

STATUS ASSESSMENT OF *ELEOCHARIS WOLFII* (CYPERACEAE) IN THE UNITED STATES

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ABSTRACT

Eleocharis wolfii (Wolf's spike-rush) is listed by NatureServe as G3G4 and as S1 (critically imperiled), S2 (imperiled), SNR/SU (not ranked or currently under review), or SH (historical) in most states where the species has been documented. Recent field studies in Arkansas, Illinois, Kansas, Louisiana, Missouri, and Nebraska suggest that the species is not as rare as previously believed but simply overlooked. Pre-1978, the species was known from 59 sites in 43 counties/parishes in 17 states and possibly two others. Post-1978, Wolf's spike-rush has been documented at 222 sites from 104 counties/parishes scattered across 16 states. Since 2000, 135 new sites distributed among 64 counties/parishes in 15 states have been discovered. *Eleocharis wolfii* is easily recognized in the field by the combination of tiny rhizomes; purple-red culm bases; blue-green, flattened and spirally twisted culms; and mostly white achenes < 1.0 mm long with 9–19 longitudinal ridges and 30–60 transverse trabeculae. The species is known from a wide variety of habitats including wet depressions of bottomland and mesic upland prairies, ephemeral pools in open grasslands, limestone and saline barrens, and ephemeral pools or shallow depressions on sandstone, granite, or quartzite outcrops. *Eleocharis wolfii* may be found in nearly pure monoculture stands but is often found with a wide variety of plant associates depending on soil and natural community type. Significant threats to *Eleocharis wolfii* habitat persist over much of its range and include the cutting of many bottomland forests; habitat destruction due to residential and commercial development; the conversion of native prairie to agricultural crops, pasture or hayfields; and the loss of wetlands. There are insufficient regulatory mechanisms in place in most states to provide any protection for the species. The potential impact of projected climate change on *E. wolfii* is unknown. Planned increases in ethanol production in the Midwest may negatively affect the species. Additional surveys are needed in the Midwest, the Great Plains states, and states bordering or adjacent to the Great Lakes. The species would benefit from additional research including studies on life history and ecology; seed viability; population genetics; germination requirements; inter-specific competition; land use changes; and the potential impacts of invasive species. Management actions that may benefit Wolf's spike-rush include prescribed fire, haying or mowing to retard the encroachment of woody vegetation on prairie habitats, and low levels of soil disturbance to enhance germination and soil growth.

RESUMEN

Eleocharis wolfii está listada por el NatureServe como G3G4 y como S1 (críticamente amenazada), S2 (amenazada), SNR/SU (no catalogada pero actualmente en revisión), o SH (posiblemente eliminada) en la mayoría de los estados donde la especie ha sido documentada. Recientes estudios de campo en Arkansas, Illinois, Kansas, Louisiana, Missouri, y Nebraska sugieren que la especie no es tan rara como se creía previamente sino que simplemente había pasado inadvertida. Antes de 1978, la especie se conocía de 59 lugares en 43 condados/

¹The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

parroquias de 17 estados y posiblemente otros dos. Después de 1978, se ha documentado en 222 sitios de 104 condados/parroquias distribuidos por 16 estados. Desde 2000, se han descubierto 135 nuevas localidades distribuidas por 64 condados/parroquias en 15 estados. *Eleocharis wolfii* se reconoce fácilmente en el campo por la combinación de rizomas finos; bases de los culmos rojo-púrpura; culmos verde-azulados, aplastados y retorcidos espiralmente; y aquenios blancos < 1.0 mm de longitud con 9–19 costillas longitudinales y 30–60 trabéculas transversales. La especie se conoce de una amplia variedad de hábitats que incluyen praderas en depresiones húmedas de fondo de valle y mésicas de tierras altas, charcas temporales en praderas abiertas, baldíos calizos y salinos, y charcas temporales o depresiones someras en afloramientos de areniscas, granitos, o cuarcitas. *Eleocharis wolfii* puede encontrarse casi en cultivos puros pero a menudo se encuentra con una variedad de plantas asociadas dependiendo del tipo de suelo y tipo de comunidad natural. Existen amenazas importantes sobre el hábitat de *Eleocharis wolfii* en gran parte de su distribución que incluyen la tala de bosques; destrucción del hábitat por el desarrollo comercial y residencial; la conversión de praderas naturales en tierras de cultivo, pastos o prados; y la pérdida de humedales. Hay insuficientes mecanismos reguladores en la mayoría de los estados para proteger la especie. El impacto potencial del cambio climático proyectado sobre *E. wolfii* no se conoce. Los planes de incrementar la producción de etanol en el medio oeste pueden afectar negativamente a la especie. Se necesitan estudios adicionales en el Medio Oeste, estados de las grandes llanuras, y estados alrededor de los Grandes Lagos. La especie podría beneficiarse de investigaciones adicionales que incluyan estudios de su ciclo vital y ecología; viabilidad de las semillas; genética de poblaciones; requerimientos para la germinación; competencia interespecífica; cambios en el uso del territorio; y los impactos potenciales de especies invasoras. Las acciones de gestión que pueden beneficiar a *E. wolfii* incluyen la prohibición del fuego, siega o desbroce para retardar la invasión de la vegetación leñosa en los hábitats de pradera, y bajos niveles de alteración del suelo para favorecer la germinación y el desarrollo del suelo.

INTRODUCTION

Eleocharis R. Br. is a cosmopolitan genus of Cyperaceae that consists of approximately 200 species worldwide. Smith (2002) recognized 67 species of *Eleocharis* in North American north of Mexico. No recent comprehensive worldwide taxonomic treatment is available. González-Elizondo and Peterson (1997) recognized four subgenera in a worldwide supraspecific classification of *Eleocharis*: subgenus *Eleocharis*, subgenus *Limnochloa* (P. Beauv. ex T. Lestib.) Torr., subgenus *Scirpidium* (Nees) Kukkonen and subgenus *Zinserlingia* T.V. Egorova. Most North American treatments of *Eleocharis* rely heavily on the extensive studies by Svenson (1929, 1932, 1934, 1937, 1939, 1957) and they include difficult species complexes that need taxonomic revision (Smith 2002).

Eleocharis wolfii (A. Gray) A. Gray ex Britton in Patt. (Wolf's spike-rush) is native but scattered and local from North Dakota south to Texas and east to Georgia, Virginia (Godfrey & Wooten 1979; Kolstad 1986; Robertson & Phillippe 1992; Yatskievych 1999; Smith 2002) and New York where it is considered by some to be adventive (e.g., Svenson 1957). Galen Smith could not locate specimens to substantiate previous reports of the species from Alberta, Saskatchewan, and Colorado (Smith 2002). *Eleocharis wolfii* is a member of subgenus *Scirpidium*. Members of this subgenus are characterized by having 3-fid styles and diagnostic trigonous to nearly terete achenes with distinct tubercles and conspicuous cancellate cells or fine horizontal ridges (trabeculae) between prominent longitudinal ridges or achene angles (Smith 2002). Smith (2002) recognized seven species within subgenus *Scirpidium* north of Mexico including *E. wolfii*. Wolf's spike-rush is named for John Wolf who collected the type specimen in Fulton County, Illinois (Gray 1874; Mohlenbrock 1976; Phillippe 2005).

Botanical nomenclature listed herein follows Yatskievych (1999) or Yatskievych and Turner (1990), except for *Carex aureolensis*, *C. opaca*, *Crataegus brachyacantha*, *Dichanthelium dichotomum* ssp. *dichotomum*, *D. scoparium*, *Isolepis pseudosetacea*, *Juncus coriaceus*, *Ludwigia linearis*, *L. palustris*, *Quercus similis*, *Ranunculus laxicaulis*, *Rhynchospora globularis* var. *globularis*, *R. recognita* and *Steinchisma hians* which follow Arkansas Vascular Flora Committee (2006); *Eleocharis coloradoensis*, *E. elliptica*, *E. montevidensis* and *E. tenuis* which follow Smith (2002); *Hierochloë odorata*, *Polygonum careyi*, and *Rhamnus frangula* which follow Swink and Wilhelm (1994); *Bidens trichosperma*, *Boltonia diffusa*, *Euthamia gymnospermoides*, *E. leptcephala*, *Doellingeria umbellata*, *Helenium flexuosum*, *Iva annua*, and *Symphytotrichum lanceolatum* which follow Yatskievych (2006); and *Eriophorum polystachion* and *Triglochin maritima* which follow Kolstad (1986). Botanical nomenclature for the mosses *Climacium* and *Sphagnum* follows United States Department of Agriculture, National Resources Conservation Service (2009). Author citations and abbreviations follow Brummitt and Powell (1992).

Plant description (from Smith 2002)

Plants perennial, rhizomatous, may grow in small circular clumps (tussocks) or often coalescing to form large mats (Fig. 1a–d); light brown to white rhizomes 0.25–0.6 mm thick (Fig. 2a), internodes 1–4 cm, the stems in erect or decumbent tufts or clumps along the rhizome (Fig. 2a), scales 2 mm. **Culms** erect (sometimes decumbent when dry), sides variably smooth or with 1 to few acute ridges (often nearly smooth or with 1 ridge on 1 side and several ridges on the other), greatly compressed (Fig. 1e–f & Fig. 2b), usually inrolled when dry, rectangular in cross section, 8 to 50 cm \times 0.3–1.5 mm, 0.2–0.5 mm thick, firm, margins often sharply acute, margins and often 1 or more ridges minutely serrulate at 20–30 \times . **Leaves:** leaf sheaths persistent, dark red, brown, or straw-colored proximally (Fig. 2a), terminating at the acute apex as a thin, hyaline tooth that may be split and free from the culm (slightly inflated). **Spikelets** ovoid or lanceoid, 3–9 \times 1.5–2.5 mm, apex acute (Fig. 2b); 15–30 imbricate, ovate floral scales with acute apexes (Fig. 2b,d), scales dark red, orange-brown, stramineous, or colorless, and generally with broad hyaline margins and tip, the prominent midrib stramineous, brown, or greenish, ovate-lanceolate, (2.2–)2.7–3.2 \times 1.5 mm (Fig. 2d). The 2 lower basal scales usually larger. **Flowers:** perianth bristles absent; anthers 3, 1.1–1.75 mm, style trifid, wind pollinated. **Achenes** brown, gray, or nearly white, lustrous, compressed-trigonous, obovoid, mostly 2 times longer than wide, 0.7–0.9(–1.1) \times (–0.4)0.5 mm, with angles and 9–19 longitudinal ridges and 30–60 transverse trabeculae (Fig. 2c). **Tubercles** brownish, pyramidal, 0.1–0.15 \times 0.2–0.25 mm (Fig. 3a, 3b). **Fruiting** late spring-early summer (May–June). Although not mentioned in most references outside of McKenzie and Jacobs (2000), Robertson and Phillippe (1992), and Phillippe (2005), the culms of *E. wolfii* are usually bluish-green and conspicuously twisted in a diagnostic spiral (Fig. 1e–f). Based on personal experience of the authors, the bluish-green and spirally twisted culms of Wolf's spike-rush provides for immediate recognition in the field, especially when associated with other species of *Eleocharis* spp.

Eleocharis wolfii most closely resembles and is sometimes confused with *Eleocharis acicularis* (L.) Roem. & Schult., especially var. *porcata* S.G. Sm. Smith (2001a) described variety *porcata* based on material that was collected mostly from the Great Plains. Due to the need to revise the taxonomy of subgenus *Scirpidium* on a global scale, and the variability associated with *E. acicularis* sensu lato, Smith (2002) did not formally recognize var. *porcata* in his *Flora of North America* treatment. Smith (2001a) provided the specific epithet *porcata* due to the presence of 6–12 prominent ridges on the culms, but also noted that this variety has flattened stems, and is therefore similar to, and possibly confused with, *E. wolfii*. *Eleocharis wolfii* can be distinguished from *E. acicularis* var. *porcata* by the combination of twisted, blue-green culms (Fig. 1e–f) with fewer (1–3) sharp ridges and usually longer spikelet scales [(2.2–)2.7–3.2 mm] (Smith 2002). *Eleocharis acicularis* var. *porcata* has dark green culms with 6–12 blunt ridges and shorter spikelet scales [(1.5–)2–2.5 mm] (Smith 2001a, 2002). *Eleocharis wolfii* also usually has wider culms (0.3–1.5 mm) than *E. acicularis* var. *porcata* (0.2–0.5 mm). The generally narrower culms of *E. acicularis* give this species a wiry appearance (pers. obs.). Additionally, *E. acicularis* usually has shorter culms that form dense, low growing, often sterile mats that superficially resemble sterile clumps of *E. parvula* (Roem. & Schult.) Link ex Bluffet al. (Mohlenbrock 1976), *E. coloradoensis* (Britton) Gilly, or the small fern *Pilularia americana* A. Braun, species with which it sometimes associates (pers. obs.). Smith (2001a, 2002) reported that *E. acicularis* var. *porcata* has been misidentified as *E. wolfii* at some localities. Although confusion between the two taxa could occur where the two taxa are sympatric (Smith 2001a), the characters identified above should readily separate *E. wolfii* from *E. acicularis* var. *porcata*, especially for culms of *E. wolfii* that are > 0.8 mm wide. Finally, *E. wolfii* is typically not found in the same habitat as *E. acicularis*. *Eleocharis acicularis* is often found on the shores of ponds, lakes, vernal pools, sloughs, ditches and frequently on disturbed habitats (Godfrey & Wooten 1979; Yatskievych 1999; Smith 2002). As noted by Robertson and Phillippe (1992), Swink and Wilhelm (1994), Smith (2002), Phillippe (2005), and others, *E. wolfii* is usually associated with native, mostly undisturbed habitats. *Eleocharis wolfii* was cited as a weed in Asia and Pacific Islands by Holm et al. (1979) and Moody (1989), respectively. There are, however, no vouchers to verify the identity of these claims (Charles Bryson, USDA, pers. comm. 2009).

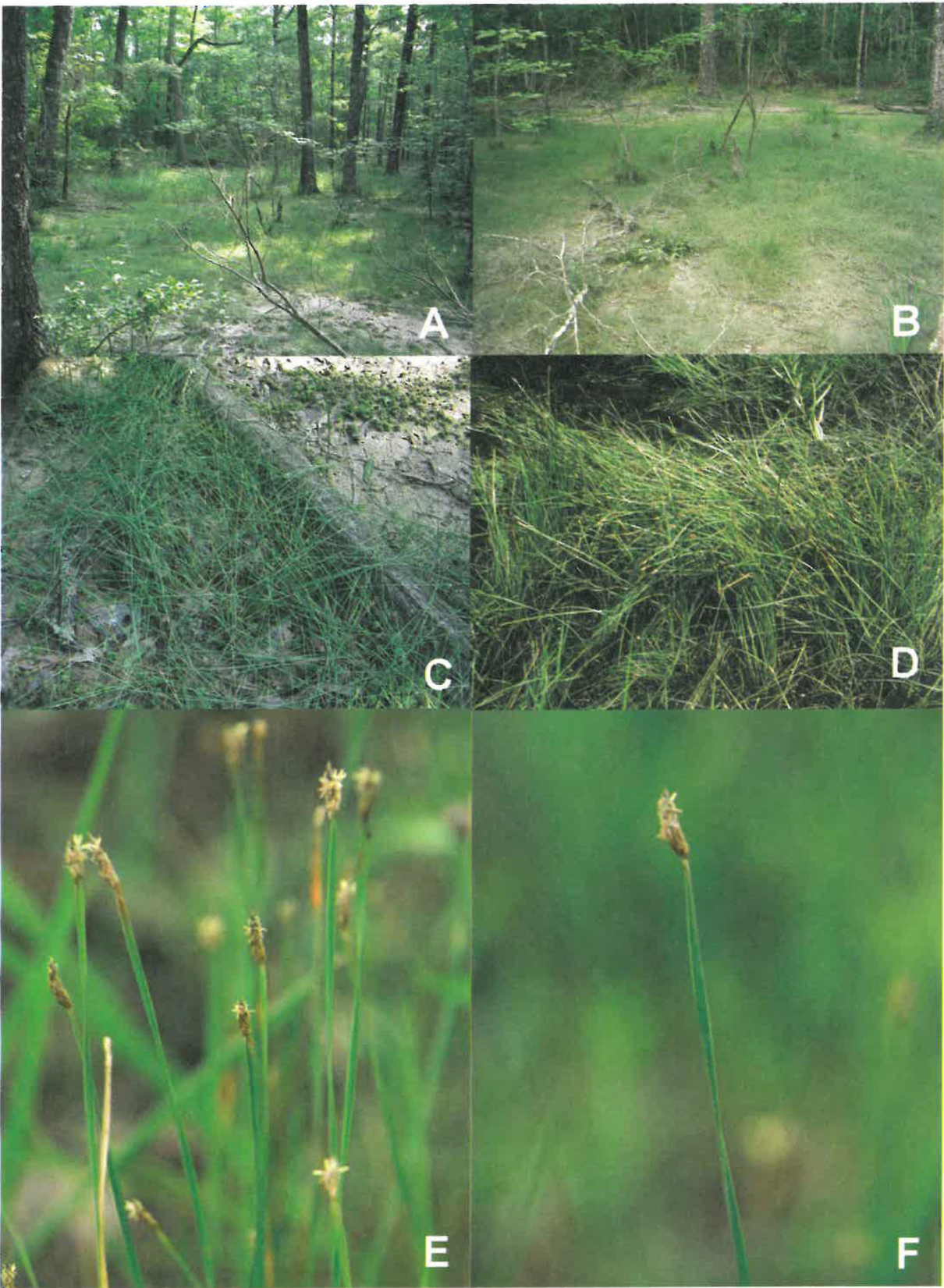


FIG. 1. a–d: Clumped habit of *Eleocharis wolfii* (a, b, & c photos by Theo Witsell, Saline County, AR; d photo by John Pelton, Prairie County, AR); e–f: flattened and spirally twisted culms of *Eleocharis wolfii* (photos by Christopher Reid, Morehouse Parish, LA).

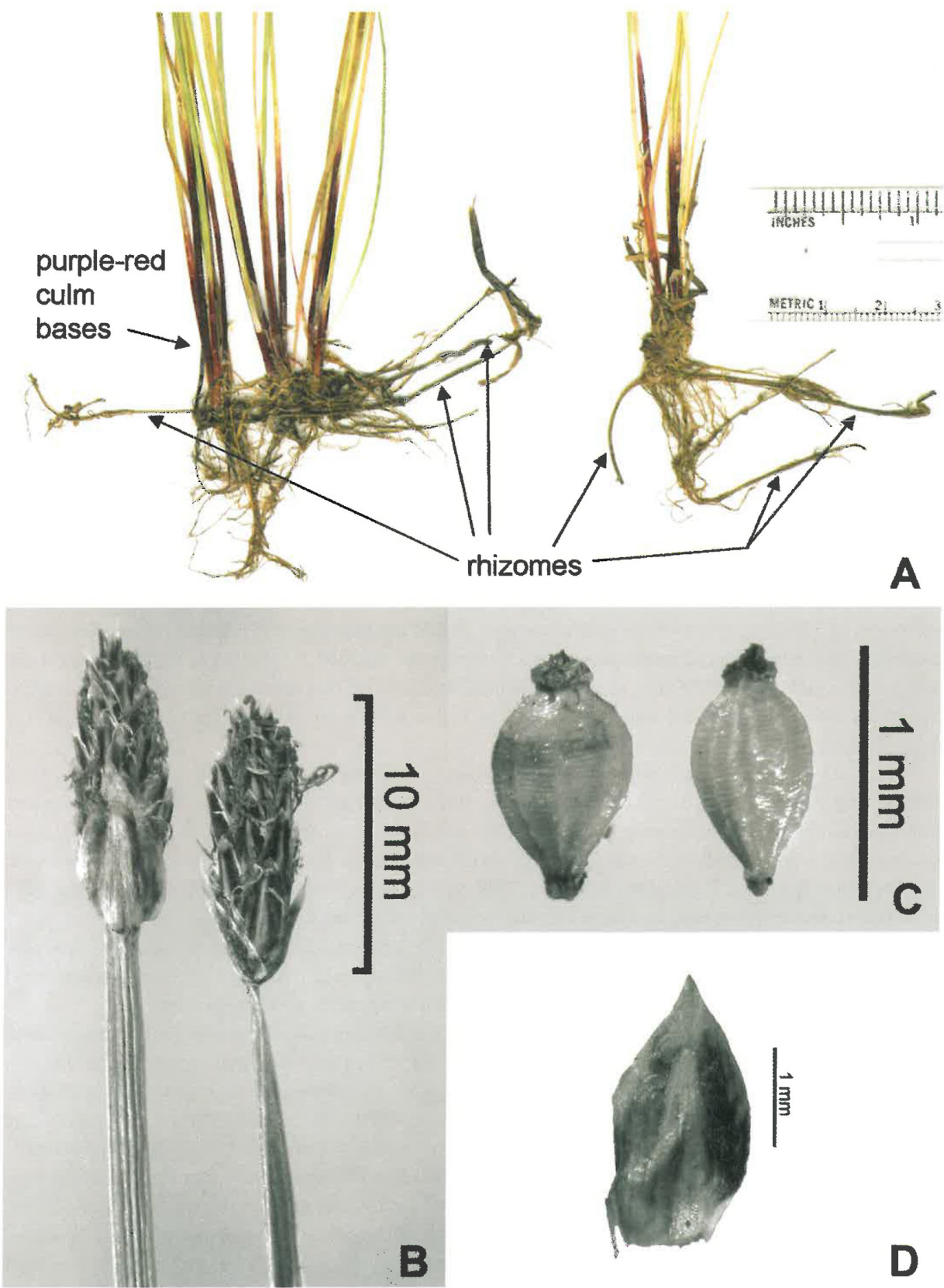


FIG. 2. a: Purple-red culm bases and very thin white to tan rhizomes of *Eleocharis wolfii* (photo by Theo Witsell, from Witsell #07-24 [ANHC]; Hempstead County, AR); b–d: closeup of spikelets, achenes, and floral scale of *Eleocharis wolfii* (photos by George Yatskievych)

Based on field observations of the authors, *E. wolfii* produces flower and fruit for about a 3–4 week period. After fruiting, spikes often become disarticulated from the stem and the stems turn brown or wither (McKenzie & Jacobs 2000). Populations of Wolf's spike-rush occurring in flatwoods under shaded conditions may contain mostly sterile culms that lie prostrate or decumbent on the forest floor (Fig. 1a–c) (Robertson & Phillippe 1992, McKenzie & Jacobs 2000, Phillippe 2005). Specimens of *E. wolfii* in such areas of reduced light intensity tend to be etiolated, and produce fewer fruiting individuals and fewer achenes per spikelet (Robertson & Phillippe 1992) and achenes are often immature or abortive (McKenzie & Jacobs 2000). Fertile and sterile culms of *E. wolfii* can be identified by the combination of very narrow rhizomes, purple-red culm bases, and conspicuously flattened and spirally twisted culms (Fig. 1e–f; 2a).

The habit of *E. wolfii* is variable depending on soil type and natural community type (see below). At many sites, the species is often hidden among taller vegetation where it can be difficult to detect, especially late in the season when spikelets are absent and the culms no longer exhibit their conspicuous blue-green color (Fig. 1e–f). At some sites, however, the species can form large colonies that are in nearly pure stands (Fig. 1a–d).

Previous evaluations by the United States Fish and Wildlife Service (USFWS)

Eleocharis wolfii was listed as a Category 2 (C2) candidate species in the USFWS's 1993 Plant Candidate Review for Listing as Endangered or Threatened Species (U.S. Fish & Wildlife Service 1993). Category 2 candidate species comprised taxa for which information indicated that a proposal to list as endangered or threatened was possibly appropriate, but for which conclusive data on biological vulnerability and threats were not currently available to support proposed rules.

On 19 Jul 1994, the Director of the USFWS issued a memorandum establishing new policy on the definition of candidate species (formerly Category 1 or C1) and how the USFWS would consider species for which they remained concerned (formerly C2). Under the new policy, candidates are defined as those species for which the USFWS has on file sufficient information on biological vulnerability and threats to support issuance of a proposed rule to list as endangered or threatened, but issuance of the proposed rule is precluded by other listing actions.

Former C2 species for which the USFWS lacks sufficient information to classify as candidate species will no longer be enumerated on an official list. Nonetheless, other agencies that have developed extensive databases on former C2 species [e.g., The Nature Conservancy (TNC) & state Natural Heritage programs] will continue to monitor these species and maintain communication with the USFWS to further assess the status of these species in their respective states. This information will be useful in determining when there is sufficient information to warrant their addition to the USFWS's list of candidate species.

Eleocharis wolfii is a species the USFWS continues to monitor and the lack of a comprehensive summary of the species' rangewide status and distribution, coupled with the large number of populations discovered in the central U.S. since 2000, is partly the impetus for initiating the current assessment.

In 2003, the authors began a status review of *E. wolfii* and solicited information from species experts and botanists throughout the range of the species. Information received from such requests is provided in this report. Although we could not find any published results of a rangewide survey of this species conducted in North America, S. Galen Smith compiled a distribution map of *E. wolfii* in his 2002 *Flora of North America* treatment (Smith 2002). Martin (1993) drafted a status report of *E. wolfii* for the USFWS but the document was never finalized (Karen Kreil, USFWS, pers. comm. 2006). Phillippe (2005) prepared a conservation assessment for the U.S. Forest Service on *E. wolfii* and provided information on the species' taxonomy, life history, habitat requirements, ecology, range-wide distribution and abundance, conservation status, population biology and viability and known or suspected threats. NatureServe (2009) provided the projected current distribution of *E. wolfii* for North America, listed global and state ranks outlining the species global rarity and conservation status in each state in the United States and included information on ecology and life history, habitat requirements, and threats to the species.

Recent field surveys conducted primarily in Arkansas, Kansas, Louisiana, Missouri, and Nebraska

between 2000 and 2008 and in Indiana between 1983 and 1995 have yielded numerous new localities for the species (Phillippe 2005). The new discoveries suggest that the species may be more common than previously believed and simply overlooked. To obtain a more complete depiction of the current range of the species, including recently collected data, we referenced recently published and unpublished survey results, published accounts (Godfrey & Wooten 1979; Kolstad 1986; Robertson & Phillippe 1992; McKenzie & Jacobs 2000; Smith 2002; Phillippe 2005; Diggs et al. 2006), as well as accounts provided by personnel of various state Natural Heritage programs and Academia.

Distribution

A summary of historical and extant documented occurrences of *E. wolfii* in the United States is provided in Table 1 and Figure 3. We define any records documented prior to 1978 to be historical and those recorded after that date to be extant. Historically (includes some counties that have extant populations), Wolf's spike-rush was known from approximately 59 sites scattered across 43 counties of 20 states (Table 1). Of these, 31 sites are known solely from historical collections (Table 2; Fig. 3). Within the last 30 years, *E. wolfii* has been collected at 222 sites in 104 counties of 16 states (Table 1) and over 61% of these sites (135) and 62% of the counties (64) have been documented since 2000 (Table 3). Although the species has disappeared from some historical locations due to habitat destruction, the large number of extant sites suggests that the species was historically widespread. The smaller number of historical records (Table 1, Table 2) is undoubtedly due, at least in part, to the lack of surveys for *E. wolfii* prior to 1978 or due to the lack of field experience of many botanists with the species. This conclusion is supported given: a) the large number of discoveries of this species since 2000 (Table 1, Table 3), b) plants are apparently long lived and individual populations may exist for hundreds of years (Phillippe 2005), c) the species occurs in a wide variety of habitats (see below), and d) there is an abundance of unsurveyed habitat, it is likely that additional populations will be found with further survey efforts.

Habitat requirements and soil types

Eleocharis wolfii has been documented from a wide variety of habitats including: "wet depressions of bottomland and mesic upland prairies;" "wet, open sites;" "wet river and lake margins;" "marshes and seeps;" "ephemeral pools in open grasslands;" "limestone barrens;" "oak flatwoods or woodlands on river terraces;" wet depressions, pond and river margins; wet sand prairies; wet meadows and other moist areas (Kolstad 1986; Godfrey & Wooten 1979; Hedge et al. 1994; Robertson & Phillippe 1992; Eilers & Roosa 1994; Swink & Wilhelm 1994; Yatskievych 1999; Smith. 2002; Diggs et al. 2006). *Eleocharis wolfii* has recently been discovered in wet areas on sandstone glades in Arkansas and Missouri and in wet saline barrens and in wet areas within shale glades in Arkansas (Witsell & McKenzie, pers. obs., 2000–2008). In Georgia, *E. wolfii* is known from ephemeral pools on granite outcrops [Tom Patrick, GA Natural Heritage Program (NHP), pers. comm. 2006] and from shallow depressions on sandstone, gneiss granite, and Sioux quartzite in Minnesota [Fred Harris, Minnesota Department of Natural Resources (DNR), pers. comm. 2007].

We could find limited information on soil types associated with the natural communities where *E. wolfii* is currently extant. Prairies in northern Illinois are open, wet and are on poorly to somewhat poorly drained soils that are nearly level or depressional on outwash plains. These soils are often ponded in spring and are dark gray and friable fine sand or sandy loam (Phillippe 2005). At prairie sites in southern Illinois, the soil type is categorized as deep gray silt loam or gray silt loam on tight clay (Robertson & Phillippe 1992). River terraces of southern Illinois flatwoods are on poorly drained silt loam and silty clay loam soils (Miles 1988; Phillippe 2005). In northern Indiana, most populations of *E. wolfii* occur on wet, acidic sandy loam (Hedge et al. 1994). In southern Indiana, the species is found on slowly permeable silt loam (Aldrich & Homoya 1984; Homoya pers. obs. 1983–1993). In Kansas, prairie soils where Wolf's spike-rush occurs range from hard-pan clay, to shallow calcareous soils over limestone, to sandy soils over sandstone (Morse, pers. obs.). Poorly drained sodic and non-sodic silt loam soils are characteristic of Louisiana *E. wolfii* stations (Edwards et al. 1991; Martin et al. 1981). A site in Juneau County, Wisconsin is described as "...moist,

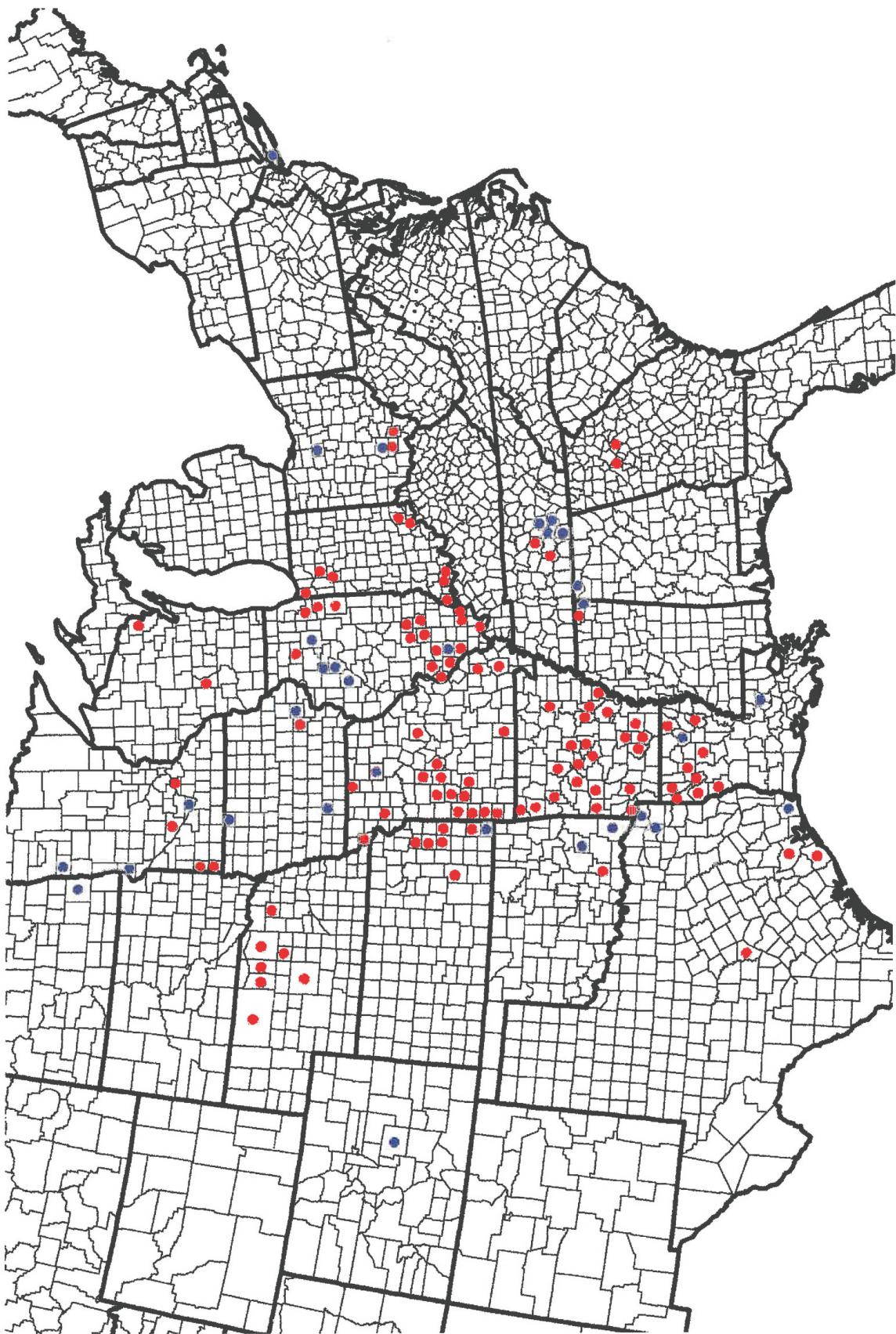


FIG. 3. County distribution map for *E. wolfii* in the United States (blue = historical; red = extant; since 1978).

TABLE 1. Number of documented historical (prior to 1978) vs. extant sites for *Eleocharis wolfii* in the United States.

State	No. of historical counties/parishes	No. of historical sites	No. of extant counties/parishes	No. of extant sites
AL	1	1	0	0
AR	2	2	22	54
CO	1?	1?	0	0
GA	0	0	2	4
IA	4	4	1	1
IL	9	21	16	47
IN	1	2	8	15
KS	1	1	6	10
LA	2	3	9	14
MN	3	3	4	5
MS	1	1	1	1
MO	2	2	18	30
NE	1	1	7	29
NY	1	1	0	0
ND	1	2	0	0
OH	2	2	2	1
OK	2	2	1	1
TN	4	6	2	2
TX	4?	2?	3	6
WI	1	1	2	2
TOTAL	43	59	104	222

TABLE 2. County/Parish records of *Eleocharis wolfii* known only from historical collections (*n* = 31).

State	Historical counties
AL	Lauderdale
CO	El Paso?
IL	Fulton, LaSalle, Peoria, Perry, Stark
IA	Cedar, Emmett, Union
KS	Cherokee
LA	East Baton Rouge, Ouachita
MN	Nicollet, Norman, Traverse
MO	Linn
MS	Tishomingo
ND	Cass
NY	Nassau
OH	Crawford, Ross
OK	Latimer, McCurtain
TN	Coffee, Franklin, Grundy, Warren
TX	Bowie, Jefferson, Morris

TABLE 3. Number of documented new sites and counties/parishes for *Eleocharis wolfii* discovered in the United States since 2000.

State	No. of new counties/ parishes	No. of new sites
AR	19	53
GA	1	1
IA	1	1
IL	3	7
KS	5	9
LA	7	11
MN	4	5
MO	16	29
MS	1	1
NE	3	10
OH	1	1
OK	1	1
TN	0	1
TX	1	4
WI	1	1
TOTAL	64	135

slightly peaty, dark gray fine sandy loam, prob, slightly acid” (<http://www.botany.wisc.edu/cgi-bin/specimen.cgi?Accession=v0008579WIS>).

Associated species

Due to the wide range of habitats recorded for *E. wolfii*, the list of plant species associated with the species is extensive and there are data from most states within its range. At *Quercus palustris* Muenchh. and *Q. stellata* Wangenh. flatwoods sites in southern Illinois common associates include *Carex annectens* (E.P. Bicknell) E.P. Bicknell var. *xanthocarpa* (E.P. Bicknell) Wiegand, *C. bicknellii* Britton, *C. caroliniana* Schwein., *C. squarrosa* L., *Cinna arundinacea* L., *Eleocharis verrucosa* (Svenson) L.J. Harms, *Galium obtusum* Bigel., *Isoetes melanopoda* Gay & Dur. and *Q. bicolor* Willd. (Phillippe 2005).

In the wet sand prairies of northern Illinois, *E. wolfii* is associated with *Agalinis purpurea* (L.) Pennell, *Andropogon gerardii* Vitman, *Carex buxbaumii* Wahl, *C. haydenii* Dewey, *C. stricta* Lam., *C. suberecta* (Olney) Britt., *Eleocharis verrucosa*, *Eupatorium perfoliatum* L., *Hypericum adpressum* Bart., *Hypericum sphaerocarpum* Michx., *Leersia oryzoides* (L.) Swartz, *Osmunda regalis* L., *Paspalum laeve* Michx., *Platanthera flava* (L.) Lindl. var. *herbiola* (R. Br.) Luer, *Polygonum careyi* Olney, *Populus tremuloides* Michx., *Rhynchospora capitellata* (Michx.) Vahl, *Rubus schneideri* Bailey, *Sisyrinchium atlanticum* E.P. Bicknell, *Verbena hastata* L., *Viola lanceolata* L., and *Viola primulifolia* L. (Phillippe 2005).

At prairie sites in northern Indiana, associates listed include *Alisma* sp., *Carex lasiocarpa* Ehrhart, *Cyperus bipartitus* Torr., *C. strigosus* L., *Drosera* sp., *Echinochloa crus-galli* (L.) P. Beauv., *Eleocharis elliptica* Kunth, *E. ovata* (Roth.) Roem. & Schult., *E. palustris* L., *Galium obtusum*, *Juncus acuminatus* Michx., *J. brachycarpus* Engelm., *J. dudleyi* Wiegand, *Lysimachia quadrifolia* Sims, *Onoclea sensibilis* L., *Panicum rigidulum* Bosc ex Nees, *Poa pratensis* L., *Polygala sanguinea* L., *Rotala ramosior* (L.) Koehne, *Spartina pectinata* Link, *Spirea alba* Duroi, and *Viola lanceolata* (Robertson & Phillippe 1992: Appendix 1; Phillippe 2005: Appendix 2).

Swink and Wilhelm (1994) also listed the following associates for sites in northeastern Illinois and northwestern Indiana: *Agrostis gigantea* Roth., *Bidens trichosperma* (Michx.) Britton, *Calamagrostis canadensis* (Michx.) P. Beauv., *Carex conoidea* Schkuhr ex Willd., *C. pellita* Muhl. ex Willd., *Cornus amomum* Mill. ssp. *obliqua* (Raf.) J.S. Wilson, *Doellingeria umbellata* (Mill.) Nees, *Eleocharis erythropoda* Steud., *Erigeron philadelphicus* L., *Eryngium yuccifolium* Michx., *Euthamia gymnospermoides* Greene, *Hierochloë odorata* (L.) P. Beauv.,

Hedyotis caerulea (L.) Hook., *Hypericum mutilum* L., *Hypoxis hirsuta* (L.) Cov., *Iris virginica* L. var. *shrevei* (Small) E.S. Anderson, *Juncus marginatus* Rostkov, *J. tenuis* Willd., *Lechea tenuifolia* Michx., *Lobelia spicata* Lam., *Lycopus rubellus* Moench, *Panicum virgatum* L., *Populus deltoides* Bartram ex Marshall, *Rhamnus frangula* L., *Rubus flagellaris* Willd., *Salix humilis* Marshall, *Saxifraga pensylvanica* L., *Thelypteris palustris* Schott var. *pubescens* (G. Lawson) Fernald and *Veronica peregrina* L.

In flatwoods in southwestern Indiana, associates include *Carex annectens*, *C. muskingumensis* Schwein., *Eleocharis tenuis* (Willd.) Schult., *Isoetes melanopoda*, *Ludwigia palustris* (L.) Elliott, *Quercus bicolor*, *Q. pagoda* Raf., *Q. palustris* *Q. stellata*, and *Ranunculus pusillus* Poiret (Aldrich & Homoya 1994).

In Kansas, *E. wolfii* has been observed with *Carex annectens*, *C. festucea* Schkuhr ex Willd., *C. frankii* Kunth, *C. granularis* Muhl. ex Willd., *C. missouriensis* P. Rothr. & Reznicek, *C. scoparia* Schkuhr ex Willd., *Eleocharis erythropoda*, *E. macrostachya* Britton, *Glyceria striata* (Lam.) Hitchc., *Juncus acuminatus*, *J. interior* Wiegand, and *Elymus smithii* (Rydb.) Gould in swales of native tall grass prairie and in disturbed wet prairies. In the floodplain of the Marais des Cygnes River in Linn County, the species was observed along the edge of a field adjacent to a pin oak-hickory-pecan forest remnant (Morse, pers. obs.).

Associated species at Missouri flatwood sites include *Carex scoparia*, *C. triangularis* Boeck., *C. tribuloides* Wahlenb., *Eleocharis verrucosa*, *Isoetes melanopoda*, *Juncus* spp., *Ludwigia peploides* (Kunth) Raven, *Steinchisma hians* (Elliott) Nash, and *Polygonum* spp. (McKenzie & Jacobs 2000). At Missouri prairie swale sites, *E. wolfii* is often associated with *Carex annectens*, *Carex bicknellii*, *C. oklahomensis* Mack., *C. tribuloides*, *Dichanthelium scoparium* (Lam.) Gould, *Eleocharis palustris*, *E. verrucosa*, *Glyceria striata*, *Juncus* spp., *Muhlenbergia* spp., *Penstemon tubiflorus* Nutt., *Physostegia virginiana* (L.) Benth., *Scirpus atrovirens* Willd., *S. pendulus* Muhl. ex Elliott, *Sporobolus heterolepis* (A. Gray) A. Gray and *Tripsacum dactyloides* (L.) L. (McKenzie & Jacobs 2000). Other species recorded at prairie sites in Missouri include *Carex conoidea*, *C. granularis*, *C. trichocarpa* Muhl. ex Willd., *Carex vesicaria* L. var. *monile* (Tucker.) Fernald, *Carex vulpinoidea* Michx., *Lysimachia* sp., *Lythrum alatum* Pursh, *Platanthera lacera* (Michx.) G. Don, *Polygonum amphibium* L., *Scutellaria galericulata* L., and *Spartina pectinata* (pers. obs.).

In Nebraska, associates recorded for *E. wolfii* include *Agrostis gigantea*, *Alisma triviale* Pursh, *Apocynum cannabinum* L., *Carex atherodes* Sprengel, *C. buxbaumii*, *C. emoryi* Dewey, *C. interior* L.H. Bailey, *C. pellita*, *C. sartwellii* Dewey, *C. scoparia*, *Dichanthelium acuminatum* (Sw.) Gould & C.A. Clark, *Dulichium arundinaceum* (L.) Britton, *Eleocharis acicularis*, *E. elliptica*, *E. erythropoda*, *E. palustris*, *Equisetum arvense* L., *Eriophorum polystachion* L., *Euthamia gymnospermoides*, *Juncus marginatus*, *J. torreyi* Cov., *Lysimachia hybrida* Michx., *L. thyrsiflora* L., *Lycopus americanus* Muhl., *Phalaris arundinacea* L., *Polygonum amphibium*, *Pycnanthemum virginianum* (L.) T. Durand & B.D. Jackson ex Rob & Fernald, *Salix eriocephala* Michx., *S. exigua* Nutt., *S. humilis*, *S. petiolaris* Smith, *Sorghastrum nutans* (L.) Nash, *Spartina pectinata*, *Symphyotrichum lanceolatum* (Willd.) G.L. Nesom, *Spiranthes cernua* (L.) Rich., *Thelypteris palustris* Schott var. *pubescens* (G. Lawson) Fernald, *Triglochin maritima* L. var. *elata* (Nutt.) A. Gray, *Typha angustifolia* L., and *Verbena hastata* L. (Robert Steinauer, pers. comm. 2007).

In Arkansas, *E. wolfii* occurs with *E. verrucosa*, *Isoetes melanopoda*, *Juncus* spp., *Rhynchospora* spp., *Steinchisma hians* on saline barrens; *Carex albolutescens* Schwein., *C. oklahomensis*, *C. opaca* (F.J. Herm.) P.E. Rothr. & Reznicek, *Dichanthelium dichotomum* (L.) Gould subsp. *roanokense* (Ashe) Freckmann & Lelong, and *Ranunculus laxicaulis* Darby in prairie swales; *Allium canadense* L. var. *mobile* (Regel) Ownbey, *E. lanceolata* Fernald, *E. verrucosa*, *Isoetes butleri* Engelm., *I. melanopoda*, *Juncus secundus* P. Beauv. ex Poir., *Ludwigia palustris*, *Sporobolus ozarkanus* Fernald, and *Steinchisma hians* on shale barrens; *Eleocharis lanceolata*, *E. verrucosa*, *Eriocaulon koernickianum* Van Heurck & Müll. Arg. in Van Heurck, *Isolepis pseudosetacea* (Daveau) Gand., *Juncus secundus*, *Rhynchospora recognita* (Gale) Kral and *Utricularia subulata* L. on sandstone glades; *Carex albolutescens*, *C. complanta* Torr. & Hook., *C. debilis* Michx. var. *debilis*, *C. flaccosperma* Dewey, *Fraxinus pennsylvanica* Marshall, *Juncus coriaceus* Mack., *Leersia virginica* Willd., *Liquidambar styraciflua* L., *Quercus lyrata* Walter, and *Q. phellos* L. in flatwoods; and *Cyperus* spp., *Eleocharis* spp, and *Fimbristylis autumnalis* (L.) Roem. & Schult. on a wet salt lick (Witsell, pers. obs.).

Associates listed at recently discovered sites in Minnesota include *Alopecurus carolinianus* Walter, *Eleocharis acicularis*, *E. compressa* Sullivant, *E. ovata*, *Hordeum jubatum* L., and *Juncus interior* (Fred Harris, MN DNR, pers. comm. 2007).

Associates of *E. wolfii* in small depressions of sodic flatwoods and prairies in Louisiana include *Quercus similis* Ashe and *Crataegus brachyacantha* Sarg. & Engelm. in the flatwoods overstory, with herbaceous associates consisting of *Carex annectens*, *C. aureolensis* Steud., *C. complanata*, *C. reniformis* (L.H. Bailey) Small, *Cyperus pseudovegetus* Steud., *Dichanthelium scoparium*, *Eleocharis verrucosa*, *Juncus marginatus*, *Juncus* spp., *Iva annua* L., *Ludwigia linearis* Walter, *L. glandulosa* Walter, *Panicum rigidulum*, *Rhynchospora corniculata* (Lam.) A. Gray, *R. globularis* (Chapm.) Small var. *globularis*, *Steinchisma hians*, and *Tridens strictus* (Nutt.) Nash. Non-sodic poorly drained flatwoods supporting *E. wolfii* have *Quercus phellos* and *Fraxinus pennsylvanica* in the overstory with an understory supporting *Boltonia diffusa* Elliott, *Campsis radicans* (L.) Bureau, *Carex complanata*, *C. lurida* Wahlenb., *C. triangularis*, *Dichanthelium dichotomum* var. *dichotomum*, *D. scoparium*, *Euthamia leptcephala* (Tor. & A. Gray) Greene ex Porter & Britton, *Helenium flexuosum* Raf., *Juncus coriaceus* Mack., and *Steinchisma hians*. The moss genus *Climacium* F. Weber & D. Mohr is often characteristic of shaded sites supporting *E. wolfii* in Louisiana and Reid has used the presence of this moss with success to locate *E. wolfii*. *Sphagnum* L. is also an occasional associate in Louisiana.

Population estimates

Other than very rough estimates, there are limited detailed demographic data available on Wolf's spike-rush at most sites in North America. Robertson and Phillippe (1992), however, closely examined two large populations of *E. wolfii* in southern Illinois (one from a prairie swale habitat and the second from a *Quercus* spp. flatwoods) and counted the number of tufts or clumps, the number of stems/tuft, and fruiting stems within eight randomly selected $\frac{1}{4}$ m² circular plots. They also counted spikelet scales and achenes from 50 randomly selected spikelets and obtained an estimate on fruit set. The total area of the prairie population was 321.4 m² and that of the flatwoods population was about 3,380 m². Measurements from the prairie population plots yielded 1,108 tufts and 5,059 stems, of which 1,807 (36%) were fruiting. By extrapolation, this population contained 178,078 tufts, 813,082 stems and 290,421 fruiting culms. The 50 spikelets produced an average of 22 scales and 10 achenes per spikelet. This yielded a total estimate of 6,389,262 scales, about 2,904,210 achenes, and a fruit set of approximately 45%. Similar procedures were performed for the flatwoods site except that 100 spikelets were collected to calculate fruit set data. The 100 spikelets produced an average of 25 scales and 14 achenes per spikelet. This yielded a total estimate of 13,308,750 scales, about 7,452,900 achenes, and a fruit set of approximately 56%.

In a second population examined in Washington County (Robertson & Phillippe 1992: collection-Phillippe & Gehlhausen 20311), results were substantially different. This population was located at an ephemeral pool surrounded by *Quercus palustris* in a *Q. stellata* flatwoods. The *Q. stellata* crowns nearly covered the ephemeral pool such that the *E. wolfii* population had low available light. The population was in an area of 122.6 m² and 33% of the site was surveyed. Robertson and Phillippe (1992) extrapolated that the total area had 1,167 tufts with a total of 5,400 stems, of which only 228 (4%) of the stems were fruiting. Rough estimates at other localities have been reported as few as 25 culms and as high as hundreds of thousands of plants (Robertson & Phillippe 1992; McKenzie & Jacobs 2000; Fred Harris, MN DNR, pers. comm. 2006). We could not find any gray or published literature on seed viability, predation, or germination requirements for Wolf's spike-rush.

Conservation status

Phillippe (2005) conducted a conservation assessment on the species for the Eastern Region of the U.S. Forest Service but his report only covered Illinois and Indiana. NatureServe (2009) listed global and state ranks outlining the global rarity and conservation status of *E. wolfii* in each state in the United States. *Eleocharis wolfii* currently has a global rank of G3G4 (NatureServe 2009). A G3 ranking indicates that a species is vulnerable globally due to a limited distribution and potential threats to its continued existence. A species

ranked G4 is one that is generally uncommon and widespread but apparently secure. The GRANK for *E. wolfii* was reviewed in 2006 in light of recent discoveries outlined in this report (Leah Oliver, NatureServe, pers. comm. 2006). NatureServe (2006) SRANK categories included SH (historical with the expectation that it still may be extant and possibly rediscovered), S1 (critically imperiled), S2 (imperiled), S3 (vulnerable), S4 (apparently secure), and SNR/SU (not ranked/under review). States and NatureServe (2009) SRANKs listed for Wolf's spike-rush are: Alabama (S1), Arkansas (S3), Georgia (S1), Illinois (S1), Indiana (S2), Iowa (S1), Kansas (S2), Louisiana (S3), Minnesota (S1), Missouri (S3S4), Mississippi (SU/NR), Nebraska (S2), North Dakota (SH), Ohio (S1), Oklahoma (SU/NR), Tennessee (S1), Texas (S1), Virginia (S1), and Wisconsin (S1) (Louisiana Natural Heritage Program 2009; NatureServe 2006, 2009; Tim Smith, Missouri Department of Conservation, pers. comm. 2005).

In some states, *E. wolfii* is given special designations separate from the NatureServe ranking. Wolf's spike-rush is listed as an endangered species in Minnesota, Ohio, Tennessee, and Wisconsin, rare in Indiana, a species of special concern in Arkansas, Georgia, and Iowa, and a species of uncertain status in Virginia (Appendix 1). Separate state designations are not provided for *Eleocharis wolfii* in Alabama, Illinois, Kansas, Louisiana, Mississippi, Missouri, North Dakota, Oklahoma, or Texas (Appendix 1).

In Nebraska, *E. wolfii* is listed as a Tier 1 At-Risk Species as part of the Nebraska Game and Parks Commission's Natural Legacy Project (Nebraska Game & Parks Commission 2009a). This program is part of the state's development of a Comprehensive Wildlife Strategy that has been initiated in all 50 states (Nebraska Game & Parks Commission 2009b). *Eleocharis wolfii* is included on the U.S. Forest Service's regional forester sensitive plant list (Phillippe 2005; U.S. Department of Agriculture 2006).

Wilhelm (1977, 1978) developed a system to assess how conservative various plant taxa were in Kane County, Illinois by giving each species a "coefficient of conservatism." Species with the least conservative value were ranked as 0 while those with the highest conservative rating were graded as 10. This system was adopted and modified by Swink and Wilhelm (1979), and further refined by Wilhelm and Ladd (1988). The methodology was summarized by Swink and Wilhelm (1994) and Taft et al. (1997). Swink and Wilhelm (1994) provided coefficients of conservatism for each plant species in the Chicago Region. *Eleocharis wolfii* was given the highest conservative rank of 10 and was listed as a representative of high quality wet prairies (Swink and Wilhelm 1994). In other states in the Midwest, however, the coefficient of conservatism ranges from 5–9 for Wolf's spike-rush.

State accounts

Alabama.—Smith (2002) listed Alabama within the range of *E. wolfii* and the species is known from a sole historical record from Lauderdale County (Al Schotz, AL NHP, pers. comm. 2009).

Arkansas.—Historically, Wolf's spike-rush was only known from two specimens with vague locality data from Arkansas and Little River counties (Table 1, Table 2). Recent surveys by Witsell, McKenzie, and others in Arkansas from 2002 to 2008 have yielded 54 new sites that are widely distributed among 22 counties, including the two historical counties (Table 1, Table 3, Fig. 3). In Arkansas *E. wolfii* is found in a wide variety of natural, historically open, wet to seasonally wet habitats. These habitats include unplowed tallgrass prairies, saline barrens, sandstone glades, shale barrens, open hydric pine flatwoods dominated by *Pinus taeda*, open hydric oak-dominated flatwoods, forested channel scar wetlands on abandoned stream terraces in the Ouachita Mountains, and a seasonally wet deer-maintained salt lick. *Eleocharis wolfii* may also occasionally occur in ditches along roads that cut through these habitats.

Colorado.—Although Smith (2002) stated that he had not seen specimens of *E. wolfii* to verify literature reports of the species in Colorado, Martin (1993) listed a record from El Paso County and noted that the specimen had been cited by Svenson. However, Svenson was unaware of *E. acicularis* var. *porcata* and misidentified specimens of this taxon for *E. wolfii* (Smith 2001a, 2002). Surveys in Colorado will be needed to assess the current status of *E. wolfii* in the state.

Georgia.—Wolf's spike-rush is currently known from three sites in Walton County and one site in DeKalb County (Jim Allison, and Tom Patrick, GA NHP, pers. comm. 2006).

Illinois.—The type locality for Wolf's spike-rush is Fulton County, Illinois (Gray 1874; Mohlenbrock 1976; Phillippe 2005) and the species has undoubtedly received more attention in this state than any other within its range. Robertson and Phillippe (1992) conducted an extensive survey for *E. wolfii* in Illinois and documented 26 populations in 11 counties. Of these, nine populations were documented from four counties and the species was collected from ephemeral pools of remnant native prairie habitat. An additional 17 populations were recorded across seven counties and were found in ephemeral pools within open oak flatwoods on river terraces (Robertson and Phillippe 1992). In Illinois *E. wolfii* often occurs in large colonies that range from "several hundred to many thousands of culms," and these populations may cover a "few hundred m² to a few thousand m² area" (Phillippe 2005; Phillippe, pers. obs.). Since 1978, *E. wolfii* has been documented from approximately 47 sites in 16 counties in Illinois (Table 1, Fig. 3).

Indiana.—*Eleocharis wolfii* was first collected in Indiana in 1935 by F.J. Hermann and C.C. Deam at apparently two separate sites (Phillippe 2005). There are currently 15 extant occurrences scattered across Lake, Pulaski, and White counties in northern Indiana and from Jefferson, Posey, Ripley, Spencer, and Warrick counties in southern Indiana (Swink and Wilhelm 1994; Phillippe 2005; Table 1, Fig. 3). Habitat for the species in Indiana is identical to that recorded for Illinois (Phillippe 2005; Indiana Natural Heritage Data Center 2009). *Eleocharis wolfii* occurs along ephemeral pools in *Quercus palustris* flatwoods in southern Indiana and is associated with wet, sandy prairies in the northern portions of the state.

Iowa.—There are four historical records for the state: one each for Cedar, Emmet, Johnson and Union counties (Eilers & Roosa 1994). The only known extant site occurs on the Williams Prairie State Preserve in Johnson County (Table 1, Fig. 3). The species was found during a floristic inventory of Williams Prairie in 2002 (John Pearson, Iowa DNR, pers. comm. 2009).

Kansas.—Wolf's spike-rush was collected as early as 1897 in Cherokee County, but not again in the state until 1986, when a specimen was taken in Crawford County (C. Freeman, pers. comm.). Since 2000, *E. wolfii* has been documented to occur at nine additional sites in Anderson, Douglas, Franklin, Linn, and Greenwood counties. The species is known in Kansas only from the eastern one-quarter of the state, where it has been observed in swales in upland prairies over both limestone and sandstone soils, in roadside ditches and disturbed wet prairies adjacent to higher quality sites, and in a disturbed, cool-season grassland adjacent to remnant bottomland pin oak-hickory-pecan forest (Table 1, Fig. 3).

Louisiana.—Historically, *E. wolfii* was collected from three localities at one site each in East Baton Rouge, Franklin, and Ouachita Parishes (= counties) between 1931 and 1970. Surveys conducted in 2007 and 2008 by Reid led to the discovery of 14 new sites in nine parishes that included seven new parish records. Previous reports recorded for Natchitoches, Richland, St. Martin, and St. Tammany Parishes proved to be misidentifications of other species, namely *Eleocharis acicularis* and *E. montevidensis* Kunth. In Louisiana, Wolf's spike-rush is found in depressions in flatwoods and saline prairies, broader wet flatwoods, and in ditches within these habitats. Several flatwoods records are from utility corridors where some portion of the native herbaceous component persists. Much of this herbaceous layer is shaded out by dense stocking of adjacent forests, due to fire exclusion or by other types of management (e.g., *Pinus taeda* L. plantations).

Minnesota.—*Eleocharis wolfii* is currently known from five extant sites in four counties (Pipestone, Renville, Rock, Scott) and the species was historically known from three additional sites in three separate counties (Nicollet, Norman, Traverse). The species is found in shallow swales over Jordan Sandstone, along margins of shallow depressions in gneiss bedrock along the Minnesota River, and in prairie swales and ephemeral pools of exposed Sioux Quartzite outcrops (Fred Harris and Welby Smith, Minnesota DNR, pers. comm. 2006, 2007). Population estimates at extant sites range from 50 to 10,000s of plants (Harris, pers. comm. 2007).

Mississippi.—*Eleocharis wolfii* was historically known from one site in Tishomingo County and was considered likely extirpated in the state until it was rediscovered in Alcorn County in 2008 by Charles Bryson (Bryson, pers. comm. 2008).

Missouri.—Wolf's spike rush was previously known in Missouri solely from collections taken in Linn and Callaway counties (Steyermark 1963; Yatskievych 1999). Even with repeated searches to document its occurrence in Missouri, the species had not been observed in recent years and was believed to be

possibly extirpated from the state (Yatskievych 1999). The species was rediscovered in 1999 along the edge of a seasonally-flooded bottomland forest in Stoddard County, in the Missouri Bootheel (McKenzie and Jacobs 2000). Subsequent to this discovery, the species was documented in wet swales of five high quality prairies in southwest Missouri, in early June 1999 (McKenzie and Jacobs 2000). In 2000, a second location was documented in seasonally-flooded bottomland in Stoddard County (Smith 2001b). Between 2000 and 2008, Wolf's spike-rush was discovered at 21 additional prairie sites at scattered localities in northern and southern Missouri and was rediscovered at its historical location in Callaway County. *Eleocharis wolfii* was discovered on a sandstone glade in Henry County in 2003 (Missouri Natural Heritage Database 2009). Currently Wolf's spike-rush is known from 30 localities scattered throughout 18 counties (Fig. 3). Most localities occur within the Unglaciaded Plains Division (Thom & Wilson 1980, 1983; Yatskievych 1999) of southwestern Missouri but there are a few records from the Glaciaded Plains (Thom & Wilson 1980, 1983; Yatskievych 1999) of central and northern Missouri and the Mississippi Lowlands (Thom & Wilson 1980, 1983; Yatskievych 1999) in extreme southeastern Missouri. Due to the numerous recent discoveries, the species is no longer being tracked as a species of conservation concern (Missouri Natural Heritage Program 2009).

Nebraska.—*Eleocharis wolfii* was first collected in Brown County in 1890 by J. Bates. Based on misidentification of *E. acicularis*, Wolf's spike-rush was deleted from the Nebraska list (Rolfsmeier 1995), but was subsequently reconfirmed after a collection by Rolfsmeier in 1996 in Cherry County (Rolfsmeier & Steinauer 1999). Rolfsmeier and Robert Steinauer collected the species in Garfield and Rock counties, respectively, in 1999. Steinauer subsequently documented *E. wolfii* from 10 sites between 2000 and 2005 while conducting surveys for *Platanthera praeclara* Sheviak & Bowles and *Schoenoplectus hallii* (A. Gray) S.G. Sm. in the eastern Sandhills of Nebraska, and discovered an additional 14 new sites on the Valentine National Wildlife Refuge in Cherry County in 2006 (Steinauer, pers. comm. 2007). Currently, *E. wolfii* is extant at 29 sites scattered across seven counties in the northern one-half of Nebraska (Table 1; Fig. 3). Because it has been estimated that there are 19,300 square miles (Knue 1997) of sandy habitat within the sandhills region of the state, ongoing surveys are likely to yield additional new populations of this species.

New York.—*Eleocharis wolfii* is known solely from historical collections taken in 1927 from an open, wet meadow adjacent to a train station on Long Island (Nassau County) (Troy Weldy, NY NHP, pers. comm. 2006). The population is now extirpated and is considered by most to be adventive (Svenson 1957; Troy Weldy, pers. comm.).

North Dakota.—Martin (1993) listed two sites from Cass County, North Dakota. Kolstad (1986) and Smith (2002) included the state within the range of *E. wolfii*. One site was known from a roadside ditch and another site has since been destroyed by development (Justin Parks, ND NHP, pers. comm. 2006). Wolf's spike-rush is considered possibly extirpated from North Dakota (Parks, pers. comm. 2006; NatureServe 2009).

Ohio.—There is one extant site for *E. wolfii* in Ohio on a TNC preserve in Jackson County and adjacent Pike County that was initially discovered in 1993 (Rick Gardner, Ohio DNR, pers. comm. 2009). There are also two historical collections taken from remnant prairies in Ross County (1945) and Crawford County west of Monnett (1953). The site in Ross County has been largely destroyed and apparently no longer supports *E. wolfii*. Although the exact location of the historical collection in Crawford County can not be determined, it is possible that it was taken from a high quality prairie that was converted to cropland in 1963 (Gardner, pers. comm. 2009). The single extant population on the TNC preserve is apparently increasing due to good management (Gardner, pers. comm. 2009).

Oklahoma.—In Oklahoma, *E. wolfii* was historically known from two collections: one taken by F.H. Means, Jr. in Latimer Co., 1968 (KANU collection) and one collected in 1969 by U.T. Waterfall from a wet prairie in McCurtain County (Amy Buthod, OK NHP, pers. comm. 2006). There have been no subsequent surveys for the species in the state (Bruce Hoagland, University of Oklahoma, pers. comm. 2007). However, in 2008, Jason Singhurst collected *E. wolfii* in Atoka County from TNC's Boehler Seeps and Sandhills Preserve where it was growing in a sandy hillside seepage bog (Singhurst, pers. comm. 2009). This record apparently represents the only known extant population in the state.

Tennessee.—Wolf's spike-rush is known historically from seven sites in five counties: (Coffee, Franklin, Grundy, Rutherford, Warren) (Table 1, Fig. 3) but currently only extant at one site each in Marshall and Rutherford counties (Roger McCoy, Tennessee Division of Natural Areas, pers. comm. 2007). A new site was discovered in 2003 in Rutherford County, but the site is threatened by construction and a new housing subdivision. Construction activities possibly altered the hydrology of the site and the *E. wolfii* was being displaced by species more typical of upland localities when visited in 2005 (McCoy, pers. comm. 2007).

Texas.—The status of reports of *E. wolfii* recorded for Texas is unclear. Diggs et al. (2006) listed the species for Bowie, Burnet, Jefferson and Morris counties, but Barney Lipscomb was only able to locate specimens for Bowie County (Botanical Research Institute of Texas [BRIT], pers. comm. 2007). S. Galen Smith has seen specimens of Wolf's spike-rush from Burnett and Jefferson counties (Smith pers. comm. 2007). David Rosen of Lee College in Baytown, Texas has collected the species from four separate sites in Brazoria County between 2004 and 2005 (Lipscomb, pers. comm. March 2007; Rosen 2007; Rosen, pers. comm. 2007). Smith noted a specimen taken by Crockett in 1944 from Beaumont, Texas, but was unsure from what county the specimen was taken (Smith pers. comm. 2007). We suspect that it is from Jefferson County. Martin (1993) listed a specimen from Harris County but neither Smith nor Lipscomb has confirmed the identification (Lipscomb and Smith pers. comm. 2007). A recent specimen collected by Jason Singhurst confirms the presence of *E. wolfii* in Harris County (pers. comm. 2009). Recent collections in Brazoria County by Rosen strongly suggest that additional survey efforts in this state are warranted. Several saline prairies/barrens were recently identified in Harrison, Marion, and Panola Counties in northeast Texas, and have received some preliminary botanical exploration (M. MacRoberts, pers. comm. 2009 and J. Singhurst, pers. comm. 2009). Given that *E. wolfii* occurs in this habitat in adjacent Caddo and De Soto Parishes, Louisiana, it will likely be found in this part of Texas.

Wisconsin.—*Eleocharis wolfii* was recently rediscovered in Wisconsin (Smith 2002) and the only extant records of the species in the state are from one site each in Juneau and Marinette counties (Craig Anderson, WI NHP, pers. comm. 2007; Galen Smith, pers. comm. 2007). There is also one historical collection taken from Juneau County. Habitat in Juneau County is a sedge and grass-dominated meadow swale between a roadside and adjoining swampy woods (<http://www.botany.wisc.edu/cgi-bin/specimen.cgi?Accession=v0008579WIS>) (Anderson, pers. comm., 2007).

Summary of threats

A. The present or threatened destruction, modification, or curtailment of the species' habitat or range.—Although numerous new populations of *E. wolfii* have been discovered in the United States since 2000, some historical locations have been destroyed and extant populations are subject to various threats. Some historical sites have been eliminated due to the conversion of native prairie and wetland habitat to agricultural crops, the conversion of native prairie to hayfields and pasture, the cutting of many bottomland forests, or the loss of habitat due to residential and commercial development (Turner 1934; Martin 1993; Greenberg 2002; Nelson 2005; Phillippe 2005). Swink and Wilhelm (1994) and Greenberg (2002) summarized the widespread destruction of native prairies and oak savannas near Chicago. Given the extent of native prairie prior to European settlement, the historical range of *E. wolfii* was undoubtedly much more extensive even than recent discoveries in the Midwest and south-central Gulf Coast would suggest.

In Illinois, Robertson and Phillippe (1992) noted that herbicide application at one site in Effingham County killed ca. 90% of the culms of a population discovered five days earlier by Phillippe. The alteration of hydrologic cycles associated with overland flooding was identified as a threat to Wolf's spike-rush in the state by Phillippe (2005).

Due to the immediacy and magnitude of threats to Wolf's spike-rush habitat in Illinois, especially on private property, Robertson and Phillippe (1992) recommended that *E. wolfii* be listed as a threatened species in that state. Despite the large number of extant sites in Illinois (Table 2, Table 3), species experts in that state have recommended that the SRANK for the species be retained as S1.

B. Over-utilization for commercial, recreational, scientific, or educational purposes.—To our knowledge there is no evidence that Wolf's spike-rush is being negatively impacted due to over-utilization for commercial, recreational, scientific, or educational purposes.

C. Disease or predation.—Phillippe (2005) included livestock grazing as a potential threat to populations of *E. wolfii*. Other than possible negative impacts from grazing, we are unaware of any additional threats to the species from disease or predation.

D. The inadequacy of existing regulatory mechanisms.—Although the NatureServe global and state rankings for *E. wolfii* do not provide any regulatory protection for *E. wolfii*, separate designations in some states afford limited regulatory protection for the species.

Nebraska's listing of *E. wolfii* as a Tier 1 At-Risk Species does not provide any regulatory protection status to the species, but the designation has heightened awareness of its management needs and the NE Department of Roads proactively consults with the NE Game and Parks Commission for highway projects that may impact the species (R. Schneider, NE NHP, pers. comm. 2006). *Eleocharis wolfii* can not be collected in the state without a permit (Schneider, pers. comm.).

A state listing as endangered provides little protection for *E. wolfii* in Wisconsin under state statutes 29.604 and NR (Natural Resources) 27.03-NR27.07 (Wisconsin Legislature 2007a, 2007b; Michigan State University 2007). Under Wisconsin law, the taking of *E. wolfii* is prohibited without a permit under section 27.05. Permits are not required, however, for persons who want to take this or other state listed species: 1) on property which they own or lease or for which they have been granted landowner permission, except if the plants or their progeny are sold or processed, 2) on property that is being used for agriculture, construction, or forestry practices, or 3) on property that is being operated or maintained as a utility facility (Michigan State University 2007; Wisconsin Legislature 2007b).

Little protection is afforded *E. wolfii* under Indiana law, but personnel with the Indiana DNR have an opportunity to provide input on state-funded projects that could negatively impact the species. In Georgia, *E. wolfii* is listed as a species of conservation concern (Appendix 1) but it is not listed as a protected species under Georgia state law (<http://georgiawildlife.dnr.state.ga.us/content/protectedplants.asp>). Region 9 of the U.S. Forest Service includes *E. wolfii* on their regional forester sensitive plant list (Phillippe 2005; U.S. Department of Agriculture 2006) but the designation does not provide any regulatory protection (Dave Moore, USFS, pers. comm., Mar 2009).

E. Other natural or manmade factors affecting its continued existence.—Global warming and climate change could contribute to loss of wetland habitat required by this species by causing droughts to be more extensive and persistent, especially in the Midwest where drought conditions have persisted for several years, and are predicted to continue with increasing frequency in the future (Hansen 1989; Rosenzweig et al. 2000). Climate models indicate that high temperatures and an increase in pests (Rosenzweig et al. 2000) and other invasive species (Vitousek 1994) will accompany the increased frequency of droughts and other extreme events (Dai et al 1996). Global warming and climate change have increasingly been identified as factors which may contribute to the loss of biodiversity and extinction of imperiled species (Wilcove et al. 1998; Thomas et al. 2004; Maschinski et al. 2006). Habitat for *E. wolfii* is likely further threatened due to projected changes in agricultural development, especially corn production that is needed for increasing demands for ethanol production (Keeney and Mueller 2006; U.S. Department of Agriculture 2007). Keeney and Mueller (2006) estimated a 254% increase in volume of water used in ethanol production from 1998 to 2008 for only one state in the Midwest. Corn production for ethanol plants is projected to increase in 2007 by 14.2% in Illinois (U.S. Department of Agriculture 2007), the state with the second largest number of extant sites for Wolf's spike-rush. Nebraska has large areas of potential habitat in its sandhills region (Knue 1997), but Keeney and Mueller (2006) postulated that increasing demand for ethanol production may result in competing water uses in that state. Increased demands for water from above ground sources and underground aquifers could prevent the formation and maintenance of important wetland habitat needed by *E. wolfii* throughout the Midwest.

Research needs

Additional surveys are warranted, especially in states where the species is known only from historical locations believed to have been extirpated. Based on recent discoveries in Arkansas, Louisiana, Missouri, and Nebraska, surveys should be conducted between March and May in the southern U.S. and between May and June in the northern limits of the species' range. Additional research on the life history and ecological requirements would be helpful in identifying areas where additional populations could be discovered. Recent discoveries of *E. wolfii* in previously unrecorded habitats (e.g., sandstone glades in AR and MO, shale glades and saline barrens in AR and LA, shallow depressions in gneiss bedrock in MN) suggests that the species occupies a broader range of habitats than reported by McKenzie and Jacobs (2000), Smith (2002), and Phillippe (2005). Natural community type, soil type, plant associates, and phenology should be recorded at each site. Other than estimates taken at different sites in Illinois by Robertson and Phillippe (1992), we are unaware of any additional reports where attempts were made to calculate different demographic parameters. Further studies on the population dynamics and genetic diversity of this species would be useful in assessing the long-term persistence and conservation status of this species in the future.

Research on seed viability, predation, population genetics and germination requirements for the species is lacking (Phillippe 2005). Phillippe (2005) postulated that gravity and flood water were likely mechanisms for seed dispersal but additional investigations are needed, especially for upland sites. Studies should be initiated to further examine competition and responses by *E. wolfii* to various levels of management and disturbance, especially grazing pressure from native and non-native herbivores. Analyses of land use changes would help researchers assess threats to the species, especially related to the conversion of native habitat for agriculture, silviculture, and residential development. Further evaluations are needed to assess differences in habit, light requirements and reproductive success of individuals of *E. wolfii* in shaded sites vs. localities in full sunlight.

Oak flatwood sites in AR, IL, IN, and MO are dependent upon flood waters or water accumulated from precipitation. The importance of seasonal flooding to the dispersal of *E. wolfii* and its germination requirements should be further studied. What role the increase and spread of invasive species has on *Eleocharis wolfii* should be investigated, particularly in light of possible scenarios associated with predicted impacts from projected changes in climate.

Results of searches conducted by authors of this report suggest that additional populations of Wolf's spike-rush are likely to be found if surveys are conducted in appropriate habitats during the proper season. Prairie swales, including those associated with remnant railroad prairies in IA, IN, MI, MN, ND, OH, OK, and TX should be targeted for surveys. Oak flatwoods in MS, western TN, and southwestern KY may yield additional populations.

Management needs

We can find little information on management recommendations to benefit Wolf's spike-rush. Phillippe (2005) suggested that the maintenance of openings in flatwood habitats, the monitoring of potential impacts of exotic species, and the use of prescribed fire to prevent the encroachment of woody vegetation were treatments that could be useful in maintaining populations of *E. wolfii*. The importance of using prescribed fire to maintain prairie, savannah, and glade habitats has been extensively reported on in the published and gray literature (e.g., Swink & Wilhelm 1994; Davit 1999; Greenberg 2002; Nowacki & Abrams 2008). Prescribed fires not only maintain open habitats and halt the spread of trees and shrubs, but the repeated practice prevents the establishment of fire sensitive species (Phillippe 2005; and exhaustively reviewed in Nowacki & Abrams 2008). Mowing and haying may also be beneficial to the species by helping control woody vegetation, by opening the canopy, and by providing a low level of disturbance necessary for colonization of rhizomes or achene germination.

Phillippe (2005) advised against actions that alter soils where Wolf's spike-rush occurs but the relationship of soil disturbance in maintaining the species' habitat is not fully understood. Bowles et al. (1990)

included *E. wolfii* on a list of species that positively responded to anthropogenic influences of humans at the Indiana Dunes National Lakeshore but Phillippe (2005) believed that the response there was likely due to increased light levels that resulted from the disturbance. Some level of disturbance from natural processes (e.g., fire, flooding) is likely important for achene germination and plant growth of *E. wolfii* but we are unaware of the initiation of any experiments to test this hypothesis. The importance of maintaining natural hydrologic regimes was noted by Phillippe (2005) and NatureServe (2009).

CONCLUSION

Although *E. wolfii* has disappeared from some historical sites across the range of the species and is threatened with various land use changes, the large number of discoveries in the central U.S. between 2000 and 2008 strongly suggest that the species is not as rare as previously believed but has been simply overlooked by botanists who were unfamiliar with the species' habitat requirements and phenology or confused it with other members of the genus. Significant threats to the habitat of *E. wolfii* still persist and, due to potential negative effects associated with climate change, the increased demand for agriculture and ethanol production, and commercial and residential development associated with population growth, we recommend that botanists continue to monitor the status of this species throughout its range. The current NatureServe global rank for this species is G3G4. Although 222 extant sites and populations at some localities numbering in the thousands of individuals may suggest a G4 ranking, *Eleocharis wolfii* remains threatened in many areas. Due to these threats, the range-wide population status is likely somewhere between a G3 and G4. Consequently, we recommend the retention of the current global rank of G3G4. If additional populations are found, however, and/or threats to extant populations are significantly reduced, the global rank of this species should be reassessed at a future date.

APPENDIX 1

Conservation status of *Eleocharis wolfii* in each state where the species has been reported and website link or literature citation for listings.

Alabama—No status: the species is not listed on Alabama's list of species of special concern (Alabama Department of Conservation and Natural Resources 2006). Available at: <http://www.outdooralabama.com/watchable-wildlife/regulations/endangeredbycounty.cfm>; <http://www.auburn.edu/herbarium/teplants.html>. Accessed 7 Mar 2009.

Arkansas—Species of conservation concern: *Eleocharis wolfii* is included in the state's list of plants of conservation concern (Arkansas Vascular Flora Committee 2006). *Eleocharis wolfii* is not listed as a protected species under Arkansas state law.

Colorado—No status: Wolf's spikerush is not included on the state's rare plant field guide (Colorado Natural Heritage Program 1999). Available at: <http://www.cnhp.colostate.edu/rareplants/masterlist.html#E>. Accessed Mar 2009.

Georgia—Species of special concern: in Georgia the species is listed as a plant species of special concern (Georgia Department of Natural Resources 2008). *Eleocharis wolfii* is not listed as a protected species under Georgia state law. Available at: <http://georgiawildlife.dnr.state.ga.us/content/specialconcernplants.asp>; <http://georgiawildlife.dnr.state.ga.us/content/protectedplants.asp>; <http://www.georgiawildlife.com/documentdetail.aspx?docid=89&pageid=7&category=conservation>. Accessed 7 Mar 2009.

Illinois—No status: although Robertson and Phillippe (1992) recommended that *E. wolfii* be included in the Illinois' list of endangered and threatened species, Wolf's spikerush is not currently so listed (Illinois Endangered Species Protection Board 2007). Available at: <http://www.dnr.state.il.us/espb/datelists.htm>. Accessed 7 Mar 2009.

Indiana—Rare: Wolf's spikerush is listed as ranked as "rare" by the Indiana Department of Natural Resources (Indiana Department of Natural Resources 2007). Available at: http://www.in.gov/dnr/naturepreserve/files/np_spencer.pdf. Accessed 7 Mar 2009.

Iowa—Species of special concern: *Eleocharis wolfii* is included on Iowa's list of "Fragile Flora" (Iowa Department of Natural Resources 2007). Available at: <http://fm.iowa.uiowa.edu/fmi/xsl/herbarium/details.xsl>. Accessed 7 Mar 2009.

Kansas—No status: *Eleocharis wolfii* is not tracked by the Kansas Parks and Wildlife Department (Kansas Department of Wildlife and Parks 2005). Available at: <http://www.gpnc.org/refuge.htm#SPECIES>; <http://www.kdwp.state.ks.us/news/Other-Services/Threatened-and-Endangered-Species/Threatened-and-Endangered-Species/Statewide-List>; <http://www.kdwp.state.ks.us/news/content/search?SearchText=endangered>. Accessed 7 Mar 2009.

Louisiana—No status: the species is included on the Louisiana Department of Wildlife and Fisheries' list of rare plant species but there is no separate status other than Natural Heritage state rank of S3 (Louisiana Department of Wildlife and Fisheries 2009). Available at: <http://www.wlf.louisiana.gov/pdfs/experience/naturalheritage/rareplant/eleocharis%20wolfii.pdf>; <http://www.wlf.state.la.us/pdfs/experience/naturalheritage/2009%20Rare%20Plant%20Tracking%20List.pdf>. Accessed 7 Mar 2009.

Minnesota—Endangered: the Minnesota DNR lists Wolf's spikerush as an endangered species on their Rare Species Guide (Minnesota Department of Natural Resources 2009). Available at: http://www.dnr.state.mn.us/rsg/a-z_search.html?action=a-zSearch&letter=E&column=SCIENTIFIC_NAME. Accessed 7 Mar 2009.

Missouri—No status: due to recent discoveries in Missouri, *E. wolfii* is no longer tracked on the state's list of species and communities of conservation concern (Missouri Natural Heritage Program 2009).

Nebraska—No status: in Nebraska, *E. wolfii* is listed as a Tier 1 At-Risk Species as part of the Nebraska Game and Parks Commission's Natural Legacy Project (Nebraska Game & Parks Commission 2009a). This program is part of the state's development of a Comprehensive Wildlife Strategy that has been initiated in all 50 states (Nebraska Game & Parks Commission 2009b). Available at: <http://www.ngpc.state.ne.us/wildlife/programs/legacy/about.asp>; <http://www.ngpc.state.ne.us/wildlife/programs/grants/tier1.pdf>. Accessed Mar 2009.

New York—No status: this species is not tracked by the New York Natural Heritage Program (New York Natural Heritage Program 2008). Available at: http://www.dec.ny.gov/docs/wildlife_pdf/nynhprpsl.pdf. Accessed 14 Mar 2009.

North Dakota—No Status: plants are not tracked by the North Dakota Natural Heritage Inventory. Available at: http://www.fs.fed.us/r2/nebraska/gpng/reports/nd_animals_1998.pdf.

Ohio—Endangered: *Eleocharis wolfii* is listed on the state's 2008–2009 list of rare plants (Ohio Division of Natural Areas and Preserves 2008). Available at: <http://www.dnr.state.oh.us/Portals/3/heritage/2008-2009%20Ohio%20Rare%20Plant%20List.pdf> <http://www.dnr.state.oh.us/tabid/2018/default.aspx#Anchor-46443>. Accessed 7 Mar 2009.

Oklahoma—No status: the Oklahoma Natural Heritage Inventory does not include Wolf's spikerush on their list of rare and vulnerable plant species for the state (Oklahoma Natural Heritage Inventory 2005). Available at: http://www.oknaturalheritage.ou.edu/plants_rare_vulnerable.htm. Accessed 7 Mar 2009.

Tennessee—Endangered: the species is included on Tennessee's Natural Heritage Program's rare plant list (Tennessee Department of Environment and Conservation. 2008). Available at: http://www.state.tn.us/environment/na/pdf/plant_list.pdf. Accessed 7 Mar 2009.

Texas—No status: Wolf's spikerush is not tracked by the Wildlife Diversity Program of Texas Parks and Wildlife Department as a state threatened or endangered species (Texas Parks and Wildlife Department 2004). Available at: <http://www.nature.org/wherewework/northamerica/states/texas/files/listofrareplants.pdf>; <http://www.tpwd.state.tx.us/huntwild/wild/species/endang/plants/index.phtml>. Accessed 7 Mar 2009.

Virginia—Status uncertain: *Eleocharis wolfii* is included on state's list of taxa whose status is uncertain (Virginia Department of Conservation and Recreation 2006). Available at http://www.dcr.virginia.gov/natural_heritage/documents/plantlist06.pdf. Accessed 7 Mar 2009.

Wisconsin—Endangered: Wolf's spikerush is included on the state's list of threatened and endangered species (Wisconsin Department of Natural Resources 2007). Available at: <http://dnr.wi.gov/org/land/er/wlist/statelisted.asp?mode=detail&Grp=9>. Accessed 7 Mar 2009.

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