Census and reassessment of the critically endangered Alabama canebrake pitcher plant (Sarracenia alabamensis), 25 years later1

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Census and reassessment of the critically endangered Alabama canebrake pitcher plant (*Sarracenia alabamensis*), 25 years later[1]

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Abstract. In this census of the Alabama canebrake pitcher plant, *Sarracenia alabamensis* Case & R.B. Case (syn. *S. alabamensis* subsp. *alabamensis*, *S. rubra* subsp. *alabamensis*), we examined and characterized all known remaining sites of the species, their habitat, associate floral communities, and soil composition. The survey methodology of Murphy and Boyd (1999) was utilized heavily in this census to directly compare 2019 data to 1995 data to determine population trends, management need, and site changes over the past 25 years. This includes assessment of population structure through size class assignments, a complete count of plants per site, a categorized associate species list, and physical soil characteristics; additionally, canopy cover and associate diversity data were collected at each site to provide further habitat status and characterization. We conclude that there are five truly viable sites (four populations) for the species, two sites with great recovery potential, five remnant sites that may be unrecoverable, and three sites that are found to be extirpated. With small populations and so few viable or recoverable sites, there is an urgent need for increased management with a focus on associated species, hydrology, maintenance of an open canopy, and landowner relationships.

Key words: conservation, C-values, diversity, monitoring, Sarraceniaceae

Alabama is host to many unique habitats and plant communities, ranging from the Appalachian foothills in the northeast, pyric coastal plain and wetland communities in the south, scattered and unique prairies in the west, and piedmont communities in the east (NatureServe 2009, Alabama Department of Conservation and Natural Resources [ADCNR] 2016). One of the more ecologically unique regions in the state, due to overlapping physiographic regions, is the montane longleaf pine ecosystem (Maceina *et al*. 2000). Separated from the Coastal Plain longleaf pine region by the fertile Black Belt prairie, the montane longleaf pine forests represent a unique ecosystem consisting of *Pinus palustris* that inhabits shallow, upland, rocky soils, compared to their deep sand, lowland, coastal counterparts (Craul *et al*. 2005, Stokes *et al*. 2010). In the central part of the state, specifically within the Tuscaloosa and Eutaw formations of the fall line, historically significant forests of longleaf pine could be found, representing the southern boundary of this montane longleaf pine community. Colloquially dubbed the "Fall Line Pine Hills," this region is characterized by low nutrient, acidic soils composed mostly of Cretaceous gravel and sandstone, forming unique topographic structures that seep water and remain permanently wet (Harper 1922, Case and Case 1974). These seepage slopes, typically found in the Coastal Plain, host a unique assemblage of plant communities located within drier, xeric, upland forests in the Pine Hills (Harper 1922, McDaniel and Troup 1982). Owing to their uniqueness, this

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specialized habitat has resulted in an extremely diverse wetland community type home to many rare and unique flora (Maceina *et al*. 2000).

Perhaps the rarest species endemic to this region is *Sarracenia alabamensis* F.W. Case & R.B. Case (syn. *S. alabamensis* subsp. *alabamensis*; *S. rubra* subsp. *alabamensis*), the critically endangered Alabama canebrake pitcher plant. This federally listed perennial carnivorous plant requires frequent fire to maintain an open canopy. Furthermore, these fires prevent biomass accumulation allowing bare-mineral soil to be exposed, which is ideal for seed germination of this species (U.S. Fish and Wildlife Service 2018). *Sarracenia alabamensis* has been extremely scarce in nature since its discovery, strictly occurring in the Pine Hills area, bounded by the Alabama River, Mulberry Creek, and Coosa River in central Alabama; however, since its listing in 1992 under the U.S. Endangered Species Act of 1973 and a consensus survey conducted in 1995 (Murphy and Boyd 1999), many sites have been declared extirpated through presence/absence surveys (U.S. Fish and Wildlife Service 2018). These losses are primarily due to habitat destruction from development, agricultural practices, gravel mining, as well as severe fire suppression, leading to subsequent forest succession and woody encroachment (Folkerts 1982, U.S. Fish and Wildlife Service 2018). Additionally, poaching has been of concern, with at least three sites presumably extirpated solely due to collecting (McDaniel and Troup 1982). Furthermore, many populations occur on remote private lands making access for management difficult.

The last species-wide population census of the Alabama canebrake pitcher plant, conducted in 1995 (Murphy and Boyd 1999), revealed extremely relevant data that better characterized the species and its critically endangered status. Every known occurrence of the species was examined in the study (11 sites), whereby individual counts and population structure were determined at each site, a floristic inventory was created, soil at each site was analyzed, and overall site health was estimated. In the 1995 census, they concluded that three sites were viable (*i.e.*, supported large genets and habitat was secure), four sites were categorized as persistent (*i.e.,* habitat destruction limits potential of site), and four sites were considered remnant (*i.e.,* habitat change has resulted in unsuitable conditions for the species). Taken together, this initial survey largely provided much-needed insight into the plants' dire need for conservation action.

In maintaining the importance of comparative data collections, a full and thorough census of *S. alabamensis* was conducted utilizing Murphy and Boyd's (1999) survey methodology. The main objectives of this present study were to: (1) determine how *S. alabamensis* sites have shifted in total counts and population structure since the last complete census, and qualify these changes as to how and why they have occurred; (2) observe changes in both plant community and soil composition since the 1995 census; and (3) determine management strategies for each site based on survey results in order to improve long-term site viability, future augmentation potential, and potential site re-establishment. The present survey involved full counts of individual plants at every known occurrence of the species, assigning size classes to determine population structure, recording reproductive ability through flower counts and evidence of active recruitment, mapping out total bog structures, analyzing soil samples from each site, recording and conducting a floristic inventory to characterize the current habitat status of each site, and briefly assessing extirpated and potential out-planting sites and their viability potential. Additionally, because most sites occur on private property, landowner relations and proper management are essential to the recovery of the species. Therefore, further positive reestablishment, outreach, and education with private landowners, especially regarding new landowners, was a top priority in this survey.

Materials and Methods. Study Species. *Sarracenia alabamensis* was first seen and collected in the early twentieth century by Charles Pollard and William Maxon near what is now the present-day city of Clanton, AL. However, Roland Harper was the first to observe and record its significance, documenting it as *Sarracenia sledgei* (synonym of *Sarracenia alata*) and later as *Sarracenia rubra* after observing it in flower (Harper 1922, McDaniel and Troup 1982). Edgar Wherry observed the plants in the 1930s with Harper and later determined it was an undescribed species. Frederick and Roberta Case continued this work and eventually recognized it as a distinct taxon, where it was described and named *S. alabamensis* (Case and Case 1974). The species is noted to be unique in both morphology and growth habits, producing three "flushes" of pitchers throughout the growing season, numerous flower scapes per rhizomatous meristem, and possessing two distinct leaf forms. In the spring, smaller diameter s-shaped leaves are produced, especially during flowering, whereas in the summer, larger, more inflated and erect leaves are produced, usually with a visually fine pubescence, slight areoles, and maroon veining (Case and Case 1974). Similar to other members in the genus, *S. alabamensis* is characterized by its occurrence in moist, acidic ecotones, predominated by *Pinus palustris*. Additionally, the species is notable in that it prefers to germinate and grow in bare-mineral soil, contrasting with other members of the genus that prefer *Sphagnum*-peat soils (Harper 1922, Murphy and Boyd 1999).

Sarracenia alabamensis occurs in unique gravelly seepage areas, usually on seepage slopes in the central Alabama Fall Line Pine Hills (*e.g.*, Harper 1922, McDaniel and Troup 1982). These slopes, and the species itself, are found in an area bounded by the Fall Line and the Coosa River, Alabama River, and Mulberry Creek, characterized by unique, mineral-deficient Upper Cretaceous rock derivatives (Harper 1922). These perpetually moist, nutrient-poor, gravelly seepage slopes are structurally defined by a water-permeable sand and gravel-rich layer situated on an impervious clay "hardpan" beneath the surface; precipitation and subsurface water gradually accumulates and surfaces at the lower portions of these sloping topographic transition zones. Most seepage slopes, though consistently moist, are limited by physical size, incline, and overall precipitation levels (U.S. Fish and Wildlife Service 2018). Historically, the species was known to occur in Elmore, Autauga, and Chilton counties in Central Alabama, but is presently listed as extirpated in Elmore County (Fig. 1).

Like many other isolated, rare, and threatened *Sarracenia* taxa, *S. alabamensis* is a member of the *S. rubra* complex (Harper 1918, Case and Case 1976). This taxonomic grouping has long been the subject of much dispute and debate, as have all members of the genus. The relationships between many species in the genus reflect their overall challenging and complex interactions, as all species readily hybridize and have been concluded to have only recently radiated and rapidly diversified (Ellison *et al*. 2012, Stephens *et al*. 2015). In this study, the usage of *Sarracenia alabamensis* F.W. Case & R.B. Case (syn. *S. alabamensis* subsp. *alabamensis*; *S. rubra* subsp. *alabamensis*) as a distinct species is upheld to maintain accurate standing with recent genetic and taxonomic work. This is supported by recent genetic analysis of both microsatellites (Furches *et al*. 2013) and target enrichment (Stephens *et al*. 2015), the latter analysis rejects the *rubra* complex as a monophyletic group.

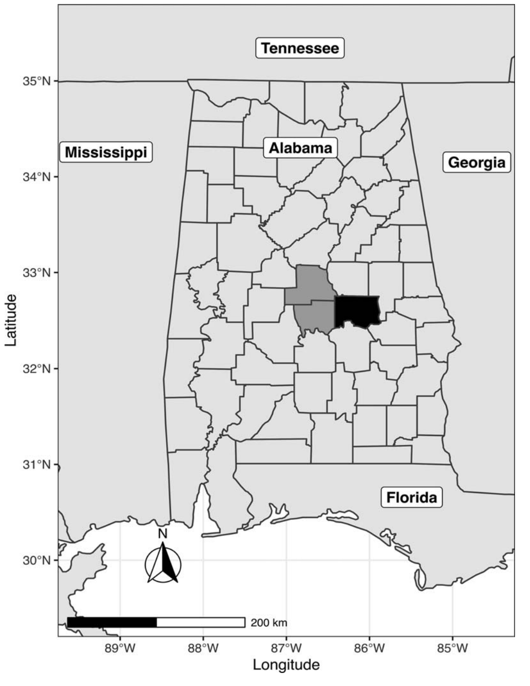

FIG. 1. Full range of *Sarracenia alabamensis*. Gray counties (Autauga and Chilton) contain extant populations. All populations from Elmore County are extirpated and are represented by black coloration.

SITE ASSESSMENT. All known and extant sites of *S. alabamensis* were assessed in this census during late May–June 2019, except site 15, which was discovered in 2020 and was subsequently evaluated during June 2021. The term "site" was preferred over "population" in this survey given that the U.S. Fish and Wildlife Service (2018) classifies *Sarracenia* populations as being at least 1 mile from their nearest neighbor. This definition change occurred after the Murphy and Boyd (1999) survey; therefore, to keep consistent with the 1995 sampling procedure, we define site as distinct locations separated by unsuitable habitat (*i.e.,* site boundaries were determined by changes in elevation, vegetation, and soil moisture content that is not suitable for *S. alabamensis*). Given the prevalence of poaching with this species, we do not provide names or exact locality information in this survey and instead use numbers for each site that correspond to those used in Murphy and Boyd (1999). Mapping of site size was conducted using a handheld Garmin Rino 655t (Olathe, Kansas, USA). To maintain direct consistency with the previous census of the species, this survey utilizes Murphy and Boyd (1999) survey methodology to determine demographic information for each site; however, we have modified the definitions for size classes to reflect clonal propagation through vegetative growth in *Sarracenia*. In the previous survey the term individual "genets" (genetic individuals) was used to determine size classes. A genet is defined as a group of ramets (*i.e.,* individuals produced by clonal propagation) from a single seed (Harper 1977). Identification of genets is an issue at sites that are densely populated (Sites 5, 8, 10, 11, 12) and while effort was made to define individuals at these sites by clearing away soil to examine rhizomes, we cannot be 100% positive that dense clusters of individual rosettes are not, in fact, the result of clonal propagation. Therefore, we use the term "ramet," a grouping or clump of rhizomatous growth points arising from the same general location either presently or previously connected (Case and Case 1974), to designate individuals within each size class. Some ramets may display the same phenotypic traits (pitcher color, degree of venation, lid shape, sepal coloration, *etc.*); in the few instances where a site was extremely dense, and these phenotypic traits are arguably distinct, ramets were determined by phenotypic differences. Furthermore, Murphy and Boyd (1999) described "seedlings" as individuals that are not of maturity and arising as a single rosette of leaves (all growth arising from the rhizome, excluding floral growth). The use of "seedling" is misleading as the definition could encompass immature ramets (*i.e.,* clonal propagates lacking flowers) as well as true seedlings derived from a single seed. Using the same definition as Murphy and Boyd (1999), we categorize that size class as "reproductively immature" (Fig. 2b). "Small" are defined as ramets of flowering ability and fewer than 20 pitcher leaves and few flowers. "Medium" are flowering ramets with 21–75 pitcher leaves and ~10 flowers. "Large" are those with 76–150 leaves and ~25 flowers. "Extra-large" are ramets with greater than 150 leaves and ~50 flowers. In addition to assigning a size class for each ramet, total flower counts were determined to assess vegetative maturity and sexual reproduction. To record recent successful sexual reproduction, juveniles (*i.e.,* individuals that were no larger than 10 cm in height and are likely true seedlings; Fig. 2a) were included in this survey; however, in order avoid underestimation because of difficulty in detecting such small plants, simply presence or absence was recorded. Sites 5, 11, and 12 have been augmented with outplanted individuals that were grown *ex situ* from seeds collected at the respective site after the 1995 survey. These individuals were included in survey efforts.

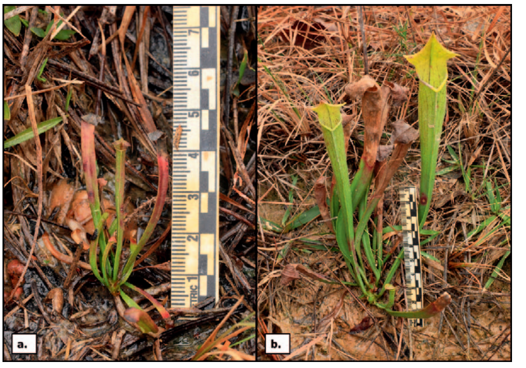

Fig. 2. Representative images of *Sarracenia alabamensis* juvenile and reproductively immature size classes with centimeter scale. (a) Juvenile plants measured under 10 cm in height and are most likely 1–2 year old seedlings. (b) Reproductively immature individuals are larger plants with no signs of reproductive capacity (*i.e.,* no past or current flower scapes).

Floristic Communities. An extremely important determining factor in the overall quality of a particular site, especially regarding pitcher plants, is the adjacent plant communities and resident bog associates within a site (Folkerts 1982; McDaniel and Troup 1982). Paralleling Murphy and Boyd (1999), we inventoried associate species at each site and classified their relative abundance into three categories. "Present" includes species that occur in low frequency or are otherwise rare; "frequent" includes species that are common to the seepage community; and "abundant" are species that are dominant members of the plant community. This method allowed a direct comparison of inventory species lists between the two studies; however, we additionally quantified the ecological integrity of each site using coefficients of conservatism (C-values). C-values range from 0–10 with each species given a specific value based on a species' fidelity to habitat and tolerance to disturbance with higher values indicating species with preferences for high quality habitat and sensitivity to disturbance (Swink and Wilhelm 1979, Swink and Wilhelm 1994). We used C-value designations for wetland species of Georgia within the same ecoregion (Zomlefer *et al*. 2013) and additional designations of Alabama endemics (*i.e., Hexastylis speciosa*; Gianopulos 2014). C-values were then averaged for each site providing a single value in which to compare ecological integrity of similar habitats and providing a baseline for future restoration and management initiatives (Dolan *et al*. 2011; Zomlefer *et al*. 2013). Mean C-values were calculated with and without woody species and nonnatives as these species can give an inaccurate picture of pitcher plant bog health since woody encroachment due to fire suppression is the greatest threat to *S. alabamensis* and bog communities in general. Lastly, to account for the influence of bog size variation on species richness, we used a 1 m^2 plot placed at five random locations per site to standardize species presence and abundance. In the case of smaller sites, 1 m^2 plots included species from bog boundaries. Data collected from standardized plots were used to calculate Shannon-Wiener Diversity Index (H') and a Floristic Quality Assessment Index (FQI) for each site. FQIs are calculated using mean C-values and multiplying by the square root of total species (Swink and Wilhelm 1979, Swink and Wilhelm 1994). Like mean C-values, FQIs give a metric of site quality that can be used to compare sites; however, FQIs account for factors that influence species richness, such as site size. FQIs were also calculated with and without woody species and nonnatives.

Sarracenia alabamensis is highly dependent on frequent (2–5 year) fire intervals, which prevent woody encroachment and provide an open canopy (Folkerts 1982, U.S. Fish and Wildlife Service 2018). Therefore, management of the species has relied on prescribed fire or in cases where fire is restricted, hand clearing (*e.g.,* trimming, mowing). Given the importance of these management practices in maintaining large, healthy population sizes, a survey of current management at each site as well as a measure of percent sun exposure was conducted. A densitometer was used to obtain the average percent sun for each site by measuring open canopy at each cardinal direction in the approximate center of each site. Together, this information can provide land stewards with an additional estimate of site health.

Physical Soil Assessment. *Sarracenia alabamensis*, like other pitcher plant species, has very specific soil requirements. Therefore, three soil samples were collected across the seepage slope at each site at a depth of 8 cm to assess soil composition and to determine whether there has been any shift since the 1995 sampling. These three samples were air-dried and homogenized prior to testing. Soil pH was determined using an automated AS-3000 pH Analyzer (LabFit, Bayswater, Western Australia, Australia) in a 1:1 Soil:0.01 M $CaCl_2$ suspension. The resulting values were then converted to soil-water pH readings by adding a conversion factor of 0.6. Phosphorus (P), calcium (Ca), magnesium (Mg), manganese (Mn), potassium (K), and zinc (Zn) were extracted from the soil sample using the Mehlich-1 extraction method (Mehlich 1953). All other elements were digested with nitric acid and brought to volume with deionized water. The quantities of each element were then determined on an Acros inductively coupled plasma atomic emission spectrograph (ICP-OES; Spectro Scientific, Massachusetts, USA). To determine carbon (C) and nitrogen (N), all samples were combusted in an oxygen atmosphere at 1350 °C, converting elemental carbon and nitrogen into CO_2 and N_2, respectively. The resulting CO_2 was then passed through the infrared cells to determine total carbon, while N_2 was passed through a thermal conductivity cell to determine total nitrogen content. Soil samples were additionally placed in a muffle furnace (Thermolyne F6000 Ashing Furnace; Thermo Fisher Scientific, Massachusetts, USA) at a combustion temperature of 360 °C to calculate percent organic matter following the Loss-on-Ignition method (Ball 1964). Lastly, percent sand was calculated using the Bouyoucos hydrometer method (Bouyoucos 1962). All soil tests were conducted at the University of Georgia Agricultural and Environmental Services Laboratories.

Data Analysis. The four new sites (12–15) were not included in the data analyses comparing the 1995 dataset to the present survey, as these sites were not surveyed in 1995. To test whether size classes across sites changed between sampling years, a zero-inflated negative binomial generalized linear model (GLM) with the glm.nb function in the *MASS* package version 7.3–51.4 (Venables and Ripley 2002) was used. All GLM model assumptions were assessed using the *DHARMa* package (Hartig 2019). The model designated frequency as the response variable with the interaction of year and size class as explanatory variables. Overall effects were examined using the ANOVA function with Type III sums of squares in the *car* package (Fox and Weisberg 2019). To assess whether outplantings contributed to any changes in size class structure the analysis was done with and without the outplantings at Sites 5, 11, and 12. After testing for normality, we used a Wilcoxon paired *t* test to examine changes in flower count, number of individuals, and bog size between the 1995 and current dataset. Flower count and number of individuals were calculated with and without outplantings. Bog floristic diversity was assessed with data collected from the m^2 sampling quadrats across sites and calculated using the Shannon-Wiener diversity index (H'; Shannon 1948) in the *vegan* package version 2.5-5 (Oksanen et al. 2013). A Principal Component Analysis (PCA) was conducted to compare changes in soil characteristics between sample years and sites using the prcomp() function in R. All statistical analyses were conducted in R version 3.5.1 (R Core Team 2018).

Results. SITE ASSESSMENT. In the 1995 census, *Sarracenia alabamensis* was inventoried at 11 total sites spanning three counties in Alabama (Fig. 1; Murphy and Boyd 1999). Since that survey, the three sites in Elmore County (Sites 2–4) have been extirpated, yet four sites have since been discovered (Sites 12–15), including an additional location discovered in 2020. However, it should be noted that Site 13 is a translocated site from a population that was being extirpated and is now maintained by a private landowner. The total bog areas across all 11 sites have decreased between the sampling years (Table 1, $Z = 55$, $P = 0.006$). However, this difference in site size may be a result of difference in methodology (*i.e.,* tape measure vs. GPS) and less about encroachment by surrounding habitat since the 1995 survey, as this decrease does not appear to have had a significant effect on the number of plants and flowers. Specifically, there was no significant difference in the number of plants between sampling years with and without outplanting/augmentations. There was also no

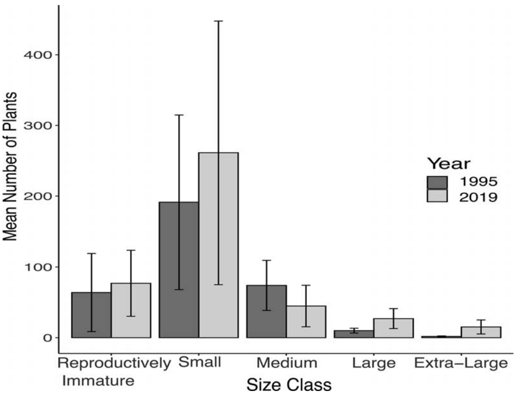

FIG. 3. Average number of *Sarracenia alabamensis* individuals in each size class compared between sampling years with standard error. Site data only included Sites 1–11, as Sites 12–15 were discovered after the 1995 census. Frequency counts include all outplanted individuals.

difference in flower counts between years, again with and without outplanting/augmentation included in Sites 5 and 11. The total number of known *S. alabamensis* during the 1995 survey was 3,752 individuals, while we counted a total of 5,561 individuals. This count includes 362 outplanted individuals since the 1995 survey. The majority of individuals were located at four sites (Sites 8, 10–12) and made up 96.6% of all known *S. alabamensis* individuals (5,373/5,561). These four sites additionally contained 82.2% of all flowers in our survey (8,713/10,599). While Site 12 was not discovered until recently, Sites 8, 10, and 11 contained 82% of all plants (3,075/3,752) and 62.9% of all flowers (3,893/6,191) in the 1995 survey. It should also be noted that outplantings at Sites 5 and 11 comprised 11% of the total flowers counted in the current survey (1,157/10,599). With the addition of Site 5, only Sites 8, 10–12 had signs of active recruitment (determined as sites that had 1–2-year-old individuals present). These data were not directly collected in the 1995 survey, although all sites except for 1, 3, and 4, produced fruit and "seedlings" in that survey.

Overall, there was no significant change in size class composition across sites between years when including outplantings (Fig. 3) and without outplantings; however, there was a lot of variation across populations and classes. Total reproductively immature individuals almost doubled since the 1995 survey; however, 488 of the 2019 reproductively immature individuals were found at Sites 12

Table 1. Summary of bog characteristics, *Sarracenia alabamensis* individuals, and bog associate diversity for all known *Sarracenia alabamensis* sites. "Juveniles present" records the presence or absence of individuals under 10 cm in size (*i.e.,* likely true seedlings, Fig 2a) at each site and is an indication of active recruitment. Site numbers match the arbitrary assignments from Murphy and Boyd (1999). Numbers listed to the right of the slash (/) are the values from the 1995 dataset for columns labeled size, number of plants, and number of flowers. Values to the left represent 2019 survey information. Species richness values represent the total number of species inventoried at each site (Appendix 1 and 2). C-values for each species (Appendix 1 and 2) were determined from Georgia Coefficients of Conservatism (Zomlefer *et al.* 2013) and averaged across sites. The first Mean C-value (to the left of the slash) includes all woody and nonnative species. The second Mean C-value (to the right of the slash) includes only herbaceous native species. The floristic quality assessment index, FQI, is determined from five random 1 m^2 plots. The first FQI value is with woody and nonnative species and the second representing FQIs of just herbaceous species. NA = not applicable. Sites 12–15 are newly discovered sites since Murphy and Boyd (1999).

Site No.	Size (m^2)	Number of plants	Bog type	Number of flowers	Current management	Juveniles present	Percent sun	Species richness (S)	Shannon-Wiener index (H')	Mean C-value	FQI
1	1 / 2	5 / 8	muck	1 / 0	None	No	4%	20	1.386	3.8 / 4.3	14.4 / 11.0
2	0 / 30	0 / 34	seepage	0 / 27	None	No	NA	14	NA	3.1 / 3.2	NA
3	0 / 10	0 / 13	seepage	0 / 5	None	No	NA	NA	NA	NA	NA
4	0 / 10	0 / 4	seepage	0 / 1	None	No	NA	NA	NA	NA	NA
5[§]	81 / 500	64 / 89	seepage	960 / 54	Fire 2–3 year interval	Yes	60%	23	1.983	4.1 / 4.5	12.3 / 8.5
6	76 / 180	7 / 129	swamp margin	2 / 98	None	No	0%	18	2.146	3.0 / 3.7	5.0 / 4.0
7	2 / 720	4 / 140	seepage	8 / 150	Hand clearing	No	39%	32	2.202	4.2 / 4.5	12.1 / 9.1
8	196 / 700	481 / 106	seepage	5,749 / 1,300	Hand clearing	Yes	62%	50	2.591	3.9 / 4.2	14.9 / 11
9	532 / 850	74 / 260	wetland margin	556 / 1963	Fire 2–3 year interval	No	100%	41	2.621	4.3 / 4.3	17.3 / 14.5
10	481 / 1500	2,873 / 728	seepage	548 / 389	Hand clearing	Yes	15%	40	2.432	3.8 / 3.9	14.8 / 11
11[§]	884 / 2200	1,169 / 2,241	seepage	1,371 / 2,204	Fire 2–3 year interval and hand clearing	Yes	45%	53	NA[a]	4.1 / 4.4	NA[a]
12[§]	330 / NA	850 / NA	seepage	1,045 / NA	Fire 2–3 year interval	Yes	80%	42	2.213	4.3 / 4.7	19.7 / 18.3
13[†]	3 / NA	19 / NA	muck/seepage	298 / NA	Hand clearing	No	80%	25	2.064	4.2 / 4.6	15.3 / 14.1
14	1 / NA	9 / NA	seepage	0 / NA	None	No	0%	20	1.669	4.2 / 4.4	8.7 / 5.7
15	100 / NA	6 / NA	seepage	61 / NA	Mowing/ Hand clearing	No	100%	43	NA	4.1 / 4.2	NA

[a] Area had just been hand cleared at time of sampling.

[†] Plants were translocated to this site in 1985 due to construction at original site.

[§] Previous outplantings at these sites were included in the survey.

Table 2. Distribution of *Sarracenia alabamensis* size classes across sites and years. Site numbers match the arbitrary assignments from Murphy and Boyd (1999). Numbers listed to the left of the slash (/) are from the 2019 survey and values to the right are from the 1995 dataset. Sites 12–15 are newly discovered sites since Murphy and Boyd (1999) and were therefore not included in statistical analyses. NA = not applicable

Site Number	Ramet size class				
	Reproductively immature	Small	Medium	Large	Extra-large
1	0 / 0	2 / 8	1 / 0	2 / 0	0 / 0
2	0 / 0	0 / 8	0 / 12	0 / 14	0 / 0
3	0 / 0	0 / 4	0 / 0	0 / 0	0 / 0
4	0 / 0	0 / 13	0 / 0	0 / 0	0 / 0
5	10 / 0	22 / 41	9 / 33	15 / 11	8 / 4
6	0 / 9	6 / 79	1 / 38	0 / 3	0 / 0
7	0 / 7	1 / 116	3 / 17	0 / 0	0 / 0
8	57 / 10	128 / 60	75 / 17	115 / 14	106 / 5
9	8 / 18	37 / 86	11 / 117	15 / 37	3 / 2
10	342 / 44	2,034 / 290	327 / 371	125 / 19	45 / 4
11	428 / 615	645 / 1,400	66 / 209	25 / 12	5 / 5
12	485 / NA	280 / NA	51 / NA	29 / NA	5 / NA
13	3 / NA	9 / NA	1 / NA	4 / NA	2 / NA
14	0 / NA	9 / NA	0 / NA	0 / NA	0 / NA
15	0 / NA	1 / NA	1 / NA	3 / NA	1 / NA
Total	1,333 / 703	3,174 / 2,105	546 / 814	333 / 110	175 / 20

and 13, both of which are new sites since the 1995 survey (Table 2). Excluding these values from the total reproductively immature counts shows little variation in this size class since the 1995 survey sites (845 in 2019 vs. 703 in 1995). Sites 5, 8, and 10 increased in number of reproductively immature individuals since the 1995 survey. Sites 8 and 10 had a positive increase in ramets across all size classes. Additionally, Site 5 had an increase in larger ramets. Taken together with the presence of juveniles and number of flowers, these suggest that these sites are benefiting from current management regimes. Reproductively immature individuals at Sites 6, 7, 9, and 11 have decreased since the 1995 survey, with Sites 6 and 7 having no signs of this size class in 2019. Particularly worrisome is that these sites also saw a sharp decline in all other size classes (Table 2). No current management is being conducted at Site 6, resulting in full canopy cover (Table 1).

Floristic Communities. Species richness ranged from 14–53 species across the current survey sites with Sites 8–12 and 15 having species richness above 40 (Table 1). Site 6, which has no current management practice and complete canopy cover, had the lowest species richness (18) for sites that had *S. alabamensis* present. To account for site size influencing species richness, we additionally calculated Shannon-Wiener Index (H') for each site based on quadrat datasets. Sites 8–10 had the highest H' values, ranging from 2.43–2.59 (Table 1). Site 11 had the highest species richness, but we were unable to calculate H' during sampling as the area around *S. alabamensis* individuals was recently hand cleared and this would have influenced the random quadrat sampling. Sites 1, 5, and 14 all had H' values under 2.0.

Coefficients of conservatism (C-values) were additionally used to quantify ecological integrity at each site. Higher values indicate the presence of species that require high quality habitat and are sensitive to human disturbance. Many sites had an average C-value above 4, both when woody and nonnative species were considered and when they were removed from the calculation. These sites included 5, 7, 9, and 11–15. Many species with high C-values (see Appendix 1) were identified at these sites, including *Hexastylis speciosa* (C-value = 9), *Calopogon tuberosus* (C-value = 7), *Cleistes divaricata* (syn. *Cleistesiopsis divaricata*) (C-value = 7), *Peltandra sagittifolia* (C-value = 7), and *Zigadenus densus* (C-value = 7). Of note, Site 12 contained three of these sensitive species (*Calopogon tuberosus*, *Hexastylis speciosa,* and *Zigadenus densus*). Sites 2, 6, and 10 had average C-values under 4.0. Since the 1995 survey, Site 2 has mostly been converted to a horse pasture and no *S. alabamensis* individuals were found in this current survey. Site 6 had the largest difference in average C-values with and without woody species and nonnatives (0.7 difference) and this is likely due to the lack of management resulting in encroachment

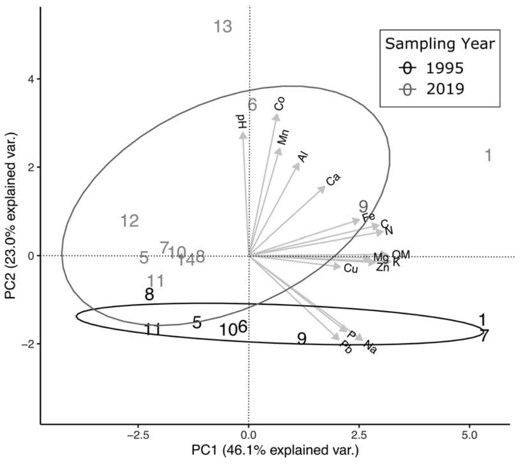

FIG. 4. Principal components analysis of soil data across both sampling years at *Sarracenia alabamensis* sites. Sites are color coded by year. Loadings for each soil component are shown with arrows. Ellipses indicate the variation within each sample year. All elements and units are listed in Appendix 3; OM = organic matter. Sites 2–4 are not included from the 1995 sampling since *Sarracenia alabamensis* have been extirpated from these locations.

of woody and nonnative species (Table 1, Appendix 2).

Like species richness, average C-values are influenced by site size. To account for this, we additionally used the Floristic Quality Assessment Index (FQI) for each site. Site 6 had the lowest FQI values followed by Site 4 (Table 1). Both sites have no management and are heavily encroached by woody species (Table 1; Appendix 2). Sites 9 and 12 had the highest FQI values indicating high ecological integrity. These sites are both managed with prescribed burns on a 2–3 year cycle leading to an open canopy. Other high FQI sites, such as 8, 10, and 13, are also managed, but with regular hand clearing techniques.

We are unable to directly compare Murphy and Boyd (1999) associated bog species from a quantitative standpoint given that sampling methods varied between the studies. However, it should be noted that many common associates listed in the previous study (*e.g., Arundinaria tecta*, *Eriocaulon decangulare*, *Smilax laurifolia, Sphagnum spp.,* and *Xyris spp.*) were still present across numerous sites (Appendix 1). Other carnivorous plant species (*e.g., Drosera capillaris* and *Utricularia subulata*) identified in Murphy and Boyd (1999) were also found across sites in this present survey. Unfortunately, we were unable to locate *Pinguicula primuliflora* at Site 10, which was a unique find in the Murphy and Boyd (1999) survey. Other noteworthy species that were identified in the 1995 survey were *Hexastylis speciosa, Platanthera ciliaris, Lilium catesbaei*, and *Zigadenus densus*. As mentioned previously, *H. speciosa* and *Z. densus* were located in our survey; however, *Z. densus* was found previously at Site 4, which has since been eradicated. *Platanthera ciliaris* was also found across sites within our present survey, while we were unable to locate *L. catesbaei* at Site 9 from the 1995 survey. Similar to Murphy and Boyd (1999), we found high abundance of *Rubus* spp., *Acer rubrum*, *Vaccinium elliottii*, and *Magnolia virginiana* across sites (Appendix 2).

PHYSICAL SOIL ASSESSMENT. The soil across the survey sites was primarily composed of sand (42–87.7%, Appendix 3), which is typical for *Sarracenia alabamensis* habitat. This sandy composition has remained relatively stable since the 1995 survey with most sites being within 10% of the sand composition from the previous survey. Only Site 1 decreased in sand percentage by a factor of 10 (–10.9%), but even then, the sand content comprises 72% of the soil. In addition to sandy substrates, *S. alabamensis* also prefers acidic, low nutrients soils with high levels of aluminum. All sites tested are within 4.3–5.8 pH. This is slightly higher than the range reported in the 1995 soil (3.9–4.7), however, Site 13 is an outlier, as this site is a translocated site and is very atypical *S. alabamensis* habitat. Comparison between surveys found that Site 6 had the largest increase in pH (+0.6, Fig. 4), while changes in pH were marginal and overall stable for all other year comparisons. Aluminum levels increased across all sites.

Sixty-nine percent of variation in soil chemistry across sites and years was explained across two PC axes (Fig. 4) with iron (Fe), carbon (C), nitrogen (N), organic matter (OM), magnesium (Mg), potassium (K), zinc (Zn), and copper (Cu) having the highest loadings on PC1. The PC2 axis explained the most variation for pH and the elements cobalt (Co), manganese (Mn), and aluminum (Al). Sites 5, 8, 10, and 11 remained relatively stable between sample years. These four sites are also some of the larger *S. alabamensis* populations and receive some habitat management. Additionally, newly found Sites 12 and 14 are also found within this cluster of sites on the PCA indicating similar soil chemistry. In contrast, Sites

1, 6, 7, and 9 have the largest shift in soil chemistry between sample years. Sites 1 and 6 had a larger shift in the soil components loading on PC2 axis. Site 9 saw similar shifts, but notably this site saw a larger shift in nitrogen content between sampling years (Appendix 3). Nitrogen shifts can have large impacts on *S. alabamensis* populations as these plants require nitrogen poor habitats. While Site 9 receives management, the upland habitat surrounding this site has shifted to cattle grazing and farming, impacting nitrogen levels. Lastly, Site 7 also saw high shifts in elements loading on the PC1 axis, but unlike Site 9, these shifts between survey periods went in the opposite direction.

Discussion. In their 1995 survey, Murphy and Boyd (1999, 109) assessed each site's viability based on site size and habitat. In their assessment they categorized sites into three groups: viable, persistent, and remnant. Viable sites were defined as "sites supporting large-sized [ramets], that have [reproductively immature individuals] present, and that have a relatively secure habitat (U.S. Fish and Wildlife Service 1992)". Persistent sites were defined as sites "containing large plants and often containing [reproductively immature individuals], but habitat disruption restricts the potential of the site." Remnant sites were defined as having "*S. alabamensis* individuals, but succession has resulted in permanent habitat change" (Folkerts 1991). Here, we propose to expand these definitions to include soil and other habitat components (*i.e.,* bog associates and management practices) given that the overall quality of a particular site is dependent, not only on the presence of *S. alabamensis*, but also on the entire bog community (Folkerts 1982, McDaniel and Troup 1982) and soil characteristics. Therefore, we propose the following updated definitions: Viable sites are defined as sites supporting large-sized ramets, signs of active recruitment (*i.e.,* juveniles present, majority of plants produce flowers), support diverse and specialized bog associates, and have a relatively secure habitat as indicated by stable soil characteristics and active management practices. Persistent sites are defined as sites containing large-sized ramets, sometimes having signs of active recruitment, but the site does not support diverse bog associates and has had changes in soil characteristics due to habitat disruption and/or lack of management. Remnant sites are defined as having *S. alabamensis* individuals, but succession has resulted in permanent habitat change leading to lack of active recruitment, a lack of bog associate diversity, and inadequate soil characteristics for bog species (*e.g.,* high levels of nitrogen), most likely due to habitat disruption and/or lack of management.

In their study, Murphy and Boyd (1999) identified sites 8, 10, and 11 as being viable. Here, we confirm that these three sites are still categorized as viable, under both definitions, and additionally include Sites 5 and 12 in this category. These sites were the only five locations that had signs of active recruitment (*i.e.,* juveniles) and Sites 10, 11, and 12 had the majority of reproductively immature individuals in the survey. Furthermore, these sites supported large ramets with sites 5, 8, and 10 having increases in large-sized ramets since the 1995 survey. Sites 8, 10, 11, and 12 also contained most of the flowering individuals in our survey. While Site 5 had a smaller number of individuals, this site is found within the same protected area as Site 11 and together these would be considered the same population per the USFWS's (2018) population definition. Furthermore, the five locations also had the most stable soil conditions between the survey years, contained diverse bog associates as represented by C-values and FQI values, and were generally free of major habitat disruptions. Since the 1995 survey, Sites 5, 8, 10, and 11 have all been actively managed either through fire or hand clearing. Sites 5 and 11 are on protected land, while the remaining sites are found on private property. Of concern is the status of Sites 8 and 10 as being in "relatively secure habitat." In particular, the area surrounding Site 8 is being actively mined, which can influence water and nutrient availability for the bog habitat. The effects of mining are not apparent in our dataset, but there is growing concern that this viable site may become persistent in the future as surrounding habitat continues to be eroded. It is imperative that agencies continue to work with the private landowner to explore ways to limit the impact of the mining operation on this site. It is also recommended that agencies continually measure site hydrology, as land modification would likely impact this key habitat feature. Site 10 has a more stable habitat surrounding its location, but the landowner is resistant to the use of prescribed fire resulting in management being solely by hand clearing. This has led to a dramatic shift in woody encroachment from outside of the bog area. Both authors R. O. Determann and D. R. Folkerts had frequented this site during the 1990s and 2000s and have noticed a substantial shift in canopy cover and overall bog health. While the individual numbers at this site are strong, most individuals lacked large, upright pitchers and are showing signs of overall decreased health (*i.e.,* etiolation and genet divisions). However, it should be noted that while prescribed fire is preferred, the willingness of the landowner to allow hand clearing has presumably allowed the site to remain viable, highlighting the importance of any management in the recovery of this species.

Persistent sites identified in the 1995 survey were Sites 5, 6, 7, and 9. Since that time, Site 5 has been managed and is considered a viable site as stated above; however, Sites 6 and 7 did not have a similar fate. Since the 1995 survey, Site 6 has received no management allowing for the development of complete canopy cover and loss of noteworthy herbaceous associates. The landowner uses the upland area for pasture and the residence is 100 m from the site. Like Site 6, Site 7 has seen a decrease in the number of individuals and bog associates. This site is unmanaged and shows signs of severe habitat loss. Given these changes since the 1995 survey, we categorize Sites 6 and 7 as remnant. Site 9 is still considered a persistent site given its management and number of large individuals, but as was reported in Murphy and Boyd (1999), the upland pasture grazing has continued to disrupt this site. In comparison to the 1995 survey, there has been a decline in the number of individuals per size class and soil characteristics have shifted. This is most likely due to runoff from upland pasture areas influencing soil structure of the bog habitat, specifically high nitrogen levels can influence growth rates of competing species. The private landowner for Site 9 has continued to allow prescribed fires to occur, maintaining an open canopy and allowing habitat associates to thrive. A new, persistent site, Site 15, was discovered after the completion of the 2019 survey, and recent assessments show promise for this location. While individual plant numbers are low, the site contains many herbaceous associates and is on protected land. While we did not sample soil at this site, it is likely that the soil has remained stable overtime as surrounding uplands have remained intact. Management of this site will also be more likely, given its location on protected land.

Murphy and Boyd (1999) classified Sites 1–4 as remnant sites in their survey, given that few individuals and bog associates remained. Their assessment was that these sites have little chance to become functional bogs in the future. Of these four sites, only Site 1 remains and is still considered a remnant site. The other three sites (Sites 2–4) have all been extirpated since the 1995 survey. Sites 13 and 14, which were discovered after the 1995 survey, are also considered remnant sites. Site 13 is a translocation conducted by a private landowner to save individuals from an area that was being converted to a pond. While the landowner continues to maintain the plants and surrounding area, the site itself is not ideal habitat for this species. Specifically, plants are within 100 m of the residence and located on a man-made pond margin. Site 14 has promising soil chemistry but has no management and is completely overgrown with woody species. This site is also on private land, but the site itself is unlikely to become a functional bog without substantial active habitat management.

Prior to the 1995 survey, little active management or protection was in place for *S. alabamensis* populations. Since Murphy and Boyd (1999), many locations are now protected under voluntary conservation easements or agreements with landowners. In addition, several sites are actively managed with fire or hand clearing, all of which has greatly improved the viability of these locations. Specifically, Site 5 was previously described as being overgrown with woody vegetation, but this protected site and its nearby neighbor, Site 11, continue to be managed with fire and hand clearing. Additionally, these sites have been augmented with outplantings from conservation-minded organizations, such as the Atlanta Botanical Garden and Alabama Plant Conservation Alliance. These outplantings have been overall successful; increasing population and ramet size at outplanting sites. Outplantings were also located at Site 12, another location that receives active management. While outplantings can improve overall population size, it is imperative that sites also receive active management to prevent woody and nonnative encroachment. As an example, Site 6 was augmented with outplantings following the 1995 survey (Denhof and Determann 2006), but management of this private property was not maintained due to budget and personnel constraints. Lack of fire and hand clearing has resulted in a closed canopy and subsequent loss of habitat associates and *S. alabamensis* individuals.

While fire suppression and incompatible human land use practices are the primary reasons for *S. alabamensis* decline, poaching is an additional threat to this species (Clarke *et al*. 2018). Throughout the survey, we noted evidence of poaching at protected sites (*i.e.,* evidence of digging and removal of seed pods) and past survey work has noted similar trends (Yawn 2018). Poaching by carnivorous plant collectors can result in serious loss of genetic diversity and long-term population declines (Meyers-Rice 2001, Clarke *et al*. 2018). The effect of poaching is exacerbated by the long time to maturity (4–5 years) in this species. Protection of site locality information and landowner property rights have been the best approaches to deter poachers; however, conservation law is particularly weak for endangered plants and prosecution of poachers is exceedingly rare (Outland 2018).

Conclusions. *Sarracenia alabamensis*, the Alabama canebrake pitcher plant, is rare in nature, occurring in the Fall Line Pine Hills of the Coosa and Alabama River drainages. Precise population counts, soil characteristics, and habitat data have been extremely limited except for a thorough census conducted in 1995 (Murphy and Boyd 1999, U.S. Fish and Wildlife Service 2018). Since that time, four additional sites have been located, however, three sites from the Murphy and Boyd (1999) survey have been extirpated, leaving a total of 12 sites remaining. Of the remaining sites, five qualify as viable, two sites are considered persistent, and five are remnant sites. Since its listing in 1992 as an endangered species under the U.S. Endangered Species Act of 1973, *S. alabamensis* has never had more than five viable sites. While the number of viable sites has increased slightly since the 1995 survey, this species is still well under the minimum requirement for reclassification (10 viable sites having been monitored for 15 years; U.S. Fish and Wildlife Service 2018).

Conservation efforts for *S. alabamensis* require a multifaceted approach. As is evident from this study, *in situ* management using prescribed fire or hand clearing is key to maintaining habitat conditions for this species and bog associates. Without land management in place, all other conservation efforts are moot, as noted with Site 6. In addition to land management, continuing to establish conservation agreements/easements with private landowners can further protect vulnerable sites. This is especially important as many sites are found on private land. Continuing to foster relationships with landowners is imperative for species recovery. This is apparent at sites (*i.e.,* Sites 8–10) where landowner's have been open to management practices that have helped sites either remain viable or persistent. In stark contrast, sites (*i.e.,* Sites 1, 6, 7, and 14) where relationships have not been established or maintained has resulted in woody encroachment and subsequent remnant site status. While management of current populations is important, extensive surveying of public land in combination with habitat suitability modeling (HSM; Guisan and Zimmermann 2000) across the Fall Line may identify new, protected sites. This is highlighted by recent survey efforts locating a new site in 2020. Private land access has always been a barrier to identifying new sites, but efforts to build community relationships can potentially yield additional sites. Furthermore, preservation of genetic diversity across sites should be maintained in seed banks and *ex situ* safeguarding collections (Center for Plant Conservation [CPC] 2019). These collections can be utilized for site augmentation. These initiatives all require funding for this species and when funds are limited, viable and persistent sites should be prioritized. In the case of a site being potentially lost due to changes in land use, translocation to protected land is another option for this species. Ideally, sites for translocations should be on protected land with bog associates and soil composition similar to that of Sites 5, 8, 10, and 11.

Finally, one of the keystones of plant conservation biology is the use of proper, thorough, and long-term monitoring strategies that can aid land management and conservation groups in assessing long term population changes. The current study, while informative, is unable to model population dynamics and direct impacts of management practices. Many effects on an ecological scale manifest and are observed over long periods of time, rather than through instantaneous, short-term windows; furthermore, the influence of short-term fluctuations in dynamics such as population counts, reproduction, and flower counts, are clarified only through long-term monitoring. Future work on this species should use monitoring protocols stretching across long periods of time to gather more thorough data on population level dynamics, ecological changes to plant communities, and responses to management (CPC 2019). Specifically, creation of long-term plots to assess demographic changes in population will further add to our understanding of the long-term viability of this species. Measures of clonal growth, seed viability, seedling establishment, and other demographic measures are vital to our understanding of how this species responds to management practices and surrounding habitat modifications (*e.g.,* mining, farming). The soil and surrounding plant community methodologies should continue in future surveys, as these habitat characteristics can additionally be an indicator of site health. While not conducted in this study or in Murphy and Boyd (1999), we recommend monitoring site hydrology changes over time. This is especially important as we noted dramatic shifts in upland habitat use and mining operations that were not present in the previous assessment. Lastly, rare species are especially vulnerable to severe stochastic events (*e.g.,* drought), which are predicted to increase in frequency and intensity with climate change (Seneviratne *et al*. 2012). This compounded with the current threats make it imperative to continue long-term surveys and vital management practices to save this rare and endangered species.

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Appendix 1

Herbaceous bog associates across *Sarracenia alabamensis* sites. Site numbers match the arbitrary assignments from Murphy and Boyd (1999). Associates for Sites 3 and 4 are not included given these sites have been extirpated. Relative abundance of each species is designated into three categories: 1 (plant present), 2 (plant frequent), 3 (plant abundant or dominant). C-values were determined from Zomlefer *et al*. (2013), with the exception of *Hexastylis speciosa* and *Zigadenus densus* (Gianopulos 2014). Numbers listed to the right of the / (/) are the values from the 1995 dataset, numbers to the left are values from this study. Species without two values are newly listed species. Sites 12–15 are newly discovered sites since Murphy and Boyd (1999). NA = not applicable, (-) = not present.

		Site Number												
Plant species	C-value	1	2	5	6	7	8	9	10	11	12	13	14	15
Aletris aurea	5	-/-	-/-	2/3	- /-	- /1	- /-	- /-	- /2	1 /2	2 /NA	- /NA	- /NA	1 /NA
Aletris farinosa	5	-/-	-/-	- /-	- /-	- /-	- /-	- /-	- /-	- /2	1 /NA	- /NA	- /NA	- /NA
Aletris obovata	4	-/-	-/-	- /-	- /-	- /1	- /-	- /-	- /-	- /1	- /NA	1 /NA	- /NA	- /NA
Andropogon spp.	-	-	-	-	-	-	1	-	-	-	-	-	-	1
Apios americana	5	-	1	-	-	-	-	3	-	-	-	-	-	-
Arundinaria tecta	5	2 /1	- /1	3 /2	1 /1	1 /1	3 /1	2 /2	- /1	- /1	3 /NA	- /NA	3 /NA	2 /NA
Asclepias incarnata	4	-	1	-	-	-	-	-	-	-	-	-	-	-
Asplenium platyneuron	4	-	-	-	1	-	-	-	-	-	-	-	-	-
Balduina spp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Balduina uniflora	6	- /-	- /-	- /-	- /-	- /-	- /-	- /-	- /-	- /1	- /NA	3 /NA	- /NA	- /NA
Buchnera floridana	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Calopogon tuberosus	7	-	-	-	-	-	-	-	-	-	2	-	-	-
Carex spp.	-	- /-	- /2	- /-	- /-	- /-	1 /2	3 /2	2 /2	- /2	- /NA	- /NA	1 /NA	1 /NA
Cleistes divaricata	7	-	-	-	-	-	-	-	-	1	-	-	-	-
Clematis spp.	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Coreopsis major	-	-	-	1	-	-	-	-	-	2	-	-	-	-
Dicanthelium commutatum	6	-	-	-	-	-	-	-	-	-	-	-	-	1
Drosera brevifolia	5	-	-	-	-	-	-	-	-	3	-	-	-	-
Drosera capillaris	5	- /-	- /-	1 /-	- /1	- /-	3 /3	1 /2	1 /3	- /3	3 /NA	- /NA	- /NA	- /NA
Eleocharis microcarpa	4	- /-	- /-	- /-	- /-	- /-	- /1	- /-	- /1	- /1	- /NA	- /NA	- /NA	- /NA
Eleocharis obtusa	4	-	-	-	-	-	-	-	-	-	-	-	-	1
Epigaea repens	-	- /-	- /-	- /-	- /-	- /-	- /1	- /-	- /1	- /-	- /NA	- /NA	- /NA	- /NA
Erianthus giganteus	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Eriocaulon decangulare	-	- /-	- /1	- /2	- /-	- /-	1 /2	3 /2	3 /2	- /2	2 /NA	- /NA	- /NA	- /NA
Eryngium integrifolium	6	- /-	- /-	- /1	- /-	- /1	- /-	3 /1	- /-	- /2	- /NA	- /NA	- /NA	- /NA
Eupatorium album	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Eupatorium altissimum	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Eupatorium perfoliatum	4	-	-	-	-	-	-	1	-	-	-	-	-	1
Eupatorium rotundifolium	4	1	-	1	-	-	-	2	-	2	2	-	-	1
Eutrochium fistulosum	4	-	-	-	-	-	-	-	-	-	-	-	-	1
Fuirena squarrosa	4	-	-	-	-	-	-	-	-	-	-	-	-	1

Appendix 1

Continued.

Plant species	C-value	Site Number 1	2	5	6	7	8	9	10	11	12	13	14	15
Galium aparine	3	-	3	-	-	-	-	-	-	-	-	-	-	-
Gelsemium sempervirens	3	-	-	1	-	1	3	1	2	2	-	-	1	1
Habenaria repens	5	-	-	-	-	-	-	-	-	-	-	1	-	-
Helianthus angustifolius	4	-	-	-	-	-	1	3	-	-	-	-	-	1
Hexastylis speciosa	9	- /-	- /-	- /-	- /-	1 /1	1 /-	- /-	- /-	- /-	1 /NA	- /NA	1 /NA	- /NA
Hypericum crux-andreae	4	-	-	-	-	1	-	1	-	-	-	-	-	1
Hypericum virginicum	-	-	2	-	-	-	-	-	-	-	-	3	-	-
Iris spp.	-	-	-	-	-	-	-	3	-	-	-	-	-	-
Lachnocaulon anceps	4	- /-	- /-	1 /-	- /1	1 /-	3 /-	3 /-	3 /2	1 /1	- /NA	- /NA	- /NA	- /NA
Lilium catesbaei	5	- /-	- /-	- /-	- /-	- /-	- /-	- /3	- /1	- /-	- /NA	- /NA	- /NA	- /NA
Lobelia spp.	-	-	-	-	-	1	1	1	-	-	-	1	-	-
Ludwigia alternifolia	3	- /-	- /2	- /1	- /2	- /-	- /1	- /-	- /2	- /1	- /NA	- /NA	- /NA	1 /NA
Lycopodiella alopecuroides	4	- /-	- /-	- /-	- /-	- /-	2 /2	- /-	2 /1	- /1	1 /NA	- /NA	- /NA	1 /NA
Lycopodiella caroliniana	4	- /-	- /-	- /-	- /-	- /-	- /3	- /-	3 /2	1 /2	1 /NA	- /NA	- /NA	- /NA
Lysimachia quadrifolia	5	-	-	-	-	-	1	-	-	-	-	-	-	-
Lysimachia tonsa	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Maianthemum racemosum	5	-	-	-	-	1	-	-	-	-	-	-	-	-
Mitchella repens	3	-	-	-	-	1	-	-	-	-	1	-	1	-
Mitreola sessiliforlium	4	- /-	- /-	- /-	- /1	- /-	- /1	- /-	- /2	- /1	- /NA	- /NA	- /NA	1 /NA
Osmundastrum cinnamomeum	5	1	-	-	-	2	1	-	3	2	2	-	1	1
Osmundastrum regalis	5	-	-	-	-	-	1	-	1	-	1	1	-	-
Parthenocissus quinquefolia	3	-	-	-	-	-	1	-	-	-	1	-	1	-
Peltandra sagittifolia	7	-	-	-	-	-	-	1	-	-	-	1	-	-
Pinguicula primuliflora	6	- /-	- /-	- /-	- /-	- /-	- /-	- /-	- /1	- /-	- /NA	- /NA	- /NA	- /NA
Platanthera ciliaris	4	- /-	- /-	2 /-	- /-	- /-	- /1	- /-	1 /1	- /-	1 /NA	- /NA	1 /NA	- /NA
Poaceae spp.	-	-	-	-	-	-	-	3	-	3	-	-	-	-
Pogonia ophioglossoides	6	-	-	-	-	-	-	-	-	-	-	-	-	1
Polygala brevifolia	6	- /-	- /-	1 /-	- /-	- /-	- /-	- /2	- /-	1 /3	1 /NA	- /NA	- /NA	- /NA
Polygala cruciata	5	-	-	-	-	-	2	2	-	-	-	-	-	-
Polygala lutea	4	- /-	- /-	- /2	- /-	2 /-	1 /2	- /1	- /1	2 /2	2 /NA	- /NA	- /NA	- /NA
Polygala nana	4	- /-	- /-	1 /-	- /2	- /-	- /1	- /-	- /-	2 /3	- /NA	- /NA	- /NA	- /NA
Pteridium latiusculum var. pseudocaudatum	-	1	-	3	-	-	2	-	-	2	3	-	-	-
Pycnanthemum spp.	-	- /-	2 /1	- /1	2 /2	- /1	- /1	3 /1	1 /1	- /1	- /NA	- /NA	- /NA	- /NA
Rhexia alifanus	5	- /-	- /-	1 /-	- /-	- /-	- /-	1 /-	- /-	3 /1	3 /NA	1 /NA	- /NA	- /NA

Appendix 1

Continued.

Plant species	C-value	Site Number 1	2	5	6	7	8	9	10	11	12	13	14	15
Rhexia mariana	4	- /-	- /-	- /3	- /3	- /1	- /2	2 /2	- /1	1 /2	3 /NA	1 /NA	- /NA	- /NA
Rhexia virginica	4	-	-	-	-	-	1	2	-	-	-	-	-	1
Rhynchospora spp.	-	- /-	- /2	- /2	- /3	- /1	- /1	1 /3	- /-	- /2	- /NA	- /NA	- /NA	1 /NA
Saururus cernuus	4	-	-	-	1	-	-	-	-	-	-	-	-	-
Scutellaria integrifolia	3	- /-	1 /2	- /-	- /3	- /1	3 /2	1 /-	- /2	- /1	- /NA	- /NA	- /NA	- /NA
Smilax auriculata	2	- /-	- /-	- /-	- /2	- /1	1 /1	- /-	1 /1	- /1	- /NA	- /NA	- /NA	- /NA
Smilax glauca	3	-	-	-	-	-	-	-	-	3	1	1	-	1
Smilax laurifolia	3	1 /1	- /-	- /3	- /2	1 /2	2 /2	1 /-	1 /2	1 /2	1 /NA	3 /NA	3 /NA	1 /NA
Sphagnum spp.	-	2 /1	- /1	- /-	1 /2	1 /2	3 /2	3 /1	3 /3	2 /1	3 /NA	3 /NA	1 /NA	1 /NA
Spiranthes spp.	-	- /-	- /-	- /1	- /-	- /1	- /-	- /-	- /2	- /2	- /NA	1 /NA	- /NA	1 /NA
Symphyotrichum dumosum	2	-	-	-	-	-	-	-	-	-	-	-	-	1
Symplocos tinctoria	5	- /-	- /-	- /-	- /-	- /-	- /-	- /-	- /-	3 /1	- /NA	- /NA	- /NA	- /NA
Tephrosia virginiana	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Triantha racemosa	5	- /-	- /-	- /-	- /-	- /-	- /-	- /3	- /2	- /1	- /NA	- /NA	- /NA	- /NA
Toxicodendron radicans	2	-	-	-	3	-	2	-	-	-	-	-	-	-
Toxicodendron vernix	5	1 /-	- /-	- /2	- /-	- /2	1 /2	1 /-	2 /-	- /1	- /NA	- /NA	- /NA	- /NA
Trifolium repens	1	-	3	-	-	-	-	-	-	-	-	-	-	-
Typha latifolia	2	- /-	- /-	- /-	- /-	- /-	- /-	- /-	- /2	- /-	- /NA	- /NA	- /NA	- /NA
Utricularia gibba	5	-	-	-	-	-	-	-	-	-	-	1	-	-
Utricularia subulata	4	- /-	- /-	- /-	- /-	- /-	1 /3	- /-	- /2	1 /2	- /NA	- /NA	- /NA	- /NA
Vitis rotundifolia	2	-	-	-	2	1	-	-	-	-	-	-	-	-
Woodwardia areolata	5	1	-	-	2	1	2	-	-	-	-	3	-	1
Xyris torta	4	1 /-	- /-	1 /2	- /3	1 /-	- /1	1 /2	2 /1	2 /3	2 /NA	- /NA	- /NA	- /NA
Zigadenus densus	7	- /-	- /-	- /-	- /-	1 /-	- /-	- /-	- /-	- /-	2 /NA	- /NA	- /NA	- /NA

Appendix 2

Woody and/or nonnative species across *Sarracenia alabamensis* sites. Site numbers match the arbitrary assignments from Murphy and Boyd (1999). Associates for Sites 3 and 4 are not included given these sites have been extirpated. Relative abundance of each species is designated into three categories: 1 (plant present), 2 (plant frequent), 3 (plant abundant or dominant). C-values were determined from Zomlefer *et al*. (2013). Numbers listed to the right of the slash (/) are the values from the 1995 dataset, numbers to the left are values from this study. Species without two values listed are newly listed species across sites. Sites 12–15 are newly discovered sites since Murphy and Boyd (1999). NA = not applicable, (-) = not present.

		Site number												
Plant species	C-values	1	2	5	6	7	8	9	10	11	12	13	14	15
Acer rubrum	3	2 / 1	3 / 1	2 / 1	3 / 1	1 / 2	3 / 3	3 / 1	3 / 1	2 / 2	3 / NA	2 / NA	- / NA	1 /NA
Alnus serrulata	4	- / -	3 / 1	- / 1	- / -	- / 1	2 / -	3 / 1	1 / 2	- / 1	- / NA	2 / NA	- / NA	- / NA
Aronia arbutifolia	5	1	-	-	-	1	3	3	-	-	-	1	-	1
Cephalanthus occidentalis	4	-	-	-	-	-	-	2	-	-	-	-	-	-
Clethra alnifolia	5	-	-	-	-	-	-	-	1	-	-	-	-	-
Cornus amomum	4	-	-	-	-	-	-	1	-	-	-	-	-	-
Cyperaceae spp.	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Cyrilla racemiflora	3	3 / -	- / -	3 / 3	- / -	- / -	2 / -	- / -	3 / -	2 / 2	- / NA	- / NA	- / NA	1 /NA
Diospyros virginiana	3	-	-	-	-	-	1	-	2	2	1	-	-	-
Gaylussacia dumosa	5	-	-	-	-	-	-	-	-	2	-	-	-	1
Gaylussacia nana	6	-	-	-	-	-	-	-	-	2	-	-	-	-
Ilex coriacea	4	3 / -	- / -	1 / -	- / -	2 / -	3 / -	- / -	3 / 1	3 / 1	3 / NA	- / NA	3 / NA	2 /NA
Ilex glabra	4	- / 1	- / -	3 / 3	- / -	- / 1	1 / 1	- / -	1 / -	2 / 2	2 / NA	- / NA	- / NA	- / NA
Ilex opaca	3	- / -	- / -	- / -	- / -	1 / -	2 / -	- / -	2 / 1	- / 1	- / NA	- / NA	- / NA	- / NA
Ilex vomitoria	3	-	-	-	-	-	-	-	1	-	-	-	-	-
Illicium floridanum	6	-	-	-	-	1	-	-	-	-	-	-	-	-
Itea virginica	6	-	-	-	-	-	-	-	-	-	-	1	-	-
Juncus effusus	3	1 / -	- / -	- / -	1 / 2	- / -	1 / 1	1 / 1	- / 1	1 / 2	- / NA	1 / NA	- / NA	1 /NA
Juncus spp.	-	-	-	-	-	-	-	-	-	1	1	-	-	1
Ligustrum sinense	0	-	-	-	3	-	1	-	-	-	-	-	-	-
Liquidambar styraciflua	3	1 / 1	- / -	- / 1	2 / 1	3 / 1	3 / 1	- / -	2 / -	1 / 1	3 / NA	3 / NA	3 / NA	- / NA
Liriodendron tulipifera	3	1 / -	- / -	- / 1	- / 1	1 / 1	2 / 1	- / -	2 / -	1 / 1	1 / NA	3 / NA	2 / NA	1 /NA
Lonicera japonica	0	-	2	-	-	-	-	-	-	-	-	-	-	-
Lyonia lucida	5	- / 1	- / -	- / 3	- / -	- / -	3 / 2	- / -	- / 2	- / 2	- / NA	- / NA	3 / NA	1 /NA
Lyonia spp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Magnolia virginiana	5	1 / 1	- / 1	- / 2	- / 1	1 / 1	1 / -	1 / -	2 / 1	1 / 1	1 / NA	- / NA	1 / NA	1 /NA
Myrica cerifera	3	- / -	1 / -	- / 2	- / 1	- / 1	- / 1	1 / -	1 / -	- / 1	- / NA	1 / NA	- / NA	1 /NA
Myrica heterophylla	-	- / -	- / -	- / 2	- / -	1 / -	2 / -	- / -	3 / 1	- / 2	- / NA	- / NA	- / NA	- / NA
Nyssa aquatica	7	-	-	-	-	1	-	1	-	-	-	-	-	-
Nyssa sylvatica	5	-	-	-	-	-	-	-	1	1	-	-	1	1
Oxydendrum arboretum	4	-	-	2	-	-	2	-	-	2	1	-	-	-

Appendix 2

Continued.

Plant species	C-values	Site number												
		1	2	5	6	7	8	9	10	11	12	13	14	15
Persea borbonia	5	-	-	-	-	-	1	-	-	-	-	-	-	-
Persea palustris	5	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinus elliotii	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinus palustris	5	-	-	3	-	-	1	-	-	3	2	-	1	-
Pinus taeda	2	3	-	1	-	2	1	-	3	2	2	3	3	1
Prunus serotina	3	-	-	-	-	-	1	-	-	1	-	-	-	-
Quercus laevis	-	-	-	1	-	-	-	-	-	2	-	-	-	-
Quercus marilandica	-	-	-	1	-	-	-	-	-	2	-	-	-	-
Quercus nigra	2	2	-	-	3	1	-	-	-	-	-	-	-	-
Quercus spp.	-	-	-	-	3	-	1	-	1	-	-	3	-	-
Rhododendron canescens	4	- / -	- / -	- / -	- / -	- / 1	- / -	- / -	1 / 1	2 / 1	- / NA	- / NA	- / NA	- / NA
Rhododendron spp.	-	-	-	-	-	-	-	-	1	1	-	-	-	-
Rhododendron viscosum	5	-	-	-	-	-	-	-	-	-	3	-	-	-
Rhus copallinum	3	-	-	-	-	-	-	-	-	2	-	-	-	-
Rubus spp.	-	- / 1	3 / 2	- / 3	3 / 2	2 / 2	1 / 1	3 / 1	1 / 2	- / 2	2 / NA	- / NA	- / NA	1 /NA
Sambucus nigra ssp. canadensis	3	-	-	-	-	-	-	1	-	-	-	-	-	-
Sassafras albidum	3	-	-	-	-	-	-	-	-	2	-	-	-	-
Vaccinium arboretum	5	-	-	-	-	-	-	-	-	-	-	-	-	-
Vaccinium corybosum	4	-	-	-	-	-	-	-	-	2	-	-	-	-
Vaccinium darrowii	5	-	-	-	-	-	-	-	-	2	-	-	-	-
Vaccinium elliotii	5	- / -	- / -	- / 2	- / 1	1 / 2	- / 1	- / -	2 / 2	1 / 2	- / NA	- / NA	- / NA	- / NA
Vaccinium myrsinites	5	-	-	-	-	-	-	-	-	2	-	-	-	-
Vaccinium spp.	-	-	-	2	-	1	3	-	3	3	1	-	-	-
Vaccinium stamenium	5	-	-	-	-	-	-	-	-	2	-	-	-	-
Viburnum nudum	5	1	2	-	-	-	1	-	-	-	-	1	-	-

Appendix 3

Summary of *Sarracenia alabamensis* soil characteristics across all sites sampled in 2019. Values under each number represent the change since the 1995 survey. Sites 2–4 were not included in the 2019 sampling given *S. alabamensis* has been extirpated and sites are not recoverable. Site 15 was also not included since the discovery of the site occurred after the initial 2019 survey.

Site No.	Sand (%)	N (%)	C (%)	Organic matter (%)	Ca (ppm)	K (ppm)	Mg (ppm)	P (ppm)	Mn (ppm)	Al (ppm)	Pb (ppm)	Fe (ppm)	Co (ppm)	Na (ppm)	Zn (ppm)	Cu (ppm)	pH
1	71.9	0.7	16.7	22.9	124.1	28.1	28.1	2.7	28.1	7433.0	1.0	673.5	0.9	23.4	2.8	2.2	4.6
	(–10.6)	(+0.3)	(+0.3)	(+10.7)	(+0.8)	(–43.6)	(–13.9)	(–3.3)	(+15.7)	(+7009.2)	(–2.7)	(+102.2)	(+0.6)	(–17.1)	(–1.0)	(–4.7)	(nd)
5	75.9	0.0	1.4	2.6	32.4	56.8	10.6	1.4	0.9	3582.0	0.9	56.8	0.2	6.7	0.4	0.4	4.4
	(+0.9)	(–0.1)	(+1.3)	(–0.7)	(–12.8)	(+30.8)	(–0.6)	(–2.5)	(–3.6)	(+3122.1)	(–1.4)	(–37.1)	(+0.1)	(–16.1)	(–0.3)	(nd)	(nd)
6	68.0	0.2	4.2	4.8	166.1	25.6	25.5	2.8	46.5	4144.0	0.6	135.0	1.3	8.7	1.8	0.9	5.0
	(–9.5)	(+0.1)	(+1.7)	(nd)	(+52.9)	(+13.0)	(+11.9)	(–1.7)	(+43.9)	(+3753.8)	(–2.3)	(–74.3)	(+1.2)	(–15.7)	(–0.5)	(+0.4)	(+0.6)
7	42.0	0.1	2.0	3.1	73.7	19.0	12.0	1.3	4.6	1911.0	1.0	178.0	0.3	6.1	0.4	0.6	4.4
	(NA)	(–0.3)	(–6.6)	(–13.4)	(–257.5)	(–55.6)	(–66.2)	(–6.9)	(–13.1)	(+1365.8)	(–3.0)	(–14.7)	(+0.1)	(–38.3)	(–1.8)	(–0.4)	(+0.1)
8	85.7	0.1	3.1	6.1	129.9	19.3	33.0	1.7	8.3	1036.0	0.5	103.0	0.3	13.3	0.6	0.2	4.4
	(–5.6)	(nd)	(+1.8)	(+3.6)	(+55.2)	(+10.1)	(+22.9)	(+0.3)	(+7.6)	(+969.2)	(–0.7)	(+77.2)	(+0.2)	(–7.6)	(+0.1)	(–0.1)	(–0.2)
9	70.0	0.5	9.3	14.6	186.9	32.2	37.0	3.0	5.6	5472.0	3.2	310.9	0.7	22.6	1.1	0.3	4.7
	(+11.2)	(+0.4)	(+2.8)	(+2.2)	(+57.2)	(+7.9)	(+13.0)	(–5.2)	(–2.3)	(+4169.5)	(–1.1)	(+240.8)	(+0.6)	(–11.9)	(+0.5)	(nd)	(nd)
10	87.7	0.1	2.6	3.6	61.0	14.9	16.9	2.6	8.8	1117.0	0.9	91.9	0.6	11.2	0.6	0.3	4.4
	(+13.9)	(nd)	(–0.2)	(–1.8)	(–63.8)	(–2.8)	(–5.6)	(–2.9)	(+2.7)	(+811.8)	(–1.5)	(+0.4)	(+0.6)	(–13.0)	(–0.1)	(nd)	(+0.1)
11	67.9	0.1	2.4	3.0	33.7	16.5	10.0	1.1	0.3	1901.0	1.0	56.3	0.3	12.0	0.5	0.9	4.3
	(–7.1)	(+0.1)	(+1.5)	(+1.3)	(+6.9)	(+3.2)	(+4.8)	(–0.7)	(–0.2)	(+1742.5)	(–0.6)	(–72.9)	(+0.3)	(–7.8)	(nd)	(+0.1)	(+0.2)
12	66.0	0.0	1.5	2.2	30.4	8.3	7.0	0.8	2.0	1939.0	0.4	203.0	0.3	5.5	0.2	0.3	5.0
13	74	0.1	2.8	2.5	404.0	17.9	26.2	1.0	46.1	1956.0	0.9	208.0	1.7	6.3	0.5	0.7	5.8
14	61.9	0.1	2.1	4.4	49.4	11.7	12.1	1.6	3.9	2009.0	1.8	296.7	0.3	9.1	0.6	0.7	4.5