Carex diandra Schrank (lesser panicled sedge): A Technical Conservation Assessment

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Cover Photo Credit

Carex diandra (lesser panicled sedge). Cover photograph by David J. Cooper; inset photograph:

Summary of Key Components for Conservation of *Carex diandra*

Status

Because of its broad distribution and local abundance throughout the northern hemisphere, *Carex diandra* (lesser panicled sedge) is considered globally secure (G5). However, the species is far rarer throughout the Rocky Mountain Region (Region 2) of the USDA Forest Service (USFS), being restricted to a limited number of sites in the states of Colorado, Wyoming, and Nebraska. As a result, the species has been ranked S1 (critically imperiled) in Colorado, S1/S2 (critically imperiled to imperiled) in Wyoming, and S2 (imperiled) in Nebraska. Because of its relative rarity, and that of the wetland types supporting known occurrences, USFS Region 2 has included *C. diandra* on its list of sensitive species. The wetlands supporting *C. diandra* in Wyoming and Colorado are largely found on lands managed by either the National Park Service or USFS, and while most of these occurrences appear to be generally secure from direct impacts, some may be vulnerable to indirect and cumulative impacts from land uses that alter their hydrologic or sediment dynamics. Of the approximately 25 known occurrences in Nebraska, only two are found on National Forest System lands and three occur on lands managed by the U.S. Fish and Wildlife Service or the Nature Conservancy. The remaining 20 populations in Nebraska are found on private lands, making their conservation status less certain.

Primary Threats

Within Region 2, *Carex diandra* is found primarily in fens, which are peat-forming wetlands influenced hydrologically and geochemically by groundwater inputs. Sites in Nebraska, however, are primarily associated with springs or seeps, which appear similarly dependant on groundwater inputs. Due to the region's relatively dry climate and high evapotranspiration rates, fens are restricted in distribution and are sensitive to any kind of perturbation altering their hydrologic regime. Because of *C. diandra*'s strong fidelity for these kinds of habitats, its ultimate fate in Region 2 is tied to the persistence and continued functioning of these sites. Historically, many peatlands have been hydrologically modified by ditching, and to a lesser degree, by peat mining activities. Both are currently uncommon on public lands and do not appear to represent a significant threat to extant *C. diandra* populations. However, many fens that suffered anthropogenic impacts in the past continue to exhibit impaired function and require active hydrologic restoration before any ecological recovery can begin. Another historical impact of unknown extent is the construction of reservoirs, which could have affected fens through flooding. Since *C. diandra* is typically associated with small ponds or lakes, which are attractive sites for impounding and storing water, past and future water resource developments may have impacted the species. An additional direct threat is road construction and expansion activities, which have the potential to affect several fens supporting *C. diandra* on the Shoshone National Forest. Of additional concern are activities (e.g., trampling by livestock, recreationists, native ungulates, or illegal off-highway vehicles) that compromise the integrity of the peat substrates that support many *C. diandra* occurrences.

Although direct impacts currently appear to pose a relatively small threat to most Region 2 *Carex diandra* populations, a wide variety of activities are known to indirectly impact wetland structure and function and thus potentially reduce the suitability of sites for this species. Activities like logging and road construction can significantly alter hydrologic or sediment dynamics in fens and consequently have a negative impact on any *C. diandra* that may occur there. Regional climate change, predicted under several different climate models, also has the potential to negatively impact fens by altering hydrology and shifting the balance of production and decomposition that is key to driving peat formation and maintaining habitat stability.

There is little evidence suggesting that the viability of known *Carex diandra* occurrences is imminently threatened, and what little data are available suggest that the majority of the Region 2 occurrences are stable. Many occurrences are found in either USFS Wilderness or national parks or other special management areas, which may afford the species some level of protection. The Nebraska occurrences on private lands lack such protections and consequently may be more vulnerable.

Primary Conservation Elements, Management Implications and Considerations

Because of the rarity of *Carex diandra* and the wetlands in which it occurs in Region 2, as well as large gaps in our understanding of the species' biology, conservation efforts should be centered on maintaining the integrity of its habitat. As with many other species whose distribution is primarily in boreal regions, *C. diandra* was likely more widely distributed in the past. Constriction of its range and the isolation of individual populations have likely occurred as a function of the warmer and drier climatic conditions since the last major period of Pleistocene glaciation. Limited dispersal distances and the small and discontinuous distribution of fens providing its habitat suggest that expansion of *C. diandra* into new sites is highly unlikely. Consequently, maintaining the functional integrity of the sites that support extant populations should be at the core of species conservation efforts.

In the course of preparing this assessment, it has become clear that there are large gaps in our understanding of the population biology and ecological relationships of *Carex diandra* in the region. For example, no rigorous demographic studies have been conducted on populations within Region 2; such data are essential to understanding natural variation in the species' abundance and its sensitivity to potential management actions. In addition, more extensive and comprehensive peatland inventories are needed to improve our understanding of the abundance, distribution, and functional diversity of peatlands in the region. These kinds of studies have an added benefit of providing a useful framework for more fine-scaled investigations of fen hydrology, vegetation, and geochemistry – the key variables driving wetland structure and function and determining the suitability of habitat for *C. diandra*.

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INTRODUCTION

To understand and mitigate the potential environmental impacts of management activities and projects on individual species, the USDA Forest Service (USFS) requires basic information about species' biology, ecology, and conservation status. Unfortunately, for many species, little information is available, and what information is available is scattered among a variety of disparate sources, largely unavailable to managers and planners needing the information. To address these information gaps, the USFS Region 2, through its Species Conservation Project, has initiated the development of Species Conservation Assessments for a number of plant and animal species.

Goal

The principle objective of this assessment is to collect and synthesize the existing information on the basic biology, ecological and habitat relationships, and conservation status of *Carex diandra* (lesser panicled sedge) in USFS Region 2. Consistent with previous assessments, we address a variety of topics such as the species' taxonomy, distribution, life history characteristics, physiology, and population biology, as well as known habitat relationships. *Carex diandra* is restricted to wetlands, so we place particular emphasis on the hydrologic regime and geochemistry of wetlands that support known populations since these represent key ecological variables driving the structure and function of wetlands. Lastly, we provide an assessment of the conservation status of the species in Region 2 and suggest possible approaches for future management, research, and monitoring of the species.

Our goal with this assessment is not to make specific management recommendations per se, but rather to synthesize basic knowledge of the species, its habitat, and potential threats. Wetlands supporting *Carex diandra* in the northern hemisphere and within Region 2 are functionally diverse, making formulation of specific predictions of the direct and indirect effects of management activities on the species impossible. However, the general principles we present should provide a useful context for managers to identify, evaluate, and mitigate the potential impacts of management actions before they have been realized.

Scope of Assessment

In this assessment, we detail the current knowledge regarding the biology, ecology, conservation status, and management of *Carex diandra* throughout USFS Region 2, which encompasses 17 national forests and seven national grasslands throughout Colorado, Kansas, Nebraska, South Dakota, and Wyoming. For this assessment, Region 2 refers to all lands within the general administrative boundaries of the USFS Rocky Mountain Region, regardless of ownership or management. However, because much of the literature available for *C. diandra* comes from outside of Region 2, data and information from a broader geographic area are included where appropriate. Likewise, while the temporal scope of the assessment is on current conditions, we include relevant information from historical and evolutionary perspectives.

Information Sources

Considering the broad geographic and topical scope of this assessment and the general scarcity of studies specific to *Carex diandra*, we have drawn upon a variety of information sources, including peer-reviewed scientific literature, gray literature (e.g., theses and dissertations, agency reports), herbarium records, and data sources such as element occurrence records from Natural Heritage Programs in the region. In addition, where available, we have also incorporated unpublished data, reports, and anecdotal accounts of known occurrences from managers or scientists who are familiar with the species or the wetlands it occupies.

The scope of this assessment is on *Carex diandra* within Region 2. However, the species has a broad global distribution, and much of the information available regarding the species' biology and ecology originates from outside of Region 2. Where appropriate, we have utilized these resources. Though topics discussed in this assessment are largely set in the context of current environmental conditions, when possible, we have incorporated information on evolutionary and biogeographic aspects of both the species and the wetland types in which it occurs. These broader perspectives are essential for developing realistic assessments of current and future conservation threats.

Treatment of Uncertainty

Science is best viewed as a process rather than an end in and of itself; what is presently assumed to be fact may well be discarded later as new information and theory become available. A corollary to the fact that our knowledge of the natural world is founded upon empirical observation is that our confidence and certainty regarding our conclusions are only as strong as the information underlying them.

Biological and ecological systems are by nature complex and highly variable. Experimental science, by necessity, reduces this complexity by making a variety of assumptions. In contrast, inductive scientific approaches, such as modeling, seek to synthesize and integrate the findings of smaller, more controlled studies; however, there are always large gaps in the extent and quality of the available information which can compromise the integrity of results and limit their applicability outside of their original research context (Holling 1996). Consequently, when preparing broad-scale, integrative assessments such as this, it is important to explicitly address issues of uncertainty and recognize the limits of available data.

Because the distribution of *Carex diandra* within Region 2 is limited to a small number of sites for which quantitative data are largely unavailable, it is impossible to make definitive statements about the species' ecology or conservation status in the region. However, *C. diandra* is widely distributed elsewhere, and numerous studies, particularly in Europe, have directly or indirectly analyzed the species. Where available, we have drawn upon these studies to make inferences about the species in Region 2, but because it is easy to misapply research findings outside of their original ecological context, we have been judicious in their use.

Given the unavailability of research specific to *Carex diandra* from Region 2, we have relied heavily upon our knowledge of the particular wetland types where this species occurs. In concert with insights provided by other scientists and managers, and careful extrapolation of work conducted outside the region, we provide a first approximation of the biology, ecology, and conservation status of *C. diandra*. However, consistent with the spirit of the Species Conservation Project and the flexibility provided through publication of assessments on the World Wide Web, we anticipate changes to our conclusions as more information becomes available.

Publication of Assessment on the World Wide Web

To facilitate their use in the Species Conservation Project, species assessments will be published on the USFS Region 2 World Wide Web site (http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml). Placing documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More importantly, it facilitates revision of the assessments, which will be accomplished based on guidelines established by USFS Region 2.

Peer Review

Assessments developed for the Species Conservation Project have been peer reviewed prior to their release on the Web. This assessment was reviewed through a process administered by the Center for Plant Conservation, employing two recognized experts in this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Carex diandra has a broad distribution throughout North America, Eurasia, and New Zealand, and has therefore been given the global rank of G5 (see **Definitions** section of this assessment for description of Natural Heritage Program ranks; NatureServe 2004). The species has not been given national ranks in either the United States or Canada. The rank ascribed to the species in individual states and provinces ranges from S5 in many of the Canadian provinces to S1 in many U.S. states. The species has been ranked S1 in Colorado, S1/S2 in Wyoming, and S2 in Nebraska (Keinath et al. 2003, NatureServe 2004); it is not known to occur in South Dakota or Kansas (**Table 1**). *Carex diandra* has been placed on USFS Region 2's list of sensitive species (USDA Forest Service 2006).

Existing Regulatory Mechanisms, Management Plans, and Conservation Practices

Carex diandra is neither listed nor is it a candidate for listing under the Endangered Species Act, and therefore, it receives no special protection under Federal law. However, *C. diandra* is an obligate wetland species (Reed 1988). Since the 1970's, most wetlands have received some measure of protection through regulations in Section 404 of the Clean Water Act. The jurisdiction to enforce Section 404 regulations resides with the U.S. Army Corps of Engineers (USACE). However, the 2001 Supreme Court's decision in Solid Waste Agency of Northern Cook County (SWANCC) vs. USACE has effectively removed the USACE's regulatory oversight for wetlands that lack surface water connections to navigable bodies of water such

Table 1. Conservation status of *Carex diandra* by state or Canadian province. See **Definitions** section for description of Natural Heritage Program ranks. Region 2 states are in bold and italics. (NatureServe 2004).

State	Status	State	Status	Province	Status
Alaska	SNR	Nevada	SNR	Alberta	S5
California	SNR	New Hampshire	S1	British Columbia	S5
Colorado	***S1***	New Jersey	S2	Labrador	S1S2
Connecticut	SNR	New York	SNR	Manitoba	S5
Idaho	SNR	North Dakota	S2S3	New Brunswick	S3
Illinois	SNR	Ohio	S2	Newfoundland Island	S3S5
Indiana	SNR	Oregon	S1	Northwest Territories	SNR
Iowa	SH	Pennsylvania	S2	Nova Scotia	S4
Maine	SNR	Rhode Island	SNR	Nunavut	SNR
Maryland	S1	Tennessee	SNR	Ontario	S5
Massachusetts	SNR	Utah	S1	Prince Edward Island	S4
Michigan	SNR	Vermont	SNR	Quebec	SNR
Minnesota	SNR	Washington	SNR	Saskatchewan	S5?
Montana	SNR	Wisconsin	SNR	Yukon Territory	SNR
Nebraska	***S2***	***Wyoming***	***S1S2***		

as streams. Since most fens lack such connections, they may be considered isolated with regards to USACE jurisdiction under the Clean Water Act (Bedford and Godwin 2003). However, the scope of USACE jurisdiction on geographically isolated wetlands is still undetermined, with cases presently under review in the courts. Also relevant to wetlands management on National Forest System lands is Executive Order 11990, which instructs agencies to "take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands."

At present, no Region-wide policy regarding peatlands is in place, but one is being developed (Austin personal communication 2004). Regional guidance is provided by USFS memo 2070/2520-72620, signed by the Director of Renewable Resources, which emphasizes the protection, preservation, and enhancement of fens to all Region 2 forest supervisors. However, the memo is not a directive, and as such, does not limit the kinds of management activities that can be pursued in wetlands supporting *Carex diandra*. Section 2670 and related chapters of the Forest Service Manual outline policies and requirements applicable to sensitive species such as *C. diandra*. It requires Regional Foresters and Forest Supervisors to include measures intended to conserve sensitive species in regional and forest-specific planning activities. Specific policies include assisting States in conserving endemic species, avoiding or minimizing impacts to designated species, and where impacts are unavoidable, analyzing the effect on species' populations and habitats (USDA Forest Service 2006). Region 6 of the U.S. Fish and Wildlife Service, which overlaps part of USFS Region 2, has a policy regarding the protection of fens, which states that mitigation for fens is not feasible due their irreplaceability (USDI Fish and Wildlife 1999).

Several of the documented occurrences of *Carex diandra* are in designated USFS wilderness areas. This presumably confers some degree of *de facto* protection to the species due to their inaccessibility and the preclusion of land uses, such as road construction, that can negatively impact wetlands. In addition, a limited number of occurrences are found in areas with other special management designations. Examples include the Swamp Lake Special Botanical Area on the Shoshone National Forest in Wyoming and the Todd Gulch Special Interest Area on the Roosevelt National Forest in Colorado. Although these designations may not prohibit actions that are detrimental to the species, they nonetheless indicate recognition of important biological resources by USFS staff, which may result in improved management for *C. diandra*.

Biology and Ecology

Classification and description

Systematics and synonymy

Carex diandra, a perennial member of the Cyperaceae, was first described by Schrank in 1781 in

Cent. Bot. Anmerk (Integrated Taxonomic Information System 2004). The common name typically used in North America is the lesser panicled sedge although in the British Isles, the species is also known as the lesser-tussock sedge (Rodwell 1991, USDA Natural Resources Conservation Service 2004). An outline of the full taxonomic classification of *C. diandra* is presented in **Table 2**.

The genus *Carex* is large, with nearly 2,000 species globally and 480 in the North American flora alone (Ball and Reznicek 2004). Species in the genus occupy a diverse range of habitats and are found across broad edaphic, hydrologic, and elevational gradients. Although they occur in uplands as well, *Carex* species are particularly prevalent in wetland environments, where they are often among the dominant vascular species present. Species in the genus are similar morphologically, and many are largely indistinguishable by vegetative characteristics alone, making sedge taxonomy difficult and field identification sometimes impossible if plants are not fruiting (Metcalfe 1969, Standley 1990).

To elucidate phylogenetic relationships among *Carex* species, taxonomists have recognized several infra-specific taxa. Hendrichs et al. (2004) place *C. diandra* in the subgenus Vignea, while at the sectional level, *C. diandra* has traditionally been placed in the section *Paniculatae* (Hermann 1970). Early sectional taxonomies for North American *Carex* (Mackenzie 1940) have been significantly revised as part of the recent Flora of North America project (Reznicek 2001, Ball and Reznicek 2004) since many of the original sections are no longer thought to be monophyletic (Waterway et al. 1997). In his treatment, Reznicek (2001) placed *C. diandra* in section *Heleoglochin*. This section, which is closely related to sections *Multiflorae* and *Vulpinae*, contains approximately 12 species distributed throughout temperate regions of North America, Eurasia, north Africa, the Canary Islands, and Oceania (Ball and Reznicek 2004).

Homonyms and infra-specific taxa for *Carex diandra* include *C. diandra* forma *congguesta* Lekavic, *C. diandra* var. *ampla* Kuk, and *C. diandra* var. *ramosa* (Boott) Fernald (MOBOT 2004). However, none of the above taxa are presently accepted by taxonomic authorities (Integrated Taxonomic Information System 2004, USDA Natural Resources Conservation Service 2004).

Morphological characteristics

Carex diandra is a perennial, tussock-forming sedge. Culms are typically 30 to 90 cm tall, sharply triangular in cross-section, strongly roughened on the angles, aphyllopodic, and equaling or exceeding the leaves. Narrow leaves measuring 1 to 3 mm in width and 14 to 30 cm in length are largely borne on the lower one-third of the culm. Membranous leaf sheaths extending 0.4 to 4 mm beyond the leaf blade are truncate or convex at the mouth and typically speckled with red dots or streaks on their ventral surface.

Carex diandra has numerous small, androgynous, few-flowered inflorescences, typically tan to brown in color and closely aggregated into a linear, simple or inconspicuously compound form, measuring 1.5 to 6.0 cm long and 0.7 to 1.4 mm wide (**Figure 1**). Pistillate scales in the species are straw-colored or brownish, measuring 1.5 to 2.7 mm long by 0.9 to 1.6 mm wide and with a pale midrib and wide-hyaline margins. Scales are as wide or wider than the perigynia but typically shorter in length. The olive to dark chestnut brown perigynia bear 4 to 6 prominent and 2 to 4 fine veins on their abaxial surface, and they often bear a membranous flap towards their apex. The typically shiny perigynia

Table 2. Taxonomy and nomenclature of *Carex diandra* (Integrated Taxonomic Information System 2004).

Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Liliopsida
Subclass	Commelinidae
Order	Cyperales
Family	Cyperacea
Genus	*Carex*
Subgenus	*Vignea*
Species	*Carex diandra* Schrank

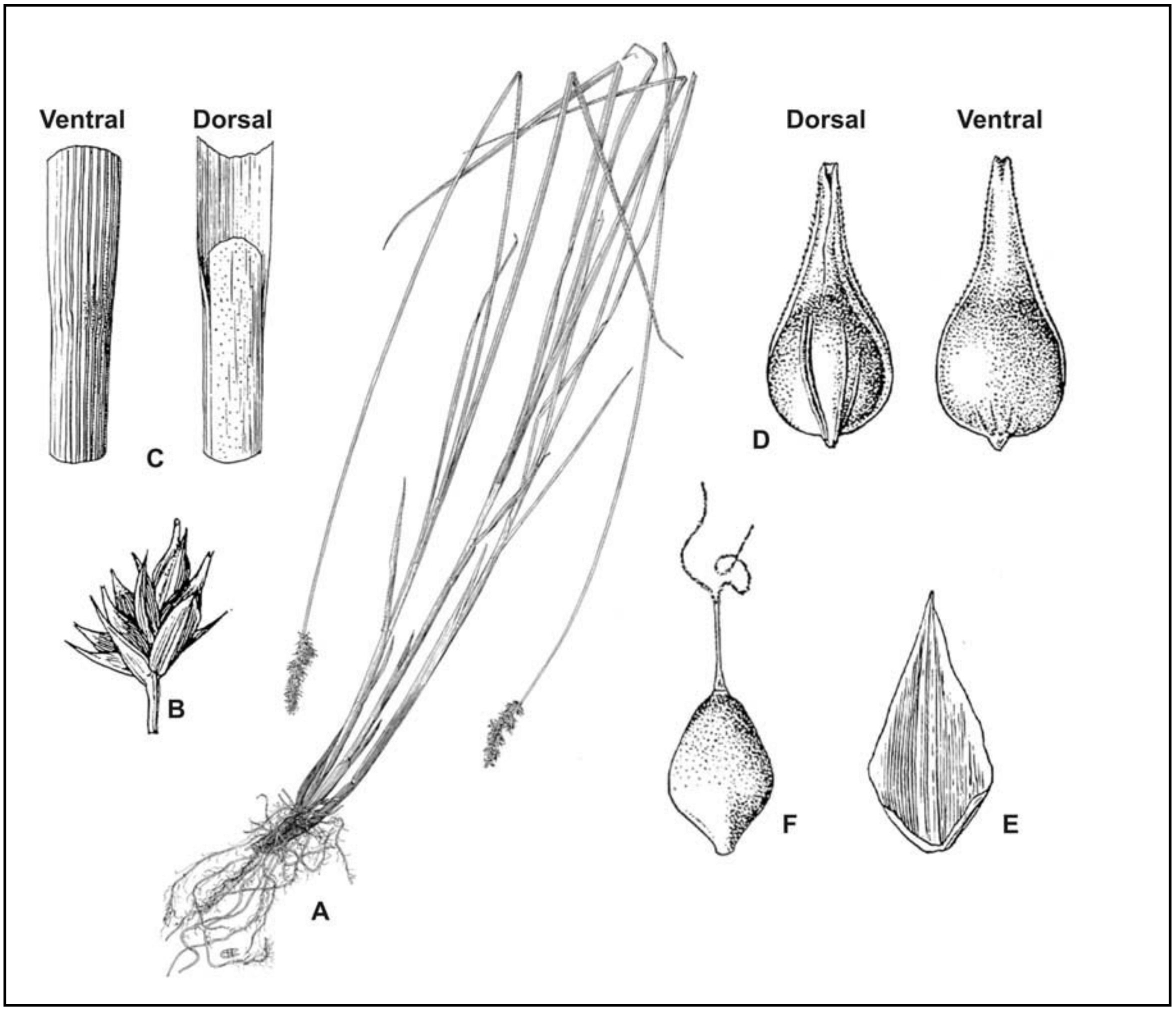

Figure 1. Key morphological structures in *Carex diandra*. (A) habit; (B) view of the predominantly pistillate inflorescence extracted; (C) dorsal and ventral views of the leaf sheath; (D) dorsal and ventral views of the perigynium; (E) pistillate scale; (F) achene with the perigynium removed. (Images extracted from plate 67 of Mackenzie 1940).

are narrowly deltoid-ovoid and unequally biconvex in shape, measuring 2.0 to 2.5 mm long by 0.9 to 1.4 mm wide, and bear a coarse, tapering, thin-walled, serrulate-margined beak 0.9 to 1.1 mm long. The achenes are brown, broadly compressed-ovoid in form, measuring 1.0 to 1.7 mm long by 0.7 to 1 mm wide, jointed to the style and bearing two stigmas (**Figure 1**). The preceding description is based on information in Hermann (1970), Hurd et al. (1998), Johnston (2001), and Cochrane (2002).

While *Carex diandra* is relatively distinct, it can be confused with several other sedges. In *C. diandra*, the inner band of the leaf sheath is whitish in color whereas in the closely related *C. cusickii* (Cusick's sedge) and *C. prairea* (prairie sedge), the band is copper-colored (Ball and Reznicek 2004). The rhizomatous growth form of *C. simulate* (analogue sedge) helps to distinguish it from *C. diandra*, which does not spread clonally and has a distinct tufted habit.

Distribution and abundance

Carex diandra is widely distributed globally, occurring throughout Europe and Asia, the Canary Islands, and New Zealand (Hulten 1968, Ball and Reznicek 2004). Within North America, it is most prevalent in the Canadian provinces, but it is discontinuously distributed in 30 U.S. states as well (NatureServe 2004). With the exception of the highest latitudes, the species typically becomes more common and abundant as one moves north. At lower latitudes, *C. diandra* is widely distributed in montane areas in North America, Europe, and Asia, presumably due to the wetter and cooler climatic conditions associated with increased elevation.

Carex diandra is documented from three states in USFS Region 2: Wyoming, Colorado, and Nebraska. With approximately 25 known occurrences, Nebraska has the greatest number of occurrences, followed by Wyoming and then Colorado (**Appendix**). Within Region 2, occurrences are discontinuously distributed, with several populations highly disjunct from one another and from populations in neighboring states (**Figure 2**). Occurrences in Nebraska are at relatively low elevations, ranging from 590 to 1,247 m (1,940 to 4,090 ft.) above sea level, in contrast to Wyoming and Colorado occurrences, most of which are found at significantly higher elevations, 1,860 to 2,931 m (6,100 to 9,614 ft.).

Herbarium and natural heritage element occurrence records (**Appendix**) document the species as occurring in the Roosevelt, White River, Routt, Medicine Bow, Samuel McKelvie, and Shoshone national forests. In addition, occurrences are documented from Grand Teton, Yellowstone, and Great Sand Dunes national parks, as well as the Niobrara and Cresent Lake national wildlife refuges in Nebraska. All occurrences in Wyoming and Colorado are on public land; however, 20 of the 25 known occurrences in Nebraska are on private lands.

Reliable abundance estimates are generally lacking for *Carex diandra* occurrences within Region 2. Although some estimates are available, none appear to have been developed through a thorough, methodological census, but rather represent qualitative estimates made as part of broader field surveys. For example, during their 1996 visit to the Lily Lake occurrence on the Shoshone National Forest, Fertig and Mellmann-Brown estimated 50 to 100 tussocks along the lake's northwest shore (Mellmann-Brown 2004). Estimates of the numbers of tussocks are similarly reported from Nebraska (see list of element occurrence records in **Appendix** for examples). For many occurrences, only qualitative estimates are provided. For instance, Heidel and Laursen (2003) noted that *C. diandra* was "uncommon" in the fen surrounding Little Moose Lake on the Shoshone National Forest while Fertig and Jones (1992) indicated that the species was "locally abundant" at the Swamp Lake site on the Shoshone National Forest. In general, even where actual numbers are presented,

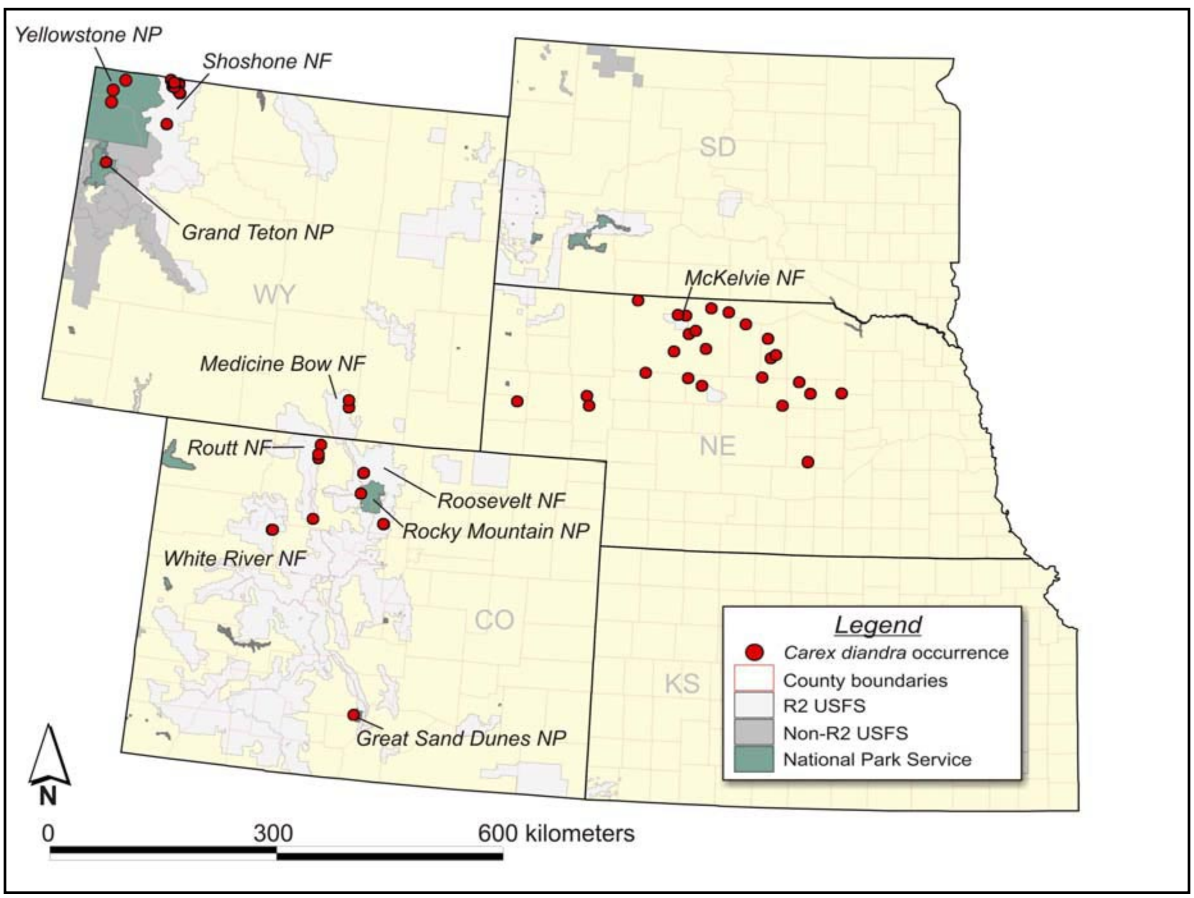

Figure 2. Distribution of *Carex diandra* within the states encompassed by USDA Forest Service Region 2.

they do not appear to be of sufficient precision to be used for monitoring purposes.

Population trend

Unfortunately, there are insufficient data from which to evaluate possible population trends in Region 2 *Carex diandra* occurrences. As mentioned earlier, the majority of occurrence records lack population estimates, and the few estimates that are presented are too imprecise to be of much use in estimating trends. In addition, many occurrences have only been visited once and consequently provide no guidance as to possible changes in species' abundance over time.

Habitat

Ecological classification can be a difficult task regardless of the kind of system in question. Many different criteria, alone or in combination, can be used to differentiate groups; ultimately, the choice of which classifying variable(s) to use dictates the utility of the resulting classification scheme. To be useful from the perspective of management and conservation, a classification should delineate classes that will respond similarly to management activities or disturbance.

At fine to intermediate spatial scales, the most intuitive and commonly used approaches are based on vegetation structure and composition. Examples include including the numerous habitat-type classifications developed by the USFS (e.g., Alexander et al. 1986, Hess and Alexander 1986) and the National Vegetation Classification System developed by the Nature Conservancy and used by Natural Heritage programs (e.g., Comer et al. 2003, NatureServe 2003).

Although vegetation is certainly useful for wetland classification, because of the predominance of hydrologic and chemical gradients in driving wetland structure and ecological function, additional approaches to wetland classification and description have been developed (Cowardin et al. 1979, Brinson 1993). For peatlands, classification schemes have typically emphasized chemical variables (pH, cation or nutrient concentrations), water source (groundwater vs. precipitation), and vegetation and peat composition (bryophyte vs. sedge). Useful general references for peatlands include Windell et al. (1986), Crum (1988), Mitsch and Gosselink (2000).

The general habitat characteristics for *Carex diandra* have been variously described as swampy, marshy, or boggy areas, including features such as wet meadows, fens, muskegs, floating mats, and shores of lakes and ponds. Less frequently, *C. diandra* has been documented from swales, ditches, and wet sandy beaches of non-alkaline lakes and pond edges (Hulten 1968, Gleason and Cronquist 1991, Ball and Reznicek 2004). The species has been recorded from such varied habitats as open fens in the Hudson Bay lowlands (Sjörs 1963) to wooded fens and floating peat mats surrounding lakes in northern Minnesota (Glaser et al. 1981, Glaser 1987). In Europe, the species is known from relatively pristine valley peatlands formed on broad floodplains to, in the Netherlands, polders, which are reclaimed areas below sea level formed and managed through diking and pumping (Wassen and Barendregt 1992, Wassen et al. 1996, Demars et al. 1997). Across its range, *C. diandra* is most commonly found in peatlands, ranging from poor fens to extremely rich fens (Wheeler 1980, Kubiw et al. 1989, Glaser 1992).

Within Region 2, *Carex diandra* occurrences occur in several general settings. The most common habitats described in Colorado and Wyoming are montane and subalpine fens, particularly those formed in depressions such as small kettles or other basins in periglacial environments (**Figure 3**, **Figure 4**). The wet and cool environments conducive to fen formation are generally restricted to higher elevations (Windell et al. 1986) where cooler and wetter climatic and hydrologic conditions prevail. As a consequence, all of the *C. diandra* occurrences in Wyoming and Colorado are found at elevations exceeding 1,830 m (6,000 ft.).

Fens supporting *Carex diandra* also occur in the Nebraska Sandhills region. In addition to *C. diandra*, these rare ecosystems support several additional fen indicators with more northern affinities such as *Menyanthes trifoliata* (buckbean), *Eriophorum angustifolium* (tall cottongrass), *E. gracile* (slender cottongrass), and *C. limosa* (mud sedge) (Steinauer et al. 1996). They are highly valued because of their unique hydrologic function and floristic composition, which are quite distinct from other wetland types generally found in the Great Plains. In addition, several *C. diandra* occurrences are associated with springs or seeps adjacent to riparian systems (**Figure 5**).

Reproductive biology and autecology

Life history and strategy

Studies of *Carex diandra* life history characteristics are generally lacking, but detailed studies of other *Carex* species can be found in the literature (Bernard and Macdonal 1974, Bernard 1976, Bedford

Figure 3. Overview of the Todd Gulch fen, Roosevelt National Forest, a montane fen on the east slope of the Colorado Front Range that supports an occurrence of *Carex diandra* (Photograph by D. Cooper).

Figure 4. Close-up photograph of the Todd Gulch fen, Roosevelt National Forest, CO. *Carex diandra* is the tufted plant in the left foreground of the image and occurs on a floating peat mat. To the right is a vegetation zone dominated by *C. utriculata*, a band of *Juncus arcticus*, and finally, upland vegetation (Photograph by D. Cooper).

et al. 1988). Extrapolation from these studies provides some insights into the life history of *C. diandra*. We have identified three primary stages in the life cycle of *C. diandra*: the seed, the seedling, and the mature plant (**Figure 6**). Some studies of other sedge species have described up to six distinct age classes. However, there are insufficient data specific to *C. diandra* to warrant such an approach for this assessment.

Reproduction, pollinators, and pollination ecology

Carex diandra can reproduce both sexually via seed and vegetatively through the formation of tussocks. The species fruits from late May to mid-August, producing numerous small achenes (Cochrane 2002). Members of the genus *Carex*, including *C. diandra*, are wind pollinated (Handel 1976, Gleason and Cronquist 1991). There are no data available describing out-crossing distances or other basic aspects of *C. diandra* pollination ecology. In the region, *C. diandra* typically flowers between late spring or early summer and bears fruit beginning in June or July (Hurd et al. 1998, Ball and Reznicek 2004).

Seed dispersal, viability, and germination requirements

Carex diandra must establish from seed, at least episodically, although it is unknown under what specific circumstances. No studies have detailed seed dispersal in *C. diandra*, but it is likely that several agents may be important, including wind, water, and animals, specifically birds or insects (Ridley 1930, Leck and Schütz 2005). The importance of any particular dispersal mechanism likely depends on the spatial scale considered and local habitat characteristics. For example, in the montane landscapes typical of Colorado and Wyoming occurrences, dispersal within individual wetlands may be effectively achieved through water or wind, but long-distance dispersal between fens may depend on animal vectors. However, in Nebraska, where

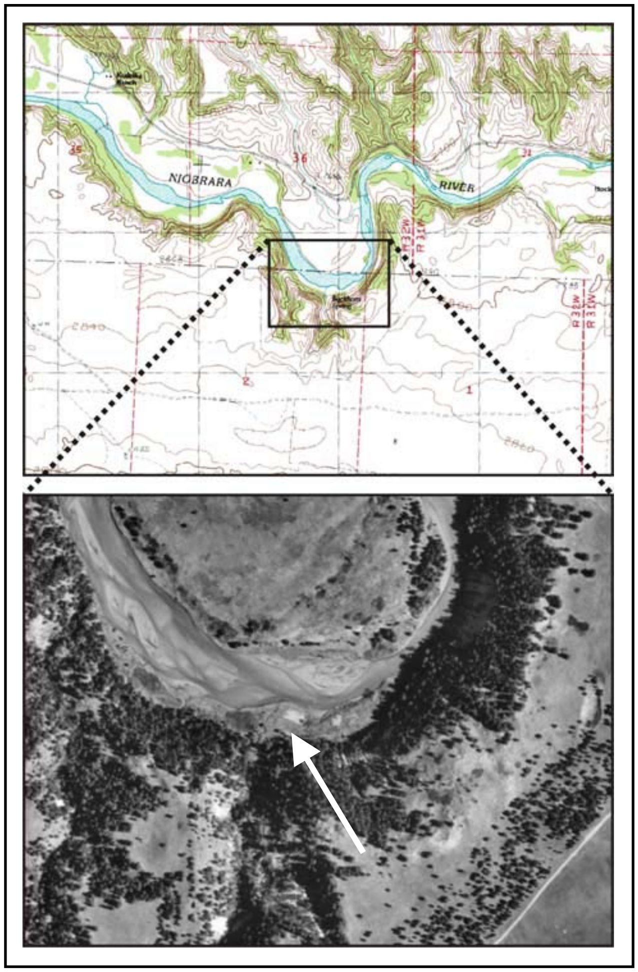

Figure 5. Spring fed wetland supporting *Carex diandra* adjacent to the Niobrara River, Nebraska on the Samuel McKelvie National Forest. Approximate location of *C. diandra* is indicated by the arrow.

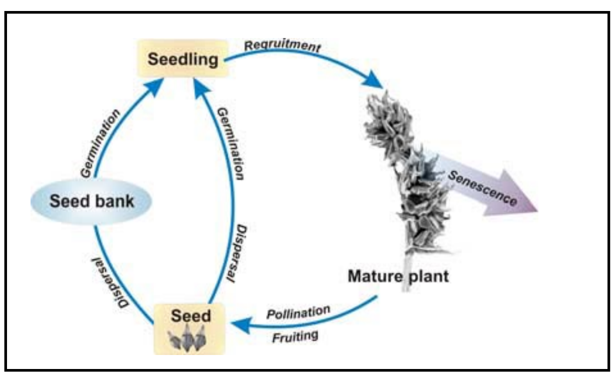

Figure 6. General life cycle diagram for *Carex diandra*.

many occurrences are found associated with springs and seeps adjacent to riparian systems, rivers may be more important in long-distance dispersal events (Nilsson et al. 1991, Johansson et al. 1996). Seed densities under *C. diandra* are relatively modest relative to other *Carex* species, ranging from 15 to 20 seeds per m^2 (Leck and Schütz 2005).

Although there are no studies specifically examining *Carex diandra* seed germination requirements, research from other *Carex* species suggests that seeds have at least limited dormancy and are capable of forming a persistent soil seed bank (Schütz 1998, Schütz and Rave 1999, Schütz 2002). Seeds likely germinate the spring following dispersal or enter the soil seed bank, germinating when more favorable conditions occur. The relative importance of seed bank processes in *C. diandra* establishment dynamics is unknown. Leck and Schütz (2005) report that most *C. diandra* seeds are found within 0 to 5 cm (0 to 2 inches) of the soil surface.

Genetic characteristics and concerns

Chromosome counts (2n) for *Carex diandra* include 48, 50, 54, and 60 (Ball and Reznicek 2004, MOBOT 2004). Other genetic characteristics for *C. diandra* are unknown since no studies have examined the species' genetics. Genetics work conducted on other *Carex* species suggests that many sedge populations show little genetic differentiation even when widely separated spatially (McClintock and Waterway 1993, Vellend and Waterway 1999). Since known occurrences of *C. diandra* in the region are relatively isolated from one another, presumably genetic crossing between occurrences is rare. However, absent further research, it is impossible to say with certainty what the underlying genetic structure is in the region.

Hybridization

Hybridization has been widely reported in the genus *Carex* (Cayouette and Catling 1992). The majority of verified crosses have been between closely related species within the same section; however, intersectional hybrids have also been described. Few crosses are known to produce fertile offspring although some exceptions have been documented (Cayouette and Catling 1992, Ball and Reznicek 2004). We found no reports of *C. diandra* hybrids from Region 2, but several hybrids have been reported from elsewhere. As examples, a hybrid between *C. diandra* and *C. secta* Boott was noted in New Zealand (Edgar 1964), and a hybrid between *C. diandra* and *C. paniculata* has been reported from Ireland (O'Mahoney 1984). Because several closely related species such as *C. cusickii* and *C. prairea* are found in the region, hybrids are possible. However, we found no evidence to suggest that this is the case; whether this is due to a lack of research directed towards the issue is unknown.

Demography

To develop an understanding of a species' population biology, information regarding the important age and life history stages and the nature of the transitions between them is essential. Such information regarding the demographic characteristics of *Carex diandra*, particularly from Region 2 occurrences, is lacking. As a result, much of the following analysis is derived from work conducted on other sedge species, and it should be viewed as hypotheses in need of further research rather than verified fact.

Following dispersal and germination, discussed earlier, *Carex diandra* seedlings can be recruited into older age classes; however, the specific factors governing this transition are unknown. Mortality due to herbivory, disease, or competition are possible constraints on recruitment (Harper 1977), but there are no data available to evaluate their relative importance for *C. diandra*. Likewise, competition from other plants for resources such as light and nutrients may also constrain recruitment (Perezcorona and Verhoeven 1996, Kotowski and van Diggelen 2004).

There is little known regarding the relative phenology and life span of *Carex diandra* shoots. Limited work on the subject has been conducted in Europe. In the Netherlands, Aerts and de Caluwe (1995) examined patterns of leaf and shoot life span among four different *Carex* species, including *C. diandra*. They found that *C. diandra* leaf and shoot life spans were the lowest among the species they examined, but that the specific length varied in relation to nutrient status. For example, mean life span of leaf cohorts ranged from approximately 98 to 140 days in the higher nitrogen treatments, and from approximately 55 to 104 days in the low nitrogen treatment. A similar pattern was observed with shoot cohorts, with average life spans of around 100 and 210 days in the low and high nutrient treatments, respectively (Aerts and de Caluwe 1995).

Work done on other temperate *Carex* species may provide some additional insights into growth dynamics in *C. diandra*. In a study of *C. rostrata* (beaked sedge) in a New York fen, Bernard (1976) found that most shoots emerged between mid-summer and early fall and lasted, at most, 20 to 25 months before senescing (Bernard 1976). Notably, only 17 percent of the shoots he followed survived to produce seeds. Similar results have been reported from Canada for the same species (Gorham and Somers 1973). Though it is unlikely that *C. diandra* exhibits exactly the same pattern, these studies suggest some possible scenarios.

Although there are no quantitative data available, *Carex diandra* tussocks appear to be quite persistent, suggesting that mature plants can be of considerable age. Unlike other wetland *Carex* species such as *C. limosa*, *C. diandra* does not spread via long runners or rhizomes. Instead, it produces only short rhizomes, resulting in its caespitose form (Bernard 1990).

Because of the extensive clonal spread characteristic of the former species, genets may be centuries or even millennia in age. However, what the mean or maximum ages of caespitose species like *C. diandra* are is unknown.

No Population Viability Analysis (PVA) has been performed for *Carex diandra*, and it is likely that data are insufficient to identify a minimum viable population size. In general, small occurrences are more susceptible to localized extinction due to environmental stochasticity (Pollard 1966). More information regarding plant growth rates and life span, rates of seed production and viability, and seed bank formation and expression would help to identify vulnerable stages in the life history of *C. diandra*.

Community and ecosystem ecology

Hydrogeomorphic, geological and landscape setting

Wetlands, in general, and peatlands, in particular, form in specific hydrogeomorphic and climatic settings. In areas with high precipitation and low evapotranspiration rates, as found in boreal regions, peatlands, ranging from ombrotrophic bogs to minerotrophic fens, can be a significant or even dominant cover type on the landscape (Zoltai et al. 1988). However, at lower latitudes including most of Region 2, peatlands are constrained to very specific geomorphic and landscape settings that possess the hydrologic and microclimatic conditions necessary to support peat accumulation (Windell et al. 1986, Cooper 1990). These can include both slope and depressional settings (**Figure 7**) and are typically found at higher elevations (Carsey et al. 2003).

Based on the premise that wetland vegetation is largely determined by hydrogeomorphic processes, the HGM approach to wetland classification groups wetlands based on their basic geomorphic and physiochemical features (Brinson 1993). Cooper applied the HGM approach in an analysis of Colorado wetlands (Cooper 1988), this work was later expanded as part of the development of a statewide classification of wetland plant communities (Carsey et al. 2003).

Although *Carex diandra* was not referenced in the analysis, it appears clear that most of the fens supporting *C. diandra* occurrences in Colorado would fall into the D1 HGM subclass, which consists of depressional wetlands found in mid- to high-elevation basins with peat soils or along lake fringes, with or without peat soils (Carsey et al. 2003). These kinds of features are particularly widespread in glaciated terrain and include features such as kettles, watershed divides, and other basins, which are common in many Region 2 mountain ranges. Although the original work was limited geographically to Colorado, it is likely that most Wyoming fens supporting *C. diandra* would also fit well into this subclass (**Figure 8**). However, none of the subclasses defined in Cooper's 1988 analysis appear appropriate for the wetlands in Nebraska supporting *C. diandra*.

Wetlands supporting *Carex diandra* occur in a variety of geological settings. The stratigraphy and mineral composition of bedrock and quaternary deposits are important variables influencing both the abundance and functional characteristics of wetlands at broad scales (Bohn et al. 2003). For example, the permeability and distribution of hydrologic flow paths, gross physiography, and groundwater chemistry often differ between areas composed of igneous or metamorphic rock versus sedimentary rocks, with significant implications for wetlands. An additional factor of key importance to wetlands is the quaternary history of an area. Glaciated landscapes typically contain a higher density of wetlands than adjacent un-glaciated terrain. *Carex diandra*, for example, often occurs in fens formed in small kettle basins created by stagnant ice deposits left behind retreating glaciers.

The actual geological configuration of sites supporting fens can be complex. For example, the Swamp Lake wetland on the Shoshone National Forest, which supports an occurrence of *Carex diandra*, is found in Quaternary glacial deposits. While the lake is underlain by impervious Precambrian granite, rising immediately to the south of Swamp Lake are the Cathedral Cliffs, composed of three discrete layers including limestone at the base, followed by dolomite, and finally a cap of volcanic rock (Heidel and Laursen 2003). The limestone and dolomite formations contribute groundwater that is high in pH, and the wetland in turn supports an extremely rich fen community, including the rare species *C. livida* (livid sedge), *C. leptalea* (bristlystalked sedge), *C. limosa*, and *C. diandra* (Fertig and Jones 1992, Heidel and Laursen 2003). Nearby fens formed in watersheds composed entirely of the granitic rock underlying Swamp Lake lack the alkaline groundwater inputs; instead of a rich fen, these wetlands support plant communities of poor and intermediate fens (Heidel and Laursen 2003, Mellmann-Brown 2004).

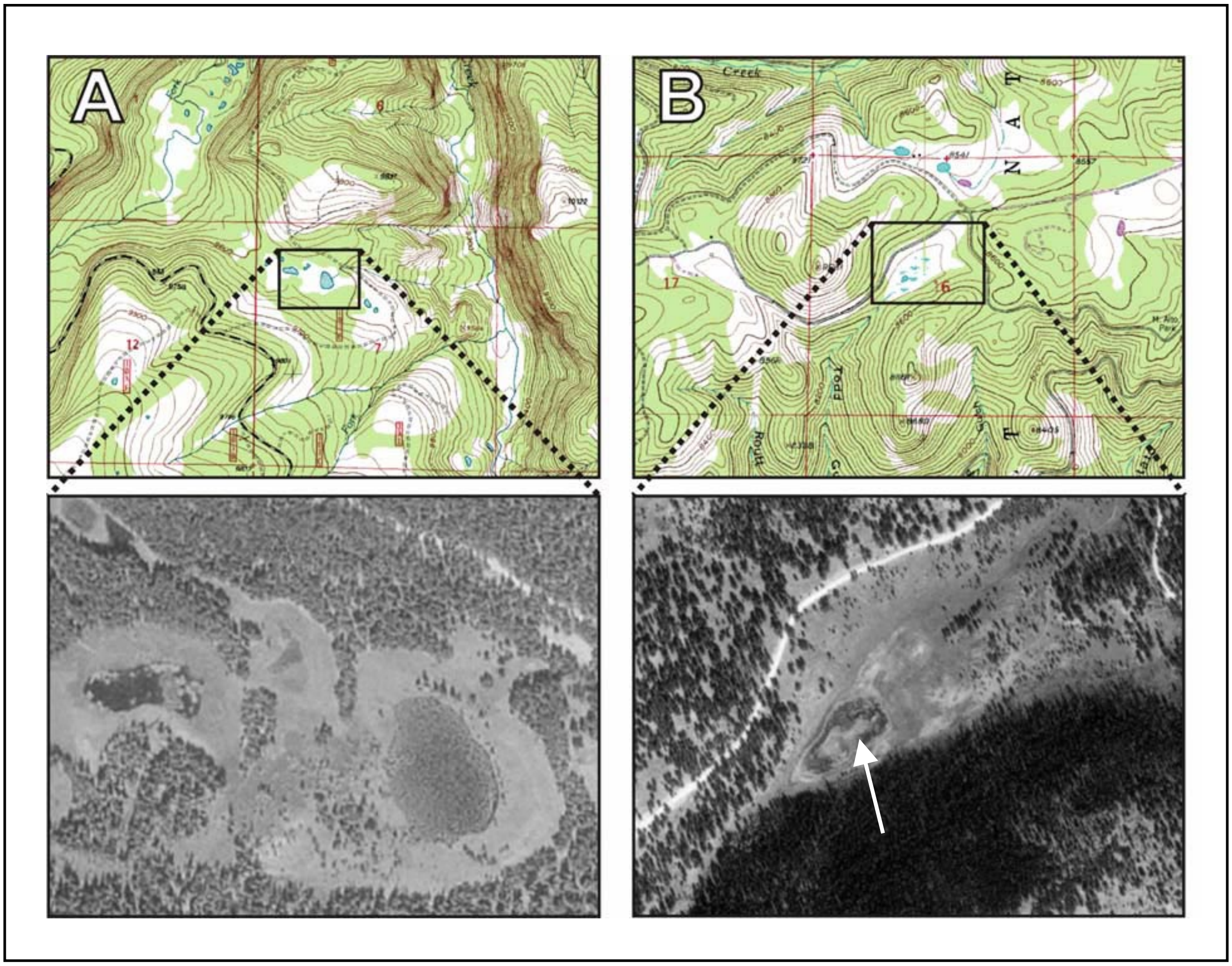

Figure 7. Two fens supporting *Carex diandra*: (A) Sand Lake fen, Medicine Bow National Forest, Wyoming; (B) Todd Gulch fen, Roosevelt National Forest, Colorado. Both fens are formed in small depressional basins, are fed principally by groundwater inputs from adjacent slopes, and support floating peat mats. Approximate location of *C. diandra* in the Todd Gulch site is indicated by the arrow. Map and aerial photograph source: USGS.

Although the majority of sites supporting *Carex diandra* occur in peatlands, the species has also been observed along the margins of lakes and ponds, in sites that would not qualify as fens. Interestingly, many of the Nebraska occurrences are found adjacent to rivers. However, habitat descriptions in element occurrence records indicate that all occurrences are associated with springs or seeps where groundwater is discharging to the surface. Though adjacent to rivers, the more stable water table dynamics typical of springs suggests that these sites function more like fens than riparian areas. *Carex diandra* also occurs on broad flood plains in Europe, where research has demonstrated that *C. diandra* communities were influenced more by groundwater inputs from adjacent valley slopes than by surface water (Wassen and Joosten 1996).

Substrate characteristics and microhabitats

Both globally and within Region 2, *Carex diandra* typically occurs in peat soils (Wassen and Barendregt 1992, Heidel and Laursen 2003, Cooper and Jones 2004) Taxonomically, most soils supporting the species would be classified as Histosols (Mitsch and Gosselink 2000). Although *C. diandra* is also known from lake and pond margins with mineral soils, within Region 2, it appears to occur primarily on either anchored or floating peat mats. The species has been observed rooted in floating logs in a Colorado pond (Rocchio et al. 2002). Peat depth in sites supporting *C. diandra* occurrences is highly variable and is driven largely by variation in fen age, basin size (for non-slope peatland types), aspect and elevation, and degree of

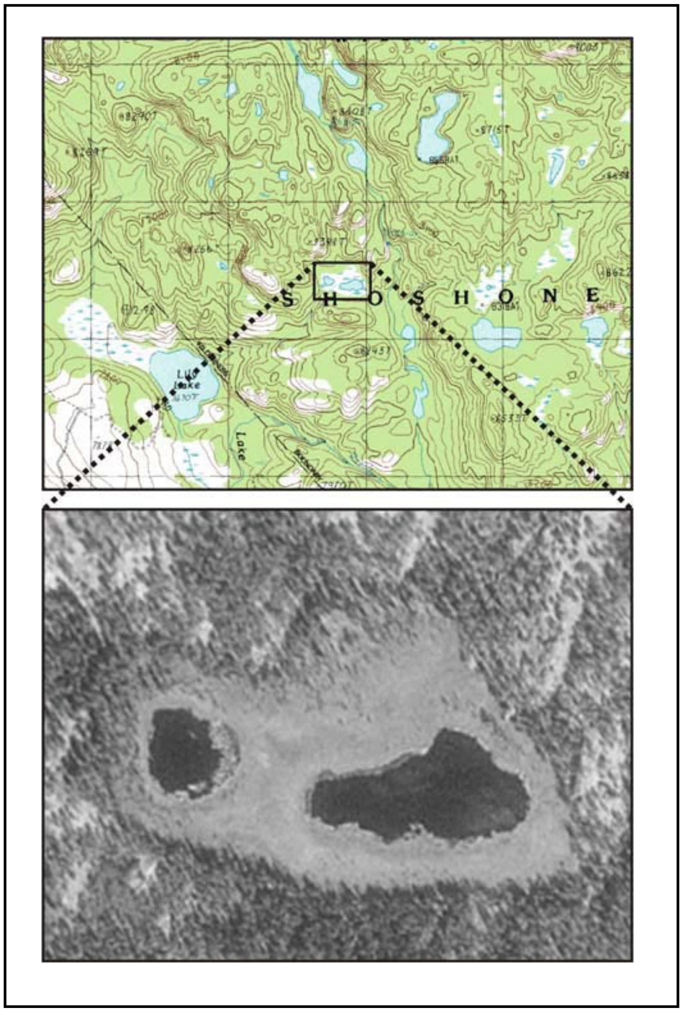

Figure 8. Unnamed fen supporting *Carex diandra* northeast of Lily Lake on the Shoshone National Forest, Wyoming. Note the presence of a large floating mat between open water areas. Map and aerial photograph source: USGS.

minerotrophy (Bauer et al. 2003, Glaser et al. 2004). Peat accumulations can be deep, commonly exceeding 1 m (3.3 ft.) (Cooper and Jones 2004). For example, Lemly and Cooper (unpublished data) observed peat depths of over 2.4 m (7.9 ft.) in several fens supporting *C. diandra* in Yellowstone National Park.

A variety of distinct micro-topographical features, such as hummocks, ridges (strings), and pools (flarks), can form in fens (Glaser 1987, Foster et al. 1988, Cooper and Andrus 1994). Water table depth, pH, and cation concentrations can vary considerably among these features, influencing vegetation patterns in these microsites. Generally, when present in any given fen, *Carex diandra* occupies the wettest, non-aquatic microsites, which can include pools, hollows, or floating mats (Wheeler et al. 1983, Glaser 1987, Chadde et al. 1998, Mellmann-Brown 2004).

Hydrology

Hydrologic regime is perhaps the single greatest factor influencing vegetation patterns in wetlands. Indeed, hydrologic regime is such an important factor driving wetland structure and function that it is one of the primary criteria implicitly or explicitly used to differentiate wetland types in many classifications (e.g., marsh, fen, riparian wetland) (Windell et al. 1986, Tiner 1999). Numerous studies have found significant correlations between such hydrologic metrics as mean water table depth and intra and inter-annual hydrologic variability and wetland vegetation patterns (Cooper 1990, Bragazza and Gerdol 1999, Wassen et al. 2003).

Water table depth is one of the dominant physical gradients controlling wetland multivariate ordinations, with most species exhibiting a unimodal distribution along water table depth gradients. *Carex diandra* is generally found in very wet microsites, such as sites adjacent to open water along the margins of ponds or floating peat mats (Konings et al. 1992, Vandiggelen et al. 1996). Floating mats are typically very stable hydrologically because the mat is able to move up or down as pond water levels fluctuate (Cooper and Arp 2002). In England, Hill et al. (1999) assigned *C. diandra* an Ellenberg value (a relative ranking of a species' affinity for particular environment conditions) for moisture of 9 on a scale of 12, identifying it as an indicator of wet, poorly aerated environments.

Although the floating mat environments typical of many *Carex diandra* occurrences in the region function rather simply hydrologically, overall hydrologic patterns in fens can be significantly more complex, with surface and groundwater from various sources affecting water table levels, as well as water chemistry. For example, Swamp Lake on the Shoshone National Forest, which supports *C. diandra*, is fed by several water sources, including toe slope seeps and springs, surface flow entering the fen, subsurface flow entering through adjacent debris fans, and groundwater discharge that emanates from glacial deposits on the margins of the fen (Heidel and Laursen 2003).

Nutrients, water and peat chemistry

Although hydrologic regime is generally regarded as the principal gradient driving species distributions and abundances in peatlands, vegetation patterns in peatlands are also strongly correlated with peat and water chemistry. Because of this, gradients in pH and the concentration of nutrients such as nitrogen and phosphorus and of ions such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) are commonly used to differentiate and classify peatlands (Crum 1988).

The concentration of mineral ions and nutrients that fen plants require are principally supplied by groundwater inputs, with minor contributions from dry and wet atmospheric deposition and surface water inflows. Consequently, the geochemistry of bedrock and quaternary deposits in contributing watersheds are key controls of fen water supply pH and nutrient and ion delivery (Glaser et al. 1981, Windell et al. 1986, Chee and Vitt 1989, Vitt and Chee 1990). Watersheds with limestone, dolomite, or shale bedrock produce water that is basic in reaction (pH 7.0 to 8.5) (Cooper 1996, Chapman et al. 2003a, Chapman et al. 2003b, Heidel and Laursen 2003) while those composed of granitic or metamorphic rocks produce acidic waters (Cooper and Andrus 1994, Cooper et al. 2002).

As applied to fens, the terms poor and rich have typically been used to describe wetland fertility gradients, specifically nitrogen and phosphorus availability (Bragazza and Gerdol 2002), as well as species richness gradients. Gradients in pH and the concentration of mineral ions such as calcium (Ca^{2+}) are generally thought to co-vary with nutrient-availability gradients, but some researchers suggest that pH and nutrient gradients should be separated (Bridgham et al. 1996, Wheeler and Proctor 2000, Bragazza and Gerdol 2002). However, within North American peatlands, most studies have found a close correlation between cation concentrations and pH, so either can be effectively used to characterize habitat.

Carex diandra has been reported from sites exhibiting a wide range of pH values (**Table 3**, **Figure 9**). These include *Sphagnum*-dominated poor fens to extremely rich fens. *Carex diandra* apparently does not occur in ombrotrophic bogs. In England, *C. diandra* was assigned an Ellenberg indicator value for reaction (pH) of 5 on a scale of 9, making the species an indicator of moderately acid soils, only occasionally occurring on very acid or basic sites. In a recent analysis of habitat preferences for a large number of northern sedges, *C. diandra* was placed in a group of sedges that occur most frequently in peatlands with a pH greater than 6.0 (Gignac et al. 2004). This is consistent with the limited data from Region 2; most occurrences where pH data are available would be classified as intermediate rich and rich fens. An exception is the Swamp Lake site on the Shoshone National Forest, which has circum-neutral to alkaline pH values characteristic of extremely rich fens (Heidel and Laursen 2003). Fertig and Jones (1992) measured pH values of 6.9 to 7.9, and pH measurements taken at calcareous springs at the site ranged from 8.0 to 8.4 (Heidel and Laursen 2003). Likewise, two new *C. diandra* occurrences reported from Yellowstone National Park were from sites with pH values of 7.6 and 8.6 (Lemly personal communication 2005).

A note of caution is warranted when reviewing water chemistry data from different studies. Research has shown that a given parameter such as pH can be highly variable over short distances within a given peatland (Tahvanainen et al. 2002, Tahvanainen and Tuomaala 2003). For example, significant differences in pH values between microtopographic features such as strings and flarks are common, with each feature supporting distinctive species adapted to more or less acid conditions (Glaser 1992). Chemical parameters in a given location can also vary seasonally (Wassen and Barendregt 1992, Tahvanainen et al. 2003), and with respect to depth in a peat profile (Shotyk et al.

Table 3. Water chemistry parameters reported from peatlands supporting *Carex diandra*. Mean values are presented unless a range is indicated; parenthetical values are standard deviations. Chemical species for which no values were reported are indicated by *na*. All ion concentrations are reported in mg per L.

Reference	Study location	pH	Ca^{2+}	Mg^{2+}	Na^{+}
Region 2					
Heidel 2003	Shoshone National Forest, Park County, Wyoming	4.34-7.9	na	na	na
Lemly and Cooper Unpublished data	Yellowstone National Park, Wyoming	7.6-8.6	13.8-25.9	6.8-13.7	4.2-9.8
Steinauer et al. 1996	Nebraska	6-6.9	9.6-115.2	7.8-13.7	na
North America					
Bayley and Mewhort 2004	Alberta, Canada	6.0 (0.13)	8.0 (0.4)	4.1 (0.2)	1.9 (0.1)
Cooper and Jones 2004	Montana	4.6-7.9	na	na	na
Glaser et al. 1990	Minnesota	7	37	na	na
Europe					
Bootsma and Wassen 1996	Netherlands	5.8 (0.9)	24.4 (17.6)	3.3 (2.0)	22.7 (21.8)
Bootsma and Wassen 1996	Poland	6.8 (0.7)	58.1 (34.1)	8.8	4.1 (6.3)
Wassen and Barendregt 1992	Netherlands	6.6 (0.3)	36 (24)	na	na
Wassen et al. 1996	Netherlands	6.4-6.9	33-61	na	na

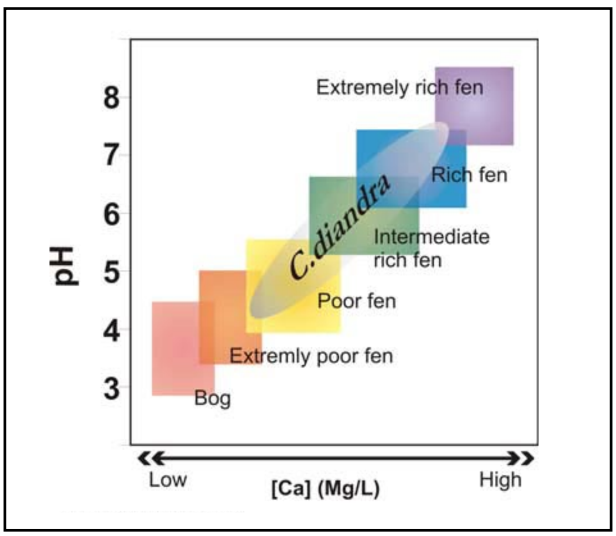

Figure 9. Approximate pH and Ca^{2+} values for different types of peatlands. Shaded area corresponds to the approximate habitat range of *Carex diandra* within Region 2.

1990, Tahvanainen and Tuomaala 2003), complicating interpretation of data from different studies. Unfortunately, methodological information important to data interpretation, such as whether samples were collected from surface water or water extracted from peat, are often lacking (Shotyk 1988).

Nitrogen is the limiting nutrient in most terrestrial plant communities although in some environments, including some wetlands, phosphorus may be limiting (Mitsch and Gosselink 2000). Nutrient concentrations can affect vegetation in a variety of ways. For example, differences in nitrate (NO_3^-), ammonium (NH_4^+), and total phosphorus (P) surface water concentrations among fen types and marshes have been correlated with total net primary productivity (Beltman et al. 1996, Thormann and Bayley 1997a) and litter decomposition rates (Thormann and Bayley 1997b). These are key determinants of the rate of peat accumulation and successional processes in peatlands (Thormann et al. 1999).

Biologically-mediated redox reactions, such as nitrate reduction, nitrogen (N) fixation, and denitrification, account for the principal fluxes of nitrogen in wetlands (Beltman et al. 1996, Oien 2004). The bacterial flora largely responsible for these transformations differs depending on site-specific hydrologic and chemical characteristics. Anoxic sites (e.g., floating mat environments) typically have low total nitrogen, and due to a lack of nitrifying bacteria, low NO_3^- concentrations (Mitsch and Gosselink 2000). Unfortunately, no studies examining nutrient dynamics in fens supporting *Carex diandra* from Region 2 have been published. However, some studies from outside of the region are available. For instance, Wassen and Barendregt (1992) report NO_3^- concentrations of 0.4 mg per L, NH_4^+ concentrations of 0.6 mg per L, and $H_2PO_4^-$ concentrations of 0.03 mg per L from a Dutch fen supporting *C. diandra*. Working in a floating sedge fen supporting *C. diandra* in Alberta, Canada, Bayley and Mewhort (2004) reported NH_4^+ concentrations of 0.013 mg per L and NO_3^- concentrations of 0.008 mg per L. Hill et al. (1999) assigned *C. diandra* an Ellenberg indicator value for nitrogen of 3 on a scale of 9, making it an indicator of infertile sites.

Considerable variation in the concentration of cations in fen water and peat is also common. Differences among fens are largely the result of different bedrock geology and hydrology (Windell et al. 1986). Due to differences in groundwater source and flux, it is also common to see large differences within microsites in individual fens (Cooper and Andrus 1994). It is important to note that point measurements in space and time may not fully represent actual plant-available nutrient and ion concentrations over the growing season, as individual sites can have significantly different flux rates due to differences in groundwater or surface water flow-through rates (Cooper and Arp 2002).

Sediment dynamics

Relative to other wetland types, sediment flux rates into peatlands are typically very small. Because of the slow peat accumulation rates typifying fens within Region 2 (Chimner and Cooper 2003), significant increases in mineral flux outside of the historic range of variability have the potential to negatively impact vegetation. While few studies have examined sediment budgets for peatlands, some data are available from fens in the San Juan National Forest (Cooper and Arp 2002).

Using sediment fences placed around the margins of fens and disks placed in the fen interior, Cooper and Arp (2002) quantified the delivery of mineral sediment and organic material (e.g., twigs, cones, spruce needles) to fens. Sediment deposition following spring runoff averaged 13 to 62 g per m^2 (<0.1 mm depth of accretion). Sediment was over 60 percent organic matter by weight, suggesting that adjacent forest communities contribute significant amounts of organic matter into fens. However, virtually no sediment was delivered to the interior of fens. Although the particular fen they studied does not support *Carex diandra*, it is similar in many key respects to fens where the species has been documented. If the comparison is valid, their results suggest that species found in the interior of fens, such as *C. diandra*, may be insulated somewhat from minor fluctuations in sediment input at fen margins.

Mass wasting events such as landslides may episodically contribute pulses of sediment. For example, Heidel and Laursen (2003) observed several debris flows entering the Swamp Lake wetland from adjacent cliff faces that were destabilized by fire and salvage logging activities. Based on the presence of ravines on the adjacent slopes, they also suggested that debris flows may have been recurrent events in the past. However, because the physiographic and geological setting of the wetlands supporting known *Carex diandra* occurrences is so variable, it is impossible to evaluate whether such episodic events are important elsewhere.

Vegetation types and associated plant species

Wetlands, and peatlands in particular, support a distinct and diverse assemblage of plants species. Because of this, they are critically important to local and regional biodiversity (Brinson and Malvarez 2002, Leibowitz 2003). Although species diversity within individual plant communities is often low, strong hydrologic and chemical gradients, which are so critical in determining the fine-scale distribution of individual species, often create multiple distinct vegetation zones dominated by a completely different suite of species. Thus, relatively high species diversity can be seen at the scale of the entire wetland.

Species diversity among peatlands is highly variable, influenced by factors such as pH, nutrient status, and disturbance history. Diversity is typically lower in nutrient poor systems, such as bogs and poor fens, and in microsites characterized by extremely wet, acidic, or basic conditions. The floating mat environment characteristic of many of the Region 2 *Carex diandra* occurrences is an example. Generally, these sites are dominated by a limited number of vascular species such as *C. lasiocarpa* (woollyfruit sedge), *C. limosa*, *C. livida*, and *Menyanthes trifoliata* (**Table 4**).

A wide variety of bryophytes are associated with *Carex diandra*; the specific species vary, with more acidic poor fens and intermediate rich fens supporting *Sphagnum* species and circum-neutral and basic systems generally supporting "brown moss" species. Examples of *Sphagnum* species reported sites supporting *C. diandra* include *S. centrale*, *S. angustifolium*, *S. capillifolium*, *S. teres*, and *S. warnstorfii*. In intermediate rich, rich, and extremely rich fens, "brown moss" species such as *Aulocomnium palustre*, *Calliergon stramineum*, *C. giganteum*, *Warnstrofia exannulata*, *Tomenthypnum*

Table 4. Common plant associates of *Carex diandra*, as reported from a sample of studies from USDA Forest Service Region 2 and elsewhere.

References	Study location	Associated species
Region 2		
Heidel and Laursen 2003	Shoshone National Forest, Wyoming	*Carex limosa, Drosera rotundifolia, Eriophorum gracile, Potamogeton praelongus, C. lasiocarpa, Menyanthes trifoliata, C. vesicara, Ledum glandulosum, Salix farriae, C. utriculata, C. simulata, Scirpus actus, Typha latifolia, Eleocharis quinqueflora, Drepanocladus aduncus.*
Fertig and Jones 1992	Shoshone National Forest, Wyoming	*Triglochlin maritium, Kobresia simpliciuscula, Thalictrum alpinum, Eleocharis rostellata, E. pauciflora, Scirpus pumilus, Carex buxbaumii, C. limosa, C. livida.*
Lemly and Cooper Unpublished data	Yellowstone National Park, Wyoming	*Carex utriculata, C. lasiocarpa, Eleocharis quinquifolia, Salix planifolia, S. candida.*
Mellmann-Brown 2004	Shoshone National Forest, Wyoming	*Carex utriculata, C. aquatilis, C limosa, Eleocharis quinqueflora, Nuphar polysepala, Menyanthes trifoliata, C. livida.*
Nebraska Natural Heritage Program 2004	Nebraska	*Carex hystericina, Thelypteris palustris, Eleocharis* spp., *Eupatorium perfoliatum, Eriphorum gracile, Drepanocladus aduncus, Bryum pseudotriquetrum, Campylium stellatum.*
Steinauer et al. 1996	Nebraska	*Carex lacustris, C. prairea, C. limosa, Eriophorum angustifolium, E. gracile, Menyanthes trifoliata, Muhlenbergia glomerata, Calamgrostis canadensis, Schoenoplctus acutus, Eleocharis elliptica, Phragmites australis.*
North America		
Bayley and Mewhort 2004	Alberta, Canada	*Agrostis scabra, Carex lasiocarpa, C. limosa, C. rostrata, Drosera rotundifolia, Menyanthes trifoliata, Potentilla palustris, Triglochin maritima, Aulacomnium palustre, Calliergonella cuspidata, Hamatocaulis vernicosus, Sphagnum warnstorfii.*
Chadde et al. 1998	Idaho	*Carex lasiocarpa, C. canescens, C. muricata, C. utriculata, Drosera rotundifolia, Betula pumila, Spiraea douglassi, Salix pedicularis, Kalmia microphylla, Sphagnum centrale, S. agustifolium, S. capillifolium.*
Cooper and Jones 2004	Montana	*Carex lasiocarpa, C. buxbaumii, C. chordorrhiza, C. flava, C. interior, C. utriculata, Forbs Menyanthes trifoliata, Comarum palustre* (=*Potentilla palustris*), *Polygonum amphibium, Bryophytes Tomenthypnum nitens, Scorpidium cossonii, Campylium stellatum, Calliergon giganteum,Hamatocaulis vernicosus, Aulacomnium palustre.*
Glaser et al. 1990	Minnesota	*Scirpus cespitosus, Cladium mariscoides, Carex limosa, C. lasiocarpa, Muhlenbergia glomerata, Campyllum stellatum, Drepanocladus revolvens, Scorpidium scorpioides.*

Table 4 (concluded).

References	Study location	Associated species
Greenlee and Jones 2000	Montana	*Carex limosa, C. interior, Menyanthes trifoliata, Comarum palustre, Sphagnum* spp.
Hansen and Hall 2002	Montana	*Carex lasiocarpa, C. lanuginosa, C. rostrata, Eriophorum polystachion, Potentilla gracilis.*
Jankovsky-Jones 1997	Idaho	*Carex lasiocarpa, C. utriculata, C. chordorrhiza, Scirpus microcarpus, Menyanthes trifoliata, Comarum palustre, Lycopus uniflorus, Aulocomnium palustre, Calliergon stramineum, Warnstrofia exannulata.*
Wheeler et al. 1983	Minnesota	*Calamagrostis canadensis, C. neglecta, Caltha palustris C. pseudo-cyperus, Cicuta bulbifera, Lysimachia thyrsiflora, Myrica gale,Potamogeton natans, Ranunculus gmelini var. hookeri, Rumex orbiculatus, Sparganium minimum.*
<u>Europe</u>		
Wassen and Barendregt 1992	Netherlands	*Carex rostrata, Comarum palustre, Equisetum fluviatile, Agrostis stolonifera, Juncus subnudulosus, Pedicularis palustris, Menyanthes trifoliata, Calliergon cordifolium.*
Wassen and Joosten 1996	Poland	*Carex rostrata, C, panicea, C. lepidocarpa, C. limosa, C. chordorrhiza, Utricuria minor, Pedicularis palustris, Menyanthes trifoliata, Comarum palustre, Campylium stellatum, Drepancladus revolvens.*
Wassen et al. 2003	Poland	*Carex lasiocarpa, C. lepidocarpa, C. panicea, Parnassia palustris, Rumex hydrolapathum, Mentha aquatica, C. disticha, C. elata, Caltha palustris, Comarum palustre.*
Wheeler 1980	England	*Carex lasiocarpa, C. rostrata, Acrocladium giganteum, Comarum palustre, Menyanthes trifoliata.*
Zimmerli 1988	Switzerland	*Carex limosa, Menyanthes trifoliata, Comarum palustre, Rhizomnium punctatum, Calliergon gigantum, Sphagnum teres.*

nitens, *Scorpidium cossonii*, *Campylium stellatum*, and *Hamatocaulis vernicosus* have been reported (Jankovsky-Jones 1997, Bayley and Mewhort 2004, Cooper and Jones 2004).

Authors have included *Carex diandra* in a variety of different vegetation types. Although regional floristic differences along with differences in methodology can make cross-walking among different classifications difficult, there are considerable similarities among many of the treatments. For example, Hansen and Hall (2002) listed *C. diandra* as a component of their *C. lasiocarpa* habitat type; this habitat type appears to be synonymous with the *C. lasiocarpa* vegetation association reported by Padgett et al. (1989) and Chadde et al. (1998). *Carex diandra* is also closely associated with *C. lasiocarpa* from fens in Alberta (Szumigalski and Bayley 1996a, Szumigalski and Bayley 1996b). Cooper and Jones (2004), working in Montana, describe *C. diandra* from two closely related associations: a *C. lasiocarpa*/"brown mosses" association and a *C. lasiocarpa*/*Sphagnum* spp. association. *Carex diandra* was also present in Cooper and Jones' (2004) *C. limosa*/"Brown mosses" vegetation association. In their report on the vegetation of Swamp Lake on the Shoshone National Forest, Fertig and Jones (1992) listed *C. diandra* as part of a *Triglochlin-Eleocharis* vegetation type.

NatureServe (2004) lists a *Carex diandra* Wet Meadow Herbaceous Vegetation Association (CEGL002549), part of the *Carex* spp. Seasonally Flooded Herbaceous Alliance, as occurring in only two locations, Manitoba and Colorado. *Carex diandra* was recorded from vegetation plots in Voyageurs National Park, Minnesota classified as *Thuja occidentalis* – (*Picea mariana*, *Abies balsamea*)/*Alnus incana* Forest Association (CEGL002456) (VegBank 2004). *Carex diandra* has also been recorded from the *C. aquatilis* – *C. utriculata* Herbaceous Vegetation Association (CEGL001803) in Glacier National Park, Montana, and the *Calamagrostis canadensis–Phalaris arundinacea* Herbaceous Vegetation in northern Michigan (CEGL0051474) (VegBank 2004).

Fen formation, development, and succession

Within Region 2, *Carex diandra* often occurs in fens formed in small pond or lake basins. Although making generalizations regarding successional processes in many ecosystems is ill-advised because of the variability of disturbance, the hydrologic stability typical of fens along with the long temporal record they preserve in the form of their accumulated peat deposits, suggest that there may be a general procession of vegetation and peatland development, at least in basin-type settings.

Fens formed in basins are often, although not always, associated with glacial activities. Kettle ponds are particularly favorable sites and are common features in many areas affected by both continental and montane glaciers. In addition, lateral moraines deposited by glaciers have blocked drainages, producing ponds similar to kettle ponds. Mass wasting events such as landslides are additional factors influencing the formation and function of some wetlands supporting *Carex diandra*. Often, fens may reflect the influence of both geomorphic processes. Although fens can form in a variety of physiographic settings including basins and slopes where springs discharge groundwater, the former is most important with regards to *C. diandra* habitat. Basin size is an additional variable influencing hydrology and vegetation.

Two general mechanisms are responsible for the formation of peatlands. Terrestrialization is the process by which a water body fills with sediments and peat, and paludification describes the conversion of uplands to peatland through increased waterlogging of soils as peat accumulation impedes drainage. Between the two, terrestrialization appears to be of greater importance in most temperate areas, and within Region 2, fen formation appears to occur primarily *via* terrestrialization (**Figure 10**).

Successional processes have been extensively studied in peatlands, but few of these studies have been conducted within Region 2. Both allogenic and autogenic processes have been postulated as drivers of peatland formation, with the relative role of each

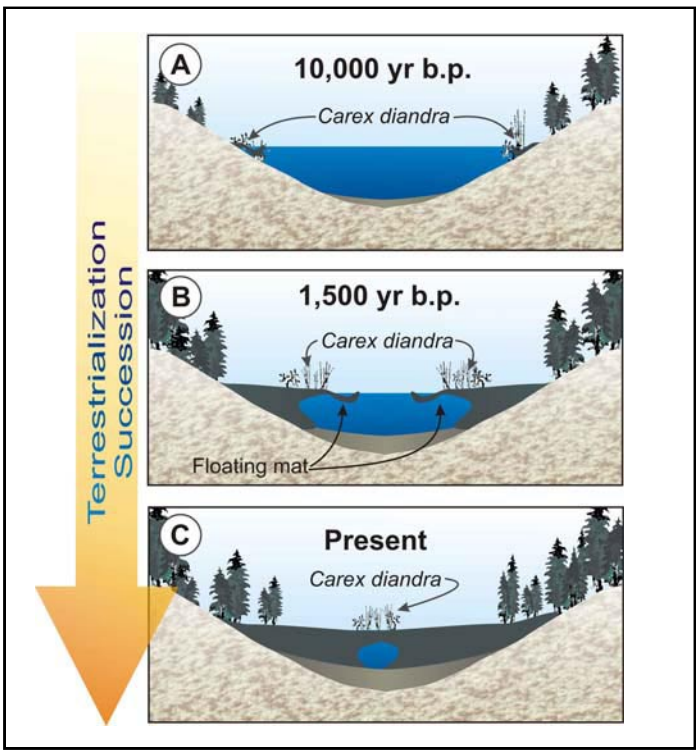

Figure 10. Schematic cross-sections illustrating the geomorphic and successional development of a hypothetical kettle lake basin supporting *Carex diandra*. Early in the basin's development (A), *C. diandra* is confined to the margin of the recently formed kettle lake. Over time, a floating mat dominated in part by *C. diandra* along with other sedges such as *C. lasiocarpa* and *C. limosa* develops (B). Continued terrestrialization in the basin results in the loss of the open water habitats characteristic of earlier stages, while competitive displacement of *C. diandra* has constrained the species to only the wettest microsites.

differing somewhat from wetland to wetland and among stages of peatland development. Allogenic processes, such as broad-scale climatic change, have been hypothesized to be the dominant control on patterns of peatland development. However, the old ages of fens, obtained from C^{14} dating of peat cores, from Region 2 suggest that the kinds of climatic fluctuations observed since the last glacial maximum are less important than autogenic processes in driving peatland development (Cooper 1990, Muller et al. 2003).

Carex diandra is typically found along pond margins or on floating mats. Ages obtained from peat coring suggest that these may represent finite stages in the terrestrialization of many small basins. Therefore, the communities found in these sites, including *C. diandra*, could be thought of as mid-seral. Because a trademark characteristic of fens is their high hydrologic stability and low frequency of disturbance, *C. diandra* may remain a viable component of plant communities for thousands of years. For instance, relict occurrences of *C. diandra* occur in filled basins in Yellowstone National Park (Whipple personal communication 2005).

There is much less known about the kinds of sites supporting *Carex diandra* occurrences in Nebraska. Coring of the Sandhills fens indicates that these are old features, but whether they follow a similar developmental pathway as montane and subalpine fens is unknown. Likewise, there is little information regarding the long-term successional patterns associated with the springs and seeps supporting the other Nebraska *C. diandra* occurrences.

Competitors and relationship to habitat

Carex diandra is typically found in open, unshaded sites (Kotowski and van Diggelen 2004). In England, ecologists assigned an Ellenberg indicator value for light of 9 out of a scale of 9, indicating that the species is a light-loving plant rarely found in less than full-sun environments (Hill et al. 1999). These results suggest that *C. diandra* may be unable to effectively compete with other larger sedge species, and it is only an effective competitor in the wet microsites in which it typically occurs.

Parasites and disease

Only a limited amount of research has been conducted examining the effects of pathogens or parasites on *Carex* species, and none apparently involving *C. diandra*. Floral smuts have been described for other *Carex* species (McIntire and Waterway 2002), but whether similar organisms affect *C. diandra* is unknown.

Herbivores and relationship to habitat

We found no specific reference to herbivory on *Carex diandra* by either native herbivores or livestock. Nutritional analysis of the species indicates that it is moderately nutritious (Catling et al. 1994) and may thus may be somewhat attractive to grazers. However, because of their boggy consistency, the wetland environments typifying *C. diandra* habitat on National Forest System lands are generally avoided by larger grazers, such as elk or cattle. Moose may use fens, but there is no evidence to suggest that they feed specifically on *C. diandra*. Because of the saturated soils typically found in fens, burrowing or root-feeding herbivores like rodents are uncommon and unlikely to significantly feed on the species.

Mycorrhizal relationships

The Cyperaceae have historically been considered non-mycorrhizal. However, research during the past few decades has identified numerous sedge taxa having mycorrhizal associations. In their recent review of the topic, Muthukumar et al. (2004) identified 88 mycorrhizal sedge species, 40 percent of the 221 sedge species they evaluated. Most instances of mycorrhizal associates were arbuscular mycorrhizae (AM), but they also noted instances of ectomycorrhizal associations. Although the mycorrhizal status of several *Carex* species were mentioned, *C. diandra* was not among them, so it is unknown whether *C. diandra* is able to form mycorrhizal relationships, and if so, under what conditions.

CONSERVATION

Threats

In general, multiple factors need to be evaluated in assessing the conservation status of a species. The relative rarity of a species, assessed at local, regional, and global scales, is of primary interest. An additional factor of critical importance is an assessment of the relative stability of the ecosystems that support known occurrences. An ecosystem's stability refers to the degree to which a particular habitat characteristic (e.g., water table depth) responds to a disturbance while ecological resilience refers to the degree to which such a characteristic returns to its original state following a disturbance (Rejmankova et al. 1999). Both attributes ought to be considered when attempting to predict the potential ecological response to different disturbance agents, as the fate of any given species is typically intimately intertwined with that of its ecological setting, particularly in species confined to small, discrete ecosystems like fens or springs, such as *Carex diandra*. However, both stability and resilience are best evaluated in terms of a species' basic life history attributes and successional status. The implications of a particular disturbance agent on an early-seral, annual species will likely differ significantly from that of a late-seral, perennial one. Likewise, species capable of vegetative growth and reproduction may have different effect thresholds and recovery times to disturbance than species lacking the capability.

Much of the following discussion, which outlines some of the basic types of disturbances likely to impact fens, is general in nature. Where possible, we attempt to specifically predict the effects of potential management actions or disturbances on *Carex diandra* occurrences. However, the data necessary for confident prediction of the response of particular occurrences to specific disturbances is largely unavailable. Therefore, our assessment is largely based on principles of extrapolation from existing case studies. Also, we try to differentiate between what appear to be specific, impending threats to *C. diandra* occurrences, and more speculative estimates of potential future threats.

Direct hydrologic alteration

Direct hydrologic alteration by ditching represents one of the most common and long-lasting anthropogenic impacts to fens in the region. For example, in a study conducted in Rocky Mountain National Park, Cooper et al. (1998) found that ditches constructed before the park's creation in 1915 were still effectively intercepting and diverting inflow to a fen nearly 75 years after ditch abandonment. The resulting lower water tables facilitated invasion of the fen by *Deschampsia cespitosa* (tufted hairgrass), a native grass common in seasonally dry, mineral soil sites (Cooper et al. 1998). Similar changes may promote invasions by non-native species such as *Agrostis gigantea* (redtop).

Although we found no specific research examining the effects of direct hydrologic disturbances on *Carex diandra*, any action that results in significant drainage of its habitat will negatively impact the viability of the species. Nearly all Colorado and Wyoming *C. diandra* occurrences are found on public lands managed by either the National Park Service or the USFS, and many of these are in special management areas like wilderness, special interest, or research natural areas, and therefore receive some degree of protection. The overall threat from future ditching or direct dewatering is presumably low for these occurrences. However, where there are pre-existing water rights, these can take precedence over regulations or management directed at ecosystem or species conservation, as has been observed for some Colorado fens (Austin personal communication 2004).

Fens located on private lands managed for agricultural production, which includes the many Nebraska *Carex diandra* occurrences, may be more vulnerable to future impacts. In addition, large numbers of fens in the region were historically ditched, and many ditches or other engineering structures continue to divert water even though they are no longer maintained; these may impair wetland function and prevent natural recovery.

Since the fens providing habitat for the majority of *Carex diandra* occurrences are principally supported by groundwater, any actions outside of their immediate boundaries that alter their hydrology, sediment budgets, or water chemistry, can potentially impact dependent wetland species. The water balance of individual basins supporting peatlands varies as a function of the precipitation inputs, evaporation and transpiration losses, and the amount of water stored as groundwater (Mitsch and Gosselink 2000, Winter et al. 2001). Vegetation in surrounding uplands influences this balance through effects on transpiration and interception of rain or snow, which is susceptible to subsequent loss through evaporation or sublimation (Kauffman et al. 1997). Thus, any natural or anthropogenic process that significantly alters upland vegetation, for example fire or timber harvest, can have impacts on nearby wetlands.

Timber harvest

Significant changes in basin vegetation cover can alter surface runoff from basins through effects on evapotranspiration rates and snowpack accumulation patterns. For example, canopy removal in a subalpine watershed in Colorado increased precipitation reaching the forest floor by approximately 40 percent and peak snowpack water equivalent by more than 35 percent (Stottlemyer and Troendle 1999, Stottlemyer and Troendle 2001). Logging, whether clearcutting or partial thinning, typically resulted in increased mean annual and peak streamflow in logged watersheds (Troendle and King 1985). However, the effects of increased water yield and surface inflows to peatlands are difficult to predict, and both positive and negative effects are possible. For example, increased water yield from upland portions of peatland watersheds could generate wetter conditions, expanding habitat conducive to *Carex diandra* establishment and persistence. However, since fens in the Southern Rocky Mountains form only in physically stable locations where stream erosion and sediment deposition is limited, increased sediment yields resulting from upland vegetation removal could negatively impact peat formation and maintenance processes, adversely affecting *C. diandra* occurrences.

Since the majority of snowmelt passes through subalpine watersheds not as surface flow, but rather as subsurface flow where soil processes can significantly alter meltwater chemistry (Stottlemyer and Troendle 1999), changes in snowpack accumulation and melt rates due to changes in upland vegetation cover can affect water chemistry in a variety of ways. For example, Stottlemyer and Troendle (1999) observed significant increases in the average snowpack Ca^{2+}, NO_3^- and NH_4^+ content, and increased K^+, Ca^{2+}, SO_4^{2-}, NO^{3-}, and HCO^{3-} flux in shallow subsurface flows following logging treatments.

Mineral sediment fluxes are typically low in peatlands. This is particularly true in fens in the central and southern Rocky Mountains (Cooper and Arp 2002). Increased sediment delivery from logged slopes could occur via two primary mechanisms: (1) increased overland flow from treated slopes, and (2) increased episodic inputs from surrounding areas due to decreased slope stability. Heidel and Laursen (2003) suggested that the latter mechanism may have increased sediment yield to the Swamp Lake wetland following crown fire and salvage logging activities, but they provided no quantitative estimates. A proposal for additional logging in the watershed as part of the Deadman's Bench vegetation treatment has been approved, but because of its location, it is not believed that it will result in an increase in sediment to Swamp Lake (Houston personal communication 2005). Although, both mineral and organic inputs to fens could change following tree harvest, what short and long-term effects there would be to fen vegetation and to *Carex diandra* occurrences, specifically, is unknown.

Fire

The indirect effects of fire occurring in adjacent uplands on fens supporting *Carex diandra* occurrences are likely similar to those described above for mechanical harvest, including increased water and sediment yield and changes in water chemistry (Ewing 1996, Battle and Golladay 2003, Meyer and Pierce 2003). As with logging, the magnitude of these changes relative to pre-fire conditions should decrease over time as the density and cover of upland vegetation increases (Troendle and King 1985). Since fire has been a natural component of Rocky Mountain landscapes for millennia (Romme 1982, Fall 1997), these indirect effects are unlikely to represent a significant threat to the future of the Colorado and Wyoming *C. diandra* occurrences. Fire can also directly impact *C. diandra* occurrences through plant mortality, but we found no specific reference to this in the literature.

Since many fens remain saturated throughout the year, their ability to support fires is low relative to drier upland areas. In addition, fire return intervals characteristic of the subalpine forests surrounding Region 2 fens are relatively long compared to many boreal landscapes where fire has been identified as a major factor influencing peatland dynamics (Kuhry 1994, Sherriff et al. 2001). This suggests that fire has had a relatively minor role in the population dynamics of the region's *Carex diandra* occurrences. However, during sustained droughts, which are well-documented throughout the Holocene using a variety of climatic proxies (Dean et al. 1996, Cook et al. 1999), peat soils can dry sufficiently to allow fires to burn surface peat deposits, retarding successional processes and possibly creating opportunities for new *C. diandra* establishment.

There is far less known, however, about fire regimes in the sites supporting *Carex diandra* in Nebraska. The prevalence of human-caused fires, both before and after Euro-American settlement, and large climatic fluctuations over time make generalizations about Great Plains fire regimes more difficult (Higgins 1986, Clark et al. 2002). Certainly, fire frequencies were greater than those typical of subalpine forests (Pyne 1997, Brown and Sieg 1999), but whether these fires significantly affected the seeps and riparian springs habitats supporting most *C. diandra* occurrences in Nebraska is unknown.

No studies differentiating fire effects from prescribed or wildfire on fens are available. However, since most Region 2 fens supporting occurrences of *Carex diandra* are found at relatively high elevations and in forest types with low natural fire recurrence intervals, they are unlikely to be targeted for prescribed burning. One exception is the Todd Gulch fen on the Roosevelt National Forest. Fuels management including selective hand-cutting of timber and possible prescribed burning in the area surrounding the fen has been proposed and will likely start sometime in 2005 (Carsey personal communication 2005). What effects, if any, such management will have on the occurrence is unknown. A 100 ft. buffer will likely surround the fen in order to minimize sediment inputs (Carsey personal communication 2005).

Roads and trails

Roads and, to a lesser degree, trail networks can have significant effects on local and watershed-scale hydrologic processes, thereby affecting fens that support *Carex diandra* occurrences. Roads, trails, and their associated engineering structures such as culverts and ditches can alter natural drainage patterns, reduce interception and infiltration rates due to the removal of vegetation and soil compaction, and alter the hydrologic response of basins to both annual snowmelt runoff episodes and isolated convective storm events (Jones et al. 2000, Forman and Sperling 2002). Increased overland flow typically results in a more rapid and extreme hydrologic response to precipitation events, potentially increasing erosion or sediment transport and deposition in affected systems. However, since most *C. diandra* occurrences are in the interior of fens formed with small contributing watersheds, they may be less likely to be strongly affected by pulses of water or sediment.

No studies have been conducted examining the effects of roads on *Carex diandra* occurrences. Roads do occur adjacent to several fens supporting *C. diandra*, such as Todd Gulch fen on the Roosevelt National Forest. In some instances, they cross fens supporting *C. diandra*. For example Highway 212 separates Little Bear Lake fen on the Shoshone National Forest into northern and southern sections, and this road likely impedes surface and subsurface flow into the southern section of the lake (**Figure 11**; Mellmann-Brown 2004). The Beartooth Plateau supports several other *C. diandra* occurrences, some of which may be currently impacted by the highway. Of greater concern for these sites is ongoing and future widening of the Beartooth Highway from its existing width of approximately 6.7 m (22 ft.) to 9.1 m (30 ft.) (Mellmann-Brown personal communication 2005). Although actions are being

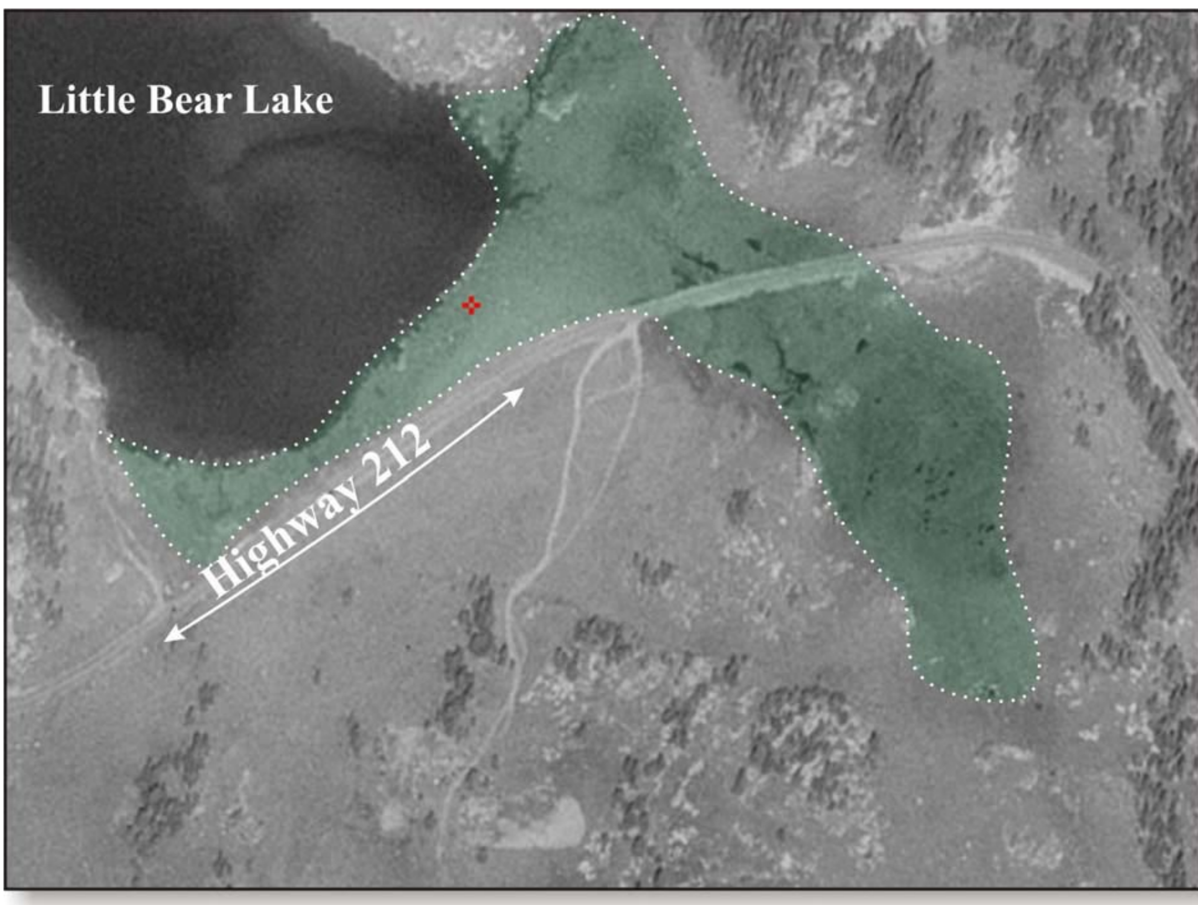

Figure 11. Little Bear Lake on the Shoshone National Forest, Wyoming. The Beartooth Highway (Hwy 212) crosses the fen on the southern flank of the lake, likely altering surface and subsurface drainage through the fen. Aerial photograph source: USGS.

undertaken to minimize effects on fens, because of the existing road grade, some impacts are unavoidable (Houston personal communication 2005). Heidel and Laursen (2003) suggested that the highway bordering Clay Butte fen on the Shoshone National Forest, which supports *C. diandra*, may impede upslope groundwater flow into the basin.

Additional effects of road and trail networks on wetlands can include the introduction of pollutants and the alteration of water chemistry (e.g., conductivity, cation concentrations, pH) due to road dust, increased sediment deposition, and chemicals used in road maintenance such as deicing agents (Wilcox 1986, Trombulak and Frissell 2000, Forman and Sperling 2002). Roads and trails can also promote the spread of weeds by creating disturbance conducive to their establishment. Additionally, vehicles and the increased human traffic associated with roads can provide an effective dispersal agent for weed propagules (Parendes and Jones 2000, Gelbard and Belnap 2003).

Numerous variables can either mitigate or exacerbate the effects of roads, including road density, road slope and surface type, and the number, size, and design of engineering structures. Since these can vary greatly within and among national forests, formulating general statements regarding the threat to *Carex diandra* due to roads or trails is difficult to make with confidence. However, there are specific instances where the presence of roads has altered fen hydrologic regimes or sediment inflows.

Off-highway vehicles

Although USFS travel management regulations specifically prohibit off-highway vehicle (OHV) use in wetlands, numerous instances of OHV trespass onto fens have been documented (**Figure 12**; Popovich personal communication 2004). Ruts caused by OHV access may function like small ditches, intercepting sheet flow on the surface of fens and altering fen hydrology. In addition, OHV use in or near wetlands may contribute pollutants from inefficient combustion and engine emissions (Havlick 2002). Anecdotal evidence suggests that "mud-bogging" is becoming more widespread as OHV use increases in many Region 2 forests (Popovich personal communication 2004); however, how much of a threat it poses to *Carex diandra* occurrences is unknown.

Peat extraction

Because of its high porosity and water holding capacity, peat has long been used as a lawn and garden soil amendment, as well as for industrial applications (WEC 2004). Because sites providing the necessary hydrologic conditions needed for peat accumulation are rare in the region and because peat formation rates are low, most of the peat sold commercially in the United States is imported from Canada. No reliable statistics are available detailing peat production within Region 2, but the amounts are small. Consequently, peat mining does not appear to represent a significant threat to known *Carex diandra* occurrences in the region.

Livestock and native ungulate grazing

Carex species are an important source of forage for both livestock and native ungulates in many western rangelands (Hermann 1970, Catling et al. 1994). The digestibility and nutrient value of sedges are highly variable. Some species, such as *C. praegracilis* (clustered field sedge), have relatively high crude protein and acid-pepsin digestibility levels and low acid detergent fiber values, making them equivalent to

Figure 12. Off-highway vehicle damage to a fen from "mud-bogging" on the Arapaho National Forest, Colorado (Photograph by S. Popovich).

a good quality grass hay; however, nutritional analysis suggest that *C. diandra* is not particularly good forage (Catling et al. 1994).

Livestock and native ungulates can have significant effects on wetland flora. These effects may be direct (e.g., herbivory and trampling) or indirect (e.g., nutrient enrichment via urine or fecal deposits). Livestock tend to avoid extremely wet sites, so their utilization of fen species occurring on floating mats, where *Carex diandra* most commonly occurs, is likely minimal. However, prolonged drought has caused the water tables in some fens to decline and thus allowed greater access for cattle, which resulted in greater impacts to fen vegetation (Houston personal communication 2005).

We have observed elk using fens, but there is no evidence of deleterious effects to fen vegetation due to their use. Like livestock, elk typically avoid extremely wet locations, so they presumably represent a minor threat to *Carex diandra* occurrences. Moose, on the other hand, are far more likely to be found in wet sites, and consequently, where moose are abundant, the impacts to *C. diandra* occurrences may be greater. Trampling from moose, for example, has been identified as primary factor threatening a Grand County, Colorado fen supporting a floating mat community similar to ones supporting *C. diandra* occurrences elsewhere in the region (Popovich personal communication 2004).

Recreational impacts

Because they are typically saturated year-round, sites supporting *Carex diandra* occurrences are generally unsuitable for the construction of roads or trails. Except perhaps in the winter, crossings must be bridged or stabilized, and this makes such sites unappealing for transportation or recreation planners (Johnston 2001). In addition, work involving disturbance to such a wetland often requires a Clean Water Act Section 404 permit, making these sites even less desirable during transportation planning.

However, since many fens do occur within a short distance of existing trails or roads, human visitation and trampling effects from hikers, campers, or recreational fishers are possible. For example, visitation from hikers and campers has been identified as a potential threat to the Big Creek Lakes fens supporting *Carex diandra* on the Routt National Forest in Colorado (Proctor personal communication 2004). Similar concerns have been raised for fens in the Arapaho National Forest in Colorado (Popovich personal communication 2004). Although there are no documented impacts from winter recreation such as cross-county skiing, snowshoeing, or snowmobiling, compaction of accumulated snow can potentially cause later spring melt and altered peat temperature profiles in fens, effectively reducing the length of the growing season for *C. diandra* (Cooper and Arp 2002).

Exotic species

Although exotic species are widely recognized as one of the principle threats to native ecological systems (Mack et al. 2000, Crooks 2002), there is no specific evidence to suggest that *Carex diandra* is directly threatened by exotic species within Region 2. While exotics such as Canada thistle (*Cirsium arvensis*) may invade fens, weed spread is typically associated with severe hydrologic alterations such as ditching. In addition, lake margin, floating mat, and spring and seep environments that typically support *C. diandra* occurrences do not appear conducive to weed invasion. Since they appear unsuitable for the most common and pernicious invasives, it appears that, absent significant hydrologic alterations, the threat of invasive species to *C. diandra* is small.

Atmospheric deposition of pollutants

Fens in general may be vulnerable to the increased deposition of airborne nitrogen observed in portions of Region 2. A wide variety of ecological responses have been shown to result from nitrogen deposition (Fenn et al. 2003), but few studies have focused on fens specifically. Exceptions include Vitt et al. (2003) and Li and Vitt (1997), who examined the response of bryophytes (*Sphagnum fuscum* and *Tomenthypnum nitens*) to nitrogen deposition in bogs and fens in western Canada. They found that the response of individual species varied, but that in general, moss productivity increased. However, the productivity of *Betula pumila* (bog birch) and *Ledum groenlandicum* (bog Labrador tea), two shrub species also examined, was unchanged (Li and Vitt 1997). There are no data to evaluate specific effects of atmospheric nitrogen deposition on *Carex diandra*, but any factor that significantly alters productivity in fens could change vegetation composition and successional development. Although most areas are exposed to some level of atmospheric nitrogen deposition, hotspots of elevated nitrogen deposition typically occur downwind of large metropolitan centers or significant agricultural operations (Fenn et al. 2003). Because *C. diandra* exists across such a wide chemical gradient, it appears unlikely that small shifts in nutrient availability will reduce species viability.

Climate change

Because temperature and hydrologic regimes largely control biological activity in peatland environments, they may be particularly vulnerable to changes predicted by several climate models (Weltzin et al. 2003). Predicting the specific responses of peatlands to climate change is difficult since there is little certainty as to how particular climatic drivers such as temperature and precipitation are likely to change, particularly at regional spatial scales. This uncertainty is compounded by the complex and varied responses of the vegetation. For instance, working in Minnesota, Weltzin et al. (2003) found that shrub cover increased in ombrotrophic bogs in response to experimentally-induced temperature increases, but the responses varied widely among species. They found that vegetation in fens responded more strongly to altered water table elevations, with higher water tables inducing increased bryophyte and graminoid cover, and reduced water tables promoting shrub invasion. However, their results again indicated that responses are species- and life form-specific, making predictions specifically for *Carex diandra* impossible.

The fidelity of *Carex diandra* to very wet sites suggests that the warmer regional temperatures predicted under some global climate change scenarios (U.S. Environmental Protection Agency 1998, Wagner 2003) could adversely affect the species. While an increase in precipitation, as some models call for, may ameliorate the negative hydrologic effects of warmer temperatures, it may still have a negative effect on the viability of *C. diandra* occurrences by shifting the balance between *C. diandra* and competing species (Moore 2002). For example, Moore (2002) observed increased graminoid and forb production in response to increasing water table elevations, as might occur under some climate change scenarios. This higher productivity could result in greater competition between *C. diandra* and associated vegetation.

The most important climatic factor influencing the future of peatlands in Region 2 is likely to be the spatial and temporal patterns of precipitation (Moore 2002). Since *Carex diandra* occurrences within Region 2 are relatively isolated from one another, the fate of the species in the region is intimately tied to that of fens where it presently occurs. Significant climate shifts could reduce the viability of fens as a whole by altering their net carbon balance, changing wetlands from carbon gaining to losing systems (Chimner et al. 2002), and thereby threatening the persistence of *C. diandra* occurrences.

Cumulative effects

Demonstrating the effects of individual stressors on species' performance and viability is difficult; however, it is even more challenging to evaluate the cumulative effects of multiple stressors. Realistically, though, cumulative effects need to be evaluated when assessing potential impacts from management activities (Reid 1993, Bedford 1999). Many individual ecological stressors act synergistically, meaning that mitigating for each individually may fail to achieve effective protection.

Conservation Status of Carex diandra in Region 2

The conservation status of *Carex diandra* is influenced by several factors: the species' rarity, its degree of habitat specialization, its sensitivity to natural and anthropogenic stressors, and known population trends. The quality of information available regarding its sensitivity to stressors and population trends is generally lacking; thus, our assessment is largely based on general knowledge of the species' life history, its habitats, and known threats to fens supporting the species in the region. Because *C. diandra* occurs exclusively in fens, which are limited in abundance and distribution, the current and future status of the species is intimately intertwined with its habitat.

We found no quantifiable evidence to suggest that the distribution or abundance of the species is declining in the region. The ability of *Carex diandra* and other sedges to persist vegetatively suggests that the species is not particularly vulnerable to moderate levels of environmental stochasticity. Periodic drought during the Holocene may have led to the local extirpation of some *C. diandra* populations, contributing to the species' current rarity, and existing occurrences may be vulnerable to future climate changes.

Carex diandra is restricted to a very limited range of wetland types. With the exception of the occurrences in the Nebraska Sandhills, most occurrences are found at relatively high elevations and remote locations and generally appear secure from direct impacts. Sandhills occurrences, on the other hand, are primarily on private lands that are subject to more intensive use than typical of most publicly administered sites supporting the species; thus, they may be more vulnerable to anthropogenic impacts.

Because of limited dispersal distances of *Carex diandra*, no new occurrences are likely to form. However, since few systematic surveys of Region 2 fens have been conducted, it is certainly possible that additional occurrences could be found. Consequently, all fens should be carefully evaluated for the presence of *C. diandra* prior to significant shifts in management.

Management of Carex diandra in Region 2

Implications and potential conservation elements

The restricted distribution of *Carex diandra* in Region 2 highlights its potential vulnerabilities. However, there are generally insufficient data from which to confidently make assessments about trends in abundance or sensitivity to particular management activities. Clearly, more research is needed on the species to develop more concrete conservation approaches.

Although information specific to *Carex diandra* is lacking on many important topics, there is a fair amount of information available regarding the structure and function of fens, the principal habitat of the species. Research in fens has clearly demonstrated the importance of hydrologic functioning in the maintenance of plant communities. Thus, a conservative approach to management, which strives to maintain the hydrologic integrity of fens by avoiding activities that alter the amount and quality of surface water and groundwater inputs, is most likely to be effective in ensuring the persistence of rare plants like *C. diandra*. Fens are also sensitive to changes in sediment inputs; thus, potential impacts from activities such as forest harvest or road construction in watersheds supporting fens should be critically examined as part of management.

Tools and practices

Species and habitat inventory

Broad-scale habitat inventories in Region 2 fens would provide valuable information for the management of a variety of rare species in addition to *Carex diandra*. For example, species such as *C. livida*, *C. leptalea*, *C. limosa*, *Drosera anglica* (English sundew), and *D. rotundifolia* (roundleaf sundew) all occur in fens. Better information regarding the distribution of *C. diandra* is important for prioritizing sites for further study and for incorporation into management activities. To maximize their value, inventories ought to be based on standard, peer-reviewed protocols such as those developed by the National Park Service (USDI National Park Service 1999). Less rigorous approaches such as photo-point monitoring can be employed in individual sites. Such approaches can provide general indications of changes in habitat condition, but they are of limited utility for forming confident assessments of trends.

Population monitoring

Quantitative population monitoring is needed to improve knowledge of the population dynamics of *Carex diandra*. Plot-based approaches are most desirable as these most reliably facilitate evaluation of long-term trends in abundance. However, even qualitative approaches such as presence/absence surveys may be of value by providing an early indication of major changes. Population monitoring is most-profitably conducted in conjunction with habitat monitoring. For example, by monitoring water levels in fens, observed changes in the abundance of *C. diandra* can be more reliably tied to changes in hydrologic drivers.

Beneficial management actions

Managers can most effectively promote the continued persistence of *Carex diandra* by striving to maintain the natural hydrologic regimes in wetlands that support the species. Management activities likely to directly or indirectly affect fen hydrologic regimes ought to be avoided where possible. If such activities cannot be avoided, then best management practices aimed at mitigating harmful effects ought to be pursued. At a broader scale, establishment of special protected areas (e.g., Research Natural Areas) would help to assure the conservation of this species. Because maintenance of the hydrologic integrity of fens supporting the species is so important, an additional step that the USFS could take is to file for water rights on wetlands that support rare species, including *C. diandra*. The collection and storage of viable seed could be pursued and utilized in future restoration activities. Other actions that could be pursued include continued listing of *C. diandra* as a Region 2 sensitive species and implementing and improving standards and guidelines within National Forest Land and Resource Management Plans to provide for an overall reduction of threats.

Information Needs

Identification of research priorities in Region 2

Within Region 2, *Carex diandra* is known from two habitats: montane peatlands in Colorado and Wyoming and low-elevation seeps, springs, and fens in Nebraska. Unfortunately, there are few quantitative data from either environment to develop specific conservation prescriptions, particularly for the Great Plains occurrences. In several respects, these environments are quite different from each other although they appear to share one critical feature: hydrologic regimes that maintain consistent soil saturation.

Many of the sites supporting *Carex diandra* occurrences also support occurrences of other rare species (e.g., *C. limosa*, *C. livida*, *Eriophorum gracile*, and *Drosera rotundifolia*). In addition, they possess unique functional attributes not represented elsewhere. Therefore, a goal of future research should include broad-scale assessments of peatland and spring-fed wetland distribution and abundance. Multiple techniques could be used, including the use of remotely sensed data (e.g., hyperspectral imagery, aerial photographs) to identify and map wetlands. These features likely exhibit distinct spectral signatures and could be readily flagged for field surveying. Geographic Information System (GIS) analyses of existing data sets such as the National Wetlands Inventory in relation to the key climatic, hydrologic, and geological drivers of wetland formation, structure, and function could be undertaken. Such an approach has been successfully applied in the Bighorn National Forest and is currently being developed for the San Juan, Gunnison, Uncompahgre, and Grand Mesa national forests (Bohn et al. 2003).

In addition, more detailed studies relating basin morphometry, sediment and peat stratigraphy, and historical changes in community composition and vegetation structure determined through techniques such as radiocarbon dating are needed. These types of studies are important for developing an understanding of peatland origin and development – essential information for predicting the long-term future of sites supporting *Carex diandra*.

It would also be useful to conduct research on the effects of specific management activities on fens and associated flora. For example, what is the effect of prescribed burning or wildfire on sediment influx rates into fens, and do these effects differ from those seen following mechanical harvest? How often and at what intensity do livestock utilize fen species like *Carex diandra*?

It has become clear in preparing this assessment, that there are few reliable estimates of population size for *Carex diandra* in the region. Comprehensive demographic surveys of known occurrences should be conducted to evaluate the current status of *C. diandra* occurrences and to provide baseline data essential for future monitoring. Known occurrences should be regularly visited and surveys conducted to identify potential population trends.

Additional information gaps include the role of seed banks in the population dynamics of *Carex diandra* occurrences and the relative importance, frequency, and prerequisite conditions necessary for seedling establishment. Such information is essential not only for understanding extant occurrences, but also for developing approaches to restore heavily degraded systems. If conducted in conjunction with studies of hydrology and vegetation patterns, these kinds of inquiries could significantly advance our understanding not just of *C. diandra*, but of the fens it inhabits.

The importance of collecting basic hydrologic and sediment data at individual wetlands cannot be overstated. These data can be extremely valuable in developing realistic models of wetland vegetation dynamics, and for understanding and evaluating the effects of management activities such as road construction or prescribed fire on wetlands in general, and on *Carex diandra* specifically. Though such studies may appear prohibitively expensive or complicated at first glance, installation of even a few simple groundwater-monitoring wells, easily accomplished by a single individual in an afternoon, when measured regularly over time, can yield invaluable data.

Additional information is needed on the physiochemical and hydrologic drivers of peatland formation and development, and their sensitivity to anthropogenic disturbance. These ecosystems provide critical habitat for other rare plant species in Region 2 in addition to *Carex diandra*, including *Drosera rotundifolia*, *D. anglica*, *C. livida*, *C. limosa*, *Eriophorum gracile*, and *Muhlenbergia glomerata* (spiked muhly), yet few have been studied in detail. Important topics relevant to conservation include identifying peat accumulation rates, characterizing mineral and organic sediment inputs into pristine versus disturbed systems, and evaluating water and nutrient fluxes and their response to forest management activities.

Definitions

Abaxial – facing away from the main axis of an organ or organism (Hurd et al. 1998).

Achene – small, dry fruit with a close-fitting wall surrounding a single seed (Hurd et al. 1998).

Androgynous – having staminate flowers above the pistillate flowers in the same spike (Hurd et al. 1998).

Aphyllopodic – with the lowermost leaves greatly reduced, bladeless or nearly so; blades, when present, non-green, short, firm, pointed (Hurd et al. 1998).

Bog – a peatland deriving water and nutrients only from the atmosphere (Crum 1988).

Bract – reduced, modified leaf associated with flowers (Hurd et al 1998).

Caespitose – growing in clumps (Weber and Wittmann 2001).

Carr – a European term referring to peatlands dominated by shrubs such as alders or willows (Crum 1988).

Climax community – the presumed endpoint of a successional sequence; a community that has reached a steady state (Begon et al. 1996).

Diploid – containing a full set of genetic material comprised of a paired set of chromosomes, usually one set from each parent (Webster and McKechnie 1983).

Fen – a peat-accumulating wetland that receives some drainage from surrounding mineral soil (Mitsch and Gosselink 2000).

Hollow – a low area within a peatlands that is wetter than surrounding hummocks (Crum 1988).

Hummock – a raised area within a peatland often formed around the roots of trees or shrubs that is generally drier and more acidic than nearby hollows (Crum 1988).

G/S1 – critically imperiled globally/state because of rarity (5 or fewer occurrences in the world/state; or 1,000 or fewer individuals), or because some factor of its biology makes it especially vulnerable to extinction (NatureServe 2004).

G/S2 – imperiled globally/state because of rarity (6 to 20 occurrences, or 1,000 to 3,000 individuals), or because other factors demonstrably make it very vulnerable to extinction throughout its range (NatureServe 2004).

G/S3 – vulnerable through its range or found locally in a restricted range (21 to 100 occurrences, or 3,000 to 10,000 individuals) (NatureServe 2004).

G/S4 – apparently secure globally/state, though it may be quite rare in parts of its range, especially at the periphery. Usually more than 100 occurrences and 10,000 individuals (NatureServe 2004).

G/S5 – demonstrably secure globally/state, though it may be quite rare in parts of its range (NatureServe 2004).

Lectotype – a specimen chosen as the standard bearer of a species, subspecies, or other taxonomic group (Wikipedia 2006a).

Marl – an unconsolidated calcium carbonate deposit typically formed in freshwater lakes, but also deposited in very alkaline wetlands (Crum 1988).

Minerotrophic – fed by groundwater that has been in contact with soil or bedrock and is therefore richer in nutrients than rainwater (Crum 1988).

Mycorrhiza – a commonly mutualistic and intimate association between the roots of a plant and a fungus (Begon et al. 1996).

Obligate wetland species – plant requiring saturated soils (Mitsch and .Gosselink 2000).

Peat – an accumulation of undecomposed dead plant matter that forms when plant production exceeds decomposition, typically in areas where oxygen levels are low due to prolonged inundation (Crum 1988).

Peatland – a general term referring to wetlands with a peat substrate; includes fens and bogs (Crum 1988).

Perigynium – (Plural: perigynia) an inflated saclike structure enclosing the ovary (achene) in the genus *Carex* (Hurd et al. 1998)

Poor fen – a weakly minerotrophic fen fed by waters that are weakly mineralized, generally with an acidic pH (about 3.5-5.0) (Crum 1988).

pH – a measure of the activity of hydrogen ions (H+) in a solution and, therefore, its acidity or alkalinity; a number without units, usually between 0 and 14, that indicates whether a solution is acidic (pH <7) (Wikipedia 2006b).

Rhizome – a usually prostrate stem, rooting at the nodes (Hurd et al. 1998).

Rich fen – a strongly minerotrophic fen fed by waters rich in minerals, generally with a circumneutral pH (Crum 1988).

Sensitive species – a species identified by the Regional Forester for which population viability is a concern as evidenced by significant current or predicted downward trends in population numbers or density and significant current or predicted downward trends in habitat capability that would reduce a species' existing distribution (USDA Forest Service 2006).

Serrulate – minutely serrate (Hurd et al. 1998).

SNR – species not assigned a NatureServe subnational rank (NatureServe 2004).

SX – NatureServe subnational rank denoting that the species is believed to be extirpated from state or province (NatureServe 2004).

References

Aerts, R. and H. de Caluwe. 1995. Interspecific and intraspecific differences in shoot and leaf lifepan of four *Carex* species which differ in maximum dry matter production. Oecologia 102:467-477.

Alexander, R.R., G.R. Hoffman, and J.M. Wirsing. 1986. Forest vegetation of the Medicine Bow National Forest in southeastern Wyoming: a habitat type classification. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Austin, G. 2004. Botanist, Gunnison National Forest, Gunnison, CO. Personal communication.

Ball, P.W. and A.A. Reznicek. 2004. *Carex* in Flora of North America, Vol 23. Available online at http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=105644.

Battle, J. and S.W. Golladay. 2003. Prescribed fire's impact on water quality of depressional wetlands in southwestern Georgia. American Midland Naturalist 150:15-25.

Bauer, I.E., L.D. Gignac, and D.H. Vitt. 2003. Development of a peatland complex in boreal western Canada: lateral site expansion and local variability in vegetation succession and long-term peat accumulation. Canadian Journal of Botany 81:833-847.

Bayley, S.E. and R.L. Mewhort. 2004. Plant community structure and functional differences between marshes and fens in the southern boreal region of Alberta, Canada. Wetlands 24:277-294.

Bedford, B.L. 1999. Cumulative effects on wetland landscapes: links to wetland restoration in the United States and southern Canada. Wetlands 19:775-788.

Bedford, B.L. and K.S. Godwin. 2003. Fens of the United States: Distribution, characteristics, and scientific connection versus legal isolation. Wetlands 23:608-629.

Bedford, B.L., N.R. Rappaport, and J.M. Bernard. 1988. A life history of *Carex lasiocarpa* Ehrh ramets. Aquatic Botany 30:63-80.

Begon, M., J.L. Harper, and C.R. Townsend. 1996. Ecology - Individuals, Populations, and Communities. Third edition. Blackwell Science, Cambridge, MA.

Beltman, B., A.M. Kooijman, G. Rouwenhorst, and M. Vankerkhoven. 1996. Nutrient availability and plant growth limitation in blanket mires in Ireland. Biology and Environment-Proceedings of the Royal Irish Academy 96B: 77-87.

Bernard, J.M. 1976. The life history and population dynamics of shoots of *Carex rostrata*. Journal of Ecology 64: 1045-1048.

Bernard, J.M. 1990. Life history and vegetative reproduction in *Carex*. Canadian Journal of Botany 68:1441-1448.

Bernard, J.M. and J.G. Macdonal. 1974. Primary production and life history of *Carex lacustris*. Canadian Journal of Botany 52:117-123.

Bohn, B., D.J. Cooper, J.D. Hamerlinck, N. Lee, J. Maxwell, D. Peterson, D. Plume, N.L. Poff, Q.M. Quimby, F.J. Rahel, D.M. Staley, and E.E. Wohl. 2003. Aquatic, Riparian, and Wetland Ecosystem Assessment - Bighorn National Forest, Wyoming. USDA Forest Service Rocky Mountain Region, Lakewood, CO.

Bootsma, M.C. and M.J. Wassen. 1996. Environmental conditions and fen vegetation in three lowland mires. Vegetatio 127:173-189.

Bragazza, L. and R. Gerdol. 1999. Hydrology, groundwater chemistry and peat chemistry in relation to habitat conditions in a mire on the southeastern Alps of Italy. Plant Ecology 144:243-256.

Bragazza, L. and R. Gerdol. 2002. Are nutrient availability and acidity-alkalinity gradients related in *Sphagnum*-dominated peatlands? Journal of Vegetation Science 13:473-482.

Bridgham, S.D., J. Pastor, J.A. Janssens, C. Chapin, and T.J. Malterer. 1996. Multiple limiting gradients in peatlands: a call for a new paradigm. Wetlands 16:45-65.

Brinson, M. 1993. A Hydrogeomorphic Classification for Wetlands. Wetlands Research Program Report TR-WRPDE-4. USACE Wetlands Research Center, Vicksburg, MS.

Brinson, M. and A.I. Malvarez. 2002. Temperate freshwater wetlands: types, status, and threats. Environmental Conservation 29:115-133.

Brown, P.M. and C.H. Sieg. 1999. Historical variability in fire at the ponderosa pine - northern Great Plains prairie ecotone, southeastern Black Hills, South Dakota. Ecoscience 6:539-547.

Carsey, K. 2005. Botanist, Roosevelt National Forest, Boulder, CO. Personal communication.

Carsey, K., D. Cooper, K. Decker, D. Culver, and G. Kittel. 2003. Statewide Wetlands Classification and Characterization - Wetland Plant Associations of Colorado. Colorado Natural Heritage Program, Fort Collins, CO.

Catling, P.M., A.R. Mcelroy, and K.W. Spice. 1994. Potential forage value of some eastern Canadian sedges (Cyperaceae: *Carex*). Journal of Range Management 47:226-230.

Cayouette, J. and P.M. Catling. 1992. Hybridization in the genus *Carex* with special reference to North America. Botanical Review 58:351-440.

Chadde, S.W., J.S. Shelly, R.K. Bursik, Moseley, A.G. Evenden, M. Mantas, R. Rabe, and B. Heidel. 1998. Peatlands on national forests of the northern Rocky Mountains: ecology and conservation. RMRS-GTR-11. Rocky Mountain Research Station, Ogden, UT.

Chapman, J.B., B. Lewis, and G. Litus. 2003. Chemical and isotopic evaluation of water sources to the fens of South Park, Colorado. Environmental Geology 43:533-545.

Chee, W.L. and D.H. Vitt. 1989. The vegetation, surface-water chemistry and peat chemistry of moderate-rich fens in central Alberta, Canada. Wetlands 9:227-261.

Chimner, R.A. and D.J. Cooper. 2003. Carbon dynamics of pristine and hydrologically modified fens in the southern Rocky Mountains. Canadian Journal of Botany 81:477-491.

Chimner, R.A., D.J. Cooper, and W.J. Parton. 2002. Modeling carbon accumulation in Rocky Mountain fens. Wetlands 22:100-110.

Clark, J.S., E.C. Grimm, J.J. Donovan, S.C. Fritz, D.R. Engstrom, and J.E. Almendinger. 2002. Drought cycles and landscape responses to past aridity on prairies of the northern Great Plains, USA. Ecology 83:595-601.

Cochrane, T.S. 2002. *Carex diandra*. Page 281 *in* Flora of North America, Vol. 23. Magnoliophyta: Commelinidae (in part): Cyperaceae. Oxford University Press, Oxford, UK.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schultz, K. Snow, and J. Teague. 2003. Ecological systems of the United States: A working classification of U.S. Terrestrial systems. NatureServe, Arlington, VA.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland. 1999. Drought reconstructions for the continental United States. Journal of Climate 12:1145-1162.

Cooper, D.J. 1988. Classification of Colorado's wetlands for use in HGM functional assessment: a first approximation. Characterization and Functional Assessment of Reference Wetlands in Colorado. Department of Natural Resources, Colorado Geological Survey - Division of Minerals and Geology, Denver, CO.

Cooper, D.J. 1990. Ecology of wetlands in Big Meadows, Rocky Mountain National Park, Colorado . Biological Report 90(15). USDI Fish and Wildlife Service, Washington, D.C.

Cooper, D.J. 1996. Water and soil chemistry, floristics, and phytosociology of the extreme rich High Creek fen, in South Park, Colorado, U.S.A. Canadian Journal of Botany 11:1801-1811.

Cooper, D.J. and R.E. Andrus. 1994. Patterns of vegetation and water chemistry in peatlands of the west-central Wind River Range, Wyoming, USA. Canadian Journal of Botany 72:1586-1597.

Cooper, D.J. and C.D. Arp. 2002. Prospect Basin fens: baseline and ski area expansion monitoring for the year 2001. Unpublished report prepared for the Prospect Basin Oversight Committee, San Miguel County, CO.

Cooper, D.J., R.A. Andrus, and C.D. Arp. 2002. *Sphagnum balticum* in a Southern Rocky Mountains iron fen. Madroño 49:186-188.

Cooper, D.J., L.H. MacDonald, S.K. Wenger, and S.W. Woods. 1998. Hydrologic restoration of a fen in Rocky Mountain National Park, Colorado, USA. Wetlands 18:335-345.

Cooper, S.V. and W.M. Jones. 2004. A plant community classification for Kootenai National Forest peatlands. Montana Natural Heritage Program, Helena, MT.

Cowardin, L.M., V. Carter, and E.T. La Roe. 1979. Classification of wetlands and deepwater habitats of the United States. USDI Fish and Wildlife Service, National Wetlands Inventory Program, Washington, D.C.

Crooks, J.A. 2002. Characterizing the ecosystem-level consequences of biological invasions: the role of ecosystem engineers. Oecologia 97:153-166.

Crum, H.A. 1988. A Focus on Peatlands and Peat Mosses. University of Michigan Press, Ann Arbor, MI.

Dean, W.E., T.S. Ahlbrandt, R.Y. Anderson, and J.P. Bradbury. 1996. Regional aridity in North America during the middle Holocene. Holocene 6:145-155.

Demars, H., M.J. Wassen, and H.O. Venterink. 1997. Flooding and groundwater dynamics in fens in eastern Poland. Journal of Vegetation Science 8:319-328.

Edgar, E. 1964. The natural sterile hybrid *Carex diandra X secta*. 64;2:279-285.

Ewing, R. 1996. Postfire suspended sediment from Yellowstone National Park, Wyoming. Water Resources Bulletin 32:605-627.

Fall, P.L. 1997. Fire history and composition of the subalpine forest of western Colorado during the Holocene. Journal of Biogeography 24:309-325.

Fenn, M.E., J.S. Baron, E.B. Allen, H.M. Rueth, K.R. Nydick, L. Geiser, W.D. Bowman, J.O. Sickman, T. Meixner, D.W. Johnson, and P. Neitlich. 2003. Ecological effects of nitrogen deposition in the western United States. Bioscience 53:404-420.

Fertig, W. and G. Jones. 1992. Plant communities and rare plants of the Swamp Lake Botanical Area, Clarks Fork Ranger District, Shoshone National Forest. Unpublished report prepared for the Shoshone National Forest by the Wyoming Natural Diversity, Laramie, WY.

Ford, B.A., D.A.R. Mcqueen, R.F.C. Naczi, and A.A. Reznicek. 1998. Allozyme variation and genetic relationships among species in the *Carex willdenowii* complex (Cyperaceae). American Journal of Botany 85:546-552.

Forman, R.T. and D. Sperling. 2002. Road Ecology: Science and Solutions. Island Press, Washington, D.C.

Foster, D.R., G.A. King, and M.V. Santelmann . 1988. Patterned fens of western Labrador and adjacent Quebec - phytosociology, water chemistry, landform features, and dynamics of surface patterns. Canadian Journal of Botany 66:2402-2418.

Gelbard, J.L. and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology 17:420-432.

Gignac, L.D., R. Gauthier, L. Rochefort, and J. Bubier. 2004. Distribution and habitat niches of 37 peatland Cyperaceae species across a broad geographic range in Canada. Canadian Journal of Botany 82:1292-1313.

Glaser, P.H. 1987. The ecology of patterned boreal peatlands of northern Minnesota: a community profile. USDI Fish and Wildlife Service, Research and Development, National Wetlands Research Center, Washington, D.C.

Glaser, P.H. 1992. Vegetation and water chemistry. Pages 3-15 *in* H.E. Wright, Jr., B.A. Coffin, and N.E. Aaseng, editor. The patterned peatlands of Minnesota. University of Minnesota Press, Minneapolis, MN.

Glaser, P.H., B.C.S. Hansen, D.I. Siegel, A.S. Reeve, and P.J. Morin. 2004. Rates, pathways and drivers for peatland development in the Hudson Bay Lowlands, northern Ontario, Canada. Journal of Ecology 92:1036-1053.

Glaser, P.H., J.A. Janssens, and D.I. Siegel. 1990. The response of vegetation to chemical and hydrological gradients in the Lost River peatland, northern Minnesota. Journal of Ecology 78:1021-1048.

Glaser, P.H., G.A. Wheeler, E. Gorham, and H.E. Wright. 1981. The patterned mires of the Red Lake Peatland, northern Minnesota - vegetation, water chemistry and landforms. Journal of Ecology 69:575-599.

Gleason, H.A. and A. Cronquist. 1991. Manual of vascular plants of the northeastern United States and adjacent Canada. New York Botanical Garden, New York, NY.

Gorham, E. and M.G. Somers. 1973. Seasonal changes in the standing crop of two montane sedges. Canadian Journal of Botany 51:1097-1098.

Greenlee, J. and M. Jones. 2000. Ecological inventory of wetland sites in the Thompson chain of lakes and vicinity . Montana Natural Heritage Program, Helena, MT.

Handel, S.N. 1976. Restricted pollen flow of 2 woodland herbs determined by neutron-activation analysis. Nature 260: 422-423.

Hansen, P.L. and J.B. Hall. 2002. Classification and management of USDI Bureau of Land Management's riparian and wetland sites in eastern and southern Idaho. Bitterroot Restoration, Inc., Corvallis, MT.

Harper, J.L. 1977. Population Biology of Plants. Academic Press Inc., New York, NY.

Havlick, D.G. 2002. No Place Distant: Roads and Motorized Recreation on America's Public Lands. Island Press, Washington, D.C.

Hedren, M. and H.C. Prentice. 1996. Allozyme variation and racial differentiation in Swedish *Carex lepidocarpa* (Cyperaceae). Biological Journal of the Linnean Society 59:179-200.

Heidel, B. and S. Laursen. 2003. Botanical and ecological inventory of peatland sites on the Shoshone National Forest. Wyoming Natural Diversity Databse, Laramie, WY.

Hendrichs, M., F. Oberwinkler, D. Begerow, and R. Bauer. 2004. *Carex*, Subgenus *Carex* (Cyperaceae) - a phylogenetic approach using ITS sequences. Plant Systematics and Evolution 246:89-107.

Hermann, F.J. 1970. Manual of the Carices of the Rocky Mountains and Colorado Basin. USDA Forest Service, Washington, D.C.

Hess, K. and R.H. Alexander. 1986. Forest vegetation of the Arapaho and Roosevelt National Forests in central Colorado: a habitat type classification. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Higgins, K.F. 1986. Interpretation and compendium of historical fire accounts in the northern Great Plains. USDI Fish and Wildlife Service, Washington, D.C.

Hill, M.O., J.O. Mountford, D.B. Roy, and R.G.H. Bunce. 1999. Ellenberg's Indicator Values for British Plants. Natural Environment Research Council, Centre for Ecology and Hydrology, Huntingdon, UK.

Holling, C.S. 1996. Surprise for science, resilience for ecosystems, and incentives for people. Ecological Applications 6:733-735.

Houston, K. 2005. Soil Scientist, Shoshone National Forest, Cody, WY. Personal communication.

Huh, M.K. 2001. Allozyme variation and population structure of *Carex humulis* var. *nana* (Cyperaceae) in Korea. Canadian Journal of Botany 79:457-463.

Hulten, E. 1968. Flora of Alaska and Neighboring Territories. Stanford University Press, Stanford, CA.

Hurd, E.G., N.L. Shaw, J. Mastrogiuseppe, L.C. Smithman, and S. Goodrich. 1998. Field guide to intermountain sedges. Rocky Mountain Research Station General Technical Report RMRS-GTR-10. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT.

Integrated Taxonomic Information System. 2004. Integrated Taxonomic Information System (ITIS) on-line database. Available online at http://www.itis.usda.gov/access.html.

Jankovsky-Jones, M. 1997. Conservation strategy for Northern Idaho Wetlands. Idaho Game and Fish Department, Boise, ID.

Johansson, M.E., C. Nilsson, and E. Nilsson. 1996. Do rivers function as corridors for plant dispersal? Journal of Vegetation Science 7:593-598.

Johnston, B.C. 2001. Field guide to sedge species of the Rocky Mountain region: the genus *Carex* in Colorado, Wyoming, western South Dakota, western Nebraska, and western Kansas. R2-RR-01-03. USDA Forest Service, Rocky Mountain Region, Lakewood, CO.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14:76-85.

Kauffman, J.B., R.L. Beschta, N. Otting, and D. Lytjen. 1997. An ecological perspective of riparian and stream restoration in the western United States. Fisheries 22:12-24.

Keinath, D., B. Heidel, and G.P. Beauvais. 2003. Wyoming Plant and Animal Species of Concern. Prepared by the Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY. Available online at http://uwadmnweb.uwyo.edu/WYNDD/.

Konings, H., J.T.A. Verhoeven, and R. Degroot. 1992. Growth characteristics and seasonal allocation patterns of biomass and nutrients in *Carex* species growing in floating fens. Plant and Soil 147:183-196.

Kotowski, W. and R. van Diggelen. 2004. Light as an environmental filter in fen vegetation. Journal of Vegetation Science 15:583-594.

Kubiw, H., M. Hickman, and D.H. Vitt. 1989. The developmental history of peatlands at Muskiki and Marguerite Lakes, Alberta. Canadian Journal of Botany 67:3534-3544.

Kuhry, P. 1994. The role of fire in the development of *Sphagnum*-dominated peatlands in western Boreal Canada. Journal of Ecology 82:899-910.

Leibowitz, S.G. 2003. Isolated wetlands and their functions: an ecological perspective. Wetlands 23:517-531.

Leck, M.A. and W. Schutz. 2005. Regeneration of Cyperaceae, with particular reference to seed ecology and seed banks. Perspectives in Plant Ecology, Evolution and Systematics 7:95-133.

Lemly, J. 2005. Graduate research assistant, Colorado State University, Fort Collins, CO. Personal communication.

Li, Y.H. and D.H. Vitt. 1997. Patterns of retention and utilization of aerially deposited nitrogen in boreal peatlands. Ecoscience 4:106-116.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689-710.

Mackenzie, K.K. 1940. North American *Cariceae*. New York Botanical Garden, New York, NY.

McClintock, K.A. and M.J. Waterway. 1993. Patterns of allozyme variation and clonal diversity in *Carex lasiocarpa* and *C. pellita* (Cyperaceae). American Journal of Botany 80:1251-1263.

McIntire, E.J.B. and M.J. Waterway. 2002. Clonal structure and hybrid susceptibility to a smut pathogen in microscale hybrid zones of northern wetland *Carex* (Cyperaceae). American Journal of Botany 89:642-654.

Mellmann-Brown, S. 2004. Botanical and ecological inventory of selected peatland sites on the Shoshone National Forest. Wyoming Natural Diversity Database, Laramie, WY.

Mellmann-Brown, S. 2005. Botanist, Wyoming Natural Diversity Database, Laramie, WY. Personal communication.

Metcalfe, C.R. 1969. Anatomy as an aid to classifying the Cyperaceae. American Journal of Botany 56:782-790.

Meyer, G.A. and J.L. Pierce. 2003. Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: a long-term perspective. Forest Ecology and Management 178:89-104.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. Third edition. John Wiley and Sons, New York, NY.

MOBOT. 2004. Missouri Botnaical Garden - W3-Tropicos Nomenclatural Database. Available online at http://mobot.mobot.org/gci-bin/search_vast.

Moore, P.D. 2002. The future of cool temperate bogs. Environmental Conservation 29:3-20.

Muller, S.D., P.J.H. Richard, and A.C. Larouche. 2003. Holocene development of a peatland (southern Quebec): a spatio-temporal reconstruction based on pachymetry, sedimentology, microfossils and macrofossils. Holocene 13:649-664.

Muthukumar, T., K. Udaiyan, and P. Shanmughavel. 2004. Mycorrhiza in sedges - an overview. Mycorrhiza 14:65-77.

NatureServe. 2003. International Ecological Classification Standard: Terrestrial Ecological Systems of the United States, US Forest Service Region 2 Subset (Updated October 2003). NatureServe Central Databases, Arlington, VA and Minneapolis, MN.

NatureServe. 2004. NatureServe Explorer: An online encyclopedia of life. Version 4.0. Available online at http://www.natureserve.org/explorer.

Nilsson, C., M. Gardfjell, and G. Grelsson. 1991. Importance of hydrochory in structuring plant communities along rivers. Canadian Journal of Botany 69:2631-2633.

Nebraska Natural Heritage Program. 2004. Nebraska Natural Heritage Program element occurrence records. Nebraska Natural Heritage Program, Lincoln, NE.

O'Mahoney, T. 1984. *Carex diandra* Shrank *X Carex paniculata* L. (*Carex X beckmannii* Keck ex. F. Schultz) in mid Cork (H4): a sedge hybrid new to Ireland. Irish Naturalists' Journal 21:298-300.

Oien, D.I. 2004. Nutrient limitation in boreal rich fen vegetation: a fertilization experiment. Applied Vegetation Science 7:119-132.

Padgett, W.G., A.P. Youngblood, and A.W. Winward. 1989. Riparian community classification of Utah and southeastern Idaho. R4-Ecol-89-01. R4-Ecol-89-01. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Parendes, L.A. and J.A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H. J. Andrews Experimental Forest, Oregon. Conservation Biology 14:64-75.

Perezcorona, M.E. and J.T.A. Verhoeven. 1996. Effects of soil P status on growth and P and N uptake of *Carex* species from fens differing in P availability. Acta Botanica Neerlandica 45:381-392.

Pollard, J.H. 1966. On the use of the direct matrix product in analyzing certain stochastic population models. Biometrika 53:397-415.

Popovich, S. 2004. Botanist, Arapahoe-Roosevelt National Forest, Fort Collins, CO. Personal communication.

Proctor, J. 2004. Botanist, Medicine Bow–Routt National Forests and Thunder Basin National Grassland, Walden, CO. Personal communication.

Pyne, S.J. 1997. Fire in America: A Cultural History of Wildland and Rural Fire. University of Washington Press, Seattle, WA.

Reed, P.B. 1988. National list of plant species that occur in wetlands: national summary. Biological Report 88(24). USDI Fish and Wildlife Service, Washington, D.C.

Reid, L.M. 1993. Research and cumulative watershed effects. USDA Forest Service, Pacific Southwest Research Station General Technical Report PSW 141, Berkeley, CA.

Rejmankova, E., M. Rejmanek, T. Djohan, and C.R. Goldman. 1999. Resistance and resilience of subalpine wetlands with respect to prolonged drought. Folia Geobotanica 34:175-188.

Reznicek, A. 2001. Sectional names in *Carex* (cyperaceae) for the Flora of North America. Novon 4:454-459.

Ridley, H.N. 1930. The Dispersal of Plants Throughout the World. L. Reeve & Co., Ltd., Ashford, UK.

Rocchio, J., P. Lyon, and J. Sovell. 2002. Survey of Critical Biological Resources of Garfield County, Colorado, Volume II: Survey of Critical Wetlands and Riparian Areas in Garfield County. Colorado Natural Heritage Program, Fort Collins, CO.

Rodwell, J.S. 1991. British Plant Communities, Volume 1, Woodlands and Scrub. Cambridge University Press. Cambridge, England.

Romme, W.H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs 52:199-221.

Schütz, W. 1998. Seed dormancy cycles and germination phenologies in sedges (*Carex*) from various habitats. Wetlands 18:288-297.

Schütz, W. 2002. Dormancy characteristics and germination timing in two alpine *Carex* species. Basic and Applied Ecology 3:125-134.

Schütz, W. and G. Rave. 1999. The effect of cold stratification and light on the seed germination of temperate sedges (*Carex*) from various habitats and implications for regenerative strategies. Plant Ecology 144:215-230.

Sherriff, R.L., T.T. Veblen, and J.S. Sibold. 2001. Fire history in high elevation subalpine forests in the Colorado Front Range. Ecoscience 8:369-380.

Shotyk, W. 1988. Review of the inorganic geochemistry of peats and peatland waters. Earth Science Reviews 25:95-176.

Shotyk, W., H.W. Nesbitt, and W.S. Fyfe. 1990. The behavior of major and trace elements in complete vertical peat profiles from 3 *Sphagnum* bogs. International Journal of Coal Geology 15:163-190.

Sjörs, H. 1963. Bogs and fens on Attawapiskat River, northern Ontario. Bulletin National Museum of Canada 186: 45-103.

Standley, L.A. 1990. Anatomical aspects of the taxonomy of sedges (*Carex*, Cyperaceae). Canadian Journal of Botany 68:1449-1456.

Steinauer, G., S. Rolfmeier, and J.P. Hardy. 1996. Inventory and floristics of Sandhills fens in Cherry County, Nebraska. Transactions of the Nebraska Academy of Sciences 23:9-21.

Stottlemyer, R. and C.A. Troendle. 1999. Effect of subalpine canopy removal on snowpack, soil solution, and nutrient export, Fraser Experimental Forest, CO. Hydrological Processes 13:2287-2299.

Stottlemyer, R. and C.A. Troendle. 2001. Effect of canopy removal on snowpack quantity and quality, Fraser Experimental Forest, Colorado. Journal of Hydrology 245:165-176.

Szumigalski, A.R. and S.E. Bayley. 1996. Net above-ground primary production along a bog-rich fen gradient in central Alberta, Canada. Wetlands 16:467-476.

Tahvanainen, T., T. Sallantaus, and R. Heikkila. 2003. Seasonal variation of water chemical gradients in three boreal fens. Annales Botanici Fennici 40:345-355.

Tahvanainen, T., T. Sallantaus, R. Heikkila, and K. Tolonen. 2002. Spatial variation of mire surface water chemistry and vegetation in northeastern Finland. Annales Botanici Fennici 39:235-251.

Tahvanainen, T. and T. Tuomaala. 2003. The reliability of mire water pH measurements - a standard sampling protocol and implications to ecological theory. Wetlands 23:701-708.

Thormann, M.N. and S.E. Bayley. 1997a. Aboveground net primary production along a bog-fen-marsh gradient in southern boreal Alberta, Canada. Ecoscience 4:374-384.

Thormann, M.N. and S.E. Bayley. 1997b. Decomposition along a moderate-rich fen-marsh peatland gradient in boreal Alberta, Canada. Wetlands 17:123-137.

Thormann, M.N., A.R. Szumigalski, and S.E. Bayley. 1999. Aboveground peat and carbon accumulation potentials along a bog-fen-marsh wetland gradient in southern boreal Alberta, Canada. Wetlands 19:305-317.

Tiner, R.W. 1999. Wetland Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping. Lewis Publishers, Boca Raton, FL.

Troendle, C.A. and R.M. King. 1985. The effect of timber harvest on the Fool Creek watershed, 30 years later. Water Resources Research 21:1915-1922.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

U.S. Environmental Protection Agency. 1997. Climate Change and Colorado. EPA 230-F-97-008f. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1998a. Climate Change and Nebraska. EPA 236-F-98-007n. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1998b. Climate change and Wyoming. EPA 236-F-98-007n. U.S. Environmental Protection Agency, Washington, D.C.

USDA Forest Service. 2006. Forest Service Manual, Rocky Mountain Region (Region 2), FSM 2600 - Wildlife, Fish, and Sensitive Plant Habitat, Chapter 2670 - Threatened, Endangered and Sensitive Plants and Animals, Supplement No.: 2600-2006-1, Approved by Rick Cables, Regional Forester on April 19, 2006. USDA Forest Service, Rocky Mountain Region, Lakewood, CO. Available online at http://www.fs.fed.us/im/directives/field/r2/fsm/2600/2670.doc.

USDA Natural Resources Conservation Service. 2006. The PLANTS Database. Available online at http://plants.usda.gov.

USDI Fish and Wildlife Service. 1999. Peatland mitigation policy considerations, Fish and Wildlife Service Region 6. Policy document available through the Ecological Services Center, Colorado Field Office, Lakewood, CO.

USDI National Park Service. 1999. Guidelines for Biological Inventories. National Park Service Inventory and Monitoring Program. Available online at http://science.nature.nps.gov/im/inventory/biology/.

Vandiggelen, R., W.J. Molenaar, and A.M. Kooijman. 1996. Vegetation succession in a floating mire in relation to management and hydrology. Journal of Vegetation Science 7:809-820.

VegBank. 2004. VegBank: Online plot data from the Ecological Society of America. Available online at http://vegbank.org/vegbank/DisplayMainMenu.do.

Vellend, M. and M.J. Waterway. 1999. Geographic patterns in the genetic diversity of a northern sedge, *Carex rariflora*. Canadian Journal of Botany 77:269-278.

Vitt, D.H. and W.L. Chee. 1990. The relationships of vegetation to surface-water chemistry and peat chemistry in fens of Alberta, Canada. Vegetatio 89:87-106.

Vitt, D.H., K. Wieder, L.A. Halsey, and M. Turetsky. 2003. Response of *Sphagnum fuscum* to nitrogen deposition: a case study of ombrogenous peatlands in Alberta, Canada. Bryologist 106:235-245.

Wagner, F.H. 2003. Preparing for a changing climate - The potential consequences of climate variability and change. Utah State University.

Wassen, M.J. and A. Barendregt. 1992. Topographic position and water chemistry of fens in a Dutch river plain. Journal of Vegetation Science 3:447-456.

Wassen, M.J. and J.H.J. Joosten. 1996. In search of a hydrological explanation for vegetation changes along a fen gradient in the Biebrza Upper Basin (Poland). Vegetatio 124:191-209.

Wassen, M.J., W.H.M. Peeters, and H.O. Venterink. 2003. Patterns in vegetation, hydrology, and nutrient availability in an undisturbed river floodplain in Poland. Plant Ecology 165:27-43.

Wassen, M.J., R. Vandiggelen, L. Wolejko, and J.T.A. Verhoeven. 1996. A comparison of fens in natural and artificial landscapes. Vegetation 126:5-26.

Waterway, M.J., E. McIntire, and R.G. Olmstead. 1997. Molecular evidence suggests that *Carex* section Limosae is not monophyletic. American Journal of Botany 84:243.

Weber, W.A. and R.C. Wittmann. 2001. Colorado Flora: Eastern Slope. Third edition. University Press of Colorado, Niwot, CO.

Webster, N. and J.L. McKechnie. 1983. Webster's New Universal Unabridged Dictionary. Second edition. Dorset & Baber, New York, NY.

WEC. 2004. Survey of World Energy Sources - Peat. Available online at: http://www.worldenergy.org/wec-geis/publications/reports/ser/peat/peat.asp. Accessed on: 01 October 2004.

Weltzin, J.F, S.D. Bridgham, J. Pastor, J. Chen, and C. Harth. 2003 Potential effects of warming and drying on peatland plant community composition. Global Change Biology 9:141-151.

Wheeler, B.D. 1980. Plant communities of rich-fen systems in England and Whales II. Communities of calcareous mires. Journal of Ecology 68:405-420.

Wheeler, B.D. and M.C.F. Proctor. 2000. Ecological gradients, subdivisions and terminology of northwest European mires. Journal of Ecology 88:187-203.

Wheeler, G.A., P.H. Glaser, E. Gorham, C.M. Wetmore, F.D. Bowers, and J.A. Janssens. 1983. Contributions to the flora of the Red Lake peatland, northern Minnesota, with special attention to *Carex*. American Midland Naturalist 110:1:62-96.

Whipple, J. 2005. Botanist, Yellowstone National Park, Yellowstone National Park, WY. Personal communication.

Wikipedia. 2006a. Encyclopedia entry for: Lectotype. Available online at http://en.wikipedia.org/wiki/lectotype. Accessed on: 10 April 2006.

Wikipedia. 2006b. Encyclopedia entry for: pH. Available online at http://en.wikipedia.org/wiki/PH. Accessed on: 10 April 2006.

Wilcox, D.A. 1986. The effects of deicing salts on water chemistry in Pinhook Bog, Indiana. Water Resources Bulletin 22:57-65.

Windell, J.T., B.E. Willard, D.J. Cooper, S.Q. Foster, C.F. Knud-Hansen, L.P. Rink, and G.N. Kiladis. 1986. An ecological characterization of Rocky Mountain montane and subalpine wetlands. U.S. Dept. of the Interior; 86; Biological report, USDI Fish and Wildlife Service, Washington, D.C.

Winter, T.C., D.O. Rosenberry, D.C. Buso, and D.A. Merk. 2001. Water source to four US wetlands: implications for wetland management. Wetlands 21:462-473.

Zimmerli, S. 1988. Vegetation und Standort von Schwingrasen in der Schweiz (Vegetation and site conditions of floating mats in Switzerland). PhD dissertation, Universitat Zurich. Zurich, Switzerland.

Zoltai, S.C., C. Tarnocai, G.F. Mills, and H. Veldhuis. 1988. Wetlands of Subarctic Canada. *In*: Wetlands of Canada. Polyscience Publications. Montreal, Quebec, Canada.

Appendix

Element Occurrence and Herbarium Records of Carex diandra from USDA Forest Service Region 2

Note that entries in the comments field are taken directly from records.

State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/observation date	Comments
Nebraska	Banner	PMCYP033R0*1*NE	1,247	Private	23 Jun 1966	Specimen collected by S. Stephens (5508; KU).
Nebraska	Rock	PMCYP033R0*2*NE	753	Private	05 Jul 1972	Uncommon; collected by R.L. Schuller.
Nebraska	Cherry	PMCYP033R0*3*NE	896	Private	16 Jun 1898	Middle Niobrara watershed; specimen collected on gordon creek. specimen collected in fruit by J.M. Bates; Specimen #192018.UL.
Nebraska	Garden	PMCYP033R0*4*NE	1,165	Crescent Lake National Wildlife Refuge	03 Jun 1982	Middle North Platte-Scotts Bluff watershed; common, specimen collected in flower in a cold, spring-fed fen at west end of crescent lake, by G. Larson.
Nebraska	Garden	PMCYP033R0*5*NE	1,128	Private	09 Jun 1994	Middle North Platte-Scotts Bluff Watershed; Specimen collected in fen-like seep by G. Steinauer.
Nebraska	Thomas	PMCYP033R0*6*NE	907	Private	23 Jun 1913	Specimen collected by J.M. Bates at Seneca, NE.
Nebraska	Thomas	PMCYP033R0*7*NE	903	Private	21 Jun 1893	Specimen collected by P.A. Rydberg on a meadow of Middle Loup River near Thedford; Specimen #193349.
Nebraska	Cherry	PMCYP033R0*8*NE	747	Fort Niobrara National Wildlife Refuge	15 Jun 1939	Specimen collected by W.L. Tolstead in swamp in the Niobrara River Valley, Specimen #201675, #200398, #202863.
Nebraska	Cherry	PMCYP033R0*9*NE	929	Private	18 Jun 1892	Specimen collected in moist hay meadow by J.M. Bates near Kennedy, NE.
Nebraska	Cherry	PMCYP033R0*10*NE	1,000	Private	06 Jun 1940	Specimen growing in Sandhill swamp, collected by W.L. Tolstead east of Merriman, NE.
Nebraska	Brown	PMCYP033R0*11*NE	661	Private	06 Jun 1940	Specimen collected by W.L. Tolstead, Plum Creek canyon.
Nebraska	Rock	PMCYP033R0*12*NE	720	Private	05 Jun 1893	Specimen collected by J.M. Bates near Bassett, NE.
Nebraska	Cherry	PMCYP033R0*13*NE	779	McKelvie National Forest	11 Jun 1995	Drinkwalter exlcosure; ca 2 mi SE of Anderson bridge; S of Niobrara River; plants clump forming and local, but common in seepy marsh area on floodplain of the Niobrara River; plants growing with *Carex nebrascensis*, *C. interior,* and *Eleocharis erythropoda.*
Nebraska	Cherry	PMCYP033R0*14*NE	811	McKelvie National Forest	11 Jun 1995	S side of Niobrara River, ca 1.5. mi SW of the Hockenbary Ranch; scattered clumps of plants (100-1000) observed in fruit by Rolfsmeierl; scattered through the seep area. growing with *Carex nebrascensis*, *C. interior*, and *Eleocharis erythropoda*.

Appendix (cont.).

State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/observation date	Comments
Nebraska	Grant	PMCYP033R0*15*NE	1,098	Private	18 Jun 1996	Small spring pool, S side of peat mound near west end, approx. 2 mi W of Gudmundson Research Lab; CD element ranking - Fair or poor estimated viability; small population.
Nebraska	Cherry	PMCYP033R0*16*NE	884	Private	21 Jun 1996	C-ranked occurrence - fair estimated viability; pop. area 30 square meters, 50-100 individuals in fruit, local on soft peat area; w/ *Carex prairea*, also forming large tussocks in ditch east of highway; some grazing, but area seems well preserved.
Nebraska	Cherry	PMCYP033R0*17*NE	963	Private	20 Jun 1996	AB-ranked occurrence - Excellent or good estimated viability; Upper North Loup watershed; pop. area 500 square meters, 1000+ individuals in fruit locally abundant-in fruit.
Nebraska	Sherman	PMCYP033R0*18*NE	598	Private	10 Jun 1997	A-ranked occurrence - Excellent estimated viability; Lower Middle Loup watershed; Fifty clumps in flower and early fruit, in 2-acre area, possibly widespread in vicinity; No apparent disturbances. Area is hayed. Actual location of plants is in the SE corner of wet-mesic prairie.
Nebraska	Cherry	PMCYP033R0*19*NE	701	Niobrara Valley Preserve	12 Jun 1988	AB- ranked occurrence - Excellent or good estimated viability; Upper North Loup watershed; 30-40 scattered emergent tussocks mostly in fruit observed. Associated species include: *Carex comosa*, *Sparganium eurycarpum*, *Typha latifolia*, *Schoenoplectus acutus*, and *Lemmna* spp.
Nebraska	Wheeler	PMCYP033R0*20*NE	591	Private	09 Jun 1999	Pelster fen; B-ranked occurrence; 100+ plants in fruit observed by Steinauer; associated species include: *Carex hystericina*, *Thelypteris palustris*, *Eleocharis* sp., *Eupatorium perfoliatum*, and *Eriphorum gracile*. Mosses include: *Drepanocladus aduncus*, *Bryum pseudotriquetrum*, and *Campylium stellatum*; entire fen was not surveyed. Fen is diverse and in good condition. Entire suitable habitat is occupied.
Nebraska	Garfield	PMCYP033R0*21*NE	695	Private	09 Jun 1999	B-ranked occurrence - good estimated viability; 100+ plants in fruit observed by Steinauer. Fairly common in *Menyanthes*/*Carex lasiocarpa* zone of the fen; associated species include: *C. lasiocarpa* and *M. trifoliata*; habitat is limited; leafy spurge is common in adjacent areas.; aerial spraying has occurred immediately s and e of the fen on Big Cedar Creek; there is a large swath of dead *Amorpha fruiticosa* with scattered live leafy spurge along the creek.
Nebraska	Rock	PMCYP033R0*22*NE	733	Private	09 Jul 1999	Iverson fen; CD-ranked occurrence - fair or poor estimated viability; upper Elkhorn watershed; 2 plants in fruit observed by Steinauer.

Appendix (cont.).

State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/observation date	Comments
Nebraska	Garfield	PMCYP033R0*23*NE	649	Private	14 Jun 2000	C-ranked occurrence - fair estimated viability; plants in fruit, fairly common in small patch suitable habitat. associated species: *Amorpha fruiticosa*, *Eleocharis erythropoda*, *Marchantia polymorpha*, and *Dulchium acundinacea*; fairly small patch of habitat. full extent of population not known, but it is likely that there are more plants in similar habitats along the creek; adjacent uplands invaded by eastern red cedar and black locust; probably not a threat to the population.
Nebraska	Rock	PMCYP033R0*24*NE	732	Private	25 Aug 2000	50+ plants in leaf and bud, fairly common along margins of oxbow of Calamus River; associated species: *Carex prairea, C. comosa*, *Thelypteris palustris*, *Plagiomnum ellipticum*, and *Onoclea sinsibilis*. BC-ranked occurrence - good or fair estimated viability; good numbers of plants, but habitat area small; site is grazed, but area with *C. diandra* is too wet for cattle.
Nebraska	Loup	PMCYP033R0*25*NE	674	Private	06 Jun 2002	10-20 clumps in flower/fruit - plant could be scattered thoughout appropriate habitat along river. Associated taxa: *Carex stipata*, *C. hystericina*, *C. comosa*, *Sparganium eurycarpum*, *Lemna* spp., *Sagittaria* spp., *Calamogrostis canadensis*, *Amorpha fruiticosa*, and exotic species; reed canary rare, *Rumex orbiculatus*; 10-20 clumps in fruit; river to south, fairly nice meadow to n on NGPC property but cedars are invading adjacent area pastures and farm land; probably appropriate habitat along this portion on N Loup River; pop. small - habitat patchy although pop. Could be larger than observed.
Colorado	Larimer	PMCYP033R0*004*CO	2,703	Roosevelt National Forest	12 Aug 1996	S. Spackman; field survey of Larimer County for Colorado Natural Heritage Program.
Colorado	Boulder	PMCYP033R0*002*CO	2,584	Roosevelt National Forest	02 Aug 1992	Andrews and Neely; field survey of 2 Aug.
Colorado	Garfield	PMCYP033R0*001*CO	2,927	White River National Forest	29 Aug 1994	J. Sanderson; field survey; wetland classification project plot #94js33.
Colorado	Boulder	442043	2,584	Roosevelt National Forest	19 Jul 1987	“Gold Hill pond”, ca 3 mi w of Gold Hill; habitat: forming floating mats in the pond; collector: D.J. Cooper #1654.
Colorado	Saguache	474239	2,340	Great Sand Dunes National Park	22 Jul 1999	West side of Great Sand Dunes National Monument; Elk Springs area; habitat: in standing water; collector: D.J. Cooper #2392.

Appendix (cont.).

State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/observation date	Comments
Colorado	Larimer	35380	2,703	Roosevelt National Forest	16 Jul 1988	Associated species: *Carex lanuginosa* and *C. limosa*; moist peat soil.
Colorado	Larimer	14044	2,703	Roosevelt National Forest	12 Jul 1989	Associated species: *Carex lanuginosa* and *C. limosa*; moist peat soil.
Colorado	Larimer	442762	2,703	Roosevelt National Forest	06 Jul 1989	Boston Peak wetland, headwaters of Laramie River, 1.5 mi N of Chambers Lake on the Laramie River Road; habitat: in filled pond, on loose, deep peat; collector: D.J. Cooper #1679.
Colorado	Grand	441739	2,833	Rocky Mountain National Park	25 Aug 1988	Slope: flat; exposure: open; substrate: saturated soil; edge of pond & on log in pond; with moss, *Carex utriculata*; infrequent and only a few clumps observed.
Colorado	Grand	443057	2,774	Routt National Forest	02 Aug 1989	Floating mat in center of lake.
Colorado	Jackson	468727	2,689	Routt National Forest	11 Sep 1997	Colorado Natural Heritage Program, Kettle Lakes RNA Plant Community Survey; large, open clumps on very wet, floating peat on the edge of a beaver pond; locally common.
Colorado	Jackson	442709	2,698	Routt National Forest	06 Jul 1988	With scattered *Picea engelmanii*.
Colorado	Jackson	442990	2799	Routt National Forest	03 Aug 1989	*Sphagnum* mat.
Colorado	Garfield	454997	2,931	White River National Forest	29 Aug 1994	Colorado Natural Heritage Program wetland classification project; growing in dense clumps on partially submerged logs in small, permanent pond.
Wyoming	Park	579439	2,009	Shoshone National Forest	18 Aug 1992	Ecotone between *Carex rostrata* marsh and *Picea glauca* swamp forest; soil saturated.
Wyoming	Park	na	2,012	Shoshone National Forest	22 Aug 1984	In open calcareous fen.
Wyoming	Park	623056	2,012	Shoshone National Forest	21 Jun 1985	Open, calcareous (marly) bog.
Wyoming	Park	644164	2,354	Shoshone National Forest	07 Aug 1995	Frequent around pond in wet soil.
Wyoming	Park	681077	2,732	Shoshone National Forest	01 Aug 1999	Wet, quaking mats at edge of open water; soil orangish organic clay mulch; community of *Carex limosa* and *C. rostrata* with patches of *C. buxbaumii* on drier sites.
Wyoming	Park	644157	2,134	Shoshone National Forest	21 Jul 1995	Along south edge of *Carex utriculata* wetland; in wet soil from residual granite influenced by limestone colluvium.

Appendix (cont.).

State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/observation date	Comments
Wyoming	Park	681120	2,476	Shoshone National Forest	21 Aug 1996	Floating mat in bog dominated by sphagnum with *Calamagrostis canadensis*, *Carex limosa*, and *Drosera anglica*.
Wyoming	Park	644156	2,134	Shoshone National Forest	03 Aug 1995	Growing out of mossy hummock in *Salix planifolia*/*Carex aquatilis* community type; with *Potentilla fruticosa*, *C. utriculata*, and *Calamagrostis canadensis*.
Wyoming	Park	644166	2,341	Shoshone National Forest	06 Aug 1995	In partial shade along lake shore in *Betula glandulosa* vegetation type with *Habenaria hyperborea*, *Geum macrophyllum*, *Fragaria virginiana*, and *Equisetum arvense*.
Wyoming	Park	644165	2,341	Shoshone National Forest	06 Aug 1995	*Calamagrostis canadensis*/*Carex rostrata* vegetation type with *Viola* spp.; soil derived from granite, saturated for much of growing season.
Wyoming	Park	703337	2,341	Shoshone National Forest	06 Aug 1996	*Carex aquatilis*/*C. rostrata* community at edge of mudflats on low hummocks.
Wyoming	Park	532266	1,860	Shoshone National Forest	14 Aug 1988	Marsh.
Wyoming	Park	644155	2,439	Shoshone National Forest	05 Aug 1995	On mossy non-floating mat in a *Salix planifolia* var. *monica*/*Carex aquatilis* community type.
Wyoming	Park	252649	2,073	Grand Teton National Park	14 Jul 1955	F.J. Hermann; wet edge of boggy island in the lake.
Wyoming	Albany	PMCYP033R0*2*WY	2,902	Shoshone National Forest	08 Aug 1962	Boggy edge of pond in lodgepole pine zone.; Laramie ranger district; Medicine Bow National Forest; north fork road 8 miles northwest of centennial; probably in wetlands along sand lake road.
Wyoming	Park	PMCYP033R0*3*WY	1,865	Shoshone National Forest	14 Aug 1988	Marsh.;Wapiti ranger district; Shoshone National Forest; Absaroka range, north fork Shoshone river drainage, on south side of river, ca 0.3-0.5 miles west of the confluence of moss creek.
Wyoming	Park	PMCYP033R0*4*WY	2,008	Shoshone National Forest	31 Jul 1999	Hummocks at the edge of *Triglochin-Eleocharis* marl vegetation and *Carex rostrata* marsh; Swamp Lake special botanical area; Clarks Fork ranger district; Absaroka range, Clarks fork valley, Swamp Lake wetland on north side of the cathedral cliffs south of WY state highway 296, ca 34 air miles northwest of Cody.

Appendix (concluded).

State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/observation date	Comments
Wyoming	Park	PMCYP033R0*6*WY	2,440	Shoshone National Forest	01 Jul 2002	Mossy non-floating mat in *Salix planifolia*/*Carex aquatilis* vegetation type. soil is histic, wet, and derived from *Sphagnum* spp. and mosses; Clarks Fork R.D.; Beartooth Range, east end of Little Moose Lake, ca 0.5 air miles south-southeast of Ivy Lake outlet, ca 3.5 air miles northeast of Jim Smith peak, ca 2.5 air miles north of us Highway 212.
Wyoming	Park	PMCYP033R0*7*WY	2,134	Shoshone National Forest	03 Aug 1995	Found in 2 community types: (1) around drier edges of *Carex rostrata* community type; (2) growing out of mossy hummock in *Salix planifolia*/*C. aquatilis* community type. Soils mossy and wet to saturated from residual granite influenced by colluvial limestone; Clarks Fork ranger district; Absaroka Range, Clarks Fork valley, 2 locations: (1) swamp ca 2 air miles south of Lily Lake; (2) swamp ca 3.5 air miles south-southeast of Lily Lake along south side of the Clarks Fork of the Yellowstone River.
Wyoming	Park	PMCYP033R0*8*WY	2,341	Shoshone National Forest	31 Aug 1996	Occurs in 2 vegetation types: (1) dense *Betula glandulosa* woods along lakeshore with forb and moss-rich understory. soil moist, derived from granitic parent material; (2) *Calamagrostis canadensis*/*Carex rostrata* community at edge of mudflats; Clarks fork ranger district; Beartooth range, 2 locations: (1) pond ca 0.75 air miles west of lily lake (east of Gilbert Creek); (2) west and south shores of Lily Lake, ca 1.5 miles north of US highway 212.
Wyoming	Park	PMCYP033R0*9*WY	2,472	Shoshone National Forest	31 Aug 1996	Edge of floating mats of *Sphagnum* spp. at edge of bog on rich organic muck and clay. Vegetative cover nearly 100%, dominated by moss and graminoids including *Calamagrostis* spp., *Carex lasiocarpa*, and *C. limosa*; Absaroka Beartooth wilderness; Clarks Fork ranger district; Beartooth Mountains, pair of unnamed ponds ca 0.7 miles northeast of Lily Lake, ca 0.2 miles west of Lake Creek, ca 1.8 miles north of US Highway 212.
Wyoming	Albany	PMCYP033R0*13*WY	2,931	Medicine Bow National Forest	05 Aug 2003	Peaty margins at the perimeter of the largest lake in a small lake complex, on glaciated terrain. In the open, and in partial shade on part of the west margin; ca. 12 miles north of hwy 130 on Sand Lake Road and ca. 0.8 miles east on FS Rd 101E; 12 air miles north of Centennial.