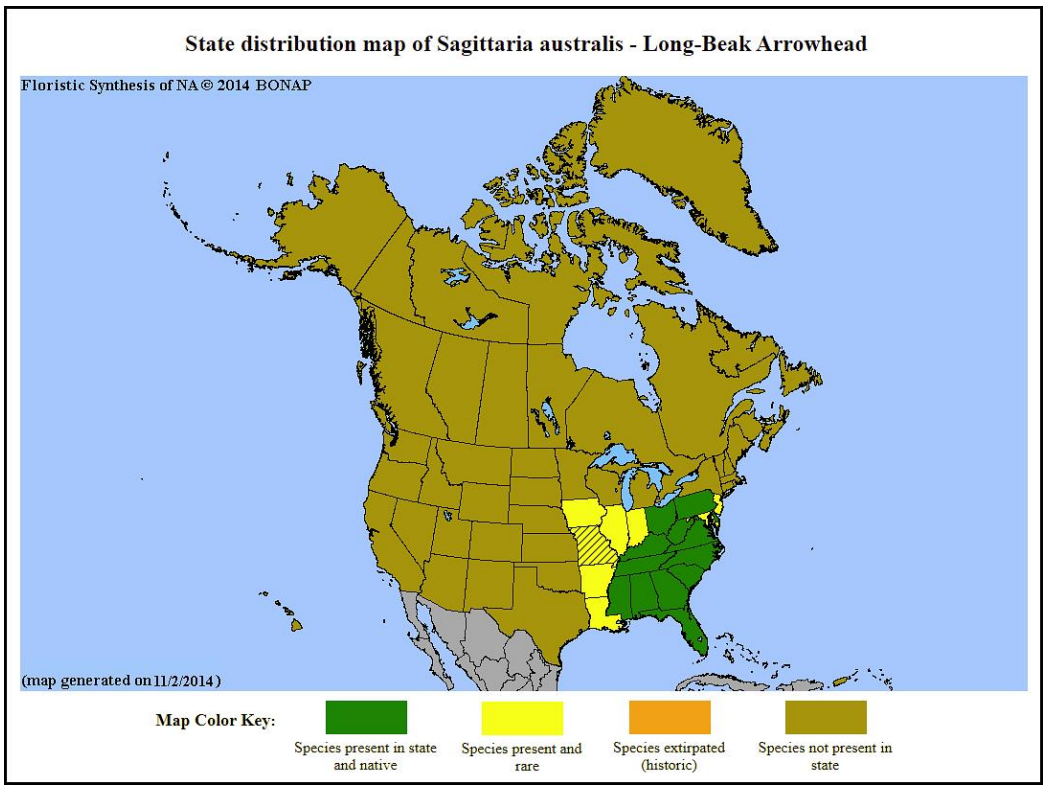


Figure 1. Distribution of S. australis in North America, adapted from BONAP (Kartesz 2015).

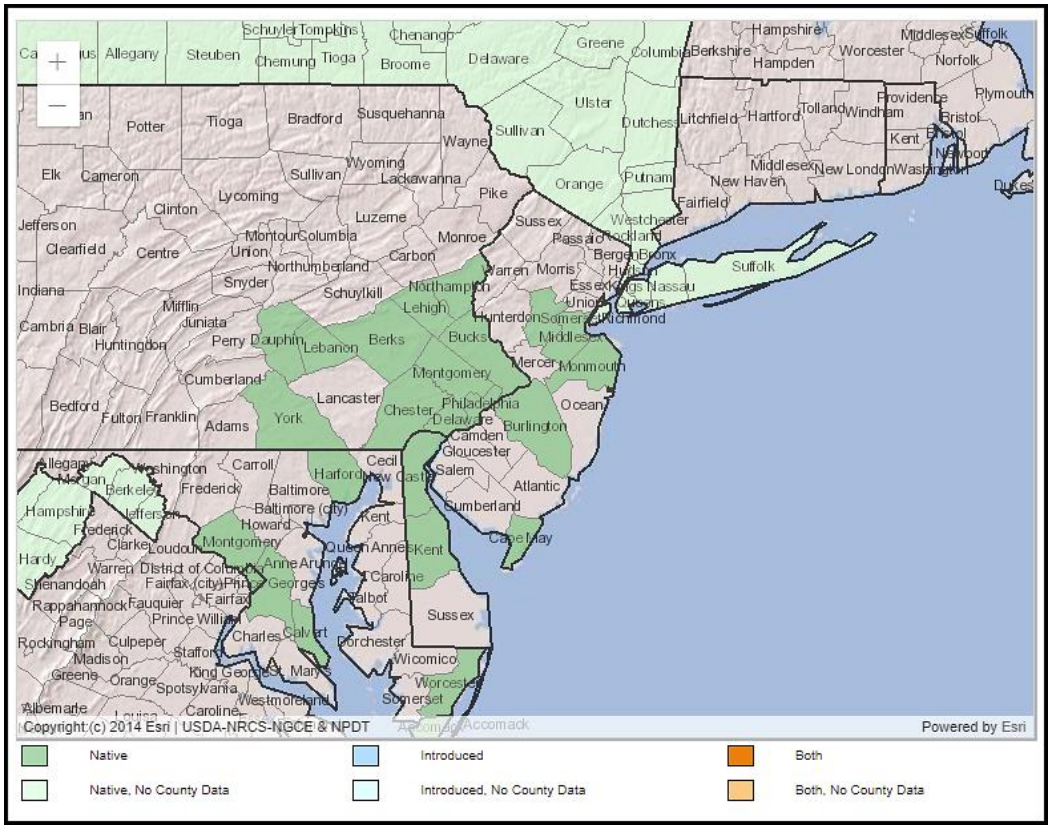


Figure 2. County records of S. australis in New Jersey and vicinity (USDA NRCS 2022).

Conservation Status

Sagittaria australis is considered globally secure. The G5 rank means the species has a very low risk of extinction or collapse due to a very extensive range, abundant populations or occurrences, and little to no concern from declines or threats (NatureServe 2022). The map below (Figure 3) illustrates the conservation status of *S. australis* throughout its range. Southern Arrowhead is critically imperiled (very high risk of extinction) in three states and vulnerable (moderate risk of extinction) in one state. In Ohio its distribution is limited to the unglaciated Allegheny Plateau in the southeastern region of the state (Silberhorn 1970). The seemingly disjunct occurrence in Vermont consists of a single population that was discovered in 2016 (Gilman et al. 2020). Although *S. australis* has been cited as occurring in New York (e.g. Profous and Loeb 1984, Gleason and Cronquist 1991), it was excluded from a recent flora of that state due to a lack of documentation (Werier 2017). Throughout the majority of its range *S. australis* is secure, apparently secure, or unranked.

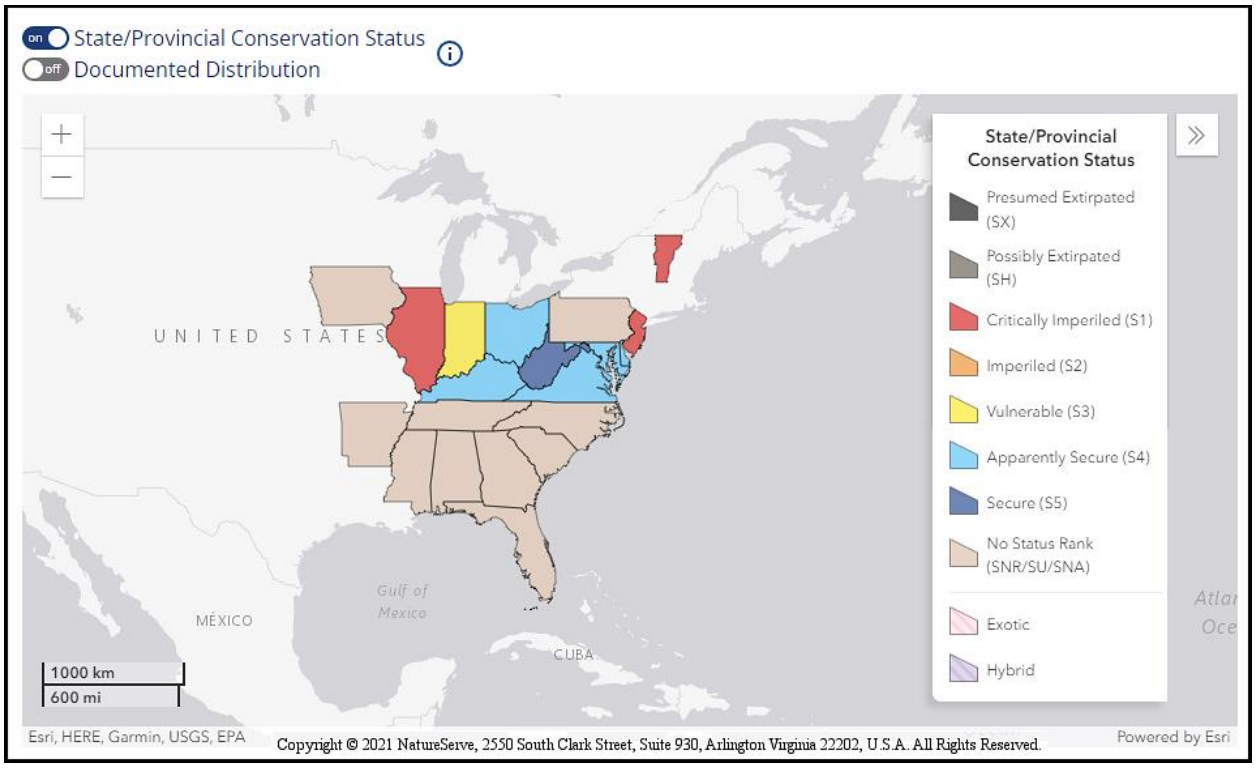


Figure 3. Conservation status of S. australis in North America (NatureServe 2022).

Sagittaria australis is critically imperiled (S1) in New Jersey (NJNHP 2022). The rank signifies five or fewer occurrences in the state. A species with an S1 rank is typically either restricted to specialized habitats, geographically limited to a small area of the state, or significantly reduced in number from its previous status. *S. australis* is also listed as an endangered species (E) in New Jersey, meaning that without intervention it has a high likelihood of extinction in the state. Although the presence of endangered flora may restrict development in certain communities such as wetlands or coastal habitats, being listed does not currently provide broad statewide protection for the plants. Additional regional status codes assigned to *S. australis* signify that the species is

eligible for protection under the jurisdictions of the Highlands Preservation Area (HL) and the New Jersey Pinelands (LP) (NJNHP 2010).

It is difficult to ascertain the early status of *Sagittaria australis* in New Jersey from the older literature due to some initial confusion around the name (see Synonyms and Taxonomy section). Nevertheless, at least nine specimens collected during the first half of the 20th century have been confirmed as *S. australis* although most of the early occurrences are now ranked as historical in the state (NJNHP 2022). One of the original populations was relocated in 1987 by Snyder, who also discovered a previously unknown population at another site in 1994 (Snyder 2000). Those two occurrences continue to be New Jersey's only known extant populations of *Sagittaria australis* (NJNHP 2022).

Threats

In the past, loss of habitat due to development has been a major factor in the decline of rare plant species in New Jersey (NJDSR 2021) and that probably contributed to the loss of some historical occurrences of *Sagittaria australis*. While laws and regulations established during the past half-century have limited the direct destruction of wetlands, the sensitive habitats can still be significantly degraded by practices elsewhere in their watersheds that alter water quality, abundance, and flow patterns. The observation by Luken and Thieret (2001) that *S. australis* was found only in the most frequently flooded locations around a lake but absent from sites where water levels had receded suggests that the species is particularly sensitive to hydrological changes.

Human activity on a much smaller scale might also imperil some *S. australis* plants, as foot traffic has been identified as a concern for other *Sagittaria* species. Muenchow and Delesalle (1992) noted that *S. latifolia* plants could be killed by trampling and took care to limit their access to pre-determined trails while studying populations, and trampling by livestock was cited as a threat to *S. fasciculata* (USFWS 2020).

Sagittaria plants can be damaged by weevils in the genus *Listronotus*, several species of which (*L. appendiculatus*, *L. caudatus*, *L. echinodori*) are known to utilize Southern Arrowhead as one of their host plants (Muenchow and Delesalle 1992, Kwong et al. 2014). The larvae of *Listronotus appendiculatus* can interfere with a plant's reproductive success by damaging seed heads or killing an entire inflorescence (Muenchow and Delesalle 1992), and Kwong et al. (2014) found that achene production was significantly lower in fruiting heads that were attacked by weevils. Tuber-feeding weevils such as *L. caudatus* deplete a plant's storage organs, which can interfere with vegetative reproduction or result in death (Kwong et al. 2014). Muenchow and Delesalle reported that *L. caudatus* larvae destroyed the tubers of *Sagittaria latifolia* plants but it is not clear whether they inflicted similar damage on the corms of *S. australis*. Lesser impacts were noted from *Listronotus echinodori*, where observed injuries were primarily due to leaf herbivory by mature weevils.

An assessment of rare species in Illinois, another state where *Sagittaria australis* is critically imperiled, concluded that Southern Arrowhead is extremely vulnerable to climate change—

meaning that the species is extremely likely to substantially decline or to disappear from Illinois by 2050 (Molano-Flores et al. 2019). Although *S. australis* is primarily a southern species that may be able to adapt to rising temperatures in places like New Jersey which are near the northern end of its range, other shifts in climactic conditions may be more problematic for the arrowhead. One consequence of shifting weather patterns in the northeast is an increase in the frequency of droughts, and regional aquifers may also become stressed by a longer growing season (Hill et al. 2020). Because *S. australis* appears to need a stable water supply, the changes could limit the plant's ability to persist in some locations. Populations in coastal areas may also be subjected to rising salinity levels. Although no studies of salinity tolerance in *S. australis* were found, research on other *Sagittaria* species has documented a number of potentially harmful effects including a reduction in photosynthetic activity, leaf damage, and decreases in aboveground or belowground biomass (Pezeshski et al. 1987, Delesalle and Blum 1994, Baldwin and Mendelssohn 1998, Howard and Mendelssohn 1999, Martin and Shaffer 2005).

Management Summary and Recommendations

Because the majority of New Jersey's known occurrences of *Sagittaria australia* have been lost, conservation of the remaining populations is particularly important. An updated assessment of the extant occurrences is recommended in order to evaluate current population status and identify potential threats. Site-specific conservation planning should consider both land protection and activities on adjacent properties that may have an impact on water availability or quality. Potential habitat is still believed to be present in the vicinity a number of the state's historical occurrences (NJNHP 2022), so searches of those areas might turn up some persistent colonies.

Some research has been done on offsite propagation of *S. australis* (e.g. Grabowski 2001) but species-specific studies of germination and establishment under natural circumstances are needed. It would also be helpful to know whether the weevils that damage the tubers of *S. latifolia* have a comparable effect on the corms of *S. australis*. Additional information regarding how well Southern Arrowhead adapts to changes in water quality would be useful in planning for its conservation. For example, different species of *Sagittaria* vary in their responses to increased salinity and, while *S. australis* is generally known to occur in habitats with a moderate pH, the species' ability to tolerate more alkaline or acidic environments has not been reported.

Synonyms and Taxonomy

The accepted botanical name of the species is *Sagittaria australis* (J. G. Smith) Small. Orthographic variants, synonyms, and common names are listed below (ITIS 2021, POWO 2022, USDA NRCS 2022). Care should be taken when using older references as there was previously some taxonomic confusion around the terminology. Although the name *Sagittaria australis* was first published in 1903 it was initially used only in reference to plants from Alabama (Small 1903). Some early authors did not distinguish the northeastern plants from *S. engelmanniana* (e.g. Stone 1911), while others applied the names *S. longirostra* or *S. engelmanniana* ssp. *longirostra* which were also sometimes utilized as synonyms for *S. latifolia* (Beal et al. 1980). While Bogin (1955) offered some more precise descriptions and range information in his

revision of the genus, *S. australis* was still treated as a subspecies of *S. engelmanniana*. Additional clarity was provided by Beal et al. (1982).

Botanical Synonyms	**Common Names**
Sagittaria longirostra (Micheli) J. G. Sm.	Southern Arrowhead
Sagittaria engelmanniana ssp. *longirostra* (Micheli) Bogin	Appalachian Arrowhead
Sagittaria longirostra var. *australis* J. G. Sm.	Longbeak Arrowhead

References

Arber, Agnes. 1920. Water Plants: A Study of Aquatic Angiosperms. Cambridge University Press, Cambridge, United Kingdom. 436 pp.

Baldwin, Andrew H. and Irving A. Mendelssohn. 1998. Effects of salinity and water level on coastal marshes: An experimental test of disturbance as a catalyst for vegetation change. Aquatic Botany 61: 255–268.

Baskin, Jerry M. and Carol C. Baskin. 2015. Inbreeding depression and the cost of inbreeding on seed germination. Seed Science Research 25: 355–385.

Beal, E. O., Sheila S. Hooper, and K. Rataj. 1980. Misapplication of the name *Sagittaria longirostra* (Micheli) J. G. Smith (Alismataceae) to *S. australis* (J. G. Smith) Small. Kew Bulletin 35(2): 369-371.

Beal, E. O., Jean W. Wooten, and R. B. Kaul. 1982. Review of the *Sagittaria engelmanniana* complex (Alismataceae) with environmental correlations. Systematic Botany 7(4): 417–432.

Block, Timothy A. and Ann Fowler Rhoads. 2011. Aquatic Plants of Pennsylvania: A Complete Reference Guide. University of Pennsylvania Press, Philadelphia, PA. 320 pp.

Bogin, C. 1955. Revision of the genus *Sagittaria*. Memoirs of the New York Botanical Garden 9: 179–233.

Britton, N. L. and A. Brown. 1913. An Illustrated Flora of the Northern United States and Canada in three volumes: Volume I (Ferns to Buckwheat). Second Edition. Reissued (unabridged and unaltered) in 1970 by Dover Publications, New York, NY. 680 pp.

Crocker, William. 1907. Germination of seeds of water plants. Botanical Gazette 44(5): 375–380.

Delesalle, Veronique A. and Stephanie Blum. 1994. Variation in germination and survival among families of *Sagittaria latifolia* in response to salinity and temperature. International Journal of Plant Sciences 155(2): 187–195.

Delph, Lynda F. 1996. Flower size dimorphism in plants with unisexual flowers. In David G. Lloyd and Spencer C. H. Barrett (eds)., Floral Biology: Studies on Floral Evolution in Animal-Pollinated Plants. Chapman and Hall, New York, NY.

Emerson, David, Johanna V. Weiss, and J. Patrick Megonigal. 1999. Iron-oxidizing bacteria are associated with ferric hydroxide precipitates (Fe-plaque) on the roots of wetland plants. Applied and Environmental Microbiology 65(6): 2758–2761.

Estes, Dwayne. 2021. Photos of *Sagittaria australis* from Tennessee. Shared via iNaturalist at https://www.inaturalist.org/observations/54229826, licensed by https://creativecommons.org/licenses/by-nc/4.0/

Faber-Langendoen, D. 2018. Northeast Regional Floristic Quality Assessment Tools for Wetland Assessments. NatureServe, Arlington, VA. 52 pp.

Fassett, Norman C. 1957. A Manual of Aquatic Plants. Second Edition. University of Wisconsin Press, Madison, WI. 405 pp.

Fernald, M. L. 1950. Gray's Manual of Botany. Dioscorides Press, Portland, OR. 1632 pp.

Gilman, A. V., E. T. Doucette, B. Engstrom, A. Marcus, and M. J. Peters. 2020. Additions to the new flora of Vermont—II. Phytoneuron 16: 1–17.

Glaettli , Mélanie and Spencer C. H. Barrett. 2008. Pollinator responses to variation in floral display and flower size in dioecious *Sagittaria latifolia* (Alismataceae). New Phytologist 179: 1193–1201.

Gleason, H. A. and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. Second Edition. The New York Botanical Garden, Bronx, NY. 910 pp.

Grabowski, Janet M. 2001. Observations on seed propagation in Mississippi wetland species. Native Plants Journal 2(1): 67–68.

Hansel, Colleen M., Scott Fendorf, Steve Sutton, and Matt Newville. 2001. Characterization of Fe plaque and associated metals on the roots of mine-waste impacted aquatic plants. Environmental Science and Technology 35: 3863–3868.

Haynes, R. R., D. H. Les, and L. B. Holm-Nielsen. 1998. Alismataceae. In Klaus Kubitzki and T. Stuzel (eds). The Families and Genera of Vascular Plants, Volume 4: Flowering Plants, Monocotyledons: Alismatanae and Commelinanae (Except Gramineae). Springer-Verlag, Berlin. 521 pp.

Haynes, Robert R. and C. Barre Hellquist. Page updated November 5, 2020. *Sagittaria australis*

(J. G. Smith) Small. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico [Online]. 22+ vols. New York and Oxford. Accessed October 19, 2022 at http://floranorthamerica.org/Sagittaria_australis

Hill, Rebecca, Megan M. Rutkowski, Lori A. Lester, Heather Genievich, and Nicholas A. Procopio (eds.). 2020. New Jersey Scientific Report on Climate Change, Version 1.0. New Jersey Department of Environmental Protection, Trenton, NJ. 184 pp.

Howard, Rebecca J. and Irving A. Mendelssohn. 1999. Salinity as a constraint on growth of oligohaline marsh macrophytes. I. Species variation in stress tolerance. American Journal of Botany 86(6): 785–794.

ITIS (Integrated Taxonomic Information System). Accessed November 13, 2021 at http://www.itis.gov

Kartesz, J. T. 2015. The Biota of North America Program (BONAP). Taxonomic Data Center. (http://www.bonap.net/tdc). Chapel Hill, NC. [Maps generated from Kartesz, J. T. 2015. Floristic Synthesis of North America, Version 1.0. Biota of North America Program (BONAP) (in press)].

Kwong, Raelene M., Jean-Louis Sagliocco, Nathan Harms, Judy Shearer, Brian Keener, and Peter Green. 2014. Prospects for the biological control of delta arrowhead (*Sagittaria platyphylla*), an invasive aquatic species in Australia. In F. A. C. Impson, C. A. Kleinjan and J. H. Hoffmann (eds). Proceedings of the XIV International Symposium on Biological Control of Weeds, 2–7 March 2014, Kruger National Park, South Africa.

Leck, M. A. and K. J. Graveline. 1979. The seed bank of a freshwater tidal marsh. American Journal of Botany 66: 1006–1015.

Leck, Mary A. and Robert L. Simpson. 1993. Seeds and seedlings of the Hamilton Marshes, a Delaware River tidal freshwater wetland. Proceedings of the Academy of Natural Sciences of Philadelphia 144: 267–281.

Les, Donald H. 2020. Aquatic Monocotyledons of North America: Ecology, Life History and Systematics. CRC Press, Boca Raton, FL. 568 pp.

Luken, James O. and Todd N. Bezold. 2000. Species richness and wetland status of different shoreline elements at Cave Run Lake, Kentucky. Castanea 65(2): 126–183.

Luken, James O. and John W. Thieret. 2001. Floristic relationships of mud flats and shorelines at Cave Run Lake, Kentucky. Castanea 66(4): 336–351.

Martin, Shannon B. and Gary P. Shaffer. 2005. *Sagittaria* biomass partitioning relative to salinity, hydrologic regime, and substrate type: Implications for plant distribution patterns in coastal Louisiana, United States. Journal of Coastal Research 21(1): 167–174.

Mid-Atlantic Herbaria. 2022. https://midatlanticherbaria.org/portal/index.php. Accessed on January 13, 2022.

Mohr, Charles. 1901. *Sagittaria australis* illustration from Plant Life of Alabama. https://creativecommons.org/publicdomain/zero/1.0/ via Wikimedia Commons.

Molano-Flores, Brenda, David N. Zaya, Jill Baty, and Greg Spyreas. 2019. An assessment of the vulnerability of Illinois' rarest plant species to climate change. Castanea 84(2): 115–127.

Muenchow, G. and V. A. Delesalle. 1992. Patterns of weevil herbivory on male, monoecious and female inflorescences of *Sagittaria latifolia*. The American Midland Naturalist 127(2): 355–367.

Muenchow, Gayle and Veronique Delesalle. 1994. Pollinator response to male floral display size in two *Sagittaria* (Alismataceae) species. American Journal of Botany 81(5): 568–573.

NatureServe. 2022. NatureServe Explorer [web application]. NatureServe, Arlington, VA. Accessed October 19, 2022 at https://explorer.natureserve.org/

NJDSR (New Jersey Division of Science and Research). 2021. Endangered Plants. From Environmental Trends: Plants and Wildlife, N. J. Department of Environmental Protection, available at https://www.nj.gov/dep/dsr/trends/

NJNHP (New Jersey Natural Heritage Program). 2010. Special Plants of NJ - Appendix I - Categories & Definitions. Site updated March 22, 2010. Available at https://nj.gov/dep/parksandforests/natural/docs/nhpcodes_2010.pdf

NJNHP (New Jersey Natural Heritage Program). 2022. Biotics 5 Database. NatureServe, Arlington, VA. Accessed February 1, 2022.

Northwest Meadowscapes. 2022. Grower's guide page for Wapato (*Sagittaria latifolia*). Available at https://northwestmeadowscapes.com/products/wapato-seeds-sagittaria-latifolia?variant=40285097459889

Ohashi, Kazuharu and Tetsukazu Yahara. 2001. Behavioral responses of pollinators to variation in floral display size and their influences on the evolution of floral traits. In Lars Chittka and James D Thomson (eds.). Animal Behavior and Floral Evolution, Cambridge University Press, Cambridge, United Kingdom.

Pezeshski, S. R., R. D. DeLaune, and W. H. Patrick, Jr. 1987. Effects of flooding and salinity on photosynthesis of *Sagittaria lancifolia*. Marine Ecology - Progress Series 41: 87–91.

Pi, N., N. F. Y. Tam., and M. H. Wong. 2010. Effects of wastewater discharge on formation of Fe plaque on root surface and radial oxygen loss of mangrove roots. Environmental Pollution 158: 381–387.

Pollux, B. J. A. 2011. The experimental study of seed dispersal by fish (ichthyochory). Freshwater Biology 56: 197–212.

POWO. 2022. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Accessed October 19, 2022 at http://www.plantsoftheworldonline.org/

Profous, George V. and Robert E. Loeb. 1984. Vegetation and plant communities of Van Cortlandt Park, Bronx, New York. Bulletin of the Torrey Botanical Club 111(1): 80–89.

Rhoads, Ann Fowler and Timothy A. Block. 2007. The Plants of Pennsylvania. University of Pennsylvania Press, Philadelphia, PA. 1042 pp.

Robinson, Franklin Delano. 1956. An Ecological Survey of the Vascular Aquatic Vegetation of the Cumberland Plateau in Tennessee. Master's Thesis, University of Tennessee, Knoxville, TN. 43 pp.

Rogers, George K. 1983. The general of Alismataceae in the southeastern United States. Journal of the Arnold Arboretum 64(3): 383–420.

Sarneel, Judith M., Roel H. Janssen, Winnie J. Rip, Irene M. A. Bender, and Elisabeth S. Bakker. 2014. Windows of opportunity for germination of riparian species after restoring water level fluctuations: a field experiment with controlled seed banks. Journal of Applied Ecology 51(4): 1006–1014.

Silberhorn, Gene M. 1970. A distinct phytogeographic area in Ohio: The Southeastern Allegheny Plateau. Castanea 35(4): 277–292.

Small, John Kunkel. 1903. Flora of the Southeastern United States. Published by the author, New York, NY. 1370 pp.

Smith, R. W. 2015. Cover photo of *Sagittaria australis*. Courtesy of the Lady Bird Johnson Wildflower Center, https://www.wildflower.org/. Used with permission.

Snyder, David. 2000. One hundred lost plants found. Bartonia 60: 1–22.

Spaulding, Daniel D., T. Wayne Barger, Howard E. Horne, and Brian J. Finzel. 2019. Flora of Northern Alabama, part 4. Basal Monocots: Acorales and Alismatales, Sweetflag to Pondweeds. Phytoneuron 47: 1–132.

Stone, Witmer. 1911. The Plants of Southern New Jersey. Quarterman Publications, Boston, MA. 828 pp.

Szakacs, Alexandria Diane. 2020. Using Multiple Approaches to Explore the Past and Present of “Piedmont Prairie” Vegetation. Doctoral dissertation, North Carolina State University, Raleigh, NC. 183 pp.

Szakacs, Alexandria D., Alexander Krings, and Thomas R. Wentworth. 2022. Shade-tolerance classification of the upland herbaceous flora of the Carolina and Virginia Piedmont. The American Midland Naturalist 187(2): 113–147.

Thompson, Ralph L. and Chris A. Fleming. 2004. Vascular flora of five reservoirs in the Berea College forest, Madison and Jackson Counties, Kentucky. Journal of the Kentucky Academy of Science 65(2): 116–131.

Thompson, Ralph L., J. Richard Abbott, and Andrew E. Shupe. 2005. Vascular flora from five plant habitats of an abandoned limestone quarry in Clark County, Kentucky. Journal of the Kentucky Academy of Science 66(1): 24–34.

U. S. Army Corps of Engineers. 2020. National Wetland Plant List, version 3.5. https://cwbi-app.sec.usace.army.mil/nwpl_static/v34/home/home.html U. S. Army Corps of Engineers Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH.

USDA NRCS (U. S. Dept. of Agriculture, Natural Resources Conservation Service). 2000. Plant guide for Broadleaf Arrowhead (*Sagittaria latifolia*). Available at https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_sala2.pdf

USDA, NRCS (U. S. Dept. of Agriculture, Natural Resources Conservation Service). 2022. PLANTS profile for *Sagittaria australis* (Longbeak Arrowhead). The PLANTS Database, National Plant Data Team, Greensboro, NC. Accessed October 19, 2022 at http://plants.usda.gov

USFWS (U.S. Fish and Wildlife Service). 2020. Bunched arrowhead (*Sagittaria fasciculata*) 5-Year Review: Summary and Evaluation. USFWS Southeast Region, Asheville, NC. 40 pp. Available at https://projects.ncsu.edu/cals/plantbiology/ncsc/rare/5YrReview_Sagittaria.pdf

Vallejo-Marín, M., M. E. Dorken, and S. C. H. Barrett. 2010. The ecological and evolutionary consequences of clonality for plant mating. Annual Review of Ecology, Evolution, and Systematics 41: 193–213.

Walz, Kathleen S., Linda Kelly, Karl Anderson and Jason L. Hafstad. 2018. Floristic Quality Assessment Index for Vascular Plants of New Jersey: Coefficient of Conservativism (CoC) Values for Species and Genera. New Jersey Department of Environmental Protection, New Jersey Forest Service, Office of Natural Lands Management, Trenton, NJ. Submitted to United States Environmental Protection Agency, Region 2, for State Wetlands Protection Development Grant, Section 104(B)(3); CFDA No. 66.461, CD97225809.

Wang, B., and Y. L. Qiu. 2006. Phylogenetic distribution and evolution of mycorrhizas in land plants. Mycorrhiza 16(5): 299–363.

Weakley, A. S. and Southeastern Flora Team. 2022. Flora of the Southeastern United States. University of North Carolina Herbarium, North Carolina Botanical Garden, Chapel Hill, NC. 2022 pp.

Werier, David. 2017. Catalogue of the vascular plants of New York state. Memoirs of the Torrey Botanical Society 27: 1–542.