

Resource Recovery Plan
for
Bicknell's sedge
***Carex bicknellii* Britton**
in Pennsylvania



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Cover: Fruiting inflorescence of *Carex bicknellii*
photographed at Campbells Ledge, Luzerne County, PA 7/11/2011

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***Carex bicknellii* Britton**

Classification

Bicknell's sedge (*Carex bicknellii*, Cyperaceae) is a member of the most speciose genus in the Pennsylvania flora. Within *Carex* it is placed in Section Ouales, the largest section in the genus.

Carex bicknellii Britton was first recognized as a distinct species by Britton and Brown (1896-1898). It had previously been treated as *Carex straminea* Willdenow ex Schkuhr var. *crawei* Boott. Subsequent studies (Mackenzie 1931; Hermann 1972) resulted in recognition of *C. bicknellii* var. *opaca* F.J. Hermann in addition to the typical variety.

Additional work by Rothrock and Reznicek, which focused primarily on perigynium size, chromosome number, and habitat, resulted in the recognition of four distinct species within Britton's *C. bicknellii*. *Carex bicknellii* var. *opaca* was raised to species status as *C. opaca*. In addition, two new species were recognized: *Carex shinersii* and *Carex missouriensis* (Rothrock and Reznicek 2001). The result is a more narrowly defined and less ambiguous *C. bicknellii* than that originally described by Britton.



Figure 1. *Carex bicknellii* inflorescence. Photographed at Brintons Quarry, Chester Co., PA 6/11/2012

Description

Morphology

Carex bicknellii is an herbaceous, caespitose perennial with up to 100 culms per clump. Fruiting stems are 1—1.2 m tall, with 6—8 narrow, alternate leaves and a terminal inflorescence; few vegetative stems are produced. Leaf sheaths are concave or truncate at the summit, white hyaline on the adaxial side, and finely papillose at the apex.

Note: Although published descriptions of *C. bicknellii* specify fewer than 25 culms per clump, (FNA 2002, Rothrock and Reznicek 2001), some of the plants we documented at sites in Luzerne and Chester Counties have 50—100 culms. However, characteristics of the leaf sheaths and perigynia place these populations unquestionably in *C. bicknellii*.

An inflorescence consists of 5—6 spikes, each 0.8—1.5 cm long, clustered at the stem tip (Figure 1); both male and female flowers are present in each spike. Perigynia are strongly flattened, 5.1—6.7 mm long, broadly elliptic to orbicular with a prominent beak. The margins of the body of the perigynia are winged with irregularly toothed or erose margins; prominent veins are present over the face of the achene (Figure 2). Achenes are oblong and 1.6—2.2 mm long (Rothrock and Reznicek 2001; Flora of North America Editorial Committee 2002).

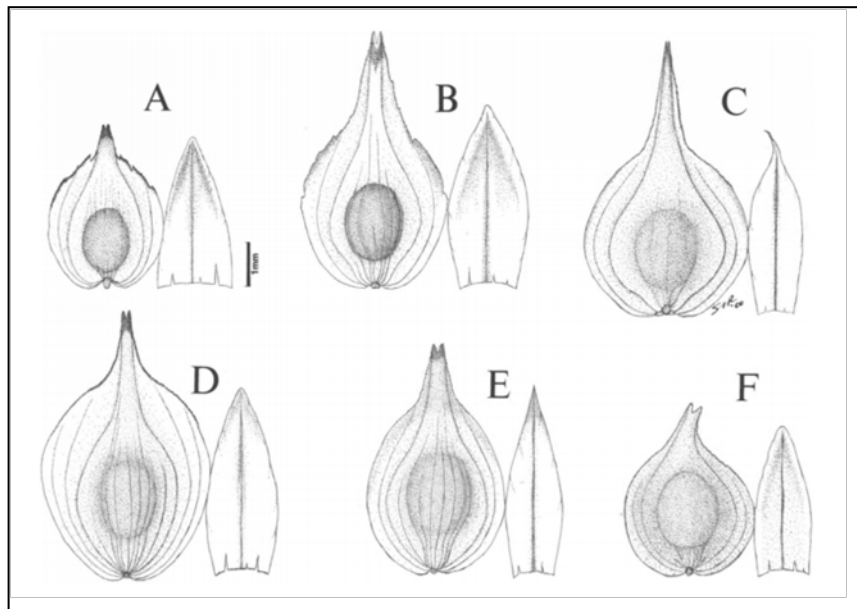


Figure 2. Perigynia and pistillate scales of: A. *Carex merritt-fernaldii*, B. *Carex bicknellii*, C. *Carex missouriensis*, D. *Carex opaca*, E. *Carex shinnersii*, F. *Carex brevior*. Source: Rothrock and Reznicek 2001.

Chromosome number

Carex bicknellii has a higher chromosome number ($n=38$, $n=39$) than other similar species (Table 1).

Table 1. Chromosome numbers of *Carex bicknellii* and related species.

Source: Rothrock and Reznicek 2001

<i>species</i>	<i>n</i>
<i>C. bicknellii</i>	38, 39
<i>C. merritt-feraldii</i>	35, 37
<i>C. opaca</i>	32,33,34
<i>C. shinnersii</i>	29,30
<i>C. missouriensis</i>	23,24,25,26,27

Reproduction

Pollination

As in all *Carex* species, the flowers of *C. bicknellii* are unisexual; staminate flowers are at the base of each spike below the pistillate flowers (Figure 3). Flowering occurs in early May, with the female flowers in each inflorescence opening first followed by the males. The plants are wind-pollinated. Available evidence suggests that most *Carex* species are self-compatible and frequently autogamous (Catling et al. 1990).



Figure 3. Flowering inflorescences of *Carex bicknellii*, left: female phase with stigmas visible; right male phase with conspicuous display of stamens. Photographed in Luzerne County, PA 5/12/2011.

Seed Dispersal

Mature perigynia of *C. bicknellii* are present by early to mid-June in Pennsylvania, by which time the fruiting stems are up to 1 m tall and overtop most surrounding herbaceous vegetation. Undisturbed spikes of mature perigynia remain intact for most of the summer. The actual means of seed dispersal of *C. bicknellii* is unknown. Considering the upper slope or ridge top locations in which they grow, and the lack of inflated perigynia, it seems unlikely that water is a major factor. However, it is possible that perigynia or achenes could be carried in surface runoff during heavy rains. Strong winds and gravity may also play a role in dispersal.

Myrmecochory (dispersal by ants) has been documented for some *Carex* species. However, *C. bicknellii* does not exhibit the associated suite of characteristics which include fruiting stems that become decumbent with age, long capillary peduncles, basal lateral spikes, and achenes with elaiosomes (Handel 1976). The strongly flattened perigynia of *C. bicknellii* (typical of the Section Ouales) with sharp beaks and toothed margins (Figure 2) may catch in the fur of passing animals and be carried short distances, an example of epizoochory. Bird dispersal cannot be ruled out; *Carex* achenes have been shown to survive passage through the digestive tracts of birds (Catling et al. 1990). Other than that possibility, specific adaptations for long distance dispersal are not apparent.

Seed Germination and Seed Banking

Germination requirements of *C. bicknellii* seeds have not been studied, nor is information available on the seed banking potential of this species.

Ecology

Range

Carex bicknellii is primarily a Midwestern prairie species. It occurs from Ontario and Manitoba south to Kansas and Arkansas, and extends east to Pennsylvania, New Jersey, and Maine with an outlier in South Carolina (Rothrock and Reznicek 2001) (Figure 4). Eastern locations may be associated with the hypsithermal interval, a warmer and drier period that occurred from 7,000 to 2,500 years ago (Deevey and Flint 1957). With the return of a cooler, wetter climate, *C. bicknellii* could have persisted on specialized substrates that mimic prairie conditions, such as serpentine barrens and dry ridge-tops.

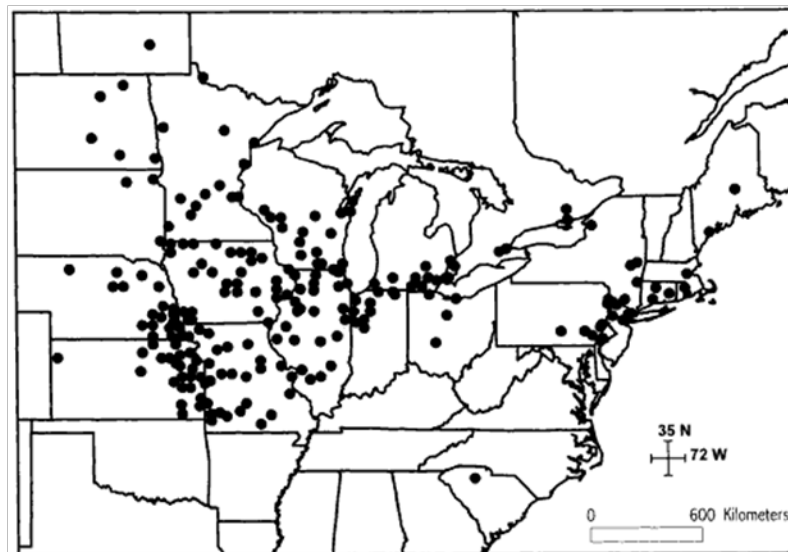


Figure 4. Range of *Carex bicknellii*
Source: Rothrock and Reznicek 2001.

Habitat

Carex bicknellii grows in dry to mesic prairies, open woodlands, and rock or sand barrens (FNA 2002). In Illinois it is an occasional or common component of moist prairies and meadows in the northern three-quarters of the state (Mohlenbrock 1986). Swink and Wilhelm (1994) describe *C. bicknellii* as a frequent and characteristic plant of tallgrass prairies associated with *Sporobolus heterolepis*, *Sorghastrum nutans*, *Andropogon gerardii*, and *Lilium philadelphicum*. They assign a conservation coefficient of 10 to *C. bicknellii*, indicating a strong association with sites with high biological integrity.

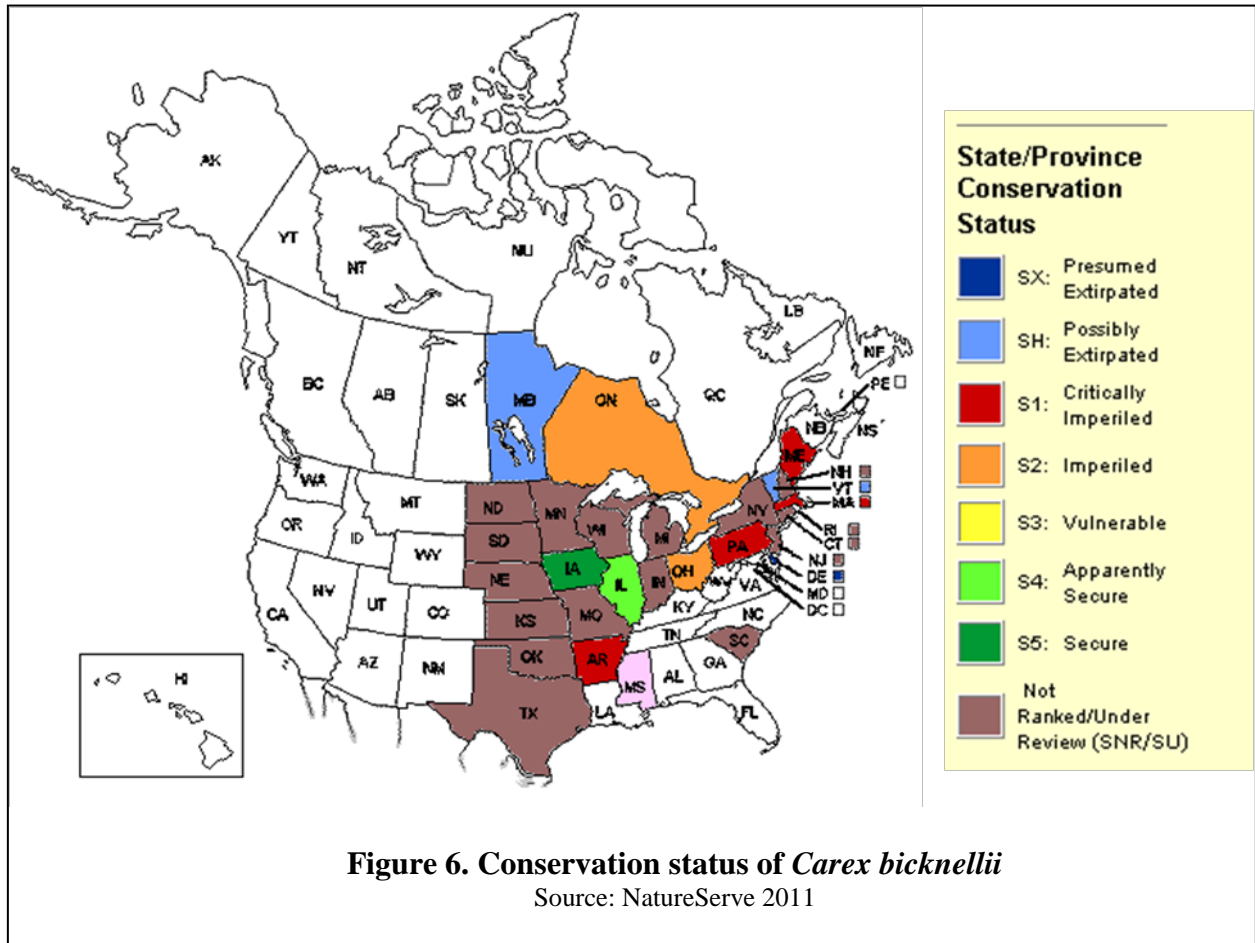
In the east, *C. bicknellii* occurs in serpentine barrens grasslands (Figure 5) as well as non-serpentine ridgetop barrens.



Figure 5. Serpentine grassland with *Carex bicknellii* at Brinton's Quarry, Chester County photographed June 11, 2012.

Conservation Status

Carex bicknellii is ranked as secure at the global (G5), and national (N5) levels (NatureServe 2011). It is unranked or considered common and secure in core Midwestern states including Illinois, Iowa, Missouri, Kansas, and Nebraska (Figure 6). However, *C. bicknellii* is of conservation concern in peripheral areas of its range, including Manitoba, Ontario, Arkansas, Ohio, Pennsylvania, New Jersey, and Maine (NatureServe 2011) (Figure 6). It is also included on the New York list of threatened species (New York Flora Assn. 2012).



Carex bicknellii in Pennsylvania

Herbarium Records

The earliest Pennsylvania records of *Carex bicknellii* are from Lehigh County (1871), Delaware County (1890), Bucks County (1894), and Chester County (1900) (Table 2).

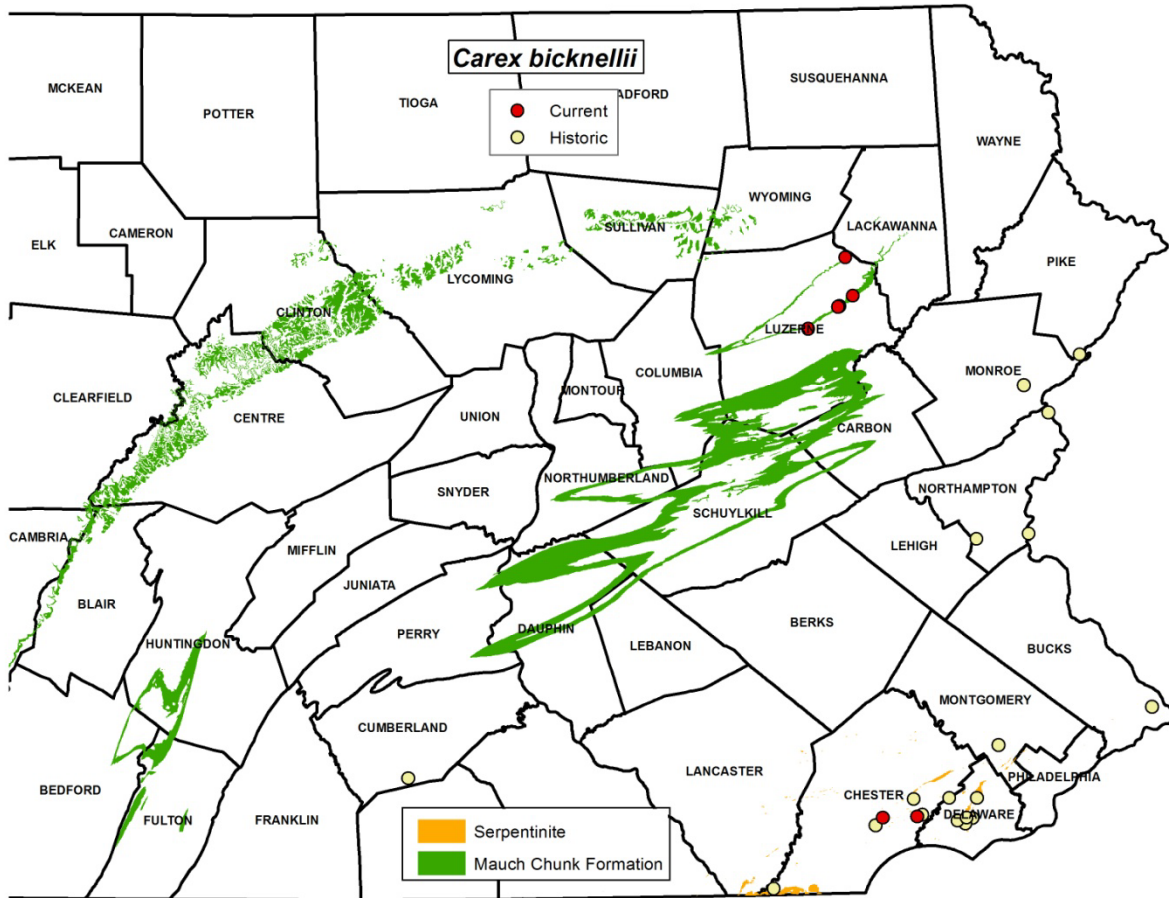
Table 2. *Carex bicknellii* specimen records from Pennsylvania

Source: Pennsylvania Flora Database 2012; Herbarium of the Academy of Natural Sciences of Philadelphia

year	county	location	collector	source	habitat
1871	Lehigh	Seidersville	Porter, T.C.	PH	
1890	Delaware	Elwyn (Pink Hill)	Brinton	PH	
1894	Bucks	Penn Valley	Crawford, J	PH	
1900	Chester	Fern Hill	Windle, Francis	PH	serpentine barrens
1908	Chester	Cedar Barrens	Pennell, F.W.	PH	
1908	Delaware	Bear Hill	Pennell, F.W. 142	PH	
1908	Delaware	Williamson School	Van Pelt, S.S.	PH	serpentine barrens
1910	Delaware	Bear Hill	Pennell, F.W.	PH	
1911	Chester	Brinton's Quarry	Pennell, F.W.	PH	
1912	Chester	Cedar Barrens	Pennell, F.W. 3912	PH	
1912	Chester	Fern Hill	Pennell, F.W. 3975	PH	
1912	Delaware	Bear Hill	Pennell, F.W. 3950	PH	
1912	Delaware	Glen Riddle (Pink Hill)	Pennell, F.W. 3798	PH	
1912	Montgomery	Ivy Rock	Long, B. 7330	PH	dry wooded slope
1916	Delaware	Wawa (Pink Hill)	Pennell, F.W. 7314	PH	dry serpentine
1923	Chester	Brinton's Quarry	Long, B. 27720	PH	dry rock exposure
1924	Delaware	Williamson School	Pennell, F.W.	CM	grassy serpentine
1924	Delaware	Williamson School	Dreisbach 2267	PH	serpentine barrens
1925	Chester	Willistown Barrens	Stone	PH	
1927	Cumberland	Pine Grove Furnace	Bright, J.	CM	dry barrens
1929	Chester	Lees Bridge (Goat Hill)	Pennell, F.W. 14739	PH	serpentine thickets
1930	Chester	Cedar Barrens	Stone, H.E.	PH	serpentine rock
1947	Monroe	Brodhead Creek	Glowenke, S.L. 9964	PH	sandy field
1947	Northampton	Raubsville	Schaeffer, R.L. 25809	PH	alluvium
1947	Northampton	Slateford	Schaeffer, R.L. 26110	PH	dry woods
1962	Chester	Unionville Barrens	Henry, L.K.	CM	
1965	Monroe	Analomink	Buser, F.	ESU	dry shale outcrop
1972	Monroe	Ressaca	Buser, F.	ESU	rock outcrop
1983	Chester	Brinton's Quarry	Newbold, A.	MOAR	
1994	Chester	Mortonville (Unionville)	Ebert, J.; Holt, J.	PH	serpentine grassland
2001	Luzerne	Penobscot Mtn.	Kunsmann, J.R.	PH	crest of ridge
2003	Chester	Unionville Barrens	Ebert, Janet	MOAR	serpentine grassland
2011	Chester	Brinton's Quarry	Rhoads, Latham, DeWolf	MOAR	serpentine grassland
2011	Chester	Unionville Barrens	Rhoads, A.; Latham, R.	MOAR	serpentine grassland
2011	Luzerne	Campbells Ledge	Rhoads, Burgess, Koval, Galenty	MOAR	grassy opening, upper slope
2012	Chester	Brinton's Quarry	Rhoads & DeWolf	MOAR	serpentine grassland
2012	Luzerne	Plains Twp.	Ebert, J. ; Holt, J.	MOAR	dry grassy glades

Carex bicknellii is known from nine counties in eastern Pennsylvania. The majority of sites are on serpentinite or Mauch Chunk formation. Additional scattered sites include several in alluvium along the Delaware and Lehigh Rivers. While a number of the early sites have disappeared or no longer support *Carex bicknellii*, several previously unknown populations in Luzerne County have been discovered recently (Table 2; Figure 7).

Figure 7. Map of current and historical occurrences of *Carex bicknellii* in Pennsylvania



Serpentine Barrens Occurrences – Herbarium specimens document the fact that *C. bicknellii* once grew at ten sites on serpentinite geology in Chester and Delaware Counties (Table 2).

Carex bicknellii was described as “local on dry, open barrens” in Delaware and Chester Counties (Pennell 1910; Pennell 1912). Sites mentioned included in Delaware County: Bear Hill, Williamson School Barrens, and Glen Riddle Barrens (=Pink Hill); in Chester County: Cedar Barrens, West Chester (= Fern Hill), and Brinton’s Quarry. Wherry (1963) described *C. bicknellii* as “especially well developed on the barrens”.

Repeated attempts to relocate the species at all but two of these sites have failed. Habitat loss or degradation resulting from land use changes have clearly caused some of the losses, but in cases where serpentine barrens have been protected, such as Goat Hill, Pink Hill, and Willistown Barrens, the reasons for the disappearance of *C. bicknellii* are not as clear.

Historical Sites on Non-serpentine Geology - Historical collections of *C. bicknellii* are scattered from Cumberland County (dry barrens near Pine Grove Furnace) and a dry wooded slope along the Schuylkill River in Montgomery County to the coastal plain in Bucks County, and north along the Delaware and Lehigh Rivers in Northampton, Lehigh, and Monroe Counties (Table 2; Figure 7). Habitat descriptions include: dry rock outcrops, alluvium, sandy field, dry woods.

Status of Current Occurrences

Brinton's Quarry – A large population of *Carex bicknellii* has been known at Brinton's Quarry Serpentine Barren in Chester County for at least 100 years (Table 2). A count of fruiting stems conducted on 6/11/2012 revealed a total of 1833 fruiting stems contained in 126 clumps (plants) scattered throughout the grassland. Most clumps also had several stems that had been grazed, presumably by deer. At this site *C. bicknellii* occupies a 2-acre open grassland (Figure 5) overlooking the quarry, where it is growing with *Arabis lyrata*, *Aristida dichotoma*, *Aristida purpurascens*, *Asclepias verticillata*, *Bouteloua curtipendula*, *Carex hirsutella*, *Dichanthelium villosissimum*, *Eragrostis spectabilis*, *Juncus secundus*, *Packera anonyma*, *Phlox subulata*, *Polygonum tenue*, *Rosa virginiana*, *Schizachyrium scoparium*, *Symphotrichum depauperatum*, and scattered *Elaeagnus umbellata* (A. Rhoads field observations, 8/30/2011 & 6/11/2012).

Unionville Serpentine Barrens – Unionville Barrens, also in Chester County, where *C. bicknellii* was first documented in 1962, currently supports a small population. In 2011 it consisted of 13 plants containing 54 fruiting stems. At this site *C. bicknellii* was growing with *Anthoxanthum odoratum*, *Celastrus orbiculatus*, *Cerastium velutinum*, *Juniperus virginiana*, *Packera anonyma*, *Phlox subulata*, *Poa pratensis*, *Quercus velutina* hyb., *Rosa multiflora*, *Sassafras albidum*, *Sorghastrum nutans* (A. Rhoads, field notes 6/7/2011). Natural Lands Trust recently acquired the Unionville site and is in the early stages of implementing a restoration and management plan (Latham and McGeehin 2012).

Luzerne County sites – Of the non-serpentinite locations, only a cluster of sites in Luzerne County are known to contain extant populations of *C. bicknellii* today. All are upper slope grasslands or ridge-top barrens underlain by rocks of the Mauch Chunk Formation, red or grayish-red shale, siltstone, and limestone of Mississippian age (PA Bureau of Topographic and Geologic Survey 2001; USGS 2012). At these sites the soil in which *C. bicknellii* is growing is mapped as Oquaga and Lordstown extremely stony silt loam or Arnot-Rock outcrop complex (Soil Conservation Service 1981). These soils are described as occurring on mountain ridges, rolling mountaintops, and inter-mountain basins. They are of medium fertility, not suited for crops due to stoniness. We observed that *C. bicknellii* was rooted in a 4–5 inch thick, dark, strongly organic A-horizon at one of these sites (A. Rhoads field notes 6/27/2011).

In addition to *C. bicknellii*, associated plants of these ridge-top sites include *Ambrosia artemisiifolia*, *Andropogon gerardii*, *Apocynum cannabinum*, *Asclepias tuberosa*, *Campanula*

rotundifolia, *Carex pennsylvanica*, *C. nigromarginata*, *Eupatorium sessilifolium*, *Euthamia graminifolia*, *Helianthemum bicknellii*, *Helianthemum canadense*, *Helianthus divaricatus*, *Lechea pulchella*, *Lechea racemulosa*, *Lechea villosa*, *Lespedeza capitata*, *Potentilla arguta*, *Pycnanthemum incana*, *Rumex acetosella*, *Schizachyrium scoparium*, *Solidago gigantea*, *Solidago juncea*, *Solidago nemoralis*, *Solidago puberula*, *Sorghastrum nutans*, *Symphotrichum patens* var. *patens*,. Shrubs include *Amelanchier spicata*, *Ceanothus americanus*, *Cornus racemosa*, *Diervilla lonicera*, *Prunus pumila* var. *susquehanae*, *Rosa carolina*, *Rubus flagellaris*, *Salix humilis*, *Vaccinium angustifolium*, *Vaccinium stamineum*, and *Viburnum rafinesquianum*, (A. Rhoads field notes 5/12/2011, 6/27/2011, 7/11/2011, 9/19/2011).

Geological Affinities of *Carex bicknellii* in Pennsylvania

Carex bicknellii is a plant of the prairie region of North America (Rothrock and Reznicek 2001). Most of the locations where it is (or was) known to occur in Pennsylvania are serpentine grasslands or prairie-like openings on ridge tops underlain by rocks of the Mauch Chunk Formation (Figure 6).

A study of 43 species Pennsylvania plants, including *C. bicknellii*, whose major centers of distribution lie in the prairie and plains region of North America, revealed that 81 percent were collected on limestone, serpentinite, diabase, or shale (Barber 1995).

The Mauch Chunk Formation is described as red to reddish-brown shale, mudstone and siltstone or greenish-gray sandstone and conglomerate that was deposited in a shallow estuary associated with an extensive inland sea that covered much of the mid-continent during the Mississippian period 330—345 mya (Shultz 1999; USGS 2012).

Mapping of the Mauch Chunk formation includes, but does not differentiate, the Loyalhanna member, a sandy cross-bedded limestone and calcareous siltstone and mudstone deposited in an arm of the inland sea that extended northeastward to Luzerne County (Shultz 1999). Edmunds (1977) described the coloration of the Loyalhanna facies north of Pittston as gray to greenish-gray, in contrast with the reddish colors of much of the Mauch Chunk, citing outcrops at Campbells ledge.

Other prairie plants that we documented growing with *C. bicknellii* in ridgetop barrens on Mauch Chunk include little bluestem (*Schizachyrium scoparium*), Indian grass (*Sorghastrum nutans*), turkeyfoot (*Andropogon gerardii*), and purpletop (*Tridens flavus*).



Figure 8. *Carex bicknellii* (foreground) at Campbells Ledge, Luzerne County. Photographed 7/11/2011.

Status in Other Peripheral States

Arkansas

Carex bicknellii is classified as an inventory element (INV) in Arkansas (Arkansas Natural Heritage Commission 2012). It is ranked critically imperiled (S1) in the state by NatureServe (2011). The only confirmed occurrence of *C. bicknellii* in Arkansas is in a tallgrass prairie remnant in the north central region of the state where it was discovered in 2005 (Mackenzie et al. 2006).

Delaware

Carex bicknellii is classified presumed extirpated (SX) in Delaware. It was known from a single serpentine grassland site in New Castle County (McAvoy 2011).

Maine

Carex bicknellii is classified as endangered by the Maine Department of Conservation; and ranked critically imperiled (S1) in the state by NatureServe (2011). It is known from a single site in “disturbed ground” along a railroad track in Penobscot County (Maine Department of Conservation and Natural Areas Program 2012).

Massachusetts

Although NatureServe (2011) shows *Carex bicknellii* ranked S1S2 (critically imperiled or imperiled) in Massachusetts, the species is not included on the list of Endangered, Threatened, or Special Concern Species in Massachusetts (MA Division of Fisheries and Wildlife 2008). Rothrock and Reznicek (2011) cite two specimens from the early 1900’s from Middlesex and Norfolk Counties.

New Jersey

Carex bicknellii has HL status in New Jersey, indicating protection under the Highlands Water Protection and Planning Act (NJ DEP 2010). It is known from a 1977 specimen from Sussex County and earlier records from three additional counties in the northern half of the state (Hough 1983).

New York

Carex bicknellii is classified as threatened in New York (NY Flora Assn. 2012). It is ranked S3 (vulnerable) by NatureServe (2011). Documented occurrences are spread over ten counties in the southern half of the state; habitat is described as dry rocky or sandy soils, rocky summits, railroad rights-of-way, and other open habitat (NY Flora Assn. 2012).

Ohio

Carex bicknellii is classified as threatened in Ohio where its occurrence in four counties has been documented since 1980 (Ohio DRN 2012). It is ranked as S2 (imperiled) by NatureServe (2011). Habitat is described as dry to moist prairies, sandy open soil and dunes; the main threat is succession (Ohio DNR 2012). At the Daughmer Savannah in north central Ohio *C. bicknellii* occurs in a mesic prairie community with *Andropogon gerardii*, *C. festucacea*, *C. normalis*, *C. radiata*, *Eleocharis compressa*, *Panicum virgatum*, *Schizachyrium scoparium*, and *Sorghastrum nutans* (Mack and Boerner 2004).

Critical Management Issues

Habitat Loss

Carex bicknellii has disappeared from numerous sites where it grew in the past, both on and off serpentinite. Habitat loss due to incompatible land uses and habitat degradation through interference with normal disturbance regimes are probable causal factors.

Succession and the Role of Fire

Carex bicknellii is a grassland species; in eastern Pennsylvania natural grassland communities occur only on soils that are lacking in critical nutrients and subject to frequent drought or excessive moisture. On dry sites, wild fire was also an important contributing factor; however, in recent years fire suppression has decreased the size and frequency of burns. In the absence of fire, accumulation of organic material buffers the effects of geology and soil and allows invasion by woody plants.

A comparison of 1937 and 2010 aerial photography of Unionville Serpentine Barrens revealed that grassland habitat had decreased from 60 acres to 7 acres accompanied by a concomitant increase in woodland and forest cover (Latham and McGeehin 2012). With the decline of wild fires, prescribed burning has become an essential tool in the maintenance of serpentine grassland communities.

Non-serpentine sites such as upper slope and ridge-top barrens are also dependent on drought and periodic fire to suppress invasion by trees.

Herbivory

While deer browse does not appear to be a severe threat to *C. bicknellii*, nipped-off stems were observed in the population at Brinton's Quarry in Chester County, PA. On the other hand, browsing of invading trees and shrubs may be helping to maintain open habitat on some ridge-top sites.

Invasive Species

Barrens habitats are not highly vulnerable to invasion by non-native invasive species, which generally require high resource availability. One exception is *Rumex acetosella*, an Eurasian plant which is a common on dry barrens and rock outcrops throughout Pennsylvania (Rhoads and Block 2007).

Changes brought on by the prolonged absence of fire may allow a build-up of organic matter that buffers the effects of the underlying geology. This allows establishment of non-native, invasive woody species such as *Celastrus orbiculatus*, *Elaeagnus umbellata*, *Lonicera japonica*, *Rosa multiflora*, and exotic grasses including *Anthoxanthum odoratum*, *Microstegium vimineum*, and *Poa pratensis* and in addition to native successional species.

On serpentine barrens the native species *Smilax rotundifolia* and *S. glauca* can create thickets that dominate openings that would otherwise support native grassland communities.

Loss of Genetic Diversity

Small, isolated populations such as the *C. bicknellii* at Unionville Serpentine Barrens may be vulnerable to loss of genetic diversity due to inbreeding depression.

Conclusions

Stabilization of Existing or Recent Populations

An effort should be made to augment the existing small population of *C. bicknellii* at Unionville Barrens. Seed collected from the existing plants should be propagated off site and the resulting plants transplanted to additional locations on the barrens.

Active management is needed to maintain the high quality serpentine grassland and its large population of *C. bicknellii* at Brinton's Quarry Serpentine Barrens. The landowner, Quarry Swim Club, should be encouraged to commission and implement an appropriate management plan for the site.

Establishment of New Populations

An effort should be made to re-establish *C. bicknellii* at sites where it occurred in the past provided suitable habitat remains. Sites that should be evaluated include Goat Hill, Willistown, Fern Hill, and Pink Hill barrens. Off site propagation using seed from the closest natural population should be employed to produce plants for this purpose.

Survey Needs

A systematic search using GIS technology should be undertaken for additional high elevation grasslands, ridge top barrens, and utility rights-of-way underlain by Mauch Chunk Formation. Follow-up field surveys of promising areas should be carried out wherever possible. Sites that should be investigated include Wilkes Barre Mountain in Luzerne County; locations with Arnot and Oquaga soils should be a high priority.

All known serpentine barrens grasslands should be thoroughly searched for remnant populations of *C. bicknellii* (Chrome, Fern Hill, Goat Hill, Nottingham, Pink Hill, New Texas, Willistown).

Measures of Success

- Establishment of three additional sub-populations of *C. bicknellii* at Unionville Serpentine Barrens.
- Appropriate active management initiated at Brinton's Quarry Serpentine Barrens.
- Location and protection of two additional ridge-top barrens populations of *C. bicknellii*.
- Completion of thorough searches for *C. bicknellii* at all known serpentine grasslands in Pennsylvania.
- Establishment (or re-establishment) of viable populations of *C. bicknellii* at 2 additional serpentine barrens.

Research Needs

- Characterize and compare soil characteristics of *C. bicknellii* sites located on serpentinite and Mauch Chunk geology.
- Conduct trials of seed germination requirements, propagation methods, and seed bank longevity of *C. bicknellii*.

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Appendix A. Field Visits

Chester County

Brinton's Quarry, 8/30/2011, A.F. Rhoads, R.E. Latham, C. DeWolf

Brinton's Quarry, 6/11/2012, A.F. Rhoads and C. DeWolf

Unionville, 6/7/2011, A.F. Rhoads and R.E. Latham

Luzerne County

Wilkes Barre Mountain, 5/12/2011, A.F. Rhoads, M. Burgess, R. Koval, S. Galenty

Wilkes Barre Mountain, 6/27/2011, A.F. Rhoads, M. Burgess, R. Koval, S. Galenty

Campbells Ledge, 7/11/2011, A. F. Rhoads, M. Burgess, R. Koval, S. Galenty

Wilkes Barre Mountain, 9/19/2011, A.F. Rhoads, M. Burgess, R.E. Latham, R. Koval, S. Galenty

Campbells Ledge, 9/19/2011, A.F. Rhoads, M. Burgess, R.E. Latham, R. Koval, S. Galenty