New England Plant Conservation Program

Linum sulcatum Riddell
Grooved flax

Conservation and Research Plan for New England

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SUMMARY

Linum sulcatum Riddell is a widespread annual in the flax family (Linaceae), distributed throughout the tall- and midgrass prairie states, extending eastward to Georgia and north into New England. In Iowa, Missouri, and other states with prairie remnants, it is a characteristic species of high-quality dry to mesic natural grassland sites. In the Midwest, it does not compete well in disturbed areas. Eastward, it occurs in cedar glades, pine-oak woodlands, serpentine barrens, steep-sloping calcareous sites, and isolated disturbed areas. *Linum sulcatum* has been recorded from 31 states and three Canadian provinces. It is listed as rare in 11 states and one province, and is known only from historical records in five states.

In New England, the more natural occurrences of *Linum sulcatum* were associated with the calcareous regions in Western Connecticut, Massachusetts, and Vermont. It has been collected in Vermont (three sites), Massachusetts (three sites), Rhode Island (one site), New Hampshire (one site), and Connecticut (16 sites), but is known currently in New England from only two sites in Connecticut. It is listed in *Flora Conservanda* as a Division 2 species, globally secure, but regionally rare. The two Connecticut sites are both privately owned and maintained by regular disturbances. One population with less than 100 plants is at the edge of an abandoned quarry that is now surrounded by residential and commercial development. The other site, with 500 plants primarily located along a power line right-of-way, is managed by periodic manual cutting of shrubs and trees and herbicide applications.

Linum sulcatum is taxonomically distinct and clearly distinguishable from the other six *Linum* species that occur in the Northeast. It is insect-pollinated, probably self-compatible, forms seedbanks, and germinates readily without cold treatment. It grows in full sun and does not compete well with other species. It is not known to form natural hybrids.

The conservation objectives for *Linum sulcatum* are to: 1) protect all New England populations that are currently known in habitat that is maintained by natural processes; 2) search for new populations in natural habitat; and 3) if additional populations are located, to protect a total of five populations in Connecticut and two each in New Hampshire, Vermont, Massachusetts, and Rhode Island, all within the historical range of the species. Populations should be managed, if necessary, to maintain a population of at least 100 plants at each site. A detailed habitat-use model should be developed. All sites should be monitored for population level, habitat extent, and associated species to develop a better understanding of population dynamics and characterize habitat in New England. Pollinators, seed viability, and self-compatibility should be examined to determine if seed set is limiting in New England. All efforts should include nearby sites in New York, where the plant is also rare and there is additional potential habitat.

PREFACE

This document is an excerpt of a New England Plant Conservation Program (NEPCoP) Conservation and Research Plan. Full plans with complete and sensitive information are made available to conservation organizations, government agencies, and individuals with responsibility for rare plant conservation. This excerpt contains general information on the species biology, ecology, and distribution of rare plant species in New England.

The New England Plant Conservation Program (NEPCoP) of the New England Wild Flower Society is a voluntary association of private organizations and government agencies in each of the six states of New England, interested in working together to protect from extirpation, and promote the recovery of the endangered flora of the region.

In 1996, NEPCoP published "*Flora Conservanda*: New England." which listed the plants in need of conservation in the region. NEPCoP regional plant Conservation Plans recommend actions that should lead to the conservation of *Flora Conservanda* species. These recommendations derive from a voluntary collaboration of planning partners, and their implementation is contingent on the commitment of federal, state, local, and private conservation organizations.

NEPCoP Conservation Plans do not necessarily represent the official position or approval of all state task forces or NEPCoP member organizations; they do, however, represent a consensus of NEPCoP's Regional Advisory Council. NEPCoP Conservation Plans are subject to modification as dictated by new findings, changes in species status, and the accomplishment of conservation actions.

Completion of the NEPCoP Conservation and Research Plans was made possible by generous funding from an anonymous source, and data were provided by state Natural Heritage Programs. NEPCoP gratefully acknowledges the permission and cooperation of many private and public landowners who granted access to their land for plant monitoring and data collection.

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I. BACKGROUND

INTRODUCTION

Linum sulcatum Riddell is a widespread member of the flax family (Lincaeae). Nomenclature follows Mitchell and Tucker (1999). *Linum sulcatum* is divided into two varieties (Rogers 1963). *Linum sulcatum* var. *harperi* (Small) C. M. Rogers is restricted to Georgia, Alabama, and Florida and is globally rare. *Linum sulcatum* var. *sulcatum* is one of the most widespread members of its genus in North America and is distributed from Manitoba south to Texas and east to Georgia and New Hampshire (NatureServe 2003). It is known from 31 states and three Canadian provinces. *Linum sulcatum* var. *sulcatum* is the subject of this plan.

Linum sulcatum is taxonomically distinct and is the only member of one of the five complexes of species within the genus *Linum* in North America (Rogers 1963). There have been numerous taxonomic studies of *Linum*, partly because of the commercial value of *Linum usitatissimum*, which is not native to the New World but is grown for its fiber for making linen and for the production of linseed oil (Rogers 1969). *Linum sulcatum* is the only species native to North America with a base chromosome number of 15, which is also the haploid chromosome number for *L. usitatissimum* (Dillman 1933). These two species are not known to hybridize. *Linum sulcatum* is easily distinguished for the other six species of *Linum* found in the Northeast. It is also fairly easy to identify in the field.

In the Midwest, *Linum sulcatum* is a characteristic species of dry to mesic tall- and midgrass prairies (Harvey 1908). In some areas, it is considered an indicator of good quality prairie. It does not compete well with other species, particularly invasives, in Midwestern disturbed sites. It does not do well after fire (Albertson 1937) or when affected by natural animal disturbances, such as gopher burrowing (Gibson 1989). It does, however, subsequently colonize newly disturbed areas.

In the East, *Linum sulcatum* occurs in a range of open, sunny communities on alkaline soils. It is found in cedar glades, oak-pine woods, serpentine barrens, and other calcareous slope communities. It is also found at some disturbed sites in the East, particularly in New England, where it has historically been collected on roadsides and in old fields. Typical associated species in New England include *Schizachyrium scoparium, Juniperus virginiana, Centaurea maculosa, Celtis occidentalis,* and *Poa compressa*. It often occurs with other state and regionally rare species, including *Bouteloua curtipendula, Draba reptans, Onosmodium virginianum, Aristolochia serpentaria, Sporobolis asper, Liatris borealis, and Hedeoma hispidum.*

Linum sulcatum is an annual that forms seedbanks. It is insect-pollinated and probably self-compatible (Vince Eckhart, Grinnell College, personal communication). Like all members of *Linum*, it contains cyanogenic glycoside linaniarin that hydrolyzes to prussic acid or hydrogen cyanide (Frohne and Pfander 1984). Plants are bitter-tasting and toxic to some animals. *Linum sulcatum* is generally not eaten by deer (Dix 1959). It has been used medicinally for a broad range of ailments including stomach distress and as a topical astringent to treat burns and ulcers (Frohne and Pfander 1984).

Linum sulcatum is rare in New England, currently known from only two sites and from an additional 22 towns documented by specimens. Most specimens were collected between 1868 and 1927. It has been collected in New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island. Most of the specimens in the eastern and southern parts of New England suggest that it is a species of disturbed areas, mainly roadsides and old fields. In the calcareous regions of New England in northwestern Connecticut and southwestern Massachusetts and in southwestern Vermont, *Linum sulcatum* occurs in successional cedar glades and in other openings on alkaline, sandy soil. One site in Connecticut has collections that span nearly 90 years.

Both currently-known sites in New England are privately owned and vulnerable. *Linum sulcatum* is listed in the *Flora Conservanda* as a Division 2 species, globally secure, but regionally rare (Brumback and Mehrhoff et al. 1996).

The conservation objective for *Linum sulcatum* is to protect all known populations in New England and to locate and protect new populations in habitat maintained by natural processes to attain a total of five populations in Connecticut and two each in New Hampshire, Vermont, Massachusetts, and Rhode Island. If populations are found in natural areas at other New England states, two populations in each state should also be protected. Conservation actions also include the development of a habitat-use model, monitoring to understand population dynamics, research to understand the biology and ecology of the species and the reasons for its rarity, and the development of an *ex situ* seedbank of New England material.

DESCRIPTION

With the exception of noted references, most of the following description of *Linum sulcatum* is taken from C. M. Rogers (1963), who is the most recent monographer of the genus *Linum* in North America. *Linum sulcatum* is a widespread herbaceous species in the Linaceae. It is generally described as an annual, but referred to as occasionally biennial in North Carolina (Radford et al. 1968). Plants vary in height from 20 to 70 cm, although some of the New England plants seen in the field grow only to a few centimeters tall (personal observation). Even the smallest plants in New England appear to flower (personal observation). Plants are erect, simple below with a few ascending branches. Leaves are simple, linear to lanceolate, entire and have a pronounced midrib that terminates in a sharp point. The lower

pairs of leaves usually fall off before the plant flowers. Each leaf has a pair of dark stipular glands.

Flowers terminate each of the branches, forming an open panicle. Pedicels are 1.3 to 4.7 mm long, articulated about 1 cm below the fruit; sepals are lanceolate, acuminate and conspicuously glandular-toothed. Flowers are pale yellow, with petals 5-10 mm long that have fine hairs at their interior base. Stamens are short, with filaments 3-5 mm long with elliptic anthers. Styles are 2-4 mm long, united only at the base. The fruit is straw-colored, globose to ovoid, 2.5-4 mm tall, and 2.5-2.8 mm in diameter. The 5-carpellate fruit dehisces into ten sharply pointed, one-seeded units. False septa are partially developed and the septae are ciliate. Seeds are elliptic, reddish brown and small (1.6-2.1 mm long).

Other yellow-flowered *Linum* species in the Northeast include *L. intercursum, L. medium* var. *texanum*, *L. virginianum*, and *L. striatum*. All are perennial, except for *L. medium* which can appear to function like an annual in New England (Rogers 1963). *Linum sulcatum* can be distinguished from these four species based on its basally united styles, five sepals with glandular teeth that persist into fruiting, and that pair of dark stipular glands on each leaf (Rogers 1963). *Linum perenne* is frequently grown in gardens and escapes into disturbed areas. It is blue-flowered and perennial. *Linum catharticum* is an annual and has been found in some disturbed sites in Vermont, Maine, and New York. It has white flowers (Rogers 1963).

Linum sulcatum is not known to hybridize with any other *Linum* species in the Northeast. *Linum sulcatum* is the only native *Linum* species in the Northeast with a base chromosome number of 15 (Dillman 1933).

TAXONOMIC RELATIONSHIPS, HISTORY, AND SYNONYMY

There are about 150 species of *Linum* worldwide, with 40 to 50 species in the New World (Rogers 1963). *Linum sulcatum* was first described from a prairie site in Ohio by Riddell in 1837. Major revisions to the genus *Linum* were made by Rogers (1963), who maintained the entity *Linum sulcatum* that was first described by Riddell (1837). The species is divided into two distinct varieties. One, *L. sulcatum* var. *sulcatum*, is widespread and globally secure, extending from the Midwest to the Northeast and from Manitoba/Quebec south to Texas and Georgia. A second variety, *L. sulcatum* var. *harperi*, is restricted to Georgia, Alabama, and Florida and is globally rare.

Rogers (1969) recognized five complexes within *Linum*, based on a series of morphological characters. The Sulcatum Complex consists of only one species, *L. sulcatum*, which he considers distinctive in many ways. It is the only New World *Linum* with partially united styles and a base chromosome number of 15 (Dillman 1933). Its pollen type and other

characters suggest that *Linum sulcatum* represents a descendant of an intermediate form between two complexes within the genus.

More detailed taxonomic work within the genus *Linum* using electron micrograph scans of pollen grains (Xavier and Rogers 1963, Xavier 1967), chromatographic work with petal pigment (Giannasi and Rogers 1970), and additional work with hybridization (Harris 1968) have all led to confirmation of the taxonomic relationships worked out by Rogers (1963).

Cultivated flax (*Linum usitatissimum*), grown for both its fibers to make cloth and for linseed oil, has been genetically altered to resist herbicides and has been evaluated by the USDA (APHIS 1999) as a potential invasive into agricultural fields that are managed with herbicides. *Linum sulcatum*, like *L. usitatissimum*, has a base chromosome number of 15 and has also been evaluated for potential invasiveness because of concern that it might hybridize with *L. usitatissimum.* The evaluation concluded that there is no risk to other commercial crops because both species of *Linum* are poor competitors and there is no evidence that they can hybridize. Although *Linum usitatissimum* hybridizes freely with other *Linum* species with a base chromosome number of 15, few of these hybrids have produced viable seed and none have demonstrated improved commercial uses (Gill and Yermanos 1967). Attempts have also been made unsuccessfully to hybridize *Linum sulcatum* with its purported near relatives to assess chromosomal similarities (Harris 1968).

At one time, *Linum intercursum* had been included as a part of *L. floridanum* and had been also confused with *L. sulcatum* in New England (Bicknell 1912). From collections on Nantucket, Martha's Vineyard, and the Hempstead Plains on Long Island, Bicknell described *L. intercursum* as a new species. Earlier, in what must be one of the first New World collections of *L. sulcatum* in 1830, a *L. sulcatum* specimen from New Haven, Connecticut was identified as *L. striatum* seven years before the first description of the taxon by Riddell. The type specimen (US) was collected in 1835 in Dover, Ohio.

Other synonyms for *Linum sulcatum* var. *sulcatum* include: *Linum bootii* Planchon, var *elatior* Planchon (1848), *Linum bootii* Planchon var *humilior* Planchon (1848), *Cathartolinum sulcatum* (Riddell) Small (1907), *Nezera sulcata* (Riddell) Nieuwland (1913), and *Mesynium sulcatum* (Riddell) A. Löve and D. Löve (1982).

SPECIES BIOLOGY

Linum sulcatum produces a large number of very small seeds (Stevens 1932; Ballard and Pruess 1979). In a germination study of *L. sulcatum*, using seed presumably collected in the Midwest, seeds were sown without cold treatment at 70 degrees with germination in seven to 14 days (Clothier 2003). *Linum sulcatum* seeds are known to persist in the soil seedbank (Blake 1935).

Germination studies have not been conducted using seeds of *Linum sulcatum* collected in New England (William Brumback, New England Wild Flower Society, personal communication). Germination experimentation has been conducted with *L. intercursum* in New England with successful germination after cold treatment. Seeds have not been collected for *L. sulcatum* in New England (Brumback, personal communication).

Linum sulcatum can colonize new sites rapidly (Cunningham 1997). Plants are first evident in early June and begin to flower by late June, continuing through the early fall with peak flower abundance from mid July to late August (personal observation). Like most annuals, even the very smallest plants, which may be as small as 4 cm, produce flowers (personal observation). Plants appear to hold individual flowers for only one day (Eckhart, personal communication). Often flowers are shed after opening for only a few hours. It is likely that pollen is transferred from anthers to the stigma as the corolla falls off. Although no details are known concerning pollination mechanisms in *L. sulcatum*, it is likely that it is insect-pollinated (Eckhart, personal communication).

It is unknown if *Linum sulcatum* is self-compatible, although it is likely given that the flowers are shed very quickly (Eckhart, personal communication). Some other members of the genus outside North American are heterostylous and self-incompatible and have been studied extensively (Murray 1982). Conversely, homostylous species in *Linum* are self-compatible. All of the *Linum* species in North America have been referred to as homostylous (Robertson 1971), suggesting that *L. sulcatum* is probably self-compatible. Studies should be undertaken to determine whether *L. sulcatum* is self-incompatible; if so, this may limit population persistence over time in fragmented habitat.

Linum sulcatum has extremely small seeds, some of the smallest of the *Linum* (Ballard and Preuss 1979). Large numbers of *L. sulcatum* seeds were found in one study of ant-caching of prairie seeds (Ballard and Pruess 1979). From the study, it was unclear if the ants were eating the seeds.

The chemical composition of *Linum* has been well studied because of the commercial use of *Linum usitatissimum* and because members of the genus have long been used for medicinal purposes (Frohne and Pfander 1984, Foster and Duke 1990). Members of the genus *Linum* contain the cyanogenic glycoside linaniarin, which upon hydrolysis forms prussic acid or hydrogen cyanide (Frohne and Pfander 1984). Byproducts of commercially grown flax have been mixed in low concentrations with other grains to feed cattle, but in high concentrations flax can be toxic and has been known to kill sheep and hogs (Pammel 1992). *Linum* is not toxic to humans, and members of the genus have been used medicinally for a broad range of ailments including colds, lung and urinary tract problems, tumors, burns, and skin problems (Frohne and Pfander 1984).

In natural settings, *Linum sulcatum* is not eaten by deer (Dix 1959, Deuley 2003). *Linum sulcatum* has been suggested as a plant to include in a garden to reduce deer herbivory

because of its bitter taste and tough leaves (Simons 2003). *Linum sulcatum* is the food plant of the Variegated fritillary (*Euptoieta claudia*) (Carleton College 2003).

Population numbers for *Linum sulcatum* can vary dramatically from year to year (Robertson 1939). During years with droughts in May and June, population numbers may be very low (personal observation).

HABITAT/ECOLOGY

Linum sulcatum has been described as an early successional species (USDA 2003). It can germinate readily from prairie soil samples grown out in a greenhouse (Blake 1935). Like most annuals, *L. sulcatum* does not do well immediately after fire, but does well in subsequent years (Albertson 1937). Similarly, during a multi-year drought, *L. sulcatum* cover and frequency were reduced, but in the years immediately following adequate rainfall, populations increased notably (Robertson 1939). In a study of the impacts of natural animal disturbances, such as gopher holes, on prairie species, *Linum sulcatum* was identified as negatively associated with animal disturbances (Gibson 1989). It has been observed in Iowa that *L. sulcatum* occurs primarily in good-quality habitat that has been little affected by human disturbance (Eckhart, personal communication).

In one study using Geographical Information System (GIS) methodology to characterize rare species habitat in Michigan, Forest Service Land Type Associations assessment was identified as an effective tool to predict occurrences of *Linum sulcatum* (Cleveland 1997). Climate, geomorphology and landform, soil association, and landscape position were all used to create a model. *Linum sulcatum* habitat was characterized as occurring on outwash deposits with deep sandy soil, only slight soil horizon development, and no textural banding caused by elevated water levels. These sites were the most xeric studied in Michigan and supported the Black oak/white oak/*Vaccinium* community.

Linum sulcatum is a characteristic species of many of the Midwestern prairies (Harvey 1908, Hall 1955, Weaver 1960, Bray 1960, Collins et al. 1989, Schwert et al. 1996). It is widespread throughout the tallgrass and midgrass prairie states. Its cover is always low, but its consistent presence in some communities has resulted in its being referred to as a characteristic species of prairies (Albertson 1937). Weaver (1960) commented that it could be extremely common at a site and yet have very low percent cover. In Tennessee and Wisconsin, *L. sulcatum* has been used as an indicator of remnant prairies (Tompson 1940, DeSelm et al. 1969). *Linum sulcatum* is suggested by several prairie management programs for planting to restore native Midwestern prairies (Cunningham 1997). Several Midwestern nurseries list *Linum sulcatum* in their holdings (Eckhart, personal communication).

In Missouri, Alabama, Virginia, and Tennessee, *Linum sulcatum* is found in cedar glades (Steyermark 1975, Baskin et al. 1995). In Michigan, it occurs in dry, open oak woodlands (Cleveland 1997). Rogers (1963) also mentions its occurrence in "interdunal flats."

In New England and in nearby Northeastern states, *Linum sulcatum* is found in successional *Juniperus virginiana* glades and in a range of disturbed areas, including roadsides, power line rights-of-way, abandoned fields, and pastures (Fernald 1950, Seymour 1969, Magee and Ahles 1999). All of the extant populations are on highly alkaline, sandy soils.

Habitat information for the Northeast includes data collected from the New York and Connecticut Natural Heritage Programs and personal observations. Associated native species in the Northeast include: *Schizachyrium scoparium, Juniperus virginiana, Celtis occidentalis, Solidago nemoralis, Carex eburnea, Antennaria* spp., *Asclepias verticillata, Minuartia stricta, Gentianopsis crinita, Potentilla simplex,* and *Cladonia* spp. *Linum sulcatum* is frequently associated with non-native species some of which are considered invasive: *Berberis thunbergii, Rhamnus cathartica, Centaurea maculosa, Poa pratensis, P. compressa*, and *Lonicera* spp.

Linum sulcatum is nearly always associated with other regionally rare species in the Northeast. These species include: *Pycnanthemum torrei* and *P. clinopodioides* (one site each), *Liatris scariosa* (one site), *Bouteloua curtipendula* (three sites), *Onosmodium virginianum* (two sites), *Draba reptans* (three sites), *Potentilla arguta* (one site), *Hedeoma hispidum* (one site), *Asclepias viridiflora* (two sites), *Gentianella quinquefolia* (one site), *Aristolochia serpentaria* (one site), *Sporobolis asper* (one site), and *S. clandestinus* (one site).

THREATS TO TAXON

Currently, the two extant New England populations of *Linum sulcatum* are threatened by succession, trampling, and potentially incompatible management. Historically, populations may have been eliminated by direct loss of habitat, fragmentation of habitat preventing effective seed dispersal, and loss of processes maintaining habitat. Other potential threats include mining and competition from invasive species.

Succession

Both of the known populations of *Linum sulcatum* in New England occur in successional cedar glades that are maintained by human activity. One is located under a power line (CT. 002 [New Milford]); another is at the edge of a quarry (CT.014 [Brookfield]). Without site management, both populations would decline as the cedar glades become more wooded. Most of the New York populations near the Connecticut border are also in post-

agricultural cedar glades that, without management, fill in with shrubs and trees, over time eliminating *Linum* habitat.

Trampling and Other Human Disturbance

At the Connecticut quarry site (CT .014 [Brookfield]), there is evidence of trampling within the occupied *Linum* habitat, probably associated with lunchtime picnics during the summer. There may also be some impact from botanists visiting the site, although the frequency of botanical visitation is probably very low.

Incompatible Management of Occupied Sites

The power line site (CT .002 [New Milford]) currently appears to be well managed to support *Linum sulcatum*. Changes in power line management, for example, an increase in herbicide use, planting with vetch, or recontouring of the land to facilitate mowing, could eliminate *Linum* habitat. The site is probably not currently managed specifically to maintain *Linum sulcatum*.

Direct Loss of Habitat

Most of the collections of *Linum sulcatum* in the Northeast indicate that it is a species of early successional habitat following agricultural abandonment or a species that colonizes and may persist in sites of other types of human disturbance. Human disturbance patterns may change over time and not favor plants, such as *L. sulcatum*, that take advantage of artificially-maintained habitat. Some populations of *L. sulcatum* could easily have been lost to site development. Some historical populations of *L. sulcatum* have undoubtedly been lost to roadside development, changes in power line management, and general residential and commercial development, where appropriate habitat for *L. sulcatum* is completely eliminated.

Limited and Fragmented Habitat and Limitations to Seed Dispersal

There is a section of limestone-based soils that extends from the Harlem Valley in eastern Dutchess County, New York into northwestern Connecticut and southwestern Massachusetts. Within this area, there are currently eight New York sites for *Linum sulcatum* and the two New England sites. Many of the specimen records are also associated with this area. Because the limestone soils are rich and support good agricultural uses such as cornfields on deeper soils and pasture or hayfields on thinner soils, farming has persisted longer in this part of the Northeast than in many other areas. Farm abandonment during the past forty years, combined with an increase in second-home and general residential development, have resulted

in increased fragmentation of the natural landscape. Even if appropriate habitat were available, the potential for successful seed dispersal to appropriate sites has been reduced over time.

Loss of Processes Maintaining Populations

The two known sites in Connecticut are associated with a quarry and a power line. The quarry (CT .014 [Brookfield]) is no longer used and has been surrounded by residential and commercial development. The harshness of the thin alkaline soil and random disturbances are all that have successfully maintained *Linum* habitat over time. The power line right-of-way (CT .002 [New Milford]) appears to be maintained by manual cutting of the trees and shrubs and probably by the use of herbicides to kill woody species. In both cases, management is not dedicated to the maintenance of *Linum sulcatum*. Management practices could change at any time.

Mining

Several New York sites with thin soils over limestone have been actively mined, in several cases completely eliminating hills and all natural habitat. Several of the New York and Connecticut sites with appropriate habitat for *Linum sulcatum* could be mined.

Competition from Invasive Species

Invasive species are present at all occupied *Linum sulcatum* sites in Connecticut and New York. The typical weedy species associated with dry alkaline soils are found in these areas, including: *Centaurea maculosa, Rhamnus cathartica, Rosa multiflora,* and *Berberis thunbergii*. None of these species appear to be about to eliminate *Linum* habitat, but a long period of moist conditions could increase their abundance and reduce habitat for *Linum sulcatum.*

DISTRIBUTION AND STATUS

General Status

Linum sulcatum is the most widespread member of its genus in North America (Rogers 1963). It has been reported to have occurred from Manitoba in the northwest south to Texas and east to Georgia and New Hampshire (NatureServe 2003). East of the Mississippi, the only states in which *L. sulcatum* var. *sulcatum* has not been recorded from Maine, Delaware, South Carolina, and Florida. *Linum sulcatum* var. *harperi* occurs in Florida, Georgia, and Alabama.

Linum sulcatum is noted as present in 34 states and three Canadian provinces (NatureServe Explorer 2003, Table 1). It is listed as "rare" in seven states and one province and "SH-Historical only" in five states. It is currently listed as present and not rare in 22 states and two provinces. Except where noted, county distribution information in Table 1 was obtained from the United States Department of Agriculture Plants Profile Database (USDA, NRCS 2003). *Linum sulcatum* is probably S4 or S5 in most of these states, although there is no verification of this. With the exception of Indiana, all the states reporting *L. sulcatum* as rare are in the eastern and northeastern part of its range. In all states with prairies, *L. sulcatum* appears to be secure.

Table 1. Occurrence and status of *Linum sulcatum* in the United States and Canada based on information from Natural Heritage Programs.

OCCURS & LISTED (AS S1, S2, OR T &E)	OCCURS & NOT LISTED (AS S1, S2, OR T & E)	OCCURRENCE REPORTED OR UNVERIFIED	HISTORIC (LIKELY EXTIRPATED)
Connecticut (S1): 2 extant and 14 historic occurrences	Mississippi (S3/S4)	Missouri (SR): 65 counties	Massachusetts (SH): 3 historic occurrences
New York (S2): 8 extant: 12 counties throughout the state.	Virginia (S3): 7 counties in the Blue Ridge Region	Florida (SR): 3 counties	Vermont (SH): 3 historic occurrences
New Jersey (S1)	Georgia (S3?): 3 counties in the extreme northwest part of the state	Wisconsin (SR): 33 counties, primarily in the southern part of the state	Rhode Island (SH): 1 historic occurrence
Pennsylvania (S1)	Ontario (S3)	Oklahoma (SR)	New Hampshire (SH): 1 historic occurrence
Maryland (S1)	Kentucky (S4): 6 counties	South Dakota (SR): 10 counties	West Virginia (SH): 1 county
North Carolina (S1): one county.	North Dakota (S4/S5): 15 counties	Iowa (SR): 11 counties	
Indiana (S2)		Alabama (SR)	
Quebec (S1)		Arkansas (SR): 7 counties	
		Nebraska (SR)	
		Kansas (SR): 68 counties	
		Louisiana (SR)	
		Manitoba (SR)	
		Tennessee (SR)	
		Ohio (SR)	
		Michigan (SR): nine counties	
		Minnesota (SR)	
		Texas (SR)	
		Illinois (SR): 43 counties	

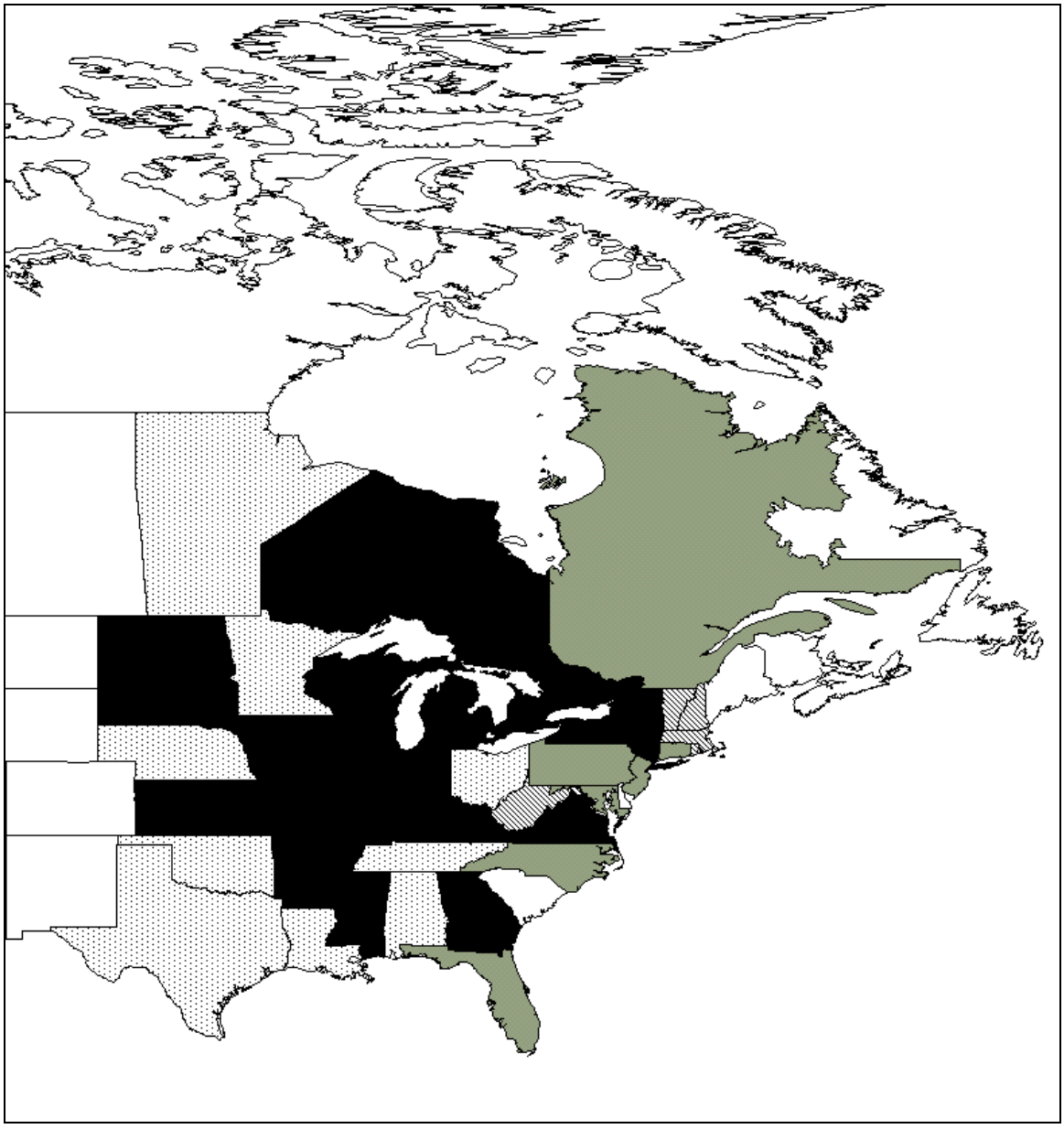

Figure 1. Occurrences of *Linum sulcatum* in North America. States and provinces shaded in gray have one to five (or an unspecified number of) current occurrences of the taxon. Areas shaded in black have more than five confirmed occurrences. States with diagonal hatching is designated "historic," where the taxon no longer occurs. States with stippling are ranked "SR" (status "reported" but without additional documentation). See Appendix for explanation of state ranks.

Status of All New England Occurrences — Current and Historical

Linum sulcatum is currently known from two sites in Connecticut. There are historical records from 14 additional towns in Connecticut, three sites in Vermont, three sites in Massachusetts, one site in Rhode Island, and one site in New Hampshire. These current and historical sites include 23 towns in five states. Seven of the towns are clustered in the limestone region of western Connecticut and southeastern Massachusetts. The two Vermont sites are in parts of the state that support other calciphiles.

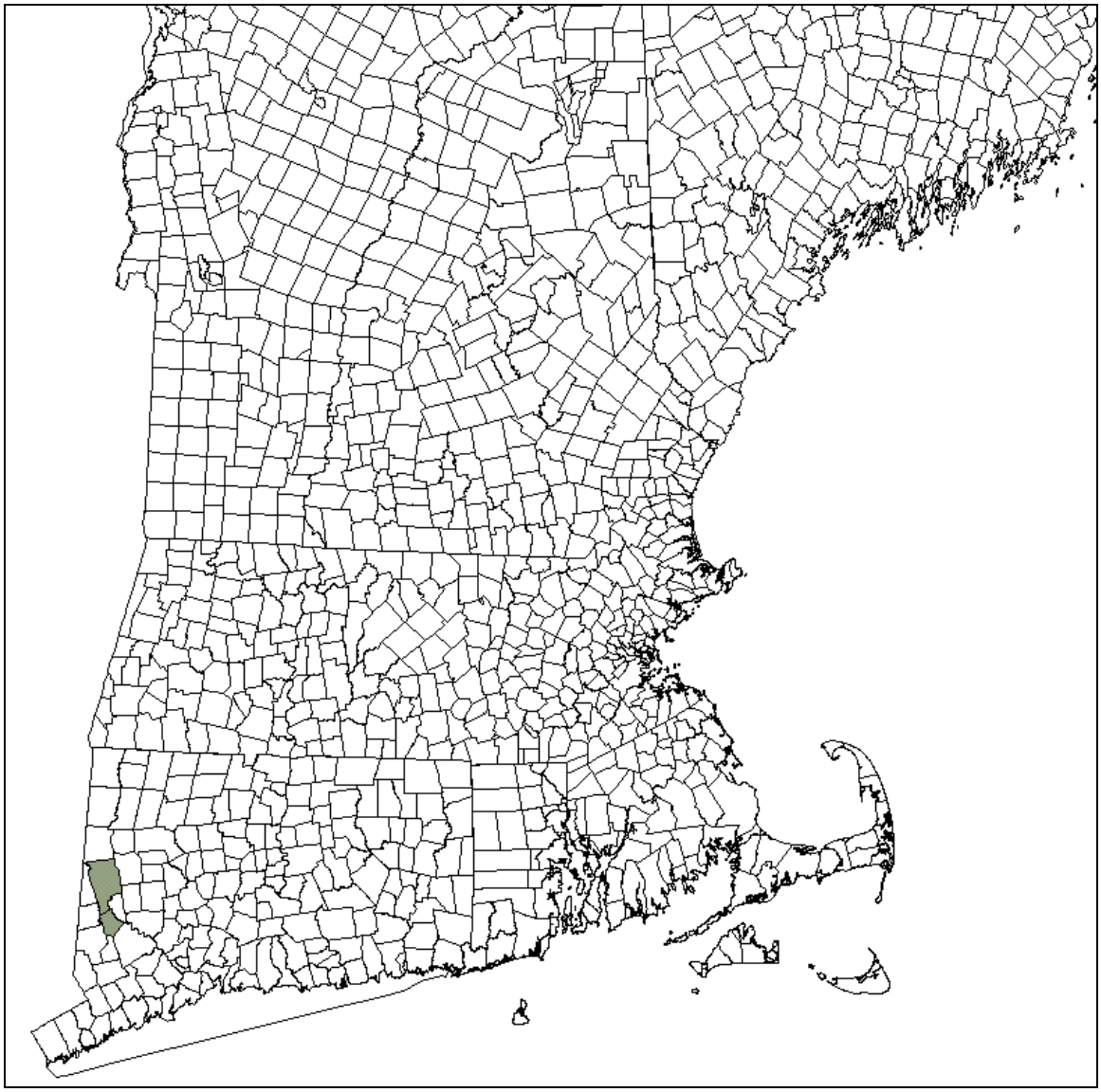

Figure 2. Extant occurrences of *Linum sulcatum* in New England. Town boundaries for New England states are shown. Towns shaded in gray have one to five extant occurrences of the taxon.

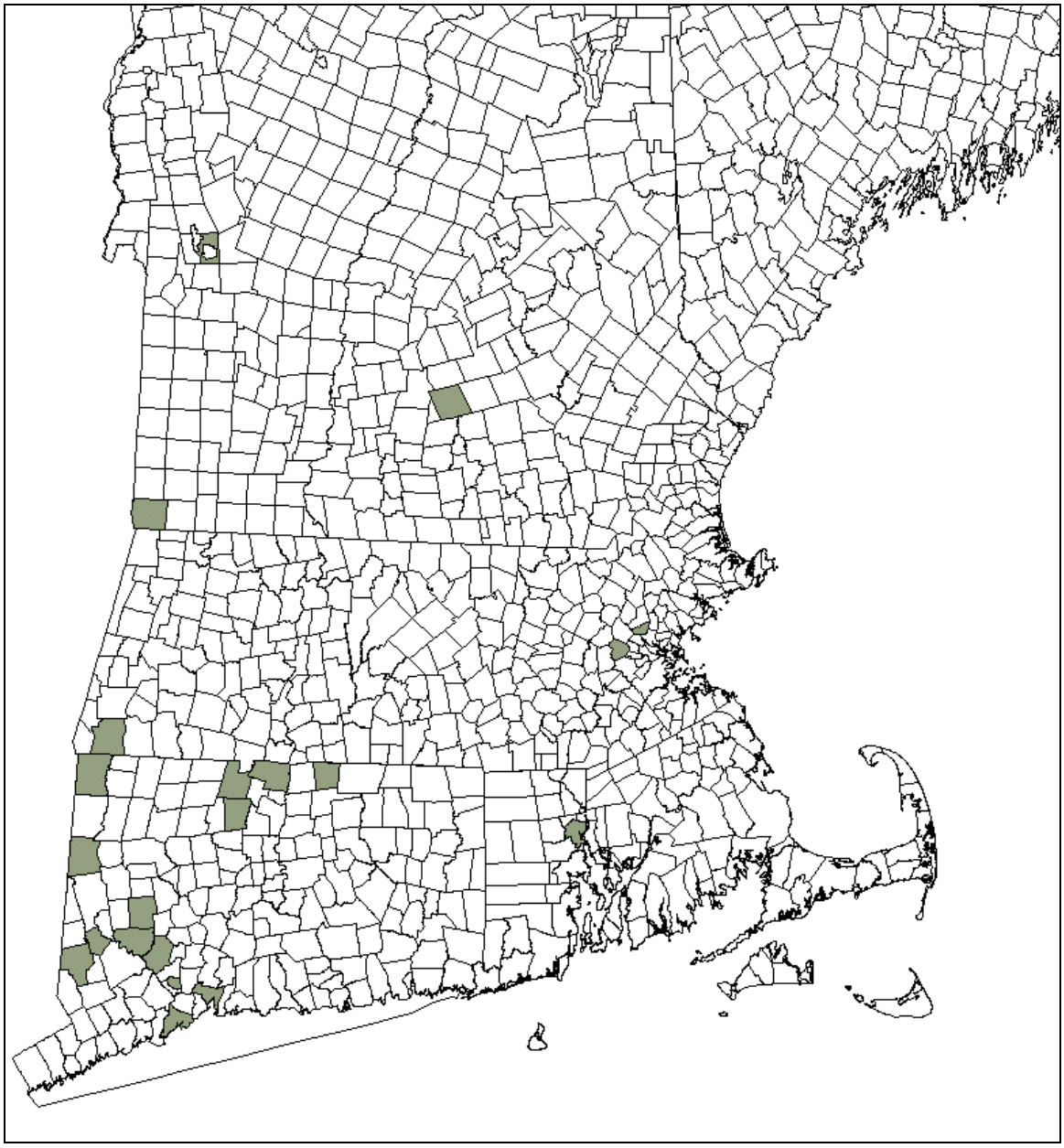

Figure 3. Historical occurrences of *sulcatum* in New England. Towns shaded in gray have one to five historical records of the taxon.

Table 2. New England Occurrence Records for *Linum sulcatum*. Shaded occurrences are considered extant.			
State	**EO Number**	**County**	**Town**
NH	.001	Hillsborough	Hillsborough
VT	No #	Bennington	Pownal
VT	No #	Bennington	Pownal
VT	No #	Rutland	Rutland
MA	No #	Middlesex	Winchester
MA	No #	Middlesex	Waltham
MA	No #	Berkshire	Sheffield
RI	.001	Providence	Providence
CT	New	New Haven	Ansonia
CT	New	Tolland	Somers
CT	New	Litchfield	Kent
CT	**.002**	**Litchfield**	**New Milford**
CT	.003	Fairfield	Brookfield
CT	.004	Hartford	Suffield
CT	.005	Litchfield	Woodbury
CT	.006	Litchfield	Salisbury
CT	.007	Fairfield	Danbury
CT	.008	New Haven	Milford
CT	.009	Hartford	Granby
CT	.010	New Haven	New Haven
CT	.011	New Haven	Oxford
CT	.012	Hartford	Simsbury
CT	.013	New Haven	Southbury
CT	**.014**	**Litchfield**	**Brookfield**

II. CONSERVATION

CONSERVATION OBJECTIVES FOR THE TAXON IN NEW ENGLAND

The primary conservation objective for *Linum sulcatum* is to protect thirteen populations in New England: five populations in Connecticut and two each in New Hampshire, Vermont, Massachusetts, and Rhode Island, all in natural habitat and within the historical range of the species. There are currently two extant populations in Connecticut and significant amounts of potential habitat that have not been surveyed. The best opportunity for conservation of *L. sulcatum* in New England is found in Western Connecticut. There is potential, but limited, habitat remaining in New Hampshire, Vermont, Massachusetts, and Rhode Island that may support *L. sulcatum*. A goal of two populations each for these states is set to capture multiple habitats and increase the potential for long term conservation success.

Each occurrence should be managed to maintain a population of at least 100 plants. The minimum viable population size for *Linum sulcatum* in New England is not known. One of the Connecticut populations has persisted for nearly 90 years and currently supports about 500 plants. Until additional information on viable population sizes is available, a minimum population size for the 13 sites is set at 100 plants at each site, averaged over 10 site-monitoring periods. *Linum sulcatum* plants produce fewer seeds than many other annuals; fruits produce a maximum of 10 seeds per flower. Some small plants have only one or a few flowers. The character of the *L. sulcatum* seedbank is also unknown.

Because there are currently only two populations in Connecticut known in New England, it will be necessary to located new populations, if possible, to achieve the main conservation objective. If additional populations of *Linum sulcatum* are found in other states or in other locations in Connecticut, Massachusetts, Vermont, Rhode Island, or New Hampshire, these occurrences should also be protected and managed if they are found in natural areas, and conservation objectives should be revised to reflect a broader geographic range for the species in New England.

Whenever possible, management for *Linum sulcatum* should be undertaken in the context of conservation management for the natural community in which it occurs. At both of the Connecticut sites, and at the nearby New York sites, *L. sulcatum* occurs in association with distinctive communities that are the subject of conservation interest. Numerous other rare species, including animals, co-occur with *L. sulcatum.* Management strategies for conservation sites with *L. sulcatum* should balance the habitat needs of all rare species and the natural communities they occupy. If new populations are located, management planning should focus on the restoration of the former natural community. Newly-located populations at disturbed sites, such as roadsides or old fields, should receive less intensive management.

A second objective is to understand the rarity and conservation needs of *Linum sulcatum* better, by conducting site monitoring and population biology studies. It is unknown what defines the northern limit of *L. sulcatum*. It appears that all sites that currently support *L. sulcatum* have highly alkaline soils and are open and sunny. The natural bedrock geology of the Northeast consists of discontinuous bands of alkaline material that trends generally north-south. Extending eastward from Northwestern Connecticut, there are few alkaline bedrock exposures, except for traprock sites in the Central Connecticut River Valley (Moorhead, personal communication). Similarly, to the north, there are discontinuities in alkaline soils in Columbia County, New York and in Berkshire County, Massachusetts. Alkaline bedrock appears again to the north in the southwestern part of Vermont, extending northward along the western slopes of the Green Mountains. These Vermont areas include three historical collections and have more severe winters than other sites that support *L. sulcatum* in the East. It is possible that *L. sulcatum* is nearing its northern climatic limit in Vermont where it has occurred in the past, perhaps as a waif unable to persist over time. Research should be conducted to determine whether the rarity of *L. sulcatum* might be related to reproductive failure such as a lack of pollinators, poor seed set, or self-incompatibility. It is quite possible that the rarity of *L. sulcatum* can be attributed to limited available habitat and habitat fragmentation, preventing the natural colonization of new sites.

A third conservation objective is to establish an *ex situ* seedbank to preserve the genome of *Linum sulcatum* in New England. If all natural populations are lost, seeds will be needed to supply material for future studies and reintroduction efforts, if called for in future iterations of this plan. Seed from New England populations has not been collected and stored for long-term use. With only two currently known populations in New England, it is desirable to retain New England seed in an *ex situ* seedbank.

III. LITERATURE CITED

Albertson, F. W. 1937. Ecology of the mixed prairie in West Central Kansas. *Ecological Monographs* 7: 481-547.

APHIS, 1999. Petition 98-335-01p. Determination of non-regulated status for the transgenic Flax line CDC Triffid Tolerant to Sulfonylurea residues in the soil, May 1999. U. S. Department of Agriculture, Washington, D. C., USA.

Ballard, J. B. and K. P. Pruess. 1979. Seed selection by an ant, *Pheidole bicarinata longula* (Hymenoptera: Formicidae). *Journal of the Kansas Entomological Society* 52: 550-552.

Baskin, J. M., D. H. Webb and C. C. Baskin. 1995. A floristic plant ecology study of the limestone glades of Northern Alabama. *Bulletin of the Torrey Botanical Club* 122: 226-242.

Bicknell, E. 1912. The ferns and flowering plants of Nantucket-X. *Bulletin of the Torrey Botanical Club* 39: 415-428.

Blake, A. K. 1935. Viability and germination of seeds and early life history of prairie plants. *Ecological Monographs* 5: 405-460.

Bray, R. J. 1960. The composition of savanna vegetation in Wisconsin. *Ecology* 41: 721-732.

Brumback W. E., L. J. Mehrhoff, R. W. Enser, S. C. Gawler, R. G. Popp, P. Somers, D. D. Sperduto, W. D. Countryman, and C. B. Hellquist. 1996. Flora Conservanda: New England. The New England Plant Conservation Program (NEPCoP) list of plants in need of conservation. *Rhodora* 98: 233-361.

Carleton College. 2003. Butterflies of the Cowling Arboretum and McKnight Prairie: Abundance and General Distribution. Available at http://www.acad.carleton.edu/curricular/ARTS/16places/backusa /Species/Lists_o_species/Butterflies/Butterflies_list_page.html (accessed April 2003).

Cleveland, A. V. 1997. *Using an Ecological Classification System to Detect Rare Plant Occurrence Patterns on the Huron-Manistee National Forest (Michigan).* Masters Thesis, State University of New York, Syracuse, New York. USA.

Clothier, T. 2003. Annual/Biennial Seed Germination Database. Available at http://tomclothier.hort.net/page06.html (accessed July 2003).

Collins, S. L., G. S. Mitchell, and S. C. Klahr. 1989. Vegetation-environment relationships in a rock outcrop community in Southern Oklahoma. *American Midland Naturalist* 122: 339-348.

Cunningham, M. A. 1997. Grasslands. *Restoration and Reclamation Review Volume Two*. Online journal. University of Minnesota, St. Paul, Minnesota. Available at http://hort.agri.umn.edu/hort5015/rrr.htm (accessed July 2003).

DeSelm, H. R., P. B. Whitford, and J. S. Olson. 1969. The barrens of the Oak Ridge area, Tennessee. *American Midland Naturalist* 81: 315-330.

Deuley, B. L. 2003. Guide to Organic Gardening. Available at http://www.htv10.com/nature/020721/ch9 (accessed July 2003).

Dillman, A. C. 1933. Chromosome numbers in flax (*Linum*). *Science* 78: 409.

Fernald, M. L. 1950. *Gray's Manual of Botany*. Dioscorides Press, Portland, Oregon, USA.

Foster, S. and J. A. Duke. 1990. *A Field Guide to Medicinal Plants and Herbs of Eastern and Central North America*. Peterson Field Guide Series, First Edition. Houghton Mifflin Company, Boston, Massachusetts, USA.

Frohne, D. and H. J. Pfander. 1984. *A Color Atlas of Poisonous Plants.* Wolfe Publishing, London, UK.

Giannasi, D. E. and C. M. Rogers. 1970. Taxonomic significance of floral pigments in *Linum* (Linaceae). *Brittonia* 22: 163-174.

Gibson, D. J. 1989. Effects of animal disturbance on tallgrass prairie vegetation. *American Midland Naturalist* 121: 144-154.

Gill, K. S. and D. M. Yermanos. 1967. Cytogenetic studies on the genus *Linum*. I. Hybrids among the taxa with 15 as a haploid chromosome number. *Crop Science* 7: 623-627.

Hall, M. T. 1955. Comparison of Juniper populations on an Ozark glade and old fields. *Annals of the Missouri Botanical Garden* 42: 171-194.

Harris, B. D. 1968. Chromosome numbers and evolution in North American species on *Linum*. *American Journal of Botany* 55: 1197-1204.

Harvey, L. H. 1908. Floral succession in the Prairie-grass Formation of Southeastern South Dakota. *Botanical Gazette* 46: 81-108.

Magee, D. W. and H. E. Ahles. 1999. *Flora of the Northeast: a Manual of the Vascular Flora of New England and Adjacent New York*. University of Massachusetts Press, Amherst, Massachusetts, USA

Mitchell, R. S. and G. C. Tucker. 1999. *Revised Checklist of New York State Plants.* New York State Museum. Albany, New York, USA.

Murray, B. 1982. Heterostyly and self-incompatibility in the genus *Linum*. *Botanical Gazette* 147:327-333.

NatureServe Explorer: An online encyclopedia of life [web application]. 2002. Version 1.6. Arlington, Virginia, USA: NatureServe. Available at http://www.natureserve.org/explorer (accessed July 2003).

Pammel, L. H. 1992. *A Manual of Poisonous Plants*. Vedam Publishing, New Delhi, India.

Radford, A. E., H. E. Ahles, and C. R. Bell. 1968. *Manual of the Vascular Flora of the Carolinas*. University of North Carolina Press, Chapel Hill, North Carolina, USA.

Riddell, J. L. 1837. A supplementary catalogue of Ohio plants. *Science* 9: 567-592.

Robertson, J. H. 1939. A quantitative study of true-prairie vegetation after three years of extreme drought. *Ecological Monographs* 9: 431-492.

Robertson, K. R. 1971. Linaceae in the Southeastern United States. *Journal of the Arnold Arboretum* 52: 649-665.

Rogers, C. M. 1963. Yellow flowered species of *Linum* in Eastern North America. *Brittonia* 15: 97-122.

Rogers, C. M. 1969. Relationships of the North American species of *Linum* (flax). *Bulletin of the Torrey Botanical Club* 96: 176-190.

Schwert, D. P., D. G. Horton, C. A. Chumbley, L. A. Gonzalez, and M. L. Reagan. 1996. Holocene paleoenvironments of northeastern Iowa. *Ecological Monographs*. 66: 203-234.

Seymour, F. C. 1969. *The Flora of New England. A Manual for the Identification of Al Vascular Plants Including Ferns and Fern Allies Growing without Cultivation in New England*. Charles E. Tuttle Company, Inc., Rutland, Vermont. USA..

Simons, P. 2003. Deer-resistant plants. Available at http://lonestar.texas.net/~jleblanc/deerplants.html (accessed August 2003).

Stevens, O. A. 1932. The number and weight of seed produced by weeds. *American Journal of Botany* 19: 784-794.

Steyermark, J. A. 1975. *Flora of Missouri*. Iowa State University Press, Ames, Iowa, USA.

Thomson, J. W. 1940. Relic prairie areas of Central Wisconsin. *Ecological Monographs.* 10: 685-717.

U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. 2003. Fire Effects Information System. Available at: http://www.fs.fed.us/database/feis/ (accessed April 7, 2003).

USDA, NRCS (U.S. Department of Agriculture, Natural Resource Conservation Service). 2003. PLANTS National Database. Natural Resources Conservation Service. Available at rhttp://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=LISU4 (accessed April 7, 2003).

Weaver, J. E. 1960. Comparisons of vegetation of Kansas-Nebraska Drift-loess Hills and Loess Plains. *Ecology* 41: 73-88.

Xavier, K. S. 1967. *Taxonomic Implications of Electron and Light Micrograph Studies in Linum Pollen*. Ph.D. Dissertation. Wayne State University, Detroit, Michigan, USA.

Xavier, K. S. and C. M. Rogers. 1963. Pollen morphology as a taxonomic tool in *Linum. Rhodora* 65: 137-145.

IV. APPENDICES

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1. An Explanation of Conservation Ranks Used by The Nature Conservancy and NatureServe

1. An explanation of conservation ranks used by The Nature Conservancy and NatureServe

The conservation rank of an element known or assumed to exist within a jurisdiction is designated by a whole number from 1 to 5, preceded by a G (Global), N (National), or S (Subnational) as appropriate. The numbers have the following meaning:

1 = critically imperiled
2 = imperiled
3 = vulnerable to extirpation or extinction
4 = apparently secure
5 = demonstrably widespread, abundant, and secure.

G1, for example, indicates critical imperilment on a range-wide basis -- that is, a great risk of extinction. S1 indicates critical imperilment within a particular state, province, or other subnational jurisdiction -- i.e., a great risk of extirpation of the element from that subnation, regardless of its status elsewhere. Species known in an area only from historical records are ranked as either H (possibly extirpated/possibly extinct) or X (presumed extirpated/presumed extinct). Certain other codes, rank variants, and qualifiers are also allowed in order to add information about the element or indicate uncertainty.

Elements that are imperiled or vulnerable everywhere they occur will have a global rank of G1, G2, or G3 and equally high or higher national and subnational ranks (the lower the number, the "higher" the rank, and therefore the conservation priority). On the other hand, it is possible for an element to be rarer or more vulnerable in a given nation or subnation than it is range-wide. In that case, it might be ranked N1, N2, or N3, or S1, S2, or S3 even though its global rank is G4 or G5. The three levels of the ranking system give a more complete picture of the conservation status of a species or community than either a range-wide or local rank by itself. They also make it easier to set appropriate conservation priorities in different places and at different geographic levels. In an effort to balance global and local conservation concerns, global as well as national and subnational (provincial or state) ranks are used to select the elements that should receive priority for research and conservation in a jurisdiction.

Use of standard ranking criteria and definitions makes Natural Heritage ranks comparable across element groups; thus, G1 has the same basic meaning whether applied to a salamander, a moss, or a forest community. Standardization also makes ranks comparable across jurisdictions, which in turn allows scientists to use the national and subnational ranks assigned by local data centers to determine and refine or reaffirm global ranks.

Ranking is a qualitative process: it takes into account several factors, including total number, range, and condition of element occurrences, population size, range extent and area of occupancy, short- and long-term trends in the foregoing factors, threats, environmental specificity, and fragility. These factors function as guidelines rather than arithmetic rules, and the relative weight given to the factors may differ among taxa. In some states, the taxon may receive a rank of SR (where the element is reported but has not yet been reviewed locally) or SRF (where a false, erroneous report exists and persists in the literature). A rank of S? denotes an uncertain or inexact numeric rank for the taxon at the state level.

Within states, individual occurrences of a taxon are sometimes assigned element occurrence ranks. Element occurrence (EO) ranks, which are an average of four separate evaluations of quality (size and productivity), condition, viability, and defensibility, are included in site descriptions to provide a general indication of site quality. Ranks range from: A (excellent) to D (poor); a rank of E is provided for element occurrences that are extant, but for which information is inadequate to provide a qualitative score. An EO rank of H is provided for sites for which no observations have made for more than 20 years. An X rank is utilized for sites that are known to be extirpated. Not all EOs have received such ranks in all states, and ranks are not necessarily consistent among states as yet.