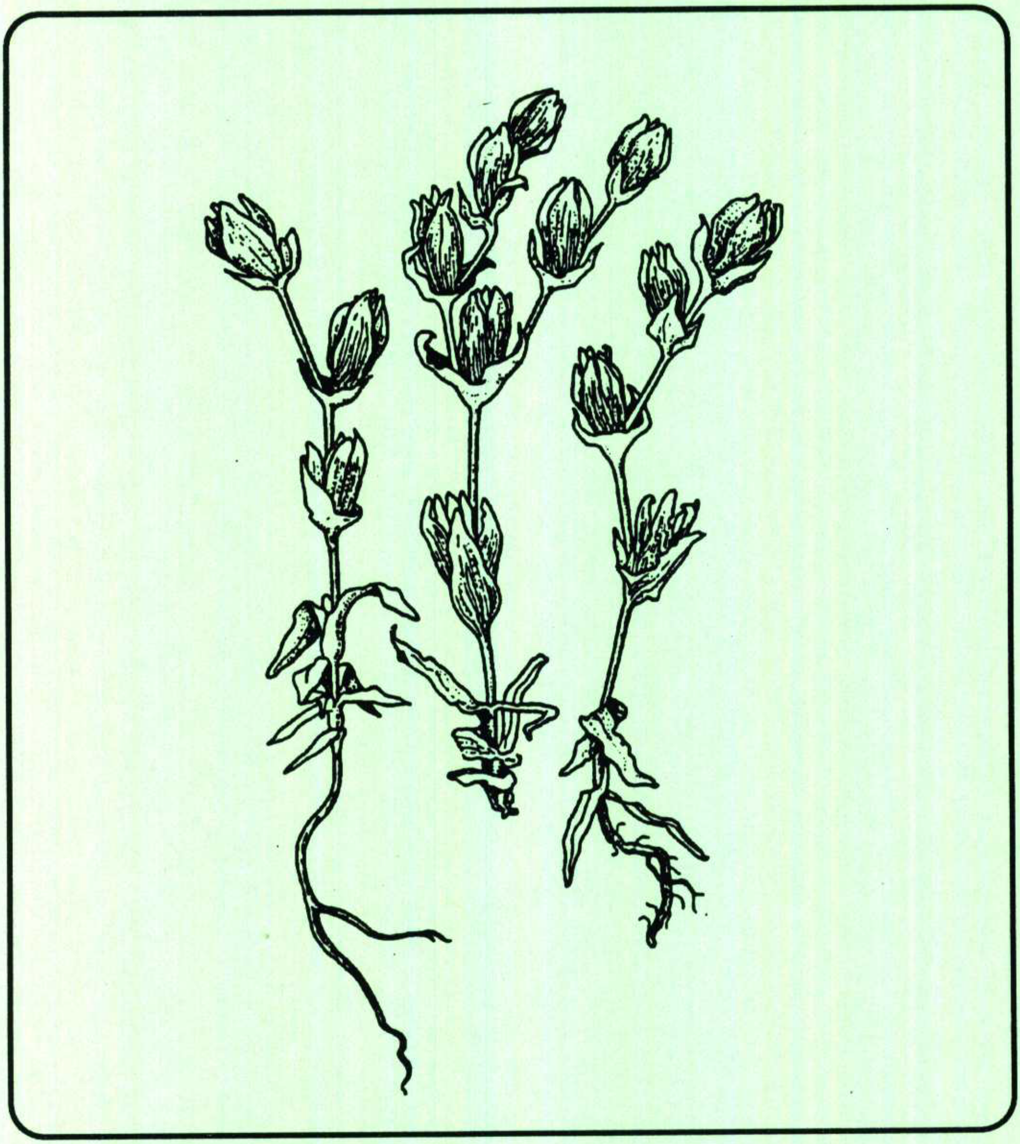
Recovery Plan

Geocarpon Minimum



U.S. Fish and Wildlife Service

Geocarpon minimum MacKenzie
Recovery Plan

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for

Southeast Region
U.S. Fish and Wildlife Service
Jackson, Mississippi

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Literature citations should read as follows:

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EXECUTIVE SUMMARY

Current Status: *Geocarpon minimum* is presently known from 27 sites in Arkansas, Louisiana, and Missouri. Only nine sites (two in Arkansas, one in Louisiana, and six in Missouri) support relatively large, vigorous populations. The species is listed as threatened without critical habitat.

Habitat Requirements and Limiting Factors: In Missouri, *Geocarpon* is limited to shallow depressions in slightly tilted sandstone strata within sandstone glade plant communities. In Arkansas and Louisiana, it occurs in saline-alkali soils at the edges of highly localized, surficial concentrations of sodium and magnesium salts. Locally known as "slick spots," these austere and nearly barren patches of mineral soil are scattered across savannah-like formations classified as saline soil prairies.

Recovery Objective: Delisting.

Recovery Criteria: *Geocarpon* will be considered for delisting when a total of 15 viable populations, representing the diversity of habitats and the geographic range of the species, are protected as necessary to ensure their continued existence. Populations should also include the wide spectrum of current genetic variation found in the species. Population viability should be confirmed through periodic monitoring for at least a 15-year period.

Actions Needed: (1) Protect viable populations across the species' geographic range; (2) evaluate potential habitat and search for additional populations; (3) continue to monitor known sites to determine population trends; (4) support basic research investigating the chemical characterization of the plant's substrate and species biology, dispersal ecology, and population genetics; (5) determine the effects of disturbance factors (natural and man-made) and incorporate findings into management prescriptions; (6) preserve genetic stock; and, (7) establish additional populations in the Arkansas Valley Natural Division, if deemed necessary.

Total Estimated Cost of Recovery: Implementation of the recovery tasks for which cost estimates have been made total $130,000. Site protection actions that require acquisition of land will increase actual recovery costs for this species.

Date of Recovery: It is not possible to determine a date of recovery at this time since the achievement of recovery depends upon the outcome of several of the recovery tasks.

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PART I: INTRODUCTION

A. Background

On July 16, 1987, the U.S. Fish and Wildlife Service (1987) published in the Federal Register, a final rulemaking determining *Geocarpon minimum* MacKenzie to be a threatened species under the Endangered Species Act of 1973, as amended. *Geocarpon minimum* is known to have occurred at a total of only 28 locations in Arkansas, Louisiana, and Missouri. The type locality (in Missouri) has been destroyed and two populations in Missouri have not been seen in the last few years (Weber, Southwest Missouri State, in litt. 1992). Only two sites in Arkansas, one site in Louisiana, and six sites in Missouri support relatively large populations.

B. Taxonomy and Description

Geocarpon MacKenzie was described as a monotypic genus new to science by K.K. MacKenzie (1914). Based upon specimens collected by E.J. Palmer in sandy barrens near Alba, Jasper County, Missouri, on April 20, 1913, MacKenzie tentatively placed this new species in the family Aizoaceae. He described the plant as being a low, diminutive annual with branches 1 to 4 centimeters (cm) (0.39 to 1.59 inches (in)) long (Figure 1, page 29). The leaves are opposite, cup-shaped, scarcely succulent, and 3 to 4 millimeters (mm) (0.12 to 0.16 in) long. The flowers are sessile in axils of the stipule-lacking leaves. The calyx lobes are free, number five, and do not appear petaloid; the corolla is absent; the stamens are five and alternate with the calyx lobes. The ovary is a three-valved dehiscent capsule with the style absent and the stigmas three. The seeds are minute and numerous. See Tucker (1983) and Kral (1983) for more detailed morphological descriptions. Biochemical analysis of plant pigments (Bogle et al. 1971) and comparative anatomy of sieve-element plastids (Behnke 1982) provide conclusive evidence that *Geocarpon* should be placed in the family Caryophyllaceae.

C. Reproductive Biology

Little is known regarding the reproductive biology of this tiny annual species. In a study of a single population of *Geocarpon* on a sandstone glade in Missouri, Morgan (1986) observed germinating seeds still attached to the previous season's crop of capsules as early as November. The plants formed basal rosettes only 1 to 2 mm (0.12 to 0.16 in) in width. As the plants matured, the stems elongated and flowered at heights up to 2.5 cm (1 in). The fruits matured and the plants died in a 4- to 6-week period. There are still questions regarding the life cycle of the Arkansas plants. Tucker (1983) states that the Arkansas plants appear to germinate in March or early April and complete their entire life cycle in 3 to 4 weeks. However, Steinauer (Peacock and Steinauer, Arkansas Nature Conservancy, in litt. 1992) reports observing rosettes in January which produced robust branched plants in the Spring. They suggest that those seeds germinating in Spring produce smally unbranched, single-flower plants. Unpublished experimental results (Weber in litt. 1992) show that a period of after ripening is necessary for successful germination. Such variables as high temperature and length of storage time seem to be most significant.

Such discrepant observations are reflected in the literature. MacKenzie (1914) states that the species is "a low glabrous winter annual." Palmer and Steyermark (1950) remark that "the usual vegetative period is probably from about the middle of April to the middle of May." As mentioned, Tucker (1983) indicates that the life cycle may be completed in 3 to 4 weeks. An exact elucidation of this species' life cycle is obviously a research priority.

The pollination and seed dispersal mechanisms and vectors are unknown. However, surface flow of rainwater is perhaps a factor in local dispersal on the glades in Missouri (Smith, Missouri Department of Conservation, in litt. 1992).

D. Distribution, Ownership, and Protection

Geocarpon is reported from a total of 28 sites in Missouri, Arkansas, and Louisiana (Figure 2, page 30). In Missouri, the species is restricted to seven counties in the unglaciated Ozark and Osage Plains Natural Divisions of the State (Thom and Wison 1980). Currently, in Missouri, 22 sites are thought extant although plants have not been seen at two of these sites in recent years (Weber in litt. 1992); and one site has been extirpated (Smith 1990). In Arkansas, there are three major sites in three southeastern Arkansas counties in the West Gulf Coastal Plain Natural Division and one site in the northwestern quarter of the State in the Arkansas Valley (Smith et al. 1984). Recently, *Geocarpon* was discovered at two new sites in the West Gulf Coastal Plain -- Winn Parish in north-central Louisiana (McInnis et al. 1991). Table 1 (page 23) summarizes information on collection data, ownership, and protection efforts for all known sites of *Geocarpon*.

E. Habitat

The biogeography of *Geocarpon* is very strongly correlated with its surrounding plant community structure, underlying geologic substrate, and local soil chemistry. For this reason, information linking the species' geographic distribution, habitat requirements, and associated plant communities will be discussed together in this section.

1. **Missouri**

All sites in Missouri are located either in or near contact zones between rocks of Mississippian and Pennsylvanian Age or on the Pennsylvanian Age (Smith 1990) Channel Sands. Recent geological studies of this formation indicate that they were formed from ancient point bars in a meandering stream system with a southerly current flow (Easson 1984). These sandstones are composed of well-rounded quartz grains with some samples containing carbonate clasts in a fine-to-coarse sand matrix. Deposits of magnesium were also observed to occur as inclusions. Superficial deposits of this and other sandstones form a terrestrial vegetation type known as a sandstone-glade outcrop community. With extensive areas of the sandstone strata exposed, they support plant communities that are composed mainly of xerophytic shrubs and trees, with grasses, mosses, and lichens covering much of the barest rocky areas. Extensive sections of the glade may at first appear almost devoid of higher plant life.

In Missouri, the distribution of *Geocarpon* is limited to sandstone glades (Steyermark 1958). But within the glade itself, *Geocarpon* distribution is quite specific. Where seepage water flows across the slightly tilted sandstone strata, shallow depressions are beveled out, leaving gritty accumulations of loose sand with very little organic matter. These depressions are often partially ringed with mats of mosses and lichens. It is only in these shallow, sandy depressions with wet-season seepage that *Geocarpon* can be found. The sandy "soil" is often glued into a tough, spongy amalgam of lower plant thalli composed of moss protonemata, algae, and liverworts. This matrix probably prevents the loose grains of sand from washing completely out of the depressions. Few, if any, vascular plants other than *Geocarpon* inhabit these "bare spots." Also, numerous coin-sized pebbles composed of iron oxide and silica, commonly hematite, may be scattered about the individual *Geocarpon* rosettes.

During a recent survey of 147 Missouri sandstone glades, five new populations for *Geocarpon* were discovered and described (Thurman and Hickey 1989). Again, all five sites are on the Channel Sands. Another interesting correlation made by Thurman and Hickey: *Geocarpon* was never found on sandstone outcrops which did not support the lichen *Xanthoparmelia* sp. Therefore, the absence of this lichen may be useful as a negative indicator of habitats not suitable for *Geocarpon* (Thurman and Hickey 1989). Other plant associates included *Draba brachycarpa* Nutt.; *Plantago pusilla* Nutt.; *Houstonia minima* Beck; *Talinum* sp.; *Krigia* sp.; and the moss *Polytrichum juniperinum* Hedw.

2. Arkansas and Louisiana

Sandstone Glades. Although sandstone glades are common in the Ozark Highlands with many potential contact zones existing between the Pennsylvanian and Mississippian Age formations, to date, no *Geocarpon* populations have been found on Arkansas sandstones. Many of the species associated with *Geocarpon* sites in Missouri also occur on many of Arkansas' glades. These associate species include *Hypericum gentianoides* (L.) BSP.; *Plantago pusilla* Nutt.; *Saxifraga texana* Buckl.; *Selaginella rupestris* (L.) Spring; and *Selenia aurea* Nutt., all of which inhabit the shallow, seasonally-wet, lichen/moss-lined depressions typical of *Geocarpon* habitat. Also, the blue-green alga, *Nostoc* sp., was noted at some sites (Tucker 1983). Physiognomically, these depressions seem to duplicate those conditions typical of the Missouri glades with *Geocarpon*, but there are some important differences. The Channel Sands geological substrate is unique to Missouri. There are no sandstones in Arkansas with a mineral content and mode of formation quite like the Channel Sands sandstones. More specifically, no Arkansas sandstones are known to have high concentrations of magnesium or sodium (Haley, B.R., pers. comm., Arkansas Geological Commission 1987). Future geochemical characterization studies may reveal the presence of similar formations and thereby provide potential habitat information for additional *Geocarpon* field surveys. To date, no such sandstones are known to occur in Arkansas.

Saline Soil Prairies. All populations of *Geocarpon* known to occur in Arkansas and Louisiana are restricted to saline ("solonetz") or natric soils in plant communities classified as "saline soil prairies." *Geocarpon* was first discovered in such a habitat by Dr. D. Moore (1958). The soils are classified as fine silty, mixed, thermic Aquic and Glossic, Natrudalfs. First proposed by Rettig (1983), there appears to be a strict correlation between these soils, the savannah-like vegetation, and *Geocarpon*. These intriguing areas are characterized by the presence of a low, extensive cover of sedges -- *Scirpus koilolepsis* (Steud.) Gleason; grasses -- *Aristida longespica* Poir; *A. oligantha* Michx.; and *A. purpurascens* Poir. in Lam.; and forbs -- *Diodia teres* Walt. and *Anemone caroliniana* Walt. Particularly striking is the absence or extremely low density of trees and shrub species. The woody vegetation is usually limited to low, rounded mounds which range from strongly to medium acid in reaction. The dominant tree species are *Pinus echinata* Mill and *Quercus stellata* Wang. var. *mississippiensis* Ashe (Little) (Pell 1983). The understory of these mounds is composed largely of acidophilus heath species such as *Vaccinium arboreum* Marsh, *V. elliotii* Chapm., *V. stamineum* L., *V. virgatum* Ait., *Rhododendron canescens* (Michx.) G. Don, and *Lyonia ligustrina* (L.) DC. See Tucker (1983) and Kral (1983) for extensive floristic lists of plant community associates.

Soil Chemistry and Morphology. Such profound effects on vegetation and plant community structure are thought to be caused not by climate or fire but by soils of high salinity and alkalinity (Horn 1962). These conditions, which may exist in combination or independently, result in at least six separate sodic or natric soil series for Arkansas: the Carytown, Grubbs, Bonn, Foley, Wing, and Lafe silt loams. Altogether, they comprise an estimated 600,000+ acres in the State (Horn et al. 1964). In Louisiana, saline soil prairies have been identified as occurring on Bonn and Brimstone silt loams. Both are high in exchangeable sodium, the latter of which supports two small populations of *Geocarpon* (McInnis et al. 1991). Approximately 600 acres of saline soil prairie have been estimated to occur in Winn, Red River, and Natchitoches Parishes. Other sites may also occur in five additional central Louisiana Parishes as well as on Lafe silt loams near Baton Rouge (Smith and McInnis 1990).

Because of their close association with the known occurrences of *Geocarpon* in Arkansas and Louisiana, the chemical properties, morphological description and characteristic vegetation of these soils will be discussed in some detail below. The presence of a subsurface sodic horizon has dramatic effects on soil morphology, structure, pH, water relations, and vegetation cover (Horn 1962). The surface horizon is usually of silt or silt loam texture with the soil reaction varying from moderately acid to moderately alkaline. The source of the high concentrations of sodium and magnesium salts is the sodic subsurface B horizon.[1]

This diagnostic horizon is most commonly a silt loam in texture (e.g., the Lafe, Foley, and Bonn Series) but also can be composed of silty clays (e.g., the Wing, Bonn, Carytown, and Grubbs series). The exchangeable sodium may reach 20 to 40 percent at about 3 feet (Horn et al. 1962). These figures are often doubled for magnesium. Such high salt concentrations are correlated with columnar and prismatic subsurface soil structure, which in turn are correlated with arid-region soils. Such soil structure is quite unusual for soils of the temperate deciduous biome (Furst 1985).

Perhaps the most important physical effects of the sodic horizon are upon those soil factors that are critical to plant growth and development; for example, soil reaction, soil drainage, and soil-plant water relations. The soil pH can be extremely high in the sodic horizon (pH 8 to 10) and is caused by the hydrolysis of sodium salts forming hydroxyl ions (Brady 1974). Acid phases of Lafe and Foley soils exist in which the entire solum is acidic. Here, magnesium is the dominant exchangeable cation (Horn et al. 1964). Water-soluble salts dramatically affect drainage by causing electrostatic dispersion of the clay micelles present in the subsurface (Horn 1962). This deflocculation produces a soil that is extremely slippery when wet and dense, compact, and only slowly permeable to soil water and gases when dry. Thus, soil water capacity is low; soil aeration negligible; root toxicity high; and soil organic matter minimal. In short, this layer can behave much like a claypan, even though the clay fraction may be so low that it is not classified as a clay but as a silt loam. Such is the case for the Lafe and Foley subsurface horizons. Finally, the high concentrations of salts greatly reduce the osmotic potential of the soil solution, thereby further reducing the level of physiologically available soil moisture. In summary, a combination of high run-off, low field capacity, little organic matter, root toxicity, poor aeration, and low osmotic potentials produce soils with very poor biophysical conditions for plant growth.

All these edaphic factors interact at the community level to produce saline soil prairies with their typical savannah-like vegetation patterns. The depth of the natric horizon (very shallow in the Lafe and Brimstone soils) is a critical factor in the suppression of woody vegetation and the creation of suitable habitat for *Geocarpon*. The massive, poorly aerated, virtually unwettable subsurface horizon

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[1] Natric horizon is defined as a horizon in which exchangeable Na exceeds 15% or in which exchangeable Na + Mg exceeds H + Ca (Horn et al. 1962).

cannot support tree growth with its immense evapotranspiration demand. Vegetation is limited to the silt loam surface and is herbaceous in habit. Woody vegetation is sparse and limited to low mounds producing a savannah-like community structure. With the grassy, treeless area covering several acres, they are reminiscent of the better known prairies of the Midwest -- hence the name saline soil "prairie." It is here that *Geocarpon* can be found, but only in highly localized areas known as slick spots (Figure 3, page 31). (For additional details on slick spots and *Geocarpon*, see discussion under "Slick Spots" below.) Likewise, in Louisiana, savannah-like vegetation has developed over soils high in exchangeable alkaline metal salts to generate conditions injurious to many plant species, particularly to the woody flora (McInnis et al. 1991). The sites that support *Geocarpon* are on relatively high terraces that never flood. Although the general topographic relief is relatively flat, localized areas may rise to approximately 25 feet above the surrounding terrain with slopes of 20 degrees (Smith and McInnis 1990). The plant community is dominated by many of the same shallow-rooted species of grasses, sedges, and forbs that occur in Arkansas saline soil prairies.

Slick Spots. There is considerable variation among the classified groups of sodic soils relative to soil morphology, plant community development, and the distribution of *Geocarpon*. Perhaps the single most important determinant factor is the depth to the natric horizon. The deeper this horizon, the less pronounced are the deleterious effects upon a given soil's physical conditions. Conversely, the closer the natric horizon is to the soil surface, the poorer are these conditions for "normal" soil formation. For example, the effect on the native vegetation is most readily apparent in the Lafe soils. Here, the natric horizon is typically less than 10 inches deep, and the effect on soil morphology and vegetation is most readily apparent. In very localized areas, the close proximity of the natric horizon to the soil surface almost totally suppresses vascular plant growth (woody and herbaceous) to form a white or gray surface. As mentioned above, such areas are termed slick spots or alkali flats. They most often occur in saline soil prairies, which, of course, are formed by the same fundamental processes. This phenomenon seems to be critical to the distribution of *Geocarpon*. All known sites of *Geocarpon* in Arkansas and Louisiana occur in slick-spots on natric soils. Three of the four Arkansas sites have soils classified as belonging to the Lafe series. In fact, more than 14 separate sites have been found on Warren Prairie, a complex mosaic of expansive saline soil prairies, slick spots, tree-covered mounds and swamps -- all ringed with smaller "satellite" prairies to form a total area of some 1300+ acres (Orzell and Bridges 1987). The soil has been identified as belonging to the Lafe series and virtually every population of *Geocarpon* is restricted to the slick spot areas. In Louisiana, the only known site for the species occurs in slick spots over the Brimstone soil series. The natric horizon is within 16 inches of the soil surface and exchangeable sodium capacity ranges from 15 to 30 percent (Smith and McInnis 1990).

The microtopographic relationships within the slick spots seem to be critical to the spatial distribution of *Geocarpon* (Figure 3, page 31). Only a few scattered individuals can be observed in the totally bare areas at the center of a slick spot. Here, the salt concentrations can become so high that white patches of salt crystals are readily visible on the soil surface during the warm-season months. The heaviest *Geocarpon* reproduction occurs at the silt loam lip near the edge of the slick, where the vascular plant density of the surrounding savannah-like vegetation begins to decline dramatically (Orzell and Bridges 1987). As the density of vascular species approaches zero and where the non-vascular cryptogamic flora dominates, a micro-ecotone is clearly evident. Although no measurements of the ionic character across the face of a slick have been reported, it would appear that the highest concentrations of salts occur in the center and diminish toward the periphery where the surface horizon forms the lip and where *Geocarpon* density is the highest. In some extreme cases, the slick appears to be the exposed sodic horizon itself with the silt loam surface horizon completely removed.

The substrate that immediately surrounds and supports Geocarpon is not merely the silt loam of the subsurface horizon. The mineral soil, plus a spongy, leathery crust of moss protonemata, lichens and liverwort thalli interact to cement the lip into place. This organic amalgam of living plant tissue and mineral soil probably provides a moist, pliable seed bed for *Geocarpon* germination that does not easily erode. Interestingly enough, this amalgam of mineral soil and cryptogamic thalli is also present at the Bona Glade, Missouri, sandstone vernal pools that harbor *Geocarpon*. Compared with the bare, almost totally barren centers of the slicks and sandstone vernal pools, considerable moisture and pliability is provided by this living layer of plant tissue and mineral soil. See Schulten (1985) for a description of the soil aggregating properties of cryptogams on highly erodible soils of a southeastern Iowa sand prairie. This very localized portion of the slick spot has been named the cryptogamic lip. Closely associated with this micro-ecotone and the presence of *Geocarpon* are the vascular plants *Hedyotis australis* Lewis and Moore, *Plantago hybrida* Bart., and *Talinum parviflorum* Nutt. Multivariate statistical analysis indicates that *P. hybrida* is the closest associate species (Shepherd et al. 1991).

Because pH values of 7.5 and greater have been found to be positively correlated with the presence of alkaline-earth carbonates (Richards 1967), pH studies in the field may be useful in the characterization of potential habitats for *Geocarpon*. Soil pH measurements were made using a Hellige-Truog soil testing kit in the field. These values were measured along transects bisecting three slick spots at the Warren Prairie Natural Area and known to have *Geocarpon*. Amazingly, the values ranged from a pH of 5.0 to 8.0 from a position just beyond the cryptogamic lip to the bare mineral soil of the slick itself. The pH of the soil immediately around the roots of *Geocarpon* ranged from values of 5.5 to 7.0. Even on a scale of only 1 or 2 meters, the soil reaction may vary as much as 2 to 3 pH units. Such a wide fluctuation in soil reaction is a significant indication of the extreme nature of these habitats and is easily detected and measured by standard field techniques.

The actual causal mechanism(s) explaining slick spot formation is not totally clear. But some understanding of this process is critical to explaining the distribution of *Geocarpon* in Arkansas and Louisiana. At least two hypotheses have been given in the literature (Horn et al. 1964). Salts can be brought to the surface from the sodic subsurface horizon during solute movement by soil capillarity or by erosion of the surface horizon by wind or water. For those soils that have very shallow natric horizons (e.g., the Lafe series), slick spots were probably formed by the first mechanism. Occurring in bottomlands, the dissolved salts easily rise to the surface and are deposited upon evaporation. Thus, the slick spots become "wick points" for the underground sodic horizon. In really extensive formation of natric soil (as at Warren Prairie), the complex of "wick points" may be relatively ancient.

Erosion. In contrast, erosion may be the most important factor operating to produce slick spots in soils with much deeper natric horizons (e.g., the Carytown, Foley, and Wing series). Undisturbed sites underlain with these soils typically support communities with much denser tree canopies. Due to the plentiful rainfall during Spring in Arkansas and Louisiana, these areas can appear quite swamp-like. Typical tree species are *Quercus nigra* L., *Q. falcata* var. *pagodaefolia* Ell., *Q. phellos* L., *Ulmus alata* Michx. and *Gleditsia triacanthos* L.. Often, the vegetation is not stunted or savannah-like as in the saline soil prairies. Here, erosion seems to be the most important factor in producing slick spots. If the vegetation is removed by fire, timbering, or grazing, wind and water evidently can erode the silt loam surface, exposing the natric horizon below. These slick spots are relatively youthful in origin and many, if not most, are artificial. Such slick spots are often encountered throughout northwest Arkansas. Much of the Arkansas Valley lowlands has been converted to grazing land and, indeed, many slick spots surveyed by the Arkansas Natural Heritage Commission in 1986-1987 were located in cow pastures. Some of the most extensive sodic soil formations occur in the confines of Fort Chaffee. Here, exploding ordinance, land clearing operations, and fires have resulted in numerous "artificial" slick spots. Surprisingly, some of these slick spots replicate all the characteristics typical of those known to have *Geocarpon*, including the typical vascular associates species, the blue-green alga *Nostoc* sp., iron nodules, and the cryptogamic "lip" or ecotone.

F. Threats

1. **Missouri**

Geocarpon appears to be an early successional species inhabiting sandy, gravelly depressions on sandstone glades in the unglaciated prairie section of southwest Missouri. Such habitats are by their nature ephemeral. Soil development and plant succession, although arrested, may, with time, fill in these depressions with more competitive vascular plant species (Morgan 1980). As later successional grasses and shrubs invade and trap more soil and moisture, an oak-juniper woodland may eventually displace *Geocarpon* and its associate species. Field observations by Weber (in litt. 1992) indicate that competition from mosses and lichens may be even more critical than that from vascular plants. Disturbance of the glade may be necessary in order to maintain this species' typical habitat of shallow, sandy depressions in a subclimax state of succession.

Evidence for this view is based upon observations made at Carmack Branch Glade in Dade County, Missouri (Smith 1990). Here, aerial photos from 1960 indicate that this *Geocarpon* site was clearly pastured well into the center of the glade. The *Geocarpon* population ranges over 5 acres of sandstone glade and numbers 10,000+ individuals. This is one of Missouri's largest and most vigorous *Geocarpon* populations. The loosely aggregated sand particles of the Channel Sands had easily eroded to fill a number of sandy washes, providing abundant habitat for *Geocarpon*.

In contrast to, but not necessarily in contradiction of, the role of disturbance factors and *Geocarpon* already discussed, another Missouri glade has been severely degraded by cattle grazing (Smith 1990). At the Corry Branch Glade, also in Dade County, grazing on deeper soils around the periphery of the glade led to increased siltation of the sandy depressions supporting known stands of *Geocarpon*. The silt provided sufficient soil depth for the migration of more competitive plant species into these once nearly barren microhabitats. The sandy/gravelly washes and *Geocarpon* had both disappeared in most of the known stands. The nearby Bona Glade Natural Area, which had continued to produce ample amounts of the plant, was used as a control in order to take into account the seasonal fluctuations in *Geocarpon* population levels as well as the effects of siltation. Such comparisons led to the recommendation that cattle be excluded from the Corry Branch Glade (Smith 1990). Apparently, the role of micro-successional processes, siltation and grazing have important effects that need to be addressed by any long-term recovery effort devoted to the protection of *Geocarpon*.

2. **Arkansas and Louisiana**

Due to the increase in human disturbance of the States' natural vegetation over the last 100 years, there probably has been a great increase in the number of slick spots and, thereby, an increase in the habitat available for the establishment of *Geocarpon*. But without any apparent mechanism for effective seed dispersal, colonization of newly available niches is probably minimal. Preliminary transect studies across several slick spots in the Warren Prairie Natural Area indicate that *Geocarpon* is not a particularly vagile species even within a given slick spot network (Shepherd et al. 1991). Given their irregular shapes, frequent occurrence, and high density in an extensive tract of high quality saline soil prairie, ample opportunity for new colony formation seems to be ideal. Yet, this does not seem to be the case for the short run. Continued monitoring of the Warren Prairie populations should provide important information concerning population dynamics for the species. In summary, even though there appear to be extensive and numerous habitats available for *Geocarpon* in the form of 600,000+ acres of sodic soils, the number of actual occurrences is quite small. Almost every mapped sodic soil formation in northwest Arkansas was surveyed and only one site was found to have *Geocarpon* (Orzell and Bridges 1987, Pittman 1988).

The exact nature of disturbance factors and their effects on the long-term viability of *Geocarpon* in Arkansas and Louisiana is not clear. Various observers have indicated that the greatest threats to *Geocarpon* are the conversion of saline soil prairies to pastureland and off-the-road vehicular traffic as discussed above. In both cases, the contention is that soil erosion could upset the seemingly delicate spatial balance of *Geocarpon* relative to its position across the face of the slick spot. A secondary effect would be the invasion of "weedy" salt-tolerant pasture species that could outcompete and replace *Geocarpon*. Preliminary observations seem to indicate that soil disturbance may actually provide the initiation of events which actually lead to slick spot formation and thereby provide additional suitable habitat for the species. But, repeated cycles of soil disturbance by cattle grazing and off-the-road vehicles, particularly during wet periods, could destroy or prevent the formation of those micro-edaphic relationships that seem to be critical to the sustainability of existing *Geocarpon* populations as now exist. Further complicating the role of disturbance is the limited knowledge concerning seed dispersal and seed germination ecology for the species. However, both grazing and off-road vehicular traffic have not destroyed Arkansas' two largest and seemingly most stable *Geocarpon* populations.

The role of disturbance factors in the formation of slick spots and in the population biology of *Geocarpon* will require critical study. Fire does not appear to be the most critical factor in the origin or maintenance of essential habitat for *Geocarpon*. The saline soils are characteristically very low in accumulated organic matter; less than 2 percent organic matter was measured from soils collected at the Warren Prairie Natural Area (University of Arkansas - Fayetteville, 1986). Although fires will carry through the slick spots as well as the open savannah-like vegetation, there is so little fuel available for combustion that fire intensity is minimal. As discussed, the lack of woody vegetation and the presence of appropriate *Geocarpon* habitat are apparently due to edaphic factors.

At the community level, fire does appear to be important in maintaining the saline soil prairies' characteristic savannah-like vegetation where the natric horizon is of sufficient depth to support stands of *Pinus echinata* Mill, *P. taeda* L., *Quercus marilandica*

Muench, *Q. stellata* Wang. and *Carya tomentosa* Nutt. Stands of *Vaccinium arboreum* Marsh, *V. elliotii*, Chapm. and *V. virgatum* Ait. will form dense thickets in the understory. Periodic burning thins this dense understory and allows for the establishment of various grass species. At the Warren Prairie Natural Area, *Sporobolus junceus* and *Anthaenantia rufa* have become established in such areas. Both these species are typical of the fire-maintained pine barrens and savannahs that once covered extensive areas along the Gulf and southern Atlantic Coastal Plains. Both of these grass species are extremely rare in Arkansas. Clearly, fire does affect the physiognomy and floristics of saline soil prairies that support Arkansas and Louisiana populations of *Geocarpon*. But, it appears that the severe effects of superficial deposits of salts in the solum have led to a stable edaphic climax with fire playing a secondary and perhaps minimal role in the ecological requirements of *Geocarpon*.

G. Conservation Measures

Systematic surveys for additional populations have been conducted in all States where *Geocarpon* is known to occur: in Louisiana, by McInnis and Smith (1991), in Missouri, by Morgan (1980) and Thurman and Hickey (1990), and in Arkansas (Pittman 1988). The Arkansas Natural Heritage Commission (ANHC) has been monitoring the Warren Prairie population (Bradley and Drew Counties) annually since 1986 through a Section 6 grant (Shepherd et al. 1991). The Missouri Department of Conservation (MDC) has been working with the U.S. Army Corps of Engineers (COE) to develop management plans for the populations on COE property (Smith in litt. 1992). Preliminary seed biology and germination studies of geocarpon have been carried out by a graduate student of Southwest Missouri State (Weber in litt. 1992). Currently, there are 600 seeds in storage at the Nebraska Statewide Arboretum as part of the Center for Plant Conservation's National Collection of Endangered Plants. The National Collection is a source of plant material for germplasma storage, research, and conservation of rare and endangered plants in the wild (Olwell, Center for Plant Conservation, in litt. 1992).

Site registration, management agreements, and land acquisition by The Nature Conservancy (TNC) and MDC in Missouri have resulted in protection for 11 sites in the Ozark Natural Division and one in the Osage Plains. This includes two MDC Designated Natural Areas, one owned by MDC, and one by the COE. A portion of the largest *Geocarpon* population in Arkansas is protected through its ownership by the ANHC and designation as the Warren Prairie Natural Area.

PART II: RECOVERY

A. Objective

The recovery goal for *Geocarpon* is to delist the species. *Geocarpon* will be considered for delisting when a total of 15 viable populations, representing the diversity of habitats and the geographic range of the species, are protected as necessary to ensure their continued existence. Populations should also include the wide spectrum of current genetic variation found in the species.

Populations are protected if they are secure from any present or foreseeable threats. Although publicly owned sites should be protected from immediate destruction by most anthropogenic agents, long-term survival of these populations may require active measures to abate less acute threats.

A viable population is one which is reproducing and stable or increasing in size. Population viability should be confirmed through periodic monitoring for at least a 15-year period.

These recovery criteria are preliminary and may be revised on the basis of new information.

B. Tasks

1. Protect viable populations of Geocarpon to include all variations in habitat across its known geographic range.

1.1 Protect existing populations in Missouri, Arkansas, and Louisiana.

1.1.1 Missouri. Some sort of protection (i.e., site registration, management agreements, land acquisition) has been achieved for 12 sites in Missouri. Protection should be sought for remaining populations on sandstone glades of the Channel Sands.

1.1.2 Arkansas. Protect populations on saline soil prairies in the West Gulf Coastal Plain and the Arkansas Valley Natural Divisions. Warren Prairie, located in southeastern Arkansas, is within the West Gulf Coastal Plain and comprises some 1300+ acres of high-quality saline soil prairie and pine woodlands. The numerous slick spots support over 25 subpopulations of *Geocarpon*, approximately half of which are within the Warren Prairie Natural

Area, owned by the ANHC. The other saline soil prairie acreage is a high-priority acquisition project for the ANHC. The Branch Saline Soil Prairie is the second largest *Geocarpon* site in the State. This area has been recommended for acquisition by ANHC.

1.1.3 Louisiana. Protect the two populations of *Geocarpon* discovered recently on saline soil prairies in Winn Parish. Both populations occur on lands owned by Cavenham Forest Industries. Appropriate personnel have been contacted and an effort is currently being made to secure a commitment from Cavenham to protect these populations (McInnis and Smith 1991).

1.2 Search for additional populations in Arkansas, Mississippi, Oklahoma, and Texas. Intensive field work for new populations of *Geocarpon* has been on-going in Missouri since the late 1950's to the present (Steyermark et al. 1959, Smith 1990). Surveys to locate additional populations in Louisiana were undertaken in March of 1991 (McInnis and Smith 1991). Potential sites were targeted through an examination of the literature, soil maps, and aerial photography. A total of 22 sites in 6 parishes was visited. Although additional small populations may occur in these States, further intensive, large-scale field surveys do not seem to be warranted in Missouri and Louisiana at this time.

1.2.1 Arkansas. Considerable field research has been devoted to reconnaissance efforts on saline soil prairies in the West Gulf Coastal Plain and the Arkansas Valley (Rettig 1983, Tucker 1983, Orzell and Bridges 1987, and Pittman 1988). Less field work has been directed to the many thousands of sandstone glades in the Arkansas Interior Highlands (Tucker 1983, Pittman 1988). Several large, flat sandstone outcrops have been discovered in the Ozark National Forest and may provide suitable habitat for *Geocarpon*. These areas should be intensively surveyed for additional populations of the species.

Less priority should be assigned to additional searches on the Arkansas saline soils.

1.2.2 Other States. Saline soils are known to occur in other portions of the humid South, including parts of Mississippi, eastern Oklahoma, and eastern Texas (Furst 1985). These areas need to be surveyed in order to determine vegetation characteristics and check for the presence of slick spots. If suitable habitat is present on these soils, such areas should also be intensively surveyed for *Geocarpon*.

2. Study the ecology and species biology.

2.1 Characterize the chemical, physical, and biological micro-environment immediately supporting Geocarpon.

2.1.1 Analyze the physical habitat. With the aid of a soil scientist, a complete soil analysis of the sandstone depressions and slick spot micro-habitats should be undertaken to describe those alkali-metal salts and their relative base saturations that exist in the soil directly supporting individual plants.

2.1.2 Determine the soil chemical profiles of saline soil prairies and the origin of slick spots. Systematically survey such soil chemical properties as soil reaction, texture, electrolytic conductivity, alkali-metal content, percentage base saturation, and depth to natric horizon in order to more precisely characterize those soil series and areas that produce *Geocarpon*-supporting slick spots and those that do not.

2.1.3 Describe the cryptogamic flora that forms the micro-ecotone which glues soil particles into place around slick spots and in sandstone depressions. Determine if this soil aggregation process is critical to the survival of *Geocarpon*.

2.1.4 Determine those factors that apparently restrict Geocarpon to a very limited set of flatrock sandstone glades. By comparing soil and mineralogical characteristics of the Channel Sands with other nearby sandstones of similar geologic age, significant differences in the underlying bedrock geology of these sandstones may be detected.

2.1.5 Determine those factors that control seed germination and phenology. Wide fluctuations in population counts of flowering individuals have been measured for *Geocarpon* in recent demographic studies in Arkansas (Shepherd et al. 1991) and in Missouri (Morgan 1986). Morgan indicates that *Geocarpon* on the Bona Glade Natural Area behaves like a winter annual by germinating as early as November and flowering in March or April. Its life cycle in Arkansas is unclear as discrepant observations are reported from Arkansas. Seed germination studies should be carried out to determine how temperature, photoperiod, soil moisture, and chemistry influence these wide population fluctuations typical of the species.

2.1.6 Conduct genetic analyses of the sandstone versus the slick spot populations. Field studies indicate that differences in habit, phenology, and micro-environment exist between the sandstone and saline soil populations. Genetic analyses would insure that distinctive ecotypes or even subspecific differences are recognized and accounted for in protection efforts devoted to this species' preservation. This task could be accomplished through allozyme or DNA sequencing technology.

2.1.7 Further investigate breeding biology, seed set, and seed banking. There are no apparent structural modifications of flowering fruit or seed that appear to promote outcrossing or long distance seed dispersal (Tucker 1983, Morgan 1986). Capsules appear to mature and dehisce and then rain seeds into the soil below; however, a significant number of seeds may remain in the capsule after it dehisces (Weber in litt. 1992). Studies of the long-term viability of seeds under field and lab conditions would give helpful information on the importance of seed banks and the widely fluctuating population levels observed in flowering stands (Shepherd et al. 1991).

3. Continue species monitoring and demographic studies at designated natural areas.

   3.1 Design experimental sampling procedures across *Geocarpon*-bearing slick spots and glades in order to monitor long-term successional relationships. Demographic studies using transects across sandstone depressions in the Bona Glade Natural Area (MO) and across slick spots on the Warren Prairie Natural Area (AR) have been used to document population changes through time. These same transects could also be adapted to study longer-term, micro-successional relationships and *Geocarpon* recruitment and survivorship. The role of disturbance factors and the relative competitive ability of *Geocarpon* is not clear. Morgan (1986) and Weber (in litt. 1992) indicate that vascular and non-vascular plants may negatively alter the species' habitat. Some levels of soil and vegetation disturbance may be critical to maintaining slick spot and sandstone micro-environments; intense levels of disturbance may destroy the soil-aggregating qualities of the cryptogamic flora and lead to loss of habitat. The nature and degree of disturbance factors needs additional scientific study.

4. Preserve genetic stock. Maintain a representative sample of the species' genetic potential by collecting seeds from across its known variation in population, habitat, and geographic characteristics and establish a permanent seed repository at a recognized botanic garden. The Nebraska Statewide Arboretum, member garden of Center for Plant Conservation (CPC), currently has 600 seeds in storage at their facility (Olwell in litt. 1992). Seed should be collected from additional populations to further preservation of genetic stock.

5. Establish additional populations in the Arkansas Valley Natural Division, if deemed necessary. Currently, there is only a single population of *Geocarpon* in the Arkansas Valley Natural Division. This population is on private land and is extremely vulnerable. An additional population may need to be established in the Arkansas Valley to ensure the survival of the species in that area. Such establishment efforts should only be initiated after extensive searches for natural populations in that area have failed.

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PART III: IMPLEMENTATION SCHEDULE

The following implementation schedule outlines recovery actions and their estimated costs for the first three years of the recovery program. It is a guide for meeting the objective discussed in Part II of this plan. This schedule indicates task priorities, task numbers, task descriptions, duration of tasks, the responsible agencies, and lastly, estimated costs.

Priorities in column one of the following Implementation Schedule are assigned as follows:

1 - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

2 - An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

3 - All other actions necessary to provide for full recovery of the species.

<u>Key to acronyms used in Implementation Schedule</u>

ANHC - Arkansas Natural Heritage Commission
COE - U.S. Army Corps of Engineers
CPC - Center for Plant Conservation
TE - Endangered Species Division, U.S. Fish and Wildlife Service
LNHP - Louisiana Natural Heritage Program
MDC - Missouri Department of Conservation
MNHP - Mississippi Natural Heritage Program
ONHI - Oklahoma Natural Heritage Inventory
Pvt. - Private individual, university, or other research organization
TNC - The Nature Conservancy
TNHP - Texas Natural Heritage Program
USFWS - U.S. Fish and Wildlife Service

IMPLEMENTATION SCHEDULE										
				RESPONSIBLE PARTY			COST ESTIMATES ($K)			
				USFWS						
PRIORITY #	TASK #	TASK DESCRIPTION	TASK DURATION	Region	Division	Other	FY 1	FY 2	FY 3	COMMENTS/NOTES
1	1.1	Protect populations.	continuous	4, 3	TE	ANHC,COE LNHP,MDC TNC	2.0	2.0	2.0	Cost estimate exclusive of land acquisition actions which will greatly increase costs for this task.
2	1.2.1	Search for additional populations in AR.	2 years	4	TE	ANHC	3.0	3.0	-	
3	1.2.2	Search for populations outside known range.	2 years	4, 2	TE	MNHP, TNHP, ONHI	7.5	7.5	-	$2500/State
2	2.1.1-2.1.4	Analyze chemical and physical environment.	2 years	4, 3	TE	Pvt.	5.0	5.0	-	
2	2.1.5	Investigate seed germination and phenology.	2 years	4, 3	TE	ANHC,CPC LNHP,MDC Pvt.	5.0	5.0	-	
2	2.1.6	Genetic analyses	1 year	4, 3	TE	Pvt.	8.0	-	-	Cost includes collecting and analyses.
2	2.1.7	Study breeding biology, seed set and seed banking.	3 years	4, 3	TE	CPC,ANHC LNHP,MDC Pvt.	10.0	10.0	10.0	
2	3	Conduct monitoring and demographic studies.	continuous	4, 3	TE	ANHC,MDC LNHP	15.0	10.0	10.0	
3	4	Preserve genetic stock.	continuous	4, 3	TE	CPC			10.0	One-time fee into National collection
3	5	Establish population in Arkansas Valley, if necessary.	3 years	4	TE	ANHC,CPC				Cost to be determined

PART IV: APPENDIX

Table 1: Site Records of *Geocarpon minimum*

Missouri

County	Site Name/Quad	Natural Division	Collection/Observation Data	Ownership/ Protection Comments
Cedar	Tara Glade Boná 7.5	Ozark	First observed 1989 Last observed 4-20-89 About 2000 plants Source: MDC	-COE- Sandstone outcrop will be posted to prevent trampling and soil erosion
Cedar	Cave Branch Glade Roscoe 7.5	Ozark	First observed 1984 Last observed 4-17-91 About 4,000 plants Source: MDC	-Private- Owner protecting but will not register with TNC
Cedar	Leila Glades Caplinger Mills 7.5	Ozark	First observed 2-5-84 Last observed 1984 About 200 plants in two small populations Source: MDC	-Private- not protected
Cedar	Coal Bank Hills Glades Caplinger Mills 7.5	Ozark	First observed 5-16-89 Last observed 4-11-91 350 plants in fruit and flower Source: MDC	-Private- not protected
Dade	Bona Glade Bona 7.5	Ozark	First observed 1973 Last observed 5-92 2000 + plants Source: MDC	-COE- Designated natural area

Dade	Corry Branch Glade Dadesville 7.5	Ozark	First observed 1978 Last observed April 1989 Form separate glade areas with thousands of plants scattered on outcrops along Stocton Reservoir Source: MDC	-COE- MDC manages
Dade	Carmack Branch Glade Bona 7.5	Ozark	First observed 1984 Last observed 4-26-88 Over 10,000 + plants scattered over several acres of severely grazed sandstone glade Source: MDC	-Private- TNC registered site
Dade	Corry Flatrocks Greenfield 7.5 Dadesville 7.5	Ozark	First observed 1984 Last observed 4-27-88 About 3,500 plants in heavily grazed pasture; one of the largest populations in Missouri Source: MDC	-Private- S 1/2 of population registered by TNC. N 1/2 owned by TNC.
Dade	Maze Creek Outcrops Dadesville 7.5	Ozark	First observed 1984 Last observed 5-8-84 About 100-200 plants on small sandstone glades along road Source: MDC	-MO Dept. of Highways and Transportation- posted to prevent vehicular traffic
Dade	Maze Branch Glade Bona 7.5	Ozark	First observed 1988 Last observed 5-2-89 About 3,500 plants Source: MDC	-COE-

Dade	Flint Hill Glades Bona 7.5	Ozark	First observed 1989 Last observed 4-19-89 1000 + plants Source: MDC	-COE & Private- most plants on private property
Dade	Rice Glade Dadesville 7.5	Ozark	First observed 1989 Last observed 4-6-89 About 1000 plants Source: MDC	-Private- not protected
Dade	Power Outcrop Bona 7.5	Ozark	First observed 1989 Last observed 4-11-89 About 1400 plants Source: MDC	-Private- not protected
Greene	Pearl Glade Willard 7.5	Ozark	First observed 1958 Last observed 4-25-84 Mosses and lichens over- growing most suitable microhabitats, only about 10 plants observed. Plants not seen in recent years. Source: MDC	-Private- not protected
Jasper	Slater Branch Prairie Neck City 7.5	Ozark	First observed 1913 Last observed 4-17-49 Type locality Palmer No. 3921, unsuccessfully surveyed 6-8-88 Source: MDC	-Private- Extirpated
Lawrence	Halltown Glade Halltown 7.5	Ozark	First observed 1979 Last observed 5-6-88 Several hundred plants Source: MDC	-Private- not protected

Polk	Eudora Glades Walnut Grove 7.5	Ozark	First observed 1978 Last observed 5-7-84 About 2,000 plants Source: MDC	-Private- TNC registered
Polk	Graydon Springs Glade Walnut Grove 7.5	Ozark	First observed 1958 Last observed 5-8-84 Mosses and lichens growing over suitable habitat. Plants not seen in recent years. Source: MDC	-Private- not protected
St. Clair	Taberville Prairie Natural Area Taberville 7.5	Osage Plains	First observed 1985 Last observed 5-26-89 Several hundred plants scattered across glade Source: MDC	-MDC- Designated natural area
St. Clair	Collins Glade Vista 7.5	Ozark	First observed 1986 Last observed 5-3-86 Several hundred plants present Source: MDC	-Private- not protected
St. Clair	T037N,R026W Section 36 Vista 7.5	Ozark	First observed 1957 Last observed 5-2-84 About 200 plants observed 1000 plants estimated to occur over an area of 1 acre Source: MDC	-Private- TNC registered
St. Clair	Charles and Elizabeth Schwartz Prairie Roscoe 7.5	Ozark	First observed 1990 Last observed 4-11-91 600 plants observed, additional suitable habitat present over 3-5 acres of sandstone glade Source: MDC	Missouri Prairie Foundation-protected

Arkansas

County	Site Name/Quad	Natural Division	Collection/Observation Data	Ownership/ Protection Comments
Bradley & Drew	Warren Prairie Natural Area Wilmar South 7.5	West Gulf Costal Plain	First observed 1958 Last observed 1990 1300+ acres of saline soil prairie and pine woodlands, 25+ small populations localized into isolated slick spots scattered throughout areas of saline soil prairie Source: ANHC	-ANHC- Designated Natural Area & Private Approximately 1/2 the saline soil prairies in the Natural Area, the other 1/2 is high priority acquisition project for ANHC
Cleveland	Kingsland Prairie New Edinburg 7.5	West Gulf Coastal Plain	First observed 1982 Last observed 4-5-84 Few plants in disturbed saline soil (Lafe series) Source: ANHC	-Private- not protected
Cleveland	New Edinburg Prairie New Edinburg 7.5	West Gulf Coastal Plain	First observed 1984 Last observed 4-7-84 3 plants seen on saline soil prairie Source: ANHC	-Private- not protected
Franklin	Branch Saline Soil Prairie Branch 7.5	Arkansas Valley	First observed 4-20-86 Last observed 4-89 Many hundreds of plants scattered around slick spots Source: ANHC	-Private- not protected, ANHC acquisition project

Louisiana

Parish	Site Name/Quad	Natural Division	Collection/Observation Data	Ownership/ Protection Comments
Winn Parish	Saline Creek Prairie Tullos 7.5	West Gulf Coastal Plain	First observed 1990 Last observed 3-15-91 Approx. 300 plants in 2 separate prairie openings Source: LNHP	-Private- not protected, LNHP protection project
Winn Parish	Castor Creek Saline Prairie Tullos 7.5	West Gulf Coastal Plain	First/last observed 3-6-91 Approx. 300 plants in 4 separate locations in prairie Source: LNHP	-Private- not protected, LNHP protection project

Codes:
ANHC = Arkansas Natural Heritage Commission
COE = Corps of Engineers
LNHP = Louisiana Natural Heritage Program
MDC = Missouri Department of Conservation
TNC = The Nature Conservancy

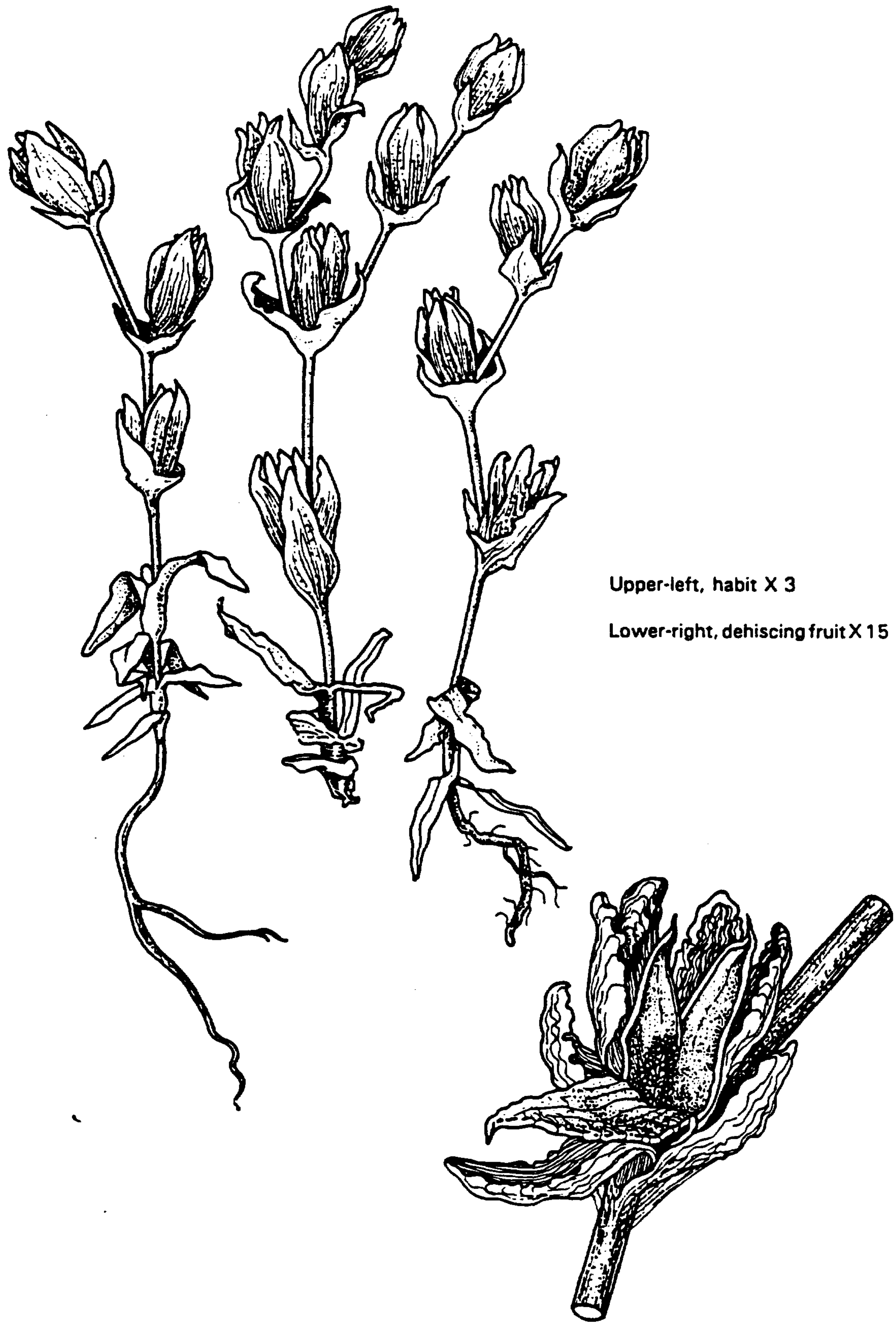

Figure 1. Line drawing of Geocarpon minimum Mackenzie.

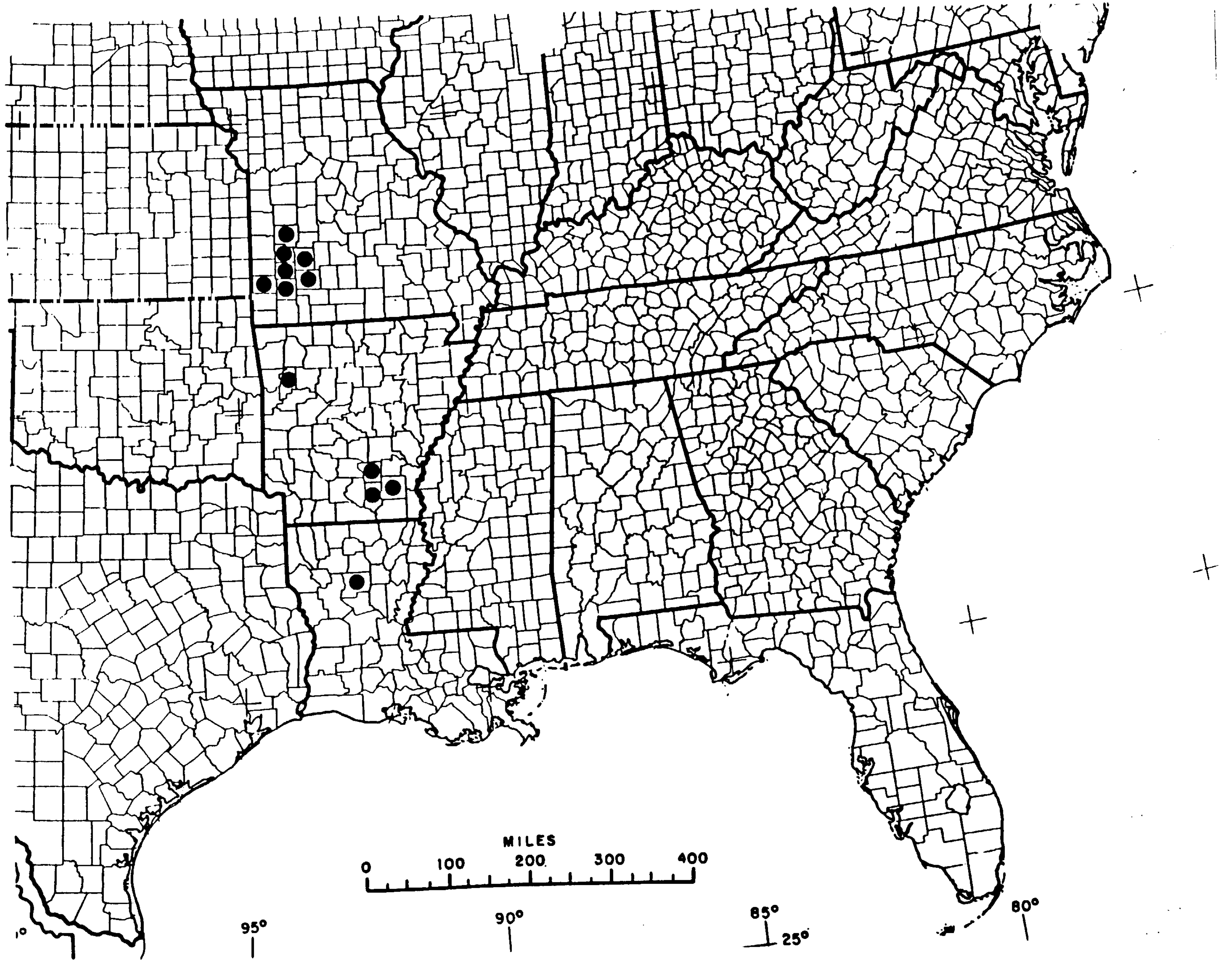

Figure 2. County distribution of Geocarpon minimum.

A silt loam surface horizon
B illuvial natric subsurface horizon
1 *Diodia teres*
2 *Aristida* sp.
3 *Saxifraga texana*
4 *Polytrichum* sp.
5 fruticose lichen
6 *Plantago hybrida*
7 crustose lichen
8 *Geocarpon minimum*
9 *Nostoc* sp.
10 *Rumex hastatulus*
11 iron nodules
12 cryptogamic lip

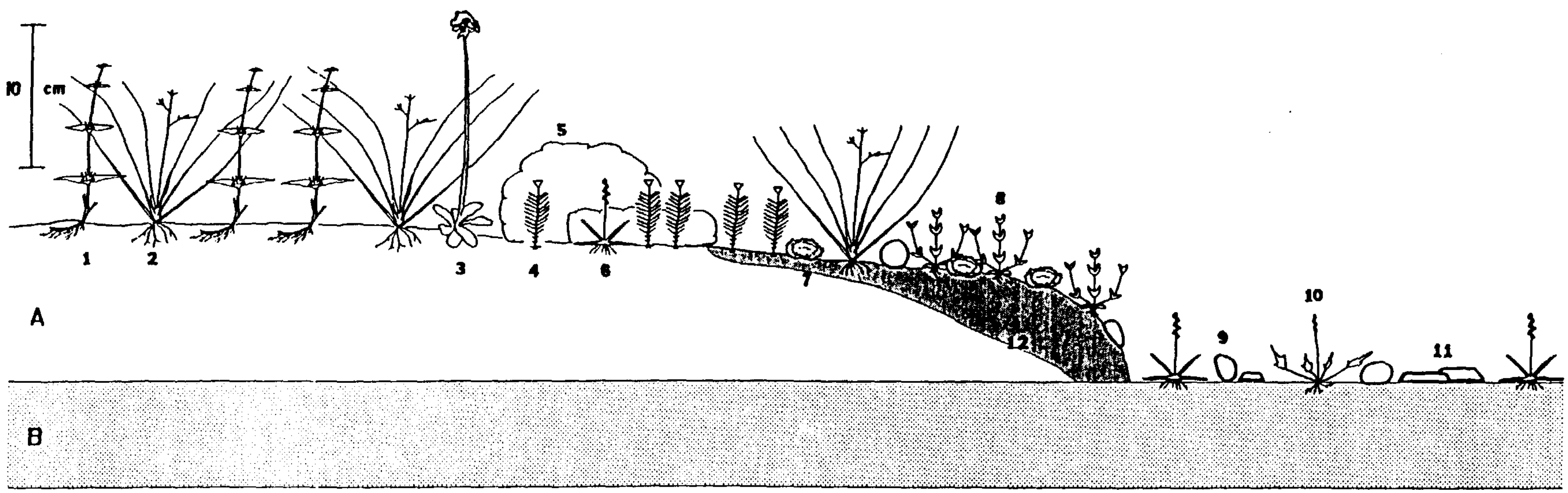

Figure 3. Profile of a slick spot indicating key microtopographic features, vegetation, and position of *Geocarpon.*

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