Eriophorum gracile W. D. J. Koch (slender cottongrass): A Technical Conservation Assessment

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Rocky Mountain Region,
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COVER PHOTO CREDIT

Eriophorum gracile (slender cottongrass). Photograph by Dave Bradford, used with permission.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *ERIOPHORUM GRACILE*

Status

Eriophorum gracile is a circumpolar species that occurs as a relictual disjunct in USDA Forest Service (USFS) Region 2. Occurrences are known from mountainous areas of Colorado and Wyoming and the Sandhills region of north-central Nebraska and southern South Dakota. Thirty-six documented occurrences include 15 on National Forest System lands in Colorado and Wyoming.

Eriophorum gracile is a sensitive species in USFS Region 2. NatureServe ranks this species G5 (secure to common, widespread and abundant in its global range), but Natural Heritage Programs in Colorado, Nebraska, South Dakota, and Wyoming consider it to be a rare (S1 or S2) species due to its limited distribution in those states. It is not listed as threatened or endangered under the Endangered Species Act, nor is it a candidate for listing (ESA of 1973, U.S.C. 1531-1536, 1538-1540).

Primary Threats

Known occurrences of *Eriophorum gracile* on National Forest System lands in Region 2 are reasonably well protected. It is very likely that additional populations will be located in the future; their status is uncertain. Occurrences in the Sandhills region are not generally on federal lands and have little protection. Probable threats to this species include, in order of decreasing priority, hydrologic alterations, grazing, motorized vehicle use, peat mining, invasive species, and global climate change. The small, isolated nature of occurrences of *E. gracile* in Region 2 and the lack of basic information about the biology of the species contribute to the possibility that one or more of these threats will decrease the probability of its long-term persistence in the region.

Primary Conservation Elements, Management Implications and Considerations

A lack of repeat observations of *Eriophorum gracile* occurrences, and the fact that past collectors have often confused it with *E. angustifolium* have resulted in varying estimates of the distribution and abundance this species. The apparent loss of historic sites indicates a decline in population numbers, at least over the past 100 years. However, most known locations have been found fairly recently, and the likelihood of finding more occurrences in Region 2 is high. Current information suggests that the presence of *E. gracile* in Region 2 is somewhat tenuous, due to the low number and small size of occurrences, the general imperilment of its wetland habitat, and the isolated nature of occurrences. Any management activities that maintain the hydrologic regime of these habitats will contribute to the persistence of *E. gracile*. This includes the regulation and monitoring of hydrological modifications, domestic grazing, and motorized vehicle use. Our current understanding of the distribution and abundance of *E. gracile* suggests that it should remain a species of concern, and that expanding our knowledge of its distribution and habitat is a high priority.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Eriophorum gracile* (slender cottongrass) is the focus of an assessment because it is a sensitive species in Region 2 (USDA Forest Service 2005). Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance and/or in habitat capability that would reduce its distribution (FSM 2670.5(19)). A sensitive species may require special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology of *E. gracile* throughout its range in Region 2. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal of Assessment

Species conservation assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of certain species based on available scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations. Rather, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications).

Scope of Assessment

This assessment examines the biology, ecology, conservation status, and management of *Eriophorum gracile* with specific reference to the geographic and ecological characteristics of the USFS Rocky Mountain Region. In the context of this assessment, Region 2 refers to all lands within the general administrative boundaries of the USFS Rocky Mountain Region, regardless of ownership or management. Wyoming occurrences of *E. gracile* that fall outside Region 2 administrative boundaries are mentioned but not discussed with the same level of detail given to occurrences within Region 2. Although much of the literature on *E. gracile* and other *Eriophorum* species originates from field investigations outside the region, this document places that literature in the ecological and social context of Region 2. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *E. gracile* in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

In producing the assessment, we reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. All known publications, reports, and element occurrence records for *Eriophorum gracile* in Region 2 are referenced in the assessment. Because little is known about many facets of the biology of *E. gracile*, literature on its congeners was used to make inferences. Specimens were viewed at CC (Colorado College), COLO (University of Colorado Herbarium), CS (Colorado State University Herbarium), KDH (Kathryn Kalmbach Herbarium, Denver Botanic Gardens), and RM (Rocky Mountain Herbarium). Specimen and occurrence data were also obtained from the Wyoming Natural Diversity Database, the Nebraska Natural Heritage Program, the South Dakota Natural Heritage Program, and the Colorado Natural Heritage Program. The assessment emphasizes refereed literature because this is the accepted standard in science. Non-refereed publications and reports were used in this assessment, as these are the only source of information for occurrences in Region 2. However, they were regarded with greater skepticism. Unpublished data (e.g., Natural Heritage Program records and herbarium specimen labels) were important in estimating the geographic distribution of this species; these data required special attention because of the diversity of persons and methods used in their collection.

Treatment of Uncertainty in Assessment

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct experiments that produce clean results in the ecological sciences. Often, observations, inference, critical thinking, and models must be relied

on to guide our understanding of ecological relations. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate.

Treatment of This Document as a Web Publication

To facilitate the use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site. Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More important, Web publication facilitates their revision, which will be accomplished based on guidelines established by Region 2.

Peer Review of This Document

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

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Eriophorum gracile is currently considered a sensitive species in USFS Region 2 (USDA Forest Service 2005). It has been documented from 36 locations within Region 2, in Colorado, Nebraska, South Dakota, and Wyoming (**Table 1**, **Figure 1**). The only Region 2 occurrences on National Forest System lands are in Colorado and Wyoming. These include nine in Colorado (four on the Routt National Forest, two on the Grand Mesa-Uncompahgre-Gunnison National Forest, and one each on the Arapaho-Roosevelt National Forest, Pike-San Isabel National Forest, and White River National Forest), and six in Wyoming (four on the Shoshone National Forest and two on the Medicine Bow National Forest). Historic records with imprecise location information indicate that *E. gracile* may have at one time occurred on or near the Nebraska National Forest. Occurrences have been documented from other federal lands in Region 2 at Rocky Mountain National Park in Colorado, Valentine National Wildlife Refuge in Nebraska, and Lacreek National Wildlife Refuge in South Dakota. Occurrences are also known from federal lands outside the Region 2 administrative boundaries: Bridger-Teton National Forest in Wyoming, Gallatin National Forest in Montana, Wallowa-Whitman and Willamette national forests in Oregon, Payette National Forest in Idaho, and from Yellowstone, Grand Teton, and Glacier national parks. There are likely to be additional documented locations throughout the global range of *E. gracile*, but a thorough search of all North American herbaria that might hold specimens of this species was beyond the scope of this assessment.

The current NatureServe global rank for *Eriophorum gracile* is G5. The global (G) rank is based on the status of a taxon throughout its range. A G5 rank is defined as "Secure – Common; widespread and abundant" (NatureServe 2005). State Natural Heritage Program ranks for this species are S1 in Wyoming and South Dakota, and S2 in Colorado and Nebraska (NatureServe 2005). The state (S) rank is based on the status of a taxon in an individual state. In Wyoming and South Dakota, the S1 rank signifies that the species is "critically imperiled in the state because of extreme rarity (often five or fewer occurrences) or because of some factor(s) such as very steep declines making it especially vulnerable to extirpation from the state." The Colorado and Nebraska rank of S2 indicates that the species is considered "imperiled in the state because of rarity (6 to 20 occurrences), or because of other factors demonstrably making it very vulnerable to extirpation from the state" (NatureServe 2005).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Eriophorum gracile is not listed as a candidate for Threatened or Endangered status under the Endangered Species Act, and there are no laws concerned specifically with its conservation. Because it is on the Region 2 sensitive species list, USFS personnel are required to "develop and implement management practices to ensure that species do not become threatened or endangered because of Forest service activities" (USDA Forest Service Manual, Region 2 supplement, 2670.22). Although such approaches include developing an individual species conservation strategy, as of this writing, a conservation strategy has not been written for this species at a national or regional level by the USFS or any other federal agency.

Seven of the 15 documented occurrences on National Forest System lands in Region 2 have special designations. Two Colorado occurrences and one Wyoming occurrence are in designated Wilderness

Table 1. Summary of occurrences of *Eriophorum gracile* in USDA Forest Service Region 2. Occurrences are arranged by location (state and county) and arbitrarily numbered. Those shown with shading are believed to be extirpated.

	State County	Land Ownership/ Management	Date Last Observed	Location	Elevation (ft.)	Habitat[1]	Population Size	Source ID[2]
1	CO Gunnison	USDA Forest Service (USFS), Grand Mesa-Uncompahgre-Gunnison (GMUG) National Forest, West Elk Wilderness Area	2002	Castle Pass ponds	10,000	Shallow water and boggy ground adjoining the margin of a small lake	~ 100 stems with seed heads	CNHP EO-17 Herbarium label: Spongberg, S.A. and T. Webb, III, #64225
2	CO Jackson	USFS Routt National Forest Parks Ranger District Kettle Lakes Research Natural Area (RNA)	1989	Kettle Lake 12, south of Big Creek Lakes	9,350	Margin of lake, with scattered *Salix planifolia*	Unknown	CNHP EO-06 Herbarium label: Neely, B. and A. Carpenter #5364
3	CO Jackson	USFS Routt National Forest Parks Ranger District Kettle Lakes RNA	1989	Large pond south of Goose Creek	8,740	Pleistocene till (hummocky, bouldery till); aspect: east; soil: floating moss mat; slope 0 to 2 percent	~ 10	CNHP EO-07
4	CO Jackson	USFS Routt National Forest Parks Ranger District	2005	Sawmill Lake South	9,000	Basin fen	50 to 75	CNHP raw data files
5	CO Jackson	USFS Routt National Forest Parks Ranger District	2005	Lily Lake	9,670	Wetland	5	CNHP raw data files
6	CO Larimer	National Park Service Rocky Mountain National Park	1897 and 1903	Moraine Park	approx. 8,000	Unknown	Unknown	Herbarium label: Osterhout, G.E. #s.n.
7	CO Las Animas	Private	1941	Stonewall	8,100	Boggy soil in wet meadow	Unknown	CNHP EO-03 Herbarium label: Robbins, G.T. #636
8	CO Las Animas	Private	1941	East of Monument Lake	7,030	Unknown	Unknown	CNHP EO-16 Herbarium label: Kalmbach, K. #279
9	CO Park	USFS Pike-San Isabel National Forest South Park Ranger District	1989	East Lost Park, downstream from Lost Park campgrounds.	9,800	In rich fens dominated by this species, with *Carex limosa*, *C. livida*, and *C. tenuiflora*; found in discrete patches in extensive wetland	Unknown	CNHP EO-04 Herbarium label: Weber, W.A. #18035
10	CO Park	Private	1990	Hollthusen Gulch/ Tarryall Creek Fen; Boreas Pass Road	9,880	Large wetland complex of an unusual nature-appears as a mix of what may be called 'rich' and 'extreme rich fen'	Unknown	CNHP EO-18

Table 1 (cont.).

	State County	Land Ownership/ Management	Date Last Observed	Location	Elevation (ft.)	Habitat[1]	Population Size	Source ID[2]
11	CO Park	Private	1995	High Creek Fen at Warm Spring	9,970	Extreme rich fen	A couple dozen stems	CNHP EO-19
12	CO Park	USFS Arapaho-Roosevelt National Forest Clear Creek Ranger District Mount Evans Wilderness Area	1993	Mud Lakes	10,660	Fen	Several thousands	CNHP EO-21
13	CO Park	Private	1999	Sheep Creek, South of Black Mountain	9,000	Extreme rich fen	~ 50	CNHP EO-22
14	CO San Miguel	USFS GMUG National Forest	1999 and 2001	Prospect Creek Drainage and Prospect Basin, south of Telluride	11,140	In circumneutral fen near upper tree line, and in string fen	Unknown	Herbarium label: Cooper, D.J. #2407 and #2442
15	CO Summit	USFS White River National Forest Dillon Ranger District	2000	Ten Mile Range, Blue Lake Dam area, Monte Cristo Creek Valley	9,840	on limestone terraces irrigated with snow-melt	Unknown	Herbarium label: Weber, W.A. and R.C. Wittmann #19433
16	NE Blaine	Private	2001	Circle 5 Ranch; 4.35 miles west of Highway 7 on North Loup River Road	2,522	Small fen	100+	NNHP EO-12 Herbarium label: Steinauer, R.F. #1569
17	NE Cherry	Private	1891	Simeon and Kennedy	n/a	Unknown	Unknown	NNHP EO-03 Herbarium label: Bates, J.M. #26
18	NE Cherry	Probable U.S. Fish and Wildlife Service Valentine National Wildlife Refuge	1897	Dewey's Lake	n/a	Unknown	Unknown	NNHP EO-02 Herbarium label: Bates, J.M. #s.n.
19	NE Cherry	Unknown	1897	Lavaca	n/a	Unknown	Unknown	NNHP EO-07 Herbarium label: Bates, J.M.
20	NE Cherry	Private	1992	Puckett Lake Fen	3,960	Fen	11 to 50	NNHP EO-04
21	NE Cherry	Private	1996	Allen Valley Fen	3,100	On sedge dominated peat mounds	Locally common	NNHP EO-05 Herbarium label: Rolfsmeier, S.B. and G. Steinauer #12139

Table 1 (cont.).

	State County	Land Ownership/ Management	Date Last Observed	Location	Elevation (ft.)	Habitat[1]	Population Size	Source ID[2]
22	NE Cherry	Private	1996	West end of Big Creek Fen north of Mullen	3,160	Soft sedge peat mat	1000+	NNHP EO-09 Herbarium label: Rolfsmeier, S.B. #12455
23	NE Cherry	Private	1996	Ebby's Fen	2,900	in calcareous mucky peat in fen	1000+	NNHP EO-08 Herbarium label: Rolfsmeier, S.B. #12463
24	NE Cherry	Private	1997	Silver Lake Fen	3,540	Fen	Several	NNHP EO-10
25	NE Garden	Private	2000	Blue Creek Seep south of Crescent Lake.	n/a	Sandhills fen in upper region of Blue Creek within large seep/marsh complex	Unknown	Steinauer, R.F. #1498
26	NE Grant	Private	1996	Sandhills Valley northeast of Whitman	3,600	In sedge peat near middle of E-W peat mound between road and tree-lined ditch; sedge peat mound	~ 500	NNHP EO-06 Herbarium label: Rolfsmeier, S.B. #12146 and #12421
27	NE Thomas	Unknown near Nebraska National Forest	1891 and 1893	On Dismal River, south of Thedford	n/a	Unknown	Unknown	NNHP EO-01 Herbarium label: N.P. Tulen [1891] P.A. Ryderg [1893]
28	NE Wheeler	Private	1999	Ken Pelster Fen east of Cumminsville, north of Beaver Creek	1,940	Extremely wet peat; moss coverage high; soil 18 inches of sedge peat over sand	100+	NNHP EO-11 Herbarium label: Steinauer, R.F. #420 Rolfsmeier, S.B. #14721
29	SD Bennett	U.S. Fish and Wildlife Service Lacreek National Wildlife Refuge	1986	Southeast of Martin	2,950	Meadow willow scrub along south side of the Lake Creek Valley; located in saturated soils with *Carex* and mosses	1 stem	SDNHP EO-02
30	SD Brookings	Private	1897	Head of Spring Creek southeast of Elkton	1,730	Spring bog	Unknown	SDNHP EO-01 Herbarium label: Saunders, D.A.
31	WY Albany	USFS Medicine Bow National Forest Laramie Ranger District Sheep Mountain National Game Refuge	2004	East slope of Medicine Bow Mountains, on Sheep Mountain – Fence Creek	8,230-9,220	Headwaters of a large, elongate rich fen with short, scattered *Salix planifolia* cover	2000 to 3000	WYNDD EO-08 Herbarium label: Heidel, B. #2272

Table 1 (concluded).

	State County	Land Ownership/ Management	Date Last Observed	Location	Elevation (ft.)	Habitat[1]	Population Size	Source ID[2]
32	WY Albany	USFS Medicine Bow National Forest Laramie Ranger District Sheep Mountain National Game Refuge	2004	East slope of Medicine Bow Mountains, on Sheep Mountain – Hecht Creek	9,100-9,220	Rich fen	1000+	WYNDD EO-09
33	WY Albany	USFS Medicine Bow National Forest Laramie Ranger District Sheep Mountain National Game Refuge	1995	Beartooth Mountains – west of Lily Lake	7,720	On floating mat; parent material granitic	~ 125 to 500	WYNDD EO-03 Herbarium label: Mills, S. 158, 162
34	WY Albany	USFS Shoshone National Forest Clarks Fork Ranger District	1995	Beartooth Mountains, east end of Little Moose Lake	8,000	Floating/quaking mats of *Sphagnum* sp. and other mosses on flooded, black organic soil; mostly on slightly elevated hummock microsites; replaced by *Eriophorum polystachion* in adjacent *Carex rostrata* meadows	Population small	WYNDD EO-04
35	WY Albany	USFS Shoshone National Forest Clarks Fork Ranger District Absaroka Beartooth Wilderness Area, Lake Creek potential Research Natural Area	1996	Beartooth Mountains northeast of Lily Lake	8,120	Edge of floating mats on low hummocks dominated by *Sphagnum* sp. with scattered *Calamagrostis canadensis* and *Carex limosa*; typically on slightly drier microsites in transition zone between floating mats and *Carex* meadows; soil moist to wet with a thick, mossy layer of organic muck	100	WYNDD EO-05 Herbarium label: Fertig, W. and S. Mellmann-Brown #17312
36	WY Albany	USFS Shoshone National Forest Clarks Fork Ranger District	1999	Beartooth Range - south of Beartooth Butte	8,890	In dense moss bed on saturated organic soil.	10 fruiting stems	WYNDD EO-07 Herbarium label: Mellmann-Brown, S. #1203

[1]Habitat type names are given as in the original source, using either scientific or common names.

[2]Sources include Colorado Natural Heritage Program data (CNHP), Nebraska Natural Heritage Program (NNHP), South Dakota Natural Heritage Program (SDNHP), Wyoming Natural Diversity Database (WYNDD), and herbarium labels. Heritage Program ID's are Element Occurrence Records (of the format EO-00). Herbarium label ID's are collector name and collection number.

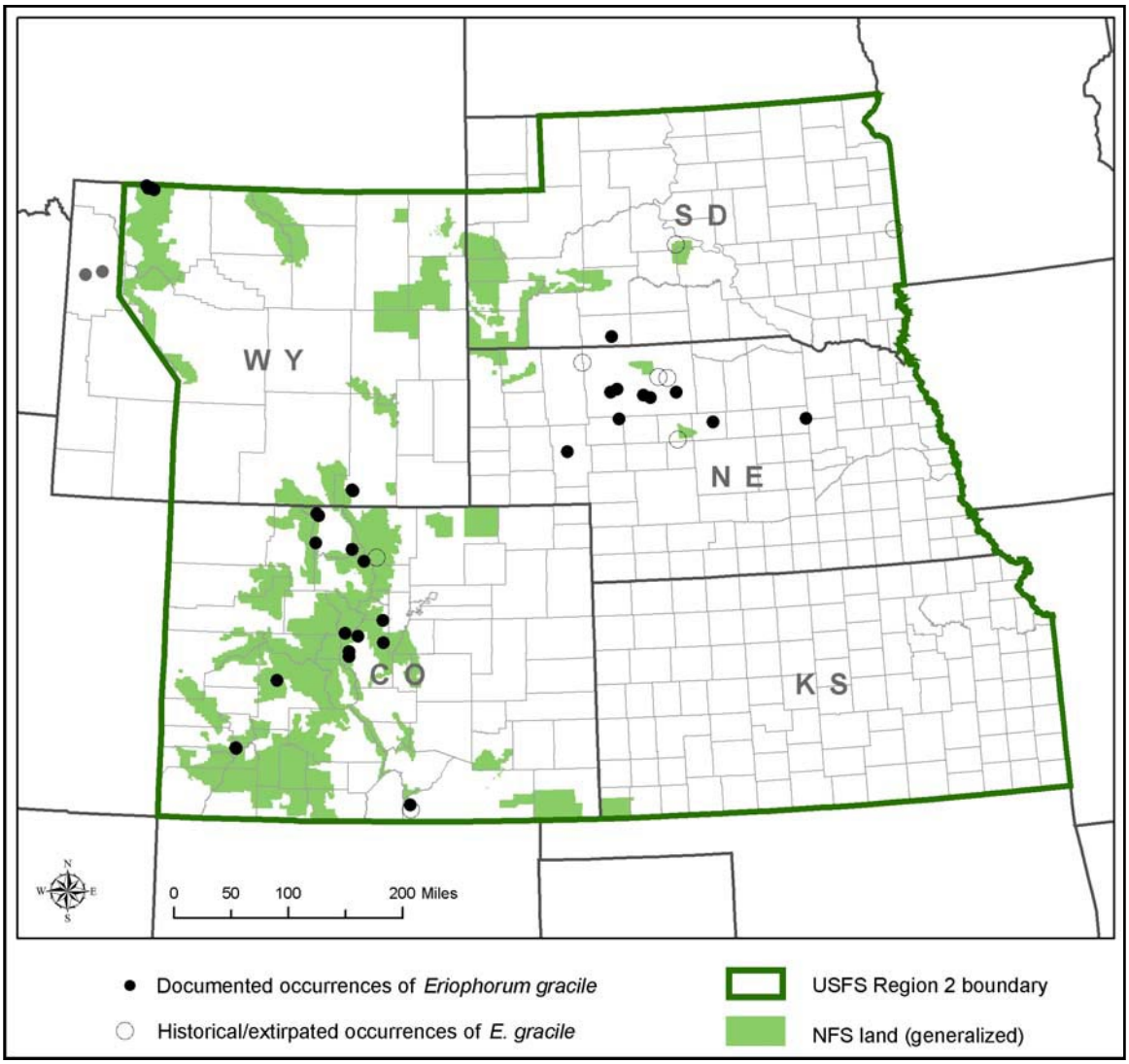

Figure 1. Documented occurrences of *Eriophorum gracile* in USDA Forest Service Region 2.

Areas (the Mount Evans Wilderness in the Arapaho-Roosevelt National Forest, the West Elk Wilderness in the Grand Mesa-Uncompahgre-Gunnison National Forest, and the Absaroka Beartooth Wilderness in the Shoshone National Forest, Wyoming). These areas are protected under the Wilderness Act of 1964 (16 U.S.C. 1131-1136, 78 Stat. 890), which prohibits the use of mechanized or motorized equipment in wilderness areas. However, other activities are permitted, including hiking, horseback riding, camping, hunting, fishing and grazing. Although wilderness area designations do not explicitly protect *Eriophorum gracile*, occurrences in wilderness areas are at lower risk than occurrences on lands where multiple uses occur.

The USFS designates and manages a network of research natural areas that are permanently protected and maintained in natural conditions, for the purposes of conserving biological diversity, conducting non-manipulative research and monitoring, and fostering education. Two Colorado occurrences are in the Kettle Lakes Research Natural Area (RNA) on the Routt National Forest, and *Eriophorum gracile* was one of the targeted species of the RNA designation (Colorado Natural Areas Program 1998). Although an RNA designation does not explicitly protect *E. gracile*, the emphasis on management for natural conditions means that these occurrences are likely to be more protected than occurrences on lands where management is less restricted. The management prescription for Kettle Lakes RNA closes the area to livestock grazing, withdraws the area from entry for locatable minerals and from oil and gas leasing, prohibits logging and construction of new trails, and discourages increased recreational use (Routt National Forest 1998).

Two Wyoming occurrences are on the Sheep Mountain National Game Refuge on the Medicine Bow National Forest. Although the management prescriptions for this area are focused on maintaining game populations, it is protected from motorized use, mining, and water development. The remaining eight occurrences on National Forest System lands in Colorado and Wyoming have no special designation.

Additional documented occurrences of *Eriophorum gracile* on federal lands within Region 2 include one in Rocky Mountain National Park (Colorado) and one in the Lacreek National Wildlife Refuge (South Dakota). Occurrences are also in Yellowstone and Grand Teton national parks in Wyoming, adjacent to areas administered by Region 2. National parks are managed by the U.S. Department of Interior to preserve the natural and cultural resources of the National Park System for the enjoyment, education, and inspiration of this and future generations. Grazing, off-road vehicle travel, and logging are only permitted for special reasons (e.g., removal of hazard trees after fire), and this provides some protection for *E. gracile* populations. National Wildlife Refuges are a network of lands and waters designated for the conservation, management, and restoration of the fish, wildlife, and plant resources and their habitats. Lacreek National Wildlife Refuge is managed with an emphasis on wildlife habitat, especially critical wintering habitat for the high plains trumpeter swan population; this does not necessarily provide increased protection for *E. gracile*.

Eriophorum gracile usually occurs in wetlands (estimated probability >99 percent) and is an obligate wetland indicator species in U.S. Fish and Wildlife Service Regions 4 (North Plains), 8 (Intermountain), and 9 (Northwest). There are a variety of federal regulations and policies that, although they do not directly address the conservation of *E. gracile*, could provide a degree of protection for its wetland habitat. The primary federal law regulating wetland habitats is Section 404 of the Federal Water Pollution Control Act (Clean Water Act) of 1977 (33 U.S.C. ss/1251 et seq.). Activities in wetlands regulated under this Act are required to avoid wetland impacts where practicable, to minimize potential impacts to wetlands, and to compensate for unavoidable impacts through restoration or mitigation. In addition, environmental impact statements, required for major federal actions affecting the environment under the National Environmental Policy Act (NEPA) of 1969 (42 U.S.C. 4321-4347), can serve to focus attention on protection of wetland habitat. Federal codes and regulations specific to the national forests include the Organic Administration Act of 1897 (16 U.S.C. 475), the Multiple Use – Sustained Yield Act of 1960 (16 U.S.C. 528), the National Forest Management Act of 1976 (16 U.S.C. 1600-1602, 1604, 1606, 1608-1614), the Federal Land Policy and Management Act of 1976 (43 U.S.C. 1701-1782, FSM 2729), the Forest Service Manual, and individual Forest Management Plans. These codes and regulations all provide some degree of focus on the preservation of water resources, including wetlands. Finally, a policy of "no net loss" of wetlands has been a national goal since first announced as an administration policy under President George H.W. Bush in 1989.

Adequacy of current laws and regulations

The above-mentioned laws and regulations provide tools for the conservation of *Eriophorum gracile* in wetland habitats, especially on National Forest System lands. This does not necessarily indicate that current regulations or their enforcement are adequate for protection of *E. gracile* or its habitat. The National Research Council Committee on Mitigating Wetland Losses (2001) concluded that mitigation criteria required for compliance with the provisions of Section 404 of the Clean Water Act have often not been attained, in part because permit expectations were unclear and compliance was never monitored. The Committee also found that although progress has been made since the 1980s, the goal of "no net loss of wetlands" is not being met (National Research Council 2001). The Committee's report indicates that enforcement of at least some current laws and regulations is inadequate to protect the unique habitat of *E. gracile*. In particular, additional protection is needed for fens in Region 2. U.S. Department of Interior and Department of Agriculture regulations still consider peat a renewable resource (USDI Bureau of Mines 1994) and a leasable mineral (FSM 2822.1). Occurrences on privately owned lands may be inadequately protected from alteration or destruction under current laws and regulations.

Adequacy of current enforcement of laws and regulations

There are several instances in which an occurrence of *Eriophorum gracile* in Region 2 may have been extirpated because of human actions, but it is not clear that this is due to inadequate enforcement of laws and regulations. These are primarily historic locations where occurrences have not been relocated since the original collection, and where the hydrology of the area may have been drastically altered, resulting

in the destruction or degradation of potential habitat. These occurrences are shown as open circles in **Figure 1**, and with a gray background in **Table 1**.

Historical occurrences fall into two categories. First, those occurrences documented only by collections from the late 1800s or early 1900s have location information is so imprecise that it is impossible to know if the population has disappeared through habitat alteration or for other reasons. These occurrences include one from the eastern edge of South Dakota, one from Colorado's Rocky Mountain National Park, and four from the Sandhills region of Nebraska. Second, in the case of two 1941 collections from Las Animas County in Colorado, the area where the collections were made has been altered for agricultural use to the extent that *Eriophorum gracile* could no longer persist there (Weber and Wittmann 2001, Colorado Natural Heritage Program 2005). The persistence of *E. gracile* at the Lacreek National Wildlife Refuge in South Dakota is questionable although this occurrence is not yet considered historic. Hydrology on the refuge has been severely altered from its pre-settlement condition, and suitable habitat for *E. gracile* was destroyed in the course of pond construction (Medicine Bow National Forest 2003). Although the persistence of a viable population at this site is doubtful, it is not certain that *E. gracile* has been eliminated from the refuge. There are no instances in which an occurrence of *E. gracile* on National Forest System land is known to have been extirpated. Although the species has been casually reported from National Forest System lands in Nebraska and South Dakota, it is impossible to confirm that it was ever present in these locations.

In Region 2, *Eriophorum gracile* is confined to a few islands of unique and relatively rare habitat. Extirpation of these isolated occurrences will not necessarily endanger the persistence of the species; however, a gradual loss of occurrences will eventually result in a contraction of its known range. Loss of the disjunct populations in Region 2 could reduce the genetic diversity of the species as a whole, as well as depress its resilience in the face of genetic, demographic, and environmental stochasticity. Careful attention to the preservation of the unique and relatively rare habitat of *E. gracile* in Region 2, using all available regulatory tools, is likely to be the most effective means of conserving the species.

Biology and Ecology

Classification and description

Eriophorum gracile is a member of the Cyperaceae or sedge family, a moderate-sized family with approximately 100 genera and 5,000 species, of which 27 genera and 843 species are North American (Ball et al. 2002). The complete taxonomic classification of *E. gracile* is available online from the PLANTS Database (USDA- Natural Resources Conservation Service 2005). The genus *Eriophorum* is distinguished from other genera in the Cyperaceae by the presence of numerous long and silky perianth bristles that appear as conspicuous cotton-like tufts on the flowering plant. These tufts give the genus its name from the Greek: *erion* (wool) and *phoreo* (to bring or carry), hence, "wool bearing" (Griffith 2002). The "woolly hairs" of cottongrass develop at the base of the ovary and are in fact modified flower petals and sepals.

There are approximately 25 species of *Eriophorum* in the northern hemisphere, and Ball and Wujek (2002) list 11 species as occurring in North America, mostly in cool temperate, alpine, and arctic regions. In some species, including *E. gracile*, the North American populations are considered to be conspecific with Eurasian populations, but Ball and Wujek (2002) suggest that these relationships should be investigated more thoroughly because of differences in achene micromorphology and isozyme data from the two regions.

History of knowledge

Eriophorum gracile was originally described in 1800 by W.D.J. Koch in Volume II of Albrecht Wilhelm Roth's *Catalecta Botanica*. Fernald (1905) described a variety *caurianum* restricted to California and Oregon; this resulted in the autonymic creation of var. *gracile* for the remainder of the species. These varieties are not discussed in the recent treatment by Ball and Wujek (2002) in the Flora of North America, and floras used in Region 2 (e.g., Great Plains Flora Association 1986, Dorn 1992, Weber and Wittmann 2001) do not generally use variety names. Since only var. *gracile* is pertinent to Region 2, it is treated as synonymous with *E. gracile* in this assessment.

Description

As described by Hitchcock and Cronquist (1972), Ball and Wujek (2002), and Dorn (1992), *Eriophorum gracile* is a perennial, colonial graminoid with creeping rhizomes and slender erect stems 20 to 60 cm high (**Figure 2** and **Figure 3**). The leaf blades are 1 to 2 mm wide and deeply channeled or triangular in cross-section, except near the stem. The uppermost leaf has a blade that is shorter than the sheathing portion surrounding the stem. Flowers are borne in 2 to 5 spikelets on short, drooping stalks that often exceed the single green, leaf-like bract that is shorter than the inflorescence. The spikelet stalks are covered with dense, short, soft hairs. Each flower consists of numerous long, shining white bristles, approximately 2 cm long, at the base of the ovary (**Figure 4**). The lance-shaped bracts are greenish black or brown scales with a slender midrib that ends well below the tip. The light brown seeds are 2 to 4 mm long and 3 to 5 times as long as wide.

Eriophorum angustifolium is very similar to *E. gracile* and occurs in similar habitat. Both species have culms with well-developed leaves and several spikelets per culm. Characters that distinguish *E. gracile* from *E. angustifolium* are listed in **Table 2**. *Eriophorum gracile* occurs in uniform stands that are often recognizable at a distance because of the reddish color at the tips of the leaves (Spackman et al. 1997, Weber and Wittmann 2001).

Published descriptions and other sources

Complete technical descriptions and illustrations are available in Fernald (1905, Britton and Brown (1913), Rydberg (1932), Hitchcock and Cronquist (1972), and Ball and Wujek (2002). A drawing and a photograph of the plant and its habitat are available in the *Colorado Rare Plant Field Guide*, in both the online and print versions (**Figure 2**; Spackman et al. 1997). Other online sources for descriptions and photographs of plants and habitat are numerous and include Larson (1993) and Flora of North America (2004). Please note that most image sources depict material from outside Region 2.

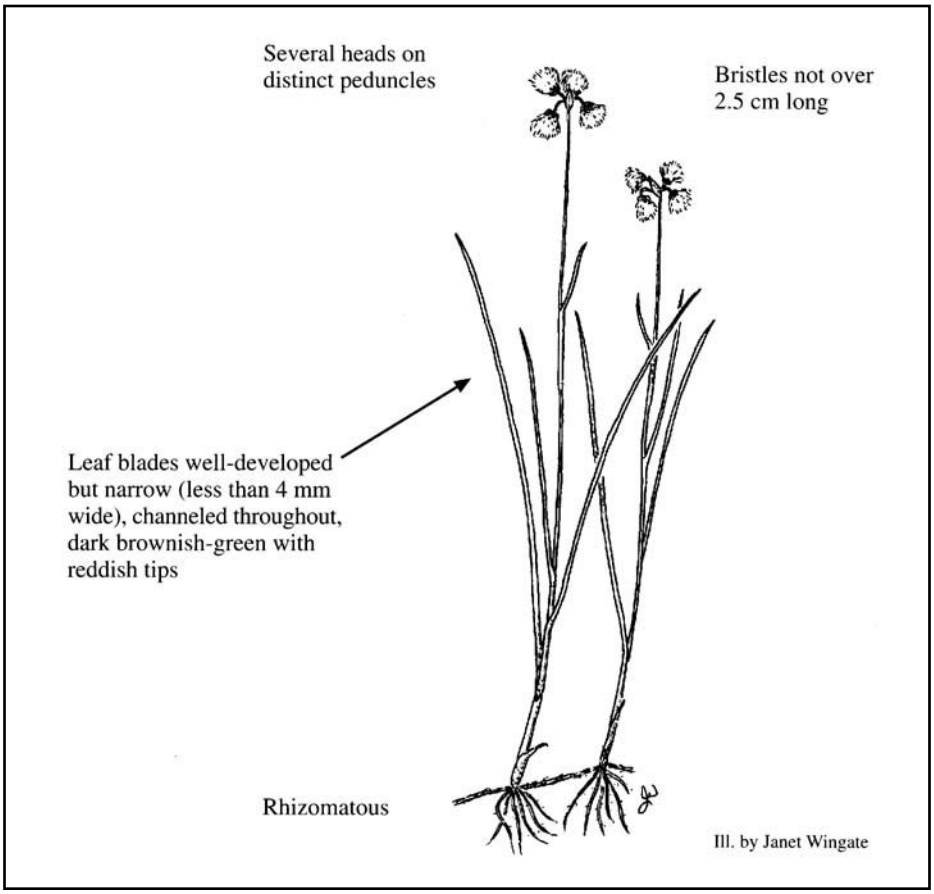

Figure 2. Illustration of *Eriophorum gracile* from Spackman et al. (1997) by Janet Wingate. Used with permission.

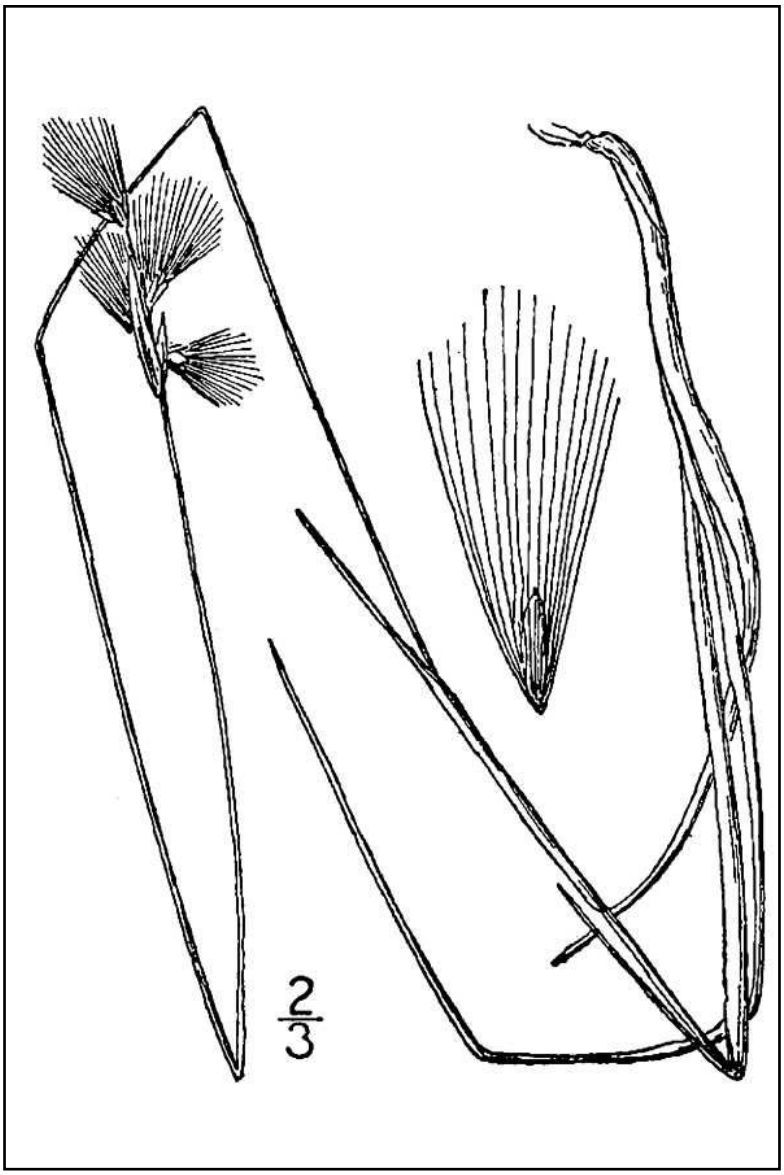

Figure 3. Illustration of *Eriophorum gracile* from Britton and Brown (1913). This image is not copyrighted and may be freely used for any purpose.

Distribution and abundance

Eriophorum gracile is a circumpolar species. It occurs in the northern tier of U.S. states north of approximately forty degrees latitude, as well as in all of the Canadian provinces (**Figure 5**) and northern Eurasia (Hultén 1968, Kartesz 1999, Ball and Wujek 2002). Although the global range of *E. gracile* is circumpolar, at the southern extent of its range in Region 2 it is found in small, disjunct populations. The current distribution of this species is essentially equivalent to its recent historical post-glacial distribution, but its disappearance from some historic sites may indicate a reduction in range (Barr 1996).

In Region 2, *Eriophorum gracile* occurs in the Temperate Steppe Division of the Dry Domain in the Ecoregion Classification of Bailey (1995). Within the Temperate Steppe Division, *E. gracile* is found in the Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province and in the Great Plains Steppe Province (Bailey 1995). In Region 2, these divisions correspond to the Utah-Wyoming Rocky Mountain / Southern Rocky Mountain Ecoregions and the Central Mixed-grass Prairie Ecoregion as defined by The Nature Conservancy (2001).

There are 36 reported locations for *Eriophorum gracile* in Region 2 (**Table 1**); eight of these are believed

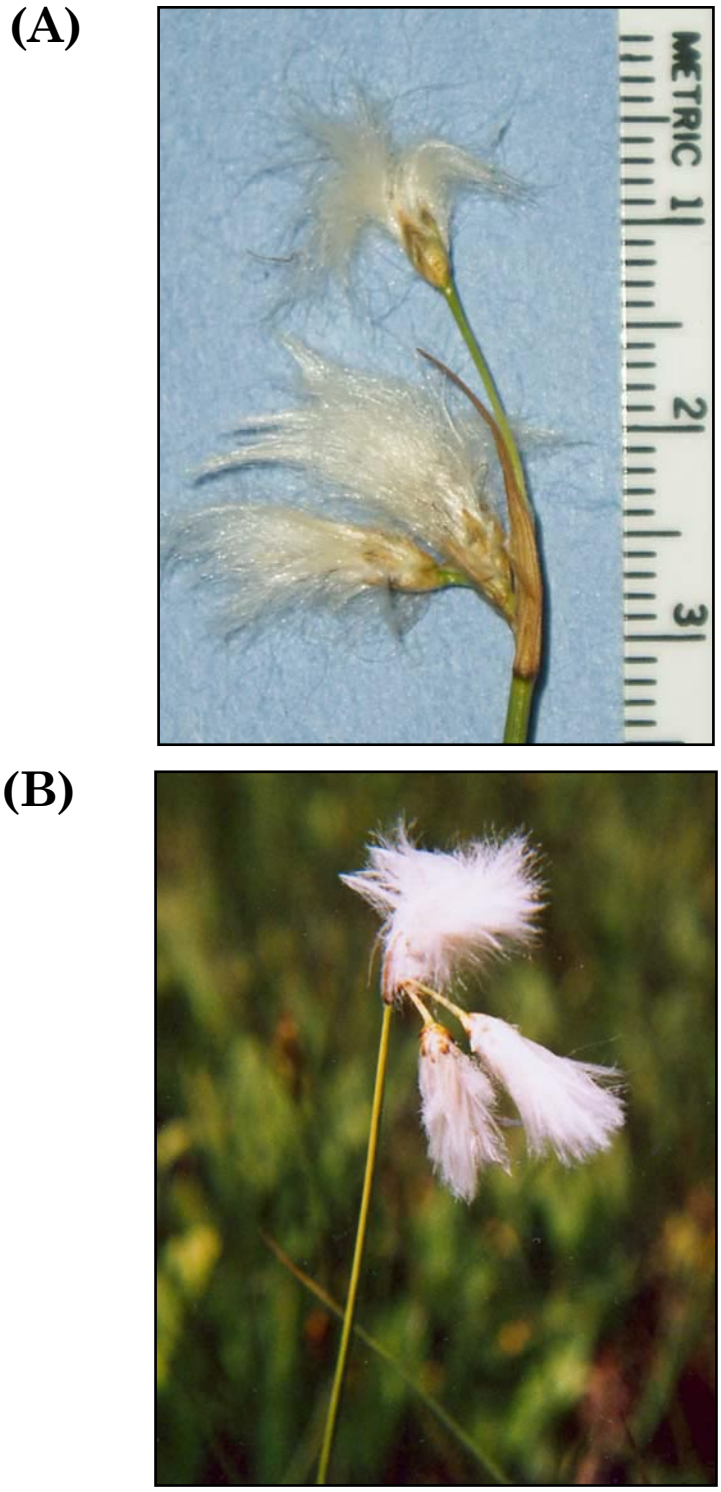

Figure 4. Flowering stalk of *Eriophorum gracile*. (A) Photograph by Annette Miller, used with permission. (B) Photograph by Dave Bradford, used with permission.

Table 2. Distinguishing characters of *Eriophorum gracile* and *E. angustifolium*.

	E. gracile	***E. angustifolium***
Uppermost culm leaf	Blade much shorter than sheath	Blade as long or longer than sheath
Lower portion of leaf blade	Channeled, 1-2 mm wide	Flat, 1-3 mm wide
Anther length	1-2.5 mm	>2 mm
Bracts	1, not longer than inflorescence	2 – 5, as long or longer than inflorescence
Mature bristles	Not over 2.5 cm	>2.5 cm

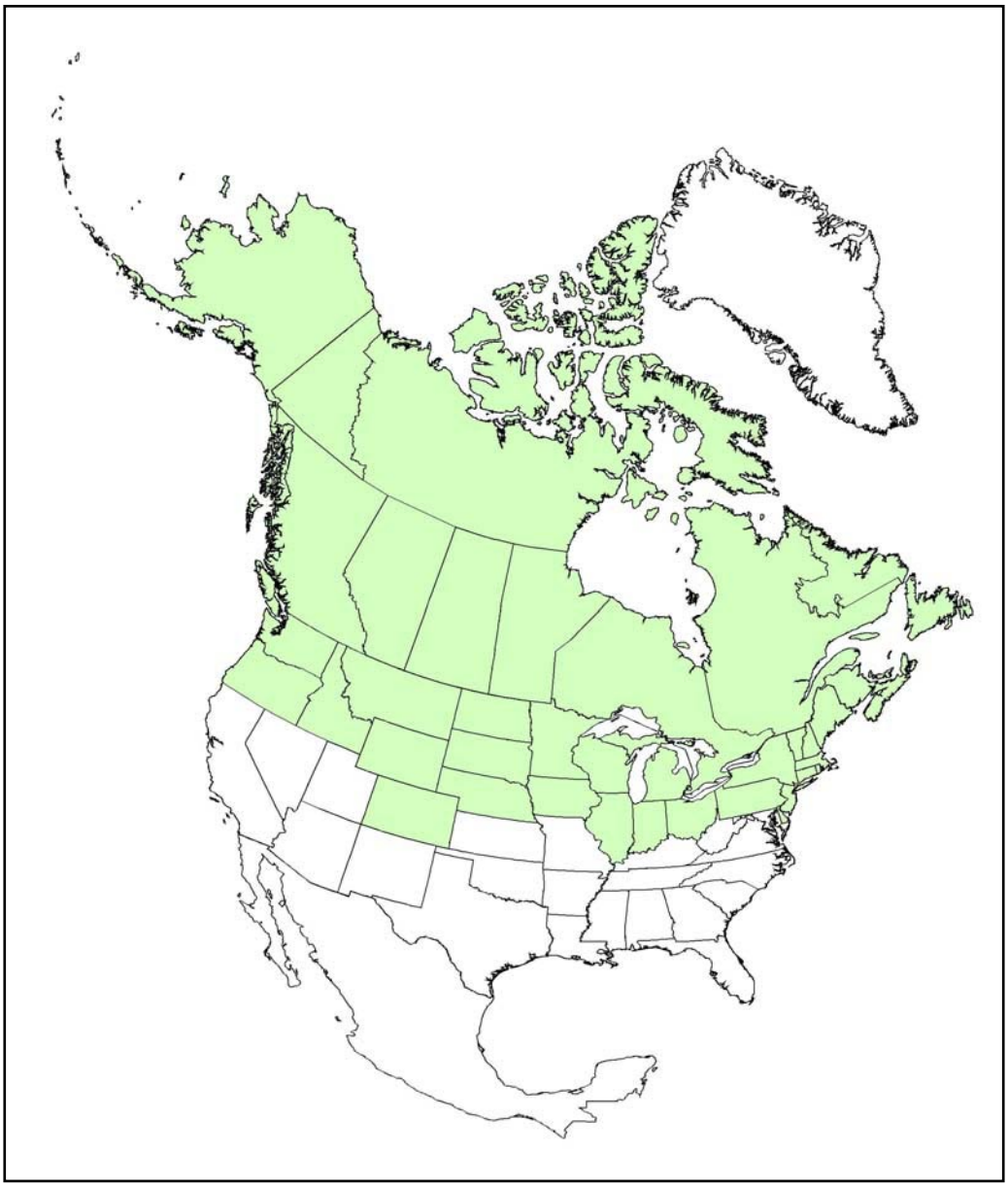

Figure 5. Generalized North American distribution of *Eriophorum gracile*.

to be extirpated. In Region 2, *E. gracile* is found in mountainous areas of Colorado and Wyoming, and in the Sandhills of north-central Nebraska and southern South Dakota. Colorado occurrences have been documented from the Park Range, Rocky Mountain National Park, the Tenmile Range, Kenosha and Tarryall Mountains, Hoosier Ridge, Mosquito Range, Mt. Evans, the San Juan Mountains, West Elk Mountains, and Culebra Range. In Wyoming, occurrences are in the Medicine Bow Range and the Beartooth-Absaroka Range. Populations in north-central Nebraska and southern South Dakota are in the Sandhills region. These disjunct populations are relicts from the Pleistocene, when boreal vegetation was widespread at more southerly latitudes in North America (Pielou 1991). Documented occurrences of *E. gracile* in Region 2 are shown in **Figure 1** and are described in **Table 1**. There may be additional material from Region 2 at herbaria not searched for this assessment, including specimens that are not currently labeled *E. gracile*. There are also likely to be locations for which no documentation currently exists. Although additional material could clarify the abundance of *E. gracile* in Region 2, it is unlikely to change the peripheral, disjunct character of occurrences in this region.

In Colorado, *Eriophorum gracile* has been documented from 15 locations in seven counties. Four locations in Jackson County include two records from the Kettle Lakes Research Natural Area on the Parks Ranger District of the Routt National Forest. One historic location is in the Larimer County portion of Rocky Mountain National Park. Sites in central Colorado include five in Park County and one site at the southern end of the Tenmile Range in Summit County. The single Gunnison County occurrence is in the West Elk Wilderness Area. Southern Colorado locations include one in San Miguel County on the San Juan National Forest, and two historic occurrences from the east slope of the Culebra Range in Las Animas County.

In Nebraska, *Eriophorum gracile* has been documented from 13 locations in six counties; four locations are considered historical. No populations can be confirmed from National Forest System land, but one historical location is probably near the southern boundary of the Nebraska National Forest. Another historical population was reported from the vicinity of the Samuel R. McElvie National Forest, but it cannot be confirmed as being within USFS boundaries. One additional historical occurrence was probably on what is now the Valentine National Wildlife Refuge. All confirmed extant populations of *E. gracile* in Nebraska are on privately owned lands.

The presence of *Eriophorum gracile* in South Dakota is doubtful. There are two South Dakota locations; one believed to be extirpated from the extreme eastern edge of the state in Brookings County, and one also likely to have been extirpated at Lacreek National Wildlife Refuge near the southern edge of the state in Bennett County (Coles personal communication 2005, Menard personal communication 2005). However, additional survey may be required to confirm these extirpations (Ode personal communication 2005).

In Wyoming, *Eriophorum gracile* is known from six occurrences on National Forest System lands in Region 2, and from four occurrences in areas outside Region 2 administrative boundaries. In Albany County in southern Wyoming, there are two occurrences on the Medicine Bow National Forest in the Sheep Mountain National Game Refuge. In Park County in northwestern Wyoming, there are four occurrences on the Shoshone National Forest, including one in the Absaroka Beartooth Wilderness Area. Three occurrences are documented from the vicinity of Grand Teton National Park, and one from Yellowstone National Park.

Detailed abundance information for occurrences of *Eriophorum gracile* in Region 2 is lacking; instead, occurrences are characterized as "rare" or "locally common." The clonal nature of *E. gracile* enhances the difficulty of obtaining accurate plant counts. Population estimates are made by counting stems and do not represent genetic individuals. Where numbers are reported, estimates range from a dozen to several thousand stems. It is difficult to estimate the total number of individuals occurring in Region 2; between 10,000 and 14,000 stems are suggested by current documentation.

Population trend

Because occurrences records do not include repeated stem counts, information is insufficient to allow an assessment of current population trends. Although trend data for individual occurrences are lacking, evidence suggests that some occurrences were extirpated during the past century. About one fourth of the documented occurrence locations in Region 2 are considered historical, and unlikely to be relocated because of habitat alteration at those sites. It is not clear that these disappearances represent a general downward population trend in Region 2.

Habitat

Globally, *Eriophorum gracile* is found in cool temperate, alpine, and arctic regions, in alpine and subalpine wetlands with peaty soils and poor drainage that are supported by groundwater discharge or snowmelt (Ball and Wujek 2002). In Region 2, *E. gracile* is typically found in fens and subalpine wet meadows with saturated soils (**Figure 6**), where vegetation is dominated by graminoids and forbs (Dorn 1992, Ball and Wujek 2002). These habitats are often described as bogs or marshes in the original source material. Elevations of occurrences range from about 7,000 to 11,140 ft. (2,125 to 3,475 m) in Colorado, from 7,700 to 8,900 ft (2,350 to 2,700 m) in Wyoming, and from 1,940 ft (590 m) in the eastern Sandhills to about 3,800 ft (1,150 m) in the western Sandhills.

Eriophorum gracile is associated with the vegetation characteristic of fens and saturated soils. Data from specimen labels and element occurrence records show *E. gracile* occurring with the species listed in **Table 3**. Many fen species, including *E. gracile*, appear to exhibit microhabitat specialization along micro-relief, hydrologic, or chemical gradients

(A)

(B)

Figure 6. Examples of *Eriophorum gracile* habitat in Colorado. (A) Photo by Janet Coles, used with permission. (B) Photo from Colorado Natural Areas Program files, used with permission.

Table 3. Species associated with *Eriophorum gracile* in USDA Forest Service Region 2.

Associated species	CO	WY	NE	SD	Associated species	CO	WY	NE	SD
Shrubs					*Muhlenbergia glomerata*			✸	
Betula glandulosa	✸	✸			*Ptilagrostis porteri*	✸			
Dasiphora floribunda	✸	✸			*Schoenoplectus acutus*			✸	✸
Salix brachycarpa	✸				*Scirpus pungens*			✸	✸
Salix candida	✸	✸			*Trichophorum pumilum*	✸	✸		
Salix eriocephala var. *ligulifolia*	✸				*Typha latifolia*				✸
Salix monticola	✸								
Salix planifolia	✸	✸			Forbs				
					Antennaria pulcherrima		✸		
Graminoids					*Cicuta bulbifera*			✸	
Agrostis scabra			✸		*Comarum palustre*	✸	✸		
Calamagrostis canadensis	✸	✸			*Drosera anglica*		✸		
Carex aquatilis	✸	✸			*Epilobium leptophyllum*			✸	
Carex buxbaumii		✸			*Eupatorium perfoliatum*			✸	
Carex canescens	✸				*Gentianopsis detonsa*		✸		
Carex capitata		✸			*Menyanthes trifoliata*	✸	✸	✸	
Carex hystericina			✸		*Mimulus moschatus*		✸		
Carex interior		✸			*Packera cymbalarioides*		✸		
Carex lasiocarpa		✸			*Packera pauciflorus*	✸			
Carex limosa	✸	✸			*Pedicularis groenlandica*		✸		
Carex livida	✸				*Platanthera dilatata*		✸		
Carex nebrascensis			✸	✸	*Rhodiola rhodantha*	✸			
Carex prairea			✸		*Spiranthes romanzoffiana*	✸	✸		
Carex scirpoidea	✸				*Thalictrum alpinum*	✸			
Carex tenuiflora	✸				*Thelypteris palustris*			✸	
Carex utriculata	✸	✸			*Utricularia ochroleuca*	✸			
Deschampsia cespitosa	✸		✸						
Eleocharis acicularis				✸	Non-vascular				
Eleocharis elliptica			✸		*Bryum pseudotriquetrum*			✸	
Eleocharis quinqueflora		✸			*Calliergonella cuspidata*			✸	
Eriophorum angustifolium	✸		✸		*Drepanocladus aduncus*			✸	
Juncus brevicaudatus			✸		*Meesia triquetra*			✸	
Juncus sp.	✸				*Sphagnum* sp.		✸		
Kobresia myosuroides	✸				Moss	✸			✸

(Sanderson and March 1996). Observers of Colorado and Wyoming populations have reported finding *E. gracile* in saturated soils with standing water or on floating peat mats (Wyoming Natural Diversity Database 2004, Coles personal communication 2005, Rocchio personal communication 2005).

In Region 2, *Eriophorum gracile* is associated with the Rocky Mountain Alpine-Montane Wet Meadow, Rocky Mountain Subalpine-Montane Fen, and the Northwestern Great Plains Open Freshwater Depression ecological systems as defined by NatureServe (2003). These three systems are defined as "small patch" types, that usually have distinct boundaries, require specific environmental conditions, and are strongly linked to and dependent upon the landscape around them (Anderson et al. 1999).

The Rocky Mountain Alpine-Montane Wet Meadow ecological system includes high-elevation herbaceous-dominated plant communities on wetter sites with very low-velocity surface and subsurface flows. These systems occur in montane and subalpine valleys throughout the Rocky Mountains as large meadows, as narrow strips bordering ponds, lakes, and streams, and in toeslope seeps. They range in elevation from montane to alpine (3,280 to 11,810 ft. [1,000 to 3,600 m]) and are typically found on flat areas or gentle slopes, but they may also occur on sub-irrigated sites with slopes up to 10 percent. In alpine regions, wet meadows are typically small depressions located below late-melting snow patches or on snowbeds. Soils of this system may be mineral or organic but have hydric soil characteristics.

The Rocky Mountain Subalpine-Montane Fen ecological system is defined by groundwater discharge, soil chemistry, and peat accumulation of at least 40 cm (NatureServe 2003). Fens form at low points in the landscape or on slopes where groundwater intercepts the soil surface. Groundwater inflows maintain a constant water level year-round at or near the ground surface. A consistent high water table leads to an accumulation of undecomposed organic material. The microtopography of a fen consists of hummocks, hollows, and other patterns on the soil surface. Some fens support floating peat mats that "quake" or move when walked upon, due to the presence of plants with air in their roots and stems (Austin 2003). Fens usually occur as a mosaic of several plant associations characterized by *Carex aquatilis*, *Betula glandulosa*, *Kobresia myosuroides*, *K. simpliciuscula*, and *Trichophorum pumilus*. Due to the slow accumulation of the organic matter, fen wetlands take centuries to develop, and loss of fen habitat is essentially irreversible.

Within the Northwestern Great Plains Open Freshwater Depression ecological system, *Eriophorum gracile* is limited to the Sandhills Fen plant association (*Carex interior-Eleocharis elliptica-Thelypteris palustris* Herbaceous Vegetation) of northwestern Nebraska and adjacent southwestern South Dakota. This community is typically found at the headwaters of Sandhills stream valleys or at the upper ends of lakes and marshes where the water table is 15 to 30 cm below the surface and soils remain saturated throughout the year without becoming flooded. The vegetation consists mainly of hydrophytic herbaceous species, and stands are typically dominated by sedges, including *C. interior*, *C. lacustris*, *C. nebrascensis*, *C. prairea*, and *C. sartwellii*. Surface mounding is an important feature of these fens, and raised peat mounds are frequently areas of groundwater discharge. Sandhill fens tend to develop at sites where an interdunal valley intercepts the water table that has "mounded" under the adjacent dunes. In some cases, valley floor seeps have flowed at the same site for hundreds or thousands of years, impeding the decomposition of plant material. Deep deposits of peat and muck soils formed, and fens have developed (Sandhills Task Force 2004).

Reproductive biology and autecology

Life history and strategy

In the Competitive/Stress-tolerant/Ruderal (CSR) model of Grime (2001), *Eriophorum* species have been diagnosed as both stress-tolerators (*E. vaginatum*) and competitors (*E. scheuchzeri*), depending on their response to nutrient availability. While their rhizomatous nature tends to argue for the competitive designation, their reliance on disturbance (open sites) for seedling establishment means that they do not precisely fit Grime's criteria (McGraw and Chapin 1989). Not enough is known about its potential relative growth-rates in different conditions to clearly identify *E. gracile* as a competitor or stress-tolerator. Grime (2001) characterizes stress-tolerant competitors as rhizomatous or tussock forming perennials that have a lower maximum potential relative growth rate and longer leaf life-span than strict competitors, and a shoot morphology that is intermediate between the stress-tolerator and competitor. Too little is known about these characters in *E. gracile* to be confident of its classification, but its apparently less aggressive growth habits in comparison with congeners such as *E. vaginatum* may best fit the concept of stress-tolerant competitor. As a long-lived perennial species that probably devotes several years to vegetative growth before reproducing, and that lives in a stable environment at or near its carrying capacity (Ball personal communication 2003), *E. gracile* can be regarded as a *K*-selected species in the classification scheme of MacArthur and Wilson (1967).

Reproduction

Eriophorum gracile is a perennial graminoid that reproduces both sexually by seed and vegetatively from long, creeping rhizomes (Ball and Wujek 2002). Like most other species in the Cyperaceae, *E. gracile* is monoecious, having separate male and female flowers on the same plant. Worldwide, this sexual system is found in five percent of species (Yampolsky and Yampolsky 1922). Some *Eriophorum* species apparently produce large amounts of seed (McGraw et al. 1991) that could be a result of selfing, but Barr (1996) reported that

E. gracile in one Pennsylvania occurrence produced very few viable seeds. Reproduction of *Eriophorum* species is reported to be primarily by vegetative growth, perhaps due to the lack of suitable open sites for germination. Although the reproductive biology of *E. gracile* has not been investigated, it is likely to reproduce primarily through rhizomatous growth as do other members of the genus.

Pollinators and pollination ecology

Eriophorum species are wind pollinated, or anemophilous (Cronquist 1988, Cronk and Fennessy 2001), as are almost all grasses, sedges, and rushes. This trait is common among species in habitats where pollinators may be scarce, and it is strongly associated with monoecy (Proctor et al. 1996). The anemophilous habit requires the production of large amounts of pollen; this is the only possible vector for gene exchange among disjunct populations of *E. gracile*. Although most pollen is deposited close to its source (Levin and Kerster 1974), weather conditions producing strong convection can carry pollen considerable distances from the source (Proctor et al. 1996). Even if pollen is occasionally exchanged among *E. gracile* occurrences, its limited viability would make successful long-distance pollination a rare event.

Phenology

Flowering and fruiting in *Eriophorum gracile* occur from mid-June through August (Mills and Fertig 2000, Ball and Wujek 2002). Flowers are mature and conspicuous after July, appearing as showy white, fluffy, seed plumes that persist for weeks (Mills and Fertig 2000).

Fertility and propagule viability

If *Eriophorum gracile* is similar to other species in the genus, then plants are several years old before they are capable of producing seed (Howard 1993, Tolvanen and Henry 2000). Seeds of many *Eriophorum* species demonstrate high initial germination rates at moderate and high temperatures (Grime et al. 1981, Gartner et al. 1986). This trait is often linked to a preponderance of seed regeneration in summer and early autumn and a diminished tendency to form large, persistent seed banks (Schutz 2000). Barr (1996) reported very low fertility for a population of *E. gracile* in Pennsylvania, where only about 4.6 percent of flowers developed into viable seeds, and the sampled plants produced fewer than five viable seeds per stem. The fertility and propagule viability of *E. gracile* under conditions in Region 2 are unknown but may be similarly low.

In peatland habitats, open sites for establishment of *Eriophorum gracile* seedlings are rare and are produced by localized disturbance such as trampling by domestic or wild ungulates. Although a positive effect of such gaps on the germination of many herbaceous fen species has been demonstrated (e.g., Isselstein et al. 2002), Stammel and Kiehl (2004) found that tolerance of the negative effects of trampling (e.g., soil compaction, changes in the availability of light and water) was not the same for all species, and they concluded that gap creation by trampling may not be a suitable conservation tool for rare species. Small-scale, infrequent surface disturbance that produces gaps without compacting soils is most likely to provide safe establishment sites for *E. gracile*.

Dispersal mechanisms

The seeds of *Eriophorum* species are dispersed by wind and water (Ball personal communication 2003). The long perianth bristles of *Eriophorum* achenes are presumed to aid in dispersal by wind (Burrows 1975).

Cryptic phases

There is evidence of a persistent seed bank in at least some *Eriophorum* species (Grime et al. 1988). *Eriophorum vaginatum* often dominates northern seed banks, where the seeds buried in peat remain viable for up to 200 years in cold arctic conditions (McGraw et al. 1991). The longevity of *E. gracile* seeds has not been investigated.

Phenotypic plasticity

Phenotypic plasticity has not been reported for *Eriophorum gracile*. In general, flowering plants are noted for their great phenotypic plasticity (Savile 1972). Other *Eriophorum* species show phenotypic plasticity in response to changes in nutrient and light levels (McGraw and Chapin 1989), and *E. gracile* is likely to share this trait. Experiments with *E. vaginatum* have suggested that phenotypic responses to environmental effects can persist in clonal offspring (Schwaegerle et al. 2002). However, McGraw and Chapin (1989) found that important characters such as root-to-shoot ratio were constant across genotypes regardless of environmental effects. In-depth investigation of the biology of *E. gracile* would be required to determine the extent of phenotypic plasticity and the persistence of environmental effects in this species.

Mycorrhizal relationships

The arctic tundra where most *Eriophorum* species have their center of distribution is a strongly nutrient-limited system, and most vascular plant species there are mycorrhizal (Urcelay et al. 2003). However, the Cyperaceae are generally non-mycorrhizal (Gardes and Dahlberg 1996), and this includes at least some *Eriophorum* species such as *E. vaginatum* (Chapin et al. 1993). Although the mycorrhizal status of *E. gracile* has not been specifically investigated, it is likely to share the non-mycorrhizal condition of its family.

Hybridization

Hybridization in *Eriophorum gracile* has not been studied. A number of other *Eriophorum* species occur in similar habitats in Region 2, including *E. callitrix*, *E. scheuchzeri*, and *E. viridicarinatum* in Wyoming and *E. altaicum* var. *neogaeum*, *E. angustifolium*, and *E. chamissonis* in both Wyoming and Colorado. Occurrences of *E. gracile* may sometimes be within a mile or two of other *Eriophorum* species populations, with some potential for gene exchange between them. The tendency of *Eriophorum* species to propagate almost exclusively by vegetative reproduction suggests that hybridization is likely to be rare.

Demography

Because most *Eriophorum* species appear to achieve most of their reproductive success through vegetative growth (i.e., "tillering"), population studies have tended to focus on the life cycle of ramets, rather than on genetic individuals. Notwithstanding the possibility of the persistence of environmental effects in later generations of tillers (Schwaegerle et al. 2000), or the chance of somatic mutation, clonal offspring of *Eriophorum* species are essentially genetically identical to the parent plant.

Tolvanen et al. (2001) developed a generalized lifecycle graph for tillers in their study of the effects of grazing on *Eriophorum angustifolium* ssp. *triste*, *Carex aquatilis* ssp. *stans* and *C. membranacea*. **Figure 7** shows this generalized tiller lifecycle diagram adapted for *E. gracile*, with the addition of sexual reproduction. Transition probabilities are unknown for *E. gracile*, but the lifespan of individual tillers was 8 to 10 years for ungrazed plants in *E. angustifolium* ssp. *triste*, and combined survival of tillers (either in same stage or progressing to the next stage) was high. A reliance on vegetative reproduction may mean that effective breeding populations are much smaller than indicated by counts of flowering stems.

No Population Viability Analysis (PVA) has been performed for *Eriophorum gracile*. Identification of a minimum viable population could assist in the formation of quantitative management objectives (Brackley 1989). However, the analysis would be impossible to complete with current levels of knowledge of *E. gracile* life history parameters. Information on tiller growth rates and lifespan, seed production and longevity, and a better understanding of the variables controlling these parameters would help reveal potential bottlenecks in the life history of *E. gracile*.

Community ecology

The community ecology and interspecific relationships of *Eriophorum gracile* have not been formally studied, but some inferences can be made from its habitual association with subalpine wetland and fen communities. Wetland habitats where *E. gracile* is found are often densely vegetated, and the species may occupy a specialized niche along a micro-topographic or hydrologic gradient.

Herbivores

While herbivory of *Eriophorum gracile* has not been explicitly documented, other species of *Eriophorum* are known to be subject to herbivory. Tolvanen et al. (2001) reported grazing on *E. angustifolium* ssp. *triste* by muskox, arctic hare, collared lemmings, and greater snow geese, and Howard (1993) reported grazing on *E. vaginatum* by sheep, cattle, lemmings, ground squirrels, caribou, and geese. These related species have no apparent mechanisms for resistance to herbivory (e.g., secondary compounds, thorns), and it is likely that *E. gracile* is palatable to the vertebrate herbivores in its environment. *Eriophorum gracile* is exposed to grazing both by domestic and wild vertebrate herbivores. In Region 2, vertebrate herbivores using fens include cattle, horses, moose, elk, deer, rodents, and waterfowl (Austin 2003). The occurrence of invertebrate herbivory or seed predation in *Eriophorum* species has not been investigated in detail, but aphids and lepidopteran larvae have been reported on some species (Phillips 1954b).

Competitors

Wetland and fen habitats are usually densely vegetated, and competition for light, water, and nutrients is probably intense. The tendency for *Eriophorum*

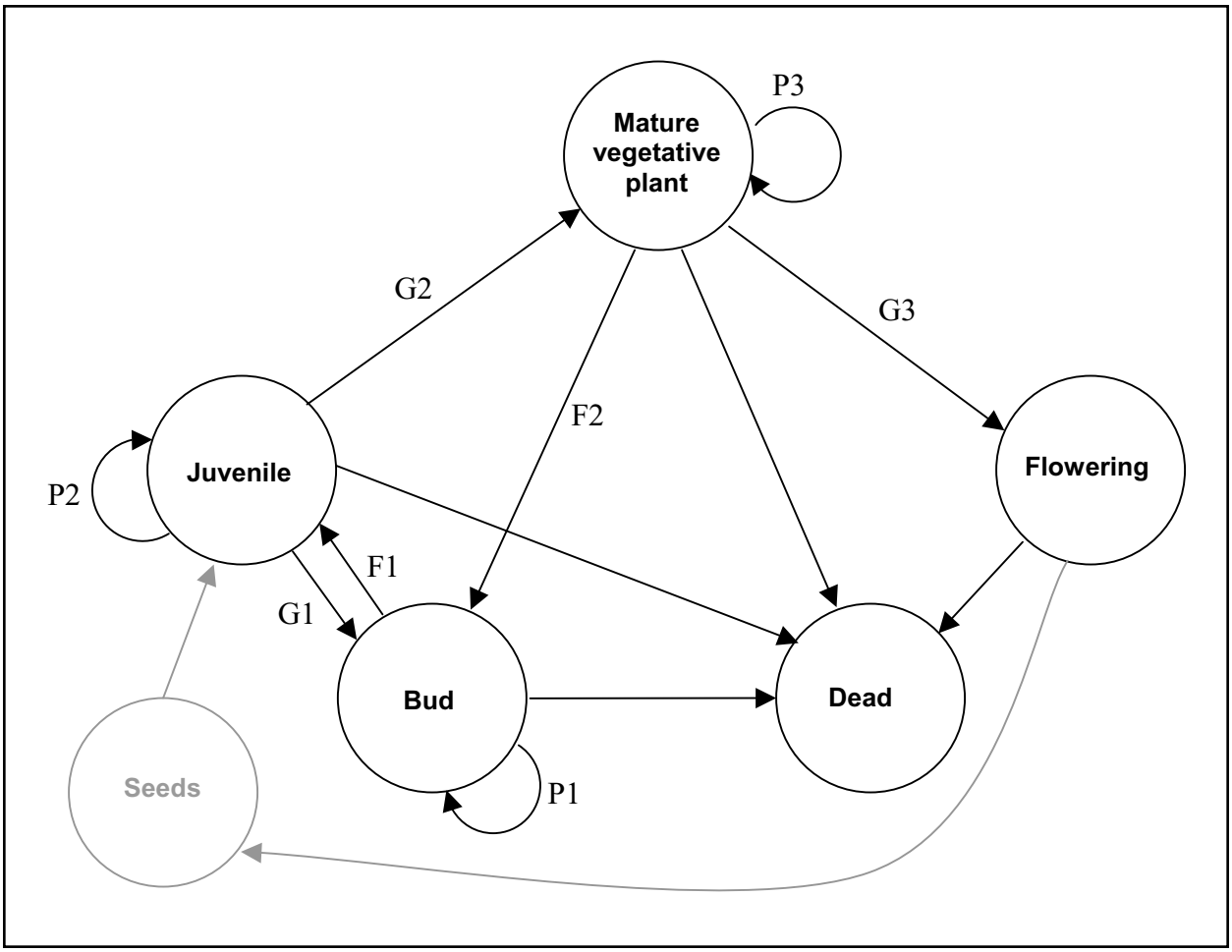

Figure 7. Generalized lifecycle diagram for *Eriophorum gracile* (after Tolvanen et al. 2001). Stage-classified projection matrix for tiller life cycle. Probabilities are P=tiller survival while remaining in same stage, G=vegetative reproduction, i.e. tillers moving to the next stage, and F=growth (number of new buds).

species to rely on disturbance to create open sites for seedling establishment means that *E. gracile* is likely to be in competition with other wetland plants for this resource. The work of McGraw and Chapin (1989) on the competitive ability of two related species, *E. vaginatum* and *E. scheuchzeri*, indicates that *Eriophorum* species can be closely adapted to specific micro-site conditions. Phillips (1954a) suggested that the tillering habit of *E. angustifolium* makes it less competitive than tussock forming species of *Eriophorum*; this conclusion could also apply to the tiller-forming *E. gracile*.

Other interactions

There have been no reports of parasites or diseases of *Eriophorum gracile*. Community interactions that affect pollination and dispersal are presumably minimal since these functions are accomplished by abiotic means.

CONSERVATION

Threats

Identifying threats to *Eriophorum gracile* is complicated by the lack of information regarding its biology and ecology. Because little is known about how *E. gracile* responds to disturbance, it is difficult to assess the immediacy of threats. In order of decreasing priority, threats to the persistence of *E. gracile* in Region 2 include hydrologic alterations, grazing, motorized vehicle use, peat mining, invasive species, and global climate change. Most of these threats are relevant regardless of land ownership or management regime. A lack of systematic tracking of population trends and conditions, and the lack of knowledge about the species' basic life cycle, population extent, and demographics contribute to the possibility that the species may decline without anyone being aware of it.

Altered hydrology

Due to the specialization of *Eriophorum gracile* on wetland habitats, hydrologic alteration is the foremost threat to the species, and this threat interacts to some degree with all of the other threats. Any alterations to a site or watershed that affect water quality or quantity will almost certainly have a negative impact on *E. gracile*. Hydrologic alteration can result from a variety of natural or human impacts, including trenching, ditching, logging, mining, fire, and grazing (Bursik and Moseley 1992). Changes in hydrologic regime can influence nutrient cycles, soil and water chemistry, sedimentation, species composition, and habitat quality in wetland systems (Mitsch and Gosselink 1993). Other threats, such as grazing, motorized vehicle use, peat mining, and climate change can influence the hydrology of *E. gracile* habitat as well as directly affect populations and individual plants.

Region-wide, the quality and availability of subalpine-montane wetland and fen habitat has probably declined due to fragmentation, hydrologic alteration, and edge effects that decrease the quality of small patches of natural vegetation. Wetland loss in Colorado and Wyoming prior to 1980 was estimated to be 1 million and 760,000 acres respectively (Dahl 1990). The Sandhills region lost 30 percent of its original wetland acreage, mainly as a result of agricultural development, including center-pivot irrigation operations, tile drainage, land-leveling, filling, and lowered groundwater levels from deep well irrigation (Tiner et al. 2002).

The USFS occurrence most likely to be affected by hydrological alteration is the Clay Butte site on the Clarks Fork Ranger District of the Shoshone National Forest in Wyoming. The wetland basin is directly down slope from a highway that may be changing runoff patterns in the area (Heidel personal communication 2004). There is no documentation of effects on *Eriophorum gracile* at this site. No other occurrences on Region 2 National Forest System lands are known to be affected by hydrologic modifications, but some locations on other federal or privately owned lands have been altered. Wetlands at Lacreek National Wildlife Refuge in South Dakota are highly manipulated (Coles personal communication 2005), and the occurrence of *E. gracile* at this site was probably impacted by pond construction (Medicine Bow National Forest 2003). At least two Nebraska occurrences (Silver Lake and Whitman) are in fens that have been altered by ditching (Nebraska Natural Heritage Program 2005). In Colorado, the Hollthusen Gulch/Tarryall Creek Fen site has been subject to hydrologic manipulation (Colorado Natural Heritage Program 2005), and the Stonewall occurrence is believed to have been extirpated because of draining for agriculture (Weber and Wittmann 2001). Although there is no information regarding specific hydrologic modifications of other historic locations in Nebraska, South Dakota, and Colorado, it is the probable cause of the disappearance of *E. gracile* from these sites. The general scope and severity of hydrological modifications throughout Region 2 means that undiscovered occurrences, especially on private lands, are likely to be affected by them.

Grazing

Cattle and sheep grazing have significantly impacted many subalpine and montane wetlands throughout the Rocky Mountains (Windell et al. 1986, Wahren et al. 1999). Major impacts of grazing include removal and reduction of vegetation, compaction of soil, and increased erosion. These impacts have been shown to affect hydrology, water chemistry, and other variables (Menke 1977, Johnston and Brown 1979). Although some observers (Olson personal communication 2004, Lamb personal communication 2004, Nebraska Natural Heritage Program 2005) suggest that cattle and horses generally avoid peatlands because of the soft substrate, the presence of domestic livestock in fens can negatively affect plant species sensitive to trampling (Pearson and Leoschke 1992, as cited in Austin 2003), alter fen hydrology, and damage the edges of fens (Mullen et al. 1992, as cited in Austin 2003). Grazing animals can create paths in peaty soils, eventually channeling water that would otherwise move through the substrate in a sheet (Windell et al. 1986, Chadde et al. 1998, Bursik 1993). If the grazing regime is intense enough to produce channeling, then these habitats may dry out and cattle traffic will further increase (Bursik 1993). Improper grazing can trigger a species shift due to the removal of native species or the introduction of non-native species. Cattle prefer grasses, sedges (including *Eriophorum* spp.), and willows. Research on *E. vaginatum* has shown that plants are able to tolerate light grazing but are killed by repeated heavy defoliation (Howard 1993). Grazing has also been shown to alter the population age-class structure in other rhizomatous species (Tolvanen and Henry 2000). This may have implications for population stability when other stresses are also applied. Grazing is potentially a threat to both plants and the quality of their habitat. Although the hoof action of large ungulates may occasionally provide open sites for recruitment of *E. gracile*, Stammel and Kiehl (2004) found that hoof print gaps are more likely to be filled by vegetative growth of surrounding plants than

by recruitment of new seedlings. The potential benefits of favorable conditions of light, temperature, and competition in hoof prints is offset by the detrimental hydrological effects of soil compaction.

All Region 2 occurrences in Wyoming are exposed to livestock grazing. The four occurrences on the Shoshone National Forest are located next to subalpine ponds that serve as sources of water for livestock and pack horses (Houston personal communication 2004). The two occurrences within the Sheep Mountain Game Refuge are in areas that receive limited pack animal use. Because intermittent or occasional livestock grazing is allowed to manage resource conditions in the Refuge (Medicine Bow National Forest 2003), these occurrences could be subjected to grazing pressures. Most Colorado occurrences on National Forest System lands are not on active grazing allotments, including the occurrences on Kettle Lakes RNA, the West Elk Wilderness Area, the Mount Evans Wilderness Area, and the Monte Cristo Creek Valley. The population at East Lost Park on the Pike-San Isabel National Forest is grazed by cattle. Although some observers report little evidence of direct grazing impact in the wetland (Lamb personal communication 2004, Leutzinger personal communication 2004), Lost Creek exhibits conspicuous stream bank erosion in some stretches (Carsey and Decker 1999). Such erosion could result in adjacent wetlands being drained, with subsequent negative impacts on the wetland communities. The Silver Lake fen, Whitman fen, and Circle 5 Ranch occurrences in Nebraska are reported to be grazed and occasionally hayed (Nebraska Natural Heritage Program 2004). Since ranching is the principal contributor to the regional economy in the Nebraska Sandhills, most other occurrences are likely to be subject to cattle grazing.

Motorized vehicle use

Threats to *Eriophorum gracile* from motorized vehicles arise from the construction and use of designated roads and trails as well as the creation of trails in wetlands by off-road vehicles. Roads, even if at a distance from a wetland, can concentrate water flows, increase flow rates and erosion, and reduce percolation and aquifer recharge rates (Forman and Alexander 1998). The major impact from off-road vehicle tracks is the creation of trails and paths that affect water levels, as well as destroy wetland habitat. Tracks intercept both the surface and groundwater, draining portions of the wetland (Forman et al. 2003).

In Region 2, five *Eriophorum gracile* occurrences are on National Forest System lands with special designations (three in wilderness areas, two in a research natural area) where mechanized vehicles are prohibited. These occurrences are not threatened by motorized vehicles except in the case of trespass. However, the other ten National Forest System occurrences are in areas where motorized vehicles are permitted but restricted to designated routes. Although no direct impacts to these occurrences have been observed, enforcement of travel regulations is difficult, and the potential for violations remains. This threat is also likely to pertain to populations that might be found in the future, especially if they are on private lands. In the Sandhills, most occurrences are on private land and have no protection from motorized vehicles.

Peat mining

Eriophorum gracile occurrences in fens are potentially threatened by peat mining. Peat mining destroys habitat for *E. gracile* by removing the substrate, reducing vegetation cover, altering species composition, eliminating microtopography, and altering edaphic and hydrologic properties. Furthermore, restoration of fens and shallow wetlands that support *E. gracile* is nearly impossible due to slow rates of peat accumulation (20 to 28 cm per 1,000 years; Cooper 1986). Once damaged, hydrologic alterations may result in the permanent degradation of habitat (Johnson 2000).

Colorado is the only part of Region 2 where commercial peat mining is permitted (USDI Bureau of Mines 1994, Austin personal communication 2004). This threat is greater for occurrences on private lands, but at least one instance of peat mining has been reported from National Forest System lands in Region 2. In this instance, the Surface Creek Ditch and Reservoir Company is removing peat from an impoundment at Kennicott Slough on the Grand Mesa National Forest in order to preserve the integrity of the dam (Federal Register 2002). None of the documented occurrences of *Eriophorum gracile* on National Forest System lands in Region 2 is known to be affected by peat mining.

Invasive species

No invasive species are known from occurrences of *Eriophorum gracile*, but many records do not list associated species. Toadflax (*Linaria vulgaris*) was reported near the Castle Pass Ponds occurrence in Colorado, but this upland species does not appear to have affected the occurrence. Canada thistle (*Cirsium arvense*) has become established around some of the lower ponds at Kettle Lakes (Carsey and Decker 1999), but it has not been reported within the *E. gracile*

occurrences there. Invasive species are generally absent from high elevation wetlands in the Southern Rockies (Rondeau et al. 2000). The threat from invasive species is most pertinent to the Sandhills populations, which are found in less extreme environmental conditions that may be more easily colonized by invaders.

The native Sandhills flora is remarkably intact; however, non-native species are more prevalent in wetland habitats than in uplands (Kaul 1990). Although not specifically known from fens in which *Eriophorum gracile* is found, invasive species are frequently mentioned in descriptions of Sandhill fens undergoing restoration or protective management (e.g., The Nature Conservancy 2004). Common invasives of wetland habitat include purple loosestrife (*Lythrum salicaria*), reed canarygrass (*Phalaris arundinacea*), and creeping meadow foxtail (*Alopecurus arundinaceus*). In addition, there are numerous exotics that invade habitats immediately adjacent to wetland and riparian areas; these may contribute to overall *E. gracile* habitat degradation.

There is not enough information to characterize the magnitude of threat to *Eriophorum gracile* from invasive species in Region 2. However, land managers should be aware of the potential of invasive species to threaten *E. gracile* and its habitat. It is important for managers to be aware of the harm to *E. gracile* that may be caused by attempts to control invasive species, and to monitor the effects of weed treatments.

Global climate change

The disjunct distribution of *Eriophorum gracile* in Region 2 is due in part to changes in global climate patterns since the Pleistocene. Although global climate change is potentially the most serious threat to the persistence of *E. gracile* in Region 2, it appears last on the list of priority threats because of the uncertainty surrounding its regional effects and severity. Global climate change is likely to have wide-ranging effects in the near future, especially in high elevation habitats. Projections based on current atmospheric CO_2 trends suggest that average temperatures will increase while precipitation will decrease in western North America (Manabe and Wetherald 1986). These changes will significantly affect hydrology, nutrient cycling, vapor pressure gradients, among other environmental variables. A decrease in precipitation (snow pack) would lead to lower water tables and reduced wetland habitat.

The effects of climate change could result in shifts in vegetation dominance that would eventually eliminate *Eriophorum gracile* from its habitat. In a global climate change study, Chapin and Shaver (1996) manipulated light, temperature, nutrients, and length of growing season in simulating global environmental change for common upland tundra plants, including *E. vaginatum*. The results of this experiment suggest that warming eventually will promote the growth of birch at the expense of sedges, forbs, and other plants that caribou and other wildlife favor as food sources in the Alaskan Arctic. During a 15-year study (1981-1995) that included the warmest decade on record, *Eriophorum* species decreased by 30 percent while birch biomass increased, even in control plots (Chapin and Shaver 1996, Hobbie and Chapin 1996). Because *E. gracile* populations in Region 2 occur in rare islands of suitable habitat, they will be unable to move to more suitable conditions nearby as their habitat deteriorates.

Influence of management activities or natural disturbances on habitat quality

There have been no studies of the effects of management activities or natural disturbances on *Eriophorum gracile*. However, some inferences can be drawn from knowledge of its preferred habitat of subalpine wetlands and fens. *Eriophorum gracile* depends on a functional hydrologic regime to maintain suitable habitat. Any management activity or natural disturbance that disrupts the hydrologic dynamics of its habitat is likely to affect habitat quality for *E. gracile*.

Influence of management activities or natural disturbances on individuals

In general, management activities or natural disturbances that affect habitats are likely to have similar or parallel effects on individuals or subpopulations. In particular, hydrological modification resulting from road building, livestock grazing, motorized vehicle use, or mining is likely to directly impact individuals and populations of *Eriophorum gracile*. Plants may be killed or damaged as a result of these activities, and population remnants may be unable to recolonize disturbed areas where local patterns of erosion and drainage have been altered.

Threats from over-utilization

There are no known commercial uses for *Eriophorum gracile*, other than as an incidental

component of peat moss or forage for domestic grazers. *Eriophorum angustifolium* has been used in northern Europe, Scotland, and England for making wicks, stuffing pillows/mattresses, dressing wounds, and for tinder and clothing (Schofield 1989), but it is extremely unlikely that any of these uses pose a threat to *E. gracile* in Region 2. *Eriophorum gracile* is occasionally collected in botanical surveys, but it has never been the subject of formal scientific investigation in Region 2. There is no evidence to suggest that past levels of collecting have endangered any populations, and limited collecting (i.e., removal of five percent or less of existing tillers) should be approved whenever it will enhance our current knowledge of its abundance and distribution.

Conservation Status of Eriophorum gracile Region 2

A lack of repeat observations of *Eriophorum gracile* populations, and the fact that past collectors have often confused it with *E. angustifolium* have resulted in varying estimates of *E. gracile*'s distribution and abundance. The apparent loss of historic sites indicates a decline in the overall Region 2 population, at least over the past 100 years. Most known locations have been found since 1990, and targeted surveys for *Eriophorum* species are likely to find more (Bradford personal communication 2004, Houston personal communication 2004, Proctor personal communication 2004). Current information suggests that the presence of *E. gracile* in Region 2 is tenuous, due to the low number of occurrences, the small size of many occurrences, the general imperilment of its wetland habitat, and the isolated nature of the occurrences.

Population sizes of *Eriophorum gracile* in Region 2 are generally not known, but when numbers are reported, they range from a few to several thousand stems. It is unclear, however, how many genetic individuals are represented by these counts. Small populations are often vulnerable to extirpation through random fluctuations in gene frequencies or reproductive rates, and unusual environmental events (i.e., genetic, demographic, and environmental stochasticity). For occurrences with thousands of stems, numbers may be sufficient to mitigate against genetic and demographic stochasticity. However, investigation of the population genetics of *E. gracile* in Pennsylvania indicated that genetic variation for some populations was essentially non-existent, suggesting that populations may have been founded by a single individual (Barr 1996). The Pennsylvania populations also exhibited a very low capacity for sexual reproduction that may make the species vulnerable to demographic stochasticity. The perennial, clonal habit of *E. gracile* buffers it to some extent against the effects of environmental stochasticity. However, the degree to which it can survive bad years depends largely on how long it can persist as an underground rhizome in unfavorable conditions or remain dormant as seeds. Occurrences are isolated, making recolonization of extirpated sites unlikely without human intervention. Stochastic events and normal environmental variation could easily result in extirpation of any of the Region 2 occurrences, regardless of current levels of protection.

Eriophorum gracile is closely tied to a small-patch type of habitat found only in a narrow range of environmental conditions. Moreover, populations in Region 2 at the edge of the species' range are probably found in environmental conditions that are different than those experienced by populations in the center of the range. Documented occurrences at high elevations in Colorado and Wyoming (including those on National Forest System lands) are found primarily in intact natural landscapes largely unaltered by anthropogenic effects. Sandhills habitats are likely to be more altered and less secure.

Management of Eriophorum gracile in Region 2

Implications and potential conservation elements

Current knowledge of the distribution and abundance of *Eriophorum gracile* in Region 2 suggests that the species' continued presence in the Region is uncertain due to its specialization on a relatively rare habitat type and the small number of isolated occurrences. However, additional information is needed to clarify its status. We know very little about patterns of abundance in the main part of the species' range, which makes it difficult to determine the conservation value of occurrences in Region 2.

Disjunct populations of *Eriophorum gracile* are of interest to conservationists even when the survival of the species does not depend directly on these populations. *Eriophorum gracile* is part of a unique relictual post-glacial community that provides information about the Quaternary natural history of the North American continent. Disjunct populations may be important as genetic reserves, since outlying populations sometimes contain atypical genetic variation in response to more difficult environmental conditions at the edge of the species ecological range. Disjunct populations

also provide an important resource for research in biogeography, metapopulation dynamics, population genetics, and other topics.

Occurrences of *Eriophorum gracile* in Region 2 are most vulnerable to changes in the environment that affect their wetland and fen habitats. Any management activities that maintain the necessary hydrologic regime for these habitats will contribute to the persistence of this species. This includes the regulation and monitoring of hydrological modifications, domestic grazing, and motorized vehicle use. Hydrological modifications are pervasive throughout the range of *E. gracile* but are forestalled by wilderness area and research natural area designations in some of the wetlands of Region 2. Regulations prohibiting man-made structures and mechanized vehicle activities in these areas have also served to preserve occurrences and potential habitat in some parts of Region 2. Natural environmental changes may affect the wetland and fen habitat required by *E. gracile*. Changes in precipitation patterns and effects of natural disturbances elsewhere in the watershed may also lead to altered hydrology that is detrimental to the persistence of *E. gracile*. In these instances, management policy should focus on mitigating these effects when feasible.

Desired environmental conditions for *Eriophorum gracile* include an intact natural hydrological regime and protected from increased or decreased drainage, clearing, livestock grazing, anthropogenic nutrient inputs, and mining. A diversity of native species and plant associations should be present. Exotic species should be absent, and native species that increase with disturbance or changes in hydrology and nutrients (e.g., *Deschampsia cespitosa* and *Carex aquatilis*) should be present in proportions typical of diverse communities, rather than in disturbed, low diversity stands. Roads or other anthropogenically induced fragmentation should be absent. Uplands surrounding the occurrence should be largely unaltered by development, mining, or agricultural uses such as clear cuts, crop cultivation, or heavy grazing. Unnatural barriers that would inhibit movement of organisms and materials across system boundaries should be absent. The hydrologic regime of the landscape should be intact and functioning within its natural range of variability. Connectivity of habitats should be sufficient to allow natural processes and species migration to occur (Rondeau and Sanderson 2000, Rondeau et al. 2000, Harkness 2003).

Tools and practices

Species and habitat inventory

Inventorying for additional occurrences is a high priority for *Eriophorum gracile*. The ideal inventory would thoroughly search all potential habitat, locate and map all occurrences, accurately count or sample each occurrence, and repeat this effort at regular intervals. Because such efforts are usually prohibitively expensive and time-consuming, inventories usually concentrate on obtaining reasonable estimates of plant density and occurrence extent. The methods used should be based on a standard protocol suitable for the scale and purpose of the inventory. The National Park Service Guidelines for Biological Inventories (National Park Service 1999) is a tested protocol for both species inventory and habitat monitoring.

Initial surveys should concentrate on similar habitats with peat soils near known occurrences, especially near recently identified sites. The wetland habitat of *Eriophorum* species is highly conspicuous and can be identified on aerial photographs (Sanderson and March 1996, Proctor personal communication 2004). Many likely areas within the known range of *E. gracile* have not been searched because they occur in remote parts of wilderness areas. Aerial photography, topographic maps, soil maps, and geology maps can be used to refine search areas when conducting inventories of large areas. This information should be cross-checked and augmented with the expert knowledge of local agency personnel and other individuals who are familiar with the area.

Ideally, surveys should be conducted by trained professionals who are familiar with *Eriophorum gracile*. In addition, USFS personnel who visit potential habitat in the course of other work should be alerted to check for the presence of *E. gracile* and to record occurrences carefully. Inventory efforts should take place from July through August when *E. gracile* is fruiting. Collection of voucher specimens is appropriate unless occurrences are very small. Due to the clonal, creeping rhizomatous habit of *E. gracile*, collecting detailed data on numbers of individuals in each population would be extremely difficult and time consuming. However, even rough estimates based on numbers of flowering stems and spatial extent would be useful in determining population trends.

Personnel conducting the initial survey should be familiar with methods of soil and habitat characterization. Surveyors can use Global Positioning System (GPS) instruments for quick and accurate data collection of location and population extent. Preparatory work should take into account the fact that many locations may be remote and difficult to access. Information from visits to known locations and details of new occurrences should be communicated to state natural heritage programs using element occurrence report forms. Conclusions about the need for further inventory, the extent of the population, and critical habitat characteristics should be shared among state and federal agencies, natural heritage programs, local and regional experts, and interested members of the public.

Population monitoring

Monitoring population trends and the effects of management would provide the most immediately useful information to land managers. Monitoring sites under a variety of land use scenarios will help to identify appropriate management practices for *Eriophorum gracile* and will help managers to understand its population dynamics and structure. To be effective, the implementation of a monitoring program must be based on a resolve to adjust management practices based on the results. Additional monitoring that collects demographic data on growth patterns, recruitment, seed production, plant longevity, and population variability can also provide useful information to both management and the scientific community, but this is a lower priority.

Quantitative data from annual monitoring of permanent plots or transects would be useful in generating information on population dynamics. However, quantitative studies are time consuming and expensive. If agency resources are limiting, a minimal level of effort could provide an ongoing qualitative awareness of population trends. Presence/absence monitoring could give early warning of declining populations. These data could be collected annually at established stations and would be most useful if combined with some form of habitat monitoring. Ideally, stations would coincide with locations already visited by agency personnel in the course of other duties. Priority sites for monitoring include the Clay Butte site on the Shoshone National Forest where the highway has altered local hydrology, and the East Lost Park site on the Pike-San Isabel National Forest where cattle grazing may be affecting wetland function.

The design of a population monitoring program for *Eriophorum gracile* should take into account the long-lived perennial, clonal character of the species, recognizing that monitoring will not determine the number of individuals present, and that accumulation of demographic data is a long-term process. Other considerations include small population sizes, disjunct locations, and sensitive habitat. The effects of disturbance and management practices on populations of *E. gracile* are of particular interest. With minimal effort, estimates of stem numbers could be made at each station (see Elzinga et al. 1998), and photographs might provide an idea of habitat condition.

Habitat monitoring

On sites occupied by *Eriophorum gracile*, habitat and population monitoring should be conducted concurrently. Because *E. gracile*'s wetland and fen habitats often support a complex of regionally rare species and communities, habitat monitoring would be the most efficient way to detect impacts and population trends in these important resources. Monitoring soil moisture, water table, and water chemistry would be useful, since the species is restricted to a narrow range of hydrologic conditions. Documenting the scope and severity of any disturbance in monitored populations would also be useful. Correlation of this information with population trends would greatly augment our present understanding of the habitat requirements and appropriate management for *E. gracile*.

Habitat monitoring of occurrences will alert managers to new impacts such as damage from ditching and draining, motorized vehicle use or grazing, and it would allow management changes to be implemented in time to prevent serious damage to the habitat. Changes in environmental variables might not cause observable demographic repercussions for several years, so resampling the chosen variables may help to identify underlying causes of population trends. Techniques are described in Elzinga et al. (1998).

Beneficial management actions

The primary consideration for any management action in or around *Eriophorum gracile* habitat is to maintain an intact hydrology, both within the occurrence and in the surrounding watershed. In general, management actions that maintain the hydrology of fens and subalpine meadows and promote natural levels of connectivity between them will tend to benefit

populations of *E. gracile*. The effects of domestic livestock grazing animals should be limited whenever possible. Motor vehicle use should be prohibited in the immediate habitat, and its effects in the surrounding watershed should be monitored for hydrologic impacts. Land managers should be aware of the potential for introducing or spreading invasive species that accompanies vehicle use in *E. gracile* habitat, and take steps to prevent infestations. Other management activities that may affect hydrology and sedimentation in wetland habitats, including fire suppression or reclamation, logging, mining, and road construction, should be minimized in both the immediate habitat and in the surrounding watershed. Surveying for this species as a part of management planning in watersheds with potential habitat will help reduce threats to this species. Establishing protected areas that are managed for the conservation of *E. gracile* and its habitat (e.g., Special Interest Areas or Research Natural Areas, especially for Medicine Bow and Shoshone national forest occurrences) would be a useful conservation strategy.

Seed banking

No seeds or genetic materials are currently in storage for *Eriophorum gracile* at the National Center for Genetic Resource Preservation (Miller personal communication 2003). It is not among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (2002). Collection of seeds may be hampered by very low seed production per individual. Propagation of tiller cuttings is another possible means of producing material for restoration. In any restoration work, it is important to use material from the closest possible source.

Information Needs

Distribution

The distribution of *Eriophorum gracile* in Region 2 is reasonably clear in a broad sense; however, it is not clear if inventory of Region 2 occurrences is complete. Occurrences of *E. gracile* in Region 2 are disjunct from the main distribution of the species and are remote from one another. It is important to locate additional occurrences, if they exist, in order to clarify the extent to which the USFS is responsible for the persistence of this species in Region 2. Many occurrences have only been identified recently, and it is likely that more are yet to be located.

Life cycle, habitat, and population trend

The fen and wetland habitats where *Eriophorum gracile* occurs are reasonably well characterized. However, the specific position of *E. gracile* within these ecological systems is not well understood, and in particular, how this position varies between montane habitats and sandhill fens. Research on this topic should focus on clarifying the exact hydrologic, chemical, and micro-topographic tolerances of the species, and how to recognize these in the field. The relative importance of reproduction through vegetative growth compared with sexual reproduction in this species has important implications for population dynamics and persistence of disjunct occurrences. Additional information on growth and recruitment patterns, as well as on importance of disturbance in creating establishment sites, would also contribute to our ability to understand population trends in *E. gracile*.

Response to change

The effects of environmental variation on the growth, reproductive rates, dispersal mechanisms, and establishment success of *Eriophorum gracile* have not been investigated. The same is true for its relationship with herbivores and exotic species. As a consequence, the effects of both fine- and broad-scale habitat change in response to management or disturbance are difficult to predict. Detailed information on the habitat requirements of *E. gracile* will enable a better understanding of the potential effects of disturbance and management actions in these habitats.

Metapopulation dynamics

The importance of metapopulation structure and dynamics for the long-term persistence of *Eriophorum gracile* at local or regional scales is unknown. It is not clear that metapopulation dynamics are in fact operating in these disjunct populations. Gene flow among Region 2 populations is probably possible only where occurrences are within a mile or two of one another. Given the level of effort that would be required to collect minimal data on migration, colonization and extinction rates, as well as environmental factors contributing to the maintenance of inter-population connectivity, this information is a low priority.

Demography

Only the broadest generalizations can be made regarding the demography of *Eriophorum gracile*. The

possibility that *E. gracile* has generally low levels of sexual reproduction (Barr 1996) emphasizes the need for including vegetative reproduction in demographic models for the species. Studies of other *Eriophorum* species have provided good generalized models with which to approach the demography of rhizomatous species, but it is not clear how *E. gracile* compares with these species in growth rates and resource allocation patterns. The detailed investigation required to parameterize a lifecycle projection matrix would involve a level of destructive sampling that is probably unacceptable for occurrences in Region 2. In the absence of more complex studies, it may still be useful to collect growth and longevity data on tillers of some marked individuals in their natural habitat.

Population trend monitoring methods

Population trend monitoring methods are complicated by the clonal, rhizomatous growth habit of *Eriophorum gracile*. Standard methods that rely on counts of individual plants will be very difficult to use without modification. Alternatives include using stems as a sampling unit, or to use a stem density per unit area estimate of abundance.

Restoration methods

Restoration methods have not been developed for this species. Fen habitats are essentially unrestorable, but it may be possible to transplant *Eriophorum gracile* to other wetland habitats. Because of the complexity of associated relictual plant communities, it is unlikely that extensive restoration efforts will be feasible. Development of restoration methods for this species should concentrate on re-establishment of plants in intact habitat and not on the creation of new habitat.

Research priorities for Region 2

In order of importance, research priorities for *Eriophorum gracile* include:

- identification of potential suitable habitat and location of additional occurrences
- development and implementation of population and habitat monitoring protocols
- quantification of the effects of invasive species, disturbance, and land management practices on the survival and persistence of the species
- investigation of the growth and reproductive requirements of individual plants.

Additional research and data resources

There are likely to be many specimens of *Eriophorum gracile* held by herbaria throughout North America, as well as an informal body of knowledge of its distribution among land managers in the area. This information could clarify the global distribution and abundance patterns of *E. gracile*, which would provide a clearer perspective of its status in Region 2. This information would be most useful if linked to investigation and explication of the disjunct post-glacial remnant communities in which it occurs.

DEFINITIONS

Achene – small, dry indehiscent, one-loculed, one seeded fruit consisting usually of a single carpel (Weber and Wittmann 2001).

Autecology – the study of the ecology of individual species (Jones et al. 1992).

Competitive/Stress-tolerant/Ruderal (CSR) model – a model developed by J.P. Grime in 1977 in which plants are characterized as Competitive, Stress-tolerant, or Ruderal, based on their allocation of resources. Competitive species allocate resources primarily to growth; stress-tolerant species allocate resources primarily to maintenance; ruderal species allocate resources primarily to reproduction. A suite of other adaptive patterns characterizes species under this model (Barbour et al. 1987).

Culm – The hollow or pithy stem of grasses, sedges, and rushes (Harris and Harris 1994).

Demography – the statistical study of populations with reference to size, density, and distribution (Jones et al. 1992).

Edaphic – of the soil, or influenced by the soil (Allaby 1992).

Element Occurrence (EO) – an animal, plant, or plant community occurrence (Nature Serve 2004).

Monoecious – having the stamens and carpels in different flowers on the same plant (Weber and Wittmann 2001).

Phenotypic plasticity – the capacity of organisms with the same genotype (genetic properties of an organism) to vary in developmental pattern in phenotype (visible properties of an organism) according to varying environmental conditions (Allaby 1992).

Ramet – an individual stem of a clonal plant.

Scale – in sedges, the bract subtending the sedge flower.

Somatic mutation – a mutation in a non-reproductive cell, not inheritable.

Stochastic – Randomly variable, governed by chance.

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