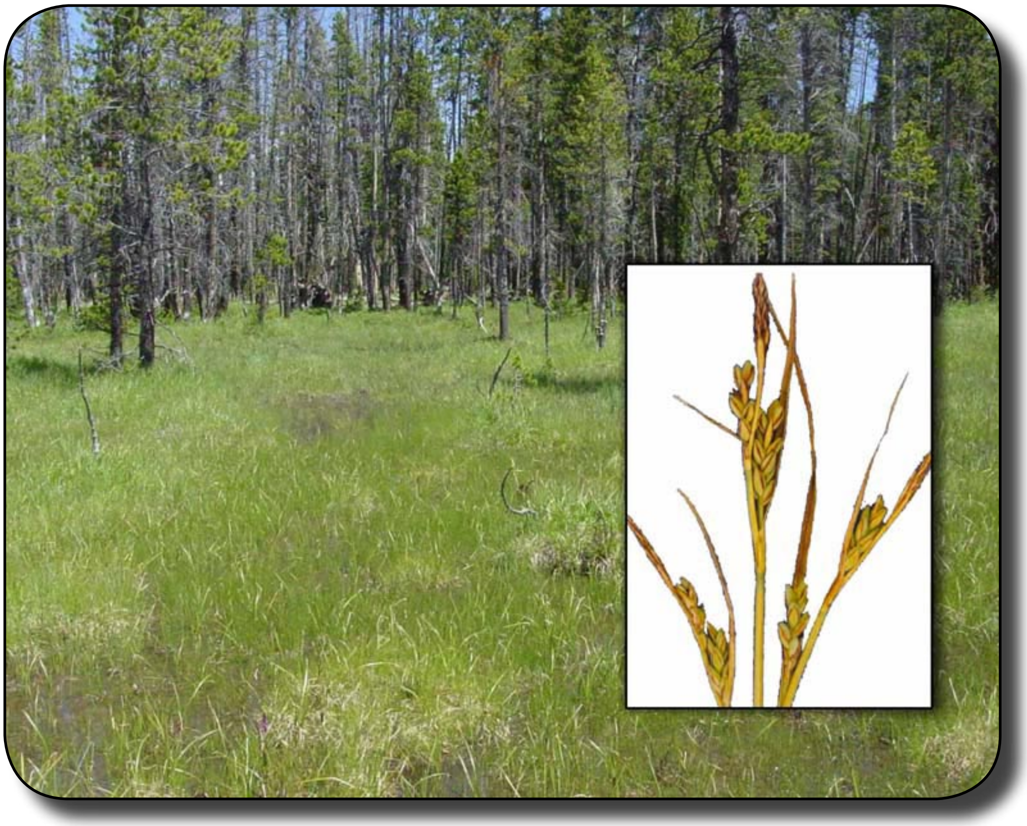
Carex livida (Wahlenberg) Willdenow (livid sedge): A Technical Conservation Assessment



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COVER PHOTO CREDIT

Carex livida (livid sedge). Cover photo by D. Cooper. Inset photo by E. Hurd, used with permission.

Summary of Key Components for Conservation of *Carex livida*

Status

Carex livida (livid sedge) is intermittently distributed throughout the northern hemisphere and is considered secure globally (G5). The species' distribution within the Rocky Mountain Region (Region 2) of the USDA Forest Service (USFS) is far more limited however. It occurs in only about nine sites in Wyoming where it is considered imperiled (S2), and it occurs in only eight sites in Colorado where it is considered critically imperiled (S1). *Carex livida* is an obligate wetland species, found primarily in subalpine fens formed in a range of geomorphic settings. Wetlands supporting known occurrences of *C. livida* are primarily located on public lands managed by either the National Park Service or the USFS; however, additional occurrences in Colorado are on land now managed by The Nature Conservancy. Several occurrences have been impacted by grazing and peat mining activities in the past, but most appear to be relatively secure from such on-site impacts at present. However, because of the strong dependence of wetlands supporting *C. livida* on groundwater inputs originating outside of their immediate boundaries, sites may be vulnerable to indirect and cumulative impacts from land uses in their contributing watersheds that alter hydrologic or sediment dynamics.

Primary Threats

Because of its limited distribution and the relative rarity of the fens providing its primary habitat, the fate of *Carex livida* is strongly tied to that of the wetlands presently supporting occurrences. Impacts from activities such as peat mining and ditching have in some instances severely impaired the function of fens and reduced their suitability for species like *C. livida*. Both peat mining and ditching are currently uncommon and do not appear to represent significant threats to extant occurrences. However, impacts from these and other activities, such as construction of reservoirs or heavy grazing by domestic livestock, in the past may have reduced the amount and quality of habitat available for the species, and in some instances they may continue to impair important wetland functions.

Although direct impacts to *Carex livida* occurrences do not appear to be a great threat in the region at present, impacts from a wide variety of activities are known to indirectly impair wetland structure and function, potentially reducing the viability of the species. Since fens providing the primary habitat for *C. livida* are supported primarily by groundwater, any activity, such as logging or road construction, that significantly alters the water or sediment yield from surrounding watersheds can deleteriously affect wetland vegetation. Climate change also has the potential to negatively impact fens supporting *C. livida* by altering their hydrologic balance and increasing decomposition rates enough to shift systems from peat-accumulating to peat-losing systems. Gradients in pH, nutrients, and cation concentrations within and among fens can strongly influence vegetation patterns. Consequently, activities that significantly alter the chemical characteristics of surface or groundwater can be expected to impact fen ecosystems and dependent species like *C. livida*.

Because most *Carex livida* occurrences are in peatlands, factors compromising the physical integrity of the peat body in which the plants are rooted may represent a localized threat. Examples include trampling by domestic livestock, native ungulates, and the feet of recreational users, as well as the use of fens by off-highway vehicles. When peat is broken apart, it is more susceptible to oxidation; the resulting increase in decomposition can shift the balance between peat accumulation and loss, with significant ramifications for fen function.

Overall, we found no evidence from the existing literature or occurrence descriptions to indicate that the persistence of the species is presently threatened by existing land management activities. What little data are available suggest that the wetlands supporting the majority of Region 2 occurrences are functioning within their historic range of variation and therefore presumably offer the habitat necessary for continued persistence of the species. However, there are insufficient data for all occurrences from which to confidently evaluate population trends.

Primary Conservation Elements, Management Implications and Considerations

Maintaining the hydrologic integrity of wetlands supporting *Carex livida* should be the central aim of conservation efforts directed towards the species. Although on-site impacts to wetland hydrology can have the greatest direct effect on *C. livida* occurrences, a variety of off-site impacts can also result in negative impacts to the species. Like many other wetland and alpine species in the region, *C. livida* may have been more widespread historically. Expansion of the species in the region, at least under current and predicted climate scenarios, appears highly unlikely due to limited habitat and potentially low dispersal distances. As a result, long-term conservation of the species in Region 2 should focus on the protection of the fens supporting the species.

To improve management of *Carex livida*, additional research is needed on a range of topics. Broad-scale peatland inventories are needed to better understand the abundance, distribution, and functional diversity of peatlands in the region. These kinds of studies also provide a useful framework for more fine-scaled investigations of fen hydrology, vegetation, and geochemistry, which are the primary variables driving fen structure and function. In preparing this assessment, it has also become clear that more studies of *C. livida* demographics and extensive population monitoring are needed in order to improve our understanding of the species and potential threats.

Table of Contents

EDITORS: Kathy Roche and Richard Vacirca, USDA Forest Service, Rocky Mountain Region

List of Tables and Figures

Tables:

Figures:

INTRODUCTION

The USDA Forest Service (USFS) is legally mandated to manage for the full complement of species occurring on USFS lands. To effectively predict and mitigate for potential environmental consequences of management activities such as timber harvest, livestock grazing, energy development, or recreation use on individual species, the USFS requires basic information about species' biology, ecology, and conservation status. Unfortunately, there is a paucity of information for many species, and what information is available is scattered among a variety of disparate sources and largely unavailable to the forest 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 of Assessment

Within the Rocky Mountain Region (Region 2) of the USFS, *Carex livida* (livid sedge) is listed as a sensitive species, a species whose population viability is identified as a concern by the Regional Forester because of significant current or predicted downward trends in abundance or habitat capability that might reduce its distribution (FSM 2670.5(19)). Such species may require special consideration in management; therefore improved knowledge regarding the biology and ecology of the species is critical. Our goal in this document is to provide a comprehensive and synthetic review of the biology, ecology, and conservation status of the wetland sedge *C. livida* in 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. Since *C. livida* only occurs in specific types of wetlands, we extensively discuss topics such as hydrology and wetland geochemistry 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 regarding *Carex livida*, its habitat, and potential threats. Wetlands supporting *C. livida* in the northern hemisphere and within Region 2 are functionally diverse, making the 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 livida* in 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 Region 2, regardless of ownership or management. The temporal scope of the assessment is on current conditions, but we also include relevant information from historical and evolutionary perspectives.

Considering the broad scope of this assessment, both topically and geographically, we have drawn upon a wide variety of information sources. These have included qualitative and quantitative sources, ranging from the peer-reviewed literature to informal discussions with managers and scientists familiar with the species, its habitat, or potential management threats. Where available, we have incorporated quantitative data, such as hydrology, vegetation, or water chemistry parameters from wetlands known to support *Carex livida* populations in the region. Rigorous, peer-reviewed literature was given the greatest weight, but there have been relatively few such studies published from the region. Consequently, we also drew from the more extensive "gray literature", such as unpublished reports and graduate theses and dissertations.

Treatment of Uncertainty

Ecological systems and the biota inhabiting them are, by nature, exceedingly complex and unpredictable. Typically, multiple variables influence any given ecological attribute, whether it be community composition, biogeochemical cycling rates, or patterns of species invasion, persistence, or extinction. Important variables are frequently strongly interdependent and difficult to isolate and effectively measure, complicating data collection and analysis. Moreover, ecological patterns and processes are frequently strongly scale-dependent, with generalizations appropriately made at one scale inappropriate at larger or smaller ones.

When preparing broad-scale assessments such this, where rigorous, quantitative data are largely unavailable, it is important to explicitly address issues of uncertainty and to draw upon whatever substantive forms of information are available. Although in this assessment we place the greatest weight upon information gleaned from the peer-reviewed scientific literature, we have also relied upon the impressions, thoughts, and ideas, even if unsubstantiated by data, of the scientists and managers familiar with the species and its habitats. These more informal information sources are generally cited in the text as "personal communication".

Because of the unavailability of research specific to *Carex livida* from Region 2, we have relied heavily upon our knowledge of the particular wetland types where the 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. livida*.

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 report was reviewed through a process administered by Center for Plant Conservation employing at least two recognized experts on 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

Due to its wide distribution throughout the northern hemisphere, NatureServe (2005) considers *Carex livida* to be globally secure (G5). No status rank at the national level has been given to the species in the United States or Canada. The species is relatively abundant in northern latitudes, and with the exception of several Maritime Provinces, it is unranked or ranked apparently secure (S4) or secure (S5) in the majority of Canadian provinces. *Carex livida* is far less common within the continental United States, where it is ranked critically imperiled (S1) or imperiled (S2) in 12 states. Within Region 2, *C. livida* occurs in the states of Colorado and Wyoming, where it is ranked S1 and S2, respectively (**Table 1**). The Wyoming Natural Diversity Database includes *C. livida* on its list of species of

Table 1. Conservation status of *Carex livida* by state or Canadian province. See **Definitions** section for explanation of Natural Heritage Program (NHP) ranks. Region 2 states are in bold and italics. Source: NatureServe 2005.

State	NHP rank	State/Province	NHP rank	Province	NHP rank
Alaska	SNR	New Hampshire	S1	Manitoba	S3
California	SH	New Jersey	SNR	New Brunswick	S1
Colorado	***S1***	New York	S1	Newfoundland Island	S3S5
Connecticut	SU	Oregon	S2	Northwest Territories	SNR
Idaho	S2	Utah	S1S2	Nova Scotia	S1
Indiana	S1	Vermont	S1	Nunavut	SNR
Iowa	S1	Washington	SNR	Ontario	S5
Maine	S2	Wisconsin	SNR	Prince Edward Island	S1
Massachusetts	SNR	***Wyoming***	***S2***	Quebec	SNR
Michigan	SNR	Alberta	S3	Saskatchewan	SNR
Minnesota	SNR	British Columbia	SNR	Yukon Territory	SNR
Montana	S3	Labrador	S3S5		

special concern, and USFS Region 1, USFS Region 2, and the Bureau of Land Management in Colorado include the species on their lists of sensitive species.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Carex livida is neither listed nor a candidate for listing under the Endangered Species Act. Consequently, it receives no specific legislative protection at the federal level. Some *C. livida* occurrences are found in wilderness areas and national parks, presumably conferring some degree of *de facto* protection to the species due to inaccessibility and the preclusion of land uses such as road construction that can negatively impact wetlands. Region 6 of the U.S. Fish and Wildlife Service has a policy regarding the protection of fens, which states that mitigation for fens is not feasible due their irreplaceability (USDI Fish and Wildlife Service 1999).

As an obligate wetland species (Reed 1997), *Carex livida* and its habitat receive limited protection under some existing federal, state, and local statutes. 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 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 connections to surface water bodies such as streams. Most fens lack surface water connections to navigable waters of the United States and may therefore 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, which include many fens, is still undetermined, with cases currently under review in the courts. Also relevant to wetlands management on USFS lands is Executive Order 11990; this order 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."

USFS memo 2070/2520-72620, signed by the Director of Renewable Resources, provides regional guidance to all Region 2 forest supervisors regarding fens and emphasizes their protection, preservation, and enhancement. However, the memo is not a directive, and as such, it does not limit the kinds of management activities that can be pursued in wetlands supporting *Carex livida*. Section 2670 and related chapters of the Forest Service Manual outline policies and requirements applicable to sensitive species. 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 effect on species' populations and habitats (USDA Forest Service 2006).

Biology and Ecology

Classification and description

Systematics and synonymy

Carex livida, a perennial member of the Cyperaceae, was first described by Willdenow in the fourth edition of *Species Plantarum* in 1805. Although Wahlenberg described the species in 1803, the name he assigned, *C. limosa* var. *livida*, was later rejected, and Willdenow's treatment was accepted. The common name typically used for the species is livid sedge, but it is also referred to as the pale stiff sedge or pale sedge (Caicco 1988, Rodwell 1991, Moseley et al. 1991, USDA Natural Resources Conservation Service 2006). An outline of *C. livida*'s full taxonomic classification is presented in **Table 2**.

Carex species are particularly prevalent in wetlands, where they are often the dominant vascular plant taxa present. Species in the genus are morphologically similar, and many are largely indistinguishable by vegetative characteristics alone; this makes sedge taxonomy difficult and field identification impossible if plants are not fruiting (Metcalfe 1969, Standley 1990).

Several infraspecific taxa have been used in the literature, only one of which is presently recognized by ITIS: *Carex livida* var. *radicaulis* Paine (ITIS 2004, USDA Natural Resources Conservation Service 2006). Other varieties described include *C. livida* var. *rufinaeformis* Fernald and *C. livida* var. *typica* Fernald, both described from Newfoundland and Labrador in Canada (IPNI 2005). Hermann (1970) described *C. livida* var. *grayana* (Dewey) Fernald as the principal variety occurring in the Rocky Mountains, but it is not presently recognized and is considered synonymous with var. *radicaulis*. *Carex livida* var. *livida* has been described as the principal variety occurring in northern

Table 2. Higher taxonomic rankings for *Carex livida*. Source: ITIS 2004.

Rank	Name
Kingdom	Plantae
Division	Magnoliophyta
Class	Lilliopsida
Order	Cyperales
Family	Cyperaceae
Genus	*Carex*
Section	*Paniceae*
Species	*Carex livida*

Europe (Hermann 1970, Wheeler et al. 1983). However, no subspecies are recognized in the recent treatment of the species in the Flora of North America (Ball and Reznicek 2004).

Morphological characteristics

Carex livida is a perennial species, 10 to 55 cm tall, with shoots arising singly or in small groups from creeping rhizomes. Its pale, bluish-green leaves are mainly basal (phyllopodic), narrow (1 to 3.5 mm wide), firm, and frequently channeled in cross-section. Plants bear a terminal, staminate flowering spike 1 to 2.5 cm in length. One to three pistillate, lateral spikes, bearing 5 to 15 flowers and measuring 1 to 2.5 cm in length, are borne on short peduncles that only slightly exceed the sheath, if at all. A green, leaf-like bract up to 7 cm long subtends the lowest spike. Pistillate scales equal or slightly shorter in length than the perigynia bear a broad, pale green midstripe and have hyaline-scarious, brown or dark brown margins. Perigynia are waxy-green (glaucous) in color, ovate-ovoid or elliptic-oblong in shape, and are generally less than twice as long (2.2 to 4.5 mm) as wide (1.2 to 2.4 mm), tapering to a small (0 to 0.2 mm), entire, darkly-rimmed beak. They are typically triangular in cross-section, lacking entirely or bearing only obscure nerves on both faces. Achenes are broadly ovoid and three-sided (trigonous) with three stigmas (**Figure 1**).

Carex livida is relatively distinctive in the field, and it can be distinguished from other sedges by its short, pale-green, or blue-green colored, stiff, and channeled basal leaves. *Carex livida* may be confused with the more commonly occurring *C. aquatilis*. However, the latter tends to be taller and more robust, has long-stalked spikes, two versus three stigmas, and it lacks the prominent, stiff, central groove characteristic of *C. livida* leaves. Although *C. livida* is described in numerous regional floras, particularly useful resources for sedge identification in Region 2, and the principle source for the preceding description, are Hermann (1970), and Hurd et al. (1998), Johnston (2001).

In Sweden, Sjörs (1991) noted that, as with several other *Carex* species examined, a considerable portion of *C. livida* growth and biomass was contained in belowground structures, with nearly 65 percent of the total living plant mass occurring as roots or rhizomes. The aboveground living component for *C. livida* consists nearly exclusively of the green leaves, with a small proportion of biomass contributed by stems with inflorescences. *Carex livida* is a clonal species spreading largely via slender underground rhizomes. Short roots form only from the branching points of the rhizome and from the bases of its aerial rosettes (Sjörs 1991). Clones are comprised of modular units called ramets; collectively, they comprise the genet, which represents the product of a single zygote (Harper 1977, Noble et al. 1979).

Distribution and abundance

Carex livida is widely distributed throughout the northern hemisphere, particularly in boreal regions. It is less broadly distributed in Europe, relative to several other circum-boreal species present in Region 2 such as *C. limosa* (mud sedge) or *Drosera rotundifolia* (roundleaf sundew). Its distribution in Europe is limited largely to Scandinavia although isolated populations are found in Siberia and along the Pacific Coast of Asia (**Figure 2**).

Within North America, *Carex livida* is relatively common in northern latitudes. It is found in all Canadian provinces and in much of Alaska. It is also known from approximately 20 other U.S. states. The species is considerably rarer in the Rocky Mountains; *C. livida* is known from a limited number of sites in Idaho and Montana (Caicco 1988) and approximately 17 occurrences within Region 2. Approximately nine of these 17 occurrences are in Wyoming and eight are in

Figure 1. *Carex livida* habit (A), ligules (B, C), staminate flower with subtending scale (D); perigynia (E, F); cross-section of achenes illustrating variation (G, H); pistillate scales (I, J); achene (K). Figure from Mason 1957.

Colorado (**Figure 3**). Wyoming occurrences are found on public lands in both Yellowstone National Park and the Shoshone National Forest. Colorado occurrences are found on the Pike, Routt, and Roosevelt national forests, as well as in fens occurring on non-federal lands. For example, High Creek Fen in Park County, Colorado, which supports an occurrence of *C. livida*, was acquired and is now managed by The Nature Conservancy, Colorado Chapter.

Globally, *Carex livida* is found across a wide elevation range, as is typical for a boreal species at the southern edge of its range. In Scandinavia, Canada, and the Northeast United States, populations are found from near sea level to several hundred meters in elevation (Zika 1982, Foster and Fritz 1987, Wells 1996). All occurrences documented in Region 2, however, are found at high elevations, which because of lower evapotranspiration rates and greater precipitation,

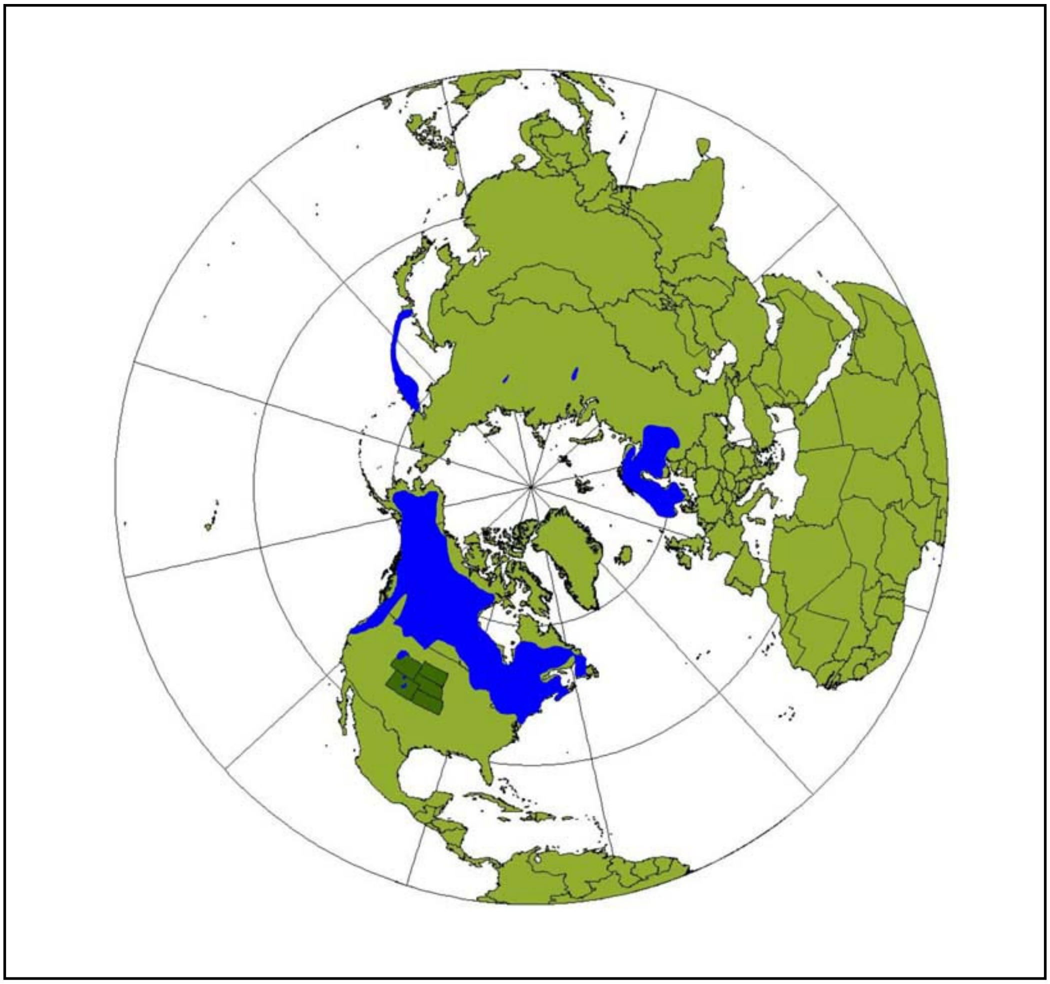

Figure 2. Approximate global distribution of *Carex livida*. Source: Hultén 1968.

support more wetlands and fens than lower elevation sites. Although *C. livida* does not occur exclusively in peatlands, fens are the principle habitat for the species. Since fens depend on stable, perennially high water tables for peat accumulation, they occur only in favorable microclimatic and hydrogeomorphic settings, which typically occur at higher elevations (Cooper and Andrus 1994, Chimner et al. 2002). Elevations of fens known to support *C. livida* in Region 2 range from approximately 2012 m (6600 ft.) in Wyoming to 3050 m (10,000 ft.) in Colorado.

Population trend

No reliable region-wide population estimates are available for *Carex livida*. Abundance estimates are included with some element occurrence records, but they do not appear to have been the product of quantitative sampling and so are of limited value. Because *C. livida* can reproduce asexually, the culms comprising a typical stand may be integrated into any number of genetically identical clones, making the identification of genetically distinct individuals (i.e., genets) difficult or impossible without the use of complex molecular techniques.

Habitat

Ecological classification is a difficult task regardless of the system analyzed. Many different criteria, alone or in combination, can be used to differentiate classes; ultimately, the choice of which variable(s) are used may determine the structure and utility of the classification scheme. At fine to intermediate spatial scales, the most intuitive and commonly used approaches are based on vegetation structure and composition. Examples include habitat-type classifications developed by the USFS (e.g., Alexander 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).

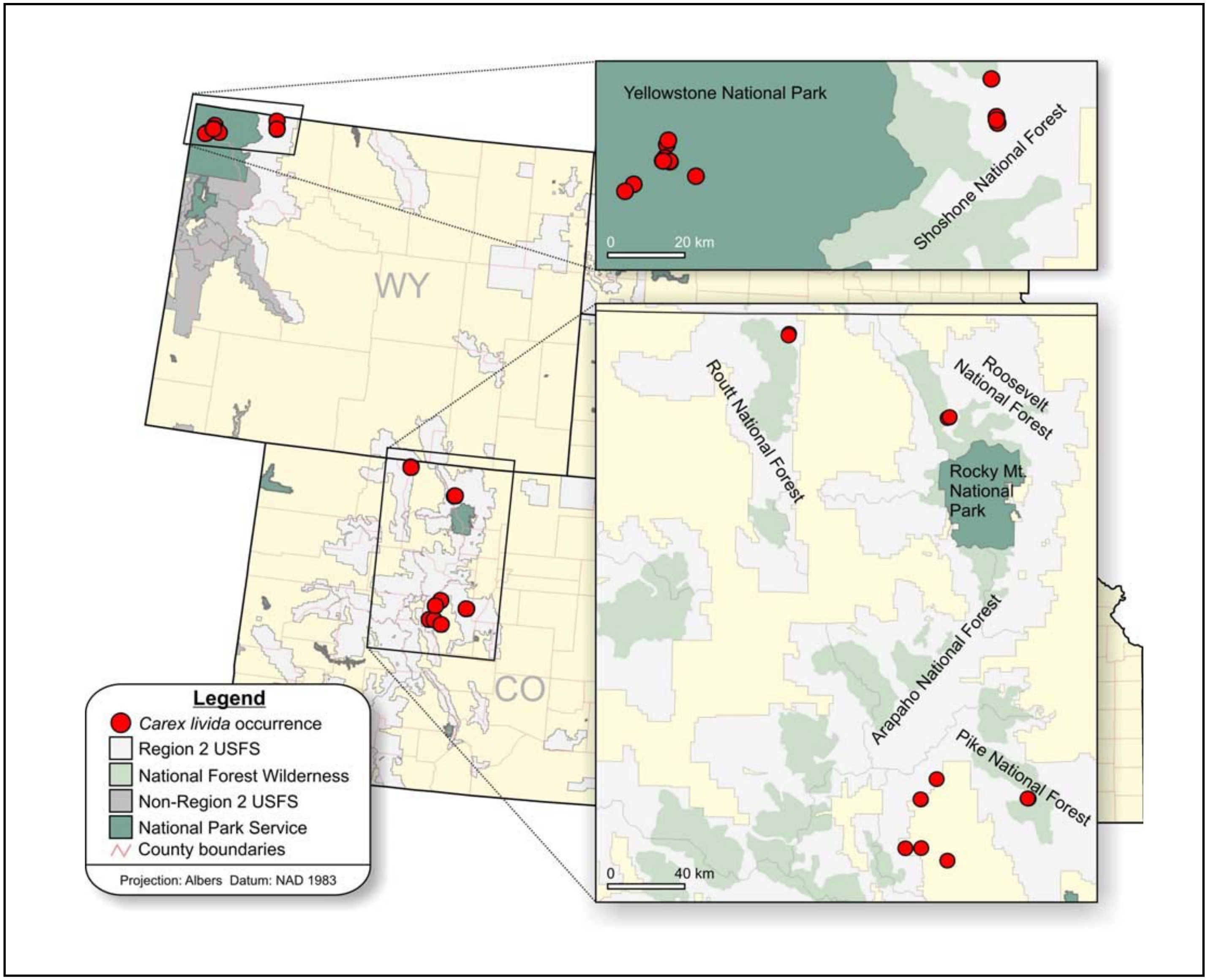

Figure 3. USDA Forest Service Region 2 distribution of *Carex livida*. Record sources include Wyoming Natural Diversity Database and Colorado Natural Heritage Program element occurrence records, Rocky Mountain Herbarium and University of Colorado specimen label information, and for Yellowstone National Park, unpublished occurrence records of the species from Lemly and Cooper.

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, the primary habitat for *Carex livida*, classification schemes have typically emphasized chemical or hydrologic variables (e.g., pH; cation or nutrient concentrations; groundwater vs. precipitation), and vegetation and peat composition (bryophyte vs. sedge). We do not assume reader familiarity with these various approaches, but we do reference some of the concepts and terms underlying them (e.g., poor fen, ombrotrophic) in subsequent sections characterizing the habitat of *C. livida*. Where used, definitions appear in the glossary. Useful general references for peatlands include Windell et al. (1986), Crum (1988), and Mitsch and Gosselink (2000).

General habitats described for *Carex livida* have included fens, peat bogs, calcareous floating mats, swampy woods, and *Carex*-dominated marls (Hurd et al. 1998, Ball and Reznicek 2004). Less commonly, *C. livida* has been described from wetlands with mineral substrates (Hulten 1968, Gleason and Cronquist 1991, Whipple personal communication 2005). Across its range, it is most commonly found in peatlands, particularly fens with moderate to high pH and Ca^{2+} concentrations (Kubiw et al. 1989, Glaser 1992).

The most common habitats described in Colorado and Wyoming are montane and subalpine fens, including those formed in depressions such as small kettle basins or at the toes of mountain slopes or alluvial fans. The 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 *Carex livida* occurrences are found at elevations over 1,950 m (6,400 ft.).

Reproductive biology and autecology

Life history and strategy

Carex livida is a perennial species that establishes from seed or via clonal expansion. We are unaware of any studies specifically examining the life history of *C. livida*, but other members of the genus have been examined in detail (Bernard 1976, Noble et al. 1979, Bernard 1990), and many of the principles described for other rhizomatous sedges should apply *C. livida*. As a long-lived perennial species that probably devotes several years to vegetative growth before reproducing, *C. livida* could be classified as a K-selected species (MacArthur and Wilson 1967).

In **Figure 4**, we present a generalized overview of *Carex livida*'s life cycle featuring four primary stages: (1) seed, (2) seedling, (3) mature plant, and (4) rhizome. Although researchers working with other clonal sedge species have described up to six distinct age classes, insufficient demographic data specific to *C. livida* are available to warrant such an approach.

Reproduction, pollinators and pollination ecology

The majority of *Carex livida* reproduction in Region 2 is asexual through expansion of rhizomes, with the possibility of sexual reproduction in rare cases. Members of the genus *Carex*, including *C. livida*, are wind pollinated (Gleason and Cronquist 1991), but there are no data available describing out-crossing distances or other specific aspects of *C. livida* pollination ecology. Flowering in the region typically occurs between late spring and early summer, and plants bear fruit from July to August (Johnston 2001).

Seed dispersal, viability, and germination requirements

Carex livida appears to establish at least occasionally from seed, but no studies have examined the conditions under which seedlings develop. While we also found no studies of *C. livida* seed dispersal, it is likely that multiple dispersal mechanisms may be involved including wind (amenochory), water (hydrochory), and animals (zoochory) (Ridley 1930). Of these mechanisms, water is the most likely vector for dispersal, as perigynia appear well adapted to water flotation. Long-distance dispersal events are probably rare, particularly given the relative isolation of many occurrences.

Regardless of dispersal mechanism, seeds may germinate during the spring following dispersal, or they may enter the soil seed bank and germinate when favorable conditions occur. The relative importance of seed bank processes in the establishment dynamics of *Carex livida* is unknown, and we found no published studies of *C. livida* seed germination requirements. Although numerous other *Carex* species have been examined, germination and establishment requirements are too variable to confidently extrapolate to *C. livida*.

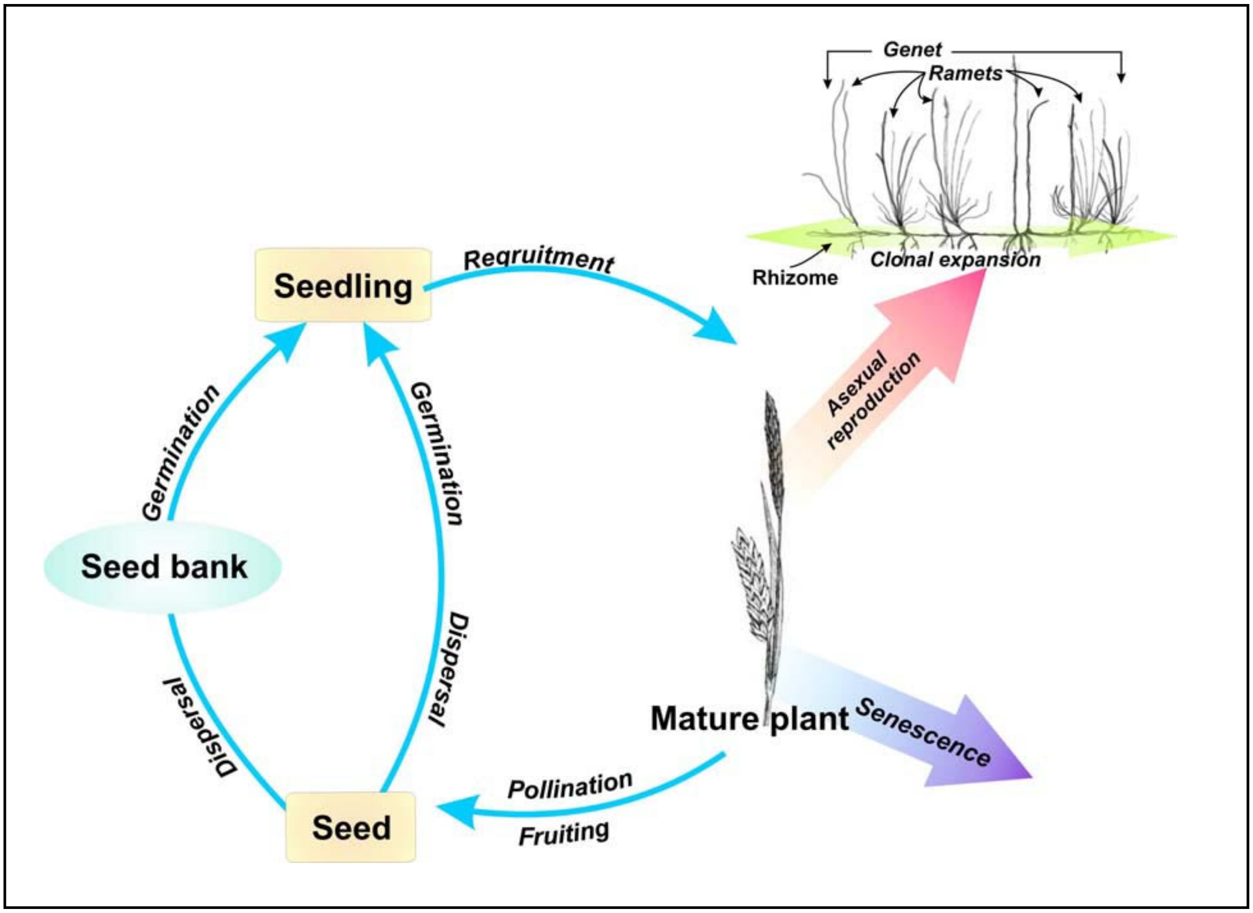

Figure 4. Generalized life cycle diagram for *Carex livida*.

Genetic characteristics and concerns

Clonal plant populations are typically assumed to have relatively low levels of genetic variation, with sites dominated by a limited number of genets (Ellstrand and Roose 1987, Vellend and Waterway 1999). We found no genetics research on *Carex livida*, but published analyses of a range of clonal sedges from outside the region suggest that most clonal *Carex* populations show little genetic differentiation even among populations from widely separated areas, and that many rhizomatous sedges share a similar overall level of genetic variability (Mcclintock and Waterway 1993, Vellend and Waterway 1999).

Waterway (1991) compared the clonal diversity and genetic variation in nine different *Carex* species commonly found in subarctic fens, and she suggested that species with a relatively broad ecological amplitude, such as *C. limosa* and *C. rostrata* (beaked sedge), had the largest percentage of unique genotypes per site as well as the highest levels of heterozygocity and polymorphism. The levels of heterozygocity were low in all of the species examined with restricted habitat preferences. In addition, she found that species with long-spreading rhizomes were more polymorphic than caespitose species or those with only short-spreading rhizomes like *C. livida* (Waterway 1991).

No data are available to evaluate the genetic structure of Region 2 *Carex livida* occurrences. Because of *C. livida*'s ability to reproduce asexually, genetic diversity within individual wetlands may be low, with one or a limited number of dominant genotypes present, as Vellend and Waterway found for other *Carex* species (Vellend and Waterway 1999). It is also unknown to what degree genetic patterns differ among occurrences. Since known occurrences of *C. livida* in the region are relatively isolated from one another, presumably genetic crossing between occurrences is rare. However, without further research, it is impossible to say with certainty what the underlying genetic structure of *C. livida* is in the region.

Hybridization

Hybridization has been widely reported in the genus *Carex* (Cayouette and Cattling 1992). Most verified crosses have been between closely related species within the same section of *Carex*; however, intersectional hybrids have been described. The majority of crosses produce infertile offspring, but some hybrids have produced partially fertile seeds (Cayouette and Catling 1992, Ball and Reznicek 2004).

Other members of section Panicea, such as *Carex vaginata* (sheathed sedge) or *C. panacea* (carnation sedge), are sympatric with *C. livida* over portions of its range, and hybrids may occur. For example, *Carex livida* x *panicea* has been documented from Sweden. However, neither *C. vaginata* nor *C. panacea* occurs in Region 2, making the presence of hybrids unlikely.

Demography

We found no information on the demography of *Carex livida* occurrences. Quantitative data regarding age and life history stages and the nature of the transitions between them are difficult to obtain, particularly for cryptic species or species capable of vegetative reproduction such as *C. livida*. Following dispersal and germination, some seedlings are recruited into older age classes, but the factors controlling the transitions are unknown. It is likely that some mortality due to herbivory, disease, or competition affect recruitment levels (Harper 1977), but no data are available to evaluate their relative importance for *C. livida* occurrences.

No published studies exist on the phenology and life span of *Carex livida* shoots. However, work on several other temperate zone *Carex* species may provide some insights into their dynamics. In a study of *C. rostrata* 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. 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). Whether similar patterns would be observed for *C. livida* is unknown.

There are no data on the age of *Carex livida* genets, but because they persist and spread vegetatively, genet life spans could be decades to centuries, or longer (Bernard 1990). Because of its clonal growth form, the basic life cycle we describe oversimplifies the processes actually driving the age and genetic structure of *C. livida* occurrences. For example, as clones expand, the connections linking different portions can be severed, resulting in multiple genetically identical clones. These complexities make the modeling of population processes in a species like *C. livida* difficult.

As is typical for many clonal sedge species, a considerable portion of *Carex livida* biomass is found below ground. Usually, the biomass of roots and rhizomes greatly exceeds that of aboveground structures. Although net productivity values for *C. livida* is lower than for other clonal sedges, such as *C. limosa*, its high allocation of biomass below ground suggests that in many of the fens in which it occurs, it is a significant contributor of organic carbon and therefore important to peat accumulation rates and fen carbon balance.

No Population Viability Analysis (PVA) has been performed for *Carex livida*, 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. livida*.

Community and ecosystem ecology

Hydrogeomorphic and geological setting

Wetlands in general, and those particular ones within Region 2 supporting *Carex livida* occurrences, have formed in very specific geomorphic and landscape settings. Most occurrences are in fens, which only form in sites that possess perennially stable water tables necessary for peat accumulation (Windell et al. 1986). Fens in the western United States typically form in one of four general landscape settings: 1) springs on hillslopes controlled by geologic discontinuities, 2) upwelling springs, 3) basins, and 4) sloping fens at toe slopes. Of the four types, basins and sloping fens at toe slopes (**Figure 5**) are known to support *C. livida* occurrences, but more thorough field characterization is required.

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

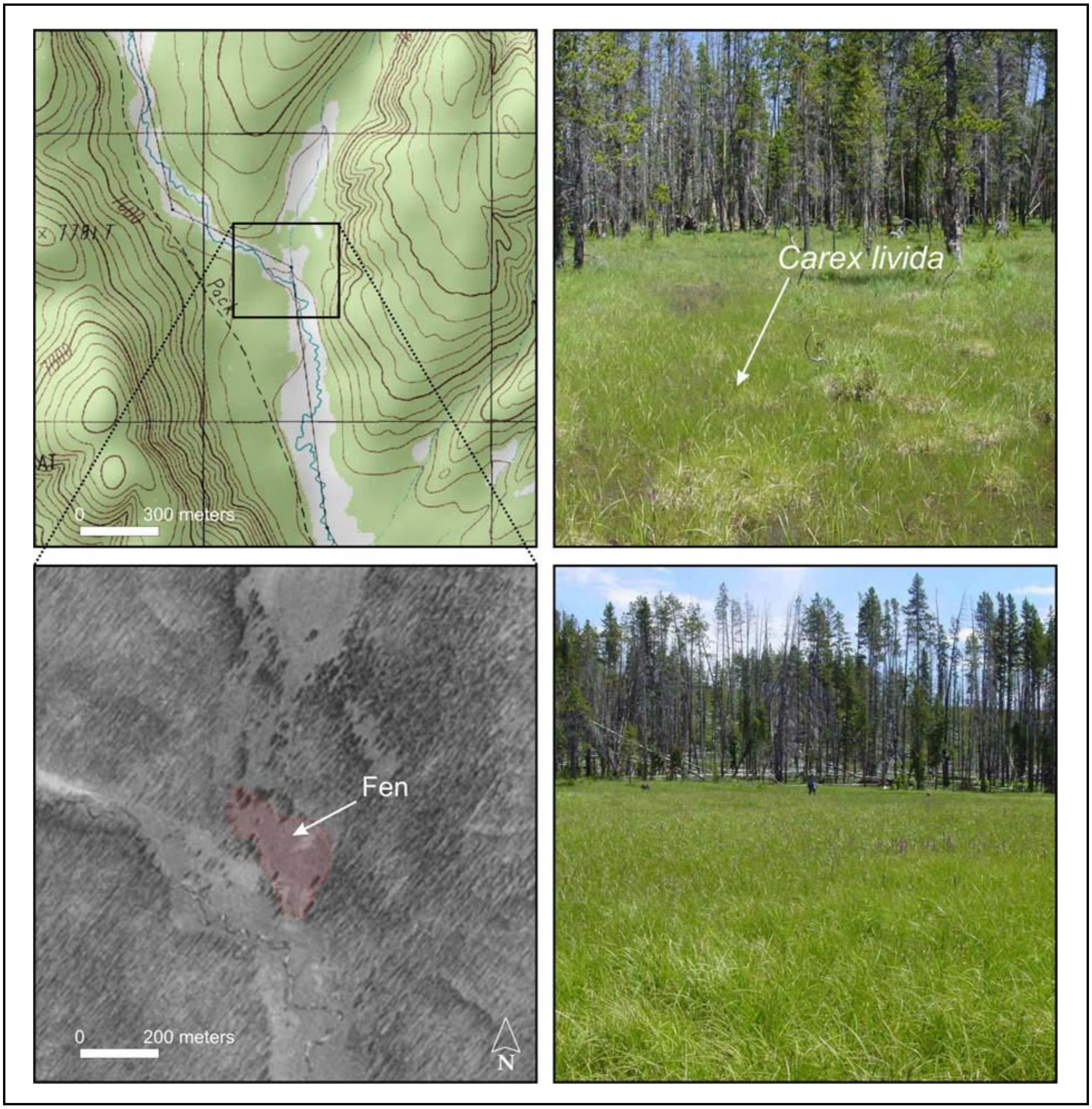

Figure 5. Topographic map, aerial photograph, and oblique photographs of the Solfatura Creek fen, Yellowstone National Park, Wyoming. This fen supports an occurrence of *Carex livida* and is an example of a sloping fen; although the slope within the fen is small, concentration and discharge of groundwater from adjacent hill slopes support the wetland hydrologically.

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 livida*, for example, often occurs in fens formed in small kettle basins created in stagnating glaciers.

The actual geological configuration of sites supporting fens can be complex. For example, Swamp Lake wetland on the Shoshone National Forest (**Figure 6**), which supports an occurrence of *Carex livida*, 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, which 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,

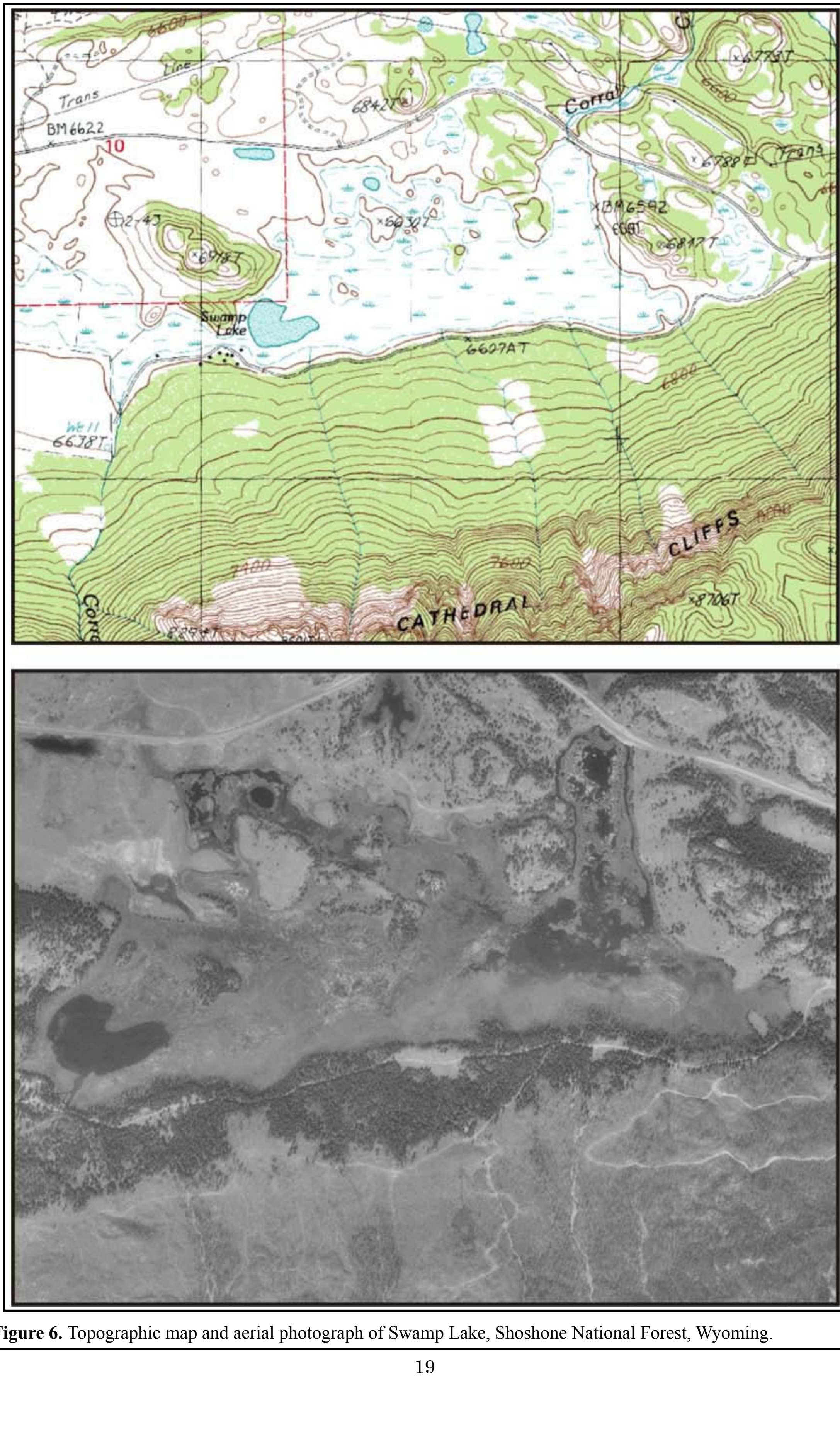

Figure 6. Topographic map and aerial photograph of Swamp Lake, Shoshone National Forest, Wyoming.

and the wetland in turn supports an extremely rich fen community, including the rare species *C. livida*, *C. leptalea*, *C. limosa*, and *C. diandra* (lesser panicled sedge) (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 rich fens (Heidel and Laursen 2003, Mellmann-Brown 2004).

An additional example of the importance of local geology in shaping the chemistry, hydrology, and vegetation of fens is from South Park in Colorado. The valley's form was created by complex faulting patterns and the action of glaciers during the Tertiary and Quaternary (Johnson and Steingraeber 2003). These formed extensive glacial outwash deposits, but unlike the majority of similar valleys in the region, which are composed of till derived from granitic parent material, the deposits underlying South Park are composed in large part by calcareous and dolomitic material derived from the adjacent Mosquito Range (Cooper 1996, Johnson and Steingraeber 2003). Local and regional groundwater flowing through these deposits and the deep limestone and dolomite bedrock formations in the area become highly mineral rich and have high pH. Where these groundwater flow systems discharge to the surface, they create extremely rich fens, such as High Creek Fen. Like the Swamp Lake site, these fens support numerous rare species and communities including *Carex livida*.

Wetland formation, development, and succession

In Region 2, *Carex livida* is generally found in fens formed in either small lake basins and depressions or sloping fens. The fens are often associated with glacial landforms, including kettle basins, formed by ice blocks stranded within stagnating Pleistocene glaciers. In addition, lateral moraines deposited by glaciers can sometimes block drainages, producing ponds similar to kettles (Cooper 1990). Mass wasting events, such as landslides, also sometimes influence the formation and function of some fens supporting *C. livida*. Often, sites reflect the influence of both glaciation and mass wasting events (Austin personal communication 2004).

Two general mechanisms are responsible for the formation of peatlands. Terrestrialization is the process of a water body filling with sediments and peat, and paludification is the conversion of uplands to peatlands by the lateral expansion of peat bodies and the formation of waterlogged soils that impede drainage. Terrestrialization is of greater importance in most temperate zones, and within Region 2, basin fen formation appears to occur exclusively via terrestrialization.

Although successional processes have been extensively studied in peatlands elsewhere, few studies have been conducted within Region 2. 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 obtained from C^{14} dating of peat cores from Region 2 fens 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). Differences in basin size, aspect, slope processes, and landform morphology can influence rates of peat formation and successional rates.

Unfortunately, too little data are available to evaluate *Carex livida*'s role in wetland succession. Where it occurs in floating mat communities that represent a stage in the terrestrialization of small basins, *C. livida* may be a mid-seral species. However, because two trademark characteristics of fens are their high hydrologic stability and low frequency of disturbance, *C. livida* may remain a viable component of plant communities for thousands of years.

How the wetlands that formed on mineral substrates supporting *Carex livida* have developed is unknown. However, in Yellowstone National Park, sites with perennially saturated soils, but lacking peat accumulations, may have formed relatively recently as spring complexes stabilized. Because of the slow accumulation rate of peat in the region, they may therefore have had insufficient time to develop peat soils.

Substrate characteristics and microhabitats

Globally and within Region 2, *Carex livida* most commonly occurs on peat substrates. However, the species has also been found in areas with mineral soils (Moseley et al. 1991, Mellmann-Brown personal communication 2005, Whipple personal communication 2005). The thickness of peat underlying *C. livida* occurrences can be highly variable and is driven largely by variation in fen age, basin size (for non-slope peatland types), aspect and elevation, and degree of minerotrophy. For example, in Yellowstone National Park, Lemly and Cooper (unpublished data) found *C. livida* in sites with mineral substrates as well as in locations with over 2.4 m of accumulated peat. The mineral soil sites supporting the species appear to have wet hydrologic regimes and to share many floristic elements with peatland locations, and they lack peat likely because they occur on recently stabilized spring complexes in the highly dynamic geothermal basins of Yellowstone (Whipple personal communication 2005). Marl, consisting of fine-textured, calcium-rich sediments, is sometime found in particularly minerotrophic rich and extreme rich fens (Fertig and Jones 1992, Chadde et al. 1998).

Within fens, 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 fine-scale vegetation patterns. Within fens, *Carex livida* generally occupies relatively wet microsites such as water tracks, pools, hollows, or floating mats. For example, in High Creek Fen in Park County, Colorado, *C. livida* was most common in water track and spring communities; it occurred less commonly on hummocks (Cooper 1996, Johnson and Steingraeber 2003). Wheeler et al. (1983), working in a large peatland complex in Minnesota, found *C. livida* commonly occurring in flarks, on newly-formed peat hummocks, and along the margins of large pools. The species was uncommon in the wettest and deepest flarks. The species was also occasionally present in open *Sphagnum* lawns and along drainage ditches in the fens.

Hydrology

Water table depth is perhaps the single greatest factor influencing vegetation patterns in wetlands. Numerous studies have correlated vegetation patterns with such metrics as mean water table depth and intra and inter-annual hydrologic variability. Typically, most wetland species exhibit a unimodal distribution along water table gradients, but the range and maximum vary among species and often within different occurrences of the same species (Tiner 1991, Mitsch and Gosselink 2000). In addition, temporal fluctuations in water table elevations between years can result in a high degree of turnover in species composition. This phenomenon is particularly important in wetland types with highly variable hydrologic regimes such as marshes (Bolen et al. 1989, Squires and van der Valk 1992), but it can also affect more hydrologically stable types like fens (Bayley and Mewhort 2004).

Hydrologic flow paths that support wetlands can be exceedingly complex and can include surface water inputs as well as groundwater from both local and regional aquifers. For example, Swamp Lake on the Shoshone National Forest, which supports an occurrence of *Carex livida*, is fed by several 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 fen margins (Heidel and Laursen 2003).

In general, *Carex livida* is found in microsites with stable and wet hydrologic regimes. This is particularly true of the floating mat habitats since these are able to rise and fall with changing surface water levels. Many peatlands exhibit fine-scale topographic and hydrologic variability, which influences the distribution of vegetation. For example, although Cooper (1996) occasionally found *C. livida* on hummocks in Colorado's High Creek Fen, the species was most commonly observed in water tracks and spring settings. Johnson (2000), also working in High Creek fen, monitored groundwater levels in a network of monitoring wells installed across the site. Water table levels in the single plot in which *C. livida* was observed fluctuated by less than 20 cm over the four years of monitoring, and the maximum water table depth during this period was only 15 cm below the ground surface (**Figure 7**).

Seasonal and inter-annual variation in water table levels can influence the abundance of particular plant species. Since many botanical surveys involve one or a few visits to a given site, unusually wet or dry conditions present at the time of sampling may obscure vegetation patterns more typically found. As a consequence, rare species such as *Carex livida* may be overlooked. For example, Heidel and Laursen (2003) surveyed the Clay Butte Fen on the Shoshone National Forest in July of 2002 when water levels were high and extensive areas were submerged, and they made no observations of *C. livida*. However, during a visit by a different researcher in August and September of 2003 when water levels were relatively low, distinct vegetation zones and species that were not observed by Heidel and Laursen were found, including patches of *C. livida* (Mellmann-Brown 2004).

Nutrients, water and peat chemistry

Most, but not all, *Carex livida* occurrences are from fens, which are peatlands influenced by the

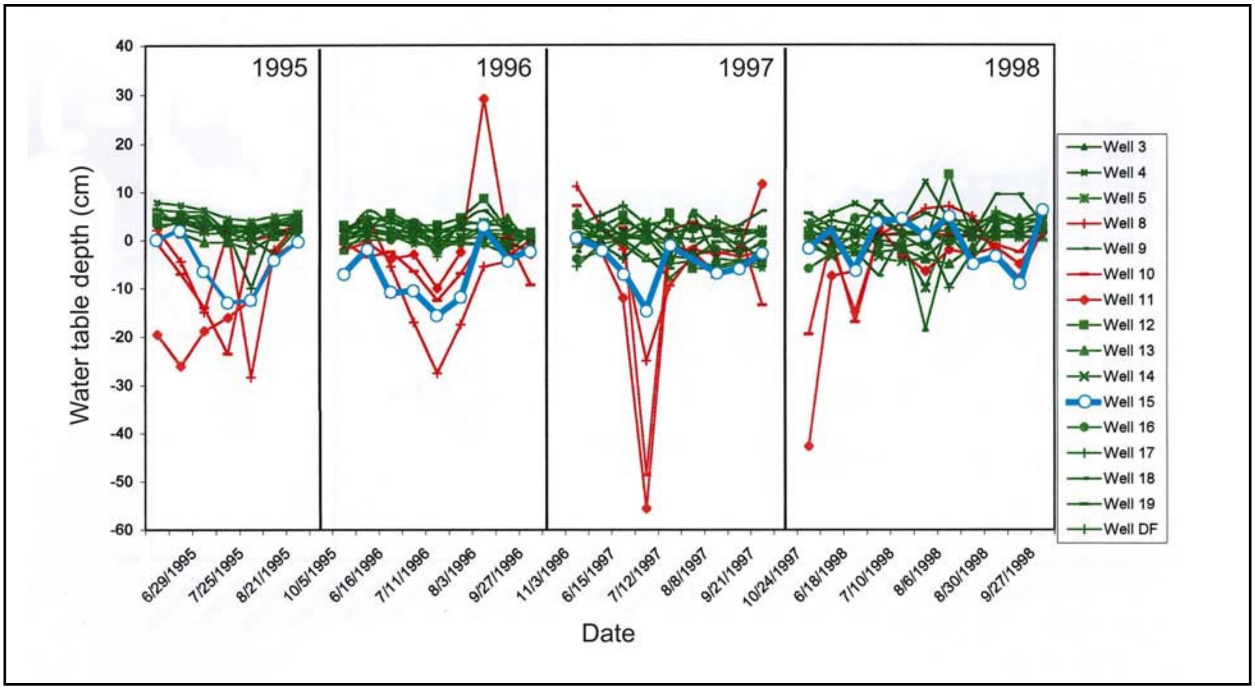

Figure 7. Hydrographs from a network of groundwater monitoring wells installed across High Creek Fen, Park County, Colorado by Johnson (2000). Johnson identified several hydrotypes, i.e. groups of wells with similar temporal patterns, with green lines corresponding to hydrotype 1 and red lines to hydrotype 2. Well 15, indicated by the blue line, corresponds to the only plot in which *Carex livida* was observed.

input of minerotrophic groundwater. Several fen types occur in Region 2, including poor, transitional rich, rich, and extremely rich fens, and each of these types can support distinct vegetation. Poor and transitional rich fens, which are only moderately influenced by minerotrophic groundwater, are the most common fen types in Region 2. They are typically relatively species poor, have a bryophyte flora dominated by *Sphagnum* mosses, and have low pH and Ca^{2+} concentrations (Windell et al. 1986, Glaser 1987). Rich fens typically support a more diverse flora, typically including non-*Sphagnum* "brown mosses". Rich fen pH values are less acidic and Ca^{2+} concentrations are higher, ranging from approximately 10 to 30 mg per L (Crum 1988, Mitsch and Gosselink 2000). Besides iron fens, extremely rich fens are the rarest type in Region 2. They are typified by high pH and Ca^{2+} concentrations and support a unique flora including calciphiles (Lesica 1986, Cooper 1996). Marl is often present due to the extremely high concentrations of Ca^{2+} (Fertig and Jones 1992, Johnson 2000).

The considerable variation in cation concentrations in fen water and peat is principally the result of differences in bedrock geology and hydrology (Windell et al. 1986). It is also common to see large differences within microsites in individual fens (Cooper and Andrus 1994). These are likely due to differences in the flow-through rate of surface water and groundwater in the individual sites.

The terms poor and rich have been used to describe fertility gradients in fens, 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 have suggested 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 livida occurs in diverse geochemical environments. For example, Wheeler et al. (1983) found *C. livida* occurring across a wide range of pH values (4.3 to 6.9) and Ca^{2+} concentration (3.2 to 19.6 mg per L), and in a range of peatland types, from poor to rich fens. Notably, the species was not present in ombrotrophic bogs, and the authors identified the species as a poor fen indicator separating weakly minerotrophic systems from truly ombrotrophic bogs. Foster and Glaser (1986), working in Labrador, also noted *C. livida* as an indicator of minerotrophic systems.

Many occurrences of *Carex livida* in the Rocky Mountains, including sites in Montana (Lesica 1986, Chadde et al. 1998), Idaho (Moesely et al. 1991), Wyoming (Fertig and Jones 1992, Heidel and Laursen 2003), and Colorado (Cooper 1996, Johnson and Steingraeber 2003), have been from rich and extremely rich fens. These appear to be the principal fen types providing habitat for *C. livida*, even though the species has also been found in more acidic poor fens as well (**Figure 8**, **Figure 9**).

Nitrogen is typically the limiting nutrient for terrestrial plants, but in some environments, including some wetlands, phosphorus may be limiting (Mitsch and Gosselink 2000). For example, total net primary productivity (NPP) has been correlated with NO_3^- and total phosphorus surface water concentrations (Beltman et al. 1996, Thormann and Bayley 1997). Biologically-mediated redox reactions account for the principal fluxes of nitrogen in wetlands, such as nitrate reduction, N-fixation, and denitrification (Beltman et al. 1996, Oien 2004). The bacteria responsible for these transformations differ, depending on site-specific hydrologic and chemical characteristics. Anoxic sites, as typified by floating mat environments, typically have low total nitrogen, and due to a lack of nitrifying bacteria, low NO_3^-.

Sediment dynamics

We encountered no quantitative data regarding sediment dynamics in sites supporting *Carex livida*. In general, though, sediment flux rates into peatlands are thought to be small. Because of the slow peat accumulation rates typifying fens in Region 2, significant increases in mineral flux outside of the historic range of variability have the potential to negatively impact vegetation. There is some evidence to suggest that much of the sediment input into fens is in the form of organic rather than mineral material, and that mineral sediment delivery is largely limited to margins of fens (Cooper and Arp 2002).

Mass wasting events, such as landslides, may episodically contribute pulses of sediment to wetlands supporting *Carex livida*. For example, Heidel and Laursen (2003) observed several debris flows entering the Swamp Lake wetland from adjacent cliff faces 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 occurred

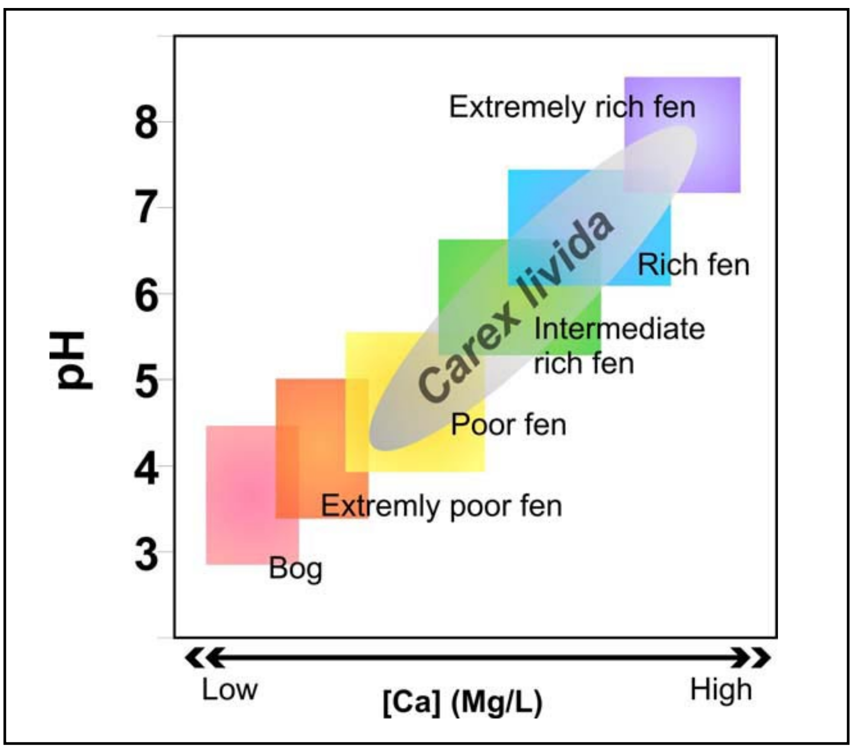

Figure 8. Diagram illustrating the approximate pH and Ca^{2+} values for different peatland types and the corresponding habitat range (shaded area) for *Carex livida*. Although found across the poor to extreme rich gradient, the species is most common in more rich systems.

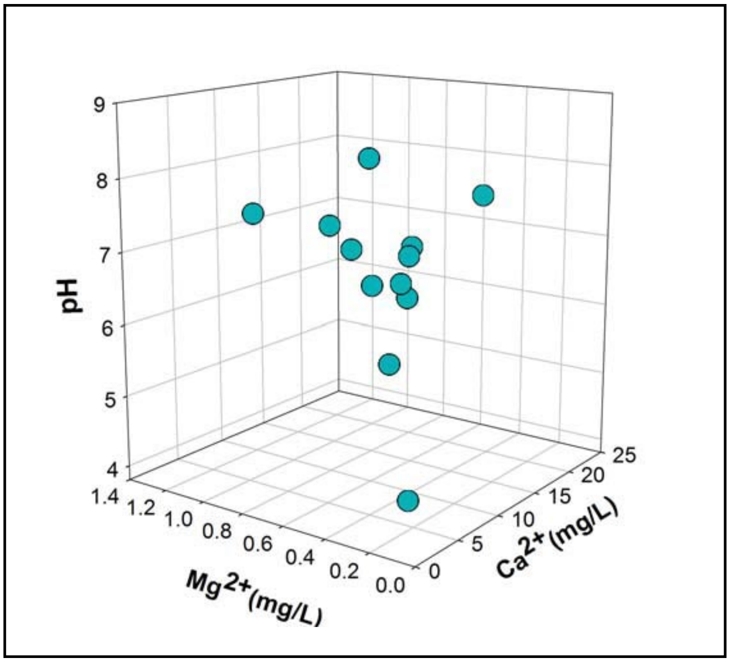

Figure 9. Water chemistry data from different peatlands in Yellowstone National Park supporting *Carex livida*. Source: Lemly and Cooper unpublished data.

in the past. However, because the physiographic and geological settings of the wetlands supporting known *C. livida* occurrences are so variable, it is impossible to evaluate whether such episodic events may be important elsewhere.

Vegetation types and associated plant species

Wetlands, and peatlands in particular, support a distinct and diverse assemblage of plants species, and 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 several vegetation zones dominated by different suites of species. 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 bogs and poor fens, and in microsites characterized by extremely wet, acidic, or basic conditions.

Vegetation diversity and specific vegetation associates for *Carex livida* vary among occurrences (**Appendix**). Bottum (2004) described a *C. livida* vegetation type in the Salmon River valley in Idaho, and includes it as a co-dominant species in a *Trichophorum caespitosum*/*Carex livida* vegetation type. Also in Idaho, Moseley et al. (1991) noted *C. livida* in several distinct communities. These included a *C. buxbaumii* (Buxbaum's sedge) community on mineral substrates; *C. lasiocarpa* (woollyfruit sedge) communities on floating peat mats with *Sphagnum* spp.; sites with organic soils, but lacking *Sphagnum* spp.; and communities with *C. lasiocarpa* and *Eleocharis pauciflora* (fewflower spikerush) as co-dominant. They note that the latter community may be the *C. livida* phase of the *Eleocharis pauciflora*-*Carex aquatilis* habitat type described by Mattson (1984). *Carex livida* has also been reported from *C. simulata* (analogue sedge) and *E. quinqueflora* (fewflower spikerush) communities (Fertig and Jones 1992, Chadde et al. 1998).

Carex livida occurrences on floating peat mats are typically dominated by a limited number of vascular species such as *C. lasiocarpa*, *C. limosa*, and *Menyanthes trifoliata* (buckbean) (**Table 3**). In extremely rich fen sites, different species characteristic of calcium-rich wetlands, such as *Triglochin maritima* (seaside arrowgrass) and *T. palustris* (marsh arrowgrass), are present (Cooper 1996, Johnson and Steingraeber 2003). The bryophyte flora associated with *C. livida* varies among sites. More acidic fens (poor to intermediate rich) typically support *Sphagnum* mosses, such as *S. subsecundum*, while circum-neutral to basic systems (rich to extremely rich systems) support "brown moss" species including *Scorpidium scorpioides*, *Drepanocladus revolvens*, and *Campylium*

Table 3. List of associated species reported from a sample of sites supporting *Carex livida*.

Location	Source	Associated species
Region 2		
Colorado	Cooper 1996	*Triglochin maritima*, *T. palustris*, *Eleocharis quinqueflora*, *Carex simulata*, *C. aquatilis*, *C. microglochin*, *Scorpidium scorpioides*
Wyoming; Shoshone National Forest	Heidel and Laursen 2003	*Carex aquatilis*, *C. leptalea*, *C. utriculata*, *C. diandra*, *C. limosa*, *Drosera rotundifolia*, *Salix farriae*, *Viola epipsela*
Wyoming; Yellowstone National Park	Mattson 1984	*Eleocharis pauciflora*, *Carex aquatilis*, *C. muricata*, *C. utriculata*, *Pedicularis groenlandica*
Wyoming; Yellowstone National Park	Moseley et al. 1991	*Carex muricata*, *C. rostrata*, *Pedicularis groenlandica*, *Gentiana detonsa*, *Comarum palustre*, *Dulichium arundinacea*, *Lycopodium inundatum*, *Scheuchzeria palustris*, *Sphagnum* spp.
North America		
Idaho	Bottum 2004	*Trichophorum caespitosum*, *Eleocharis quinqueflora*, *Carex limosa*, *C. buxbaumii*, *C. aquatilis*, *Drosera anglica*, *Calamagrostis canadensis*, *Menyanthes trifoliata*, *Sphagnum* spp.
Idaho	Caicco 1988	*Carex rostrata*, *Andromeda polifolia*, *Kalmia microphylla*, *Lycopodium inundatum*, *Scheuchzeria palustris*, *Vaccinium oxycoccus*, *Sphagnum* spp.
Montana	Chadde et al. 1998	*Eleocharis quinqueflora*, *E. rostellata*, *E. tenuis*, *Betula glandulosa*, *Tomenthypnum nitens*, *Drosera anglica*, *Aulacomnium palustre*, *Bryum pseudotriquetrum*, *Campylium stellatum*, *Drepanocladus revolvens*, *Scorpidium scorpioides*
Montana	Cooper and Jones 2003	*Carex simulata*, *C. aquatilis*, *Eleocharis quinqueflora*, *Menyanthes trifoliata*, *Utricularia minor*, *U. vulgaris*, *Betula glandulosa*, *Salix serissima*, *S. planifolia*, *Muhlenbergia glomerata*, *Symphyotrichum boreale*, *Drepanocladus revolvens*, *Campylium stellatum*, *Scorpidium scorpioides*
Minnesota	Glaser 1990	*Scirpus hudsonianus*, *Cladium mariscoides*, *Parnassia palustris*, *Muhlenbergia glomerata*, *Trichophorum caespitosum*, *Carex lasiocarpa*, *Drosera anglica*, *D. rotundifolia*, *D. intermedia*, *Utricularia intermedia*
Minnesota	Glaser 1992	*Carex oligosperma*, *C. pauciflora*, *Eriophorum spissum*, *Chamaedaphne calyculata*, *Kalmia polifolia*, *Drosera rotundifolia*
Idaho	Hansen and Hall 2002	*Carex lanuginosa*, *C. aquatilis*, *C. diandra*, *Calamagrostis stricta*, *Drosera anglica*, *Menyanthes trifoliata*
Minnesota	Weltzin et al. 2003	*Carex limosa*, *C. lasiocarpa*, *C. diandra Rhynchospora alba*, *R. fusca*
Minnesota	Wheeler et al. 1983	*Carex lasiocarpa*, *C. livida*, *C. limosa*, *C. leptalea*, *Drosera anglica*, *Cladium mariscoides*, *Eriophorum angustifolium*, *Menyanthes trifoliata*, *Rhynchospora alba*, *Drepanocladus revolvens*, *Campyllium stellatum*, *Sphagnum subsecundum*
Europe		
Sweden	Foster and Fritz 1987	*Carex lasiocarpa*, *C. buxbaumii*, *C. rostrata*, *C. limosa*, *Eleocharis pauciflora*, *Menyanthes trifoliata*, *Eriophorum angustifolium*, *Drosera anglica*, *Scorpidium scorpioides*, *Sphagnum majus*
Sweden	Sjors 1991	*Carex limosa*, *C. lasiocarpa*, *Menyanthes trifoliata*, *Equisetum fluviatile*, *Utricularia intermedia*

stellatum, (Lesica 1986, Glaser 1992, Cooper and Jones 2003).

Competitors and relationship to habitat

Carex livida typically occurs in open, relatively unshaded habitats. Wheeler et al. (1983) described *C. livida* as occurring in open fen environments. This is consistent with observations in Region 2 and suggests that *C. livida* may be unable to effectively compete with larger sedge species in some microsites. However, whether competition with other species is a significant factor in limiting *C. livida* to the wet microsites it occupies is a hypothesis in need of testing.

Parasites and disease

Only a limited amount of research has been conducted on the effects of pathogens or parasites on *Carex* species, and none involving *C. livida*. Mcintire and Waterway (2002) document the incidence of a smut on several sedges, including *C. limosa*, *C. rariflora*, and their hybrid in a Quebec peatland. Whether this organism or any other parasites or pathogens affect *C. livida* in the region is unknown. Although extant Region 2 *C. livida* occurrences are relatively isolated from one another, because the species likely once had a broader distribution, and given the generalist nature of many plant pathogens, we cannot rule out the possibility that some parasites or pathogens affect Region 2 occurrences.

Herbivores and relationship to habitat

No descriptions of herbivores feeding on *Carex livida* were found in the literature. While native ungulates likely feed on this species, larger grazers, such as elk (*Cervus canadensis*) and cattle, generally avoid the boggy wetlands it inhabits. However, during prolonged droughts, sites supporting *C. livida* may be more accessible to animals. Moose (*Alces alces*) utilize fens, but there is no evidence to suggest that they feed specifically on *C. livida*. Because of the saturated soils typically found in fens, burrowing or root-feeding herbivores like rodents are uncommon and are unlikely to feed on the species. However, impacts from trampling may be as great as, or greater than, the effects of herbivory.

Ants may also affect sedges such as *Carex livida*, directly through herbivory or indirectly through the building of mounds. For example, Lesica and Kannowski (1998), working in Pine Butte fen, a calcareous fen supporting *C. livida* in Montana, studied the influence of mound-building ant species on the wetland's topography, vegetation, and chemistry. Of the several species they noted, only *Myrmica fracticornis* and *Formica podzolica* were observed in the open fen plots where *C. livida* occurred. Worker ants foraged on the vegetation over an area of ca. 30 to 50 m^2 around their nests, but the researchers did not note any specific impacts to *C. livida*. Ants have also been shown to be dispersal agents for some sedges, but there is no specific research particular to *C. livida* (Handel 1978).

Mycorrhizae

Although mycorrhizae are common throughout the plant kingdom, several families including the Brassicaceae, Juncaceae, and Amaranthaceae are considered non-mycorrhizal (Muthukumar et al. 2004). Historically, the Cyperaceae have also been considered non-mycorhizal; however, research during past decades has identified several sedge taxa with 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 that they evaluated. While most instances of mycorrhizal associates were arbuscular mycorrhizae (AM), there were some instances of ectomycorrhizal associations. Although several *Carex* species were mentioned, *C. livida* was not among the species they examined. Whether *C. livida* forms mycorrhizal relationships is unknown.

CONSERVATION

Threats

In general, an assessment of the conservation status of any species should take into account a variety of factors. The relative rarity of a species, assessed at local, regional, and global scales is, of course, of primary interest. An additional factor of critical importance is an assessment of the relative stability of the ecosystems that support known occurrences. The degree to which a particular habitat characteristic (e.g., water table depth) responds to a disturbance can be characterized as an ecosystem's stability while ecological resilience is the degree to which such a characteristic returns to its original state following a disturbance (Rejmankova et al. 1999). Both attributes should be considered when attempting to predict the potential ecological response of an individual species to different disturbance agents; the fate of any species is intimately intertwined with that of its ecological setting, particularly for species confined to small, discrete ecosystems like fens.

However, both stability and resilience should be evaluated in terms of a species' basic life attributes and successional status since the implications of a particular disturbance agent on an early-seral, annual species will likely differ significantly from that on a late-seral, perennial species. Likewise, species capable of vegetative growth and reproduction may have different effect thresholds and recovery times to disturbance than species lacking the capability.

In the following discussion, we outline the basic types of disturbances likely to impact fens. Where possible, we attempt to predict disturbance effects on *Carex livida* occurrences. However, the data necessary to predict the response of particular occurrences to specific disturbances are unavailable. Therefore, our assessment is based on a first-principles extrapolation from existing case studies. Also, we try to differentiate between specific, impending threats to *C. livida* occurrences, and more speculative estimates of potential future threats.

Direct hydrologic alteration

Direct hydrologic alteration by ditching is one of the most common and long-lasting anthropogenic impacts to fens in Region 2. For example, 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 flow through a fen nearly 75 years after the ditches were abandoned (**Figure 10**). 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. Similar changes may promote invasions by non-native species as well. Fens have historically been ditched to promote tree growth, to make sites more attractive or accessible to livestock, or to dry sites to facilitate peat mining, as occurred in High Creek fen in Colorado (**Figure 11**).

Dewatering of fens generally reduces the habitat suitability for species such as *Carex livida*. Since the majority of sites supporting *C. livida* are on public lands managed by either the National Park Service or the USFS, these sites receive some degree of *de facto* protection due to their inaccessibility or because of restrictions for wilderness areas in which the species occurs. Therefore, the overall threat from future ditching or dewatering is presumably low for most *C. livida* occurrences. However, where there are pre-existing water rights, these can take precedence over regulations or management directed at ecosystem or species conservation. In addition, large numbers of fens in the region were historically ditched, and many ditches or other engineering structures continue to function although they are no longer maintained or used.

Because fens are principally supported by groundwater, a variety of actions outside of their immediate boundaries can alter their hydrology, sediment budgets, or water chemistry, with potentially significant ramifications for dependent wetland species. The water balance of basins supporting peatlands varies as a function of precipitation inputs, evaporation and transpiration (ET) losses, and the amount of water stored as groundwater (Mitsch and Gosselink 2000). Vegetation in surrounding uplands influences this

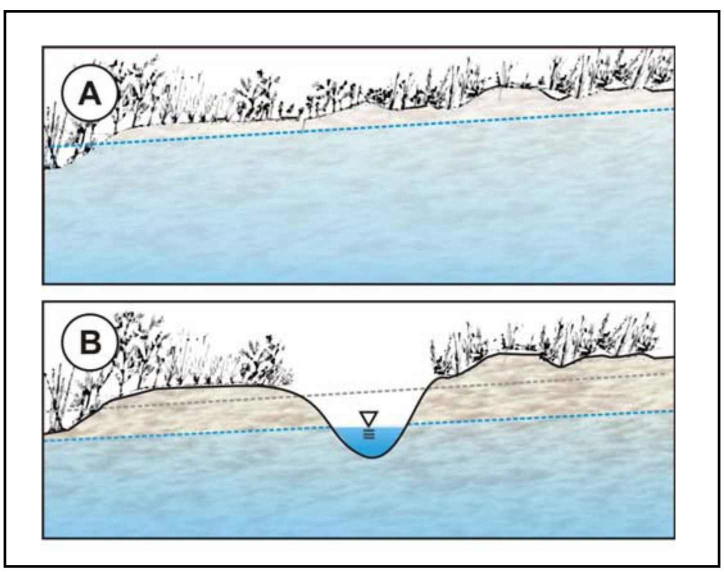

Figure 10. Schematic diagram illustrating the water table in a hypothetical fen before (A) and after (B) ditching.

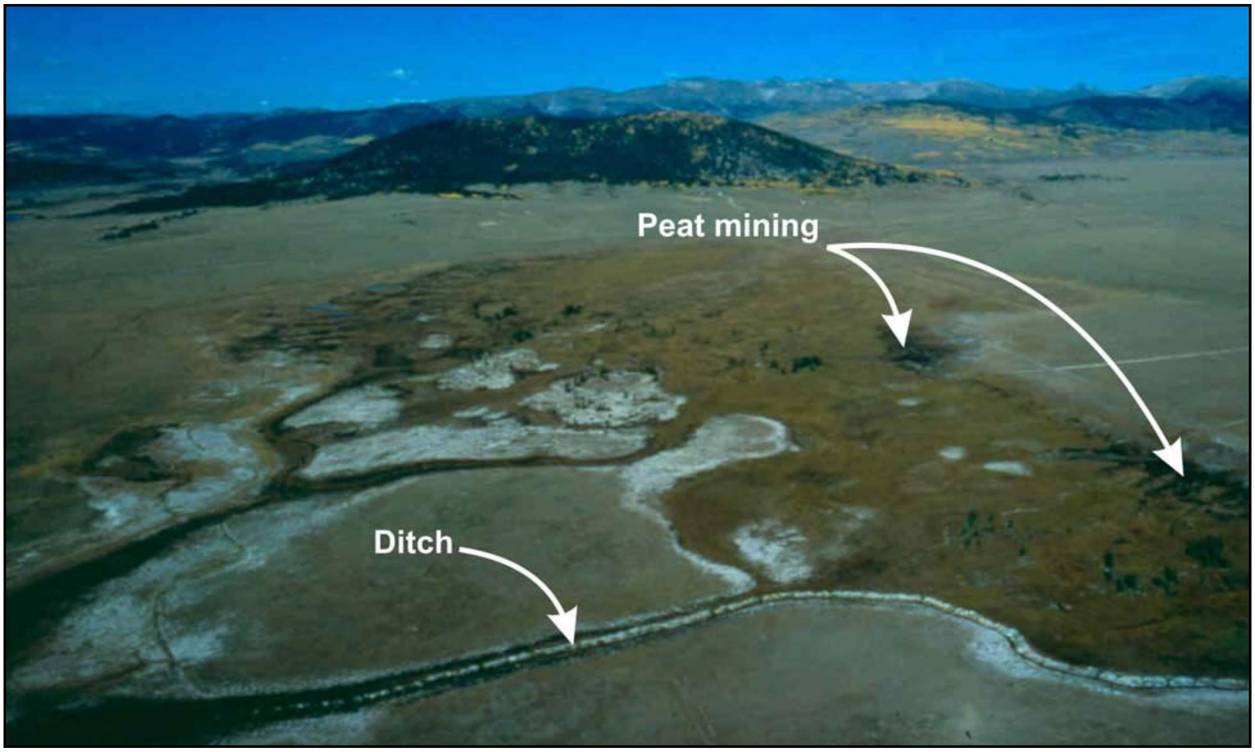

Figure 11. Aerial photograph of High Creek Fen, Park County, Colorado, an extreme rich fen supporting *Carex livida*. Prior to its acquisition by The Nature Conservancy, the fen was privately held and was ditched and mined for its peat.

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 by affecting evapotranspiration rates and snow accumulation patterns. Canopy removal in a subalpine watershed in Colorado increased precipitation reaching the forest floor by approximately 40 percent, and it increased peak snowpack water equivalent by more than 35 percent (Stottlemyer and Troendle 1999, Stottlemyer and Troendle 2001). While logging, whether clear cutting or partial thinning, typically results in increased annual and peak stream flows in logged watersheds (Troendle and King 1987), the effects of increased water yield and surface inflows to peatlands are difficult to predict, and both positive and negative effects are possible. As an example, increased water yield from upland portions of peatland watersheds could generate wetter conditions conducive to *Carex livida* establishment and persistence. However, since fens in the southern Rocky Mountains form only in physically stable locations where stream erosion and sediment deposition are limited, increased sediment yields resulting from upland vegetation removal could negatively impact peat formation and maintenance processes, adversely affecting *C. livida* occurrences.

Since the majority of snowmelt passes through subalpine watersheds not as surface flow, but rather as subsurface flow, soil processes can alter meltwater chemistry (Stottlemyer and Troendle 1999). Thus, changes in snow accumulation and melt rates due to changes in upland vegetation cover can affect water chemistry in a variety of ways. 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. The effects of these changes in surface and subsurface flows on peat chemistry, and the potential effects on wetland flora, are unknown. Because *Carex livida* naturally occurs across a wide pH and nutrient gradient, such indirect effects of basin vegetation removal on the species may be small.

Mineral sediment fluxes to peatlands are typically low. This is particularity true in fens in the central and southern Rocky Mountains (Cooper and Arp 2002). Both mineral and organic inputs to fens could change following tree harvest, but the short and long-term effects of harvest are unknown.

Fire

The indirect effects of fire in uplands adjacent to fens supporting *Carex livida* occurrences are likely similar to those from tree harvest, including increased water and sediment yield and changes in water chemistry. However, nutrient pulses following fire have no analog in mechanical treatments. The effects of such rapid increases in nutrient influx to wetlands on species such as *C. livida* are unknown. 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 increase (Troendle and King 1985). Since fire has been a natural component of Rocky Mountain landscapes for millennia (Fall 1997), these indirect effects are unlikely to represent a significant threat to the future of *C. livida*.

In addition to the indirect effects on fens, fire can directly impact *Carex livida* populations through plant mortality. However, since fens typically 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 (Sherriff et al. 2001), suggesting that fire has a relatively minor role in the population dynamics of the region's *C. livida* occurrences. However, during sustained droughts, well documented throughout the Holocene using a variety of climatic proxies (Cook et al. 1999), peat soils can dry sufficiently to allow fires to burn surface peat. Such fires may destroy *C. livida* seedbanks and rhizomes, thus negatively affecting the viability of individual occurrences.

Roads and trails

Roads, and to a lesser degree, trail networks, can significantly affect local and watershed-scale hydrologic processes of fens that support *Carex livida*. 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 the compaction of soil, and alter the hydrologic response of basins to both annual snowmelt runoff episodes and isolated convective storm events (Jones 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. How *C. livida* would respond to these changes is unknown.

Road and trail networks can have a variety of additional effects on wetlands, including the introduction of pollutants and the alteration of water chemistry (e.g., electrical 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). Several factors can 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 so greatly within and among national forests, formulating general statements on the threat to *Carex livida* from roads or trails will be difficult. However, there are specific instances where the presence of roads has altered fen hydrology or sediment inflows. For example, Heidel and Laursen (2003) suggest that the highway bordering Clay Butte Fen on the Shoshone National Forest, which supports an occurrence of *C. livida* (Mellmann-Brown 2004), may impede upslope groundwater flow into the basin.

Although USFS travel management regulations 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 livida* 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 accumulation 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 in

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

Region 2, but the amounts are small. Consequently, peat mining does not appear to represent a significant threat to most known *Carex livida* occurrences in the region. Historically, fen mining was more widespread in the region, and it has impacted fens supporting *C. livida*, such as High Creek Fen (**Figure 11**).

Livestock and native ungulate grazing

The effects of livestock grazing on *Carex livida* are largely unknown. In general, livestock tend to avoid extremely wet sites. Consequently, their utilization of species occurring on floating mats, like *C. livida*, may be minimal. Native ungulates can significantly affect wetland plants, directly through herbivory and trampling, and indirectly through nutrient enrichment via urine or fecal deposits. Like livestock, elk typically avoid extremely wet locations, so they presumably represent a minor threat to *C. livida* occurrences. However, moose are far more likely to be found in wet sites, and consequently, they may locally impact *C. livida* occurrences. Periodic droughts resulting in lowered water tables in fens may make sites more accessible to livestock and native ungulates like elk. In such instances, plants may be vulnerable to negative impacts. However, where *C. livida* occurs on floating mats, this is not likely to be an issue since these features are able to rise and fall with fluctuating water tables.

Recreational impacts

In general, the sites supporting *Carex livida* occurrences are unsuitable for road or trail construction since they are saturated year-round. Except perhaps in winter, crossings must be bridged or stabilized, making such sites unappealing for transportation or recreation planners (Johnston 2001). In addition, work involving disturbance to wetlands often require a Clean Water Act Section 404 permit, making sites less desirable during transportation planning. Many fens do occur within a short distance of existing trails or roads, which may facilitate human visitation and trampling effects resulting from hikers, campers, or recreational fishers. However, we found no evidence that such use is negatively affecting *C. livida*.

There are no documented impacts on *Carex livida* occurrences from winter recreation such as cross-county skiing, snowshoeing, or snowmobiling. However, compaction of accumulated snow can potentially cause later spring melt and change peat temperature profiles in fens, effectively reducing the length of the growing season for plants (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 evidence to suggest that *Carex livida* is directly threatened by exotic species within Region 2. Although exotics such as Canada thistle (*Cirsium arvense*) may invade fens, this typically occurs following severe hydrologic alterations such as ditching. In addition, the wet microsites supporting Region 2 *C. livida* do not appear conducive to weed invasion, and none of the herbarium or element occurrence records indicate large problems with exotics.

Atmospheric deposition of pollutants

A wide variety of ecological responses result from atmospheric nitrogen deposition (Fenn et al. 2003), but few studies have focused specifically on fens. Exceptions include Li and Vitt (1997) and Vitt et al. (2003), 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, productivity of *Betula pumila* and *Ledum groenlandicum*, two shrub species also examined, was unchanged (Li and Vitt 1997). There are no data to evaluate effects on *Carex livida*, but any factor significantly altering the productivity of fens has the potential to change vegetation composition and successional development.

Climate change

Because of their strong dependence on watershed-scale hydrologic processes, wetlands, and peatlands in particular, may be especially sensitive to major shifts in temperature or precipitation. The fidelity of *Carex livida* to perennially saturated habitats suggests that warmer regional temperatures predicted under some global climate change scenarios (U.S. Environmental Protection Agency 1998, Wagner 2003) may adversely affect the species. An increase in precipitation, called for by some models (**Table 4**), may ameliorate the negative hydrologic effects of warmer temperatures, but still have a negative effect on the viability of *C. livida* occurrences by shifting the balance between it and competing species (Moore 2002). For example, Moore (2002) found that the production of graminoids and forbs increased 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. livida* and associated vegetation.

Ultimately, the most important climatic factor influencing the future of peatlands in the region is likely to be the spatial and temporal patterns of precipitation (Moore 2002). Because of the region's dry climate, areas capable of accumulating peat are rare on the landscape, and rates of peat formation are exceedingly slow (Chimner et al. 2002, Chimner and Cooper 2003). Since *Carex livida* occurrences in Region 2 are widely separated from one another, the fate of the species in the region is intimately tied to the fens in which they occur. Significant shifts in climate could reduce the viability of fens as a whole by altering their net carbon storage, changing wetlands from carbon gaining to losing systems (Chimner et al. 2002), and threatening the persistence of *C. livida* occurrences.

Cumulative effects

While it is often difficult to demonstrate the effects of individual factors on a species' performance, it is even more challenging to evaluate the cumulative effects of multiple stressors. However, cumulative effects need to be considered when discussing threats and evaluations

Table 4. Potential climate change scenarios for the Rocky Mountain Region (Wagner 2003).

Scenario and consequences	Northern subregion	Southern subregion
Precipitation	Increased winter precipitation, especially rain	Reduced winter rain, increased summer rain
Temperature	Warmer fall, winter, spring	Warmer winter, late summer
Expected hydrologic response	Reduced snowpack	Snowpacks reduced or eliminated
	Earlier spring flows	Reduced peak spring flows
	Increased annual and base flows	Reduced annual and base flows
	Reduced summer flows	Reduced infiltration
	Increased flood magnitudes	Reduced flood magnitudes
	Increased baseflow temperatures	Increased evaporation

of potential impacts from management activities (Reid 1993, Bedford 1999). Many individual ecological stressors act synergistically, and mitigating for each stressor individually may fail to achieve effective protection. Since the wetlands supporting *Carex livida* depend on their surrounding watershed for hydrologic function, this is the appropriate scale for evaluating potential management impacts to the species.

Conservation Status of Carex livida in Region 2

Carex livida has been designated a sensitive species in Region 2 principally because of its rarity. However, additional factors need to be examined when assessing a species' conservation status including its degree of habitat specialization, its sensitivity to natural and anthropogenic stressors, and known population trends. Unfortunately, there are insufficient data regarding population trends, so our assessment is, by necessity, largely based on general knowledge of the life history and habitat relationships of *C. livida* and known threats to wetlands supporting the species in the region.

Because occurrences in Region 2 are largely disjunct from one another and because dispersal distances are likely limited, natural establishment of new occurrences is unlikely. The species is easily overlooked in botanical surveys, particularly if plants are not fruiting. This, coupled with the fact that many Region 2 fens have never been inventoried, suggests that additional occurrences may be discovered. Thus, potential habitats such as fens, springs, and seeps should be examined for the presence of the species prior to major shifts in management (e.g., changes in grazing intensity).

We found no specific information suggesting that the distribution or abundance of *Carex livida* is changing in Region 2. However, there is insufficient information available to place a high degree of confidence in this assessment. Extant occurrences may be of significant age as the presence of large peat bodies indicates stable hydrologic regimes on the scale of centuries to millennia (Chimner et al. 2002). The persistence of occurrences through the well-documented climatic fluctuations of the Holocene suggests that the species may be relatively resistant to broad-scale environmental stochasticity. Unknown, however, is whether the species and its habitat are vulnerable to future changes in climate, particularly if they deviate from the range of historic variability.

Management of Carex livida in Region 2

Implications and potential conservation elements

Maintaining the integrity of the wetlands supporting *Carex livida* is essential to the long-term persistence of the species in the region. Specifically, this includes minimizing anthropogenic impacts to hydrologic, sediment, and disturbance regimes resulting from management actions. Because so little information regarding the sensitivity of the species and its habitat to anthropogenic activities is available, basic hydrologic and vegetation data should be collected prior to, during, and following significant changes in management (e.g., timber sales, prescribed fires, changes in grazing management).

Perennial groundwater inflows are critical drivers of hydrologic and geochemical functioning in the wetlands supporting *Carex livida*. Consequently, maintaining the hydrologic integrity of the basins surrounding the wetlands that support *C. livida* occurrences is critical. Therefore, when evaluating potential impacts of management actions on the species, an assessment of indirect and direct hydrologic impacts should be included.

In addition to minimizing hydrologic alterations, management resulting in physical trampling of wetlands supporting the species should be avoided. Possible sources of trampling include livestock, native ungulates, and recreational visitors, including illegal trespass of OHVs into wetlands. Where particular wetlands supporting the species appear vulnerable, mitigation, such as construction of exclosures, should be considered.

Tools and practices

Species and habitat inventory

Conducting habitat inventories in Region 2 fens would provide valuable information for the management of *Carex livida* as well as other rare species such as *C. limosa*, *C. leptalea*, *C. diandra*, *Drosera anglica* (English sundew), and *D. rotundifolia* (roundleaf sundew). Such inventories would result in improved information regarding the distribution of *C. livida*; this information would be 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. However, these approaches are poorly suited to species like *C. livida*, which are difficult to discern in photographs.

Population and habitat monitoring

The development and implementation of quantitative population monitoring protocols would improve our knowledge of the population dynamics of *Carex livida*. Plot-based approaches are most desirable since these most reliably facilitate the 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. livida* can be more reliably tied to changes in hydrologic drivers. Because of the difficulty in identifying genetically unique individuals (i.e., genets), methods aimed at estimating the population of genets are less feasible than those tracking the numbers of ramets.

Beneficial management actions

The main way that managers can promote the continued persistence of *Carex livida* in the region is through maintenance of natural hydrologic regimes in wetlands supporting 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, 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 the 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. livida*. Other actions such as the collection and storage of seed could be pursued.

Information Needs

Carex livida occurs in a small range of wetland types, habitats that often support occurrences of other rare species and are unique functionally. Consequently, a goal of future research should include broad-scale assessments of peatland distribution and abundance. Multiple techniques could be used, including the use of remotely sensed data (e.g., hyperspectral imagery, color aerial photographs) to identify and map wetlands. GIS (Geographic Information System) 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.

In addition, more detailed studies relating wetland hydrology, landscape setting, and peat stratigraphy to historical changes in community composition and vegetation structure should be undertaken. Using techniques such as radiocarbon dating of peat layers, it is possible to develop a better understanding of the age of peatlands and processes of peat ecosystem development. This information is essential for predicting the long-term future of sites supporting *Carex livida*.

Since few data on *Carex livida* population size are available, comprehensive demographic surveys of known occurrences should be conducted to better evaluate the current status of *C. livida* and to provide baseline data essential for effective monitoring. Known occurrences should be periodically revisited, and follow-up surveys should be conducted in order to identify potential trends in abundance.

Additional information gaps regarding *Carex livida* include the role of seed banks in the population dynamics of this species and the relative importance, frequency, and prerequisite conditions necessary for sexual establishment. Such information is essential not only for understanding existing occurrences, but also for developing approaches for restoring degraded habitats. If conducted in conjunction with studies of fen hydrology and vegetation patterns, these inquiries could significantly advance our understanding not just of *C. livida*, but also of the fens that the species 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 fen vegetation dynamics, and for understanding and evaluating the effects of management activities such as road construction or prescribed fire on fens in general, and on *Carex livida* 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, can yield invaluable data.

More research needs to be done to improve our understanding of the history and underlying genetic structure characterizing Region 2 *Carex livida* occurrences. Key questions include the genetic variability among clones within a wetland, among wetlands in Region 2, and among occurrences globally. Also of interest is the spatial structure of genetic variation among clones. Both questions could be addressed through allozyme polymorphism analysis (Hedren and Prentice 1996, Ford et al. 1998, Huh 2001), and the results would provide important insights useful for conservation or restoration.

More information is needed regarding specific restoration approaches for *Carex livida*. The limited research into fen restoration in Region 2 suggests that effective restoration of fen vegetation is contingent upon restoration of appropriate wetland hydrology (Cooper et al. 1998, Cooper and MacDonald 2000). This typically requires removing obstacles or diversions in the groundwater flow systems historically supporting the wetland. In practice, even simple actions such as filling in drainage ditches can begin to improve hydrologic function. Although propagation and revegetation techniques have been developed for other species of *Carex* (Cooper and MacDonald 2000), none have been developed for *C. livida*. However, these approaches including growing plants from field-collected seeds in small containers for eventual outplanting and live-plant transfer from existing occurrences presumably could be modified for use with *C. livida*.

Definitions

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

Anoxic – Area with very low oxygen concentrations, created during waterlogging (Mitsch and Gosselink 2000).

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

Flark – Hollow or pool formed in patterned peatlands (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 2005).

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 2005).

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 2005).

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 2005).

G/S5 – Demonstrably secure globally/state, though it may be quite rare in parts of its range (NatureServe 2005).

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).

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 which is therefore richer in nutrients than rainwater (Crum 1988).

Mycorrhizae – Symbiotic association between a fungus and the root of a higher plant (Wikipedia 2005).

Ombrotrophic – Receiving nutrients exclusively form the atmosphere (Crum 1988).

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).

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

Redox – Referring to reduction and oxidation potential, a measure of the electron pressure or availability in a solution (Mitsch and Gosselink 2000).

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

Sensitive species – 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 2004).

SNR – Species not assigned a NatureServe subnational rank (NatureServe 2005).

SX – NatureServe subnational rank denoting that the species is believed to be extirpated from state or province (NatureServe 2005).

Water track – A peatland drainage area clogged with vegetation, somewhat richer in minerals than the rest of the boggy surface (Crum 1988).

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APPENDIX

USDA Forest Service Region 2 Carex livida Herbarium and Natural Heritage Program Element Occurrence Records

The following table contains a list of USDA Forest Service Region 2 element occurrence records (EOR) for *Carex livida*. Record sources listed include the Wyoming Natural Diversity Database (WYNDD), Colorado Natural Heritage Program (CNHP), University of Colorado Herbarium (CU), Colorado State University Herbarium (CSU), and the Rocky Mountain Herbarium (RMH). Records from Yellowstone National Park, which is not part of Region 2, are from unpublished survey data by J. Lemly and D. Cooper that have not yet been entered into the WYNDD database.

Source	State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/ observation date	Comments
CU	CO	Jackson	499697	2,744	Routt National Forest	7/28/2001	Locally common in moist fen with *Carex lasiocarpa*, *C. buxbaumii,* and *Eriophorum angustifolium*; mostly vegetative, but blue-green color is conspicuous.
CNHP	CO	Jackson	PMCYP037L0*006*CO	2,756	Routt National Forest	8/13/1996	Barrett, N. and M. Zimmerman. 1995.
CSU	CO	Larimer	14032	2,703	Roosevelt National Forest	7/12/1989	Moist deep peat; associated species: *Carex aquatilus* and *C. buxaumii*.
CU	CO	Larimer	442763	2,724	Roosevelt National Forest	7/6/1989	In filled pond, on loose, deep peat.
CNHP	CO	Larimer	PMCYP037L0*003*CO	2,713	Roosevelt National Forest	8/12/1996	Spackman, S, J. Sanderson, S. Kettler and K. Fayette. 1996. Larimer County inventory for CNHP.
CSU	CO	Park	51078	2,987	Pike National Forest	1989	Rich fens, Mount Evans Wilderness; associated species: *Eriophorium gracile*, *Carex limosa,* and *C. tenuiflora*.
CU	CO	Park	442612	2,988	Pike National Forest	1989	In rich fens dominated by *Eriophorum gracile*, with *Carex limosa* and *C. tenuiflora*. Mount Evans Wilderness; used physical description for location.
CU	CO	Park	442759	2,832	The Nature Conservancy	7/28/1989	In rich calcareous fens; collected by D. Cooper.
CU	CO	Park	448185	2,746	The Nature Conservancy	7/18/1991	High Creek Fen; collected by D. Cooper.
CU	CO	Park	457300	2,835	The Nature Conservancy	7/8/1995	On wet ground, with *Carex aquatilis*, *C. simulata*, and others; rare; Park County Peatland Inventory.
CU	CO	Park	459845	3,049	Pike National Forest	8/5/1995	On the side of a calcareous hummock in a fen; Mount Evans Wilderness; Colorado Natural Heritage Program South Park Fen Inventory.
CNHP	CO	Park	PMCYP037L0*001*CO	2,988	Pike National Forest	8/16/1989	Weber, W.A. Mount Evans Wilderness.
CNHP	CO	Park	PMCYP037L0*002*CO	2,832	The Nature Conservancy	7/28/1989	Cooper, D.J. 1989. Specimen (1685) at University of Colorado herbarium.
CNHP	CO	Park	PMCYP037L0*004*CO	3,024	Pike National Forest	8/26/1995	Sanderson, J. South Park fen inventory, Mount Evans Wilderness.
CNHP	CO	Park	PMCYP037L0*005*CO	3,061	Pike National Forest	8/5/1995	Crooked Creek Spring, J. Sanderson, South Park fen inventory; Mount Evans Wilderness.

Appendix table (cont.).

Source	State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/ observation date	Comments
CNHP	CO	Park	PMCYP037L0*007*CO	2,872	The Nature Conservancy	9/1/1999	Sheep Creek, south of Black Mountain, D. Culver; rapid ecological assessment of two properties for The Nature Conservancy.
RMH	WY	Park	544820	2,073	Shoshone National Forest	6/24/1989	Calcareous bog with *Carex* spp. and *Scirpus*.
RMH	WY	Park	579437	2,009	Shoshone National Forest	8/21/1992	Open canopy quaking marl mat in water on west side of rocky isthmus; marl saturated, but not flooded; site dominated by *Carex simulata* and *Triglochin maritimum*.
RMH	WY	Park	623092	2,012	Shoshone National Forest	6/21/1985	Open, calcareous (marly) bog.
RMH	WY	Park	645413	2,732	Shoshone National Forest	8/1/1999	Mossy hummocks at edge of *Picea engelmannii* forest dominated by *Salix eastwoodiae* and *S. planifolia* thickets; graminoid understory of *Carex aquatilis* and *C. livida*.
RMH	WY	Park	na	2,012	Shoshone National Forest	6/25/1989	Hummocks in marly wetlands.
RMH	WY	Park	na	2,012	Shoshone National Forest	6/26/1989	In marl and water.
Lemly and Cooper	WY	Park	na	2,287	Yellowstone	2004	Norris Junction Drosera Spring; patchy; calcareous fen with low water tracks dominated by *Eleocharis quinqueflora* and/or *Drosera angelica*.
Lemly and Cooper	WY	Park	na	2,299	Yellowstone National Park	2004	Solfatara Creek Fen; small fen located at base of slope, primarily dominated by *Eleocharis quinqueflora*.
Lemly and Cooper	WY	Park	na	2,311	Yellowstone National Park	2004	Solfatara Creek Floating Mat; large basin peatland with a well developed floating mat edge of *Carex limosa* and *Menyanthes trifoliata*.
Lemly and Cooper	WY	Park	na	2,213	Yellowstone National Park	2004	Secret Valley; very large peatland valley with high species diversity and many distinct community types.
Lemly and Cooper	WY	Park	na	2,287	Yellowstone National Park	2004	Norris Junction Picnic Area; gently sloping site with pillows of Sphagnum moss and open water tracks dominated by *Carex livida* and *Eleocharis quinqueflora*.
Lemly and Cooper	WY	Park	na	2,305	Yellowstone National Park	2004	Powerline Spring Slope; small sloping peat lobe on the bank of a tributary stream; *Salix planifolia* is the dominant shrub with a diverse understory.
Lemly and Cooper	WY	Park	na	2,299	Yellowstone National Park	2004	Powerline Fen; gently sloping site dominated by *Carex livida and Sphagnum warnstorfii*;site has a pH of 6.19.

Appendix table (concluded).

Source	State	County	Accession/EOR #	Elevation (m)	Ownership	Collection/ observation date	Comments
Lemly and Cooper	WY	Park	na	2,512	Yellowstone National Park	2004	Cygnet Lake Trail Fen.
Lemly and Cooper	WY	Park	na	2,287	Yellowstone National Park	2004	Norris Junction Service Road, North Side.
Lemly and Cooper	WY	Park	na	2,287	Yellowstone National Park	2004	Norris Junction Service Road, South Side.
Lemly and Cooper	WY	Park	PMCYP037L0*1*WY	2,988	Shoshone National Forest	8/21/1992	Five subpopulations documented in survey; often locally abundant; occurs with *Carex limosa*, *Eriophorum viridicarinatum*, *Aster junciformis* [*A. borealis*], and *Kobresia simpliciuscula*; plants in fruit.
Lemly and Cooper	WY	Teton	na	2,110	Yellowstone National Park	2004	Tuff Cliff Fen.

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