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LAMONT, E. E. (Torrey Botanical Society, Local Flora and Vegetation Committee, The New York Botanical Garden, Bronx, NY 10458), R. SIVERTSEN (Longwood Gardens, Kennett Square, PA 19348), C. DOYLE (Allied Biological Inc., 580 Rockport Road, Hackettstown, NJ 07840), AND L. ADAMEC (Institute of Botany, Academy of Sciences of the Czech Republic, Section of Plant Ecology, Dukelská 135, CZ-379 82 Třeboň, Czech Republic). Extant populations of *Aldrovanda vesiculosa* (Droseraceae) in the New World. J. Torrey Bot. Soc. 140: 517–522. 2013.—A summary of the recent introduction of *Aldrovanda vesiculosa* to eastern United States is presented, with discussion on the status of the species in New Jersey, New York, and Virginia. Several introduced populations include millions of individuals and have been self-sustaining for more than a decade. *Aldrovanda* is a globally endangered species and may soon be extinct in its natural Old World habitats.

Key words: *Aldrovanda vesiculosa*, assisted migration, carnivorous plants, globally endangered species, non-native species.

*Aldrovanda vesiculosa* L. is a globally endangered, free-floating aquatic carnivorous plant. Although native to the Old World, it is established in the eastern United States with populations in New Jersey, New York, and Virginia that currently rival or surpass the largest populations in its entire natural range. The introduction of *A. vesiculosa* in 1999 to a pond in Orange County, New York, has resulted in an extensive, self-perpetuating population numbering several million individuals. In 2012, another population was located in Lake Owassa, Sussex County, New Jersey. This occurrence may be the first reported case of natural dispersion for *A. vesiculosa* in the New World. Although *A. vesiculosa* is apparently thriving in the eastern United States, it is precariously teetering on the brink of extinction in many of its natural Old World localities, distributed across four continents (Adamec 1995, 1997a; Cross 2012a,b).

The following report is largely based on the observations and activities of Sivertsen in the eastern United States, and the work of Doyle at Lake Owassa, New Jersey. Adamec, a Czech ecophysiologist specializing in *A. vesiculosa*, has added his perspective on assisted migration. Sivertsen has been growing carnivorous plants since childhood and has been studying them in the field for more than 40 years (Sivertsen 1973); he currently works part time managing the *Nepenthes* collections and displays at Longwood Gardens, Pennsylvania. Doyle is an aquatic biologist; for the past 23 years he has worked in the field and is currently Senior Aquatic Biologist for Allied Biological, a private lake management firm

[1] This report is the 9th in a continuing series of floristic studies prepared by the Local Flora and Vegetation Committee of the Torrey Botanical Society.

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that serves New Jersey, New York, and Pennsylvania. Adamec has been studying *A. vesiculosa* and other aquatic plants for more than 20 years and has published more than 80 papers on the biology, ecology, and conservation of Old World aquatic carnivorous plants.

**Introduction of *Aldrovanda* to North America.** During the mid-1970s, several Japanese growers of carnivorous plants began corresponding with American carnivorous plant enthusiasts and offered to trade dormant turions of *A. vesiculosa*, mostly from the Kyoto and Tokyo areas (for localities see Elansary et al. 2010), in exchange for plants from their American counterparts. While the successful cultivation of *A. vesiculosa* has been well documented (Cross 2012a, Adamec 1997b), American growers were unable to cultivate the Japanese strain in artificial containers. Mazrimas (1974) reported some initial success in growing Japanese plants in plastic containers, however was unable to keep them alive over numerous seasons (J. Mazrimas, pers. comm.). The causes of rapid and often catastrophic decline in cultivated Japanese populations remain unknown; similar declines in other regions have been linked to small fluctuations in water chemistry or other environmental factors (Cross 2012a). However, observation suggests that Japanese plants may be more temperamental in cultivation than individuals from other regions.

The introduction of *A. vesiculosa* to suitable locations as a means of preserving the species has long been employed in Europe, where the species is most imperiled (Koch 1950; Kamiński 1987; Akeret 1993; Adamec 1995, 1999, 2005). While assisted dispersal is an often contentious method, and has been utilized with mixed success, controlled introductions are identified as a potentially useful management tool in the conservation of *A. vesiculosa* (Cross 2012a).

**Virginia Sites.** A few growers of carnivorous plants from north-central Virginia had small backyard ponds supporting several native species of *Utricularia*. During the late 1980s to early 1990s, some of these growers introduced dormant turions of *A. vesiculosa* from Japan into their backyard ponds. These shallow ponds, about 2 m deep or less, are part of a larger stream system with several small beaver dam features. The pond margins and hummocks are dominated by *Typha* sp., *Juncus* spp., *Carex* spp., large grasses, and other graminoids.

For the next two years, it appeared that the introduced *A. vesiculosa* did not survive in the Virginia ponds as no plants were observed. However, in the third year, small populations of *A. vesiculosa* appeared in several ponds, and by season's end dense colonies were growing along pond margins and around raised hummocks. By the late 1990s, *A. vesiculosa* had become naturalized at several Virginia sites in Caroline, Hanover, Louisa, Orange, and Spotsylvania counties, and was growing in the millions at a few localities.

Approximately seven discrete populations of *A. vesiculosa* currently exist in Virginia. Most occur in slow flowing beaver impounded creeks with high emergent vegetation cover of floating aquatics and graminoids, but some occur in small catchment basins. The largest population comprises several million individuals. During the past 20 years, populations have experienced marked fluctuations in numbers of individuals; the factors responsible for these fluctuations are not known. There is no tangible evidence to date that *A. vesiculosa* has had any negative impacts on natural ecosystems in Virginia; however, this inference cannot be quantified as no data was collected on the biomass or abundance of companion species before and in the early stages of colonization.

**New Jersey Sites.** In 1999, Sivertsen planned and implemented an assisted colonization of *A. vesiculosa* in northern New Jersey because the action might save the genome for future studies and conservation initiatives if the species becomes extinct in its natural Old World habitats. Criteria for choosing localities included: sites must be isolated from pristine wetlands, not too close to larger water bodies, relatively small in size, and contain ecological characteristics similar to those identified by Adamec (1995, 1997b, 1999) as favorable for its growth. Permission from property owners was obtained, water tests were conducted, and plant associations recorded. A dozen potential sites were chosen including abandoned sand and gravel pits, small ditches under power lines, a rainwater discharge basin behind a shopping mall, and some artificial koi (*Cyprinus carpio*) ponds.

In the early summer of 1999, Sivertsen visited a grower of carnivorous plants near

Ladysmith, Virginia, and harvested approximately 10 to 15 kg of *A. vesiculosa*. During the next two days he drove around northern New Jersey and introduced a small number of plants into each site previously surveyed. After completing the introductions, he visited a friend on Big Pond in the vicinity of Cuddebackville, Orange Co., New York, and introduced the last handful of *A. vesiculosa* into a small, isolated cove on the southeastern section of the pond.

The following year, Sivertsen checked each New Jersey site where *A. vesiculosa* had been introduced and found no trace of the plant. A visit to New York revealed that Big Pond had been drained by the complete destruction of a large beaver dam that had maintained high water levels and Sivertsen concluded that the *A. vesiculosa* in the cove had not survived.

One New Jersey site, a rainwater discharge basin behind a shopping mall in Succasunna, Morris County, was inaccessible at the time of Sivertsen's first survey in 2000 due to construction. This site was dominated by dense mats of invasive *Hydrocharis morsus-ranae* L., and green algal blooms were frequent during summer. The basin released foul odors from decaying vegetation and supported healthy populations of brown rat (*Rattus norvegicus*), tubifex worms (*Tubifex* sp.), and a high diversity of zooplankton, small crustaceans, and snails. The water had a conspicuous presence of clay, with a pH around 7.0. Summer water temperatures ranged from approximately 28°C to nearly 38°C. Although the site initially appeared unsuitable, Sivertsen introduced *A. vesiculosa* because he happened to meet the owners who granted permission and the site reminded him of photographs of Old World localities that support extant populations of *A. vesiculosa*.

In 2001, Sivertsen again surveyed the New Jersey sites and saw no signs of *A. vesiculosa* anywhere. In late April 2002, he finally gained access to the Succasunna site and, to his surprise, he noticed a shoot of *A. vesiculosa* floating near a small *Juncus* hummock. He waded into the basin and began removing *Hydrocharis*. Within a few weeks, the *A. vesiculosa* population was flourishing, along with mixed populations of *Utricularia intermedia* Hayne and *U. minor* L. There is a deeper area at this site where water depth ranges from approximately 1 to 1.5 m; *A. vesiculosa* did not grow in these waters, and when forced out in floating cages the plants almost immediately went into decline and died within a few weeks. Walking through the mucky sediments of shallower parts of the basin was rather arduous, and after a day's work the bottom layers of clay and detritus were so stirred up it took several days for the water to clear again. A visit to the site one week later revealed that the *A. vesiculosa* shoots had made a quantum leap in growth, more than doubling in size in areas that had been stirred-up and cleared of *Hydrocharis*. Water depth at these locations was less than 40 cm. As the season progressed the algal blooms declined, the foul odor diminished, and the water seemed to have a fresh quality about it.

The Succasunna site completely dried up from most of July to mid August 2002 and Sivertsen considered the *A. vesiculosa* to have become extirpated. However, after late summer rain refilled the basin, *A. vesiculosa* made a remarkable recovery. During the next few years Sivertsen continued to remove *Hydrocharis*, and the *A. vesiculosa* persisted. However, after 2009, management of the site ended. Subsequently, *Hydrocharis* overwhelmed the entire surface of the basin, resulting in the loss of all submerged species. *Aldrovanda vesiculosa* is now considered extirpated at the site.

Continued monitoring during the mid-2000s of the other New Jersey sites revealed no presence of *A. vesiculosa*. In hindsight, these sites may not have provided suitable habitat for at least some of the following reasons: site was too dark (surrounded by trees that cast long, dark shadows on the pond surface); water was too acidic, or too deep, or too clear (not rich in zooplankton), or too cold (some sites were spring fed by underground feeds); absence of specific plant associations (site lacked large hummocks dominated by graminoids).

**New York Site.** In 2006, Sivertsen revisited Big Pond, New York, which had been restored to previous high water levels, and he was surprised to find shoots of *A. vesiculosa* in the small cove where it had been introduced in 1999. Presumably, prevailing winds and floating bog mats at the cove's entrance had kept the *A. vesiculosa* contained. The cove is composed of a mosaic of open, shallow water interspersed with small, mucky islands, hummocks, and floating mats of dwarf shrub bog (see Edinger et al. 2002, for a description of

the biological diversity of the bog). The cove also supports several native species of carnivorous plants including *Sarracenia purpurea* L., *Drosera intermedia* Hayne, *D. rotundifolia* L., and several species of terrestrial and aquatic *Utricularia*.

By 2010, several strong storms had shifted some of the floating *Sphagnum* mats in Big Pond and by 2012 *A. vesiculosa* had escaped the small cove and colonized the entire periphery of the pond. *Aldrovanda vesiculosa* plants mostly occur along the margins of shallow, coastal areas and around floating *Sphagnum* mats and islets. The most dense colonies and most robust plants grow in full sunlight, adjacent to hummocks with edges dominated by graminoids, and in warm to tepid water where pH does not fall below 5.8. A roughly calculated estimate of the 2012 summer population suggests it included some 25 to 30 million *A. vesiculosa* individuals. Voucher specimens were collected by Barre Hellquist in 2013 and deposited at HUH (herbaria acronyms follow Thiers 2012).

At Big Pond, *A. vesiculosa* does not flower frequently and pollinators are unknown at this time. Plants mature in July and continue to flower into August and usually senesce in late October to November when dormant turions are produced. Waterfowl, including ducks and geese, have been observed feeding on the floating turions at Big Pond both before winter when they are full of starch and in the spring when they emerge from dormancy full of sugars (Adamec 1999, 2003). So far, despite its dense stands, *A. vesiculosa* does not appear to have displaced any native aquatic plants at Big Pond.

**Lake Owassa, New Jersey.** On 11 October 2012, a few floating shoots of *A. vesiculosa* were collected from the southern end of Lake Owassa, Sussex County, New Jersey, by Glenn Sullivan. A further investigation on 17 October 2012 of the southern inlet stream leading into the lake, by Doyle and Sullivan, revealed a thriving population of *A. vesiculosa* consisting of thousands of individuals. The locality is a sluggish stream flowing through a freshwater marsh in Bear Swamp Wildlife Management Area, owned by New Jersey Department of Environmental Protection. Associated species includes *Utricularia vulgaris* L. ssp. *macrorhiza* (Le Conte) Clausen, *Ceratophyllum echinatum* A. Gray, *Potamogeton epihydrus* Raf., *Najas flexilis* (Willd.) Rostk. & Schmidt, *Nymphaea odorata* Ait., *Riccia fluitans* L., *Lemna minor* L., *Spirodela polyrrhiza* (L.) Schleid., *Sparganium eurycarpum*, Engelm. *ex* A. Gray, and several species of *Carex* and *Juncus*. Water pH at the time of collection was 6.2. Voucher specimens (deposited at BKL, CHRB, and PH) and digital photographs document the find and identification was initially verified by Barre Hellquist. A more detailed survey of the stream and lake was not conducted in 2012, mostly due to the occurrence of Hurricane Sandy a few weeks later. Doyle speculates that *A. vesiculosa* had been established at the site for a few seasons before 2012, based on the relatively large size of the population.

In 2013, Doyle confirmed the presence of *A. vesiculosa* in the outlet stream at the north end of Lake Owassa, 2.3 km from the inlet stream. Associated species includes *Typha* sp., *Sparganium* sp., *Sagittaria* sp., *Carex* spp., *Juncus* spp., *Decodon verticillatus* (L.) Ell., *Pontedaria cordata* L., *Nymphaea odorata* Ait., and *Brasenia schreberi* J. F. Gmel.

The Old World distribution of *A. vesiculosa* has been linked to the routes of migratory birds (Berta 1961, Adamec 2005, Cross 2012a), and the Lake Owassa population may have been established by waterfowl transporting turions, small vegetative fragments, and/or seeds from Big Pond, New York, or from Succasunna, New Jersey. While studies have shown that seeds are incapable of retaining viability after ingestion by waterbirds (endozoochory), both vegetative fragments and seeds are capable of withstanding a degree of desiccation and may be transported externally (epizoochory) over large distances (Cross 2012a). Both Big Pond and Succasunna are approximately 50 km away from Lake Owassa, a distance not prohibitive to dispersal by migratory or nomadic waterfowl (Cross 2012a).

**Discussion.** The topic of assisted colonization, also known as managed relocation, is controversial and especially complicated when a globally endangered species threatened by extinction is involved. Assisted colonization has been proposed as one option to avoid extinctions and mitigate the loss of biodiversity (Hoegh-Guldberg et al. 2008). The major objections levied against this option have been the ecological risks of relocated species becoming invasive or creating new pest problems

at the target site (Ricciardi and Simberloff 2009).

Assisted colonization of *A. vesiculosa* has been conducted in Europe for more than 100 years and two introductions in Switzerland share some similarities with the recent introductions in New York and New Jersey. In 1908, *A. vesiculosa* plants from Lake Constance in southern Germany were introduced to a small peaty lake near Zurich, approximately 50 km away. At the time, the German population was large and stable (Koch 1950). The introduction was successful and the Swiss population continues to persist, but the source German population became extinct in the 1970s (Adamec 1995). A second Swiss population was found in 1993 approximately 12 km from the first and Akeret (1993) considered the plants to have been transferred by migratory waterfowl. Thus, as a result of the assisted colonization conducted in 1908, the genetic pool of the German population has been preserved in Switzerland and now represents the last semi-natural occurrence of *A. vesiculosa* in Western Europe (Cross 2012b).

Another example of a successful introduction of *A. vesiculosa* in Europe has been summarized by Adamec (2005). In the Czech Republic, *A. vesiculosa* was considered extinct in the 1950s after the last population perished in northern Moravia. Between 1994 and 2000, *A. vesiculosa* was introduced to ten localities in the Trebon basin of southern Bohemia and after 15 to 19 years only two of the localities still supported self-sustaining populations. These results are consistent with those of Sivertsen in New Jersey and New York where a dozen introductions were conducted in 1999 and after 12 years only one persisted.

In Europe, decline of *A. vesiculosa* at target localities due to eutrophication or overgrowing by reeds has been simultaneously accompanied by a decline in native species (Adamec and Lev 1999, Adamec 2005). Thus, the vigor of an *A. vesiculosa* population may be considered a bioindicator of wetland health (Cross 2012a). Although *A. vesiculosa* sometimes produces dense stands of 80–100% coverage during hydrologically favorable seasons (Adamec 2005), there has been no evidence of it outcompeting and displacing native species. However, newly established *A. vesiculosa* populations in the New World could possibly have unforeseen negative impacts on native species. Adamec (2005) discussed both the benefits and risks of assisted colonization as an option to conserve plant diversity.

Most discussions relating to the translocation of endangered species have focused on intracontinental movements; far less common are reports of intercontinental movement (Thomas 2011). The recent translocation of *A. vesiculosa* from the Old World to eastern North America may ultimately preserve the endangered genome for future conservation initiatives if the species becomes extinct in its natural Old World habitats. For more than 20 years Adamec (1995) has been advocating assisted colonization of *A. vesiculosa* on an intracontinental scale: ''Thus, the chances for the survival of *Aldrovanda* are based on the maintenance and protection of new potential sites (shallow lakes, peaty lakes and pools, swamps, shallow reed belts, etc.) and on the introduction of *Aldrovanda* to these sites.'' Similarly, Cross (2012a) concluded: ''The likelihood of persistence [of *Aldrovanda*] in many of these areas [extant Old World sites] is slim due to extensive wetland degradation, and it is undeniable that this species faces a potentially severe outlook if attempts to mediate the species decline are not swiftly made.'' One issue that now needs to be assessed is how to evaluate the successful intercontinental introduction of *A. vesiculosa* to North America, and whether the populations should be destroyed, safeguarded, actively managed, or considered as naturalized sites to be included in the species global management.

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