# A 36-year history (1978-2013) of the plant community in Pickerelweed Pond, a naturally occurring sinkhole pond in Missouri

EMILY A. GEEST  $^1$  AND BRUCE SCHUETTE  $^2$ 

ABSTRACT. — From 1978-2013, an annual summer vegetation survey occurred at Pickerelweed Pond, a naturally occurring sinkhole pond in Cuivre River State Park near Troy, Missouri. Surveys recorded pond characteristics, plant species, and plant cover. Pond characteristics varied by year with the pond at its widest in 2011 and smallest in 1988; pond depth ranged between 30-122 cm. Over the 36-year span of the study, surveys recorded 17 plant species with the highest species richness occurring in 1994 and the lowest occurring in 1978, 1981, 1998, and 2013. Plant communities varied by year and transect direction. Along the north-south transect there were distinct clusters of years with a plant species most associated with each cluster including *Typha latifolia*, *Sparganium androcladum*, and *Utricularia gibba*. *Nelumbo lutea* and *Pontederia cordata* exhibited an inverse relationship, with *Utricularia* presence high in years that *Pontederia* presence was low, and pickerel weed presence high in years that American lotus presence was low. Multiple flora and fauna of conservation concern were recorded in the pond during the study. To our knowledge, this is the first long-term vegetation study of a sinkhole pond, an understudied wetland system.

### Introduction

Sinkhole ponds only occur in areas of karst topography where dissolution of carbonate bedrock forms natural depressions (sinkholes). Seasonal or perennial wetlands can become established in these sinkholes if internal drainage becomes blocked (Homoya & Hedge 1982, Nelson 2005). The resulting wetlands are closed and isolated systems, with plant communities determined by the size, depth, water chemistry, water fluctuations, and vegetation characteristics (Nelson 2005). Seasonal flooding can occur (Bartgis 1992), with ponds filling with water from intermittent streams or direct rainfall (Homoya & Hedge 1982).

Naturally occurring sinkhole ponds are an uncommon landscape feature but have been recorded in Virginia (Ludwig et al. 1991), Maryland (Bartgis 1992), Florida (Wallis 2016), West Virginia (Bartgis 1992), Indiana, Kentucky, and Missouri (Homoya & Hedge 1982). Sinkhole ponds have always been uncommon because three conditions must be met for this feature to form: 1) it can only occur in areas where the geology supports karst topography, 2) the bedrock must dissolve to create the sinkhole, and 3) the sinkhole must become blocked to hold water in order to become a pond (Nelson 2005, Baryakh & Fedoseev 2011). During post Euro-American settlement, many of these ponds were destroyed by clearing, intense grazing, draining, converting to livestock

<sup>&</sup>lt;sup>1</sup> EMILY A. GEEST — Oklahoma City Zoo and Botanical Gardens, Department of Conservation, Education, and Science, 2101 NE 50th Street, Oklahoma City, OK 73111. email: <a href="mailto:egeest@okczoo.org">egeest@okczoo.org</a>.

<sup>&</sup>lt;sup>2</sup> BRUCE SCHUETTE — Missouri Department of Natural Resources, Division of State Parks (retired), P.O. Box 176, Jefferson City, MO 65102. email: bschuette303@gmail.com.

watering ponds, and conversion of the vegetation (Nelson 2005). Although vegetation in sinkhole ponds often includes rare plants (Bartgis 1992), little is known about plant communities and long-term vegetation trends in these rare natural systems. To better understand sinkhole pond plant diversity and community assemblages, we present a 36-year study of vegetation in a naturally occurring sinkhole pond in Missouri.

### **METHODS**

Study Site: Pickerelweed Pond is in Cuivre River State Park, a 2,617 ha (6,468 acre) state park in Lincoln County, Missouri. According to the *Atlas of Missouri Ecoregions* (Nigh & Schroeder 2002) the park is located in the Mississippi River Hills subsection of the Central Dissected Till Plains section of northern Missouri. The Mississippi River Hills area is characterized as a broad belt of hills where the pre-settlement vegetation was oak and mixed hardwood woodland and forest, with savannas and prairies on flatter uplands. Karst features are locally prominent (Nigh & Schroeder 2002) and — similar to the Ozark Ecoregion — this terrain is riddled with karst features including sinkholes (Leahy 2011). Historically the park's terrain was covered by drymesic upland woodlands, with savanna and prairie on broad ridgetops. Limestone glades and numerous features of karst topography further contribute to its resemblance to the Ozark region. Prescribed burns and woodland thinning are restoring the historical condition to much of the park's landscape (Schuette 2004, Blake 2005). Mississippian age Burlington-Keokuk limestone underlies the central portion of the park and is associated with numerous karst features, including sinkholes, caves, and springs. Additionally, a layer of Pleistocene glacial till and loess covers the limestone on the ridges (Schuette 2004).

Pickerelweed Pond is a 0.25 ha (0.61 acre) sinkhole pond on the broad north-south ridge in the central portion of the park (**Figure 1**). The pond is one of three sinkholes in close proximity. One of these sinkholes drains with no evidence of ever holding water. The second sinkhole held water and appeared as a pond on 1934 and 1942 USGS Elsberry 15' topographic maps, but by 1970 the internal drainage reopened and the pond had drained (USGS Okete 7.5 minute quadrangle, 1975). The third sinkhole is an established sinkhole pond, now called Pickerelweed Pond due to the presence of uncommon pickerel weed (*Pontederia cordata*) (**Figure 1**). Pickerelweed Pond is sinkhole pond wetland classified as a pond marsh natural community, and is considered one of best remaining examples of this rare community type (Nelson 2005). Pond marsh natural communities are ranked S1 (critically imperiled) natural communities in Missouri (MDC 2024) due to their rarity as intact habitats. In 1978, Pickerelweed Pond and its approximately 1.2 ha (3 acre) watershed was designated a Missouri State Natural Area. In 1997, the Pickerelweed Pond Natural Area was included in the surrounding landscape scale 757.6 ha (1,872 acre) Lincoln Hills Natural Area designation.

Unique flora and fauna of the pond include pickerel weed, bur-reed (*Sparganium androcladum*), slender naiad (*Najas gracillima*) – a species of conservation concern – the spatterdock darner (*Rhionaeschna mutata*), pickerel frog (*Lithobates palustris*), a state record

pickerelweed longhorn bee (*Melissodes apicatus*) and the ringed salamander (*Ambystoma annulatum*) – a species of conservation concern.

Pickerelweed Pond has undergone minimal management, with two exceptions. In 1992, common cattail (*Typha latifolia*) was controlled, since common cattails were not listed in the pre-1978 description of the pond (Cuivre River State Park 1974) and its aggressive spread through the pond was threatening to dominate the pond marsh community. The stems were cut with a handheld sickle below the surface of water, allowing the hollow stems to fill with water, thus killing the plant without the use of herbicides. The second intervention occurred in 1995, with the addition of two deer exclosures placed around portions of pickerel weed to protect plants from white-tailed deer (*Odocoileus virginianus*) herbivory (Schuette 1995). One exclosure was 7.01 m x 4.42 m (23 ft x 14.5 ft) and the other exclosure was 7.62 m x 5.79 m (25 ft x 19 ft), with a total combined area of 76.18 m<sup>2</sup> (840 ft<sup>2</sup>) (Schuette 1995).

Surveys: From 1978-2013, annual vegetation surveys were conducted in July/August to record plant species, pond width, and plant cover. Two vegetation transects were placed perpendicular to each other, along cardinal directions and spanning the widest parts of the pond (Figure 2). Stakes were placed around the border of the pond to demarcate the positions of the transects at the high-water level. The length and width of the pond were calculated from wet edge to wet edge. Transects were walked (stake to stake) with every plant species recorded at first and last sighting along each transect, measuring the total coverage of the plant species. Beginning in 1979, the depth of the pond was measured with a ruler at the deepest point, from the top of the sediment to the water surface. In 1979, American lotus (Nelumbo lutea) covered a large portion of the pond. American lotus total flower count was recorded every year thereafter to measure lotus blooming abundance. Beginning in 1989, plant species density data was added to better understand the structure of vegetation occurring in the pond. Every plant species within 5 cm of the transects had density estimated in 5% intervals every 1.52 m (5 ft) along the transect. Nomenclature follows Yatskievych (1999, 2006, 2013) with plant vouchers deposited in the Missouri Department of Natural Resources, Division of State Parks Herbarium (MODNR) in Jefferson City or the Missouri Botanical Garden's Herbarium (MOBOT) in St. Louis.

Analysis: Descriptive statistics were used to analyze pond characteristics (width and depth). Due to plant species growing in overlapping clusters, to calculate frequency of occurrence, the total length of area occupied by a plant species was divided by the total length of the transect surveyed. Thus, if American lotus was recorded from 30 m (98.40 ft) through 50 m (164.00 ft) of a 200 m (656.20 ft) transect, American lotus occupied 10% of the transect (20 m/200 m = 0.1). Vegetation community measures including species richness, Shannon-Wiener diversity, and Pielou's evenness were calculated annually in package *vegan* in program R (R Core Team 2024). Generalized linear models were used to determine pond characteristics' impact on community measures using *lme4* in R (R Core Team 2024). Principle component analysis (PCA) ordination biplots were created to evaluate annual patterns in vegetation assemblages (Amoros & Bornette 1991) using CANOCO 5 (Lepš & Šmilauer 2003) with total length of transect occupied per species as a metric for comparison. Species that occupied  $\leq 2.0\%$  of total length surveyed in the study

were removed to reduce biplot noise (Balmer & Erhardt 2001). Due to the overlap of transects and inherent correlation between north-south and east-west transects, each transect was analyzed independently.

### **RESULTS**

Pond width varied over the years but averaged 42.60 m x 50.17 m (139.76 ft x 164.60 ft). The pond was widest in 2011 at 64.62 m x 59.74 m (212.01 ft x 196.00 ft) and smallest in 1988 at 11.58 m x 11.28 m (37.99 ft x 37.01 ft) with notes indicating heavy rain before the 2011 survey and an ongoing drought in 1988 (**Figure 3**). Pond depth varied from a low of 30.48 cm (12 in) in 1986 to a high of 121.92 cm (48 in) in both 2005 and 2008, with an average depth of  $77.72 \pm 4.02$  cm (30.60  $\pm$  1.58 in) (**Figure 3**).

Across the 36-year span of the project a total of 17 plant species were observed along the transects (**Table 1**). The highest species richness occurred in 1994 at 10 species, with the lowest in 1978, 1981, 1998 and 2013 at 5 species each (**Table 1**). Average species richness was  $6.94 \pm 0.26$  on the north-south transect and  $6.81 \pm 0.26$  on the east-west transect. The average species diversity and evenness was higher along the east-west transect (H:  $1.49 \pm 0.04$ ; J:  $0.34 \pm 0.02$ ) than the north-south transect (H:  $0.66 \pm 0.05$ ; J:  $0.79 \pm 0.01$ ). Pond characteristics (width and depth) had no effect on richness, diversity, and evenness for either transect (**Table 2**).

Species varied by total length of transect occupied by year, with year-to-year fluctuations in the relative dominance of certain species including American lotus, bur-reed, common cattail, rice cutgrass (*Leersia oryzoides*), pickerel weed, mild water pepper (*Persicaria hydropiperoides*), and water shield (*Brasenia schreberi*) dependent on year (**Figure 4**). American lotus flowering stems increased from 1978 until 1983 with a high of 1400 flowering stems in 1983. After 1983, surveys recorded fewer than 100 flowering stems or no flowers at all.

Plant communities varied by year and transect orientation. The north-south PCA biplot had distinct clusters of years with cluster one consisting of years 1978-1988, cluster two 1989-1999, and cluster three 2000-2013 (**Figure 5**). Each cluster of years had a plant species most associated with that cluster, including common cattails (1978-1988), bur-reed (1989-1999), and bladderwort (*Utricularia gibba*) (2000-2013) (**Figure 5**). The north-south PCA biplot had 53.13% of variation explained in the first two axes (eigenvalues: Axis I = 0.35; Axis I = 0.19). In comparison, the eastwest PCA biplot had 62.89% of variation explained in the first two axes (eigenvalues: Axis I = 0.44; Axis I = 0.19) (**Figure 6**). In the east-west biplot, years 1978-1988 were most similar to one another with the rest of the years more interspersed. Bur-reed was most associated with post-1999 surveys in this biplot (**Figure 6**).

Species exhibited clear trends in cover and dominance over time, with some species increasing or decreasing in the area occupied depending on the survey years. Pre-1992, common cattails were a dominant plant present in  $9.38 \pm 3.14\%$  of the north-south transect with an average density of  $6.00 \pm 2.04\%$  and present in  $26.58 \pm 1.93\%$  of the east-west transect with an average

density of  $37.04 \pm 0.48\%$ . Water shield became a dominant plant in the later years of the study, with the species occupying an average of  $11.08 \pm 3.52\%$  of the north-south transect and an average of  $9.08 \pm 2.77\%$  of the east-west transect in years 1-18 (1978-1995) but increasing to an average of  $36.95 \pm 7.53\%$  (north-south) and  $25.45 \pm 4.78\%$  (east-west) in years 19-36 (1995-2013). Similarly, water shield density increased over time from an average of 2-3% pre-2001 to 37-50% post-2001. Two species that increased and decreased in frequency over time were American lotus and pickerel weed, with American lotus high in years that pickerel weed was low, and pickerel weed high in years that American lotus was low (**Figure 7**). Other plant species only appeared for a short time throughout the study. These included barnyard grass (*Echinochloa muricata*), duckweed (*Lemna minor*), spikerush (*Eleocharis obtusa*), black willow (*Salix nigra*), rush (*Juncus* spp.), and slender naiad – and would each occupy < 10% of the transect each time.

# **DISCUSSION**

Over a 36 year span, the width and depth of the pond remained relatively stable, shrinking during dry summers and expanding during wet years. Vegetation community measures (species richness, diversity, and evenness) were similar over time. However, the east-west transect when compared to the north-south transect had higher species diversity and evenness on average. The differences between vegetation based on transect orientation could be due to landscape and environmental characteristics such as sunlight exposure, with the surrounding vegetation being trees that cast shadows. Even minor differences in sunlight exposure can impact vegetation growth patterns (Evans et al. 1960, Ishihara et al. 2015).

Plant communities varied by year and transect direction, with a distinct plant species associated with each cluster of years. Common cattails were associated with the early years of the survey and are a species that are known to grow in dense monocultures and aggressively dominate areas (Apfelbaum 1985). Control of *Typha* spp. has long been discussed from a wetland management perspective with research investigating herbicide treatments (Steenis et al. 1958, Bansal et al. 2019), water level and water quality manipulations (Harris & Marshall 1963, Nelson & Dietz 1966, Mallik & Wein 1986, Bansal et al. 2019), and mechanical treatments (Svedarsky et al. 2016, Bansal et al. 2019) to help control *Typha* spp. After common cattails in this study were hand-cut in 1992 they failed to re-establish for the reminder of the study (21 years), suggesting at least in this system that hand-cutting was an effective means of control.

Bur-reed had higher relative dominance during the middle years of the study. Like common cattails, bur-reed is an aquatic plant that mitigates nitrogen and phosphorus (Alsharekh et al. 2018, Bansal et al. 2019). With the removal of common cattails, it is possible that bur-reed was able to thrive as an aquatic nitrogen and phosphorus mitigating plant. However, more research is needed to understand the chemical components and potential sources of runoff that could be driving aquatic plant dynamics. For example, bladderwort did not appear in the sampling data until 2005.

Interestingly, American lotus and pickerel weed appeared to have an inverse relationship, with American lotus high in years that pickerel weed was low and pickerel weed high in years that

American lotus was low. American lotus is a rhizomatous perennial plant that grows densely and expands rapidly (Whyte et al. 1997, Burlakova & Karatayev 2007), and is known to lower oxygen concentrations in lakes (Turner et al. 2010). In comparison, pickerel weed is an obligate emergent aquatic plant (Harrell & Bohn 1996, Gettys & Wofford 2007) with a low chance of lowering oxygen concentrations to hypoxic conditions compared to other emergent plants (Bunch et al. 2010). Survey notes indicate that herbivory by white-tailed deer on pickerel weed and by American lotus borer moth (*Ostrinia penitalis*) on the American lotus impacted each plant (Schuette 1995, 1997). Extensive deer herbivory was noted on pickerel weed, beginning in 1988. As a result, pickerel weed had a lower presence in transects in the following years. Similarly, notes indicate caterpillar herbivory occurring profusely on American lotus leaves in 1995, which possibly allowed pickerel weed an opportunity to dominate the habitat in 1996 by reducing competition. However, further research is needed to better understand interspecific interactions in a pond marsh natural community system.

Sinkhole ponds are now very rare wetland communities. These features are uncommon due to the specific conditions required for their formation: the presence of karst topography, the dissolution of bedrock dissolve to create a sinkhole, followed by the sinkhole becoming blocked to form a pond (Nelson 2005, Baryakh & Fedoseev 2011). Today, many sinkhole ponds have been destroyed due to high levels of human disturbance (Homoya & Hedge 1982, Nelson 2005), leaving only a small number of intact sinkhole pond natural communities. The few remaining sinkhole ponds in relatively unaltered states continue to face significant threats.

High levels of white-tailed deer herbivory (Schuette 1995, Nelson 2005) can adversely affect certain species (Anderson et al. 2001, Horsley et al. 2003, Rossell et al. 2005). Wetlands, including sinkhole pond systems, are also prone to ongoing threats from invasive species (Pegg et al. 2022), including moneywort (*Lysimachia nummularia*) and barnyard millet (*Echinochloa crusgalli*), which occur in the park. An additional invasive species threat is the release of fish into ponds. Two ponds in the park have had mosquitofish (*Gambusia affinis*), green sunfish (*Lepomis cyanellus*), and common goldfish (*Carassius auratus*) released by unknown individuals. The release of aquatic fish into fishless ponds reduces amphibian diversity (Hecnar & M'Closkey 1997) and degrades the habitat (Tiberti & Cardarelli 2021).

Another threat to sinkhole ponds and other wetlands is increased extreme weather frequency (Čížková et al. 2013, Mitsch & Hernandez 2013) such as prolonged periods of drought and excessive rains and floods that may alter cyclical processes (Rodo 2003, Mitsch & Hernandez 2013). Inland wetlands may be even more at risk than coastal wetlands to effects from extreme weather patterns (Čížková et al. 2013). While little is known about sinkhole pond wetland systems, even less is understood about the future threats these systems face from climate change.

Overall, sinkhole ponds are rare wetland systems that have been understudied. Long-term studies, such as this 36-year survey, are invaluable for measuring complex processes that occur over long periods of time and documenting data patterns (Müller et al. 2010, Lindenmayer et al. 2012). Over the course of this study there have been no appreciable changes in the watershed, with

the area surrounding the pond consisting of anthropogenic woodland, old fields, and scattered larger trees. However, the implementation of special deer hunts starting in 1996 has significantly reduced deer populations, minimizing browsing pressure on aquatic vegetation like pickerel weed and eliminating the need for deer exclosures in the pond. Similarly, mechanical removal of cattails has proven effective, with no regrowth observed. These findings emphasize the importance of continued monitoring and proactive measures to prevent unwanted species presence and improve overall habitat quality. To our knowledge, this is the first long-term vegetation study of a sinkhole pond. Our findings document vegetation patterns and highlight the unique biodiversity of sinkhole ponds, emphasizing the need for greater research on these uncommon and ecologically important systems.

### **ACKNOWLEDGMENTS**

Thanks to David Gronefeld, Ken McCarty, Judy Richey, Florence DiTirro, Lia Heppermann, Cassie Gibson, Keri Freeman, Rex Hill, Frank Crimmins, Ann Schuette, and others for their assistance with this annual survey. We would also like to thank the anonymous reviewers whose comments improved this manuscript.

# LITERATURE CITED

- Alsharekh, A., L.J. Swatzell, & M.T. Moore. 2018. Leaf composition of American bur-reed (*Sparganium americanum* Nutt.) to determine pesticide mitigation capability. Bulletin of Environmental Contamination and Toxicology 100: 576-580.
- Amoros, G., & C. Bornette. 1991. Aquatic vegetation and hydrology of a braided river floodplain. Journal of Vegetation Science 2(4): 497-512.
- Anderson, R.C., E.A. Corbett, M.R. Anderson, G.A. Corbett, & T.M. Kelley. 2001. Highwhite-tailed deer density has negative impact on tallgrass prairie forbs. Journal of the Torrey Botanical Society 128: 381-392.
- Apfelbaum, S.I. 1985. Cattail (Typha spp.) management. Natural Areas Journal 5: 9-17.
- Balmer, O., & A. Erhardt. 2001. Consequences of succession on extensively grazed grasslands for central European butterfly communities: rethinking conservation practices. Conservation Biology 14(3): 746-757.
- Bansal, S., S.C. Lishawa, S. Newman, B.A. Tangen, D. Wilcox, D. Albert, ... & L. Windham-Myers. 2019. *Typha* (cattail) invasion in North American wetlands: biology, regional problems, impacts, ecosystem services, and management. Wetlands 39: 645-684.
- Bartgis, R.L. 1992. The endangered sedge *Scirpus ancistrochaetus* and the flora of sinkhole ponds in Maryland and West Virginia. Castanea 57: 46-51.
- Baryakh, A.A. & A.K. Fedoseev. 2011. Sinkhole formation mechanism. Journal of Mining Science 47: 404-412.
- Blake, J.G. 2005. Effects of prescribed burning on distribution and abundance of birds in a closed-canopy oak-dominated forest, Missouri, USA. Biological Conservation 121(4): 519-531.
- Bunch, A.J., M.S. Allen, & D.C. Gwinn. 2010. Spatial and temporal hypoxia dynamics in dense emergent macrophytes in a Florida lake. Wetlands 30: 429-435.

- Burlakova, L.E. & A.Y. Karatayev. 2007. The effect of invasive macrophytes and water level fluctuations on unionids in Texas impoundments. Hydrobiologia 586: 291-302.
- Čížková, H., J. Květ, F.A. Comín, R. Laiho, J. Pokorný, & D. Pithart. 2013. Actual state of European wetlands and their possible future in the context of global climate change. Aquatic Sciences 75: 3-26.
- Cuivre River State Park. 1974. Special Botanical Areas in Cuivre River State Park. Unpublished internal report, Missouri Department of Natural Resources, Division of State Parks.
- Evans, G.C., T.C. Whitmore, & Y.K. Wong. 1960. The distribution of light reaching the ground vegetation in a tropical rain forest. Journal of Ecology 48: 193-204.
- Gettys, L.A. & D.S. Wofford. 2007. Inheritance of flower color in pickerelweed (*Pontederia cordata* L.). Journal of Heredity 98(6): 629-632.
- Harrel, R.M. & R.E. Bohn. 1996. Emergent vegetation: pickerelweed. Cooperative Extension Service. University of Maryland. UM-SG-MAP-96-05.
- Harris, S.W. & W.H. Marshall. 1963. Ecology of water-level manipulations on a northern marsh. Ecology 44(2): 331-343.
- Hecnar, S.J. & R.T. M'Closkey. 1997. The effects of predatory fish on amphibian species richness and distribution. Biological Conservation 79(2-3): 123-131.
- Homoya, M.A. & C.L. Hedge. 1982. The upland sinkhole swamps and ponds of Harrison County, Indiana. Proceedings of the Indiana Academy of Science 92: 383-388.
- Horsley, S.B., S.L. Stout, & D.S. DeCalesta. 2003. White tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 13(1): 98-118.
- Ishihara, M., Y. Inoue, K. Ono, M. Shimizu, S. Matsuura. 2015. The impact of sunlight conditions on the consistency of vegetation indices in croplands—effective usage of vegetation indices from continuous ground-based spectral measurements. Remote Sensing 7(10): 14079-14098.
- Leahy, M. 2011. Discover Missouri Natural Areas A Guide to 50 Great Places. Missouri Department of Conservation, Jefferson City. 140pp.
- Lepš, J. & P. Šmilauer. 2003. Multivariate analysis of ecological data using CANOCO. Cambridge University Press.
- Lindenmayer, D.B., G.E. Likens, A. Andersen, D. Bowman, C.M. Bull, E. Burns, ... & G.M. Wardle. 2012. Value of long-term ecological studies. Austral Ecology 37(7): 745-757.
- Ludwig, J.C., J.B. Wright, & N.E. Van Alstine. 1991. The rare plants of False Cape State Park, Virginia Beach City, Virginia. Proceedings of the Back Bay Ecological Symposium pp. 149-256.
- Mallik, A.U. & R.W. Wein. 1986. Response of a Typha marsh community to draining, flooding, and seasonal burning. Canadian Journal of Botany 64(9): 2136-2143.
- Missouri Department of Conservation. 2024. Missouri species and communities of conservation concern checklist. Missouri Department of Conservation Publication SCI077.
- Mitsch, W.J. & M.E. Hernandez. 2013. Landscape and climate change threats to wetlands of North and Central America. Aquatic Sciences 75: 133-149.
- Müller, F., C. Baessler, H. Schubert, & S. Klotz. 2010. Long-term Ecological Research. Springer, Berlin. <a href="https://doi.org/10.1007/978-90-481-8782-9">https://doi.org/10.1007/978-90-481-8782-9</a>.

- Nelson, N.F. & R.H. Dietz. 1966. Cattail control methods in Utah. Utah State department of Fish and Game, Salt Lake City.
- Nelson, P.W. 2005. The Terrestrial Natural Communities of Missouri. Missouri Natural Areas Committee.
- Nigh, T.A. & W.A. Schroeder. 2002. Atlas of Missouri Ecoregions. Missouri Department of Conservation, Jefferson City.
- Pegg, J., J. South, J.E. Hill, A. Durland-Donahou, & O.L. Weyl. 2022. Impacts of alien invasive species on large wetlands. pp. 487-516 in: Dalu, T & R.J. Wasserman, eds. Fundamentals of Tropical Freshwater Wetlands. Elsevier, Amsterdam.
- R Core Team. 2024. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org/.
- Rodo, X.E. 2003. Interactions between the tropics and the extratropics. pp. 237-274 in: Rodo XE, & F.A. Comín, eds. Global Climate: Current Uncertainties and Research in the Climate System. Springer, Heidelberg.
- Rossell, C.R., Jr., B. Gorsira, & S. Patch. 2005. Effects of white-tailed deer on vegetation structure and woody seedling composition in three forest types on the Piedmont Plateau. Forest Ecology and Management 210(1-3): 415-424.
- Schuette, B. 1995. Deer seem to love pickerel weed to death. Petal Pusher Nov.-Dec.: 5.
- Schuette, B. 1997. Lotus 'bored to death' by moth. Petal Pusher Jan.-Feb.: 2.
- Schuette, B. 2004. Cuivre River State Park Natural Resource Management Plan. Unpublished report, Missouri Department of Natural Resources, Division of State Parks. 86pp.
- Steenis, J.H., L.P. Smith, & H.P. Cofer. 1958. Studies on cattail management in the northeast. Transactions of the 10th Annual Meeting, Northeast Wildlife Conference: 149-155.
- Svedarsky, D., J. Bruggman, S. Ellis-Felege, R. Grosshans, V. Lane, R. Norrgard, ... & T. Brenny. 2016. Cattail management in the northern Great Plains: implications for wetland wildlife and bioenergy harvest. University of Minnesota, Crookston. 56pp.
- Tiberti, R. & E. Cardarelli. 2021. Some like it fishless: the reasons and potential for eradicating alien fish from European mountain lakes. Biodiversity 22(1-2): 95-99.
- Turner, A.M., E.J. Cholak, & M. Groner. 2010. Expanding American lotus and dissolved oxygen concentrations of a shallow lake. American Midland Naturalist 164(1):1-8.
- United States Geological Survey. 1934. Missouri Elsberry Quadrangle. State of Missouri Geological Survey and Water Resources. U.S. Department of the Interior, Reston, VA.
- United States Geological Survey. 1942. Elsberry Quadrangle. State of Missouri Geological Survey and Water Resources, H.A. Buehler, State Geologist. U.S. Department of the Interior, Reston, VA.
- United States Geological Survey. 1975. Okete Quadrangle. United States Department of the Interior Geological Survey. Reston, VA.
- Wallis, N.J. 2016. Climate change and ritual intervention? An enigmatic sinkhole pond and the end of Cades Pond Culture. Florida Anthropologist 69: 89-110.
- Whyte, R.S., D.A. Francko, & D.M. Klarer. 1997. Distribution of the floating-leaf macrophyte *Nelumbo lutea* (American water lotus) in a coastal wetland on Lake Erie. Wetlands 17: 567-573.

- Yatskievych, G. 1999. Steyermark's Flora of Missouri, revised edition, volume 1. Missouri Department of Conservation, Jefferson City.
- Yatskievych, G. 2006. Steyermark's Flora of Missouri, revised edition, volume 2. Missouri Botanical Garden Press, St. Louis.
- Yatskievych, G. 2013. Steyermark's Flora of Missouri, revised edition, volume 3. Missouri Botanical Garden Press, St. Louis.



**Figure 1**. **A**. Pickerelweed Pond, date unknown (estimated early 1980s). **B**. Pickerel weed (*Pontederia cordata*) 2011. Photos by Bruce Schuette.

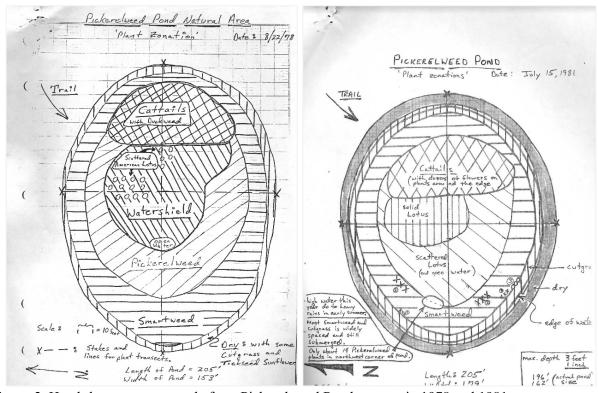
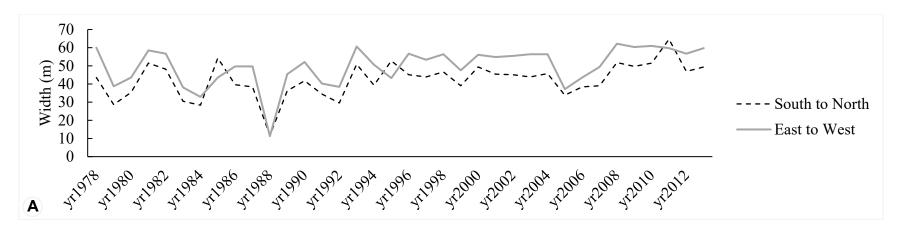
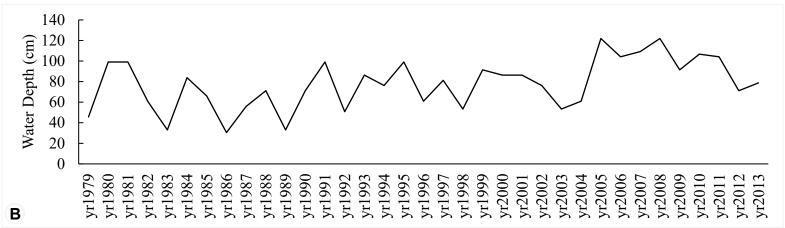


Figure 2. Hand-drawn maps to scale from Pickerelweed Pond surveys in 1978 and 1981.





**Figure 3**. Total width and depth of Pickerelweed Pond in Cuivre River State Park, Troy, Missouri, USA from 1978-2013. **A**. Water was measured from the widest point south to north (SN) and east to west (EW) in August of every survey year. The pond was the smallest in 1988 (11.58 m SN x 11.28 m EW) and widest in 2011 (64.62 m SN x 59.74 m EW). Total water depth (cm). **B**. Water depth was recorded from top of sediment to surface water edge in August of each survey year. Water depth was lowest in 1986 at 30.48 cm and highest in 2005 and 2008 at 121.92 cm. Water depth was not measured in 1978.

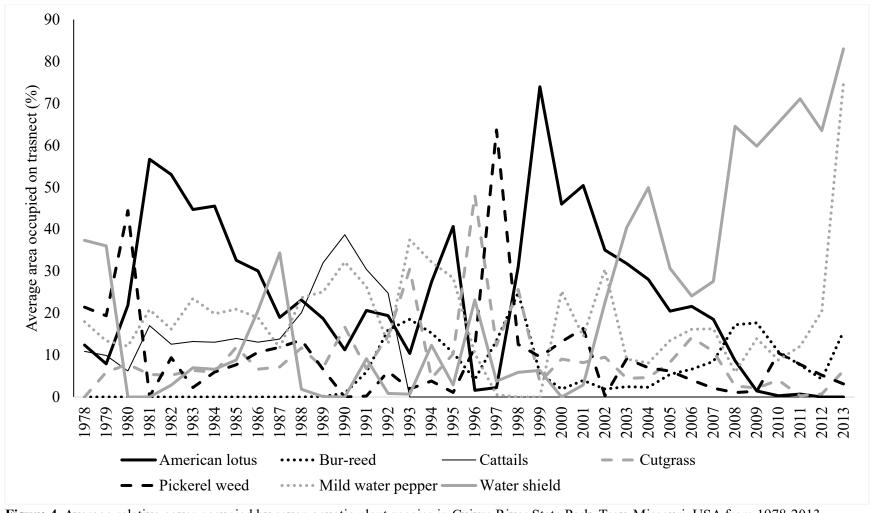
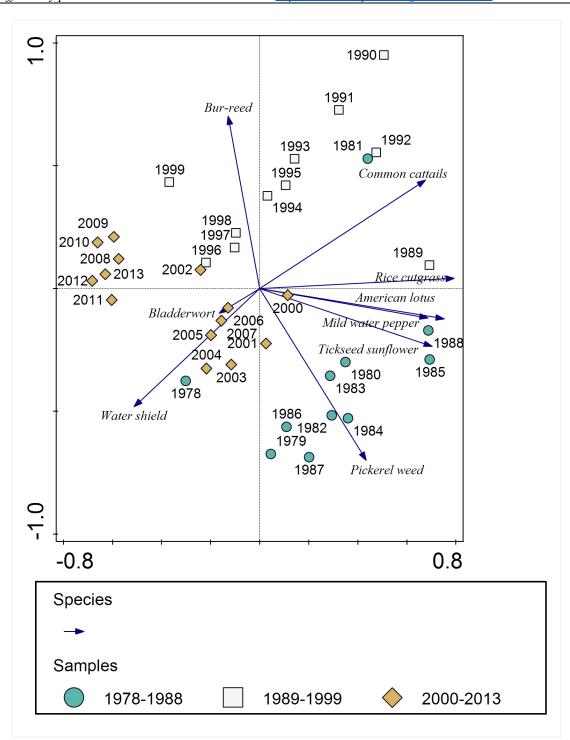
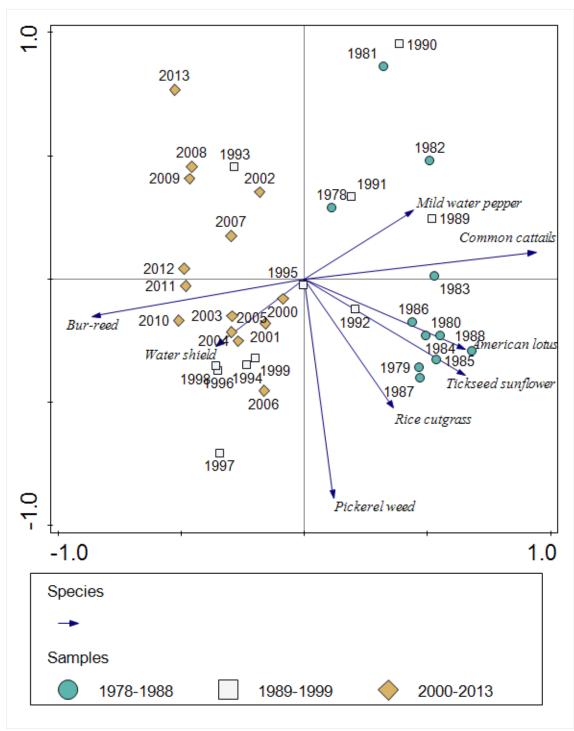


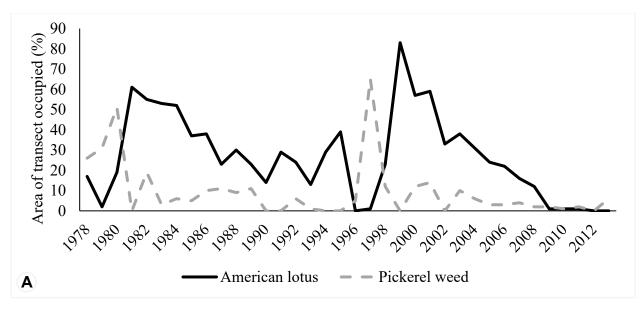
Figure 4. Average relative cover occupied by seven aquatic plant species in Cuivre River State Park, Troy, Missouri, USA from 1978-2013.

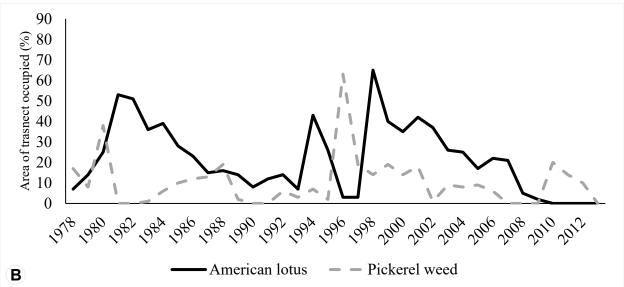


**Figure 5**. A principal component analysis biplot comparing vegetation community in Pickerelweed Pond in Cuivre River State Park from 1999-2013 along a <u>north-south transect</u>. The closer the years are clustered together, the more similar the plant communities are to one another. Axis I explained 34.60 variation with 53.13 explained in Axis II with eigenvalues 0.35 and 0.19 respectively.



**Figure 6.** A principal component analysis biplot comparing vegetation community in Pickerelweed Pond in Cuivre River State Park from 1999-2013 along an <u>east-west transect</u>. The closer the years are clustered together, the more similar the plant communities are to one another. Axis I explained 44.34% of the variation with 62.89% explained in Axis II, with eigenvalues 0.44 and 0.19 respectively.





**Figure 7**. Total area of transects occupied by American lotus (*Nelumbo lutea*) and pickerel weed (*Pontederia cordata*) in Pickerelweed Pond in Cuivre River State Park, Troy, Missouri, USA from 1978-2013. **A**. One transect was orientated north-south across the widest portion of the pond. **B**. One transect was orientated east-west across the widest portion of the pond.

Table 1. Seventeen plant species' presence recorded in Pickerelweed Pond, Cuivre River State Park, Troy, Missouri over 36 years (1978-2013).

-	-		_																																	
		Year																																		
Species	1 9 7 8	1 9 7 9	1 9 8 0	1 9 8 1	1 9 8 2	1 9 8 3	1 9 8 4	1 9 8 5	1 9 8 6	1 9 8 7	1 9 8 8	1 9 8 9	1 9 9	1 9 9	1 9 9 2	1 9 9 3	1 9 9 4	1 9 9 5	1 9 9 6	1 9 9 7	1 9 9 8	1 9 9	2 0 0 0	2 0 0 1	2 0 0 2	2 0 0 3	2 0 0 4	2 0 0 5	2 0 0 6	2 0 0 7	2 0 0 8	2 0 0 9	2 0 1 0	2 0 1 1	2 0 1 2	2 0 1 3
Pontederia cordata	Х	Х	Χ	Х	Χ	Χ	Χ	Х	Х	Χ	Χ	Χ	Χ	Х	Х	Х	Χ	Х	Χ	Х	Х	Х	Χ	Χ	Χ	Х	Х	Χ	Χ	Х	Χ	Х	Χ	Х	Х	Х
Nelumbo lutea	Х	Х	Χ	Х	Χ	Χ	Χ	Х	Х	Χ	Χ	Χ	Χ	Х	Х	Х	Χ	Х	Χ	Х	Х	Х	Χ	Χ	Χ	Χ	Х	Χ	Χ	Х	Χ	Х	Χ	Х	Х	Х
Leersia oryzoides		Х	Χ	Х	Χ	Χ	Χ	Х	Х	Χ	Χ	Χ	Χ	Χ	Х	Х	Χ	Х	Χ	Χ	Х	Х	Χ	Χ	Χ	Χ	Х	Χ	Χ	Х	Χ	Х	Χ	Х	Х	Х
Persicaria hydropiperoides	Х	Х	Χ	Х	Χ	Χ	Χ	Х	Χ	Χ	Χ	Χ	Χ	Х	Х	Х	Χ	Х	Χ	Х			Χ	Χ	Χ	X	Х	Χ	Χ	Χ	Χ	Х	Χ	Х	Х	Х
Brasenia schreberi	Х	Х			Χ	Χ	Χ	Х	Χ	Χ	Χ	Χ		Х	Х	Х	Χ	Х	Χ	Х	Х	Х		Χ	Χ	X	Х	Χ	Χ	Χ	Χ	Х	Χ	Х	Х	
Sparganium androcladum												Χ	Χ	Х	Х	Х	Χ	Х	Χ	Х	Х	Х	Χ	Χ	Χ	X	Х	Χ	Χ	Х	Χ	Х	Χ	Х	Х	Χ
Typha latifolia	Х	Х	Χ	Х	Χ	Χ	Χ	Х	Х	Χ	Χ	Χ	Χ	Х	Х																					
Bidens frondose		Х	Χ		Χ	Χ	Χ	Х		Χ	Χ	Χ	Χ	Х	Х		Χ	Х		Х		Х			Χ				Χ	Х				Χ		
Lemna minor								Х																												
Eleocharis obtuse															Х				Χ										Χ						Х	<u> </u>
Najas gracillima																Х																				<u></u>
Juncus effusus																																		Х	Х	
Utricularia gibba																												Х	Х	Х	Х	Х	Χ		Х	ı
Echinochloa muricata											Χ	Χ					Χ	Х					Χ	Χ												
Persicaria spp. (1)																	Χ	Х					Χ	Χ		Χ										
Persicaria spp. (2)																	Χ																			
Salix nigra																																Χ	Χ	Χ		
Total species richness	5	7	6	5	7	7	7	8	6	7	8	9	7	8	9	7	10	9	7	7	5	6	7	8	7	7	6	7	9	8	7	8	8	9	9	5

**Table 2.** The effects of pond characteristics (width of pond and depth of pond) on vegetation species richness (richness), Shannon-Wiener diversity (diversity), and Pielou's evenness (evenness) using two transects (north-south orientation and east-west orientation). Generalized linear model results are presented as  $\beta$  = estimated coefficient, SE = standard error, z = z-statistic, and p = p-value.

	β	SE	Z	p										
North-south transect														
richness~width	< 0.00	< 0.01	0.30	0.77										
diversity~width	<-0.01	0.01	-0.12	0.90										
evenness~width	<-0.00	0.01	-0.13	0.90										
richness~depth	< 0.01	0.01	0.46	0.65										
diversity~depth	<-0.01	0.02	-0.06	0.96										
evenness~depth	<-0.01	0.02	-0.09	0.93										
East-west transect														
richness~width	< 0.00	< 0.00	0.68	0.50										
diversity~width	< 0.00	< 0.00	0.12	0.91										
evenness~width	<-0.00	0.02	-0.17	0.87										
richness~depth	< 0.00	0.01	0.012	0.91										
diversity~depth	<-0.01	0.02	-0.08	0.94										
evenness~depth	<-0.01	0.02	-0.13	0.89										

41