SPECIES STATUS ASSESSMENT FOR HALL'S BULRUSH (*SCHOENOPLECTIELLA HALLII*)

Photo: Gary A. Reese, Michigan Natural Features Inventory

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EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) completed for Hall's Bulrush, *Schoeonoplectiella hallii*, to assess the species' viability over time.

Schoenoplectiella hallii has been historically found across 14 states: Massachusetts, Georgia, Ohio, Kentucky, Michigan, Indiana, Wisconsin, Illinois, Iowa, Missouri, Nebraska, Kansas, Oklahoma, and Texas. Biologists have confirmed the species is extirpated from a single population in Missouri, two populations in Massachusetts, and one Georgia population. To our knowledge state-wide surveys have not been conducted within Massachusetts or Georgia to locate *S. hallii* beyond the known extirpated sites. Within the last 25 years, *S. hallii* has been confirmed in eleven states: Ohio, Kentucky, Michigan, Indiana, Wisconsin, Illinois, Missouri, Nebraska, Kansas, Oklahoma, and Texas.

To assess the species' viability, we used the three conservation biology principles of resiliency, representation, and redundancy (collectively the "3Rs"). Specifically, we identified the species' ecological requirements for survival and reproduction at the individual, population, and species levels, and described the risk factors influencing *S. hallii* viability.

Ecological needs for individuals to survive and reproduce were identified using the known life history of *S. hallii*. There are several crucial conditions that must occur during a year for this species to germinate and persist as a mature plant. Two flooding events timed to break achene dormancy (late winter or spring) and to initiate germination (spring through early fall) are required. Other components required to initiate germination include exposure to ethylene, fluctuating temperatures, light, and receding floodwaters providing bare soil. Seedlings and mature plants share the same needs for survival: light, space, nutrients, and moist soil. The specific requisites for population viability are unknown for *S. hallii*. However, generally speaking, population viability (the ability of a population to sustain itself over time) requires healthy demographics and genetics, available suitable habitat for all life stages, and stressors that do not exceed manageable levels. Therefore, a healthy population of *S. hallii* would require a robust, genetically diverse seed bank and favorable hydrologic conditions every few to several years within suitable habitat to persist and provide a functioning population size with a growth rate greater than or equal to one. A persistent seed bank allows this species to remain dormant at a site but reappear as many as 25 years later if suitable conditions are present. The species level needs for long-term viability requires having multiple (redundancy), self-sustaining populations (resiliency) distributed across ecological gradients (representation) to maintain ecological and genetic diversity of *S. hallii*.

We considered risk factors that may be affecting the ecology and viability of *S. hallii*, and these included alterations to hydrology and water quality, alterations and disturbance to the seed bank, competition from invasive species and encroachment of woody vegetation, alteration and destruction of populations on private land, impacts to genetic diversity from hybridization, and grazing pressures. Most alterations or disturbances are associated with urbanization, agricultural

practices, or recreational use. Competition from invasive species includes common wetland invaders such as cattail species (*Typha* spp.), reed canary grass (*Phalaris arundinacea*), and *Phragmites australis* (Blann *et al.* 2009, p. 959). Purple loosestrife (*Lythrum salicaria*) and leafy spurge (*Euphorbia esula*) have been identified as threats at specific *S. hallii* populations in Indiana, Massachusetts, and Nebraska. Woody plant encroachment can convert emergent wetlands into forested wetlands. Hybridization of *S. hallii* and *S. saximontana* will reduce the reproductive output for the year. However, hybridization threats are considered low because introgression into *S. hallii* has not been observed in genetic studies, suggesting that it occurs rarely, if at all. *Schoenoplectiella hallii* seems to be reasonably tolerant to grazing but at high intensities, it can be a potential threat.

Schoenoplectiella hallii is listed as endangered in Kentucky, Indiana, Ohio, and Wisconsin, threatened in Illinois and Michigan, a species of special concern in Iowa, and a Tier 1 At-Risk Species in Nebraska. However, little protection is given with these listings. While nine of the 40 current populations (22.5%) are located on public land, very few of them have management plans that include *S. hallii* or additional protection beyond the state regulations.

Historic and current survey data are infrequent and typically limited to presence/absence level data, thereby making abundance and population trends difficult to analyze. We assessed the population status based on the condition of the habitat in reference to the resource needs. This is based on the assumption that healthy habitat will support a healthy population.

The overall current condition for *S. hallii* can be summarized by having mostly moderate resiliency, redundancy of seven ecoregion units, and representation in terms of ecological diversity based on the notion that species that span environmental gradients are assumed to have variation. Due to the wide distribution of the species, it is not likely that a range-wide environmental or stochastic event would affect all populations. Depending on the severity, environmental variation and stochastic events (e.g., extreme drought or agricultural practices) could impact individual sites or entire populations. The quality and quantity of habitat has been reduced historically, though, and is likely partially due to the increase in urbanization and agricultural lands and the alteration of hydrology across the range. The health of *S. hallii* populations likely decreased with the reduction of quality and quantity of habitat. However, populations that occur on agricultural land have indicated some resiliency to the disturbance to soil and water alterations, as germination still periodically occurs when hydrologic conditions are met and agricultural practices are not conducted in an area in a particular year. The 44 historic *S. hallii* populations range across seven ecoregions (Figure 2.2), which represent a range of ecological settings and serve as a proxy for describing potential adaptive capacity for the species. *Schoenoplectiella hallii* is still well represented over the historical range even though four populations are now considered to be extirpated. *Schoenoplectiella hallii* populations are highly clonal, such that many individuals in a population are genetically identical, and the same genotypes are often found across different sites, indicating high genetic redundancy but little genetic variation to adapt to environmental changes and local environmental conditions. While redundancy has been reduced from historic conditions, *S. hallii* has a high level of redundancy due to the wide distribution of populations and long-lived viable seed bank (up to 25 years), minimizing the ability of a single catastrophic event to affect numerous populations sufficiently to lower the species' viability.

In this assessment, we assessed future condition using ongoing anthropogenic and natural factors to predict future species resiliency, representation, and redundancy under four scenarios. We assessed a range of plausible conditions extending only so long as the Service can reasonably determine the likelihood of future threats and *S. hallii* responses. We were not able to predict the number of remaining populations within ecoregions because two of the condition metrics were qualitative, not quantitative. In scenarios A and B, the majority of populations are projected to decline in condition by 2050. Therefore, although our future scenarios do not predict any population extirpations, we expect resiliency to decline in many populations by 2050. The species is likely to retain its current low genetic diversity into the future, which is exacerbated in Scenarios A and B, and may have difficulty adapting to rapidly changing environmental conditions. However, the wide range of environmental diversity will continue to support the species' level of representation. It is predicted that the species will retain its redundancy driven by the wide geographic distribution and a variety of environmental settings. However, the species' low genetic variation and very limited sexual reproduction will limit its ability to adapt in response to long-term environmental changes.

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CHAPTER 1. INTRODUCTION AND ANALYTICAL APPROACH

This report summarizes the results of a species status assessment (SSA) conducted for Hall's bulrush (*Schoenoplectiella hallii*). The SSA report, the product of conducting an SSA, is a review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability.

1.1. Background

The U.S. Fish and Wildlife Service was petitioned to list Hall's bulrush on April 20, 2010 along with 403 other aquatic, wetland and riparian species from the Center for Biological Diversity (CBD), Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry and Noah Greenwald. The Service issued a positive 90-day finding for 379 of the 404 petitioned species, including Hall's bulrush, on September 27, 2011.

1.2. Analytical Framework

For the purpose of this SSA, we define viability as the ability of a species to maintain populations in the wild over a biologically meaningful timeframe. To assess viability, we use the conservation biology principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 308-311). To sustain populations over time, a species must have a sufficient number and distribution of healthy populations to withstand:

1) annual variation in its environment (Resiliency),

2) catastrophes (Redundancy), and

3) novel changes in its biological and physical environment (Representation).

Viability is a measure of the likelihood that the species will sustain populations over a specified time period and can be defined in relative terms, such as "low" or "high" viability. A species with a high degree of resiliency, redundancy, and representation (the 3Rs) is generally better able to adapt to future changes and to tolerate stressors (factors that cause a negative effect to a species or its habitat), and thus, typically has a high viability.

Resiliency is "the ability of a species to withstand stochastic disturbance; resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations" (Smith *et al*. 2018, p. 304). Simply stated, resiliency refers to a species' ability to sustain populations through periods of both favorable and unfavorable environmental conditions and/or anthropogenic impacts.

Redundancy is "the ability of a species to withstand catastrophic events by spreading risk among multiple populations or across a large area" (Smith *et al*. 2018, p. 304), thereby reducing the likelihood that all populations are exposed simultaneously and possess similar vulnerabilities to catastrophes. A minimal level of redundancy is essential for long-term viability (Shaffer and Stein 2000, pp. 307, 309-310), and greater redundancy likely results in higher viability for a species. In short, redundancy is about spreading the risk and can be measured by the number and distribution of resilient populations across a species' range.

Representation is "the ability of a species to adapt to changing environmental conditions over time as characterized by the breadth of genetic and environmental diversity within and among populations" (Smith *et al*. 2018, p. 304). Simply stated, representation is the evolutionary or adaptive capacity of the species (Beever *et al.* 2015, p. 132; Nicotra *et al.* 2015, entirety) and its ability to persist in the face of multiple threats (Lankau *et al.* 2011, p. 323). Thus, it is essential for species viability (Lankau *et al.* 2011, p. 316).

In summary, long-term species viability requires having multiple (redundancy), healthy populations (resiliency) distributed across the species' range to maintain the ecological and genetic diversity (representation).

1.3. Analytical Approach

Our analytical approach for assessing the viability of *S. hallii* involved three stages (Fig. 1.1). In Stage 1 (Chapter 2), we described the species' needs in terms of the 3Rs. Specifically, we identified the ecological requirements for survival and reproduction at the individual, population, and species levels. In Stage 2 (Chapter 4), we determined the baseline condition of the species using the ecological requirements previously identified in Stage 1. That is, we assessed the species' current condition in terms of the 3 Rs and past and ongoing factors influencing viability (Chapter 3) that have led to the species' current condition. In Stage 3 (Chapter 5), we projected future conditions of *S. hallii* using the baseline conditions established in Stage 2 and the predictions for future risk and beneficial factors. Lastly, we provide a status assessment summary of the species' viability over time, given our analyses of current conditions and projections of future conditions relative to historical conditions.

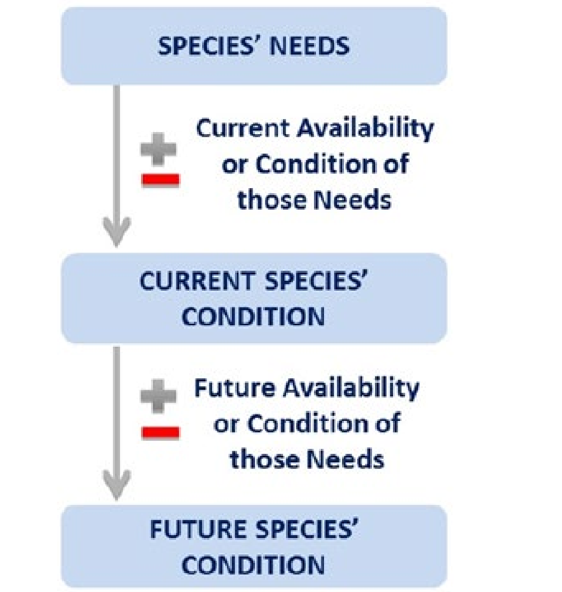

Figure 1.1. Species Status Assessment Framework.

CHAPTER 2. SPECIES BIOLOGY AND NEEDS

2.1. Description and Taxonomy

Schoenoplectiella hallii is a tufted annual bulrush (McKenzie *et al.* 2007, p. 458) with a stem length ranging from 4–80 centimeters (Beatty *et al.* 2004, p. 12; McKenzie *et al*. 2007, p. 458). Three to four leaf blades are clustered near the stem base (Beatty *et al.* 2004, p. 12; McKenzie *et al.* 2007, p. 458) and one cauline (along the stem) leaf is present (McKenzie *et al.* 2007, p. 458). Stomata are not responsive to changes to the difference between the vapor pressure of the leaf and air vapor pressure (Smith and Houpis 2004, p. 273) and therefore continuously transpire, leading to desiccation if levels of moisture are not maintained. An involucral bract, resembling a continuation of the stem, surpasses the spikelets, which are the flowering units (Beatty *et al.* 2004, p. 12). The terminal inflorescence is composed of 1–7 sessile spikelets at the end of the stem in a head-like cluster (Beatty *et al.* 2004, p. 12; McKenzie *et al.* 2007, p. 458). The spikelet scales (the leaf-like structures at the bases of flowers) range in color from greenish-brown, tan or orangish-brown (Beatty *et al.* 2004, p. 12; McKenzie *et al.* 2007, p. 458). *Schoenoplectiella hallii* in some instances has short, slender rhizomes (stem underground parallel to the surface; Beatty *et al.* 2004, p. 12) among aerial stem bases (McKenzie *et al.* 2007, p. 458). Refer to Figure 2.1. for representative photographs of *S. hallii*.

Figure 2.1. *Schoenoplectiella hallii* photographs (A) in natural habitat in Mason County, Illinois, and (B) specimen collected during 2019 survey in Mason County, Illinois. Photographs by Paul McKenzie.

Schoenoplectiella hallii is classified as amphicarpic (Beatty *et al.* 2004, p. 12; McKenzie *et al.* 2007, p. 458), a reproductive strategy of producing two types of fruit, one terminal and the other basal. The styles of basal flowers are longer and exhibit more structural branching than styles of terminal flowers (Smith et al. 2006, p. 1166). Achenes (the indehiscent fruit body containing a single seed) are two-sided (McKenzie *et al.* 2007, p. 458) and as they mature become dark brown to black (Beatty *et al.* 2004, p. 12; McKenzie *et al.* 2007, p. 458). Basal achenes are produced by solitary pistillate flowers at the culm base (Smith *et al.* 2006, p. 1160). Refer to Figure 2.2. from Smith *et al.* 2006 (p. 1164) for morphological differences between basal and terminal achenes and styles.

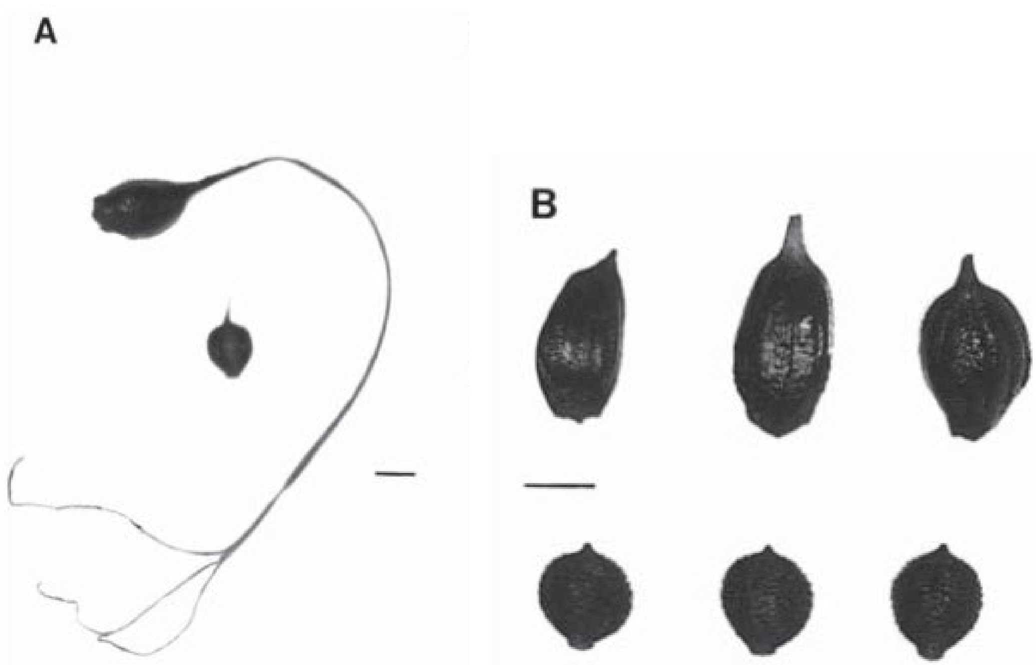

Figure 2.2. A. Basal (top) and terminal achenes of *Schoenoplectiella hallii* with attached styles; B. adaxial view of basal achenes (top) and terminal achenes of *S. hallii*. Source: Smith *et al.* 2006 (p. 1164).

Schoenoplectiella hallii was first described by Asa Gray in 1863 as *Scirpus hallii* A. Gray (Gray 1863, p. 96) but moved in 1995 to *Schoenoplectus hallii* (A. Gray) S.G. Smith (Smith 1995, p. 101). Members of *Schoenoplectus* that are mostly annual, amphicarpic species were moved into the new genus *Schoenoplectiella*, making the combination for Hall's bulrush *Schoenoplectiella hallii* (A. Gray) Lye (Lye 2003, p. 25). Research defining members of *Schoenoplectiella* (Hayasaka 2012, pp. 179–180) and DNA sequencing (Shiels *et al.* 2014, pp. 139–140) likely secures the current combination for *S. hallii*. However, the Flora of North America (Ball et al. 2003, pp. 44, 59) and the Integrated Taxonomic Information System (ITIS: https://www.itis.gov/) still recognize *Schoenoplectus hallii* (A. Gray) S.G. Smith.

2.2. Habitat and Ecology

Schoenoplectiella hallii is an obligate wetland species (Beatty *et al.* 2004, p. 30). It occurs on a variety of soil substrates including sandy-silty soils, mud flats, sandy-peaty substrates, loam, sandy-loam, clay and occasionally cobbly, rocky habitats (Beatty *et al.* 2004, p. 17; Chester 2013, p. 35). *Schoenoplectiella hallii* is associated with areas that experience widely fluctuating water levels that may prevent establishment of competing vegetation (Beatty *et al.* 2004, p. 17).

Habitats that meet the soil and hydrology requirements can include emergent wetlands (Young 2002, p. 43), sand prairies (KS and NE, Beatty *et al.* 2004, p. 17), coastal plain marshes (MI, Penskar and Higman 2002, p. 2; Beatty *et al*. 2004, p. 17), the sandy or rocky shorelines of freshwater lakes (Young 2002, p. 43; Beatty *et al.* 2004, p. 17), sandy swales (Beatty *et al.* 2004, p. 17), sandy clay ponds (O'Kennon and McLemore 2004, p. 1202), temporary ponds (KY, Chester and Palmer-Ball 2011, p. 1), the shores and bottoms of shallow ephemeral pools (Beatty *et al.* 2004, p. 17), artificial impoundments (Young 2002, p. 43), sand pits (Beatty *et al.* 2004, p. 17), and sinkhole ponds (MO, Young 2002, p. 43, Beatty *et al.* 2004, p. 17).

Other habitats where *S. hallii* can be found are anthropologically altered former sand plains and prairie systems. These include roadside ditches (Beatty *et al.* 2004, p. 17), stock ponds, and depressions in cultivated fields (Beatty *et al*. 2004, p. 17). The cultivated field depressions have habitat present during years of high spring rainfall or river levels, often associated with sites in Illinois, Kentucky, and Missouri (Chester 2013, p. 35; McClain *et al.* 1997, p. 66). When these depressions hold water that slowly recedes in late spring or summer, it provides suitable exposed soil for *S. hallii* to establish. In drier years the wetland habitats are not present and areas are cultivated for crops (Chester 2013, p. 36; McClain *et al.* 1997, p. 65). *Schoenoplectiella hallii* has been found in agriculture fields that had been corn, soybean, and wheat fields the previous year (McKenzie *et al.* 2010, p. 100). Within Kentucky, the habitat of *S. hallii* had not been noted prior to European settlement (D. Rodgers, pers. comm., 2020). While this area occupied by *S.*

hallii is no longer the pre-settlement prairie system, *S. hallii* continues to persist in agricultural fields when the habitat and resources are present (D. Rodgers, pers. comm., 2020). In Ohio, the known site is at the eastern limit of the historical Pickaway Plains. Thomas Worthington's plat of the section from his original land survey from ca. 1800 shows prairie occurring around the two depressions where *S. hallii* and *S. saximontana* occur (R. Gardner pers. comm. 2020).

2.3. Reproduction and Gene Flow

Germination of *S. hallii* can occur sporadically from year to year depending on the availability of suitable habitat and presence of conditions noted above. The species may remain dormant at a site for long periods of time and then emerge when favorable conditions occur (Smith 2003, p. 23; McKenzie *et al.* 2007, p. 462). For example, a population in Indiana, while not surveyed annually, had *S. hallii* present in 1993, negative surveys in 2007, 2013, and 2017 while mowing was occurring, but then *S. hallii* was present in 2019 once mowing had ceased at the site. Smith (2003, p. 17) determined the seed bank for *S. hallii* may contain thousands of achenes.

Although very little information is known regarding pollination for *S. hallii*, most members of the sedge family are wind pollinated. Observations by Beatty *et al.* (2004, p. 23) suggest that flooding and moisture fluctuations can affect reproductive phenology. The impact that amphicarpy has on *S. hallii*'s reproductive success has not been studied (Beatty *et al.* 2004, p. 19). Knowledge regarding pollination aspects for *S. hallii* have not been researched such as pollination efficiency, pollination effects on gene flow, effects on pollination from plant density (Beatty *et al.* 2004, p. 20), or pollen dispersal distance. Wind-pollinated plants require relatively large amounts of pollen for effective pollination.

Very little information is known regarding gene flow within and between populations. A study of populations within the Oklahoma Wichita Wildlife Management Area suggested relatively little gene flow between disjunct populations, even when spatial distance was small (Young 2002, p. 42), but that gene flow was occurring between individuals at the Grama Lake site (Young 2002, pp. 52–53). Young (2002, p. 54) looked at samples from five different states (Oklahoma, Missouri, Illinois, Kentucky, and Wisconsin) and concluded that genetic differences increased as distance increased. Edwards et al. (2019, p. 14) indicates that *S. hallii* genetic patterns match with the specifics associated with clonality. While *S. hallii* is currently classified as an annual, it has been suggested from an expert that it is a short-lived perennial (Beatty *et al.* 2004, p. 12). The likely mechanism causing clonality if *S. hallii* is a perennial would be vegetative reproduction, which is frequently achieved through rhizomes or stolons (Edwards *et al.* 2019, p. 14). However, if *S. hallii* is an annual, then vegetative reproduction is unlikely to be the mechanism of clonality. Based on the genetic analysis by Edward *et al.* (2019, p. 15), facultative apomixis (partial asexual reproduction) is the speculated mechanism that can explain why interspecific hybrids infrequently form, and multiple genotypes were observed, but the genetic pattern associated with clonality is present. From 11 sites sampled across three states (Oklahoma, Missouri, and Ohio), 230 samples of *S. hallii* were collected and only 40 individual multilocus genotypes were observed. The number of multilocus genotypes ranged from 2–14 per site within the study. Young (2002, p. 55) found populations differed in levels of genetic diversity. The population size appeared to not be a predictor of genetic diversity. One of the largest populations in the study located in Oklahoma had low levels of genetic diversity, compared to the small population in Kentucky, which had the highest genetic diversity of the populations studied (Young 2002, pp. 55–56). While only a couple studies have researched genetic diversity, they suggest low rates of sexual reproduction and low levels of gene flow occurring within and between populations, and that most reproduction is asexual.

Schoenoplectiella hallii is thought to be dispersed by migrating waterfowl or large herbivores (Beatty *et al*. 2004, pp. 21, 29; McKenzie *et al*. 2007, p. 463; McKenzie *et al*. 2015, p. 480). It is hypothesized that waterfowl species feed on the vegetation and achenes of bulrush species (McKenzie *et al*. 2007, p. 470). Waterfowl species within *S. hallii* sites may pick up achenes on feathers or through muddy feet, and thus subsequently transport achenes to other water habitats when flying locally or during migration. There is no information available for *S. hallii* regarding rates of dispersal, colonization, establishment, or minimum viable population size, but the results of the genetic study (Edwards et al. 2019) found that multiple genotypes are distributed across populations, indicating that clonal genotypes are in some way dispersing across populations. Whether this is through the transfer of vegetative material across sites or seed produced via apomixis is yet unknown.

2.4. Historical and Current Range and Distribution

Schoenoplectiella hallii has been found across 14 states: Massachusetts, Georgia, Ohio, Kentucky, Michigan, Indiana, Wisconsin, Illinois, Iowa, Missouri, Nebraska, Kansas, Oklahoma, and Texas (Figure 2.3.). Biologists have confirmed that the species is extirpated from the historical sites in Massachusetts and Georgia, along with a single population in Missouri. Within the last 25 years, *S. hallii* has been observed in eleven states: Ohio, Kentucky, Michigan, Indiana, Wisconsin, Illinois, Missouri, Nebraska, Kansas, Oklahoma, and Texas. Surveys have been negative in Iowa; however, surveys have not been completed frequently. *Schoenoplectiella hallii* was recently discovered in Ohio during surveys for the closely related *S. saximontana.* Since these two species are distinguishable through subtle differences in achene morphology, *S. hallii* was detected only when achenes from the site were closely investigated. It was speculated that *S. hallii* was recently dispersed to Ohio from migrating waterfowl, likely from Indiana, Illinois, Kentucky or Michigan because evidence of hybridization has not yet been discovered (McKenzie *et al.* 2015, p. 477). However, a survey of the Ohio site by McKenzie and others in September of 2018 detected the hybrid at one of two ponds on the site (R. Gardner, pers. comm., 2020). Of the 20 *S. x magrathii* individuals collected, Edwards *et al.* (2019, p. 14) indicates only 2 unique individual multilocus genotypes, speculating all *S. x magrathii* individuals collected originated from two hybridization events. Further research has not been conducted to speculate if

S. hallii was recently dispersed to Ohio, or if the presence of hybrid individuals means early surveys did not detect *S. hallii*.

The majority of surveys for *S. hallii* are conducted as presence/absence surveys. Records of presence are from years when germination occurred and it is unknown if 100% of *S. hallii* achenes in the seed bank germinate with favorable conditions. The seed bank itself has rarely been surveyed. Misidentifications have occurred in the past. A botanist/biologist is needed to conduct surveys due to the difficulty in distinguishing achenes of *S. hallii* from *S. saximontana* or *S. erecta*, especially in mixed populations where *S. hallii* achenes are greatly outnumbered by the more common similar species. In such situations, the rarer *S. hallii* can be easily overlooked. This has been observed in Oklahoma, Ohio, and Nebraska (McKenzie *et al.* 2015, p. 480). Surveys are inconsistent across the range. Some states conduct annual surveys, while other states are only surveyed periodically when a species expert is available to conduct the surveys. Not all surveys coincide with optimal germination conditions, resulting in false negative surveys, whereas if they were completed during optimal conditions it may have resulted in a positive survey. Furthermore, optimal conditions do not occur every year, i.e. drought conditions, and therefore some of the negative data may be attributed to a lack of emergence rather than a negative occurrence of *S. hallii*. A clearer picture of the abundance and distribution of *S. hallii* is needed to assess the population trends and overall viability of this species.

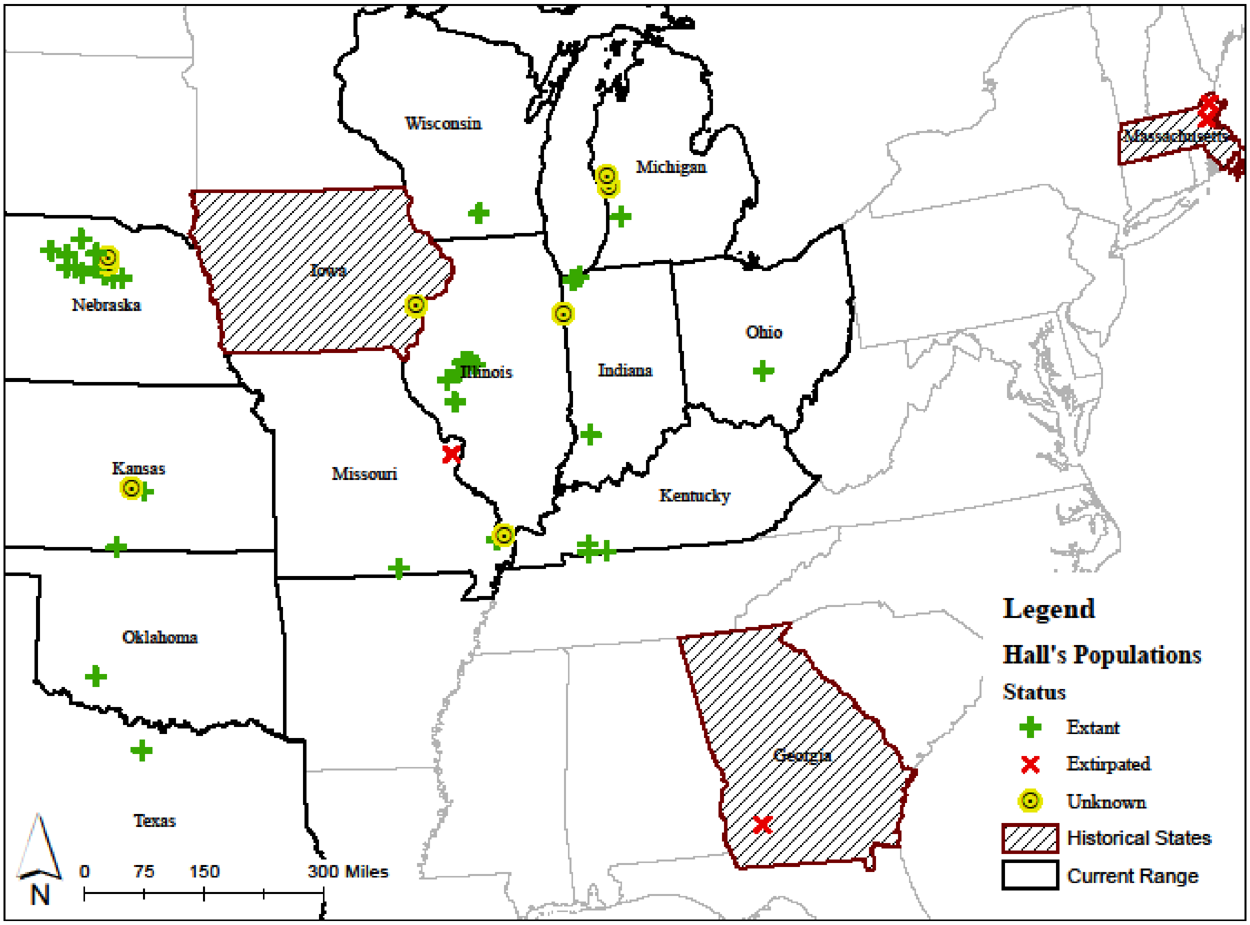

Figure 2.3. Current and historic distribution of *Schoenoplectiella hallii*. Extant sites are confirmed occurrences of *S. hallii* since 1994. Extirpated sites are confirmed by local experts. Unknown sites are those that could not definitively be described as being extant or extirpated.

2.5. Life History and Individual Level Ecology

Ecological needs for individuals to survive and reproduce were identified using the known life history of *S. hallii* (Table 2.1.). There are several crucial conditions that must occur during a year for this species to germinate and persist as a mature plant.

2.5.1. Dormancy and Germination

Schoenoplectiella hallii achenes are dormant when produced (Smith 2003, p. 2) and therefore require two flooding events timed to break achene dormancy (late winter or spring) and to initiate germination (spring through early fall). Other components required to initiate germination include exposure to ethylene, fluctuating temperatures, light, and receding floodwaters providing bare soil. If achenes only experience a subset of these factors, germination will not occur. For example, if an achene is exposed to appropriate temperatures and ethylene, and experiences flooding in late winter and again in April but achenes were not exposed to light, germination will not occur (Baskin *et al.* 2003, p. 626). Ethylene production depends on microbial activity, temperature and oxygen concentration (Baskin *et al.* 2003, p. 625). Ethylene levels that promote germination are reached in flooded soils with organic matter (Baskin *et al.* 2003, p. 625). Ethylene may act as an indirect indicator that water and nutrients are available for germination and that flooding has kept competing species from occurring (Baskin *et al.* 2003, p. 620). Temperature fluctuation association with shallow water had higher germination rates than the minimal temperature fluctuation associated with deeper water (Baskin *et al.* 2003, p. 626). Baskin *et al.* (2003, p. 626) found that if achenes were first exposed to light in the presence of ethylene and then covered in soil, they would be able to germinate, but if achenes were covered with soil, darkness would prevent germination if they were not exposed to the necessary light requirement.

2.5.2. Seedlings and Mature Plants

Receding floodwaters allow the establishment of seedlings (Beatty *et al.* 2004, p. 38). Seedlings and mature plants share the same needs for survival: light (Baskin *et al.* 2003, p. 626; Smith and Houpis 2004, p. 273), space (Beatty *et al.* 2004, p. 24), nutrients (Beatty *et al.* 2004, p. 24), and moist soil (Beatty *et al.* 2004, p. 25; McKenzie *et al.* 2007, p. 462; Smith and Houpis 2004, p. 273). Once established, *S. hallii* require at least 10–14% soil moisture (Smith 2003, p. 12), but unflooded conditions. Individuals transpire continuously because of open stomata and therefore require a continuous source of water (Smith and Houpis 2004, p. 273). Smith (2003, p. 29) found that Missouri populations need groundwater levels to remain within one meter of the surface during the growing season.

Table 2.1. Species ecology during each life stage for individuals of Hall's Bulrush (*Schoenoplectiella hallii*).

Life Stage		Resource (Habitat Needs)	References
Seed-achene	Dormant	Cold conditions in winter or spring	Beatty *et al.* 2004, p. 22
		Flooding in late winter or spring	Beatty *et al.* 2004, p. 22; Baskin *et al.* 2003, p. 626; McKenzie *et al.* 2007, p. 462
	Non-Dormant	Bare soil from receding flood waters	McKenzie *et al.* 2007, p. 461; Beatty *et al.* 2004, p. 38
		Flooding in spring through early fall - with optimal flooding between April and June	Baskin *et al.* 2003, p. 626; Beatty *et al.* 2004, p. 38
		Ethylene	Baskin *et al.* 2003, p. 625; Beatty *et al.* 2004, p. 22
		Light	Baskin *et al.* 2003, p. 626; Smith and Houpis 2004, p. 273
		Temperature fluctuating daily	Baskin *et al.* 2003, p. 626; Beatty *et al.* 2004, p. 22
		Moist soil	Beatty *et al.* 2004, p. 25; McKenzie *et al.* 2007, p. 462; Smith and Houpis 2004, p. 273
Seedling		Receding water	McKenzie *et al.* 2007, p. 461; Beatty *et al.* 2004, p. 38
		Light	Baskin *et al.* 2003, p. 626; Smith and Houpis 2004, p. 273
		Moist soil	Beatty *et al.* 2004, p. 25; McKenzie *et al.* 2007, p. 462; Smith and Houpis 2004, p. 273
		Space	Beatty *et al.* 2004, pp. 17, 24
		Nutrients	Beatty *et al.* 2004, p. 24
Mature Plant		Light	Baskin *et al.* 2003, p. 626; Smith and Houpis 2004, p. 273
		Moist soil	Beatty *et al.* 2004, p. 25; McKenzie *et al.* 2007, p. 462; Smith and Houpis 2004, p. 273
		Space	Beatty *et al.* 2004, pp. 17, 24
		Nutrients	Beatty *et al.* 2004, p. 24
		Pollination	Hill 2006, p. 16

2.6. Population Level Ecology

In this section, we review ecological requirements for *S. hallii* at the population level (Table 2.2.). The specific requisites for healthy populations are unknown for *S. hallii*. A recent genetic study (Edwards *et al.* 2019, entirety) provided some details on the number of unique individuals within a few extant populations across the range. We have no data on how much habitat is needed to support a viable population. However, generally speaking, population viability (the ability of a population to sustain itself over time) requires healthy demographics and genetics, available suitable habitat for all life stages, and stressors at manageable levels. Therefore, a healthy population of *S. hallii* would require a robust, genetically diverse seed bank and favorable hydrologic conditions every few to several years within suitable habitat to persist and provide a functioning population size with a growth rate greater than or equal to one.

2.6.1. Habitat

We suspect that generally population viability requires sufficient habitat quality and quantity to support sustainable population sizes, reproductive capacity, and survival rates. We assume that sufficient habitat quality includes appropriate soil types and widely fluctuating water levels with low levels of interspecific competition. However, sufficient patch size and level of quality are unknown, along with the connectivity between sites, to assess population viability further.

2.6.2. Genetic Diversity

Generally, sufficient levels of genetic diversity are required for population viability. *S. hallii* is highly clonal so each site generally contains a limited number of genotypes, but as long as environmental conditions are stable and suitable for clonal reproduction, populations should be stable and viable. However, the limited genetic diversity and low rates of sexual reproduction indicate that if the environment changes significantly, that *S. hallii* may insufficient genetic diversity required to adapt to environmental changes in order to maintain population viability.

2.6.3. Seed Bank

A persistent seed bank allows a population to disappear from a site but reappear as many as 25 years later if suitable conditions are present (Smith 2003, p. 23). The Nature Conservancy considers extant sites as those with recorded observations of *S. hallii* in the last 25 years (McKenzie *et al.* 2007, p. 459). Smith (2003, p. 17) studied the Scott County population in Missouri predicting the differences in population growth rate for years when the population was primarily shorter individuals (<5 cm) and years when the population was dominated by larger individuals (>5cm) based on the assumption of 100% survival of individuals and average seed production. During Smith's (2003, p. 17) research, 89 seedlings survived to flower and collectively produced approximately 21,900 seeds in October. The number of achenes produced depends on the number of inflorescences produced, which is based on the size and health of the individual plant. When plants with small or few inflorescences dominate populations for several years, it could lead to significant population decline with the potential to not recover as the seed bank becomes depleted.

2.6.4. Achene Dispersal

Achenes are thought to be dispersed by migrating waterfowl or large herbivores, such as cattle or bison (McKenzie *et al*. 2007, p. 463) allowing new genetic material and variation to be introduced into a given population. Migratory waterfowl have been noted as the seed exchange mechanisms between populations for other species in Cyperaceae, such as *Schoenoplectiella purshiana,* but this is thought to happen infrequently (Hill 2006, p. 18). Long-distance migratory waterfowl dispersal is potentially the way *S. hallii* was introduced to Ohio, likely dispersed from populations in either Indiana, Illinois, Kentucky or Michigan (McKenzie *et al.* 2015, p. 477). However, Beatty *et al.* (2004, p. 21) stated that achenes appear to lack any adaptation that would enable wind or animal dispersal. It may be possible that waterfowl species feed on the vegetation and achenes of a variety of bulrush species (McKenzie *et al.* 2007, p. 470); however, it has not been studied if *S. hallii* achenes are viable after passing through a digestive tract. We have very little information about the level of genetic exchange from achene dispersal between populations. Edwards *et al.* (2019, p. 12) observed five clonal individuals identified across multiple populations within the study, indicating genetic exchange has occurred, but the mechanism and rate are still unknown.

Table 2.2. The population-level requisites for Hall's Bulrush (*Schoenoplectiella hallii*).

	Resource	Description
Demography	Population growth	λ ≥1, which is a function of survivorship, recruitment, population structure
	Population size	Minimum N required, but unknown
	Achene abundance	Need healthy individuals producing large quantities of achenes every few years
	Achene dispersal	Waterfowl or large herbivores must visit sites and move to suitable habitat
	Persistent seed bank	Achenes remain viable for up to 25 years (Smith 2003, p. 23)
Habitat	Low interspecific competition	Need low levels of competition for establishment and growth
	Intact hydrologic processes	Widely fluctuating water levels
	Sufficient suitable habitat	Suitable soil type with widely fluctuating water levels.

2.7. Species Level Ecology

In this section, we describe the species-level ecological requirements in terms of the 3Rs (Table 2.3.).

2.7.1. Resiliency

Resiliency describes the ability of populations to withstand environmental or demographic stochastic events. It can be measured by the population size and growth rate, along with the quality and quantity of habitat. It can be influenced by connectivity among populations for gene flow and achene dispersal. In general, the likelihood of sustaining populations over time increases as the number of healthy populations that can occupy a variety of habitats increases. Therefore, the greater the number of individuals within habitat of adequate quantity and quality, the more resiliency the species maintains.

We do not have demographic data that allows us to evaluate the health of any *S. hallii* populations within its range in regards to its ability to withstand demographic stochastic events. For some sites, we have an estimate of vegetative population size. However, for these sites, there are insufficient data to determine if the habitat, population growth rate, or population size are able to maintain the population over time. For the majority of sites, we have even less data and therefore cannot evaluate population health.

Environmental stochasticity can act at local and regional scales. Populations' ability to withstand environmental conditions can occur simultaneously over a broad geographic area. Having populations distributed across a diversity of environmental conditions reduces concurrent losses of populations across a geographic area. We know that *S. hallii* requires widely fluctuating water levels; therefore, it is reasonable to assume that the seasonal and annual precipitation and flooding patterns may be an important driver in habitat suitability. We know that achenes require fluctuating temperatures; therefore, it is reasonable to assume that the temperature patterns are important for maintaining a population. We know that achenes can persist dormant in the seedbank up to 25 years, providing a buffer to withstand some short-term changes to hydrological and temperature patterns.

As described in the reproduction and gene flow section (2.3.), there is low sexual reproduction within and among populations but population connectivity has occurred through the transfer genetically identical clonal material among populations. It is unknown if the lack of sexual reproduction was historically the natural state for *S. hallii* populations, therefore we do not know if connectivity had been a historical requisite for resiliency.

In summary, we do not have a full understanding of need for *S. hallii* resiliency.

2.7.2. Representation

Representation is the evolutionary capacity or flexibility of the species, i.e. its ability to adapt to physical and biological changes in its environment. Representation is the range of variation (adaptive diversity) found in a species. Adaptive diversity includes ecological diversity and genetic diversity, which along with evolutionary processes, are the species' evolutionary potential.

Species that span environmental gradients are assumed to have phenotypic and genetic variation. We used the Environmental Protection Agency (EPA) level II Ecoregions (Omernik and Griffith 2014, entirety) to understand the range of ecological settings (including climate) that *S. hallii* occupies. These ecological classifications incorporate all major components of the ecosystems: air, water, land, and all biota, including humans with the purpose to facilitate ecosystem management and broad environmental understanding. *Schoenoplectiella hallii* populations span 7 ecoregions, with the majority found in the west-central semi-arid prairies, as Nebraska has the most known populations (Figure 2.4). The other ecoregions include mixed wood plains, central USA plains, southeastern USA plains, Ozark Ouachita-Appalachian forests, Mississippi alluvial and southeast USA coastal plains, and south central semi-arid prairies. Wetland soil type and hydrology vary across the range of *S. hallii*. These varying environmental conditions can influence species evolution over time. Without further knowledge regarding the variation across environmental conditions, it appears wise to maintain populations across the range of environmental conditions.

Edwards *et al*. (2019) observed high genetic similarity amongst *S. hallii* individuals. This observation led them to research clonal diversity. The number of multilocus genotypes ranged from 2–14 per site within the study. The average number of alleles ranged from 1.867–2.267 per site (p. 12). While Edwards *et al.* did not include all populations across the range of *S. hallii*, the study gives insight to the low level of genetic diversity due to the patterns of clonality observed. Low genetic diversity can decrease the ability of *S. hallii* to adapt to environmental change. It is therefore pertinent to preserve the populations in order to preserve genetic diversity.

As previously described, there is very little knowledge about gene flow between *S. hallii* populations. Based on a couple genetic studies, it is suggested there is very little sexual reproduction occurring within or among populations (Young 2002, entirety; Edwards *et al.* 2019, entirety). It is thought that waterfowl moving between habitats may occasionally disperse achenes or vegetative material, but this likely occurs infrequently (Hill 2006, p. 18). The main mechanism of reproduction is facultative apomixis (partial asexual reproduction; Edwards *et al.* 2019, p. 15). Thus, most achenes may be produced via asexual reproduction, with sexual reproduction occurring very infrequently via wind pollination (Hill 2006, p. 16). Based on this information it is likely that sexual reproduction is not a driver of evolutionary change for *S. hallii*.

Given the above, we are using general principles regarding diversity across environmental gradients and the available information that S. hallii has relatively few numbers of genotypes that are relatively widely dispersed may be the natural state for *S. hallii* populations. Thus, in order to conserve representation of *S. hallii*, populations need to be maintained across the distinct ecological regions.

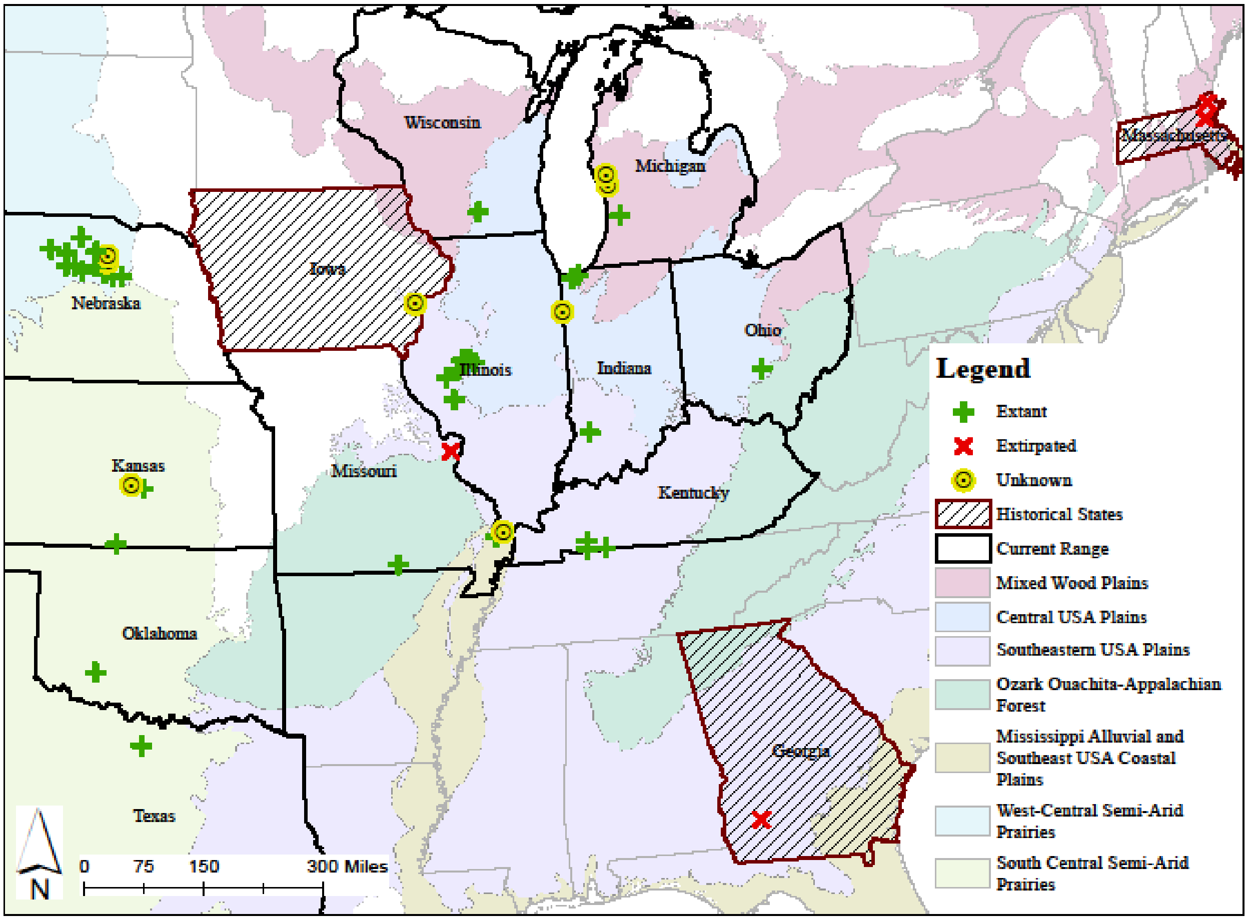

Figure 2.4. The distribution of *Schoenoplectiella hallii* populations across EPA level II Ecoregions (Omernik and Griffith 2014, entirety) within the USA. Refer to Section 4.4. for individual ecoregion extent figures.

2.7.3. Redundancy

Redundancy is the ability of a species to withstand catastrophic events. Redundancy is achieved by having multiple, widely distributed populations that are beyond the spatial impact of catastrophic events. Having multiple, healthy populations widely distributed will also preserve the range of adaptive diversity. This means having a sufficient number of populations and distribution across and within the ecological regions.

We identified long-term alterations to hydrology as the most likely potential catastrophic event of pertinence to *S. hallii*. Widely fluctuating water levels are important drivers for suitable habitat. Thus, alterations to the fluctuating hydrology, either by too much flooding or by drought, may impact *S. hallii* (McKenzie *et al.* 2015, p. 481).

2.7.4. Summary

The species level needs for long-term viability require having multiple (redundancy), self-sustaining populations (resiliency) distributed across ecological gradients (representation) to maintain ecological and genetic diversity of *S. hallii*.

Table 2.3. General requisites for species-level viability.

3 Rs	**Requisites of long-term viability**	**Description**
Resiliency (able to withstand stochastic events)	Interconnected, healthy populations across a diversity of conditions	Populations with 1) robust demography, 2) sufficient quality and quantity of habitat, and 3) connectivity among populations that are dispersed across diverse conditions
Representation (to maintain evolutionary capacity)	Maintain adaptive diversity of the species	Healthy populations distributed across areas of unique adaptive diversity
	Maintain evolutionary processes	Maintain evolutionary drivers—gene flow, natural selection, genetic drift—to mimic historical patterns
Redundancy (to withstand catastrophic events)	Sufficient distribution of populations	Sufficient distribution to guard against catastrophic events wiping out portions of the species adaptive diversity, i.e., to reduce covariance among populations
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity

CHAPTER 3. RISK FACTORS AND CONSERVATION EFFORTS

This chapter provides a summary of past, current, and plausible future factors that are affecting or could be affecting the current and future condition of *S. hallii* throughout some or all of its range.

3.1. Habitat Alteration, Destruction, and Conversion

3.1.1. Hydrological changes

The removal and conversion of emergent wetlands can extirpate, reduce the abundance of, or affect the health of a population. Agricultural drainage removes water from low elevation spots in fields, which can be occupied by *S. hallii* during wet years. Commercial and residential urbanization can destroy some or all of a population. The Essex County population in Massachusetts has been commercially developed and no longer has suitable habitat for *S. hallii* to persist at this location. Sand depressions are another habitat type that is occupied by *S. hallii* and can be destroyed with the filling of sand depressions. Climate change, and levee or dam installation can alter the flood regime necessary to break achenes out of dormancy and allow germination (Blann *et al.* 2009, p. 914; McKenzie *et al.* 2007, p. 472). Roadside ditches can provide suitable habitat for *S. hallii*, as documented in Nebraska. Maintenance of these roadside ditches and farming ditches can remove the water requirements of *S. hallii* during its life cycle (Beatty *et al.* 2004, p. 31; McKenzie *et al.* 2007, p. 468). Water quality can become a stressor in areas that can have contaminants and herbicide inputs, such as in urban and agricultural areas (Blann *et al.* 2009, p. 910).

3.1.2. Soil disturbance

Disruption to the soil may alter or destroy the seed bank. Common farming practices such as disking can disrupt or bury achenes in the seed bank. Recreational/off-road vehicles, heavy machinery associated with residential development, and dredging, and filling inshore areas have been identified as disturbing soils at *S. hallii* sites in Michigan (Penskar and Higman 2002, p. 3).

3.1.3. Invasive Species

Schoenoplectiella hallii sites may be threatened by the spread of invasive species and the encroachment of woody vegetation. Woody encroachment can convert emergent wetlands into forested wetlands. Competition from invasive species includes common wetland invaders such as cattail species (*Typha* spp.), reed canary grass (*Phalaris arundinacea*), and *Phragmites* (Blann *et al.* 2009, p. 959). Purple loosestrife (*Lythrum salicaria*) and leafy spurge (*Euphorbia esula*) have been identified as threats to specific populations. Purple loosestrife has been identified in as a threat in Indiana, Massachusetts, and Nebraska to *S. hallii* populations (McKenzie *et al.* 2007, p. 469, Beatty *et al.* 2004, p. 30) and likely to affect populations in Kansas and Nebraska (Beatty *et al.* 2004, p. 31). Leafy spurge has been marked as a potential threat in Nebraska as it has been identified near *S. hallii* sites (McKenzie *et al.* 2007, p. 469).

3.1.4. Private Land

The majority of populations occur on private land. Alterations and destruction to these sites are not actively monitored.

3.2. Hybridization

Hybridization can result in loss of pure individuals of a rare species leading to potential decline when a parental taxon is rare while the other is widespread. Because the widespread species is more common, the rare species may reproduce more frequently with it.

It is postulated by P. McKenzie (pers. comm. 2020) that historically *S. hallii* and *S. saximontana* were probably allopatric and their ranges did not overlap. Subsequently, likely due to settlement disturbance and the construction of many man-made ponds, it is possible that the two species became sympatric increasing the opportunity for the formation of hybrids. Currently there are six states where both species occur: Kansas, Missouri, Nebraska, Ohio, Oklahoma, and Texas. Of these states, S. x magrathii has been confirmed in Nebraska, Ohio, Oklahoma, and Texas (Smith and McKenzie 2003, entirety; McKenzie *et al.* 2015, entirety; P. McKenzie, pers. comm. 2020)

Edwards *et al.* (2019, p. 5) sampled 16 localities across three states (Ohio, Missouri, and Oklahoma) where *S. hallii*, *S. saximontana*, and/or *S. x magrathii* (hybrid of *S. hallii* and *S. saximontana*) have been observed. The results of this study indicate that the formation of *S. x magrathii* is infrequent (p. 14; 23%). It had previously been suggested that the gene flow between these two taxa is limited even in the areas that they co-occur (Young 2002, p. 42). In areas where *S. saximontana* and *S. hallii* co-occur, *S. hallii* reproduction output can be reduced for the year if reproducing sexually (Edwards *et al.* 2019, p. 17). There is not a practical or feasible control measure to prevent interaction between *S. hallii* and *S. saximontana* as waterfowl or large herbivores are likely the achene dispersal agents (Esselman *et al.* 2012, p. 7; McKenzie *et al*. 2007, p. 463). Local and migrating movements of waterfowl likely increase the opportunity for hybridization to occur in Texas, Nebraska, and Kansas (Smith and McKenzie 2013, p. 7).

Schoenoplectiella x magrathii appears to be reproductively isolated from its parents indicating backcrossing would rarely occur (Edwards et al. 2019 p. 17). Therefore, the threats of introgression into the parental species and the genetic swamping of either species are very low (Edwards *et al.* 2019, p. 17). Edwards et al. (2019, p. 14) suggests that *S. x magrathii* has the genetic patterns associated with clonality, just as the parent taxa.

3.3. Grazing

Schoenoplectiella hallii seems to be reasonably tolerant to grazing but it can be a potential threat at high intensities. Grazing was identified by Beatty *et al.* (2004, p. 31) as most likely to affect Kansas and Nebraska populations. Grazing pressures were high at the Wisconsin population until 2007 when grazing was occurring in a paddock adjacent to the lake (Wisconsin National Heritage Inventory (NHI) Program, 2019). The Wisconsin population does not experience grazing pressures as the cattle and horse enclosure was moved away from the lake in 2011

(Wisconsin NHI Program, 2019). The Howell County, Missouri population was noted to have heavy grazing in 1997, but found grazing was no longer occurring during the 2006 survey (Missouri NHI Program). Grazing at the Quanah Parker Lake site in Oklahoma was identified by Watson (1993) as a threat with the potential need to be managed. Beyond consumption, cattle within a population of *S. hallii* may cause damage by excessive trampling of vegetation. Beatty *et al.* (2004, p. 23) thinks that trampling may have caused plants in Nebraska and Wisconsin to be smaller in size. In addition to large herbivores, waterfowl species feed on the vegetation and achenes of many bulrushes (McKenzie *et al.* 2007, p. 470).

However, in addition to consuming *S. hallii*, McKenzie et al. (2007, p. 463) proposed that cattle and waterfowl may act as dispersal mechanisms for *S. hallii*. The high tolerance *S. hallii* is thought to have towards low levels of grazing, combined with the ability of cattle and waterfowl to act as dispersal mechanisms, further reduce the likelihood of the species being negatively impacted by grazing animals. Therefore, we consider grazing a minor threat, even at high levels of intensity.

3.4. Conservation Efforts

3.4.1. State Regulations

Schoenoplectiella hallii is listed as endangered in Kentucky, Indiana, Ohio, and Wisconsin (Kentucky State Nature Preserves Commission 2018; Indiana Department of Natural Resources 2020; Ohio Department of Natural Resources 2018; Wisconsin Department of Natural Resources 2019), threatened in Illinois and Michigan (Illinois Endangered Species Protection Board 2015; Michigan Natural Features Inventory 2009), a species of special concern in Iowa (Iowa Department of Natural Resources 2009), and a Tier 1 At-Risk Species in Nebraska (Schneider *et al.* 2018, p. 64.). However, little protection is given with these listings. Indiana statutes prohibit the removal of endangered or threatened plants from state dedicated nature preserves, an environmental review process to comment on expected impacts by proposed projects that are within 0.5 mile of documented occurrences, and all state agencies should take into account environmental resources during all state actions (S. Namestnik, pers. comm., 2020). The Endangered Species Act of Michigan (Michigan Natural Features Inventory 2009) protects listed plants from being removed from the site without a permit. Wisconsin has similar protections, requiring permits for endangered plants to be taken (Wisconsin Statue § 29.604). Ohio's rare plant law provides limited protection for state endangered and threatened plants. The Ohio Department of Natural Resources can recommend avoiding or transplanting state listed plants that may be impacted by state funded projects. In addition to the State's rare plant law, Ohio's isolated wetland law provides some additional protection. Wetlands with a state endangered or threatened plant are automatically considered a Category 3 wetland, which is the highest protection for a wetland. This category of wetlands must be avoided unless it is demonstrated there is a high need for the wetland to be impacted (R. Gardner, pers. comm., 2020). Nebraska's listing of *S. hallii* as Tier 1 At-Risk Species means it cannot be collected in the state without a permit (Schneider, pers. comm. with P. McKenzie, 2007). The Rare Plant Act of Kentucky permits the listing and monitoring of rare plant species by the Office of Kentucky Nature Preserves (OKNP), but grants no official protection to those species. The only exceptions are that OKNP can recommend avoiding impacts to development projects during the environmental review process and all natural, geological, and archaeological resources lands owned/protected by OKNP (D. Rodgers, pers. comm., 2020).

3.4.2. Populations on Protected Conservation Land

While nine of the 40 current populations are located on public land, very few of them have management plans that include *S. hallii* or additional protection beyond the state regulations. Michigan has populations within the Allegan State Game Area that are under the jurisdiction of the Wildlife Division of the Michigan DNR. These populations are protected by barriers that control access, and are regularly patrolled and managed with prescribed fire (Penskar, pers. comm. with P. McKenzie, 2006). The Pine Island population within Muskegon County is located on a dedicated Research Natural Area within the Forest Service's Huron-Manistee National Forest, and the Carr Lake population is protected as part of a nature preserve owned by the Michigan Nature Association (Penskar, pers. comm. with P. McKenzie, 2006). The Allegan County population is located on a Michigan State Game Area. Populations occur on the Indiana Dunes National Lakeshore, owned by the National Park Service; however, there is no specific species management plan for *S. hallii*. The Ohio site is located on the Floyd Bartley Nature Preserve, owned and managed by a local non-profit conservation organization, Appalachia Ohio Alliance (McKenzie *et al*. 2015, p. 478.). The Ohio Department of Natural Resources Division of Natural Areas and Preserves has a conservation easement on the preserve and assists with management of the two wetlands where *S. hallii* occurs (R. Gardner, pers. comm., 2020). The only population of *S. hallii* in Oklahoma occurs on a U.S. Fish & Wildlife Service Wildlife Refuge, but the species is not covered under a management plan (C. Kimball, Wichita Mountains Wildlife Refuge, pers. comm. with P. McKenzie, 2006). The only known population in Texas is on the Lyndon B. Johnson National Grasslands, but no information on management actions for the species was identified by O'Kennon & McLemore (2004, entirety). The Burrton, Kansas population is located within the Sand Prairie Natural History Reservation owned by Bethel College. However, there is no information provided indicating levels of management or protection for *S. hallii* on the Sand Prairie Natural History Reservation.

3.4.3. Conservation Challenges

There are a few major concerns about the ability to achieve conservation for *S. hallii*. The majority of populations occur on private land making it difficult to prevent or monitor threats on *S. hallii* individuals and populations. This also makes these populations vulnerable to habitat change. In addition, management of *S. hallii* populations may be difficult due to the specific habitat requirements. Hydrological cycles are necessary for creation of habitat and germination requirements; however, hydrological cycles are impacted at a large geographic scale, making it difficult to manage at a population geographic scale. In recent years a number of ponds and pools have appeared near the Floyd Bartley Nature Preserve, Ohio, from the above normal rainfall. These 'resurrected' ponds have not been surveyed and may contain populations of *S. hallii, S. saximontana*, or both. The area is currently for sale and being considered as a potential multi-family and industrial development (R. Gardner, pers. comm., 2020). Conservation agencies and organizations do not have the funds to purchase these top dollar properties.

Controlling invasive species is a difficult task. Invasive species management takes people, time, and money which not all conservation land managers have access to for successful removal. Ohio has specifically expressed concern that there is high effort needed to maintain the population wetlands in early successional condition.

There are gaps in knowledge for *S. hallii*'s ecology and life history. Much is still unknown regarding demographics, reproduction, and dispersal mechanisms for *S. hallii*. This knowledge may be important to implementing high performing conservation measures.

CHAPTER 4. CURRENT CONDITION

4.1. Occurrence Data

Historic and current survey data are infrequent and typically limited to presence/absence level data. Abundance and population trends are difficult to analyze. We garnered *S. hallii* occurrence data from multiple sources, including State Natural Heritage Databases, survey reports, published literature, and species experts. Some site information comes from collected specimens and Natural Heritage databases, which do not always contain information regarding the abundance. Records of presence are from years when germination occurs and it is unknown if 100% of *S. hallii* achenes in the seed bank germinate with favorable conditions. The seed bank itself has rarely been surveyed. Therefore, even when surveys estimate plant abundance, it only captures a portion of the population abundance (i.e., achenes in the seed bank that do not germinate). The lack of detailed abundance information restricts an analysis of population trends.

We added a 5 km radius buffer around each occurrence record in ArcMap (ESRI 2018) to capture the potential pollination range around known occurrences. Buffers that overlapped were merged and defined as a single population. We defined population to this scale based on the genetic research completed by Young (2002) that found gene flow was occurring, though at very low levels, within the Wichita Wildlife Management Area, which occurs across approximately 10km (pp. 42, 53).

4.2. Historical and Current Conditions

To assess the health, number, and distribution of populations through time, we defined a population's status as extant, extirpated, or unknown. All sites with confirmed occurrences of *S. hallii* since 1994 are considered extant. This timeframe was based on the persistent seed bank

(Smith 2003, p. 23). Extirpated sites are those that local experts have described as extirpated, or where satellite imagery confirms that development has destroyed suitable habitat. Any sites that could not definitively be described as being extant or extirpated were evaluated as unknown.

4.2.1. Population Status

Schoenoplectiella hallii has little population abundance information available across its range. For populations that are monitored for abundance, the number of plants is not a predictor of genetic diversity due to the clonality patterns (Edwards *et al.* 2019, p. 12; Young 2002, p. 55). *Schoenoplectiella hallii* populations are cyclic and dependent on water fluctuations, making it difficult to describe resiliency. Therefore, we assessed the population status based on the condition of the habitat in reference to the resource needs. This is based on the assumption that healthy habitat will support a healthy population.

4.3. Methods for Estimating Current Condition

Table 4.1. Current condition category table for *Schoenoplectiella hallii*.

	Demographic Factors	**Habitat Factors**	
Condition Category	Occurrence of *S. saximontana*	Average Habitat Condition Score from HUC 12 Indicators	Average Condition Score from NRCS Depth to Water Table
High	Out of *S. saximontana* range	≥ 2.5	≥ 2.5
Moderate	Within *S. saximontana* range but not present within 10 km of known *S. hallii* population	1.5 – 2.49	1.5 – 2.49
Low	*S. saximontana* co-occurs with *S. hallii*	< 1.5	< 1.5

4.3.1. *Schoenoplectiella saximontana* Occurrence Metrics

The co-occurrence of Rocky Mountain Bulrush (*Schoenoplectiella saximontana*) with *S. hallii* was determined by contacting agency personnel or experts from those states, Natural Heritage databases, herbarium databases, and published literature. Condition was assessed as high if the *S. hallii* population was out of the species range (Natural Resources Conservation Services (NRCS) Plant Profile). Moderate condition was assigned to populations within the range of *S. saximontana* but not present within 10 km of the *S. hallii* population. Low condition referred to populations of *S. saximontana* and *S. hallii* that co-occur (Table 4.1.).

4.3.2. HUC 12 Watershed Index Online Indicator Metrics

Habitat metrics and associated data at the sub-watershed level (12-digit hydrologic unit code or HUC 12) were downloaded using the EPA's Watershed Index Online (WSIO) tool. The SSA team reviewed each metric to determine whether it was indicative of suitable habitat or a known stressor to assess the current condition of sub-watersheds where *S. hallii* had been found. We identified nine indicator metrics (Table 4.2.) to consider and divided indicator results into three conditions: "low", "moderate", and "high", based on the species' habitats and potential impact on the species. For example, we assumed that an increase in the amount of wetland cover within the sub-watershed could have a positive impact on the species, whereas an increase in developed impervious cover could have a negative impact. We sent our condition categories and indicator descriptions to species experts for review and feedback before assessing the current condition of each population.

Using ArcMap, we overlaid each documented *S. hallii* population with the WSIO HUC 12 data to include sub-watersheds within the population. The area of each population in hectares was determined and the percentage of each sub-watershed area within the population was calculated. Using the WSIO data for each sub-watershed and our condition categories, each indicator was assigned a score based on the condition of the sub-watershed. The score was then weighed against the percentage of the sub-watershed within the population. This prevented sub-watersheds that only accounted for 1% of the total population from having the same weight of a sub-watershed that made up over 50% of the overall population. The weighted condition score, ranging from 1-3 (low, moderate, high) was averaged for each sub-watershed within the population and the combined scores were used to determine the population's current condition (Table 4.1.). An example of calculations for the WSIO indicator metrics for the *S. hallii* Mixed Woods Plains ecoregion populations is provided below (Table 4.3.).

Table 4.2. Watershed Index Online (WSIO) indicator metrics used to assess current condition at the sub-watershed level. Scale data reflect the minimum and maximum scores for each metric.

Indicator	Description of Indicator	Scale	High Condition (3)	Moderate Condition (2)	Low Condition (1)
% Imperviousness, Mean in WS (2011)	Percent of the HUC12 with developed impervious cover. Calculated as the mean value of percent developed imperviousness in the HUC12.	0-100%	0.03-5%	5-25%	25-100%
PHWA Watershed Vulnerability Index, ER (2016)	The Watershed Vulnerability Index characterizes the vulnerability of aquatic ecosystems in a watershed to future alteration based on Land Use Change, Water Use Change, and Wildfire Vulnerability Sub-Index scores. Higher scores correspond to greater potential vulnerability of aquatic ecosystems to future degradation.	0-1	0.027-0.25	0.25-0.5	0.5-1.0
% Agriculture Change in WS (2001- 11)	The change in the percentage of the HUC12 with agriculture cover from 2001 to 2011. Positive values denote an increase in agriculture; negative values denote a decrease in agriculture. Equation used: (Area Changing to Agriculture – Area Changing From Agriculture)/(HUC12 Area) * 100.	-3.8-5%	-3.8-0.00%	0-1%	1-5%
% Agriculture in WS (2011)	Percent of the HUC12 classified as agriculture cover by the 2011 CDL-NLCD Hybrid Land Cover dataset. Calculated as agriculture area in the HUC12 divided by HUC12 area, multiplied by 100.	0-100%	0-10%	10-25%	25-100%
% Urban in WS (2011)	Percent of the HUC12 classified as urban cover by the 2011 CDL-NLCD Hybrid Land Cover dataset. Calculated as urban area divided by HUC12 area, multiplied by 100.	0-100%	0-25%	25-50%	50-100%
PHWA Watershed Health Index, ER (2016)	The Watershed Health Index is an integrated measure of watershed condition that combines Landscape Condition, Hydrologic, Geomorphology, Habitat, Water Quality, and Biological Condition Sub-Index scores. Higher scores correspond to greater potential for a watershed to have the structure and function in place to support healthy aquatic ecosystems.	0-1	0.75-1	0.5-0.75	0-0.5
% Wetlands Remaining in WS	Percent of wetland cover remaining relative to pre-development wetland cover in the HUC12. Equation used: Existing Wetland Area in HUC12 / Pre-Development Wetland Area in HUC12 * 100. Only calculated for HUC12s with pre-development wetland area greater than or equal to 1% of HUC12 area.	0-100%	50-100%	10-50%	0-10%
% Wetlands Change in WS (2001-11)	The change in the percentage of the HUC12 with wetland cover from 2001 to 2011. Equation used: (Area Changing To Wetlands – Area Changing From Wetlands)/(HUC12 Area) * 100.	-9.64-2.63%	1-5%	0-1%	-10-0%
% Emergent Herbaceous Wetlands in WS (2011)	Percent of the HUC12 classified as 'Emergent Herbaceous Wetlands' (code 195) by the 2011 CDL-NLCD Hybrid Land Cover dataset. Calculated as 'Emergent Herbaceous Wetlands' area divided by HUC12 area, multiplied by 100. (See also 2011 CDL-NLCD Hybrid Land Cover glossary definition).	0-22.5%	10-25%	1-10%	0-1%

Table 4.3. An example of calculations for the Watershed Index Online (WSIO) indicator metrics used to assess current condition at the sub-watershed level for the *Schoenoplectiella hallii* Mixed Woods Plains ecoregion populations. A strikethrough indicates the population is extirpated. (Status; "X" = extirpated, "U" = unknown, and "E" = extant)

State	Population	Status	PHWA Watershed Vulner-ability Index, ER (2016)	% Impervious-ness, Mean in WS (2011)	% Agriculture in WS (2011)	% Urban in WS (2011)	PHWA Watershed Health Index, ER (2016)	% Wetlands Remaining in WS	% Emergent Herbaceous Wetlands in WS (2011)	% Agriculture Change in WS (2001-11)	% Wetlands Change in WS (2001-11)	HUC 12 Weighted Averaged Condition
Massachusetts	~~Middlesex Co., MA~~	~~X~~	~~High~~	~~Low~~	~~High~~	~~Low~~	~~Low~~	~~Moderate~~	~~Moderate~~	~~High~~	~~Low~~	~~Moderate~~
	~~Essex Co., MA~~	~~X~~	~~High~~	~~Moderate~~	~~High~~	~~High~~	~~Moderate~~	~~Moderate~~	~~Moderate~~	~~High~~	~~Low~~	~~Moderate~~
Michigan	Pine Island, Muskegon Co., MI	U	High	High	Moderate	High	High	High	Moderate	High	Low	High
	Carr Lake, Muskegon Co., MI	U	Moderate	High	Moderate	Moderate	Moderate	High	Moderate	High	Low	Moderate
	Allegan Co., MI	E	High	High	Low	High	Moderate	High	Low	High	Low	Moderate
Indiana	Dune Lake Playground, Porter Co., IN	E	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	High	Low	Moderate
	Coulter Sand Prairie, Porter Co., IN	E	Low	Moderate	Moderate	Low	Moderate	Moderate	Low	High	Low	Moderate

4.3.3. NRCS Web Soil Survey Metrics

We downloaded the depth to water table habitat factor using the Web Soil Survey (WSS) Application produced by the National Cooperative Soil Survey and operated by the NRCS. Depth to Water Table is part of the Water Features available from the Soil Properties and Qualities tab within the application. Soil data was downloaded for 100 m buffers around each known occupied site within a population. The Soil Data Viewer application was used within ArcMap (ESRI 2018). We calculated a percentage of area for each WSS Area Symbol from the area of each symbol and the total area for the population. Each WWS Area Symbol's associated data was categorized as high or low condition with the value of 3 or 1, respectively. High condition is categorized as areas that depth to water table is less than 100 cm. Low condition is categorized as areas that depth to water table is greater than or equal to 100 cm. The condition value was then multiplied by the percentage of area to get a weighted average for each WWS Area Symbol. We summed the weighted averaged condition scores for each population to get an overall weighted condition. This method was utilized to prevent small WWS Area Symbols within the evaluated area to skew the population condition by being given the same weight as larger WWS Area Symbols within the population area. The weighted population condition was then assessed as either high (greater than or equal to 2.5), moderate (1.5–2.49), or low (less than 1.5) condition (Table 4.1.).

4.4. Current Condition Results

4.4.1. Mixed Wood Plains Ecoregion Populations

The Mixed Wood Plains ecoregion is glaciated, rolling to level terrain with mixed land cover including agricultural lands, forests, wetlands, and glacial lakes (Sleeter *et al.* 2014, p. 19). The climate is warm summers with cold and snowy winters (Sleeter *et al.* 2014, p. 19). There are seven populations within the Mixed Wood Plains ecoregion and ranging across Massachusetts, Michigan, and Indiana (Figure 4.1.). All extant populations within the Mixed Wood Plains ecoregion are considered to be at a low risk of hybridization because they are outside of *S. saximontana* range.

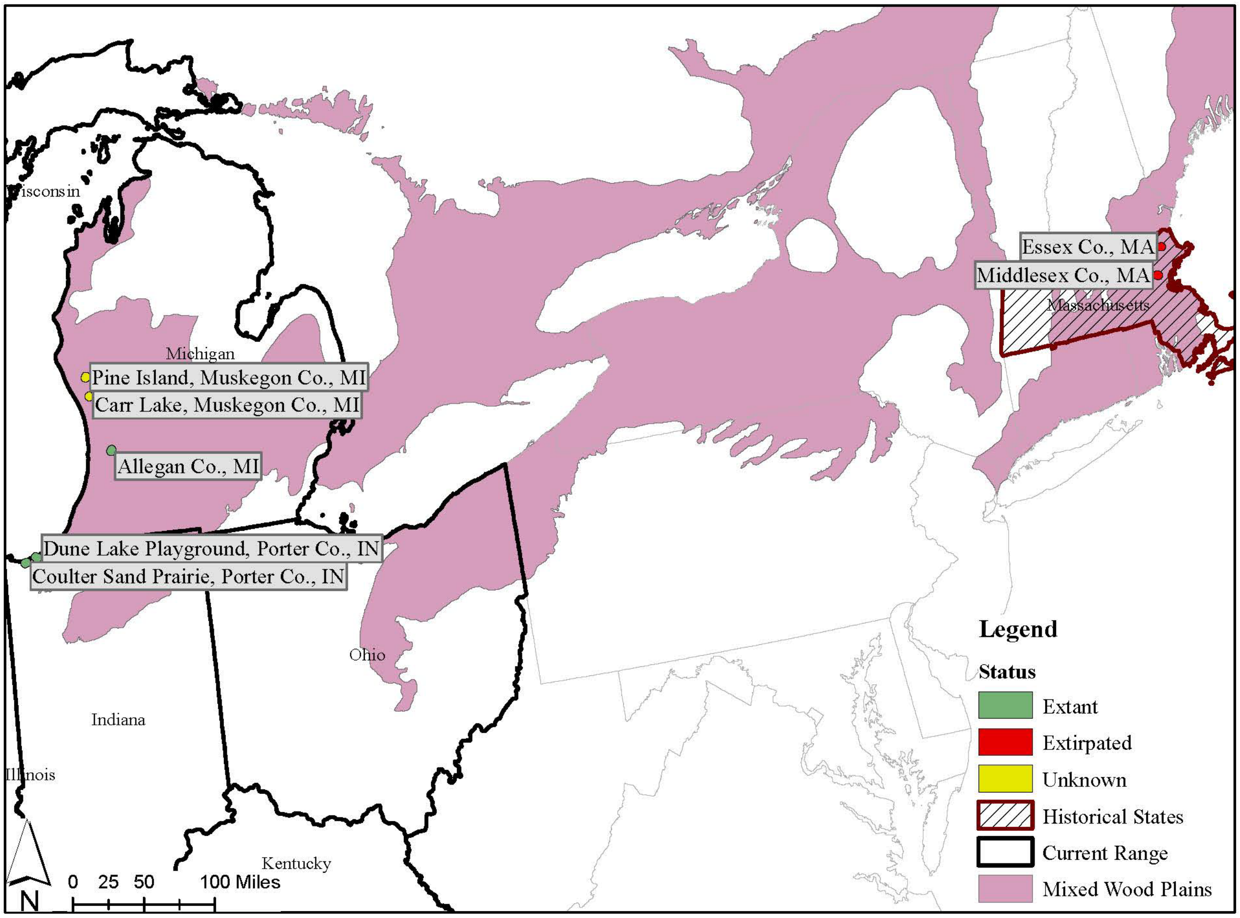

Figure 4.1. Current and historic distribution of *Schoenoplectiella hallii* in the Mixed Wood Plains Ecoregion.

The two populations located in Massachusetts are extirpated. The Massachusetts populations are based on knowledge from historic collections. The population located in Essex County is now developed. The population site in Middlesex County appears to be suitable habitat for *S. hallii*. The site is described as a sandy pond shore in the occurrence records provided by the state. It was thought to have been extirpated in 1986. This population was surveyed in 2002, and again categorized as extirpated; notes from that year indicate that suitable habitat is available. Based on the history of surveys, state biologists do not consider continued surveys for *S. hallii* a high priority at this time.

The two populations in Muskegon County, Michigan, Pine Island and Carr Lake, are both categorized as unknown. These populations' last positive surveys were conducted in 1986. Surveys were conducted in 1999–2006 though S. hallii was not observed at these populations (Penskar and Higman 2008, p. 20). Michigan populations occur within intermittent wetlands, typically associated with coastal plain marsh habitats. The Pine Island population is located on a dedicated Research Natural Area on the Forest Service's Huron-Manistee National Forest, and the Carr Lake population is protected as part of the Five Lakes Muskegon Nature Sanctuary owned by the Michigan Nature Association. Both populations are given some protection from off-road vehicle use and invasive species. The Pine Island population is ranked as high condition for the average habitat condition from HUC 12 indicators, likely due to the location occurring on the National Forest. Even though surveys have not been conducted, and therefore the population statuses are unknown, it appears the areas have suitable habitat and provide some protection from threats for *S. hallii*. The third population in Michigan, and the only confirmed extant one, is located in Allegan County within the Allegan State Game Area. Off-road vehicles still threaten the *S. hallii* population on the state land (Penskar and Higman 2002, p. 3). This population has been surveyed more frequently than the Muskegon County populations. It was discovered in 1989, but then experienced drought conditions for an extended number of years. *S. hallii* was observed in 2002 in modest numbers (Penskar and Higman 2002, p. 2), and again in 2009 and 2011. This population is considered the highest quality of the state's populations, despite not having any protection from off-road vehicle damage.

There are two populations in Indiana that are within the Mixed Woods Plains ecoregion: Dune Lake Playground and Coulter Sand Prairie. A couple of sites make up the Dune Lake Playground population in Porter County. The playground site had a positive survey for *S. hallii* in 1993. Three additional surveys conducted throughout the 2000's, were negative until 2019, when *S. hallii* once again germinated at the site. The occurrence records provided by the state include notes from 2017 that the town had stopped mowing the perimeter to encourage the growth of *S. hallii*. In addition to the perimeter, the town stopped mowing the former soccer field (S. Namestnik, pers. comm., 2020). It could be reasoned that the removal of this disturbance allowed individuals to grow during the next year that had ideal conditions, which is why *S. hallii* was seen in 2019. The other site, located about a mile and a half away from the playground site, is located within the Indiana Dunes National Park. This site had *S. hallii* consistently germinating throughout the 2000's: surveys generally averaged 50 individual plants on positive surveys, with a single exception in 2007 when a survey documented 1,000's of individuals. This site is small and closing in with trees reducing the size of the opening (S. Namestnik, pers. comm., 2020). Based on historic surveys and trends, this site has the necessary conditions to germinate plants approximately once every 5 years. The state botanist reasons the timing of mowing has been altered to avoid disturbing *S. hallii* growth, but keeping dense vegetation from encroaching the population (S. Namestnik, pers. comm., 2020). Now that the threat of mowing during growth at the playground site has been removed, the Dune Lake Playground population as a whole has suitable habitat and hydrology to persist.

The Coulter Sand Prairie population within Lake and Porter counties is made up of two sites approximately a mile apart. Both sites were discovered in the 1980's. Surveys resumed in the early 2000's, where both sites had *S. hallii* germinating. The Coulter Nature Preserve was mined for sand and disturbed in prior to *S. hallii* being discovered (S. Namestrik, pers. comm., 2020). This site is now ranked as extirpated by state heritage personnel due to succession and competition (S. Namestrik, pers. comm., 2020). The other site within this population is located on the Indiana Dunes National Park Tolleston Unit. This site has been surveyed in 2007 (17 individuals), 2014 (100–1,000 individuals), 2017 (50–100 individuals), and 2019 (1,000+ individuals). As the Coulter Nature Preserve site has undergone succession to the point that *S. hallii* has not been observed since 2001, the Indiana Dunes National Park Tolleston Unit site is the remaining extant population for the Coulter Sand Prairie population. Based on the historic germination trends, this area appears to exhibit necessary hydrology for germination and growth of *S. hallii* on average once every five years.

In summary, the Mixed Wood Plains ecoregion has three extant populations, one in Michigan, and two near the shore of Lake Michigan in Indiana. These three populations have suitable habitat and hydrology sufficient for germination and growth of *S. hallii* throughout the growing season. These three populations are located on public land; however, there currently are no management plans or protections for these populations. These three populations' overall health was evaluated to be of moderate condition (Table 4.4.). The two populations in Indiana may be connected, as they are both along the shoreline of Lake Michigan; however, it is less likely that there is any movement between the Indiana population and the extant Michigan population.

Table 4.4. Current conditions table for *Schoenoplectiella hallii* populations within the Mixed Wood Plains Ecoregion. Status categories are X = extirpated, U = unknown, and E = extant. A strikethrough indicates the population is extirpated.

Mixed Wood Plains Ecoregion			**Demographic Factors**	**Habitat Factors**		**Overall Current Condition**
State	**Population**	**Status**	**Absence of *S. saximontana***	**Average Habitat Condition from HUC 12 Indicators**	**NRCS Depth to Water Table**	
~~Massachusetts~~	~~Middlesex Co., MA~~	~~X~~	~~High~~	~~Moderate~~	~~Low~~	~~Moderate~~
	~~Essex Co., MA~~	~~X~~	~~High~~	~~Moderate~~	~~Low~~	~~Moderate~~
Michigan	Pine Island, Muskegon Co., MI	U	High	High	Low	Moderate
	Carr Lake, Muskegon Co., MI	U	High	Moderate	Low	Moderate
	Allegan Co., MI	E	High	Moderate	Moderate	Moderate
Indiana	Dune Lake Playground, Porter Co., IN	E	High	Moderate	Low	Moderate
	Coulter Sand Prairie, Porter Co., IN	E	High	Moderate	Low	Moderate

4.4.2. Central USA Plains Ecoregion Populations

The Central USA Plains ecoregion is dominated by agriculture and is classified as glaciated, flat to gently rolling plains (Sleeter *et al*. 2014, p. 20). The climate is warm to hot summers and cold winters (Sleeter *et al*. 2014, p. 20). These populations are located in Illinois, Ohio, and Wisconsin. There are seven populations within this ecoregion (Figure 4.2.). Of these seven populations, five occur in Illinois. The Kankakee County, Illinois population is along the eastern state border and is categorized as unknown status. The other four Illinois populations in this ecoregion are all mostly within Mason County. Ohio and Wisconsin both have one population each. The Ohio population is located at the Floyd Bartley Nature Preserve. The Dane County, Wisconsin population is located at a state prison.

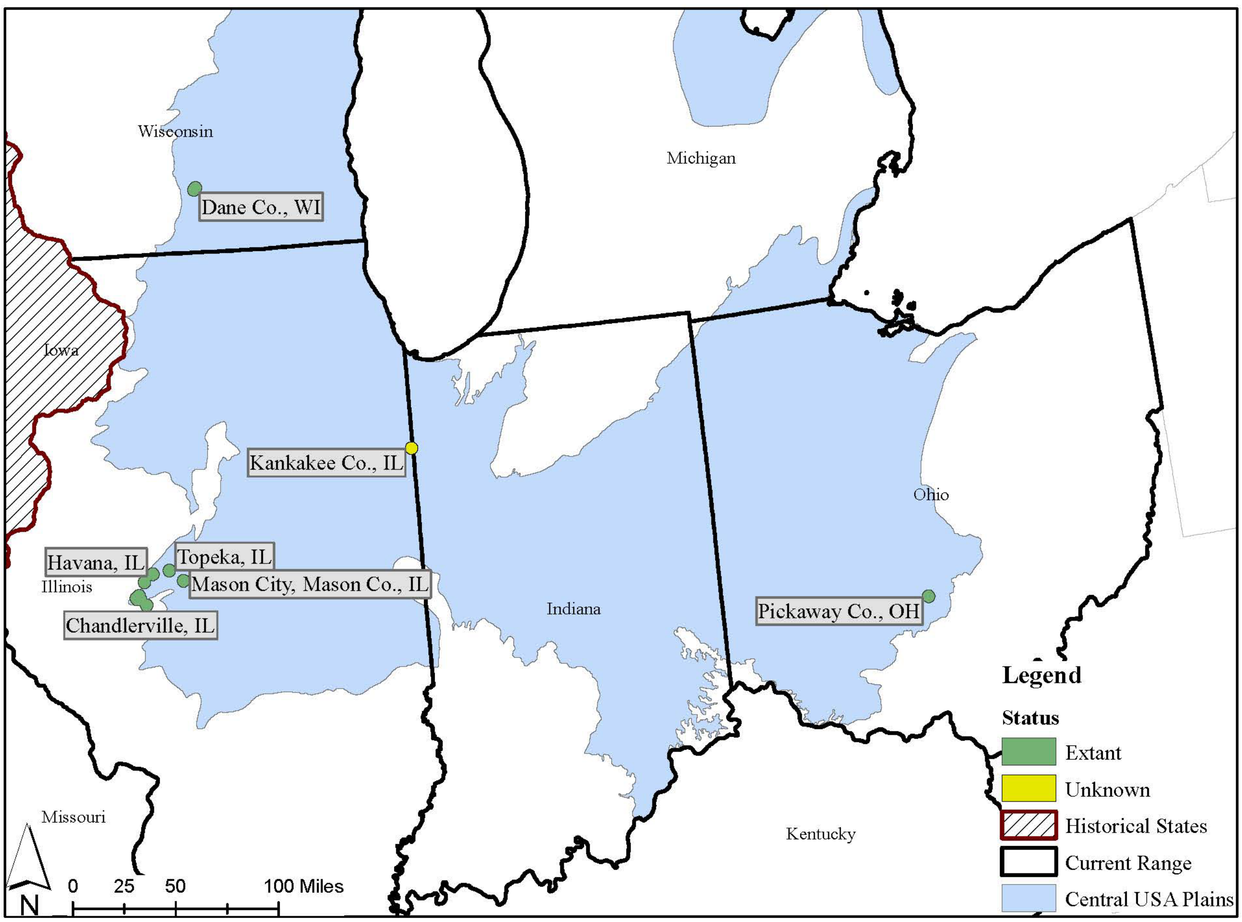

Figure 4.2. Current and historic distribution of *Schoenoplectiella hallii* in the Central USA Plains Ecoregion.

There are five populations in Illinois within the Central USA Plains ecoregion: Mason City, Topeka, Havana, Chandlerville, and Kankakee. The Mason City, Mason County, IL population is comprised of one site. This site is a sand depression located in an agricultural field. In wet years with ideal hydrology, when the site cannot be cultivated, *S. hallii* germinated. The last positive survey was in 2015 where 10,000's of plants were observed. In 2019, the area did not have *S. hallii*, though it was noted that the area looked suitable. The Topeka, IL population is also comprised of one site and is also a sand depression located in an agricultural field. The last positive survey was in 2009; prior to that, because surveys had not been conducted frequently, the population had not been seen since 1993 when it was discovered. In 2019, the area was too dry to find any wetland vegetation; however, this population is evaluated as high condition. The Havana, IL population is comprised of two sites approximately 5 miles apart. One site is a pond in agricultural fields while the other occurs at a sandy pond within the Sand Prairie-Scrub Oak Nature Preserve. The site within the agricultural field was discovered in 1985, found multiple years throughout the 1990's, and again in 2001 and 2009. In 2019, the site had over a million plants. When the hydrology is ideal, this site produces numerous plants. The site on the Sand Prairie-Scrub Oak Nature Preserve was discovered in 1985 as well. Surveys were positive throughout the 1990's, in 2009, and 2010. However, since then, during survey years, the water levels were too low to produce the necessary hydrology for *S. hallii*. The Havana, IL population is evaluated as high condition. The Chandlerville, IL population is comprised of five sites. One site has not had a positive survey since 1995. Two sites last had *S. hallii* in 2009. Two sites had *S. hallii* present in both 2009 and 2010. All five of these sites within this population are located in sand depressions within agricultural fields. The Kankakee County population is located on the eastern border of Illinois and is comprised of one site located in a large sand depression that is part of an agricultural field. This site was discovered in 1993 and has not been surveyed since, making the status of this population unknown. When surveyed in 1993, there were approximately 250 plants. While its status is unknown, the habitat factors evaluated for this population indicate that the condition is high.

In the fall of 2019 the Illinois Department of Natural Resources (DNR) developed a rudimentary habitat model to assess the availability of habitat that fits parameters for S. hallii provided by John Wilker, the Illinois Natural Heritage Field Section Manager. They focused their model to Cass, Mason, Menard, and Tazewell counties. Their model was based on soils, wetlands, depressions, intersections with agriculture, and proximity to road (to allow surveys to be conducted without the additional time dedicated to obtaining landowner permissions). Due to some technical error during data transfer this information was not received by the SSA team until April 2020, and therefore not included in the current condition assessment. The surveys were conducted in seven areas as driving routes containing 112 points across the above four counties. Some points were not accessible to survey or the area had already been harvested making the presence of S. hallii unknown, though the exact number is not currently known due to the errors during data transfer. Thirteen of the sites had S. hallii present during the survey. Six of these sites are new locations. Two of the new locations occur within the Chandlerville, IL and Havanna, IL populations. Four of the new sites are located near the Mason City, Mason Co., IL population (Appendix G). This would expand the population to include five sites instead of one. The Illinois DNR intends to refine the habitat model and continue to search new areas for S. hallii into the future. The above information was provided by Joe Kath, the Endangered Species Program Manager, and Andrew Hulin, Geographic Analyst, in April 2020 via emails and conference call.

The Ohio population is located on the Floyd Bartley Nature Preserve, owned and managed by a local non-profit conservation organization, Appalachia Ohio Alliance (McKenzie *et al.* 2015, p. 478). The Ohio population was discovered in 2011 after achenes from *S. saximontana* were closely inspected. This site is the only known population of *S. saximontana* within Ohio and it is unknown if and how long *S. hallii* has been overlooked at this location (McKenzie *et al.* 2015, p. 477). This population is the only one with a low condition due to the presence of *S. saximontana* at the site. There is speculation that *S. hallii* is a recent dispersal by waterfowl to this site (McKenzie *et al.* 2015, p. 477). The second survey in 2014 did not have *S. hallii* present. The last positive survey was in 2017. The site is cultivated during dry years, but ponding water during wet years prevents farm equipment from entering, as is common at other *S. hallii* populations (McKenzie *et al.* 2015, p. 478). This population appears to germinate when the conditions are ideal. Even though it is a recent discovery, in the last decade *S. hallii* has been observed twice. The Ohio Department of Natural Resources Division of Natural Areas and Preserves has a conservation easement on the preserve and assists with management of the two wetlands where *S. hallii* occurs (R. Gardner, pers. comm., 2020).

The Wisconsin population is located on state prison land and is a sandy, gravelly shoreline. The site was discovered in 1950, however, consistent surveys did not occur until the 2000's, but these surveys did not find individuals, until 2013, when 34 individuals were observed. The next year, the population recorded over 400 individuals. The last positive survey for this population was in 2016, when two individuals were observed. The state prison does not have a management plan for *S. hallii*, though in past years the prison personnel have kept threats and disturbances away from the shoreline.

In summary, 6 of the populations within the Central USA Plains Ecoregion have persisting *S. hallii* populations when conditions are ideal (Table 4.5). The Ohio and Wisconsin populations are located in areas that protect the site, but only the Ohio population is managed for *S. hallii*. Two extant populations are evaluated to have high overall conditions, and the remaining four extant populations in the Central USA Plains ecoregion have moderate conditions. There may be connectivity between the Illinois populations, as they are relatively close to one another. Long-distance movement of waterfowl may provide connectivity between Wisconsin and Illinois; however, this movement while possible, is likely an infrequent occurrence. As connectivity within this ecoregion is thought to occur from migratory waterfowl movement, we consider the Ohio population to be isolated, as it does not occur within the same migratory flyway.

Table 4.5. Current conditions of Central USA Plains *Schoenoplectiella hallii* populations. Status categories are X = extirpated, U = unknown, and E = extant.

Central USA Plains Ecoregion			**Demographic Factors**	**Habitat Factors**		**Overall Current Condition**
State	**Population**	**Status**	**Absence of *S. saximontana***	**Average Habitat Condition from HUC 12 Indicators**	**NRCS Depth to Water Table**	
Illinois	Kankakee Co., IL	U	High	Moderate	High	High
	Chandlerville, IL	E	High	Moderate	Moderate	Moderate
	Havana, IL	E	High	Moderate	High	High
	Topeka, IL	E	High	Moderate	High	High
	Mason City, Mason Co., IL	E	High	Moderate	Moderate	Moderate
Ohio	Pickaway Co., OH	E	Low	Moderate	Moderate	Moderate
Wisconsin	Dane Co., WI	E	High	Moderate	Low	Moderate

4.4.3. Southeastern USA Plains Ecoregion Populations

The Southeastern USA Plains ecoregion is mostly unglaciated, and has smooth to irregular plains and areas of karst plains. The climate consists of hot, humid summers and mild winters (Sleeter *et al*. 2014, p. 20). This ecoregion is the largest level II ecoregion in the eastern U.S. and encompasses forest, pasture, cropland, and developed areas (Sleeter *et al.* 2014, p. 20). The Southeastern USA Plains is also one of the ecoregions with a higher number of populations located within it. Georgia, Indiana, Illinois, Kentucky, Iowa, and Missouri populations are located within this ecoregion (Figure 4.3.). The population in Georgia is extirpated and has not been collected since 1946 in Dougherty County. The lack of surveys and collections likely means *S. hallii* is no longer a part of Georgia's flora. The population located in St. Louis County, Missouri is also extirpated. This population was destroyed due to highway construction. This population was the only one within the ecoregion to have a low condition in regards to presence of *S. saximontana*. The flood conditions along the Missouri River in 1993 created habitat and S. saximontana was first documented in Missouri in 1994 (P. McKenzie, pers. comm., 2020). *Schoenoplectiella saximontana* was extant in 2017.

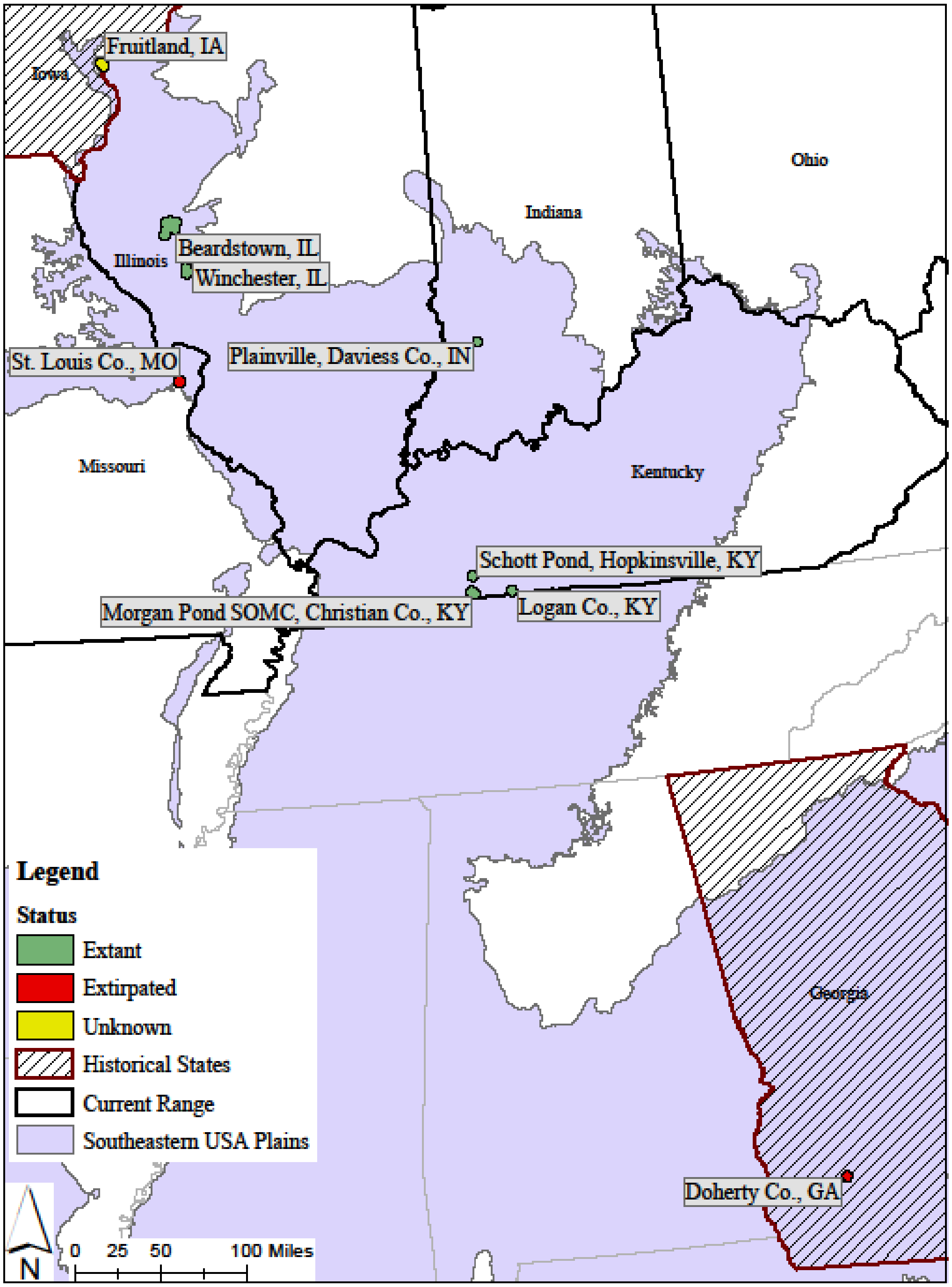

Figure 4.3. Current and historic distribution of *Schoenoplectiella hallii* in the Southeastern USA Plains Ecoregion

The status of *S. hallii* in Iowa is unknown and surveys have been infrequent. Surveys were completed in 2019; however failed to result in the documentation of *S. hallii* at any of the three locations. Big Mound Sand Preserve has sandy depressions that fill during flood events that could provide necessary habitat and condition requirements for *S. hallii*. The other historic site no longer provides suitable habitat as it is now overgrown with cedar trees. Reviewing aerial imagery of the area, the SSA lead biologist noted a county park (Deep Lakes Park, Muscatine County, Iowa) that had previously been a sand and gravel quarry that features numerous small lakes and ponds that total over 120 acres of clear water lakes. The county park allows many recreational activities, including motorized and non-motorized boating, fishing, swimming, and hiking. During a survey conducted in 2019 it was found that the habitat is of low quality for *S. hallii* and likely does not have a population at this location.

The Plainville, Daviess County, Indiana population is a shallow depression within a farm field. This site is cultivated in row crops during dry years. During ideal hydrology, the population germinates. Since 2000, the population has been surveyed eight times and had positive occurrence records from six of those surveys, each time producing numerous plants.

Two populations within Illinois occur within this ecoregion: Beardstown and Winchester. The Beardstown IL, population is composed of eight sites, five of which have not had positive surveys since 1993. These sites are sand depression within agricultural fields, a landfill, and a mowed area. The most recent positive survey was in 2008 at one site, the next recent being in 1996 at a different site. The Winchester population is comprised of three sites all discovered in 1993 or 1994. Only one of these sites has had a positive survey since it was discovered, which was during 2008.

Three populations within the Southeastern USA Plains ecoregion occur in Kentucky. All three Kentucky populations occur along the southern edge of the state within ephemerally ponded depressions. The surrounding landscape is highly agricultural and when the depressions are dry, they are tilled in the spring (Chester 2013, p. 35). Chester and Palmer-Ball (2011) note that these ponded depressions are common in occupied and surrounding counties; however, most are on private property and not accessible to survey (p. 2). The Morgan Pond SOMC, Christian County population is made up of multiple sites. Two sites were discovered in 1983 and have been surveyed consistently. These two sites have ideal conditions for *S. hallii* to germinate on average once every five years. The other sites have not been consistently surveyed, but have at least one positive observation within the 1990's and 2000's. The Schott Pond, Hopkinsville population was discovered in 2011. It was surveyed the next year, but had negative results. This population has not been surveyed since. The Logan County population was discovered in 2010 and is comprised of two sites located only 150 meters apart. The last positive survey was in 2013, but this population has not been surveyed since.

Overall, this ecoregion has high numbers of populations; however two are extirpated, one has an unknown status, and two have had very few positive surveys at sites (Table 4.6.). Therefore, the four populations in Indiana and Kentucky carry the persistence within this ecoregion. These same populations may have some connectivity as migratory waterfowl move between breeding and wintering grounds. The Logan county population in Kentucky is categorized as having a high overall condition, while the other three populations in Kentucky and Indiana have moderate overall conditions.

Table 4.6. Current conditions of *Schoenoplectiella hallii* populations within Southeastern USA plains ecoregion. Status categories are X = extirpated, U = unknown, and E = extant. A strikethrough indicates the population is extirpated.

Southeastern USA Plains Ecoregion			**Demographic Factors**	**Habitat Factors**		**Overall Current Condition**
State	**Population**	**Status**	**Absence of *S. saximontana***	**Average Habitat Condition from HUC 12 Indicators**	**NRCS Depth to Water Table**	
~~Georgia~~	~~Doherty Co., GA~~	~~X~~	~~High~~	~~Moderate~~	~~Moderate~~	~~Moderate~~
Indiana	Plainville, Daviess Co., IN	E	High	Moderate	Low	Moderate
Illinois	Winchester, IL	E	High	Moderate	Moderate	Moderate
	Beardstown, IL	E	High	Moderate	Moderate	Moderate
Kentucky	Morgan Pond SOMC, Christian Co., KY	E	High	Moderate	Moderate	Moderate
	Schott Pond, Hopkinsville, KY	E	High	Moderate	Moderate	Moderate
	Logan Co., KY	E	High	Moderate	High	High
Iowa	Fruitland, IA	U	High	Moderate	Low	Moderate
~~Missouri~~	~~St. Louis Co., MO~~	~~X~~	~~Low~~	~~Moderate~~	~~Moderate~~	~~Moderate~~

4.4.4. Ozark Ouachita-Appalachian Forests Ecoregion Populations

The Ozark Ouachita-Appalachian Forest ecoregion is made up of unglaciated forested mountains with little area occupied by agriculture (Sleeter *et al*. 2014, p. 21). The climate is warm summers and cold winters, but can vary significantly depending on elevation (Sleeter *et al.* 2014, p. 21). There is only one population located in Missouri that occurs within this ecoregion (Figure 4.4.). The Howell County population is made up of three sites. Myatt Pond is surveyed on average every 3 to 5 years and has germination and growth present during all surveys with the exception of the 2002 survey. The last survey, 2018, millions of plants were noted (P. McKenzie, pers. comm., 2020). The last positive surveys for the other two sites within this population were in the 1990's. Both of these sites were noted to have heavy grazing by cattle, one of which had removed cattle near the pond and allowed thick vegetation to take over the margins of the pond, outcompeting *S. hallii*. However, the Myatt Pond site has not had grazing identified as a threat. The Missouri Natural Heritage database classifies the Myatt Pond site as excellent condition, while the other two sites are in poor condition.

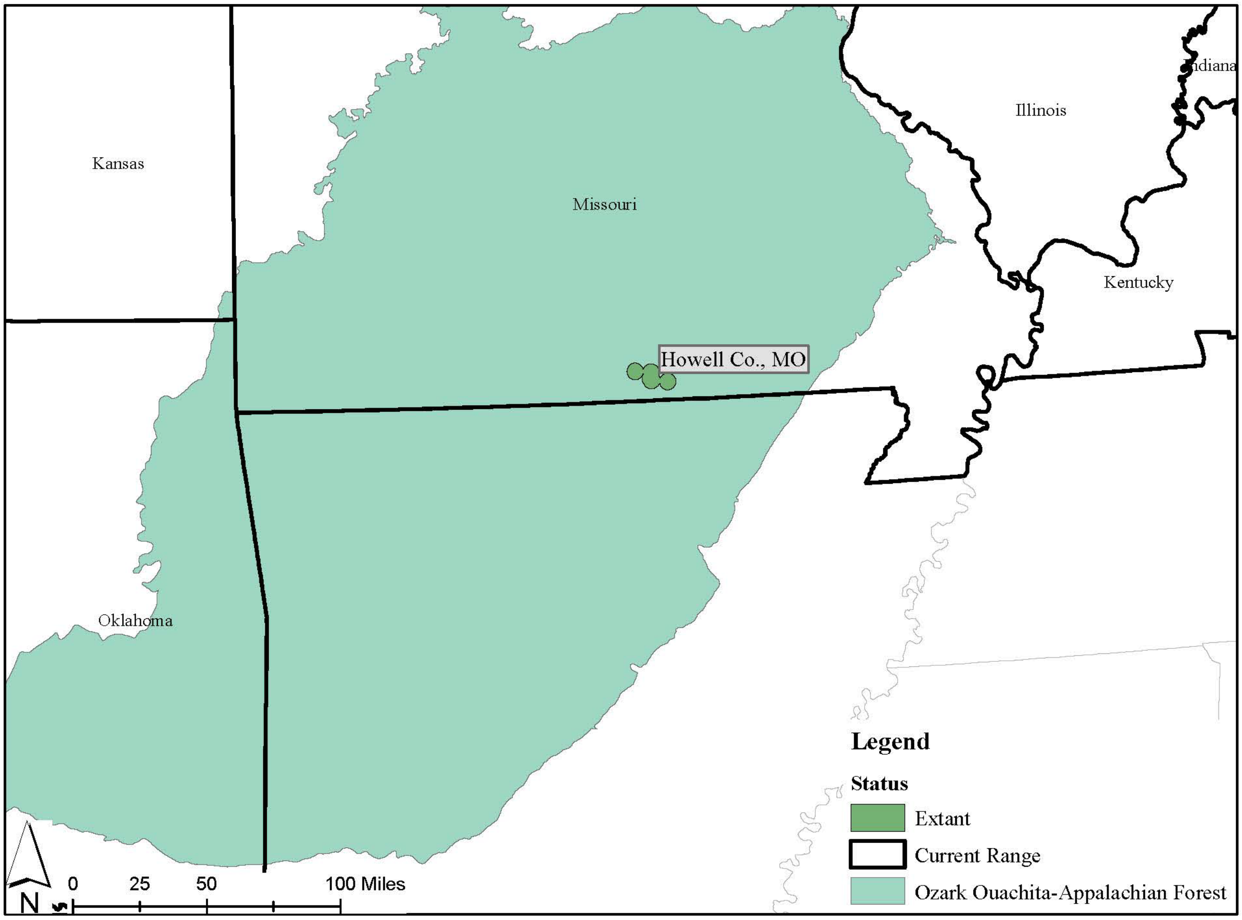

Figure 4.4. Current and historic distribution of Schoenoplectiella hallii in the Ozark Ouachita-Appalachian Forest Ecoregion.

This ecoregion is represented by a single population, which has continued to persist due to the large number of individuals at the Myatt Pond location (Table 4.7.). This location is not on public land or managed to maintain current habitat conditions.

Table 4.7. Current conditions of *Schoenoplectiella hallii* populations within the Ozark Ouachita-Appalachian Forest Ecoregion. Status categories are X = extirpated, U = unknown, and E = extant.

Ozark Ouachita-Appalachian Forest Ecoregion			**Demographic Factors**	**Habitat Factors**		**Overall Current Condition**
State	**Population**	**Status**	**Absence of *S. saximontana***	**Average Habitat Condition from HUC 12 Indicators**	**NRCS Depth to Water Table**	
Missouri	Howell Co., MO	E	High	Moderate	Moderate	Moderate

4.4.5. Mississippi Alluvial and Southeast USA Coastal Plains Ecoregion Populations

The Mississippi Alluvial and Southeast USA Coastal Plains ecoregion is unglaciated and made up of coastal plains and low-lying floodplains that includes agriculture, wetlands, water, forest, and developed areas (Sleeter *et al*. 2014, p. 22). The climate is similar to the Southeastern USA Plains ecoregion of hot and humid summers and mild winters (Sleeter *et al*. 2014, p. 22). There are two populations located in the ecoregion (Figure 4.5.). One is located in Illinois, the other in Missouri.

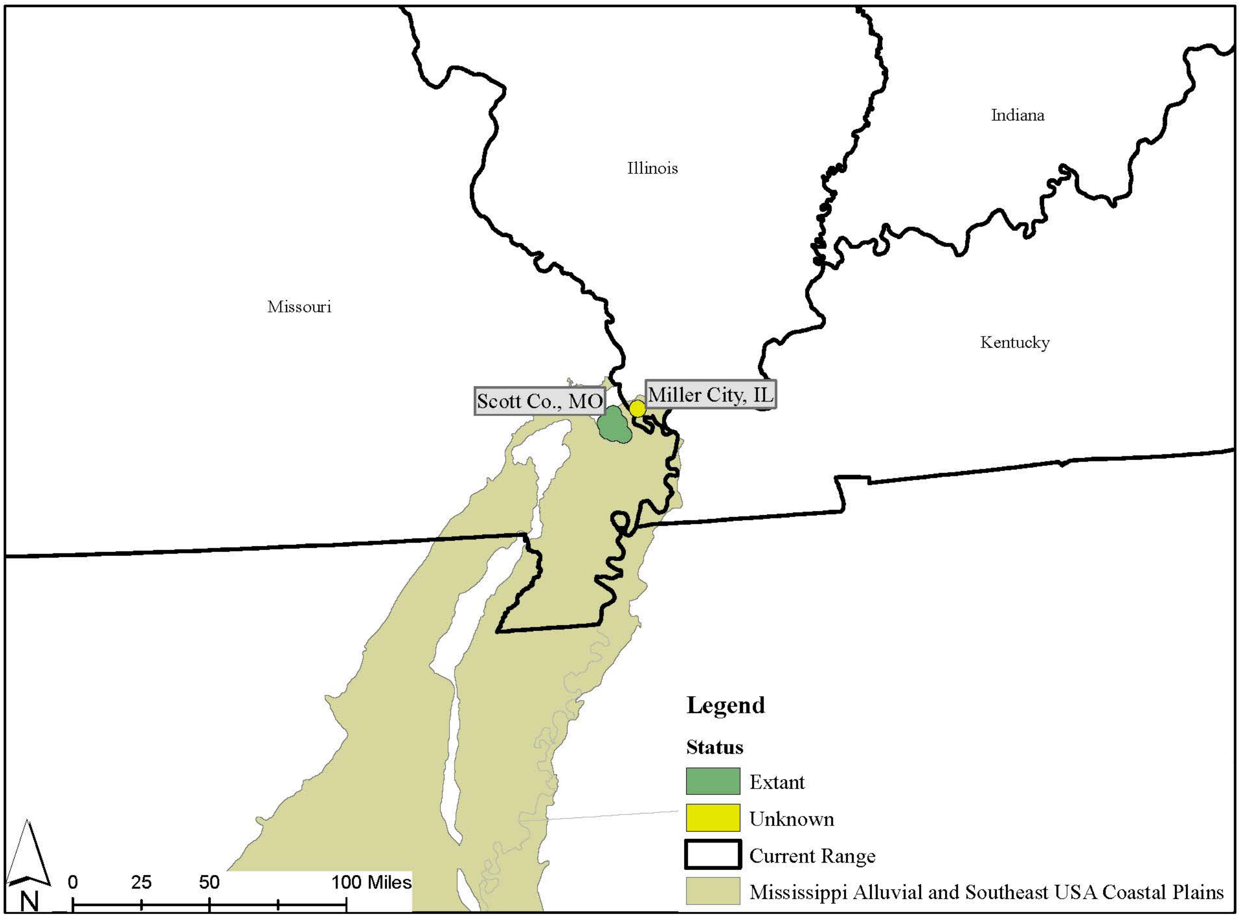

Figure 4.5. Current and historic distribution of *Schoenoplectiella hallii* in the Mississippi Alluvial and Southeast USA Coastal Plains Ecoregion

The Miller City, IL population has an unknown status. The population is located on Horseshoe Lake State Fish & Wildlife Area, operated by the Illinois Department of Natural Resources. This population was observed in 1993 and a specimen was confirmed from this survey. This population was surveyed only once more, in 2007, and did not have *S. hallii* present.

The Scott County, MO population is comprised of numerous sites within an approximately 50-square mile area, including the Charleston Baptist Camp, the intersection of Interstate 55 and

Highway U, and Xyris sand hollow sites. Sand prairie swales in shallow depressions of agricultural fields and roadside ditches make up the habitat within this population. All of the sites within this population are privately owned. The above listed sites had large populations in 2007 and 2008 in undisturbed areas. Xyris sand hollow is the only location that had been surveyed again, in 2014, and had 1,000's of *S. hallii* germinating. The other four sites within this population have very few plants and degraded habitat noted in 2018.

The persistence of *S. hallii* within this ecoregion relies on the Scott County, Missouri population, which is mostly made up of three main privately owned sites. This extant population is categorized as a moderate overall current condition (Table 4.8.). There may be connectivity between these populations as they are located across the Mississippi River from each other.

Table 4.8. Current conditions of *Schoenoplectiella hallii* populations within the Mississippi Alluvial and Southeast USA Coastal Plains Ecoregion. Status categories are X = extirpated, U = unknown, and E = extant.

Mississippi Alluvial and Southeast USA Coastal Plains Ecoregion			**Demographic Factors**	**Habitat Factors**		**Overall Current Condition**
State	**Population**	**Status**	**Absence of *S. saximontana***	**Average Habitat Condition from HUC 12 Indicators**	**NRCS Depth to Water Table**	
Illinois	Miller City, IL	U	High	Moderate	Moderate	Moderate
Missouri	Scott Co., MO	E	High	Moderate	Moderate	Moderate

4.4.6. West-Central Semi-Arid Prairies Ecoregion Populations

The West-Central Semi-Arid Prairies Ecoregion has diverse topography and a semi-arid climate with seasonal precipitation, hot summers, and cold winters. Historically, this ecoregion was covered by short- and mixed-grass prairie. This ecoregion is now significantly devoted to agriculture, more as grazing land than cropland. This ecoregion has the most populations of *S. hallii*, though they are all concentrated across six adjacent counties covering approximately 3,000 square miles in north-central Nebraska (Figure 4.6.). Many of these populations were discovered during surveys for western prairie-fringed orchid contracted by the Nebraska Game and Fish (P. McKenzie, pers. comm., 2020). Two of these populations are categorized as having an unknown status. These are the S. of O'Neil Road Ditch population in Holt County and the Chambers population in Holt County. A large number of these populations consist of sand hill wetlands that are typically fed by groundwater rather than surface runoff (Beatty *et al.* 2004, p.17).

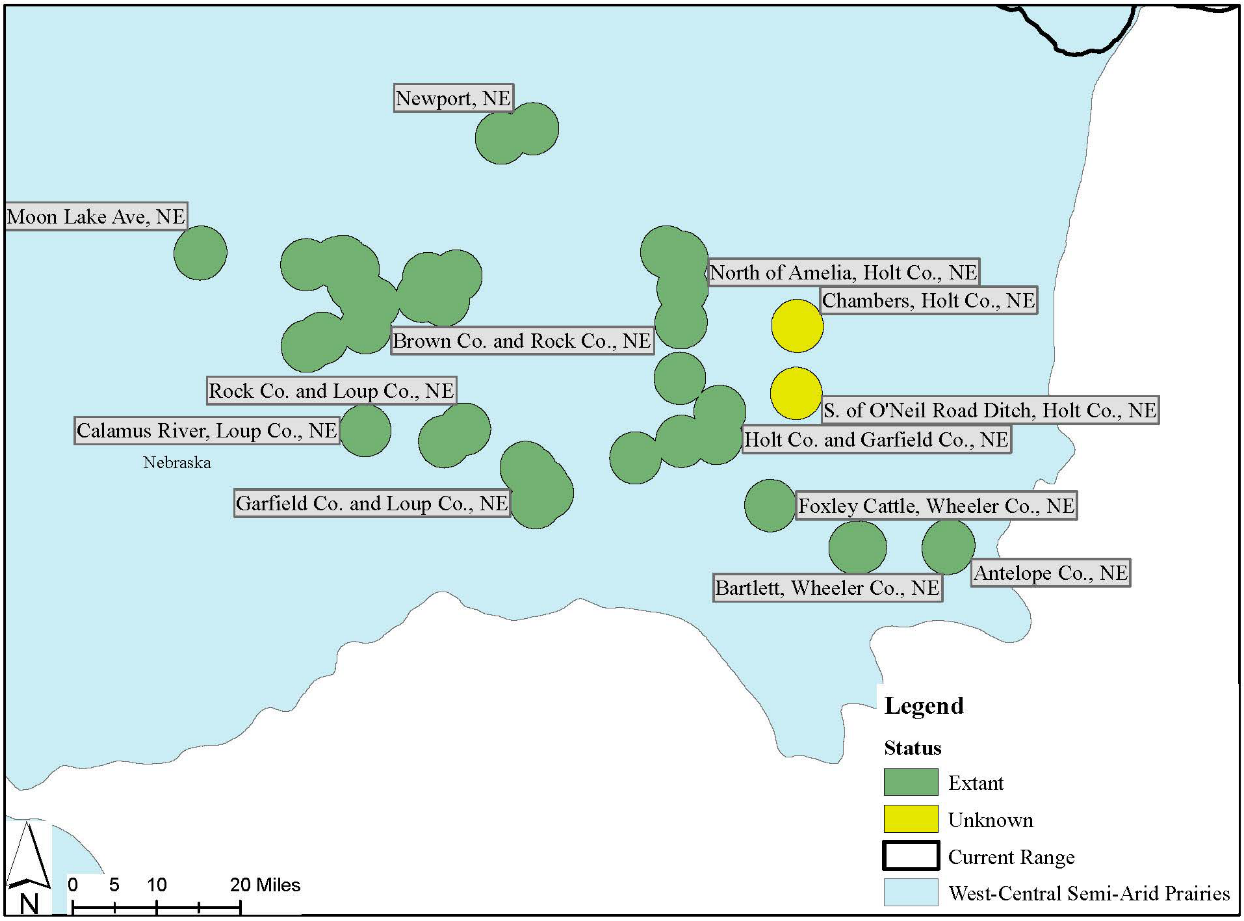

Figure 4.6. Current and historic distribution of Schoenoplectiella hallii in the West-Central Semi-Arid Prairies Ecoregion

The Newport population is comprised of two sites approximately four miles apart. These sites, only surveyed once in the early 2000's, have limited habitat and are within roadside ditches. Not many individuals were observed at these sites.

The Moon Lake Ave. population was discovered in 2000, the only year that it was surveyed. The habitat was minimal and was mostly along a roadside ditch.

The Brown County and Rock County population is the most expansive in this ecoregion, covering approximately 200 square miles. Most of the sites within this ecoregion were discovered in 2000, one site in 2001, a couple in 2012, and another in 2014. Most sites are found on the margins of drying sandhill wetlands, with the remaining few being along roadside ditches. All of the sites have only been surveyed once. Surveys indicated individuals ranging from few scattered single plants, to 1,000's of plants, depending on the availability of habitat.

The Calamus River, Loup County population has one site. This site is located across sand depressions and experiences heavy grazing and trampling from cattle. The individuals found during the only survey in 2000 were small, possibly due to the disturbance from cattle. The population was comprised of a couple hundred individuals scattered over sand depressions.

The Rock County and Loup County population consists of two sites approximately three miles apart. Both were discovered and were only surveyed in 2000. Both sites are noted to have available habitat, but during the one survey only had a few plants present. This population has *S. saximontana* that co-occurs in the same areas as *S. hallii*.

The Garfield County and Loup County population is composed of numerous sites, including Nichols Lake. The majority of sites were found in 2012 on moist sands along the edge of drying sandhills wetlands or the edge of the lake. The majority of the sites have available habitat and range from scattered individuals to 10,000's of plants. *Schoenoplectiella saximontana* has been identified in this population.

The North of Amelia population consists of roadside ditch sites. A few scattered plants have been found at these sites. Like most other populations, these sites have only been surveyed once. The majority of them were surveyed in 2000 or 2001. Only one site was surveyed in 2011, though this survey found only one plant.

The Holt County and Garfield County population is spread out across approximately 130 square miles and consists of five sites. One site has not been surveyed since 1999, when only scattered individuals within the sandy ditch of an abandoned road were observed. Three sites were surveyed in 2000, all of which have limited habitat available. Two of these sites occur along roadside ditches, the other site occurs within a sandhill wetland that is heavily vegetated, likely outcompeting *S. hallii* for resources. The final site within this population was surveyed in 2007 and occurred in a roadside ditch were individuals were found to be uncommon. *Schoenoplectiella saximontana* has been found to co-occur with *S. hallii* within this population.

The Chambers population has one site that was surveyed in 1971, and therefore has a status of unknown. A specimen was collected at this site, but population numbers were not recorded. The habitat was a broad roadside ditch that had moist, sandy soil.

The S. of O'Neil Road Ditch population also has very little information recorded and has an unknown status. The population is located in a roadside ditch and had 20 specimens collected in 1941. It has not been surveyed since.

The Foxley Cattle population is comprised of one site within a county road ditch that was surveyed in 2000. Habitat was limited within the road ditch and only supported 10–20 plants.

The Bartlett population is located on the margin of a small borrow pit that acts as a wetland. When the site was surveyed in 2001, there were 10,000 individuals. The site is possibly threatened by woody encroachment from willows. This site has not been visited again to know if this threat has occurred in the last 19 years.

The Antelope County population was discovered in 2009. Plants were scattered along small marshes throughout the private property and estimated to total over 1,000 individuals in an area grazed by cattle. In 2011, an area approximately half a mile away was surveyed. Habitat was limited along the margin of a wet depression, but plants were common in the limited areas. It was estimated to have 100 individuals during the survey.

In summary, the majority of populations within this ecoregion had low population numbers when surveyed and limited habitat. There are only two populations, the Brown County and Rock County population and the Garfield County and Loup County population that have recorded large numbers of individuals, though they have only been surveyed once. The Brown County and Rock County population has a high habitat condition (Table 4.9.). Three of the populations co-occur with *S. saximontana*, while the other ten populations occur within the range of *S. saximontana* and have a moderate risk of co-occurrence. The overall current conditions of all populations in this ecoregion were categorized as moderate. Local movements of waterfowl may provide connectivity between these 13 populations. Local movements occur more often than long-distance migratory movements, making the likelihood of dispersal between populations in this ecoregion higher.

Table 4.9. Current conditions of *Schoenoplectiella hallii* populations within the West-Central Semi-Arid Prairies Ecoregion. Status categories are X = extirpated, U = unknown, and E = extant.

West-Central Semi-Arid Prairies Ecoregion			Demographic Factors	Habitat Factors		Overall Current Condition
State	Population	Status	Absence of *S. saximontana*	Average Habitat Condition from HUC 12 Indicators	NRCS Depth to Water Table	
Nebraska	Newport, NE	E	Moderate	Moderate	Moderate	Moderate
	Moon Lake Ave, NE	E	Moderate	High	Low	Moderate
	Brown Co. and Rock Co., NE	E	Moderate	High	Low	Moderate
	Calamus River, Loup Co., NE	E	Moderate	High	Low	Moderate
	Rock Co. and Loup Co., NE	E	Low	Moderate	Moderate	Moderate
	Garfield Co. and Loup Co., NE	E	Low	Moderate	Moderate	Moderate
	North of Amelia, Holt Co., NE	E	Moderate	Moderate	High	Moderate
	Holt Co. and Garfield Co., NE	E	Low	Moderate	Moderate	Moderate
	Chambers, Holt Co., NE	U	Moderate	Moderate	Low	Moderate
	S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate	Moderate	High	Moderate
	Foxley Cattle, Wheeler Co., NE	E	Moderate	Moderate	High	Moderate
	Bartlett, Wheeler Co., NE	E	Moderate	Moderate	Moderate	Moderate
	Antelope Co., NE	E	Moderate	Moderate	Moderate	Moderate

4.4.7. South Central Semi-Arid Prairies Ecoregion Populations

The climate of the South Central Semi-Arid Prairies ecoregion is a cold semi-arid climate typically on the drier end of a humid subtropical climate, while becoming more arid towards the west. This region is mostly utilized for cropland and grazing land, with some localized urbanization. Populations located within this ecoregion are in Kansas, Oklahoma, and Texas (Figure 4.7.). Three populations occur in Kansas, with the Hutchinson population categorized as unknown status.

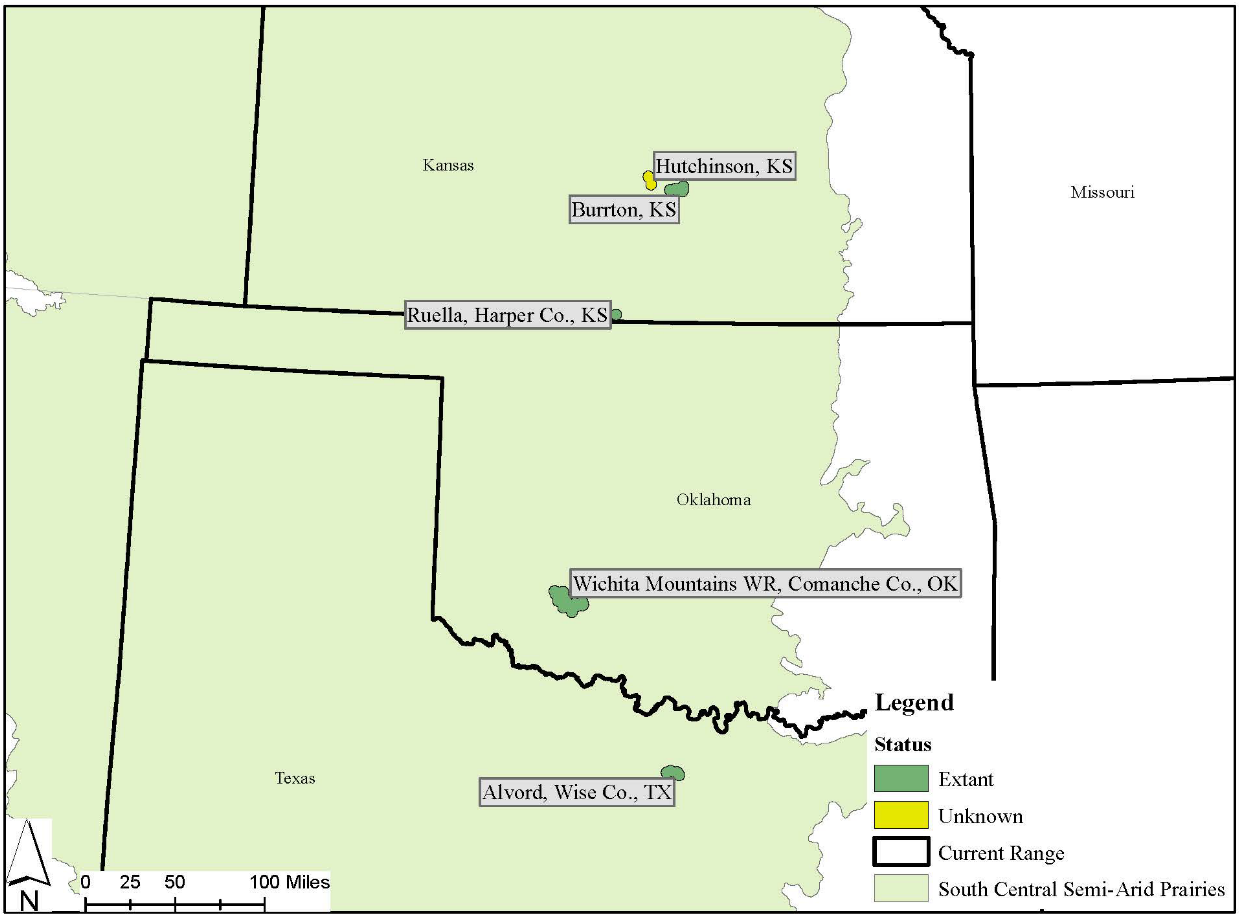

Figure 4.7. Current and historic distribution of *Schoenoplectiella hallii* in the South Central Semi-Arid Prairies Ecoregion

Kansas has three populations that occur within the state. The Hutchinson population, status unknown, is comprised of two sites approximately four miles apart. One was surveyed in 1993 and the other in 1949. There is not much information about these surveys. Neither habitat type nor population estimates were recorded. The Burrton population is comprised of four sites; three of them were surveyed between 1951 and 1978 and have not been surveyed since. One site was surveyed in 2007 and 2008, with *S. hallii* present both years. The Burrton population sites do not have information about the habitat type or population estimates. A portion of the Burrton population is part of the Sand Prairie Natural History Reservation, a property established with the help of the Nature Conservancy in 1965 and currently managed by Bethel College. This area is virgin prairie covered in sand dunes and marshes. Areas that are within interdunal valleys are typically fed by groundwater rather than surface runoff (Ostlie *et al.* 1997). It is managed to maintain the natural prairie ecosystem. The Ruella population is located in southern Kansas, approximately 75 miles south of the other two Kansas populations. This population was surveyed in 1997; however, information about this habitat type or population estimates was not recorded.

The Wichita Mountains Wildlife Refuge (Refuge) population consists of many sites throughout approximately 200 square miles occurring on the Refuge along with Fort Sill Military Reservation. A refuge-wide search for *Schoenoplectiella* species was conducted in 2000 and 2001 and *S. hallii* was observed at 18 ponds. During these years, it was estimated that 90% of the plants had grazing pressure by August (Wichita Mountains Wildlife Refuge 2002). Most bodies of water on the refuge are known to have or previously had documented populations of *S. hallii*, *S. saximontana*, or *S. x magrathii*. These areas on the refuge typically have limited active management (C. Deurmyer, pers. comm., 2019; D. McDonald, pers. comm., 2019). The Refuge and Fort Sill have ongoing feral hog control efforts (C. Deurmyer, pers. comm., 2019; D. McDonald, pers. comm., 2019). While the impacts of feral hogs to *S. hallii* populations have not been studied, it can be assumed that the rooting behaviors of feral hogs can pose a threat. Fort Sill includes *S. hallii* as a special interest plant species in their integrated natural resources management plan (C. Deurmyer, pers. comm., 2019). Fort Sill also implements active invasive species control, specifically targeting Johnson grass (C. Deurmyer, pers. comm., 2019). The majority of sites in this population had positive surveys in the early 2000's. Sites in the western portion of the population within the Refuge and Fort Sill were surveyed annually 2007–2012, with most years having positive surveys.

The Alvord population is the only one within Texas and it occurs on the Lyndon B. Johnson National Grasslands. There are approximately five units on the grasslands that have *S. hallii* present. Between herbarium specimens and surveys, 18 ponds contain *S. hallii* currently or historically. The sites in Texas are all margins of sandy clay ponds that are often shallow. Plants are generally observed in at least a few sites every year since the discovery of the species in 2003 (Taylor 2017, p. 5.). *Schoenoplectiella hallii* individuals persist throughout the year in this population. This is due to the ponds not freezing and water temperatures that never drop below 55 degrees Fahrenheit, even if the air temperature is below freezing, allowing plants under water to persist (Taylor 2017, p. 5). Many of these sites experience grazing by cattle and encroachment of woody taxa, even some of the larger populations.

The overall conditions of populations in this ecoregion are categorized as low (Table 4.10.). The four extant populations have *S. saximontana* co-occurring with *S. hallii*. The Hutchinson, Kansas population, since it has not recently been surveyed and is within close proximity to the Burrton population, may have *S. saximontana* present. Three of these populations occur on managed lands; although *S. hallii* is not managed for specifically, management plans address associated threats within two population areas. These populations are located in sandy ponds and rely heavily on the hydrology to maintain populations. Migrating waterfowl within the Central Flyway may connect these populations.

Table 4.10. Current conditions of *Schoenoplectiella hallii* populations within the South Central Semi-Arid Prairies Ecoregion. Status categories are X = extirpated, U = unknown, and E = extant.

South Central Semi-Arid Prairies Ecoregion			**Demographic Factors**	**Habitat Factors**		**Overall Current Condition**
State	**Population**	**Status**	**Absence of *S. saximontana***	**Average Habitat Condition from HUC 12 Indicators**	**NRCS Depth to Water Table**	
Kansas	Hutchinson, KS	U	Moderate	Moderate	Low	Moderate
	Burrton, KS	E	Low	Moderate	Low	Low
	Ruella, Harper Co., KS	E	Low	Moderate	Low	Low
Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	Low	Moderate	Low	Low
Texas	Alvord, Wise Co., TX	E	Low	Moderate	Low	Low

4.5. Current Resiliency, Representation, and Redundancy

The overall current condition for *S. hallii* can be summarized by having mostly moderate resiliency, redundancy of seven ecoregion units, and representation in terms of ecological diversity based on the notion that species that span environmental gradients are assumed to have variation (Table 4.11.).

Table 4.11. Summary of average current condition of *Schoenoplectiella hallii* populations within ecoregions.

Ecoregions	Overall Current Condition
Mixed Wood Plains	Moderate
Central USA Plains	Moderate
Southeastern USA Plains	Moderate
Ozark Ouachita-Appalachian Forests	Moderate
Mississippi Alluvial and Southeast USA	Moderate
West-Central Semi-Arid Prairies	Moderate
South Central Semi-Arid Prairies	Low

4.5.1. Current Resiliency

In general, the likelihood of sustaining populations over time increases with a greater number of healthy populations that occupy a variety of adequate quality habitat. Due to the wide distribution of the species, it is not likely for a range-wide environmental or stochastic event to occur that would affect all populations. Depending on the severity, environmental variation and stochastic events (e.g., extreme drought or agricultural practices) could impact individual sites or entire populations. The quality and quantity of habitat has been reduced historically. This is likely partially due to the increase in urbanization and agricultural lands and the alteration of hydrology across the range. The health of *S. hallii* populations likely decreased with the reduction of quality and quantity of habitat. However, populations that occur on agricultural land have indicated some resiliency to the disturbance to soil and water alterations, as germination still periodically occurs when hydrologic conditions are met and agricultural practices are not conducted in that area that particular year.

Of the 32 known extant populations of *S. hallii*, there are three in high condition, 25 in moderate condition, and four in low condition (Table 4.12.). Most populations have moderate resiliency as they continue to persist in areas that have reduced available habitat and lower quality available habitat than historically. Few populations occupy higher quality habitat, and therefore having higher resiliency. The extant populations that exhibit higher resiliency are restricted to Kentucky (Logan County population) and Illinois (Havana population and Topeka population; Table 4.13.). The four low condition extant populations exhibit lower resiliency likely due to reduced available habitat and a greater risk of hybridization with *S. saximontana*. These populations are isolated to the South Central Semi-Arid Prairies ecoregion (Table 4.13.) resulting in the overall ecoregion current condition to be categorized as low (Table 4.11.).

Table 4.12. Summary of *Schoenoplectiella hallii* population status and overall current condition within ecoregions.

Ecoregion	Number of Extant Populations			Number of Unknown Populations			Number of Extirpated Populations	Total Number of Populations
	High Condition	Moderate Condition	Low Condition	High Condition	Moderate Condition	Low Condition		
Mixed Wood Plains	0	3	0	0	2	0	~~2~~	7
Central USA Plains	2	4	0	1	0	0	0	7
Southeastern USA Plains	1	5	0	0	1	0	~~2~~	9
Ozark Ouachita-Appalachian Forest	0	1	0	0	0	0	0	1
Mississippi Alluvial and Southeast USA Coastal Plains	0	1	0	0	1	0	0	2
West-Central Semi-Arid Prairies	0	11	0	0	2	0	0	13
South Central Semi-Arid Prairies	0	0	4	0	1	0	0	5
Total Number of Populations	3	25	4	1	7	0	4	44

Table 4.13. Summary of *Schoenoplectiella hallii* populations and their overall current condition. A strikethrough indicates the population is extirpated.

Ecoregion	State	Population	Status	Overall Current Condition
Mixed Wood Plains	~~Massachusetts~~	~~Middlesex Co., MA~~	~~X~~	~~Moderate~~
		~~Essex Co., MA~~	~~X~~	~~Moderate~~
	Michigan	Pine Island, Muskegon Co., MI	U	Moderate
		Carr Lake, Muskegon Co., MI	U	Moderate
		Allegan Co., MI	E	Moderate
	Indiana	Dune Lake Playground, Porter Co., IN	E	Moderate
		Coulter Sand Prairie, Porter Co., IN	E	Moderate
Central USA Plains	Illinois	Kankakee Co., IL	U	High
		Chandlerville, IL	E	Moderate
		Havana, IL	E	High
		Topeka, IL	E	High
		Mason City, Mason Co., IL	E	Moderate
	Ohio	Pickaway Co., OH	E	Moderate
	Wisconsin	Dane Co., WI	E	Moderate
Southeastern USA Plains	~~Georgia~~	~~Doherty Co., GA~~	~~X~~	~~Moderate~~
	Indiana	Plainville, Daviess Co., IN	E	Moderate
	Illinois	Winchester, IL	E	Moderate
		Beardstown, IL	E	Moderate
	Kentucky	Morgan Pond SOMC, Christian Co., KY	E	Moderate
		Schott Pond, Hopkinsville, KY	E	Moderate
		Logan Co., KY	E	High
	Iowa	Fruitland, IA	U	Moderate
	~~Missouri~~	~~St. Louis Co., MO~~	~~X~~	~~Moderate~~
Ozark Ouachita-Appalachian Forest	Missouri	Howell Co., MO	E	Moderate
Mississippi Alluvial and Southeast USA Coastal Plains	Illinois	Miller City, IL	U	Moderate
	Missouri	Scott Co., MO	E	Moderate
West-Central Semi-Arid Prairies	Nebraska	Newport, NE	E	Moderate
		Moon Lake Ave, NE	E	Moderate
		Brown Co. and Rock Co., NE	E	Moderate
		Calamus River, Loup Co., NE	E	Moderate
		Rock Co. and Loup Co., NE	E	Moderate
		Garfield Co. and Loup Co., NE	E	Moderate
		North of Amelia, Holt Co., NE	E	Moderate
		Holt Co. and Garfield Co., NE	E	Moderate
		Chambers, Holt Co., NE	U	Moderate
		S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate
		Foxley Cattle, Wheeler Co., NE	E	Moderate
		Bartlett, Wheeler Co., NE	E	Moderate
		Antelope Co., NE	E	Moderate
South Central Semi-Arid Prairies	Kansas	Hutchinson, KS	U	Moderate
		Burrton, KS	E	Low
		Ruella, Harper Co., KS	E	Low
	Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	Low
	Texas	Alvord, Wise Co., TX	E	Low

4.5.2. Current Representation

We assume that a species' ability to adapt to changing environmental conditions over time can be characterized by the range of environmental and genetic diversity within and among populations. The 44 historic *S. hallii* populations range across seven ecoregions (Figure 2.2, Table 4.14), which represent a range of ecological settings and serve as a proxy for describing potential adaptive capacity for the species. *Schoenoplectiella hallii* is well represented over the historical range even though four populations are now extirpated. Two of the historical states, Massachusetts and Georgia, were on the edge of the historical range. Unique ecological niches were likely lost when these populations were extirpated. Extant populations utilize a variety of soil substrates and occur in a variety of habitats, such as sand prairies in Kansas and Nebraska, coastal plain marshes in Michigan, temporary ponds in Kentucky, cultivated field depressions in Illinois, and sinkhole ponds in Missouri, to name a few. While four populations are extirpated and eight are of unknown status, the range of extant populations still exists across seven ecoregions, filling a large scope of ecological niches (See Sections 4.4.1. – 4.4.7.).

Table 4.14. Summary of *Schoenoplectiella hallii* population status within ecoregions.

Ecoregion	Number of Extant Populations	Number of Unknown Populations	Number of Extirpated Populations	Total Number of Populations
Mixed Wood Plains	3	2	2	7
Central USA Plains	6	1	0	7
Southeastern USA Plains	6	1	2	9
Ozark Ouachita-Appalachian Forest	1	0	0	1
Mississippi Alluvial and Southeast USA Coastal Plains	1	1	0	2
West-Central Semi-Arid Prairies	11	2	0	13
South Central Semi-Arid Prairies	4	1	0	5

Few studies have been conducted on the genetic diversity of *S. hallii*, and typically only focus on a small portion of populations across the range. Young (2002, p. 54) compared single populations from Missouri, Wisconsin, Illinois, and Kentucky to the Oklahoma population. Edwards *et al.* (2019, p. 15) compared samples from Oklahoma, Missouri, and Ohio.

Based on the results of these studies, *S. hallii* populations appear to have few genotypes per population, but with several genotypes widespread across populations. Based on this information, *S. hallii* has varying levels of low genetic diversity within populations, with relatively low ability to adapt to specific local environmental condition.

Overall, *S. hallii* occupies a diverse range of environmental conditions but has low levels of genetic diversity. The limited genetic diversity could provide some ability to adapt to slowly changing environmental conditions but *S. hallii* is unlikely to adapt at a rate that would be needed for more severe or rapid environmental changes.

4.5.3. Current Redundancy

We characterize redundancy as having multiple healthy populations distributed across ecological settings of the species' range to minimize the potential loss of the species from catastrophic events. We did not identify any catastrophic events during our analysis, as an event that could remove vegetative structures as well as the seedbank is unlikely. The forty-four *S. hallii* historic populations (with a mix of high [4], moderate [36], and low [4] resiliency categories) ranged across fourteen states within seven ecoregions. The current range has been reduced to eleven states within seven ecoregions with a total of 32 extant populations. There is a low potential of connectivity between populations. Therefore, if one population is lost, it is unlikely that another population will be able to reestablish the lost unit. Most ecoregions have multiple populations with the exception of the Ozark Ouachita-Appalachian Forests ecoregion (one population) and the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion (two populations in close proximity). These two ecoregions are at a higher risk than the other five ecoregions for potential loss of the ecoregion from a catastrophic event. While redundancy has been reduced from historic conditions, *S. hallii* has a high level of redundancy due to the wide distribution of populations and the 25-year longevity of seed bank viability; thus, a single catastrophic event would be unlikely to affect numerous populations.

CHAPTER 5. FUTURE CONDITIONS AND VIABILITY

5.1. Introduction

In this chapter, we predict the future condition of *S. hallii*, in terms of its resiliency, representation, and redundancy. We identify anthropogenic and natural factors that are occurring and predict the future condition of the species based on those factors. Predictions of future species' condition are dependent on the current species' condition and the understanding of how the species interacts with its environment. Our future conditions were projected out to 2050, since the achenes of *S. hallii* can remain viable in the seed bank at least 25 years.

Predicting the future condition requires us to make plausible and logical assumptions. Our analysis is predicated on multiple assumptions, which could lead to over- and underestimates of viability. The anthropogenic and natural factors used in the analysis may be independent of each other, and actual future conditions and viability may result from a combination of scenarios. In addition, we made the assumption the future response of populations is within the range of scenarios evaluated. The hybridization rate is based on the best available data, though it is based on a single study. We did not have the data to directly forecast changes to the water table therefore we used the United States Geological Survey (USGS) National Climate Change Viewer (NCCV) soil water storage future climate projections dataset to evaluate impacts to the water table as a proxy. Overall, we made the assumption (for all three factors evaluated) that the extent and magnitude of future influences are accurately predicted, using the best available information. Whenever we project into the future (and are forced to make assumptions), there is a certain level of uncertainty and inherently there will be over- and under estimations in future scenarios.

5.2. Methods for Evaluating Future Scenarios

5.2.1. Expansion of *Schoenoplectiella saximontana*

Due to the threat hybridization can pose to rare species*,* we modeled the rate of expansion of Rocky Mountain bulrush (*S. saximontana*) and projected its impacts on *S. hallii* populations. An expansion distance for *S. saximontana* was chosen based on the documented distance that migratory waterfowl travel for short- and long-distance movements and the frequency of these movements. In general, waterfowl local movements within approximately ten kilometers (km) happen once per week. Long distance movement (approximately 500 km) occurs once annually. The frequency of waterfowl movement is based on a conceptual diagram provided from Kleyheeg (2015, p. 150) published with their thesis researching seed dispersal by mallards (*Anas platyrhynchos*).

Using the information mentioned above, we modeled the percent of *S. hallii* populations within the area of waterfowl short- and long-distance movements from known *S. saximontana* populations. Where both plants co-occur we assumed a hybridization rate of 23% based on the work of Edwards *et al.* (2019, entirety). Additionally, within the areas representing the short-distance movements and within waterfowl migratory flyways, we estimated a higher risk of co-occurrence and hybridization (see Scenario A, Expansion of *Schoenoplectiella saximontana* below). Which *S. hallii* populations within that distance are projected to have hybridization potential in the future are based on our best professional judgement, using migratory flyways and distances between major migratory routes as a guide.

This metric is the only one that the team is able to predict a change in condition category of the population.

5.2.2. Land Use Change

Because we did not have the data to forecast most of the HUC 12 indicators into the future, we evaluated the change of habitat condition by using the Conterminous United States Land Cover Projections - 1992 to 2100 from the USGS. We used this proxy to calculate the projected change in developed, agriculture, and herbaceous wetland land cover types within *S. hallii* populations based on the 2000 Special Report on Emission Scenarios (SRES) by the Intergovenmental Panel on Climate Change (IPCC; Nakićenović *et al.* 2000, entirety). There are four story lines called "families". These four story lines (named A1, A2, B1, and B2) describe the relationships between emission driving forces and their evolution, along with representing different demographic, social, economic, technological, and environmental developments (Nakićenović *et al.* 2000, entirety). We evaluated one SRES scenario group from each story line to encompass the range of emission scenarios available - A1B, A2, B1, and B2. We evaluated the land cover at 2030, 2040, and 2050 for each of the scenarios. The square acreage of each land cover type was calculated within each population boundary for each SRES scenario group for 2020, 2030, 2040, and 2050. Using the land cover acreage, a percent change based on the 2020 acreage was calculated for each year within each scenario.

Because land use was only a portion of the HUC 12 indicators used to evaluate current condition, the future scenarios do not have categorical conditions assigned to them. We did not have sufficient data to project all of the HUC 12 indicators into the future. Instead, populations were evaluated as either increasing, maintaining, or decreasing in condition, based on projected land use change alone.

5.2.3. Soil Water Storage

We used the USGS (NCCV) soil water storage future climate projections dataset to evaluate impacts to the water table. We used this proxy because we did not have the data to directly forecast changes to the water table. We chose this metric to forecast changes from the current condition related to the water table. The USGS NCCV is based on predicted air temperature and precipitation data to project a water-balance model to simulate surface water for two of the 2010 Representative Concentration Pathways (RCP): RCP 4.5 and RCP 8.5. County level was the finest scale data available through the NCCV, therefore, populations that expanded across more than one county had soil water storage downloaded for each county and averaged. We evaluated the averaged projected soil storage for each decade 2030, 2040, and 2050 across the species range. In order to capture long-term trends and exclude annual variation, we evaluated the average for each decade because it represented the overall change within the decade, instead of the annual increases and decreases. The percent change was based on the decade 2010–2019 to represent the average for 2020.

Soil storage tangentially represents the ability for an area to maintain similar water table depths. In other words, soil water storage is a different metric than depth to water table, which is the metric used in our population resiliency analysis for current condition. Data were not available to forecast depth to water table into the future. We chose this analysis as a proxy. Therefore, the populations were evaluated as either increasing, maintaining, or decreasing in condition based on soil water storage projections.

5.3. Future scenarios

We developed four future scenarios combining one future projection from each of the three metrics (Table 5.1.).

Table 5.1. Overview table of future scenario projections for *Schoenoplectiella hallii*.

	Scenario A	Scenario B	Scenario C	Scenario D
Expansion of *Schoenoplectiella saximontana*	Expansion, increase hybridization rate	Expansion, current hybridization rate	No expansion, current hybridization rate	No expansion, decrease hybridization rate
USGS Conterminous United States Land Cover Projections	SRES A2	SRES A1B	SRES B2	SRES B1
USGS National Climate Change Viewer Soil Water Storage	RCP 8.5	RCP 8.5	RCP 4.5	RCP 4.5

5.3.1. Scenario A

Scenario A includes projected land use change (SRES A2) and soil water storage (RCP 8.5) representing the highest emission scenarios. This scenario predicts *S. saximontana* expands into *S. hallii* populations, based on waterfowl movements, and populations experience an increased rate of hybridization. See Table 5.2. for a summary of predicted trends for populations in this scenario. For geographical locations of populations mentioned in the following sections, refer to Figures 4.1–4.7.

5.3.1.1. Expansion of Schoenoplectiella saximontana

Within Scenario A, the hybridization rate is projected to be higher than current levels from Edwards *et al.* (2019, entirety). Of the 30 samples taken of *S. x magrathii*, results indicate only nine unique multilocus genotypes, or nine unique hybridization events. There were 145 total individual samples taken from three locations (Fort Sill, Wichita National Mountain Refuge, and Bartlett Preserve) of *S. saximontana*, *S. hallii*, and *S. x magrathii*. Of these 145 samples, there were 18 unique genotypes for *S. hallii*, 12 unique genotypes for *S. saximontana*, and nine unique genotypes for *S. x magrathii*. Of these 39 unique genotypes collected at the three locations, 23% were *S. x magrathii*.

Populations in the western portion of the Central Flyway currently have the highest concentration of co-occurrences of *S. hallii* and *S. saximontana.* This includes Texas, Oklahoma, Kansas, and Nebraska. Local movements of waterfowl occur more frequently than long distance movements, therefore, dispersal from local movements is a higher risk.

Local waterfowl movements could disperse *S. saximontana* achenes from the Burrton, KS population to the Hutchinson, KS population within the South Central Semi-Arid Prairies. As these two populations are within ten kilometers from each other, we project that the Hutchinson population will have co-occurrence by 2030 based on the frequency of local waterfowl movement and increased rates of hybridization.

Three populations in Nebraska co-occur with *S. saximontana* —Rock Co. and Loup Co., Garfield Co. and Loup Co., Holt Co. and Garfield Co.— and are centralized to the other *S. hallii* populations in Nebraska (Figure 4.6.). Localized movements of waterfowl can move *S. saximontana* achenes to four other populations of *S. hallii* in Nebraska: Foxley Cattle, S. of O'Neil Road, North of Amelia, and Calamus River. Only two of these populations— North of Amelia and Calamus River population— are projected to co-occur with *S. saximontana* by 2030 based on the distance to current co-occurring populations, the frequency of waterfowl local movements, and the increased rate of hybridization. The other two populations, Foxley Cattle and S. of O'Neil Road, are slightly further away from current co-occurrences, though still within ten kilometers. Therefore, they are projected to co-occur with *S. saximontana* by 2040. The other six populations within Nebraska could have *S. saximontana* occur due to long distance movements of waterfowl from the current sites that co-occur or taking more years for local movements from co-occurrences to spread *S. saximontana* across the landscape. Therefore, based on the risk for dispersal through both local and long-distance movements, along with the distance between populations, and the increased rate of hybridization, Moon Lake Ave, Brown Co. and Rock Co., and Antelope Co. population are projected to have *S. saximontana* co-occurring by 2050.

The other co-occurring populations in the Central Flyway are more isolated from one another; therefore, dispersal of achenes would require long distance movement by waterfowl. The St. Louis *S. saximontana* population occurs near the Mississippi River, a major migratory route used by waterfowl. Long-distance movement could disperse achenes at a higher risk to populations along the river. Dispersal to Scott Co., MO, Miller City, IL, Fruitland, IA are those along the river. Based on the lower frequency of long-distance movement and the higher rate of hybridization, the Scott county population is projected to have *S. saximontana* co-occur by 2050. Because the Scott Co. Missouri population and the Miller City, Illinois population are less than ten kilometers away, if one has *S. saximontana* occurring, the other would also have a low condition. Populations set further from the river, including Howell Co., MO, Winchester, Beardstown, Chandlerville, Mason City, Havana, and Topeka, IL, and Dane Co., WI, would have a lower risk of *S. saximontana* being dispersed into the population. In addition, with the higher rate of hybridization, *S. saximontana* would be expected to spread to a couple of these populations listed above. Based on the distance to the river, the Winchester population and the Beardstown population are projected to have co-occurrences by 2050. The Pickaway Co., Ohio *S. saximontana* population may be accessible by waterfowl moving towards the Mississippi River or those moving towards the Atlantic coast. Populations with low risk of dispersed *S. saximontana* achenes include Allegan Co., Carr Lake, and Pine Island, MI, Logan Co., Morgan Pond, and Schott Pond, KY. These areas would be considered low risk, as the populations are not along a major path, such as a river. Based on the lower risk of waterfowl movement, but the higher rate of hybridization, as well as proximity to migratory routes, the Schott Pond, KY populations are projected to have co-occurrence by 2050.

5.3.1.2. Land Use Change

Land use change is based on the SRES A2 story line. The main aspects of this storyline are the continuously increasing global population and slow economic and technological growth.

The Mixed Wood Plains ecoregion extant populations are not projected to decrease overall in condition. The Dune Lakes Playground, Porter Co. population decreases in condition in 2050 with an increase in developed land.

It is anticipated that the Central USA Plains ecoregion extant populations will mostly maintain their current conditions. The Dane Co., WI population is the only one that is projected to decrease in condition each year, due to increases in development and decreases in wetland area. The Mason City, Mason Co., IL population is projected to decrease in condition by 2030 due to an increase in development; after this initial decrease, the projections do not continue to increase in developed land. The remaining four extant populations and single unknown population are projected to maintain their moderate conditions into the future.

We project that three extant populations in the Southeastern USA Plains ecoregion will experience a decrease in their current conditions, while the remaining three extant populations and single unknown population will maintain their moderate current conditions. The Winchester, IL population is expected to decrease in condition due to an increase in developed land by 2040. Two of the three Kentucky populations are expected to decrease in condition, both due to an increase in developed land.

The single population, Howell County, Missouri, in the Ozark Ouachita-Appalachian Forest ecoregion, is projected to decrease in condition. Both development area and cropland are projected to increase in this population.

The Mississippi Alluvial and Southeast USA Coastal Plains ecoregion populations are projected to decrease in condition, but not until 2050. The Miller City, IL population, status unknown, is projected to maintain its condition because the population is located within the Horseshoe Lake State Fish and Wildlife Area and is not likely to experience an increase in development or change in wetland acreage by 2050. The Scott County, Missouri population is projected to decrease in condition due to the loss of wetland acreage and increase in development by 2050.

Of the eleven extant populations within the West-Central Semi-Arid Prairies ecoregion, one is projected to increase in condition, three are projected to maintain their current conditions, and seven are projected to decrease in condition. The Foxley Cattle, Wheeler County, NE population is projected to increase in wetland acreage, thereby providing additional potential habitat and increasing condition. The seven extant and two unknown populations that are projected to decrease in condition share the general trend of increase in agricultural land and decrease in wetland acres.

Only two populations in the South Central Semi-Arid Prairies ecoregion are projected to decrease in condition. The Hutchinson, KS populations, currently of unknown status, are projected to decrease in condition due to the increase in developed acres in 2050. The Wichita Mountains Wildlife Refuge, OK population is projected to maintain its condition because an increase in development is not likely to occur on a National Wildlife Refuge.

5.3.1.3. Soil Water Storage

Soil Water Storage is projected utilizing the RCP 8.5 high-emissions pathway for Scenario A. All but one of the *S. hallii* populations are projected to have minor decreases in soil water storage; however, these minor changes are not expected to affect the current water depth condition for these populations. Wichita Mountains Wildlife Refuge has a 17% decrease in water soil storage starting in 2040. This decrease is expected to lower the condition, though the Wichita Mountains Wildlife Refuge population is currently ranked at a low condition for depth to water table. Therefore, this projected decrease in soil water storage could pose a threat for this population by changing the necessary hydrology required to have a persisting population.

5.3.1.4. Overall 2050 Current Condition Summary

The 32 extant populations in 2050 are projected to increase in condition (1 moderate), maintain current condition (4 low, 7 moderate, 3 high), or decrease in condition (17 moderate; Table 5.2.). The eight unknown populations in 2050 are projected to maintain current conditions (4 moderate, 1 high) or decrease in condition (3 moderate). Of the 20 moderate populations that are projected to decrease in condition, 14 populations are at an increased risk of hybridization and 18 populations are projected to experience land use changes that will affect suitable habitat. The overall resilience of *S. hallii* is projected to decrease by 2050 in Scenario A (Appendix C). With two of the categories evaluating populations as either increasing, maintaining, or decreasing in condition, we could not quantitatively assess redundancy and representation for 2050.

5.3.2. Scenario B

Scenario B includes the land use change SRES A1B projections and soil water storage RCP 8.5 projections. Based on carbon emissions, SRES A1B more closely aligns with RCP 6.0; however, the NCCV does not provide soil water storage projections for that pathway. Under Scenario B we predict that *S. saximontana* will expand into *S. hallii* populations based on waterfowl movements, and populations will experience the same rate of hybridization that is currently observed. See Table 5.3. for a summary of predicted trends for populations in this scenario. For geographical locations of populations mentioned in the following sections, please refer to Figures 4.1–4.7.

5.3.2.1. Expansion of Schoenoplectiella saximontana

The hybridization rate projection under Scenario B is similar to that described in Edwards *et al.* (2019, entirety; i.e. 23%).

The expansion of *S. saximontana* would be very similar to Scenario A but with the current rate of hybridization. Due to that lower risk, not as many populations would have *S. saximontana* co-occurring by 2050. Local waterfowl movements could disperse *S. saximontana* achenes from the Burrton, KS population to the Hutchinson, KS population within the South Central Semi-Arid Prairies. As these two populations are within ten kilometers of each other, it was projected that the Hutchinson population would have co-occurrence by 2040. Localized movements of waterfowl can move *S. saximontana* achenes to populations of *S. hallii* in Nebraska. The North of Amelia population is projected to have co-occurrence by 2030 due to its close proximity to current *S. saximontana* populations. The Foxley Cattle, S. of O'Neil Road, and Calamus River populations are projected to have co-occurrences by 2040 as they are slightly further from current *S. saximontana* populations. The other six populations within Nebraska could have *S. saximontana* occurrences due to long distance movements from the current co-occurrence sites. Additionally these six populations within Nebraska could have S. saximontana occurrences due to a slower spread across the landscape as waterfowl make local movements between populations. Therefore, based on the risk for dispersal through both local and long-distance movements, along with the distance between populations and the current rate of hybridization, the Brown Co. and Rock Co. and Antelope Co. populations are projected to have *S. saximontana* co-occurring by 2050.

The St. Louis *S. saximontana* population may allow dispersal to the Scott Co., MO, Miller City, IL, and Fruitland, IA populations along the river due to long-distance migratory waterfowl. Based on the lower frequency of long-distance movement and the current rate of hybridization, the Scott County population is projected to have *S. saximontana* co-occur by 2050. Because the Scott Co., Missouri population and the Miller City, Illinois population are less than ten kilometers away, if one has *S. saximontana* occurring, the other would also have a low condition. Populations set further from the river would have a lower risk of *S. saximontana* being dispersed into the populations at the current rate of hybridization.

5.3.2.2. Land Use Change

Land use change for Scenario B is the SRES A1B story line. The main aspects of this story line are: Rapid economic growth; global population peaks during mid-century and then declines; rapid introduction of efficient technologies; and a balance between fossil and non-fossil energy sources.

Of the three extant populations in the Mixed Wood Plains ecoregion, one is projected to maintain its current condition, while the other two are projected to increase in condition as agricultural land decreases.

The Central USA Plains has six extant populations. Four of them are projected to maintain current conditions. The other two, Mason City, Mason Co., and Dane Co., are projected to decrease in condition due to an increase in developed acres. The Kankakee Co., IL population is of unknown status and is projected to maintain its current condition.

Of the six extant populations in the Southeastern USA Plains ecoregion, five are projected to decrease in condition. The Winchester, IL, Beardstown, IL, Morgan Pond SOMC, KY, and Schott Pond, KY populations are expected to decrease in condition based on increases in developed acres within the population area. The Logan Co., KY population is expected to decrease due to an increase in agricultural development. The Plainville, Daviess Co., population is projected to maintain its current condition.

The only population in the Ozark Ouachita-Appalachian Forest ecoregion is projected to decrease in condition. This is due to a large increase in acres of cropland – an increase of over 300% by 2050.

The Scott Co., Missouri population in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion is projected to decrease in condition. This is due to the projected decreased acreage of wetlands in the population areas. The Miller City, IL population is projected to maintain its current condition as it is located within the Horseshoe Lake State Fish and Wildlife Area and is not likely to experience an increase in development or change in wetland acreage by 2050.

Of the eleven extant populations in the West-Central Semi-Arid Prairies ecoregion, only one is projected to maintain its current condition – Moon Lake Ave, NE. The other ten populations are projected to decrease their current conditions due largely to the trend of major increases in pastureland. The two populations that are of unknown status are projected to decrease in condition as well. They are projected to have increased acres in pasture and cropland and decrease acres of wetlands.

Two populations within the South Central Semi-Arid Prairies ecoregion are projected to decrease in condition due to an increase in developed and cropland acres. The remaining three populations are located on protected land and are projected to maintain their current condition because an increase in development is highly unlikely.

5.3.2.3. Soil Water Storage

We projected the Soil Water Storage based on the RCP 8.5 high-emissions pathway for Scenario B. As such, this scenario shares the same projections as Scenario A.

5.3.2.4. Overall 2050 Current Condition Summary

The 32 extant populations in 2050 are projected to increase in condition (2 moderate), maintain current conditions (5 moderate, 3 low, 2 high), or decrease in condition (1 low, 18 moderate, 1 high; Table 5.3.). The eight unknown populations are projected to maintain current conditions by 2050 (2 moderate, 1 high) or decrease in condition (5 moderate). The overall resilience of *S. hallii* is projected to decrease by 2050 under Scenario B (Appendix D). With two of the categories evaluating populations as either increasing, maintaining, or decreasing in condition, we could not quantitatively assess redundancy and representation for 2050.

5.3.3. Scenario C

Scenario C includes the land use change SRES B2 projections and soil water storage RCP 4.5 projections. This scenario predicts that *S. saximontana* will not expand into additional *S. hallii* populations and those populations that currently co-occur with *S. saximontana* will continue to experience the same rates of hybridization that are currently observed and described in Edwards *et al.* (2019, entirety). See Table 5.4. for a summary of predicted trends for populations in this scenario. For geographical locations of populations mentioned in the following sections, please refer to Figures 4.1–4.7.

5.3.3.1. Expansion of Schoenoplectiella saximontana

Scenario C projects that the current *S. saximontana* populations do not disperse into other *S. hallii* areas. The rate of hybridization for this scenario is the same as the current rate.

5.3.3.2. Land Use Change

Land use change for Scenario C is the SRES B2 story line. The main aspects of this story line are local solutions to economic, social, and environmental sustainability, a lower rate of increase for the global population, and less rapid and more diverse technological changes.

All three extant populations in the Mixed Woods Plains ecoregion are projected to maintain their current conditions. Of the two unknown populations, both are projected to maintain their current conditions.

Of the six extant populations in the Central USA Plains ecoregion, two are projected to increase in condition, three are projected to maintain current conditions, and one is projected to decrease in condition. Chandlerville, IL and Havana, IL are projected to increase in condition with the trend of decreasing acres of agriculture and increasing wetland acres. Dane Co., WI is projected to decrease due to an increase in developed land.

The Southeastern USA Plains ecoregion has six extant populations. The Beardstown, IL population is projected to increase in condition based on agriculture acres decreasing and wetland acres increasing. The Plainville, IN, Morgan Pond SOMC, KY, and Schott Pond KY populations are projected to decrease in condition. The population projections in Kentucky are based on an increase in development acres, while the Indiana population is projected to decrease in condition due to the increase in pastureland/hay acres. The other two extant populations are projected to maintain current conditions.

The Howell Co., Missouri population in the Ozark Ouachita-Appalachian Forest ecoregion is projected to decrease in condition by 2030 due to an increase in cropland acres; subsequently, we project the condition will remain stable through 2050.

The extant population in Scott Co, Missouri, in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion, is projected to increase in condition due to the decrease of agricultural acres in the population area. The unknown population in Miller City, IL, is projected to maintain its current condition.

The West-Central Semi-Arid Prairies has eleven extant populations. Of these eleven, eight are projected to increase conditions in this scenario. The general trend for this increased condition is based on a decrease in agricultural acres, with some populations including an increase in wetland acres. The Antelope, NE and Calamus River, NE populations are projected to maintain their current conditions. There are two unknown populations. The Chambers, NE population is projected to maintain its current condition. The S. of O'Neil Road, NE population is projected to increase in condition based on cropland acres decreasing in the population area.

Of the four extant populations in the South Central Semi-Arid Prairies, two are projected to increase in condition, two are projected to maintain conditions, and one is projected to decrease in condition. The projections of increased population conditions are based on the increase in wetland acres within the population areas, thus increasing potential habitat.

5.3.3.3. Soil Water Storage

We projected Soil Water Storage based on the RCP 4.5 emissions pathway for Scenario C. All but one of the *S. hallii* populations are projected to have minor decreases in soil water storage; however, these minor changes are not expected to affect the current water depth conditions for these populations. Wichita Mountains Wildlife Refuge has a 17% decrease in soil water storage starting in 2040. This decrease is expected to lower the condition, though the Wichita Mountains Wildlife Refuge population is currently ranked at a low condition for depth to water table. Therefore, this projected decrease in soil water storage could pose a threat for this population by altering the necessary hydrology required to have a persisting population.

5.3.3.4. Overall 2050 Current Condition Summary

The 32 extant populations in 2050 are projected to increase in condition (2 low, 11 moderate, 1 high), maintain current conditions (2 low, 8 moderate, 2 high), or decrease in condition (6 moderate; Table 5.4.). The eight unknown populations in 2050 are projected to increase in condition (1 moderate) or maintain current conditions (6 moderate, 1 high),. The overall resilience of *S. hallii* is projected to maintain or increase by 2050 in Scenario C (Appendix E). With two of the categories evaluating populations as either increasing, maintaining, or decreasing in condition, we could not quantitatively assess redundancy and representation for 2050.

5.3.4. Scenario D

Scenario D includes the lowest carbon emission scenarios from land use change (SRES B1) and soil water storage (RCP 4.5). This scenario predicts that *S. saximontana* will not expand into additional *S. hallii* populations and those populations that currently co-occur with *S. saximontana* will experience lower rates of hybridization than currently observed. See Table 5.5. for a summary of predicted trends for populations in this scenario. For geographical locations of populations mentioned in the following sections, please refer to Figures 4.1–4.7.

5.3.4.1. Expansion of Schoenoplectiella saximontana

Scenario D projects that the current *S. saximontana* populations do not disperse into other *S. hallii* areas. The rate of hybridization for this scenario decreases from the current rate. The decrease in hybridization rate would not change the conditions of populations, but would reduce the threats associated with hybridization, such as reduced reproductive output.

5.3.4.2. Land Use Change

Land use change is the SRES B1 story line for Scenario D. The main aspects of this story line are that global population peaks in mid-century and then declines as well as the introduction of clean resource-efficient technologies; and an emphasis on global solutions to environmental sustainability.

The Mixed Wood Plains ecoregion has three extant populations, two of which will maintain current conditions while the other increases condition due to a decrease of agriculture in the population area.

Of the extant populations in Central USA Plains, four are projected to maintain current conditions while the other two are projected to decrease in condition. The Mason City, IL, and Dane Co., WI populations are projected to decrease in condition due to an increase in developed acres in the population area.

Three of the six extant populations in the Southeastern USA Plains ecoregion are projected to decrease in condition. The Beardstown, IL, Morgan Pond, KY, and Schott Pond, KY populations are projected to decrease in condition even though they are projected to have a decrease in agricultural area because they are also projected to increase in developed acres. The remaining three extant populations are projected to maintain current conditions.

The Howell, Missouri population in the Ozark Ouachita-Appalachian Forest ecoregion is projected to decrease in condition. It is projected that by 2050, this area will experience a 360% increase in cropland acres.

The Miller City, IL unknown population in the Mississippi Alluvial and Southeast USA Coastal Plains is projected to maintain its current condition. The Scott Co., Missouri extant population is projected to decrease by 2050 due to an increase in developed acres and a decrease in wetlands.

Of the eleven extant populations in the West-Central Semi-Arid Prairies ecoregion, three populations are projected to increase in condition due to the trend of decreasing acres in agriculture; in addition, the Foxley Cattle population is projected to increase in wetland acres. The Moon Lake Ave, NE extant population is projected to maintain current conditions. The remaining seven extant populations are projected to decrease in condition. The general trend for the projected decrease in condition for these populations is the increase of agricultural acres within the population area, especially an increase in pasture/hay acres. One of the two unknown populations is projected to maintain its current condition, while the other population is projected to decrease in condition due to an increase in pasture/hay acres within the population area.

All four extant populations in the South Central Semi-Arid Prairies ecoregion are projected to maintain their current conditions. The Hutchinson, KS unknown population is projected to decrease in condition in 2050.

5.3.4.3. Soil Water Storage

Soil Water Storage is projected utilizing the RCP 4.5 high-emissions pathway for Scenario D. As such, this scenario shares the same projections as Scenario C.

5.3.4.4. Overall 2050 Current Condition Summary

The 32 extant populations in 2050 are projected to increase in condition (4 moderate), maintain current conditions (4 low, 7 moderate, 3 high), or decrease in condition (14 moderate; Table 5.5.). The eight unknown populations in 2050 are projected to maintain current conditions (5 moderate, 1 high) or decrease in condition (2 moderate; Appendix F). With two of the categories evaluating populations as either increasing, maintaining, or decreasing in condition, we could not quantitatively assess redundancy and representation for 2050.

Table 5.2. Summary of projected trends for population conditions by 2050 for Scenario A.

Ecoregion	Status	Number of Populations	Overall Current Condition rated High that is projected to ↑ by 2050	Overall Current Condition rated High that is projected to → by 2050	Overall Current Condition rated High that is projected to ↓ by 2050	Overall Current Condition rated Moderate that is projected to ↑ by 2050	Overall Current Condition rated Moderate that is projected to → by 2050	Overall Current Condition rated Moderate that is projected to ↓ by 2050	Overall Current Condition rated Low that is projected to ↑ by 2050	Overall Current Condition rated Low that is projected to → by 2050	Overall Current Condition rated Low that is projected to ↓ by 2050
Mixed Wood Plains	Extant	3				1	1	1			
	Unknown	2					2				
Central USA Plains	Extant	6		2			2	2			
	Unknown	1		1							
Southeastern USA Plains	Extant	6		1			1	4			
	Unknown	1					1				
Ozark Ouachita-Appalachian Forest	Extant	1						1			
	Unknown	0									
Mississippi Alluvial and Southeast USA Coastal Plains	Extant	1						1			
	Unknown	1					1				
West-Central Semi-Arid Prairies	Extant	11					3	8			
	Unknown	2						2			
South Central Semi-Arid Prairies	Extant	4								4	
	Unknown	1						1			

Table 5.3. Summary of projected trends for population conditions by 2050 for Scenario B.

Ecoregion	Status	Number of Populations	Overall Current Condition rated High that is projected to ↑ by 2050	Overall Current Condition rated High that is projected to → by 2050	Overall Current Condition rated High that is projected to ↓ by 2050	Overall Current Condition rated Moderate that is projected to ↑ by 2050	Overall Current Condition rated Moderate that is projected to → by 2050	Overall Current Condition rated Moderate that is projected to ↓ by 2050	Overall Current Condition rated Low that is projected to ↑ by 2050	Overall Current Condition rated Low that is projected to → by 2050	Overall Current Condition rated Low that is projected to ↓ by 2050
Mixed Wood Plains	Extant	3				2	1				
	Unknown	2						2			
Central USA Plains	Extant	6		2			2	2			
	Unknown	1		1							
Southeastern USA Plains	Extant	6			1		1	4			
	Unknown	1					1				
Ozark Ouachita-Appalachian Forest	Extant	1						1			
	Unknown	0									
Mississippi Alluvial and Southeast USA Coastal Plains	Extant	1						1			
	Unknown	1					1				
West-Central Semi-Arid Prairies	Extant	11					1	10			
	Unknown	2						2			
South Central Semi-Arid Prairies	Extant	4								3	1
	Unknown	1						1			

Table 5.4. Summary of projected trends for population conditions by 2050 for Scenario C.

Ecoregion	Status	Number of Populations	Overall Current Condition rated High that is projected to ↑ by 2050	Overall Current Condition rated High that is projected to → by 2050	Overall Current Condition rated High that is projected to ↓ by 2050	Overall Current Condition rated Moderate that is projected to ↑ by 2050	Overall Current Condition rated Moderate that is projected to → by 2050	Overall Current Condition rated Moderate that is projected to ↓ by 2050	Overall Current Condition rated Low that is projected to ↑ by 2050	Overall Current Condition rated Low that is projected to → by 2050	Overall Current Condition rated Low that is projected to ↓ by 2050
Mixed Wood Plains	Extant	3					3				
	Unknown	2					2				
Central USA Plains	Extant	6	1	1		1	2	1			
	Unknown	1		1							
Southeastern USA Plains	Extant	6		1		1	1	3			
	Unknown	1					1				
Ozark Ouachita-Appalachian Forest	Extant	1						1			
	Unknown	0									
Mississippi Alluvial and Southeast USA Coastal Plains	Extant	1				1					
	Unknown	1					1				
West-Central Semi-Arid Prairies	Extant	11				8	2	1			
	Unknown	2				1	1				
South Central Semi-Arid Prairies	Extant	4							2	2	
	Unknown	1					1				

Table 5.5. Summary of projected trends for population conditions by 2050 for Scenario D.

Ecoregion	Status	Number of Populations	Overall Current Condition rated High that is projected to ↑ by 2050	Overall Current Condition rated High that is projected to → by 2050	Overall Current Condition rated High that is projected to ↓ by 2050	Overall Current Condition rated Moderate that is projected to ↑ by 2050	Overall Current Condition rated Moderate that is projected to → by 2050	Overall Current Condition rated Moderate that is projected to ↓ by 2050	Overall Current Condition rated Low that is projected to ↑ by 2050	Overall Current Condition rated Low that is projected to → by 2050	Overall Current Condition rated Low that is projected to ↓ by 2050
Mixed Wood Plains	Extant	3				1	2				
	Unknown	2					2				
Central USA Plains	Extant	6		2			2	2			
	Unknown	1		1							
Southeastern USA Plains	Extant	6		1			2	3			
	Unknown	1					1				
Ozark Ouachita-Appalachian Forest	Extant	1						1			
	Unknown	0									
Mississippi Alluvial and Southeast USA Coastal Plains	Extant	1						1			
	Unknown	1					1				
West-Central Semi-Arid Prairies	Extant	11				3	1	7			
	Unknown	2					1	1			
South Central Semi-Arid Prairies	Extant	4								4	
	Unknown	1						1			

5.4. Resiliency, Representation, and Redundancy under Future Conditions

In scenarios A and B, the majority of populations are projected to decrease in condition by 2050 (50% and 63% of populations in each scenario, respectively; Tables 5.2. and 5.3.). In scenario D, the majority of populations are projected to maintain current conditions into 2050 (50%); however, 40% of populations are projected to decrease in condition by 2050. The reduced resiliency for these populations in scenarios A, B, and D is due to the projected higher risk of hybridization and the projected reduction of quality and quantity of available habitat. The reduced resiliency means the populations would be more susceptible to negative impacts from stochastic events in these scenarios. Due to the wide distribution of the species, it is not likely in these scenarios that a range-wide environmental or stochastic event would occur that would affect all populations. It is difficult to predict the number of remaining populations within ecoregions because two of the condition metrics were qualitative, not quantitative. Therefore, we can project the change in overall condition, but not the extirpation of a population.

In Scenario C, more extant and unknown populations are projected to maintain the current condition into 2050 (47.5%), with 37.5% of populations projected to increase in condition by 2050 (Table 5.4.). Due to the SRES B2 incorporating environmental sustainability efforts, it projects a more positive land use change future scenario. This led to the trend within *S. hallii* population areas to have a decrease in agricultural land, which removes threats of altering the hydrology or the seed bank; in some populations, an increase in herbaceous wetland acres creates additional potential habitat. With the large majority of populations maintaining or increasing in condition across the wide distribution of the species, it is unlikely for a range-wide environmental or stochastic event to occur that would affect all populations. For the populations that increased in condition, a higher level of severity of stochastic event would be needed for environmental variation to impact an entire population.

The predicted ability of *S. hallii* to adapt into the future conditions focuses mainly on the genetic diversity within and among populations. Due to the qualitative nature of two condition metrics, we could not assess how many populations within each ecoregion may decline to the point of extirpation in the future. Scenarios A and B project an overall decrease in extant and unknown population conditions across all ecoregions, while Scenario D projected 40% of populations would decrease in condition. If populations were to become extirpated, the ecoregions with small numbers of current populations would be at a higher risk, and thereby at risk of losing adaptive capability. Overall representation is projected to be affected in Scenarios A and B. Scenarios A and B have an increased number of populations that are at risk of hybridization with *S. saximontana,* which directly impacts genetic diversity. Hybridization in these populations affects future annual reproductive output and competition for resources. *Schoenoplectiella hallii* already exhibits low gene flow within and between populations. Co-occurrence with *S. saximontana* may further reduce gene flow and genetic diversity, thereby affecting the species' ability to adapt to environmental changes. Scenario D is projected to reduce the rate of hybridization, allowing for a reduced loss of diversity due to hybridization. However, current studies show a low level of sexual reproduction, so a decrease in hybridization will increase the likelihood of gene flow between individuals of *S. hallii*, but the species may still not exhibit the rate of adaptation needed to respond to severe environmental changes.

As stated previously, due to the qualitative nature of two condition metrics, we could not assess how many populations within each ecoregion may decline to the point of extirpation in the future. Scenarios A and B project an overall decrease in extant and unknown populations' conditions across all ecoregions, with Scenario D projecting 40% of extant and unknown populations decreasing in condition. The reduction in condition across all ecoregions does not affect the potential, but infrequent, gene flow vectored between populations by herbivores or waterfowl. However, if the reduction in condition reaches extirpation of populations, the likelihood of gene flow between populations will decrease. As the predicted decline of population conditions is distributed across the occupied seven ecoregions, it is likely that the wide distribution of populations will minimize the impact of a single catastrophic event. If the level of reduced conditions causes extirpations, the risk is still likely to be distributed across the range. While ecoregions with low numbers of populations may be lost, *S. hallii* was still projected to have a wide distribution, and therefore is not anticipated to be impacted by a single catastrophic event.

5.5. Future Scenario Summary

We used four future scenarios to assess a range of plausible conditions extending only so long as the Service can reasonably determine the likelihood of future threats and *S. hallii* responses. We assessed future conditions using prevailing anthropogenic and natural factors to predict future species resiliency, representation, and redundancy under four scenarios. These anthropogenic and natural factors may be independent of each other, and actual future conditions and viability may result from a combination of scenarios. We were not able to project the number of remaining populations within ecoregions because two of the condition metrics were qualitative, not quantitative. In Scenarios A and B, most population conditions are projected to decline along with 40% in Scenario D; therefore, we expect resiliency to decline in many populations by 2050. Nevertheless, our future scenarios cannot project any population extirpations. The species is likely to retain its current low genetic diversity into the future, which is exacerbated in Scenarios A and B, and may have difficulty adapting to changing environmental conditions. However, the species representation will continue to be mitigated by the wide range of environmental diversity. We project that the species will retain its redundancy driven by the wide geographic distribution and variety of environmental settings. However, the species' low genetic variation and very limited sexual reproduction will limit its ability to adapt or shift its range in response to rapid or continuous long-term environmental changes.

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APPENDICES

- Glossary of Terms
- Current Condition Watershed Index Online (WSIO) Indicator averaged metrics for all populations.
- Overview Population Condition Table for Future Scenario A
- Overview Population Condition Table for Future Scenario B
- Overview Population Condition Table for Future Scenario C
- Overview Population Condition Table for Future Scenario D
- Map indicating the location of new Schoenoplectiella hallii sites in Illinois found during the 2019 survey season utilizing a habitat model by the Illinois Department of Natural Resources.

Appendix A: Glossary of Terms

Achene: a small, dry one-seeded fruit that does not open to release the seed

Allele: one of two or more alternative forms of a gene that arise by mutation and are found at the same place on a chromosome.

Amphicarpic: producing fruit of two kinds; in the case of *S. hallii,* it produces terminal inflorescences as well as basal flowers.

Annual: a plant that completes its life cycle within one year

Apomixis: Ability to produce seeds that are clones of the parent plant, rather than through sexual fertilization.

Cauline leaf: leaf along the stem

Germinate: The initiation of shoot and root growth from a seed.

Inflorescence: the complete flower head of a plant; in the case of sedges, clusters of spikelets.

Involucral bract: conspicuous terete leaf-like structure appearing to be a straight continuation of the stem

Multilocus genotype: a unique combination of alleles across two or more loci

Perennial: a plant that lives more than two years

Rhizomes: a continuously growing horizontal underground stem, which puts out lateral shoots and adventitious roots at intervals.

Seed bank: collection of seeds within the soil at population location

Spikelet: the basic unit of a grass or sedge flower, has one or more florets.

Stolon: a creeping horizontal, above-ground plant stem or runner that takes root at points along its length to form new plants.

Stomata: the plural form of stoma; minute pores in the epidermis of the leaf or stem of a plant that allows movement of gases.

Appendix B. Summary of Current Condition Watershed Index Online (WSIO) Indicator averaged metrics for all populations. A strikethrough indicates the population is extirpated.

Ecoregion	State	Population	Status	PHWA Watershed Vulnerability Index, ER (2016)	% Impervious-ness, Mean in WS (2011)	% Agriculture in WS (2011)	% Urban in WS (2011)	PHWA Watershed Health Index, ER (2016)	% Wetlands Remaining in WS	% Emergent Herbaceous Wetlands in WS (2011)	% Agriculture Change in WS (2001-11)	% Wetlands Change in WS (2001-11)	HUC 12 Weighted Averaged Condition
Mixed Woods Plains	~~Massachusetts~~	~~Middlesex Co., MA~~	~~X~~	~~High~~	~~Low~~	~~High~~	~~Low~~	~~Low~~	~~Moderate~~	~~Moderate~~	~~High~~	~~Low~~	~~Moderate~~
		~~Essex Co., MA~~	~~X~~	~~High~~	~~Moderate~~	~~High~~	~~High~~	~~Moderate~~	~~Moderate~~	~~Moderate~~	~~High~~	~~Low~~	~~Moderate~~
	Michigan	Pine Island, Muskegon Co., MI	U	High	High	Moderate	High	High	High	Moderate	High	Low	High
		Carr Lake, Muskegon Co., MI	U	Moderate	High	Moderate	Moderate	Moderate	High	Moderate	High	Low	Moderate
		Allegan Co., MI	E	High	High	Low	High	Moderate	High	Low	High	Low	Moderate
	Indiana	Dune Lake Playground, Porter Co., IN	E	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	High	Low	Moderate
		Coulter Sand Prairie, Porter Co., IN	E	Low	Moderate	Moderate	Low	Moderate	Moderate	Low	High	Low	Moderate
Central USA Plains	Illinois	Kankakee Co., IL	U	High	High	Low	High	High	Moderate	Low	High	Moderate	Moderate
		Chandlerville, IL	E	High	High	Low	High	Moderate	Moderate	Low	High	Moderate	Moderate
		Havana, IL	E	High	High	Low	High	Moderate	Moderate	Low	High	Moderate	Moderate
		Topeka, IL	E	High	High	Low	High	Moderate	Moderate	Low	High	Moderate	Moderate
		Mason City, Mason Co., IL	E	High	High	Low	High	Moderate	Low	Low	High	Moderate	Moderate
	Ohio	Pickaway Co., OH	E	Moderate	High	Low	High	Moderate	Moderate	Low	High	Low	Moderate
	Wisconsin	Dane Co., WI	E	High	High	Low	High	Moderate	High	Moderate	High	Low	Moderate
Southeastern USA Plains	~~Georgia~~	~~Doherty Co., GA~~	~~X~~	~~Moderate~~	~~High~~	~~Low~~	~~High~~	~~Moderate~~	~~High~~	~~Moderate~~	~~Moderate~~	~~Moderate~~	~~Moderate~~
	Indiana	Plainville, Daviess Co., IN	E	High	High	Low	High	Moderate	Low	Low	High	Low	Moderate
	Illinois	Winchester, IL	E	High	High	Low	High	Moderate	Moderate	Low	High	Moderate	Moderate
		Beardstown, IL	E	High	High	Low	High	Moderate	Moderate	Low	High	Moderate	Moderate
	Kentucky	Morgan Pond SOMC, Christian Co., KY	E	High	High	Low	High	Moderate	Moderate	Low	High	Moderate	Moderate
		Schott Pond, Hopkinsville, KY	E	High	High	Low	High	Moderate	Low	Low	Moderate	Moderate	Moderate
		Logan Co., KY	E	High	High	Low	High	Moderate	Low	Low	Moderate	Moderate	Moderate
	Iowa	Fruitland, IA	U	High	High	Low	High	Moderate	Moderate	Moderate	High	Moderate	Moderate
	~~Missouri~~	~~St. Louis Co., MO~~	~~X~~	~~Moderate~~	~~Low~~	~~High~~	~~Low~~	~~Low~~	~~Moderate~~	~~Low~~	~~High~~	~~Low~~	~~Moderate~~
Mississippi Alluvial and Southeast USA Coastal Plains	Illinois	Miller City, IL	E	High	High	Low	High	Moderate	Moderate	Low	Moderate	Low	Moderate
	Missouri	Scott Co., MO	U	High	High	Low	High	Low	Low	Low	High	Low	Moderate
Ozark/Ouachita-Appalachian Forests	Missouri	Howell Co., MO	E	High	High	Low	High	Moderate	Low	Low	High	Low	Moderate
West-Central Semiarid Prairies	Nebraska	Newport, NE	E	Moderate	High	High	High	High	High	Moderate	Moderate	Moderate	Moderate
		Moon Lake Ave, NE	E	High	High	High	High	High	High	Moderate	Moderate	Low	High
		Brown Co. and Rock Co., NE	E	High	High	High	High	High	High	Moderate	Moderate	Moderate	High
		Calamus River, Loup Co., NE	E	High	High	High	High	High	High	Moderate	Moderate	Moderate	High
		Rock Co. and Loup Co., NE	E	High	High	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate
		Garfield Co. and Loup Co., NE	E	High	High	High	High	High	Moderate	Low	High	Low	Moderate
		North of Amelia, Holt Co., NE	E	Moderate	High	Moderate	High	High	High	Moderate	High	Low	Moderate
		Holt Co. and Garfield Co., NE	E	Moderate	High	Moderate	High	High	High	Moderate	High	Low	Moderate
		Chambers, Holt Co., NE	U	Moderate	High	Moderate	High	Moderate	High	Moderate	Moderate	Low	Moderate
		S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate	High	Low	High	Moderate	High	Moderate	High	Low	Moderate
		Foxley Cattle, Wheeler Co., NE	E	Moderate	High	Moderate	High	High	High	Moderate	Moderate	Low	Moderate
		Bartlett, Wheeler Co., NE	E	High	High	Moderate	High	Moderate	High	Moderate	Moderate	Low	Moderate
		Antelope Co., NE	E	High	High	Moderate	High	Moderate	High	Moderate	Moderate	Low	Moderate
South Central Semiarid Prairies	Kansas	Hutchinson, KS	U	Moderate	High	Low	High	Moderate	Moderate	Low	High	Low	Moderate
		Burrton, KS	E	Moderate	High	Low	High	Moderate	Moderate	Low	High	Low	Moderate
		Ruella, Harper Co., KS	E	High	High	Low	High	High	Moderate	Low	High	Low	Moderate
	Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	High	High	Moderate	High	High	Moderate	Low	High	Low	Moderate
	Texas	Alvord, Wise Co., TX	E	Moderate	High	Moderate	High	Moderate	Low	Low	High	Moderate	Moderate

Appendix C. Overview Population Condition Table for Future Scenario A. A strikethrough indicates the population is extirpated.

Ecoregion	State	Population	Status	Absence of S. saximontana Current Condition	Dispersal of S. saximontana			Average Habitat Condition from HUC 12 Indicators Current Condition	Land Use Changes			NRCS Depth to Water Table Current Condition	Soil Storage			Overall Current Condition	Overall Current Condition
					2030	2040	2050		2030	2040	2050		2030	2040	2050		2050
Mixed Wood Plains	~~Massachusetts~~	~~Middlesex Co., MA~~	~~X~~	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
		~~Essex Co., MA~~	~~X~~	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
	Michigan	Pine Island, Muskegon Co., MI	U	High	High	High	High	High	→	→	→	Low	→	→	→	Moderate	→
		Carr Lake, Muskegon Co., MI	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
		Allegan Co., MI	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Indiana	Dune Lake Playground, Porter Co., IN	E	High	High	High	High	Moderate	→	→	↓	Low	→	→	→	Moderate	↓
		Coulter Sand Prairie, Porter Co., IN	E	High	High	High	High	Moderate	→	↑	↑	Low	→	→	→	Moderate	↑
Central USA Plains	Illinois	Kankakee Co., IL	U	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Chandlerville, IL	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		Havana, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Topeka, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Mason City, Mason Co., IL	E	High	High	High	High	Moderate	↓	→	→	Moderate	→	→	→	Moderate	↓
	Ohio	Pickaway Co., OH	E	Low	Low	Low	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Wisconsin	Dane Co., WI	E	High	High	High	High	Moderate	↓	↓	↓	Low	→	→	→	Moderate	↓
Southeastern USA Plains	~~Georgia~~	~~Doherty Co., GA~~	~~X~~	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	↓	↓	↓	~~Moderate~~	→	→	→	~~Moderate~~	↓
	Indiana	Plainville, Daviess Co., IN	E	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	Illinois	Winchester, IL	E	High	High	High	Low	Moderate	→	↓	→	Moderate	→	→	→	Moderate	↓
		Beardstown, IL	E	High	High	High	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	↓
	Kentucky	Morgan Pond SOMC, Christian Co., KY	E	High	High	High	High	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
		Schott Pond, Hopkinsville, KY	E	High	High	High	Low	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
		Logan Co., KY	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
	Iowa	Fruitland, IA	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	~~Missouri~~	~~St. Louis Co., MO~~	~~X~~	~~Low~~	~~Low~~	~~Low~~	~~Low~~	~~Moderate~~	→	→	→	~~Moderate~~	→	→	→	~~Moderate~~	→
Ozark Ouachita-Appalachian Forest	Missouri	Howell Co., MO	E	High	High	High	High	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
Mississippi Alluvial and Southeast USA Coastal Plains	Illinois	Miller City, IL	U	High	High	High	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Missouri	Scott Co., MO	E	High	High	High	Low	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
West-Central Semi-Arid Prairies	Nebraska	Newport, NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
		Moon Lake Ave, NE	E	Moderate	Moderate	Moderate	Low	High	→	→	→	Low	→	→	→	Moderate	↓
		Brown Co. and Rock Co., NE	E	Moderate	Moderate	Moderate	Low	High	↓	→	↓	Low	→	→	→	Moderate	↓
		Calamus River, Loup Co., NE	E	Moderate	Low	Low	Low	High	→	→	↓	Low	→	→	→	Moderate	↓
		Rock Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		Garfield Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		North of Amelia, Holt Co., NE	E	Moderate	Low	Low	Low	Moderate	↓	↓	↓	High	→	→	→	Moderate	↓
		Holt Co. and Garfield Co., NE	E	Low	Low	Low	Low	Moderate	↓	→	↓	Moderate	→	→	→	Moderate	↓
		Chambers, Holt Co., NE	U	Moderate	Moderate	Low	Low	Moderate	↓	↓	↓	Low	→	→	→	Moderate	↓
		S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate	Moderate	Low	Low	Moderate	↓	↓	↓	High	→	→	→	Moderate	↓
		Foxley Cattle, Wheeler Co., NE	E	Moderate	Moderate	Low	Low	Moderate	→	↑	→	High	→	→	→	Moderate	→
		Bartlett, Wheeler Co., NE	E	Moderate	Moderate	Low	Low	Moderate	↓	→	↓	Moderate	→	→	→	Moderate	↓
		Antelope Co., NE	E	Moderate	Moderate	Moderate	Low	Moderate	↓	→	↓	Moderate	→	→	→	Moderate	↓
South Central Semi-Arid Prairies	Kansas	Hutchinson, KS	U	Moderate	Low	Low	Low	Moderate	→	→	↓	Low	→	→	→	Moderate	↓
		Burrton, KS	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→
		Ruella, Harper Co., KS	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→
	Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	↓	→	Low	→
	Texas	Alvord, Wise Co., TX	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→

Appendix D. Overview Population Condition Table for Future Scenario B. A strikethrough indicates the population is extirpated.

Ecoregion	State	Population	Status	Absence of S. saximontana Current Condition	Dispersal of S. saximontana			Average Habitat Condition from HUC 12 Indicators Current Condition	Land Use Changes			NRCS Depth to Water Table Current Condition	Soil Storage			Overall Current Condition	Overall Current Condition
					2030	2040	2050		2030	2040	2050		2030	2040	2050		2050
Mixed Wood Plains	~~Massachusetts~~	~~Middlesex Co., MA~~	~~X~~	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
		~~Essex Co., MA~~	~~X~~	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
	Michigan	Pine Island, Muskegon Co., MI	U	High	High	High	High	High	→	↓	↓	Low	→	→	→	Moderate	↓
		Carr Lake, Muskegon Co., MI	U	High	High	High	High	Moderate	→	→	↓	Low	→	→	→	Moderate	↓
		Allegan Co., MI	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Indiana	Dune Lake Playground, Porter Co., IN	E	High	High	High	High	Moderate	→	→	↑	Low	→	→	→	Moderate	↑
		Coulter Sand Prairie, Porter Co., IN	E	High	High	High	High	Moderate	↑	↑	↑	Low	→	→	→	Moderate	↑
Central USA Plains	Illinois	Kankakee Co., IL	U	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Chandlerville, IL	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		Havana, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Topeka, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Mason City, Mason Co., IL	E	High	High	High	High	Moderate	↓	↓	→	Moderate	→	→	→	Moderate	↓
	Ohio	Pickaway Co., OH	E	Low	Low	Low	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Wisconsin	Dane Co., WI	E	High	High	High	High	Moderate	↓	↓	↓	Low	→	→	→	Moderate	↓
Southeastern USA Plains	~~Georgia~~	~~Doherty Co., GA~~	~~X~~	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	↓	↓	↓	~~Moderate~~	→	→	→	~~Moderate~~	↓
	Indiana	Plainville, Daviess Co., IN	E	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	Illinois	Winchester, IL	E	High	High	High	High	Moderate	↓	↓	→	Moderate	→	→	→	Moderate	↓
		Beardstown, IL	E	High	High	High	High	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
	Kentucky	Morgan Pond SOMC, Christian Co., KY	E	High	High	High	High	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
		Schott Pond, Hopkinsville, KY	E	High	High	High	High	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
		Logan Co., KY	E	High	High	High	High	Moderate	→	→	↓	High	→	→	→	High	↓
	Iowa	Fruitland, IA	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	~~Missouri~~	~~St. Louis Co., MO~~	~~X~~	~~Low~~	~~Low~~	~~Low~~	~~Low~~	~~Moderate~~	→	→	→	~~Moderate~~	→	→	→	~~Moderate~~	→
Ozark Ouachita-Appalachian Forest	Missouri	Howell Co., MO	E	High	High	High	High	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
Mississippi Alluvial and Southeast USA Coastal Plains	Illinois	Miller City, IL	U	High	High	High	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Missouri	Scott Co., MO	E	High	High	High	Low	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
West-Central Semi-Arid Prairies	Nebraska	Newport, NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
		Moon Lake Ave, NE	E	Moderate	Moderate	Moderate	Moderate	High	→	→	→	Low	→	→	→	Moderate	→
		Brown Co. and Rock Co., NE	E	Moderate	Moderate	Moderate	Low	High	↓	↓	↓	Low	→	→	→	Moderate	↓
		Calamus River, Loup Co., NE	E	Moderate	Moderate	Low	Low	High	↓	→	↓	Low	→	→	→	Moderate	↓
		Rock Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
		Garfield Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
		North of Amelia, Holt Co., NE	E	Moderate	Low	Low	Low	Moderate	↓	↓	↓	High	→	→	→	Moderate	↓
		Holt Co. and Garfield Co., NE	E	Low	Low	Low	Low	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
		Chambers, Holt Co., NE	U	Moderate	Moderate	Moderate	Low	Moderate	↓	↓	↓	Low	→	→	→	Moderate	↓
		S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate	Moderate	Low	Low	Moderate	↓	↓	↓	High	→	→	→	Moderate	↓
		Foxley Cattle, Wheeler Co., NE	E	Moderate	Moderate	Low	Low	Moderate	↓	↓	↓	High	→	→	→	Moderate	↓
		Bartlett, Wheeler Co., NE	E	Moderate	Moderate	Moderate	Low	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
		Antelope Co., NE	E	Moderate	Moderate	Moderate	Low	Moderate	↓	↓	↓	Moderate	→	→	→	Moderate	↓
South Central Semi-Arid Prairies	Kansas	Hutchinson, KS	U	Moderate	Low	Low	Low	Moderate	→	↓	↓	Low	→	→	→	Moderate	↓
		Burrton, KS	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→
		Ruella, Harper Co., KS	E	Low	Low	Low	Low	Moderate	→	→	↓	Low	→	→	→	Low	↓
	Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	↓	→	Low	→
	Texas	Alvord, Wise Co., TX	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→

Appendix E. Overview Population Condition Table for Future Scenario C. A strikethrough indicates the population is extirpated.

Ecoregion	State	Population	Status	Absence of S. saximontana Current Condition	Dispersal of S. saximontana			Average Habitat Condition from HUC 12 Indicators Current Condition	Land Use Changes			NRCS Depth to Water Table Current Condition	Soil Storage			Overall Current Condition	Overall Current Condition
					2030	2040	2050		2030	2040	2050		2030	2040	2050		2050
Mixed Wood Plains	~~Massachusetts~~	~~Middlesex Co., MA~~	X	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
	~~Massachusetts~~	~~Essex Co., MA~~	X	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
	Michigan	Pine Island, Muskegon Co., MI	U	High	High	High	High	High	→	→	→	Low	→	→	→	Moderate	→
		Carr Lake, Muskegon Co., MI	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
		Allegan Co., MI	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Indiana	Dune Lake Playground, Porter Co., IN	E	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
		Coulter Sand Prairie, Porter Co., IN	E	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
Central USA Plains	Illinois	Kankakee Co., IL	U	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Chandlerville, IL	E	High	High	High	High	Moderate	→	→	↑	Moderate	→	→	→	Moderate	↑
		Havana, IL	E	High	High	High	High	Moderate	→	↑	↑	High	→	→	→	High	↑
		Topeka, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Mason City, Mason Co., IL	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Ohio	Pickaway Co., OH	E	Low	Low	Low	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Wisconsin	Dane Co., WI	E	High	High	High	High	Moderate	↓	↓	↓	Low	→	→	→	Moderate	↓
Southeastern USA Plains	~~Georgia~~	~~Doherty Co., GA~~	X	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	↓	~~Moderate~~	→	→	→	~~Moderate~~	↓
	Indiana	Plainville, Daviess Co., IN	E	High	High	High	High	Moderate	→	→	↓	Low	→	→	→	Moderate	↓
	Illinois	Winchester, IL	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		Beardstown, IL	E	High	High	High	High	Moderate	→	↑	↑	Moderate	→	→	→	Moderate	↑
	Kentucky	Morgan Pond SOMC, Christian Co., KY	E	High	High	High	High	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
		Schott Pond, Hopkinsville, KY	E	High	High	High	High	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
		Logan Co., KY	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
	Iowa	Fruitland, IA	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	~~Missouri~~	~~St. Louis Co., MO~~	X	~~Low~~	~~Low~~	~~Low~~	~~Low~~	~~Moderate~~	→	→	→	~~Moderate~~	→	→	→	~~Moderate~~	→
Ozark Ouachita-Appalachian Forest	Missouri	Howell Co., MO	E	High	High	High	High	Moderate	↓	→	→	Moderate	→	→	→	Moderate	↓
Mississippi Alluvial and Southeast USA Coastal Plains	Illinois	Miller City, IL	U	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Missouri	Scott Co., MO	E	High	High	High	High	Moderate	→	↑	→	Moderate	→	→	→	Moderate	↑
West-Central Semi-Arid Prairies	Nebraska	Newport, NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	↑	Moderate	→	→	→	Moderate	↑
		Moon Lake Ave, NE	E	Moderate	Moderate	Moderate	Moderate	High	↑	↑	→	Low	→	→	→	Moderate	↑
		Brown Co. and Rock Co., NE	E	Moderate	Moderate	Moderate	Moderate	High	→	↑	↑	Low	→	→	→	Moderate	↑
		Calamus River, Loup Co., NE	E	Moderate	Moderate	Moderate	Moderate	High	→	→	→	Low	→	→	→	Moderate	→
		Rock Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	↑	↑	↑	Moderate	→	→	→	Moderate	↑
		Garfield Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	↑	→	→	Moderate	→	→	→	Moderate	↑
		North of Amelia, Holt Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	↓	→	High	→	→	→	Moderate	↓
		Holt Co. and Garfield Co., NE	E	Low	Low	Low	Low	Moderate	→	↑	→	Moderate	→	→	→	Moderate	↑
		Chambers, Holt Co., NE	U	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	→	Low	→	→	→	Moderate	→
		S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate	Moderate	Moderate	Moderate	Moderate	→	↑	↑	High	→	→	→	Moderate	↑
		Foxley Cattle, Wheeler Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	↑	↑	↑	High	→	→	→	Moderate	↑
		Bartlett, Wheeler Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	↑	↑	Moderate	→	→	→	Moderate	↑
		Antelope Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
South Central Semi-Arid Prairies	Kansas	Hutchinson, KS	U	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	→	Low	→	→	→	Moderate	→
		Burrton, KS	E	Low	Low	Low	Low	Moderate	→	↑	→	Low	→	→	→	Low	↑
		Ruella, Harper Co., KS	E	Low	Low	Low	Low	Moderate	→	↑	→	Low	→	→	→	Low	↑
	Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	↓	→	Low	→
	Texas	Alvord, Wise Co., TX	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→

Appendix F. Overview Population Condition Table for Future Scenario D. A strikethrough indicates the population is extirpated.

Ecoregion	State	Population	Status	Absence of S. saximontana Current Condition	Dispersal of S. saximontana			Average Habitat Condition from HUC 12 Indicators Current Condition	Land Use Changes			NRCS Depth to Water Table Current Condition	Soil Storage			Overall Current Condition Current Condition	Overall Current Condition
					2030	2040	2050		2030	2040	2050		2030	2040	2050		2050
Mixed Wood Plains	~~Massachusetts~~	~~Middlesex Co., MA~~	X	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
		~~Essex Co., MA~~	X	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	→	→	~~Low~~	→	→	→	~~Moderate~~	→
	Michigan	Pine Island, Muskegon Co., MI	U	High	High	High	High	High	→	→	→	Low	→	→	→	Moderate	→
		Carr Lake, Muskegon Co., MI	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
		Allegan Co., MI	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Indiana	Dune Lake Playground, Porter Co., IN	E	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
		Coulter Sand Prairie, Porter Co., IN	E	High	High	High	High	Moderate	↑	↑	↑	Low	→	→	→	Moderate	↑
Central USA Plains	Illinois	Kankakee Co., IL	U	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Chandlerville, IL	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		Havana, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Topeka, IL	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
		Mason City, Mason Co., IL	E	High	High	High	High	Moderate	→	↓	→	Moderate	→	→	→	Moderate	↓
	Ohio	Pickaway Co., OH	E	Low	Low	Low	Low	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Wisconsin	Dane Co., WI	E	High	High	High	High	Moderate	↓	↓	↓	Low	→	→	→	Moderate	↓
Southeastern USA Plains	~~Georgia~~	~~Doherty Co., GA~~	X	~~High~~	~~High~~	~~High~~	~~High~~	~~Moderate~~	→	↓	↓	~~Moderate~~	→	→	→	~~Moderate~~	↓
	Indiana	Plainville, Daviess Co., IN	E	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	Illinois	Winchester, IL	E	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
		Beardstown, IL	E	High	High	High	High	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
	Kentucky	Morgan Pond SOMC, Christian Co., KY	E	High	High	High	High	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
		Schott Pond, Hopkinsville, KY	E	High	High	High	High	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
		Logan Co., KY	E	High	High	High	High	Moderate	→	→	→	High	→	→	→	High	→
	Iowa	Fruitland, IA	U	High	High	High	High	Moderate	→	→	→	Low	→	→	→	Moderate	→
	~~Missouri~~	~~St. Louis Co., MO~~	X	~~Low~~	~~Low~~	~~Low~~	~~Low~~	~~Moderate~~	→	→	→	~~Moderate~~	→	→	→	~~Moderate~~	→
Ozark Ouachita-Appalachian Forest	Missouri	Howell Co., MO	E	High	High	High	High	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
Mississippi Alluvial and Southeast USA Coastal Plains	Illinois	Miller City, IL	U	High	High	High	High	Moderate	→	→	→	Moderate	→	→	→	Moderate	→
	Missouri	Scott Co., MO	E	High	High	High	High	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
West-Central Semi-Arid Prairies	Nebraska	Newport, NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	↓	Moderate	→	→	→	Moderate	↓
		Moon Lake Ave, NE	E	Moderate	Moderate	Moderate	Moderate	High	→	→	→	Low	→	→	→	Moderate	→
		Brown Co. and Rock Co., NE	E	Moderate	Moderate	Moderate	Moderate	High	↓	↓	↓	Low	→	→	→	Moderate	↓
		Calamus River, Loup Co., NE	E	Moderate	Moderate	Moderate	Moderate	High	↑	→	→	Low	→	→	→	Moderate	↑
		Rock Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	→	↑	→	Moderate	→	→	→	Moderate	↑
		Garfield Co. and Loup Co., NE	E	Low	Low	Low	Low	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
		North of Amelia, Holt Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	↓	↓	High	→	→	→	Moderate	↓
		Holt Co. and Garfield Co., NE	E	Low	Low	Low	Low	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
		Chambers, Holt Co., NE	U	Moderate	Moderate	Moderate	Moderate	Moderate	→	↓	↓	Low	→	→	→	Moderate	↓
		S. of O'Neil Road Ditch, Holt Co., NE	U	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	→	High	→	→	→	Moderate	→
		Foxley Cattle, Wheeler Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	↑	→	→	High	→	→	→	Moderate	↑
		Bartlett, Wheeler Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	↓	→	Moderate	→	→	→	Moderate	↓
		Antelope Co., NE	E	Moderate	Moderate	Moderate	Moderate	Moderate	→	↓	↓	Moderate	→	→	→	Moderate	↓
South Central Semi-Arid Prairies	Kansas	Hutchinson, KS	U	Moderate	Moderate	Moderate	Moderate	Moderate	→	→	↓	Low	→	→	→	Moderate	↓
		Burrton, KS	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→
		Ruella, Harper Co., KS	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→
	Oklahoma	Wichita Mountains WR, Comanche Co., OK	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	↓	→	Low	→
	Texas	Alvord, Wise Co., TX	E	Low	Low	Low	Low	Moderate	→	→	→	Low	→	→	→	Low	→

Appendix G. Map indicating the location of new Schoenoplectiella hallii sites in Illinois found during the 2019 survey season utilizing a habitat model by the Illinois Department of Natural Resources.